ACCELERATED BRIDGE CONSTRUCTION

Best Practices and Techniques

Mohiuddin Ali Khan



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Best Practices and Techniques

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Preface

This textbook has been developed for the purpose of incorporating the latest developments in accelerated bridge construction (ABC) projects. Its objectives are to focus on creating awareness, educate, train, and inform bridge engineers in the art and science of effective rapid construction and delivery to the public. It will entice State Department of Transportations and their staff to select rapid construction techniques and save travel time of public and money especially during construction.

The applications of routine design procedures using AASHTO LRFD Specifications, State Design Manuals with specific reference to ABC, and the vast amount of bridge design software will not change except for new load combinations resulting from: Lifting, transporting, erection, roll-in, slide-in, or float-in loads, etc.

Users following the guidelines in this book will be able to perform the following new tasks:

- Understand the different types of ABC technologies that can be used or are in use today in USA and in other countries.
- Understand the various types of prefabricated elements used in bridges.
- Assess specific sites for the most appropriate ABC technology for the project.
- Plan and implement an ABC program as recommended by Federal Highway Administration (FHWA).
- Examine the success and limitations of the techniques in terms of time savings and cost.
- Understand the construction aspects of Prefabricated Bridge Elements & Systems (PBES) projects and ready-made modular bridges.
- Understand the long-term durability of bridges built with ABC.

The presentation of text is kept simple and straight forward so that the reader does not have to look to other books for explanation. The book deals with concepts and methodology to promote rapid construction. Emphasis is placed on case studies of successful projects completed in several states in the recent years. Bridge design specifications and construction provisions are kept to a minimum. The author is indebted to a few stalwarts in this new technology:

Benjamin Beerman of FHWA Every Day Counts Program for his help with the one-day course on ABC organized at Temple University by American Society of Civil Engineers (ASCE) (of which the author is a Board Member and Ex-Chairman of Structural Engineering Institute in Philadelphia).

Professor Atorod Azizinamini of Florida International University (FIU) for organizing useful continuing education seminars from experts and from which the author has benefited.

Tom Macioce, Chief Bridge Engineer at PennDOT for presenting a seminar to Structural Engineering Institute (SEI) and highlighting the current progress in bridge engineering.

Dr Ehsan Minai of Pennoni Associates for conducting ASCE Report Card and research with the author, for evaluation and recommendations for Pennsylvania State Bridges for using ABC. The criteria of an independent study to review infrastructure is also applicable to other states in USA.

This book is about problem solving for the chronic construction delays, removing bottlenecks, and providing an insight into related important issues causing them. As a bridge engineer and teacher of modern bridge engineering, I find that there is a need for a book to address new technology on rapid construction for many practical reasons, such as minimizing public discomfort during extended years of construction. Modern topics such as availability of Self-propelled modular transporters (SPMTs), heavy capacity lifting cranes, temporary bents for lateral slide-in construction, prioritization and selection of bridges for retrofit and replacement, value engineering and selection of design-build and alternate methods of construction.

AASHTO LRFD and State codes are still applicable as live loads govern but the minor changes will take time to catch up with the innovations and incorporating new procedures for lifting and erection of assembled bridges. The updated provisions will not aim at educating or inspiring the reader with fundamentals. This process is possible by highlighting required changes through textbook chapters.

Practicing engineers continuously find the need for a textbook, which can simplify the interpretation of guidelines and make it more palatable for office use. A book should address the state of art of bridge construction, highlight major issues by offering necessary explanations, and use case studies of the associated practical problems. If the developments in the subject are understood by teachers and students at university level, the future practicing engineers will have a jump start and the purpose of the book will be well served. Some State codes have been more enterprising in developing the technology as compared to the Federal codes. The textbook can serve basically as a companion reference manual to the codes and specifications, with an emphasis on the newer topics and will focus on both traditional and nontraditional methods of construction.

Objectives

The issues are basically presenting a method of safe, economical, and durable construction of the multibillion dollar transportation industry, the resulting advantages of which to the society appear to be significant, for example avoiding being stuck in traffic jams while commuting to work or delayed by a roadway closed for repairs or taking undesirable detours.

Innovative ideas and engineering for structural planning, prefabrication of components. and precast connection details developed by design and construction teams over the years are referred to, making the textbook useful for design and constructability. In particular studying and applying the following aspects:

1. Recent advancements in construction techniques, such as design-build management, prefabrication, typical modular bridge manufacture, and transporting to the site and alternate slide-in methods.
2. Revisions to design criteria based on splicing of long members, lifting, and erection.
3. Increase in the volume of vehicular traffic on highways results from enhancement in automobile industry production and with their marketing motto "one car for each family." This has resulted in an overload of existing bridges and highways, increased wear and tear, and in the number of accidents. The highway network should be able to accommodate increases in average daily traffic and average daily truck traffic. Frequent traffic counts may be necessary for adjusting direction of flow in the network.
4. Modern materials technology, the developments in new types of concrete, steel, and other construction and repair materials.
5. Developments in construction methodology, the use of long span cranes, hauling of long span girders, and improvements in erection on sites.

6. Updates on important developments in bridge and highway maintenance and use of asset management techniques of bridges and highways based on structural health monitoring by remote sensors.

Need to incorporate growing technologies

There are relatively few books on similar topics or on developments in modern technology on design and rapid construction disciplines. Maintenance may include the much neglected highway structures, such as precast modular retaining walls, providing emergency relief bridges and scour countermeasures, retrofits at bridges and embankments.

A fresh approach to the topics is reflected in the proposed chapter contents given below. This book may be used both as a textbook or a desk reference. In addition, the textbook will address:

A review of ABC philosophy and its benefits to society;
Management aspects of ABC such as design-build, Progress in design-build, prefabrication, precasting, and the role of the construction manager/general contractor (CM/GC);
Safety and structural performance of existing bridges;
ABC planning for new and replacement bridges;
Traffic volume data, traffic counts, and maps availability;
Urgency in fixing defective bridges and rapid bridge insertions ability following failures;
Funding needs and promoting investments for ABC projects each year such as P3 Programs;
Variations in ABC methods;
Need for modular ABC drawings, details, and contract documents;
Accelerated bridge rehabilitation (ABR);
Problems of ABC for bridges located on waterways;
FHWA initiatives to promote design-build contracts such as Every Day Counts Program;
Limited need for traffic control during construction;
The need for training of engineers and research in further innovations;
The benefits of easier compliance with the environmental and permitting regulations, coordination with utility companies for early delivery of utility pipes on site and rapid assembly;
ABC applications in railway bridges;
Emphasizing the need for a national center devoted to ABC;
Introducing new concrete materials, fiber-reinforced polymer concrete, lightweight concrete for prefabricated bridge decks and overlays;
Alternative use of hybrid-composite beam;
Types of precast components for substructures;
Surges in transportation, publications, and workshops;
Case studies of prefabricated substructures and integral abutment and piers;
Advancing lateral slide in methods and use of SPMTs.

Track record of successful bridge design and construction

The bridge engineer needs to be groomed to a technical decision making position to use ABC. There is a need to develop an engineering sense to address the issues and resolving them in the limited time available.

Audience for whom the book is intended include practicing structural and bridge engineers in USA and abroad, government agency engineers, planners, highway and traffic engineers, manufacturers of SPMT and high capacity cranes, geotechnical engineers, transportation specialists, contractors, prefabrication product vendors, senior engineering students, university professors. The job titles include engineering managers, project managers, design engineers, construction supervisors, instructors and engineering students.

Professional associations and organizations with which audience might be affiliated: AASHTO, FHWA, TRB, Design-Build Institute of America, American Society of Civil Engineers, American Society of Highway Engineers, American Concrete Institute, American Institute of Steel Construction, State boards and professional engineering licensing agencies.

Research departments at universities have advanced the new technology. Notable among them are FIU, Maine, Iowa State, and few other universities.

Conference proceedings & periodicals on bridge engineering

There is a wealth of information available in research publications, in the proceedings of international conferences, technical journals, and periodicals, where papers were presented by learned authors and speakers from all over the world.

Notable among the conferences are FHWA Every Day Counts Program, Web site resources, and construction industry publications by participating contractors such as ACROW, High Steel, Jersey Precast, and many others. FIU Specialty Conferences and seminars. The textbook will contain the much needed information on innovations presented in all the technical resources.

Study of FHWA, AASHTO, ACI, PCA, AISC, NCHRP, and TRB publications

Many chapters and the solved examples will contain references to the applicable codes and specifications. This is also a legal requirement. The engineer needs to be well versed with codes.

Professional societies, which will benefit are ASCE, SEI, and FHWA. Any conferences or trade shows, which would benefit by displaying the book are ASCE-SEI International Congress, TRB, and Pittsburgh Bridge Conference. Web site links are given in addition to Bibliography.

SECTION

1

Innovative Construction Methods

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CHAPTER 1

Introduction to Modern Accelerated Bridge Construction

1.1 Rapid construction and early delivery of bridges

This book deals with new construction technology. With the advent of high-capacity machinery, new materials, and new management methods, we are now able to manufacture bridge assemblies and lifting them in position. The new structures can be described as the application of:

Accelerated construction,
Rapid construction,
Modular construction,
Mechanized construction, or
Ready-made construction.

There is a year-round need for infrastructure improvements and maintenance in the form of rapid replacement and rehabilitation of many thousands of bridges. Although most of us have heard the expression accelerated bridge construction (ABC), few of us know the intricate details. In this book, an attempt is made to bring up to date the latest knowledge of the multibillion dollar construction industry.

This introductory chapter gives salient features of the book chapters, which describe individual specialized topics of ABC. Hence, an overview of the subject is presented here. The topics cover the need for ABC, differences in conventional methods, the state of the art, the scope of work, and the many advantages and existing constraints in achieving rapid delivery. Using a point system, Tables 1.2(a) and 1.2(b) give a method of priority selection of projects for ABC, in terms of relative benefit compared to conventional construction. A spreadsheet can also be used with the same criteria given in the tables.

Funding limitations, review of progress in other structural disciplines, notable ABC projects being built in several US states, recommendations, and the need for a code of practice for accelerated construction are addressed.

The chapters that follow this introductory chapter will cover the following theme:

Recent developments in ABC concepts (Chapter 2), research and training in ABC structural systems (Chapter 3), introducing innovative ABC techniques (Chapter 4), modular bridge construction issues (Chapter 5), rapid bridge insertions following failures (Chapter 6), planning and resolving construction issues (Chapter 7), prefabrication of the superstructure, (Chapter 8), prefabrication of the substructure and construction management (Chapter 9), alternative ABC methods and funding evaluation (Chapter 10), American Society of Civil Engineers (ASCE) infrastructure evaluation, review of chapters, bridges on rivers, and conclusions (Chapter 11). Additional information is provided in the appendices at the end of the book.

This first section introduces a variety of topics, including the background on ABC, the drawbacks of conventional bridge construction (CBC), promoting ABC, categorizing applicable bridges, typical span lengths, selecting projects for ABC, its multiple types, and successful modular construction.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00001-0

1.1.1 Background

The United States has the largest network of highways in the world. Its economy depends a great deal on vehicular travel and distribution of goods in the 50 states. The construction industry contributes to the nation's economy. It is a major industry like car manufacturing and provides many jobs for skilled and unskilled workers. It also contributes to an increasing need for developing new construction materials, mechanical and electrical equipment, lifting cranes for erection, and special tractors for transportation.

Construction is backed up by analysis and design methods requiring special software and graphics, thereby generating supporting jobs in the information technology and computing sectors. Thus it has far-reaching impacts on the economy. Rapid construction would benefit travel and commerce because of the increased number of duly completed bridges each year and far earlier availability of construction teams with specialized experience to handle more bridge work.

ABC consists of a number of design, construction, and contracting practices that speed up construction, improve safety, and minimize traffic disruption. Bridge engineering, whether conventional or using ABC, is linked to the public domain.

Bridges are essential for daily transportation; for access to workplaces, markets, restaurants, schools, and hospitals; for linking towns with cities; and also for the defense of the nation.

Compared to conventional design, there is little change in the structural design of bridge components because the principles and mathematical theorems have not changed. However, any introduction of splices and joints using ABC affects the geometry and configuration of deck slabs and girders and needs to be considered in analysis and design. One example of this is construction loads encountered in segmental bridge construction.

ABC is a relatively new subject. It is more of an art than a science. Research on various aspects is in progress and is being supervised by management agencies and proprietary construction companies. Construction management techniques play an important role in completing a bridge as quickly as possible, without lowering the quality or the life expectancy of the bridge.

1.1.2 Use of new ABC technologies

Approximately one-fourth of the nation's 600,000 bridges require rehabilitation, repair, or total replacement. However, on-site construction can have significant impacts on mobility and safety.

In many cases, the direct and indirect costs of traffic detours and use of temporary bridges during construction can exceed the cost of the structure itself. For example, full-lane closures in large urban centers, or on highways with heavy traffic volumes, can have a significant economic impact on commercial and industrial activities in the region.

Partial lane closures and other bridge activities that occur alongside adjacent traffic can also lead to safety issues. Because of the potential economic and safety impacts, minimizing traffic disruptions is a goal that should be elevated to a higher priority when planning bridge-related construction projects.

(Chapter 6 addresses the reasons for numerous failures of bridges in United States and abroad, which can be prevented by the introduction of new technologies of ABC).

1.1.3 The United States must lead the way in mechanized bridge construction

Mechanized bridge construction (MBC) is a branch of ABC in which sophisticated construction equipment and machinery such as high-capacity, long-arm cranes and self-propelled modular transporters

(SPMTs) are used. The international bridge industry is moving to MBC because it saves on labor costs, accelerates construction, and improves quality. This trend is evident in many countries and is particularly accelerated in the field of prestressed concrete bridges (which are the most economical solution for medium-span and segmental long-span bridges).

Several high-tech construction methods for prestressed concrete (PC) bridges have been developed and brought to technological maturity during the last decades. Examples include:

Incremental launching.
Span-by-span casting with movable scaffolding systems (MSS).
Macrosegmental balanced-cantilever casting with suspension-girder MSS.
Span-by-span macrosegmental casting.
Full-span precasting of light rail transit and high-speed rail bridges.
A new generation of derived methods.

Despite their diffusion abroad, high-tech bridge construction methods are rarely used in the United States. The US bridge industry is still focused on first-generation methods such as precast girders, match-cast segments, and in-place casting with form travelers.

High labor costs and long project durations limit the advantages of design–build procurement, and poor familiarity with mechanized bridge construction adversely affects the export capability of the US bridge industry.

New-generation bridge construction methods can be brought to common practice in the United States by cooperation with foreign partners and in particular with those who invented these methods.

1.1.4 Drawbacks of conventional construction

Being trapped in traffic jams, loss of labor hours, and the resulting gasoline wastage experienced by millions of commuters during bridge reconstruction and rehabilitation cause discomfort daily. These have become a regular feature of CBC.

With the passage of time there is greater wear and tear of concrete decks and fatigue in steel girders. Routine inspections place additional bridges for repair and rehabilitation each year (reference Khan, M., 2010. Repair and rehabilitation of bridges and highway structure, McGraw-Hill.), and the inventory of state highway agencies for fixing all the listed defective bridges grows.

Maintenance of the infrastructure to the required standards requires billions of dollars in funding. The returns should provide minimum discomfort and traffic disruptions during lingering months and prolonged years of bridge work involving structural integrity. Bridges serve as bottlenecks in the transportation system. Simple defects and minor damages to bridge components can require miles of highway to close down, as a detour is not always an option.

Twin bridges are preferred for one-way travel in each direction with independent sidewalks and parapets. This helps in future maintenance and avoiding collisions with the median barrier from either side.

The construction management system is different for ABC. The design–build (D–B) system serves as a bonus for the contractor. Both conventional and ABC bridges will be designed to withstand identical long-term live loads long with wind, snow, and other environmental loads. With lighter density materials, member cross sections would be smaller, and dead load and thermal and seismic forces would be lower. The difference is in the magnitude and nature of construction loads.

(Our failing infrastructure and transportation problems are discussed in Chapter 7).

1.1.5 Promoting ABC

A review of scientific literature on the subject of ABC shows that certain aspects are addressed in greater detail, such as:

- Introduction and selection of design–build engineering teams.
- Conventional site work transferred to factories.
- Improved prefabrication methods.
- Transportation of components such as use of long vehicles and SPMTs.
- Use of high-capacity cranes and equipment.
- Timely coordination between the stakeholders and highway agencies for required design approval and coordination with utility companies.
- Handling of construction management jointly by the contractor and the consultant, any specialty sub-contractors, and suppliers of materials or products.
- Availability of skilled labor and their training relevant to the rapid type of bridge design and construction.
- Planning to include an alternative approach utilizing cost-benefit analysis.
- Modified progress inspection techniques during construction.

Many of today's bridge construction and replacement projects take place in areas of heavy traffic, where detours and bridge closures severely impact the flow of people and goods on transportation corridors. One of the most common ways to accelerate bridge construction is to use prefabricated bridge elements and systems (PBES) to construct the bridge. These are prefabricated off-site or adjacent to the actual bridge site ahead of time, and then moved into place when needed, resulting in closure of the bridge for only a short duration. Very frequently, these PBES are constructed with concrete (reinforced, pretensioned, post-tensioned, or a combination thereof).

The distinct major features especially applicable to the structural and other associated aspects of ABC are the following:

Lightweight materials: For ease of transportation and erection from reduced dead loads.
Precast abutment walls: Quick construction and backfill (not required for conventional construction).
Precast pier columns: Quick construction (not required for conventional construction).
High-strength girder steel and high-performance concrete: Lighter girder sizes and more durable deck slab are suitable for easy transportation. Their durability reduces life-cycle costs.
Prefabricated deck panels: Quick construction and avoiding expensive formwork (not required for conventional construction).
Precast prestressed girders: Suitable for small and medium spans.
Elastomeric bearing pads: Allow six degrees of freedom at the girder ends.
Partially site-assembled bridge components: Easily lowered into position (not usually required for conventional construction).
Robotics features: Quick concrete pours in multiple joints and tightening nuts and bolts (not required for conventional construction).
Use of high early-strength grout in joints: Allow live loads within a week of casting concrete.
Use of SPMT and high-capacity cranes: An essential feature of ABC for transportation and erection (not required for conventional construction).

Speedy utilities coordination: Quick provision of bridge lighting and signage.
Prefabricated approach slabs: Subgrade needs to be prepared (not required for conventional construction).

(For promoting ABC, design–build method of construction management is described in Chapter 3, modern concrete technology in Chapter 4, prefabrication of bridges and technical issues in Chapter 5, and stakeholders of ABC in Chapter 8).

1.1.6 Construction and maintenance of essential bridge structures

The importance of bridges has been highlighted in novels and in films. One notable example is *The Bridge on the River Kwai*. The largely fictitious plot is based on the construction in 1943 of one of the railway bridges over the Mae Klong (renamed Khwae Yai in the 1960s). During its construction, approximately 13,000 prisoners of war died and were buried along the railway.

The old bridge construction technology used in those days is changing now. There are millions of highways of varying widths, heights, and span lengths serving interstate, arterial, and local locations. Generally, span lengths and locations govern the type of the bridge to be selected. The associated construction problems will vary with the large number of parameters involved. For example, bridges construction issues related to easy access for foundation construction of bridge piers built over wide rivers will be different from those built on small streams or land overpasses.

ABC methodology is applicable to nearly all the bridges but to a varying degree. While building structures basically comprise slab, beams, and columns using steel, concrete, and timber or masonry, bridges comprise beams, trusses, arches, or cables, and variations thereof. Besides steel, aluminum is being used for small-span bridge girders and for pedestrian bridges. Concrete girders are generally precast and prestressed for bridges, while they are mostly reinforced concrete in buildings. Live loads in buildings seldom exceed those used for pedestrian bridges. Live loads in bridges tend to be very high given vehicular loads and truck traffic.

1.1.7 Classification of span lengths for ABC

The span length, live loads, and extreme loads determine the bridge selection, such as slab–beam bridges, truss bridge, arch bridge, cable-stayed, suspension, or segmental bridge. Slab–beam bridges are the most common type. Bridge beams are generally much longer than those in buildings, depending on site requirements. Longer spans are chosen to avoid too many piers, which are at times obstructions to traffic flow. However, when replacing a bridge, the existing substructure is often used. As stated earlier, construction takes less time with ABC, and the construction duration for different materials and configurations varies greatly in proportion with span lengths. Each type of span uses a different selection of concrete and/or steel girders and method of erection:

- Small spans (less than 60 ft): timber-reinforced concrete, steel and prestressed concrete girders
- Medium spans (greater than 60 ft and less than 120 ft): steel and prestressed girders
- Long spans (greater than 120 ft and less than 300 ft): high-performance steel (HPS), hybrid girders, and steel trusses
- Very long spans (300–600 ft): segmental construction and cable-stayed bridges.

1.1.8 Bridge categories for ABC

Bridge engineers need to design a wide category of bridges on land, in valleys, on rivers, and in coastal areas, presenting many challenges. Environmental loads and soil conditions tend to be different. Table 1.1 presents modern-day bridge categories. Some of them present special demands for both substructures and superstructures when using ABC methods.

Analysis and structural design aspects are different in most cases based on the geometry for straight, skew or curved decks in the plan.

1.1.9 Multiple types of structural design

ABC applies to a wide variety of structural variations. Conventional bridges take more time to construct, but even these types of bridges are also using partial ABC methods with prefabricated components. Deck slab is normally constructed using formwork and wet concrete. High early-strength concrete may be used to minimize curing time. Planning aspects for new bridges are different as compared to replacement bridges or widening of a bridge.

Figure 1.1 shows the construction sequence for ABC.

The methods of construction can be summarized as follows:

- Partial ABC: no formwork required
- Fully ABC: prefabricated and partially assembled in factory
- Super ABC: fully assembled on site.

Table 1.1 Bridge Engineering Comprises Many Categories of Structures (compiled by author)

S. No.	Bridge Category or Location	Description
1.	Pedestrian bridges	Small spans and small pedestrian live loads
2.	Over streams	Small single spans
3.	Over wide rivers	Requiring multiple spans
4.	In coastal areas	Subjected to daily tides
5.	Overpass second level	Curved or straight deck
6.	Overpass third level	Curved deck only
7.	Concrete arch bridges	Aesthetic small spans
8.	Steel arch bridges	Aesthetic medium or long spans
9.	Steel truss bridges	Medium or long spans
10.	Segmental construction	Prestressed post-tensioned concrete segments
11.	Suspension cable bridges	Aesthetic long single spans with approach spans
12.	Cable-stayed bridges	Aesthetic medium or long single spans with approaches
13.	Railway bridges	Very heavy live loads
14.	Military bridges	Temporary steel bridges on rivers to carry heavy loads
15.	Floating bridges	On rivers with no tides
16.	Temporary detour bridges	Proprietary steel bridges

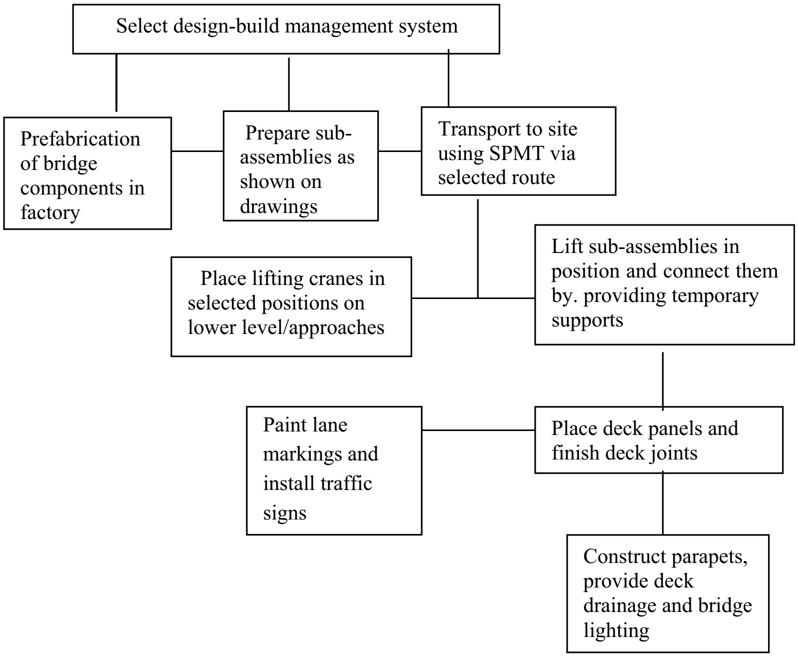

FIGURE 1.1

Typical flow diagram for construction sequence for ABC.

New bridges in new locations: Except for construction loads, there are hardly any traffic issues for maintenance and protection of traffic (MPT). There are fewer constraints and the bridge engineer can exercise planning principles and use the latest design and construction specifications.

Replacement bridges in existing locations: The existing traffic route will be adversely affected. Detours if available will extend the travel distance and duration. One option is to replace the bridge in stages. Generally, the existing substructure is used and only the bearings and entire superstructure are replaced.

Widening of bridges: This type of construction is difficult because it requires additional substructure and foundations and new wing walls. The marrying of the old structure with the new widened deck is required. Maintaining and protecting traffic while heavy construction is going on takes more time. Some lanes need to be closed. Labor also needs to be shielded from any accidents. Night-time work is more difficult and dangerous.

Deck replacement Only: On bridges carrying heavy average daily traffic (ADT), the wearing surface does not last long. It is customary to replace the partially cracked deck, roughly every 20 years, i.e., several times during to the life of the bridge.

Although it is preferable to use precast deck panels over existing girders, maintaining the continuity of the deck over supporting girders and restoring the original full composite action between slab and beams with existing shear connectors in position is difficult. Due to the lack of continuity, the bending moments in the deck slab will be higher.

Repair and rehabilitation of existing bridges: This may require bearings upgrade such as replacing them with seismic isolation bearings for new seismic criteria. The girders and deck need to be lifted to replace old bearings with new bearings of equal height.

1.1.10 Selection of suitable bridge projects for ABC

ABC will not be the optimum solution in every case such as when:

- Experienced labor is not readily available,
- Factory facilities for pre-fabrication are limited,
- SPMT or heavy lifting cranes are not available.

The conventional method of construction is still being followed on many projects and it will take a long time before ABC is fully adopted or enforced by state departments of transportation (DOTs). Most projects require early completion and will use limited if not total ABC. The following information (listed in Tables 1.2a and 1.2b, prepared by the author) can help to make decision toward selecting bridges for the new system of construction management.

A highway agency has hundreds of bridges on their list and a funding priority needs to be established since there will not be enough funding and engineering workforce to work on all bridges in the same year. Projects that can be finished in shortest possible time by using ABC methods have a better chance of being short-listed for construction.

Applying Criteria for ABC Selection—Each item will receive relative points as follows:
Comparative Study for ABC Selections:

(Items in Tables 1.2a and 1.2b) A + B + … + H (Out of 100) for Initial Screening.
(Items in Tables 1.2a and 1.2b) A + B + … + H + … + Z (Out of 200) for Final Screening.

Recommended Points Allocation:

Small advantages or impacts **(30%)**,
Medium advantages or impacts **(70%)**,
High advantages or impacts **(100%)**
Total Maximum Points 200

Table 1.2a Primary Consideration for Selection of Suitable Projects for ABC in Terms of Benefit

Important Primary Considerations for Selecting ABC	Maximum Points Based on Project Features	Advantage Points Using ABC	Advantage Points (Using Routine Construction)
A. Estimated duration and importance of early completion	15		
B. Complexity, river location, or seismic vulnerability	15		
C. Located on interstate/inter-county/local route	15		
D. Feasibility of D–B management	15		
E. Estimated cost of bridge and availability of huge funds per year	10		
F. Bridge replacement or new bridge	10		
G. Contractor's experience on similar projects	10		
H. Span length, deck width, and number of traffic lanes	10		
Total points (ABC versus routine construction) 100			

Table 1.2b Secondary Considerations for Selection of Suitable Projects for ABC in Terms of Benefit

Important Practical Considerations for Selecting ABC	Maximum Points Based on Project Features	Advantage Points Using ABC	Advantage Points (Using Routine Construction)
I. Shallow foundation/piles/drilled shaft from soil report	7.5		
J. Impact of construction on environment	7.5		
K. Type of deficiencies outlined in inspection reports for rehabilitation	7.5		
L. Demolition easy/difficult	7.5		
M. Deck geometry straight/skew/curved	5		
N. Feasibility of detour/lane closure/use of temporary bridge during construction	5		
O. SPMT length of girders	5		
P. Maximum crane capacity	5		
Q. Precast deck panel sizes	5		
R. HPC concrete strength	5		
S. HPS girder strength	5		
T. Precast concrete substructure strength	5		
U. mechanically stabilized earthwork (MSE) wing walls/precast retaining walls	5		
V. Easy access to site	5		
W. Site office/easy mobilization	5		
X. Availability of labor	5		
Y. Present/projected average daily truck traffic (ADTT)	5		
Z. General/extreme weather conditions	5		
Total points (ABC vs routine construction) 100			

Note: Points allocation can vary from those given, based on complexity of project using engineering judgment.

As an alternative approach, a computer program or Excel spreadsheet can be developed.

However, overacceleration of the construction schedule may affect the quality of construction; for example, site welds may not be tested and concrete closure pour of joints may not be given the required curing time. Sufficient time must be available for initial inspection followed by checking. One difficulty may be a shortage of engineers who can be relocated to a new site and be readily available for work at a distant site, to perform the fast-paced work. More than one daily shift and night-time work may be required to avoid extreme weather conditions.

1.1.11 Other examples of successful modular construction

There are similar or parallel problems in the construction of tall buildings, where modular construction is seen to be on the rise. Construction duration or delays of building projects do not affect the public directly daily or to the same extent as slower bridge construction. Spans in buildings are much smaller, and both dead and live loads are smaller and construction problems are fewer. Sears and Roebuck supplied components of simple modular timber buildings in the United States, which were assembled by purchasers using supplied building plans and catalogs. There are suppliers of light-weight precast concrete segments for buildings and factories listed in yellow pages of telephone books.

Precast multi-story car parks are now being successfully constructed. They are designed for vehicular loads that are similar to bridge live loads. Hence prefabricated structures seem to have merit and are in common use.

1.2 A review of the many aspects of ABC philosophy and benefits to society

This section introduces a variety of topics and gives an overview of ABC, including its benefits, the logistics surrounding it, and various strategies related to it. ABC consists of a number of design, construction, and contracting practices that would speed construction, improve safety, and minimize traffic disruption. Many of today's bridge construction and replacement projects take place in areas of heavy traffic, where detours and bridge closures severely impact the flow of people and goods on transportation corridors.

1.2.1 Benefits of ABC: Using modern methods

In this book, many benefits of various aspects of ABC are explained. Although precast construction techniques such as Inverset with composite girders are being used in conventional steel construction, the major benefits of ABC can be achieved with alternative construction management such as the more effective design–build methods. The sooner the joint contractor-consultant team completes a project, the sooner the team can start work on another project. The added production then becomes a win-win situation.

Examples are the topics addressed in Federal Highway Administration (FHWA) sponsored committees, meetings, and publications, including "National Perspective on ABC" by Vasant Mistry from the 2007 American Association of State Highway and Transportation Officials (AASHTO) Bridge Subcommittee Annual Meeting and "Prefabricated Bridge Elements and Systems" by Benjamin Tang and Mary Lou Ralls from the AASHTO HSCOBS Meeting, June 2005.

Rapid construction has several advantages over conventional construction methods. The main advantages of innovative rapid construction technology can be summarized as follows:

- Reduced construction time on highway projects, applicable both to bridges and road work,
- An improved construction quality,
- An improved work-zone safety,
- An improved constructability,
- Minimized traffic disruption and reduced adverse impacts on the traveling public.
- Minimized environmental impact,
- Lower life-cycle costs.

The importance of rapid construction technologies has been recognized by FHWA and adopted by many states such as the Iowa DOT Office of Bridges and Structures. In this day and age of jet travel, speedy bridge construction in terms of months rather than in years does not come as a surprise. ABC aims at making the engineer–contractor team a united force rather than two weaker separate entities with different ideas. As a result, all the team members (client, consultant, and contractor) can focus more on the technical aspects and can come up with the ways and means for rapid construction.

There is an old saying that "time is money." Early completion means being able to reaping the benefits of new or repaired bridges and highways sooner rather than later. For speedy implementation, incentives need to be given. For example, in conventional bridge construction, the contractor is awarded a bonus for completion ahead of the schedule. Such incentives will lead to more efficient decision making and more effective utilization of resources by the contractor and serve as a successful business trend in the lucrative construction industry. Design–build team work is one example.

Factors governing design and rapid construction include planning concepts and designing for constructability, erection, serviceability, durability, maintainability, inspectability, economy, and aesthetics. By taking advantage of the recent developments and innovations in computing, analytical and sensing technologies, accelerated design and construction is possible.

One of the most common ways to accelerate bridge construction is to use Prefabricated Bridge Elements and Systems (PBES) to construct the bridge. These are prefabricated off-site or adjacent to the actual bridge site ahead of time, and then moved into place when needed, resulting in closure of the bridge for only a short duration. Very frequently, these PBES are constructed with concrete (reinforced, pre-tensioned, post-tensioned, or a combination thereof).

1.2.2 ABC logistics

ABC is a means to an end and not an end in itself. It is a convenient but special path to take for rapid construction. A return to the forgotten fundamentals in construction for some cases may be desirable. We may also need to revisit the original decisions made by pioneer bridge builders as a result of which there are still so many century-old historical bridges in Europe and the United States.

As an example of old ingenuity, the use of double rows of bearings in continuous bridges is a sign of added security against total bridge collapse. Also, fully covered bridges with canopies increase the life of the bridge deck and prevent accidents due to the absence of deck drainage problems. Such bridges are artistic and are open to traffic even in snow-fall and are generally free from the adverse effects of deicing salts.

1.2.3 ABC strategic topics and their advancement

Technical issues are addressed in Chapter 5, progress of asset management in Chapter 6, and planning issues and resolving ABC issues in Chapter 7. Advancement in ABC is seen by many states and transportation agencies implementing ABC methods.

Constructability and Planning: A common and viable reason for using ABC is dealing with site constructability issues. Oftentimes long detours, costly use of a temporary bridge structure, remote site locations, and limited construction periods due to bad weather present opportunities where the use of ABC methods can provide more practical and economical solutions as compared to conventional construction methods. As such, project planning tools with innovative solutions are provided to help streamline the development process and ensure successful implementation of ABC.

ABC uses innovative planning, designs, materials, and construction methods for bridges, in a safe and cost-effective manner. It reduces the onsite construction and project delivery time without sacrificing quality or increasing the cost.

The following physical concepts may be helpful in achieving these benefits:

Labor teams—Timely and experienced labor (engineers, foremen, technicians, and site workers) would be available for performing established repetitive items on more than one project.
Prefabrication—Bad weather problems are avoided due to indoor factory work.
Product support—ABC schedule allows acquiring products made in other states and throughout the world.
Working area—Storage yard area for materials, equipment, and assembly of components is generally available at or near construction sites.
Quality control—Factory construction allows temperature and humidity control.
Using the critical path method (*CPM*)—Time of construction is shorter thanks to parallel activities.
Daily progress—Reduced construction inspection time as construction progresses with ABC.

Obtaining environmental permits—Infrastructure owners, designers, and builders will continue to struggle with the costly challenges of environmental permitting and the schedule delays that result. Planning measures can help reduce the unit cost of construction by at least 10%, say from $200 to say $180/ft^2.

Chapter 3 addresses permits issues, Chapters 7 and 9 describe environmental issues, and impacts of rapid construction are given in Chapter 10.

Cost savings—Improved communications, engineering, logistics, and construction technologies now allow construction companies to take advantage of cost-saving techniques. Achieving economy because of rapid labor utilization during speedy construction is possible. Individual construction versus mass production is more expensive.

Hazards control—Accidents, crane collapses, casualties, and injuries need to be avoided. Improving work-zone safety for the labor and traveling public would help.

Provisions for future widening and other modifications—ABC goes hand in hand with accelerated bridge planning (ABP). To implement ABC with confidence, an applicable code for ABP and relevant specifications are needed. It is desirable to develop recommendations for adopting an innovative approach and for further research in the emerging construction technology.

Based on the author's experience, the New Jersey DOT (NJDOT) has been at the forefront of promoting and implementing innovative technologies for deck replacement, superstructure replacement, and bridge replacement. Some of the methods to achieve these benefits include the following:

- Improved work zone safety.
- Minimum environmental disruption.
- Providing rider safety and comfort by using jointless decks and integral abutments. No more inspections of the delicate bearings are required.
- Audits are in place at NJDOT to ensure actions from designers and project managers for the following:
  - New manufacture processes for rapid construction,
  - Durable connection details for prefabricated bridge elements,
  - Management programs,
  - Quality assurance,
  - Studying and adopting alternatives.

1.2.4 Redefining modern ABC

ABC can be defined as a paradigm shift in the project planning and procurement approach. The onsite construction activities are performed as a higher priority. The following details the benefits of all aspects of ABC:

- Reduces overall project costs.
- Reduces inspection, police work, and flagging.
- Reduces field office rentals.
- Reduces inflationary bid costs.
- Reduces indirect costs to society (user costs and/or project costs).
- Reduces environmental impacts.
- Leads to improved constructability.

The "every day counts" (EDC) initiative by FHWA dovetails with the intrinsic benefits of the ABC approach to achieve improvements in safety, durability, social costs, environmental impacts, ease of future widening, and other modifications. The following ideas in particular are being considered and explored for implementation: traffic impacts, life-cycle costs, maintenance requirements, and reliability.

1.3 Scope of ABC work

This section describes need for team work; reorganization of construction management; the role of consultant, contractor, and client; ABC training requirements; and topics of staged construction and alternative design–build construction procedures.

Need for Team work for Early Completion: Early completion is the paramount project consideration. Nothing should stand in the way of completing a project in the most efficient, cost-effective, and highest-quality manner.

When the owner, engineers, and contractor work together early in the process, good things happen. Many experts are better than one. Good engineering also minimizes quick fixes and changes in the field.

The time factor becomes more important when work needs to be completed in good weather. Extreme cold or hot weather is inconvenient for the workforce. It always costs more and is likely to affect quality (for example, curing time and the process required for cast-in place/in situ concrete). Minimizing adverse impacts on traffic is the legislative requirement of some states. Further research on this new rapid construction technology is in progress by FHWA and National Cooperative Highway Research Program (NCHRP).

A wide-ranging program on the idea of rapid renewal for highway infrastructure reveals that three objectives can be identified to achieve renewals:

Perform construction rapidly: Resources are committed by the contractor and the consultant to meet agreed milestones shown in the schedule.

Cause minimal disruption: Provisions should be made to overcome bad weather, labor shortage, and equipment breakdown, etc.

Produce a durable structure: Life-cycle costs of repairs can be minimized by durable bearings and deck slab, etc.
Use of relevant codes and manuals: The FHWA manual will complement ABC work (Reference Project R04: Innovative Bridge Designs for Rapid Renewal). Project R04 documents innovative designs in more detail than the FHWA manual.

1.3.1 Segmental bridges for long span ABC

There are various types of segmental bridges to which PBES is applicable, such as the following:

- Balanced cantilever construction using cast in situ or precast segments,
- Spliced girder superstructure constructed using concrete stitch or epoxy joint, etc.
- Precast segmental superstructure, simply supported or continuous (internally or externally prestressed), epoxy jointed or dry jointed.

There are many forms of segmental construction. However, the most popularly known form of segmental construction is precast segmental superstructure, constructed by the span-by span method of construction. In this technique, precast box girder segments, aggregating a total length equal to approximately one span at a time, are assembled and prestressed. Thereafter, segments of similar total length are assembled for each subsequent span.

At each stage, prestressing has to be carried out, in order to make the constructed structure self-supporting. It may be noted that the precast segmental superstructure, so constructed, has to necessarily be prestressed, as untensioned reinforcement cannot continue through the joints of precast segments.

Assembling of precast segments is facilitated through either underslung assembly truss or an overhead assembly truss.

Underslung Assembly Truss.
Overhead Assembly Truss.
Derivative of Overhead Launching System.

Incremental Launching Erection Methods Using,

Balanced Cantilever Construction,
Spliced Girder System, or
Launching of Full Span Box Girder.

Speed of construction is of paramount importance because the infrastructure facility is always a prerequisite to development of an area. Furthermore, in externally financed projects, the investor has a commercial stake, wherein he has to start collecting toll as soon as possible. A careful planning of erection techniques for the launching of segmental bridges can lead to the desired speed and economics. Use of precast concrete makes the structure amenable to better aesthetic appeal, due to better finish and adaptability to innovative designs.

1.3.2 Reorganizing construction management directives and chain of command

The organization of a contractor-consultant team usually reduces any disagreements between the consultant and the contractor that are encountered when the consultant has an upper hand. Contractors can play a greater role than before, in the planning of the bridge and in applying value-engineering methods for cutting overhead costs to achieve earlier completion of the project. ABC can best be promoted by analyzing alternate approaches for arriving at shortcuts to months of activities. For large transportation projects, the following options are available:

- The *design/build/finance/operate/maintain* (*D-B-F-O-M*) system is likely to be a complete situation. Long-term toll bridge projects with long spans and complex geometry may use this system.
- The *design/build/operate* (*D-B-O*) *system* is also used. Wide rivers that allow navigation of ships require bridges to be operated several times a day. Additional costs are involved for opening and closing river bridges for daily ship traffic.
- The *simpler design/build (D-B) system* is more common and places the builder and designer in one team. This approach has had some leadership snags but in the interest of rapid construction the contractor is also a decision maker and not just the consultant alone. This management option has led to faster turnout than the first two options.
- The *Build/operate/transfer (BOT) system* is similar to the design–build system. The contractor delivers the bridge, then operates and transfers it to the client after an initial fixed period. The initial performance period removes any snags.

1.3.3 Use of negotiated contracts

The types of contract generally in vogue use one of the following

- Unit rates for major or selected items
- Lump sum for selected items
- Lump sum for the entire project.

Lump sum contracts are simpler to manage since unit rates for hundreds of items are not directly applicable. In all cases, the parties adhere to estimates of quantities as shown on drawings.

1.3.4 Alternative design–build construction procedures

Chapter 2 addresses design–build contracting system and the role of the Design Build Institute of America (DBIA) in promoting ABC. Chapter 3 describes training programs in ABC organized by DBIA; Chapter 4 deals with design–build construction management, and the progress of design–build is the subject of Chapter 7.

The issues related to bridge construction or the reconstructions of bridges in the United States are manifold. Each scenario requires a different construction sequence. Usually the construction sequence of a bridge, including the approaches, is coordinated with highway construction for streamlining traffic flow.

New bridge construction on a new highway: ABC can be more easily applied for brand new sites.
Replacing an existing bridge: After a useful (minimum) life of 75 years, bridges are due for replacement. Common reasons are increase in the volume of traffic, increase in truck live loads, wear and tear, or low rating from structural deficiencies.
Widening the deck for providing additional lanes: A partial new bridge may be more economical when an existing bridge is not likely to be replaced in the next 20 years. Additional lanes are constructed on one or both sides of the bridge. This helps reduce traffic congestion.

In the absence of a suitable detour route, staged construction would be required to maintain the flow of traffic during construction. During construction, the number of available traffic lanes may be reduced.

Staged construction: Due to MPT requirements, construction in stages would be more difficult to implement than the un-staged construction of a new bridge since safety and traffic issues would not arise.

MPT issues are described in Chapter 7 and traffic volume and lane closures in Chapter 10.

Use of temporary bridge in place of detour: On essential routes where a detour is not feasible, a temporary bridge may be erected on either side of the existing bridge (similar to a military bridge erection and demolition). An example is a Mabey bridge.

The latest research and study of successful ABC projects will help the client in receiving an early finished project and releasing the project manager and his team from the day-to-day management duties so that the team can move on to another project. The ABC aspects and related implications for projects costing hundreds of millions of dollars are reviewed in the chapters to follow.

1.3.5 Consultant's modified role in ABC contracts

Modern consulting applications of ABC would include technical consultancy, testing, inspections and certification, risk management, and verification.

For accelerated construction, team coordination is necessary. It helps the consultant in taking all physical factors into consideration in the detailed design. Final changes will arise out of transportation of sub-assemblies or development of an erection design.

Consulting engineers are expected to advise support organizations along the energy value chain (producers, suppliers of solar energy panels for bridge lighting, equipment and crane manufacturers). Consultants can focus more on research into new materials, sophisticated mathematical methods of analysis, computer applications, and detailed design.

It is a return to forgotten fundamentals. In the olden days, there were no water-tight compartments between the contractor (who was not regarded as an "engineer") and the consultants. One such example is the pioneer construction of Brooklyn Bridge foundations under difficult conditions by unified team work.

1.3.6 Contractor's leadership role in achieving early completion

Various aspects of contractor's role such as that of construction manager/general manager are described in Chapters 2 and 7. Alternative ABC contracting methods are described in Chapters 6 and 9. The consultant's requirements may sometimes reflect "easier said than done" type of demands. On medium and large projects, the difference of opinion on technical matters may cause friction and may not be in the best interests of the project completion.

The structural design developed by the consultant may not always embrace construction conditions and construction load combinations. Special provisions are written by the consultant before a contractor is selected, and there may be a certain lack of a realistic approach that is too difficult to amend once construction has started. "Changing horses midstream" is not always feasible. The quality of construction drawings prepared by consultant may not always be complete to the minutest details. Sometimes, the most capable designer or senior engineer in charge of the project may have left the company, creating an information gap.

On any contract, it is customary for the contractor to ask for clarifications in writing in the form of request for information (RFI) or changes in field data leading to a design change notice (DCN). This leads to cost increases and delays in completion.

In conventional practice, a contractor may not get involved with the planning of the bridge or selection of materials. Some clients encourage value-engineering exercises to reevaluate costs. Even this indirect approach may be a little too late. The contractor is not being given his due share of decision making, including in selection of technical details, which could help the contractor finish the job to the best of his ability with limited resources. He is under bureaucratic pressure from the client and often has to comply with the consultant's overemphasis of certain formalities of trivial nature. The projects take longer to finish and overheads increase the cost to the client, which are shared by the public.

Unlike the contractor's selection, the consultant's selection by the client is not based on minimum cost, but rather on his technical know-how and experience. The team effort in conventional construction is usually nonexistent as the contractor has to "do as told." Also, contractual obligations may restrict improvements during construction. Hence the detailed design should be merged with construction practice in close conformity to the resources available. A design–build approach seems to eliminate many such difficulties. Both the contractor and his selected consultant agree up front to submit a practical solution that will lead to minimum cost and be implemented in the minimum possible time.

In the recent past, the design–build approach has shown promise and is being applied to a greater number of projects. It is based on friendship between the consultant and contractor and minimizing or eliminating friction. New ideas are generated because of mutual effort. Also, the design aspects conform to the pre-agreed solution.

1.3.7 Providing management opportunities and incentives to contractor

Incorporating unforeseen factors such as soil conditions or possible delays in supply of materials may be out of the jurisdiction of the contractor. Progress planning for safe and rapid construction and efficient implementation requires the selection of alternative construction methodologies and techniques. There is generally a bonus if a contractor finishes the work ahead of the agreed schedule, but there are in-built penalties such as losing any retention money if he does not. In addition, if there is any deficiency related to design, drawings, or construction specifications (in which he was not involved), he is supposed to spot it using his judgment, expertise, and experience and bring it to the timely notice of the client.

It is therefore logical that to achieve reasonable rapid progress, the contractor is given a due role in planning, coordination, and progress management of the project through the ABC methodology.

ABC aims at promoting value-engineering methods to arrive at innovative and novel solutions. In many cases, contractor has a better feel of the smaller but practical issues and is entrusted and receives or is rewarded with a much higher share of the construction budget than the consultant.

Encouraging the use of modern sophisticated equipment (by increasing the number of ABC projects) reduces overheads and allows the contractor repeated usages of investments in lifting cranes and machinery. For example, overheads will be less in small projects compared to medium projects (that may not come at regular intervals). As a result, because of repeated use, the equipment/cranes will not remain idle and investments will have good returns.

1.3.8 Contractor's responsibility toward maintaining the schedule

In conventional contracts, the contractor must stick to the agreed schedule. On major projects, there is a resident engineer on the site representing the client or the consultant and who is a watchdog that monitors the day-to-day progress and safety during construction. Hence construction progress, according to the bar chart or using the CPM in terms of milestones, is a highly sensitive issue, and the selected contractor is paid handsomely for his many resources and experience and for the ordeal.

Progress charts: Bar charts showing the duration of each activity are now being replaced by network using CPM. Computer software will show which activities are on the critical path and those that should be performed in parallel (simultaneously but without interference with each other).

Unpredictable weather, timely supply of materials, and trained labor are other issues. No wonder bridge projects extend over years and cost a fortune. Recent examples of huge investments are Boston Big Dig, the Bay Bridge near San Francisco, and the planned Tappan Zee, Verrazano, Goethals, and other bridges in the Northeast, to name a few. There are many other projects spread all over the country, the prolonged construction duration of which will adversely affect public comfort and wasted dollars. They cause immense difficulties to users of the road in terms of traffic disruption.

1.3.9 Registration requirements for selection of design–build teams

On important bridge projects, besides the lowest bid, adequate successful experience of the contractor and design experience of consultant in ABP and accelerated bridge design (ABD) are required, preferably for both the contractor and consultant.

Every DOT has established procedures for selection of consultant and contractors. However, ABC would require additional demands. The following information will be helpful to the client for screening and in prequalification, but the client is free to make his own rules from experience acquired on past or ongoing projects:

Special registration with the client as an ABC contractor: Proof of practical experience in ABC is required.
Normal registration with the client as contractor on routine bridge projects: Proof of practical experience on conventional projects is also required.
Volume of past experience on ABC projects as a specialized contractor or sub-contractor: A minimum three ABC projects should have been successfully completed. Subcontracting experience is also acceptable.
Volume of past experience on routine bridge projects as a contractor or sub-contractor: A minimum of three ABC projects should have been successfully completed. Subcontracting experience is also acceptable.
Size of projects successfully completed (small/medium/large): The smallest job should not be less than $0.5 million.
Was there any dispute or arbitration? Details need to be submitted.
Was the contractor ever blacklisted? If so, how long ago?: Details need to be submitted.
Contractor's resourcefulness in terms of cranes, heavy machinery, and equipment: Ownership or rental records need to be submitted.

Experience of consultant on similar projects and ability to guide the technical aspects: A record of working on similar types of bridge projects needs to be submitted.
Has the design–build team received training in ABC as recommended by FHWA? A minimum one week's training course carrying professional development hours is required.
Amount of earnest money or security deposit to be received from the contractor: A 1.0–2.0% deposit is required as earnest money. It is refunded after successful completion of the project.

The above considerations in selection will prevent future hiccups during construction.

1.3.10 Client's perspective and ABC training requirements

Chapter 3 describes training of personnel in ABC for meeting registration requirements to become a licensed engineer. Owners of bridges are mostly state and local governments, cities, and townships. Sometimes, corporations and non-governmental organizations also own the bridges on their properties. Special education and training of bridge engineers and constructors is necessary for ABC and should be encouraged by the client.

Current management can best be described as an "indirect" control over daily progress. It is in place partly because of proxy representation of the owner by the consultant (who has won his job owing to technical abilities lacking in the owner). The client has a need to rely on the consultant for assistance as a middle man, rather than be misled by the contractor. The contractor is generally more experienced at manipulation of contractual clauses.

The flip side is that the contract document in the conventional method gives the contractor certain security against losses from circumstances out of his control, such as price increase or extreme weather. Quick interpretation may sometimes be difficult for the owner. Issues can be more easily resolved in the presence of the consultant and every effort is made to resolve any dispute that arises. If a contractor's claim for unforeseen items is referred to arbitration, it may delay the project, especially if the decision goes in favor of the contractor.

1.3.11 Training of personnel and ABC topics

Providing training facilities to engineers and also to technicians (representing the client, consultant, and contractor) helps in the successful management of rapid construction projects. Training topics may include presenting important material from a variety of highway organizations and regulatory agencies in a classroom environment, such as the following:

Advantages of ABC techniques, including utility management: All team members should be on the same page about achieving the agreed benefits and early coordination with utility agencies.
Methods of preparing proposals for new projects: White papers and written reports that demonstrate thought leadership on ABC issues may be discussed,
Staying abreast of energy efficiency and sustainability developments: On any project, the use of the power supply for equipment, the site office, and site lighting is important. The modern trend is to minimize dependency on oil usage for power generation and adopt less expensive solar power.
Design and construction codes: Recent advancements in developing and applying knowledge about current and notable codes, market issues, and technology advancements should be addressed.

Specialty Conferences: Participation in relevant trade shows and events relating national, regional, and local ABC initiatives should be encouraged.
Use of lightweight materials: Greater attention can be paid to enhance bridge architecture and aesthetics, by introducing lighter and properly anchored components using stronger materials. Rapid construction should not be at the expense of quality, cost, or aesthetics. According to the poet John Keats, "*A thing of beauty is a joy forever*" and bridges seem to uplift the landscape.

1.4 Multiple factors that may affect ABC progress and benefits

This section deals with multiple factors affecting ABC costs and progress, including financial issues, influential engineering operations linked to ABC, mobilization, demolition, construction inventory such as bridge lighting and traffic signs, and easy accessibility to the site. Many construction activities in conventional construction and ABC happen to be similar. However, minor differences between the two construction methods and the management structure involved lead to more rapid completion.

Unfamiliarity of the process: Modular design is tested beyond the first use and tends to be more reliable. Technical experience is the best guide, as the saying goes "practice makes perfect."
Cost of training for staff: With new technology there is always a need for training, but it is a good investment.
Fabrication timeline: A realistic duration is required for new factory products.
Repetition of use of similar modular elements: No training is needed for the specific task.
Repetition of continued work by the same labor on similar projects: No training is needed to perform the tasks for similar new projects, resulting in cost saving and early completion.

1.4.1 Constraints affecting timely completion

On any million-dollar project, these are independent linked activities, both administrative and technical. They occur mainly before starting construction, but also during the postconstruction stage, slowing down ABC. These may be summarized as follows:

Financial approval of millions of dollars: The need for increased funding because of rising costs, inflation, and unforeseen circumstances is always the biggest problem. The state budget and Highway Trust Fund are the usual sources. Projects can get delayed indefinitely even though compensated to some extent by using ABC.
Preparing bid documents for a design–build contract: The success of any project is based on accurate documents on which cost of the project is calculated. After funding, the contract documents are the most critical for project implementation and completion.
Selection process for contractor and consultant team: The aim should be to acquire the right people for the right job. It is not easy to change horses midstream.
Structural planning and design for speedy construction: Prefabricated, lightweight, and durable structures are preferred.
Feasibility of construction schedule: Use of computer software for the program evaluation and review technique (PERT), CPM, and parallel activities should identify activities on the critical path.

Value engineering: An in-depth practical approach for comparing the merits of alternative solutions would help identify expensive items for design modifications before the start of the project.
Environmental permits approval: Any adverse impacts on the environment such as loss of fauna and flora need to be examined. The project should not just solve one problem but create others.

1.4.2 Construction sequence and inventory

Utilities relocation for water, gas, and other pipes: During construction, coordination with the agencies will be required for provision of utility pipes supported by cross beams under the bridge (such as for water, gas, telephone, and cable).

Providing easy access to site: Lack of easy access would adversely affect progress of the job.

Site preparation: Site preparation requires providing easy access to labor and equipment for foundation construction at the level below the bridge and also at the deck level. Space needs to be provided for the storage of materials and for a yard for assembling the girders close to the site.

Mobilization: A temporary site office with computing, telephone, parking, and other facilities needs to be set up. It will be used by for 4–12 engineers and inspectors, depending on the size of project. The full-time engineers will be resident to monitor daily progress, quality control, and cost control. A backup team at the main office will support them. Mobilization will require setting up storage depots near bridge approaches.

Office and storage facilities need to be arranged.

Demolition: Existing superstructure can be cut and removed in stages or in one go. Recycling would meet environmental regulations.

Entry and exit ramps: These may be located a long distance away from the site since not every ramp has a gentle curve for long trailers to negotiate.

Approaches to bridges: Access to the site may be provided at the “begin bridge” or at the “end bridge” side. One or more lanes may be closed as required. Both daytime and night-time work may be required to meet the completion milestone.

Using grouting methods or soil injections: This can be used for improving foundation soil, including liquefaction mitigation to protect foundations in salt water against corrosion; resistance to earthquakes, liquefaction, and erosion of soil under footings; preventing fender damage from vessel collision.

Wing walls, retaining walls, MSE walls, and noise walls: Precast, modular, or quicksetting walls are preferred for an early completion. For example, the proprietary design and construction drawings for MSE walls are provided by a vendor or wall manufacturer.

Acceleration and deceleration lanes: In planning a new bridge, an acceleration and deceleration lane will be required when the decks are located close to exit or entry ramps.

Foundations (*a geotechnical discipline*): For the soil report borings need to be made preferably at the approaches and behind proposed wing walls. Soil reports and the type of foundation to be selected are usually recommended by a geotechnical engineer with the necessary expertise. The type of foundation is least affected when using either conventional construction or ABC methods. However, with ABC a lighter superstructure will be designed, thus reducing the foundation loads. With ABC, the foundations will be lighter and the design–build method will be an advantage.

Improving bearings performance: Use of multi-rotational and isolation bearings in seismic zones is recommended.

Staged construction: For replacement projects, it is desirable to reconstruct one travel lane at a time after that lane is cut and removed so that most of the bridge is usable and traffic disruption is minimized.

Timely construction of approaches: Concrete slab on grade with retaining walls are generally used.

Bridge Lighting: Temporary generators will be required for lighting for night-time work. An electrical engineer will ensure coordination with the utility company for long-term deck and overhead lighting. The locations of overhead lighting poles at the approaches and the deck need to be identified. The use of solar panels is encouraged for energy saving. The installation of solar panels at approaches for bridge lighting and signage is performed by an electrical engineer. Coordination with the utility company is required.

Deck drainage: Longitudinal and cross slopes will be provided for rapid drainage of rainwater. In keeping with the maximum intensity of rainfall, the sizes of scuppers and inlet and outlet pipes will be computed. Vertical pipes spacing on the deck and approaches will follow maximum spacing as required by the state bridge design manual and AASHTO code. The maximum rainfall intensity will dictate the sizes and spacing of scuppers. The deck drainage system needs to be connected to the public sewer system. Meetings need to be held with the utility company and advance approval obtained.

Constructing bio-retention ponds: These will collect and filter runoff from the bridge deck.

1.4.3 Engineering tasks preceding ABC

Accelerated construction is not possible without effective mobilization and demolition. It is preceded by ABP and staged construction (SC) for replacement. Replacement may be for the entire bridge and its approaches or of a bridge component, for example, bearings only.

The owner's requirements are clear: reduction in schedule, wider decks, reduced seismic effects, increased bridge ratings, longer service life, cost savings, and lower maintenance.

Hence, ABP must promote durability and compliance with environmental/preservation laws. An evaluation matrix for construction cost, life-cycle cost, environmental and social impact, constructability, future maintenance, inspection, and aesthetics needs to be prepared at the planning stage. Planning must address differences in ABC of small, medium, and long spans. Efficient structural planning can minimize the constraints in meeting accelerated construction goals such as erection during extreme weather. The following factors may be considered:

Improving aesthetics: To improve appearance, an exterior arched beam can be provided to hide fascia girders.

Installing interactive touchscreens: Featuring bridge information for motorists.

Increasing rider comfort: By using a durable deck overlay protective system to prevent deck cracking, post-tensioning to prevent cracks in concrete and non-corrosive reinforcement; and also improving crash worthiness of barriers and parapets. Latex modified concrete is one such application.

1.4.4 Influential engineering operations linked to ABC

The major practical aspects can be listed as follows:

- Use of prefabricated deck panels and composite girders such as Inverset.
- Avoidance of splices in long-span girders: planning for river navigation (or designating highway routes) for rapid delivery of heavy girders or precast units from fabrication yards.
- Use of special construction cranes and modern equipment for rapid construction.
- Improvement of cold weather concreting methods to achieve higher strengths.
- Improvement of safety by reducing construction accidents on sites.

Traffic signs, variable-message signs (VMS), and warning signs: Temporary warning signs are important during construction. Electronic VMS signs are preferred over fixed sign boards. Warning, exit, and directional signs must be displayed and conveniently located.

Easy accessibility of the site: The location should be easily accessible for delivery of materials and for feasible transport, allowing for lane closure and temporary ramp construction.

1.4.5 Construction equipment

Manufacturer warranties are desirable against inefficient performance of construction equipment. The need for specialized equipment may be considered for improved performance. Rapid construction is related to modern construction equipment. Examples include the following:

- Excavators
- Mobile cranes
- Truck-mounted cranes
- Jib cranes
- Fork lifts
- Winches and cable pullers
- Waste handlers.

Timely availability of modern construction equipment with an experienced erection team will be necessary. Different erection equipment is required for girders, box beams, trusses, arches, and cable-stayed and suspension cable bridges. An erection contractor must be equipped with the following:

- Tower cranes for maximum lightweight pickup of 20 tons and heights greater than 400 ft.
- Lattice boom crawler cranes for lightweight to medium pickup to 400 ft.
- Mobile lattice boom cranes for lightweight to medium pickup to 300 tons.
- Mobile hydraulic cranes for lightweight to medium pickup to 650 tons.
- Lattice ringer cranes for heavy weight pickup to 1400 tons and 400 ft.

Accessories include separate foundations, crane mats, temporary bents, hydraulic jacks, and temporary pier brackets.

1.5 ABC planning for new and replacement bridges

This section deals with the planning and design aspects for substructure and superstructure components. AASHTO specifications for conventional design and construction lay down basic planning issues. Structural requirements will then follow depending on the geometry and construction materials used. The following aspects applicable to all bridges, including conventional bridges built in the past, need to be covered and if possible refined and addressed for framing a new construction code for ABC.

1.5.1 ABC is linked to accelerated highway construction

It so happens that bridges are a small but unavoidable part of the highway. There are likely to be many bridges located on a given highway. Highways are linked to bridges by bridge approaches resting on grade. The approach sections of the highways are designed by bridge engineers and the long highways are designed by highway engineers.

According to a number of reliable studies on infrastructure maintenance, nearly a third of the nation's major roads need significant repair or replacement, with a far higher percentage in the busiest urban areas. In Washington and its suburbs, it soars to 62%. In the United States, 210 million drivers are affected daily by the condition of the highways and bridge approaches. Some highway and bridge need-based restoration studies are presented below.

1.5.2 Impact of ABC on AHC and vice versa

Highway reconstruction is a subject in itself. Since a highway surface is supported by subgrade material, geotechnical issues are involved. The cross section of highway, cross slopes, lighting, median barriers, and roadway finishes requires special consideration. It generally involves a much larger volume of work and percentage of funding than is allocated for bridge reconstruction. It will be covered in a separate volume.

Generally the transportation agencies plan windows of simultaneous construction work on bridges and on the highway that carries the bridges and culverts scheduled for reconstruction. This approach saves construction time and minimizes adverse traffic impacts and has the advantage of "killing two birds with one stone." The work can be carried out by more than one contractor team, for which coordination is required for activities such as sharing the highway for site access, storage of materials, night-time work, and parking. The coordination is organized by the client and under their guidance.

1.5.3 ABC primary objectives

ABC aims include a range of techniques and processes to reduce costs, duration of construction, and traffic congestion. The primary objectives are therefore constructability, erection, serviceability, durability, maintainability, inspectability, economy, and aesthetics. Detailed primary objectives are as follows:

> *Develop modern codes and construction specifications*: Construction mistakes, ship collision, scour, design deficiency, overload, fatigue, and earthquake are the main causes of failure, which need to be avoided through updated design codes using ABC.

A new design code for each type of construction, accompanied by construction specifications in this specialized area, is required. ABC-related design needs to be made part of AASHTO and state bridge design codes and specifications.

It also requires the development of technical specifications relevant to ABC.

Introduce specialized training of designers and field staff: Repetitive training module for field personnel increases their mobility.

Use of applied mathematical methods of analysis: Apply fracture mechanics in design. Introduce computer modeling applicable to the discontinuities of components and develop and refine further for a representative solution.

Component testing: To gain confidence in the structural behavior, scaled model testing of joints in precast concrete decks of skew and curved plan shapes is required. Monitor construction activities on the critical path to save time and long-term rehabilitation costs.

Ensure safety during construction and after completion for the bridge users.

Uniform mass-scale production of structural components: Improved workmanship under factory conditions. Simplify method of construction, repair and rehabilitation, and implement value engineering principles to reduce costs.

Communications with environment agencies makes it easier to obtain environmental permits,

Short cut to construction administration: Use one experienced team instead of many teams, leading to improved coordination. The contractor employs the type of experienced consultant needed to meet the project requirements. Design is developed with full utilization of the contractor's resources with minimum possible changes. The design–build method has reduced procrastination and has led to increased innovation through competition.

Going green construction: Use of solar technology and alternative energy-saving techniques.

Reduced any overheads: Allow repetitive use of cranes and construction equipment. Small savings would help maintain the completion of project within budget.

Application of the latest techniques in concrete manufacture, fiber reinforced polymer (FRP) concrete, and composites and use of HPS girders and hybrid materials are required.

The FHWA has been pushing the concept of "*Get in, get out and stay out*" and has been advocating ABC techniques. It solves traffic problems.

1.5.4 ABC secondary objectives

The secondary objectives may be summarized as bridge maintenance cost reduction through life-cycle cost analysis, minimizing maintenance frequency and rehabilitation schedules is required.

Optimization: Economy can be achieved by reducing the number of girders through increased spacing for which integrated software, covering all aspects of ABC design and drawings, should be developed. The project should optimize the size and number of girders and use modern material and equipment.

Selecting pleasant bridge colors and aesthetics would promote "*America the Beautiful*."

Designing longer lasting bridges for seismic design and modern scour countermeasures needs to be promoted for ABC.

The project should obtain traffic counts for selecting full or partial detour and apply temporary construction staging. On important highway routes carrying heavy traffic (high ADT), a deteriorated bridge may become a hazard to users. Emergency replacement would be required to reduce the impacts of bridge work on traffic.

1.5.5 Minimizing bridge failures by applying modern ABC methods

There are about 600,000 bridges in the United States, with 500,000 of them over water. Between 1966 and 2005, there have been approximately 1500 bridge collapses in the United States, and those causes are documented. According to J. L. Breau (First International Conference on Scour held at Texas A&M University), in terms of causes of bridge failures, historically scour (soil erosion around bridge pilings) accounts for about 60% of collapses (also called hydraulic). A distant second involves ship collisions at 12% (Figure 1.2).

Improve construction zone safety: Because prefabrication moves much of the preparation work off-site for bridge construction, the amount of time that workers are required to operate on-site, frequently in or near traffic or at elevations or over water, is greatly diminished. Job site constraints such as nearby power lines are minimized when contractors can complete most of their construction off-site.

Improved traffic control and MPT: Contractor and motorist safety is improved by reducing the time that a work zone is in use.

Work on approaches and the bridge deck will require a detour.

The project planners should investigate alternatives, either to detour one direction of traffic or both directions and provide for pedestrians. An 8–10 h night window is required. A traffic count needs to be performed to assess the impact on traffic flow during construction.

Using prefabricated bridge elements and systems means that time-consuming formwork construction, curing, and other tasks associated with fabrication can be done off-site in a controlled environment, without affecting traffic.

Minimizing Failures during Construction: The contractor has a better grip of the construction activities including the safety of labor. He will try his utmost to avoid any failure during construction especially if it results in the loss of life. Figure 1.2 shows that the largest number of failures occurs at bridge sites.

ABC is linked to HC. Night-time construction needs to be kept to a minimum since labor charges are higher and power supply for night-time work adds to the cost. This would apply to a brand new bridge on a new highway or to a replacement bridge on an existing highway.

Approaches on both sides of the bridge are usually required. Instead of conventional cast in place retaining walls, MSE walls will be preferred and coordinated with the construction schedule of the ABC.

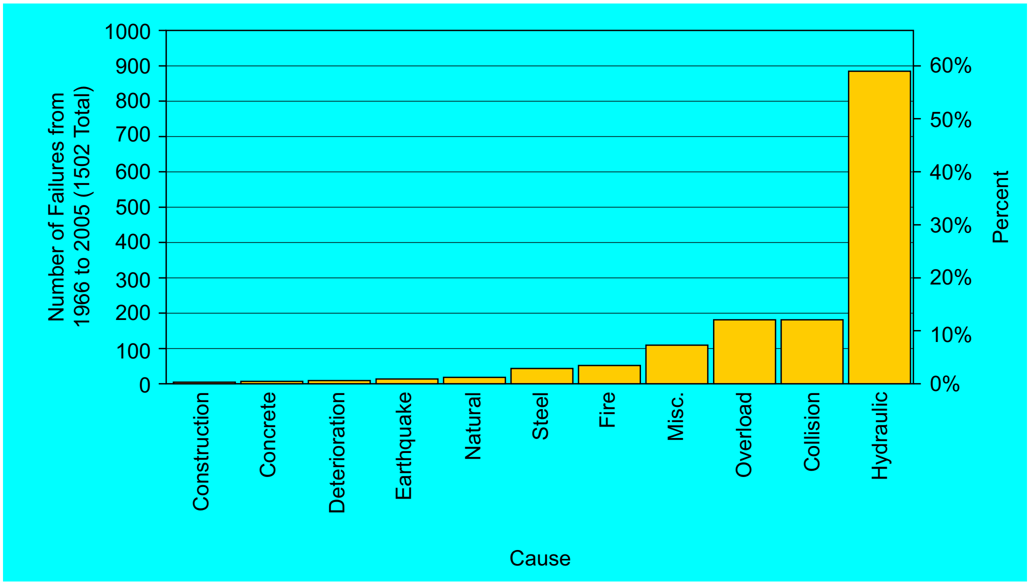

FIGURE 1.2

Causes of bridge failures (reported by Professor Jean Louis Briaud) of Texas A & M University.

1.5.6 Planning and design of substructure

This method of substructure construction is most sensitive to tolerance requirements since it supports the entire bridge. The substructure work consists of the following components:

Foundations: Use of grouting methods for improving foundation soil.
Abutments: Use of semi-integral and integral abutments, with a single row of piles.
Retaining walls: Use of three-sided precast wall culverts; use of modular retaining walls.
Precast concrete sheeting: It has been used as retaining walls, wing walls, and components of the bridge abutment. Due to precast construction, there are many advantages such site impacts are reduced and forming and curing times are eliminated. Construction of these types of walls requires detailed geotechnical reconnaissance, and careful attention to permitted tolerances, and precast multiple pile bent piers avoid large excavations to construct a spread footing. It avoids taking considerably more mainline traffic out of service (to perform the excavation to build a spread footing). It allows for faster construction as all elements are precast. It eliminates the need for constructing formwork, reinforcement steel placement, concrete pouring, and curing.
Piers: Use of precast concrete pier caps and at river locations; piers need to be avoided as their construction adversely affects the fauna and flora. Another goal is to prevent timber fender damage around piers from vessel collision.
Bearings: Elastomeric, multi-rotational, or isolation types.
Foundation protection: Use modern scour countermeasures, other than riprap.
Improving drainage: At bridge sites during construction.

1.5.7 Planning and design of superstructure

Chapter 8 addresses in detail prefabrication of superstructure.

Superstructure construction includes girders, deck, surfacing, median barriers, and parapets.

For ABC, girders or trusses will be assembled before placing them in position on fixed and free bearing types. Cranes will be located on both sides of the bridge to lift assembled girders or trusses into position. Cross frames and bracings will be assembled. Suitable adjustments need to be made for arch bridges and suspension bridges, in accordance with the drawings.

ABC progress includes the following tasks in planning and design:

Girders: Optimization of girders, use of HPS 100W steel girders, long-span segmental bridges design and construction.
Decks: Use of orthotropic and exodermic decks, increasing rider comfort by using a durable deck overlay protective system and methods for preventing deck cracking; use of FRP concrete, corrosion inhibitors, and other chemicals. The deck geometry will be straight, skew, or curved in the plan.
Sight distances and deck super-elevation: To avoid any accidents, the degree of horizontal and vertical curvatures must meet code requirements.
Deck surface: Special finishes such as latex modified concrete may be used.
Deck joints: These will be filled up with grout for unifying precast panels.
Parapets: Improving crash worthiness of barriers and parapets. For areas subjected to high wind and floods, open parapets will be preferred.
Transverse and longitudinal slopes: The minimum slopes for drainage of rainwater will be provided.

Use of deicing salts: Rapid deicing of snow during construction may be required. Deicing salts will be made available at the storage.
Signage: Use of electronic VMS and dynamic message signs structures.
Lighting: Improved bridge lighting methods.

Detailed planning requirements for ABC for each type of bridge are discussed in a later chapter.

1.5.8 Variations in bridge construction completion time

Practical solutions cannot always be just one single solution owing to alternative approaches.

Projects are likely to get delayed for the following reasons:

- Ineffective construction management,
- Planning reasons,
- Funding provisions,
- Specialized bridge engineering workforce is at times limited, restricting the ability to finish the job in time,
- Delays in acquiring construction permits,
- Lane closures leading to traffic jams,
- Detours increasing daily commute time,
- Speed restrictions.

The impacts are generally greater at recurring exits for towns and cities and on emergency routes designated for:

- Hospitals (delaying ambulances),
- Schools (delaying buses),
- Military (defense readiness).

To solve these perennial problems, timely fixing of the bridges is therefore of the essence. Hence the construction process needs to be accelerated and rapid completion is the order of the day.

1.5.9 Use of special traffic engineering techniques during ABC

ADT and ADTT on a given highway will influence the method of construction. Traffic engineering to permit uninterrupted traffic will be necessary.

The use of staged construction for replacing, widening, or deck resurfacing of existing bridges will be required. Lane closures and detours require intensive traffic planning with temporary traffic lights. Night work is generally required to complete the bridge in minimum possible time. Providing temporary steel bridges (such as Mabey) during construction is an alternative approach.

An ASCE report states that 42% of urban roadways suffer from congestion, costing an estimated $101 billion in wasted time and gasoline each year. It is important to protect, maintain, and preserve the aging population of bridges and to achieve durability in new construction. As discussed earlier, we need innovative techniques, strategies, and technologies in modern construction.

1.5.10 Time metrics for ABC

To gauge the effectiveness of ABC, two time metrics are used:

On-site construction time: The period of time from when a contractor alters the project site location until all construction-related activity is removed. This includes, but is not limited to, the removal of maintenance of traffic, materials, equipment, and personnel.
Mobility impact time: Any period of time the traffic flow of the transportation network is reduced because of onsite construction activities.

Traffic impacts within 1–24 h.
Traffic impacts within 3 days.
Traffic impacts within 2 weeks.
Traffic impacts within 3 months.
Due to fewer construction delays and traffic impacts, the overall project schedule is significantly reduced by months to years.

Using Information Technology in Construction Technology: ABC is a modern approach applied to bridge engineering. The construction industry has made significant progress in the recent past with improvements in materials, equipment, communications, and information technology. The impact of improved communications resulting from the internet, e-mails, cell phones, fax, and camera and video technology have also contributed to improved bridge construction duration, to some extent.

1.5.11 Resolving utility relocation issues

The utility task is usually on a critical path; the project manager will begin coordination with utility owners right after the notice to proceed. The contractor must have state-of-the-art equipment and custom rigs to provide a full array of field services for subsurface utility assignment. Utility relocation and replacement need to be coordinated with the utility company to complete the work on time.

Sign structures need to be planned and accommodated within the construction schedule. The power supply requirements need to be approved by the power supply company.

ABC can help build bridges safer, faster, and better. We must balance speed, quality, and economy to achieve these goals. ABC is useful for emergency replacement of bridges damaged from vehicular accidents, ship collision, flood, or earthquake, for which accelerated planning and design will also be necessary.

Using ABC, formwork and much of the usual concrete placement and curing are not required. However, activities such as borehole tests, pile driving, shop drawing review, and closure pour are unchanged. An ABC design code based on ABP for alternatives and new connection design for segmental PC beams or steel pin connections will be required. While there are savings in construction time, design effort is increased because of numerous precast joints and components.

Span lengths in concrete bridges are restricted to about 100 ft due to transport restrictions of heavy components. While cast in place construction is time tested, ABC applications are of recent origin.

Compared to a unified integral abutment bridge, a precast bridge with numerous deck joints is likely to be a little weaker during earthquakes. Full-scale testing is required to develop confidence, especially for curved bridges.

MPT, approach slab construction, permits, utility relocation, etc., are unavoidable constraints.

1.6 Urgency in fixing defective bridges

1.6.1 Surge in new projects using ABC and hidden benefits to economy

This section deals with the surge in new projects that need attention to maintain the current highway system using ABC. ASCE released a report on the US infrastructure rating of D+ in 2013. Even if only a percentage of the ailing highways and bridges are scheduled for repairs, there will likely be a big surge in construction, emphasizing the need for accelerated bridge and highway construction.

The best of roads might last 50 years, perhaps longer if set in a forgiving climate. But once age gets the best of a road, smacking a fresh coat of asphalt on it is like pinning leaves on a dead tree. The subgrade of a roadway develops potholes very much like the ones seen on the surface. That process of erosion advances with the age of the road, and new asphalt or concrete becomes a waste of time and money.

1.6.2 Usual deterrents and bottlenecks

Figure 1.3 shows major bottlenecks that slow down quick construction. Items such as environmental permitting and utilities relocation are outside the control of the construction team.

It is not easy to reduce the bureaucratic setup.

1.6.3 Added drawbacks in conventional methods and proposed solutions for ABC

All types of construction have varying degrees of difficulties with the use of new materials and construction equipment. As a result, safe bridge construction or reconstruction can take months to complete if not years, thus causing enormous problems for daily users. Hence rapid and safe construction methods have become relatively more important than the established conventional analysis and design methods.

We are engineers and not magicians. Some of the difficulties encountered in rapid construction can usually be resolved in the following manner:

Assembling the bridge segments: A site location on an approach next to the bridge is preferred as a temporary workshop to assemble the longitudinal girders and cross frames. This may not always be possible, in which case segments manufactured in factories need to be transported to the distant site, adding to the cost of the bridge.

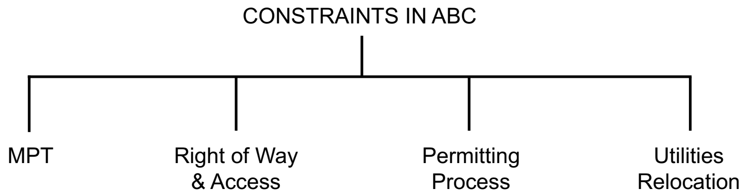

FIGURE 1.3

ABC requires overcoming bottlenecks.

Transporting large pre-assembled components: A long span of bridge can be split into segments at the theoretical point of contra-flexure where dead load bending moments are small or zero. Very long SPMT trailers can be used to transport the segments and they can be assembled at site by pin joints. A river transport facility such as a barge can be used for transport of long members.
Loading and unloading ports: These should be made available within a reasonable distance of the site.
Night-time travel and arranging for police escort: Most states require a police escort and night-time travel, when there is much less traffic on highways for hauling wide loads or long loads. These are precautions required for safety of public; in heavy gusts of wind these loads could become unstable and overturn, causing accidents.
Selecting highway routes with gentle ramps for negotiating wide and long loads when making an exit: A reconnaissance of the proposed travel route is performed to select an optimum route. The radii of entry and exit routes must be large enough so that it is feasible for the trailers to make a sharp turn.
Federal restrictions on very heavy trucks plying on all national highways: US Senator Frank R. Lautenberg from New Jersey reintroduced legislation designed to keep bigger, heavier trucks off all highways. The Safe Highways and Infrastructure Preservation Act of 2013 would apply to existing federal truck sizes of a maximum length of 53 ft and weight limits of 80,000 pounds to the entire National Highway System. Currently, these restrictions apply only to interstate highways.

When super-sized tractor-trailers are on the road, they are a threat to drivers and the integrity of highways and bridges. Closing the loophole that keeps these long, overweight trucks on the National Highway System will protect families and preserve the nation's infrastructure.

Selecting crane locations at both the approaches for erection: For replacing an existing bridge, there may be existing overhead power or telephone lines. To avoid interference, the optimum locations of cranes on approaches or abutments/piers are determined from a site visit in order to satisfy the required length of the boom and height of the crane for lifting the very heavy load. Lifting points should give rise to dead load bending moments that do not exceed the design moments.

Erection conditions: Lifting and erection of trusses or girder assemblies will be carried out when wind velocity is low. Otherwise wind sway may topple the crane, causing injuries to the labor force.

Avoiding flood season when constructing over a river: Flood and rainy seasons are avoided for bridge work over rivers. However, there is little warning of a sudden earthquake.

Precautions for extreme weather: Extreme cold and hot conditions need to be avoided for erection, because of issues with lack of fit of the assembly due to contraction and expansion.

Demolition conditions: Similarly, demolition of an existing bridge for a replacement project is a reverse operation to construction but has added issues of recycling and healthy disposal of materials.

Associated legal, administrative, and technical procedures: Certain procedures still need to be resolved as in conventional bridge construction. All administrative procedures need to be simplified to further facilitate ABC. Examples are as follows:

- MPT for staged construction,
- Safety and protection of labor,
- Construction easement,
- Right of way,
- Temporary traffic signals and warning signs,
- Permit approvals, and
- Utilities relocations.

1.6.4 Challenges and solutions for ABC

Beyond these difficulties, there is a need to improve the management system and the output from both the contractor and consultant. Fullest cooperation by the contractor is likely if he is in charge of the decision making and guiding the consultant into more practical solutions.

There is also a need to determine all applicable construction loads and load combinations for earthquakes and flood events.

Resident engineer on site: Based on the author's site supervision experience, the consultant's engineer is present on site almost every day until the completion of the project. This is important for quality control and cost control. He has his head office as a backup for quick technical advice such as checking new design not covered by the original drawings and performing new analysis to check stresses. Progress meetings are held every week with the contractor and the client and as and when required.

1.6.5 Contractor's ingenuity in effective team formation helps achieve ABC

Careful teaming ensures speedy construction. In the design–build system, the contractor has a free hand to select a single consultant or a number of sub-consultants before submitting a bid. They would be selected on the basis of their skill and experience for performing the design tasks as required. In the conventional system, this would not be available.

Similarly, any sub-contractors would be selected to assist the contractor in disciplines where the main contractor requires help. The number of sub-contractors is determined by the need for speedy construction, in order to finish the project as quickly as possible. Thus the design–build system usually results in a strong team.

The freedom in teaming would result in the contractor taking a greater interest in generating meticulous details and refining tasks for quality control and with an eye on greater profit as reward.

1.6.6 Erection methods and precautions to prevent construction failures

Erection methods for curved girders are described in Chapter 6. A study on bridge failures carried out by the author (Chapter 3, "Bridge failure studies and safety engineering," Bridge and Highway Structure, McGraw-Hill, 2010) concluded that most failures occur during construction or erection. The ABC system must avoid future failures.

- Failure of connections due to overstress from bolt tightening, failure of formwork, local buckling of scaffolding, crane collapse, and overload were some of the causes.
- Stability of girders during stage construction and deck placement sequences need to be investigated and temporary bracing provided. Expansion bearings need to be temporarily restrained during erection.
- Some flexibility in selecting bolt splice locations may be permitted with the approval of the designer.
- Curved and skew bridges require special considerations such as uplift at supports, achieving the required cambers, and reducing differential deflections between girders during erection.
- Complying with permitting regulations and insurances against liability: The purpose of permits is to maintain air and water quality, health, and noise abatement. Projects must deal with stream encroachment, navigation permits, etc., grants (tideland, riparian etc.), environmental assessment, environmental impact statement, and categorical exclusions (CE). Contractors will expedite the acquisition of applicable construction permits. Each type of insurance will be covered by state law and will be project specific, e.g., workers compensation and employers liability.

1.6.7 Less disruptive construction for the environment

Keeping equipment out of sensitive environments is less disruptive to those environments.

Using prefabricated substructure elements reduces the amount of heavy equipment required and the amount of time required on-site for heavy equipment.

1.6.8 Making bridge designs easily constructible

Many job sites impose difficult constraints on the constructability of bridge designs. Heavy traffic on a provincial highway that runs under a neighborhood bridge, difficult elevations, long stretches over water, and restricted work areas because of adjacent stores or other facilities are some of the issues that need to be addressed. Using prefabricated bridge elements and systems relieves such constructability pressures.

1.6.9 Extending the service life of a bridge by monitoring and maintenance

Maintenance has its own challenges, such as:

- The use of remote sensors for increased monitoring
- Improved maintenance of movable bridges
- Using special foundation rehabilitation methods, minipiles, or underpinning.

1.6.10 Need for research

Chapter 3 addresses research needs in this new technology.

Since ABC methods have evolved well ahead of design codes, research is required in many aspects. Additional research is needed in the following areas:

- Development of strengthening methods and corrosion mitigation techniques; fabrication of stronger girders by eliminating the need for shear stiffeners with the use of folded web plates in steel girders.
- New methods to monitor foundations and to strengthen against scour, earthquake, and impact damage.
- Development and revival of the concept of full canopy on bridges and approach slabs to facilitate mobility and improved drainage, preventing skidding.

Research findings will result in improved codes of practice.

1.6.11 Lowering the life-cycle costs through prefabrication

Chapters 8 and 9 describe several aspects of prefabrication of the superstructure and substructure. Prefabricating elements and systems removes them from the critical path of a project schedule: work can be done ahead of time, using as much time as necessary, in a controlled environment. This reduces dependence on weather and increases the control of quality of the resulting elements and systems. All projects that use prefabricated bridge elements and systems increase the quality of their structures; most also lower life-cycle costs.

Prefabricated box beams were designed by the author for rapid replacement of a bridge over a creek in south New Jersey.

Figure 1.4(a) shows the box beams lowered into position on bearings.

Traffic and environmental impacts are reduced, constructability is increased, and safety is improved because work is moved out of the right-of-way to a remote site, minimizing the need for lane closures, detours, and the use of narrow lanes. River bridges and those in coastal areas have unique planning, design, and construction problems. An analysis by the author (Tables 1.3 and 1.4) shows the possible benefits for rapid completion for each type of bridge.

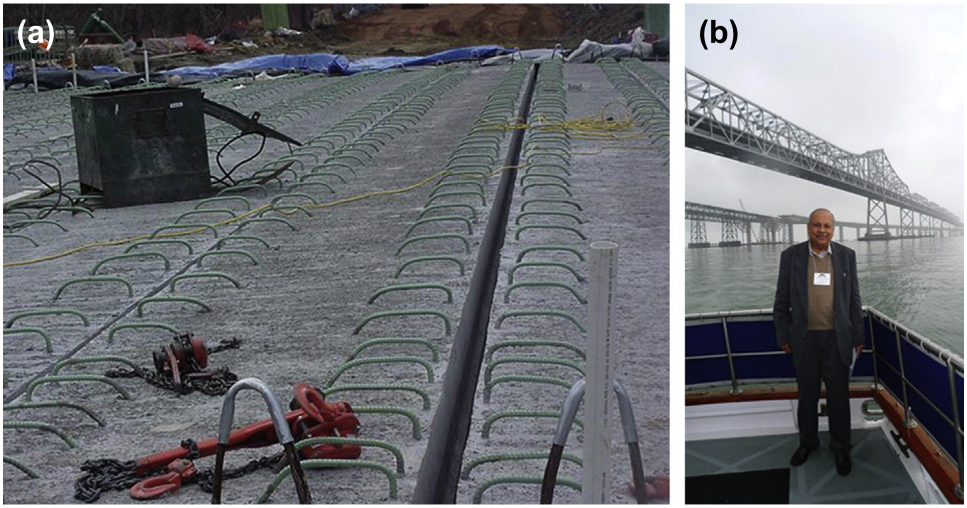

FIGURE 1.4A and FIGURE 1.4B

(a) Rapid placement of adjacent box beams in position at Lumberton, New Jersey. (b) Author as member of ASCE team reviewing the new Bay Bridge design.

Table 1.3 Current Status of the Type of Bridge Construction on Rivers

Type of Bridge	Type of Construction	Remarks
1. New bridge on river	Conventional, partial ABC, or full ABC	Conventional takes longer time, but is less expensive. More contractors can compete. Flood season may delay work with conventional.
2. Replacement bridge on river	ABC use is desirable	Saving in time for superstructure. Deep foundations can increase cost.
3. Bridge widening on river	Conventional, partial ABC, or full ABC	Conformity to existing structural system is required.
4. Deck replacement on river	Conventional as old shear connectors need to connect with precast	Night-time work is okay to be performed in stages.
5. Superstructure replacement	Staged construction with ABC is desirable	Detour or lane closure is required with staging.
6. New or replacement bridge on railway tracks	ABC use is desirable	Construction timings restricted.

Table 1.4 Current Status of the Type of Bridge Construction on Highways

Type of Bridge	Type of Construction	Remarks
1. New bridge on new highway	Conventional, partial ABC, or full ABC	Conventional takes longer time, but currently more contractors can compete.
2. Replacement bridge on existing highway	ABC use is desirable	Saving in time.
3. Bridge widening	Conventional, partial ABC, or full ABC	Conformity to existing structural system is required.
4. Deck replacement	Conventional since old shear connectors need to connect with precast	Night-time work is okay to be performed in stages.
5. Superstructure replacement or bearing retrofit or repairs	Staged construction with ABC desirable, conventional	Detour or lane closures required with staging ABC is not applicable.

1.6.12 ABC methods and applications vary in different states

Case studies of a variety of bridges using PBES in the United States are summarized in Chapters 5, 8, and 9. Bridges in the following states are selected as examples:

Washington, DC, and Maryland bridges: According to Ashley Halsey III (The Washington Post transportation section dated April 2013), "Officials say 62 percent of roads in the Washington region need significant repair or replacement. The Capital Beltway, a politically iconic and locally vital highway, is dying beneath your turning wheels, fissures are spreading, cracks are widening and the once-solid road bed that carries about a quarter-million cars a day is turning to mush. Closing down whole sections of it would tie one of the most congested regions in the nation into a Gordian knot." Doug Simmons, deputy highway administrator in Maryland (home to almost two-thirds of the 64-mile Beltway) states "With the older base layers under the asphalt, the surface is not able to absorb the pounding the way it used to. It is at that 50-year age point, which is too close to the end of its life. It's a good example of the challenges we're going to be facing not only in Maryland but other places in the country."

Maryland and Virginia approved tax increases to generate funding for fixing deteriorating highways such as the Beltway and the deteriorating bridges providing continuity to the highways. Closing several lanes for months would have nightmarish consequences on traffic and ingenuity of traffic engineering would be required.

Port Authority of New York and New Jersey (PANYNJ) bridges: A new US $1.5 billion bridge linking New Jersey and New York City is proposed to be built.

A consortium led by Australia-based Macquarie Group and Kiewit of the United States, known as NYNJLink, is to build a new bridge connecting New Jersey and New York City. The Chairman of PANYNJ said that the Authority will hold onto the ownership of the existing Goethals Bridge. It is expected that upon completion, 35 yearly payments of roughly US $60 million will be made to the consortium.

A maximum of a $500 million FHWA low-interest loan, and $363 million from the Port Authority, will go toward the new bridge's construction. A four-decade contract to construct, maintain, finance, and design the bridge will be given to NYNJLink. The proposed bridge, which has been billed as the biggest transportation project, is to be constructed with private funding in the region. The project delivery and construction management for the three Port Authority Bridges (Goethals, the Outer Bridge, and Bayonne Bridge, all of which connect New Jersey with Staten Island) need to be reviewed. As part of the program, the Goethals Bridge will be replaced, the Outer Bridge Crossing will be resurfaced and the roadway of the Bayonne Bridge will be raised. The projects are expected to generate about 5000 construction jobs. The work will be conducted between 2014 and 2017, which in author's opinion can be expedited.

Indiana bridges: Northern Indiana Commuter Transportation District (NICTD) has come up with roll-in roll-out technique for many important bridges, e.g., a 400 ft double track truss span using SPMTs for the NICTD bridge over Torrence Avenue, Chicago in 2013 and roll-in 65 ft thru-girder span over Trail Creek, Michigan City.

Florida bridges: Florida DOT is also ahead in this game. Segmental precast segments were constructed by Figg Engineering using a design–build method. Edison Bridge in Fort Myers, Florida, was completed in 1993. Figg Engineering has constructed a number of long-span bridges. They tend to call themselves magicians not engineers, for constructing long-span bridges using ABC methods.

Iowa bridges: Iowa DOT is using the lateral slide-in technique on the Massena Bridge. (See http://www.iowadot.gov/MassenaBridge/projectinfo.html.)

Construction zone safety will be greatly improved by the introduction of innovative ABC methods. Traffic will be detoured for nine days only. The replacement structure will be a single-span 120′ × 44′ bridge with precast abutment footings, precast wing walls, and a precast superstructure fabricated adjacent to the existing bridge and moved into position by lateral slide.

California bridges: An ASCE team that included the author reviewed the design criteria of Bay Bridge near San Francisco. Figures 1.4(b) and 1.5 show the field visit to review construction of famous Bay Bridge in progress. The Bay Bridge was scheduled for completion and opening in 2013.

Caltrans was concerned about the now-broken bolts on the new Bay Bridge long before they actually failed. The agency wanted tests done 5 years ago. New bolts are in position.

New York bridges: The Structural Engineering Institute of ASCE in Philadelphia (under the chairmanship of the author) had a very informative presentation last year from Bob Cisneros of High Steel of PA. (Figure 1.6 shows an Erie–Niagara Counties Bridge).

Pennsylvania bridges: According to Edward G. Rendell, former Philadelphia mayor and Pennsylvania governor who now heads an infrastructure advocacy group, "There's too much money spent on just patching, on the quick fix, rather than the long term, and eventually it's going to catch up on us."

A nearly 300-ft long-span steel girder continuous bridge for Mon-Fayette Expressway located in a deep valley near Pittsburgh was constructed (Figure 1.7).

Construction of nearly 200 ft high piers is shown in Figure 1.8(a) and the long-span steel girders in Figure 1.8(b).

Projects in Kentucky: Public-private partnerships or "P3s" are being used in Kentucky and across the United States to meet ever-growing needs in transportation. This management method often leads to more affordable and effective project delivery than the traditional model (the government hiring a private company to accomplish a specific task). By harnessing creativity and exchanging costs, responsibilities, and ownership, P3s open up a range of solutions to many seemingly intractable problems affecting the state. The benefits of P3s can be seen in many aspects of development. (See http://www.lanereport.com/21213/2013/05/kentuckys-5-billion-p3-play/.)

FIGURE 1.5

A view of Bay Bridge under construction (photo by author).

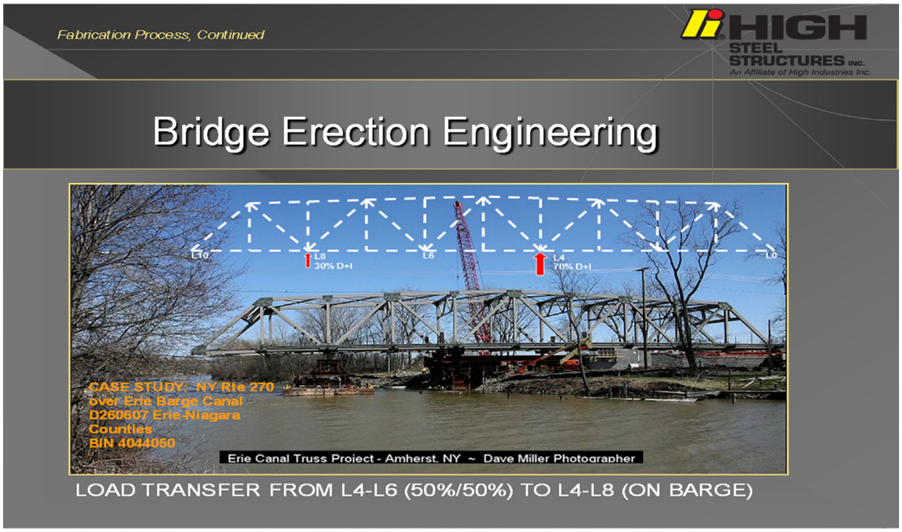

FIGURE 1.6

High Steel constructed truss bridge over Erie Barge Canal in New York.

Figure 1.9 shows an aesthetic long-span lightweight aesthetic looking pedestrian bridge. The $2.6 billion project involves construction of two new crossings, with approaches, to help alleviate the traffic congestion for which the Interstate 65 corridor through Louisville and southern Indiana is known.

Financing: In some P3 arrangements, the private sector provides much-needed funds for the project or serves as a conduit for more creative financing options.

FIGURE 1.7

Completed Route 43 Bridge on Mon-Fayette Expressway near Pittsburgh (photo by the author).

FIGURE 1.8A

Mon-Fayette Expressway bridge piers under construction.

Operations: The private sector often provides expertise in operations and execution. Private contractors typically pay for cost overruns, manage design problems, ensure timely delivery, and assume other risks associated with the project.

Timing: P3s expedite projects by streamlining strategies, approval processes, and implementation.

Affordability: By providing avenues to alternative financing and increasing efficiency, P3s often make projects more affordable. This is increasingly important as governments across the country face mounting budgetary constraints.

FIGURE 1.8B

Mon-Fayette Expressway long-span girders under construction.

FIGURE 1.9

East End Bridge walkway, part of the Louisville-Southern Indiana Ohio River Bridges Project.

Growth: Perhaps most important, public-private partnerships spur employment, economic development, and opportunities for citizens. To date, Kentucky has embarked on dozens of P3 projects that have generated tens of thousands of jobs and more than $5 billion in construction spending over the last decade. These successes include many different types of projects and illustrate a broad spectrum of P3 possibilities.

Louisville-southern Indiana Ohio River bridges: The Kentucky governor and a former Indiana governor developed a unique P3 solution to address both states' needs and policy objectives. Each state agreed to take the financial and construction responsibility for roughly half the project, thereby speeding delivery and lowering cost. Kentucky is responsible for the Downtown Crossing, and Indiana the East End Crossing. Both states are using different and creative financing strategies.

1.6.13 International ABC projects

The US Agency for International Development (USAID) has found rapid construction techniques particularly useful in overseas relief and disaster management projects. Examples from Pakistan earthquake damaged structures are presented. In the case of floods, Acrow truss bridges were used. For earthquake disasters, there was a simultaneous need for developing seismic code to resolve the widespread problem and design and construct bridges using ABC methods.

October 2005 earthquake reconstruction efforts: US Department of State embassy press releases are given. Technical issues are addressed and are to some extent similar to earthquake disasters the world over.

Figure 1.10 shows team work between US and Pakistan Government for reconstruction of flood-damaged bridges. US Embassy News is reported here:

> The U.S. Government is providing the people of KPk Province [Khyber Pakhtunkhwa] with pre-fabricated bridging material to build eight new bridges to replace those destroyed by the recent monsoon floods. When built, these light, easily transportable bridges will support heavy vehicle traffic and greatly assist the people of KPk to rebuild their communities and livelihoods. At a ceremony at the U.S. Embassy Wednesday, U.S. Ambassador to Pakistan Cameron Munter, accompanied by Brigadier General Michael Nagata, Deputy Commander, Office of the Defense Representative-Pakistan, presented the General (Ret.) Nadeem Ahmed, Chairman of the National Disaster Management Agency (NDMA), with a plaque signifying the friendship between the people of the U.S. and Pakistan. Similar plaques will be placed on each of the bridges. The U.S. Government previously provided 12 pre-fabricated bridges to the NDMA during the early days of flood relief.

FIGURE 1.10

U.S. Ambassador Cameron Munter, Deputy Commander, Office of the Defense Representative-Pakistan Brigadier General Michael Nagata, and National Disaster Management Authority Chairman Gen. (Ret.) Nadeem Ahmed participate in a bridge handover ceremony.

> Ambassador Mr. Munter said "We are joined by common values and interests - and by our common humanity. We provide aid to Pakistan not only because we value our relationship, but because it is the right thing to do." The U.S. Government is providing more than a half a billion dollars (Rs 42.5 billion) for flood relief and recovery efforts. Also, to date, U.S. aircraft have evacuated more than 40,000 people and delivered more than 26 million pounds (nearly 12 million kilograms) of relief supplies. (Reference: 2005–2011 ACROW Corporation of America).

Review of postearthquake structural and bridge damage in Pakistan. US Embassy News is reported here:

> A delegation of top American scientific experts led by the U.S. National Academy of Sciences has arrived in Pakistan to begin consultations with the Pakistani government and scientific community regarding earthquake reconstruction policy and planning. The select team includes leading American structural engineers and urban planning specialists, representing decades of experience in seismic zones.
>
> The team's goal is to assist the Pakistani government and scientific community to develop policies and strategic reconstruction plans to ensure that the massive loss of life attributable to inadequate construction methods, materials and codes does not recur. Team members will draw on recent earthquake reconstruction experiences in India and Iran as well as the best U.S. scientific and engineering resources. With relief operations continuing, this USAID-funded initiative recognizes the need to simultaneously focus on reconstruction planning and concerns.
>
> On Monday, December 12, 2005, the delegation met with ERRA Chairman Lt. General Zubair as well as senior officials in the two entities charged by ERRA with the "construction" aspect of reconstruction—Ministry of Housing Secretary and Pakistan Engineering Council Chairman. Through these meetings the delegation will further their understanding of the status of Pakistani reconstruction policy, planning and implementation. The delegation also met on Monday with the Higher Education Commission, the conduit to the Pakistani scientific community.

Delegation members look forward to a fruitful exchange with Pakistan's leading reconstruction experts. Their goal is the formulation of state of the art policies and implementation plans that incorporate local conditions and culture.

Delegation members included:

1. Team leader Melvyn Green, expert on residential construction in seismic areas;
2. Mohiuddin Ali Khan, structural engineer with over 30 years of experience in seismic analysis, seismic retrofit of buildings and bridges, and low cost housing;
3. William T. Holmes, expert in seismic vulnerability of buildings and loss estimation;
4. Marjorie Greene, an urban planner, with experience in research and policy development in earthquake recovery and rebuilding, (having worked or done research on rebuilding in Macedonia, Mexico City, the Loma Prieta and Northridge earthquakes in California; and the Maharashtra and Gujarat earthquakes in India); and
5. Michael Sanio, director of the International Office of American Society of Civil Engineers."

The advisory visit resulted in publication of a seismic design code, feasibility reports on utilization of resources for rapid replacement of damaged structures including bridges, introduction of research projects, and shake table tests for the future.

Segmental prestressed concrete bridges in India: India has witnessed large growth in the field of construction, with construction sector comprising 40–50% of India's capital expenditure on the projects in various sectors. While the growth has been equally high in real estate and other infrastructure projects, much larger growth has been witnessed in the field of segmental bridge construction. This is due to the distinct advantage of speed and aesthetics that this technology provides. Until 2005, Indian codes did not cover design and construction of segmental superstructures. Now, a new document, IRC: SPs: 65-2005, developed under the aegis of the IRC code committee, has been published. This document covers design and construction aspects of segmental bridges.

1.7 Impact of ABC on long-term life-cycle costs

Probabilistic life-cycle analysis of deteriorating structures: Life-cycle cost analysis deals with long-term costs for maintenance. For example, a bridge constructed for $10 million now may require increasing repair costs from 1–10% of additional bridge costs between now and 75 years. Engineering and administrative costs for 2 year cycle and emergency inspections (for accidents, earthquakes, and flood, etc.) may be extra.

A probabilistic model is used to predict the evolution in time of three performance indicators: condition, reliability, and cost. The uncertainties associated with these performance indicators and their time-dependent interactions are considered.

High-performance materials that promise minimal maintenance for as long as 100 years will accelerate the trend toward greater attention to the life cycle of new construction. The aim will be to minimize life-cycle costs:

Deck concrete durability: use of corrosion inhibitor concrete, HPC,
Deck joints performance: use of integral abutments,
Bearings performance: use of elastomeric pads and isolation bearings,
Corrosion of steel girders,
Erodibility of soil under footings,
Resistance to earthquakes, floods, and other natural disasters.

Greater incentives must be given to contractor to finish earlier. However, achieving accelerated schedules must not be at the cost of quality control or cost control. Use of software such as Primavera (applying CPM and PERT methods) must be adopted on every project. Activities on critical paths must be monitored closely. Additional resources should be provided for critical path activities to finish the project earlier.

Innovative technologies in construction should be studied:

- Incremental launching for segmental construction.
- Superstructure roll-in and roll-out method
- Superstructure lift-in.

1.7.1 Distribution of project costs

The contractor is given the lion's share of the project costs while the consultant receives only about 10%. It is only logical to give the contractor the upper hand in running of the project.

1.8 Recent advancements in ABC methods, literature, and design codes

Chapters 3 and 4 and Appendix 1 (Bibliography) provide a list of relevant references on all aspects of ABC. This section deals with available literature on the subject of ABC and those developed by FHWA, AASHTO, NCHRP, state design manuals and other highway agencies. Constructing and rehabilitating bridges with minimal impact on traffic has become a transportation priority as traffic volumes nationwide increase. Renewal of the infrastructure in the United States is necessary for several reasons, including increases in population, projected increase in vehicle miles traveled, presence of obsolete or deficient structures, impact of road construction, and injuries and fatalities related to work zones (NCHRP 2003).

Besides the continued guidelines published by management and scientific agencies, conferences are being organized. Research papers are being published in conference proceedings, relevant structural and bridge engineering journals, textbooks on related subjects, university theses, student's project dissertations, bridge design codes, and construction specifications outlining method of construction. The available technical information is sometimes supported by dynamic analysis theory, computer software and laboratory studies on structural components, or shake table testing of typical prototype models.

1.8.1 Developing the next generation of bridges with ABC

Many state DOTs have been active in developing and applying ABC methods based on the merits and benefits of using ABC. Design, construction specifications, and memorandums are being issued by state highway agencies. For example, with the focus on improved post-earthquake serviceability, the consideration of the economic impacts of traffic disruption is having a profound effect on Caltrans' bridge design practices in the future.

References to other useful publications are addressed in the text in this chapter and in the chapters that follow. The bibliography at the end of the chapter includes important code references such as by management agencies such as AASHTO, FHWA, NCHRP, and the Transportation Research Board (TRB), who are at the forefront of promoting ABC. Applications include development of software, use of FRP and composites, connection details for seismic design, and dismantling components and reusing at another site.

1.8.2 FHWA initiatives to promote design–build contracts

Please see references to FHWA publications in Appendix 1 (Bibliography) for Chapter 1 for details. Chapter 3 reports FHWA initiatives for using innovative techniques, and Chapter 5 describes various measures for promoting ABC.

According to the US Department of Transportation, there are numerous reasons why owners choose to use design–build, but the primary reason is the potential for shortened project duration.

Because of coordinated efforts between the designers and the builders, construction can begin before the completion of construction documents. A design–build contract allows the public-sector owner to shift risks that have traditionally been assumed by the public sector to the private sector. The primary risk that is shifted is that of design errors and omissions that resulted in a number of failures or early deterioration of bridges in the past.

Because the design–builder owns the details of the design, it is responsible for all errors and omissions that occur after award of the project. Conversely, for accepting this risk, the design–builder also is entitled to value-engineering savings that are traditionally shared with the owner.

When design–build is used in conjunction with financing or operation, the risk shift is much more significant.

Detailed information is now available from a number of reliable sources and websites:

- PBES framework for decision making
- Some manufacturers of PBES in the northeastern United States are Jersey Precast, Oldcastle Precast, Schuyllkill Products, High Steel, and Acrow.
- PBES and ABC Websites, cost study of ABC success stories, state ABC projects, and manual on SPMT.

In reaping the benefits of accelerated construction in US highway management, leadership is being provided at the highest level, both through US Congress Oversight Committees and the FHWA Team. There are publications by Vasant Mistry, Benjamin Tang, Helene Bowman, and other FHWA members with the objectives to "improve transportation for a strong America." See FHWA Website (http://www.fhwa.dot.gov/research/fhwaresearch) for research publications.

In support of the vision to provide safe, durable, and strong bridges by FHWA, the bridge-building community is dedicated to working with national and international partners in areas of:

- Research in innovative technologies,
- Deployment, and
- Education.

ABC and FHWA's "Every Day Counts" initiative: On May 22, 2010, FHWA announced the technologies selected for its new "Every Day Counts" initiative. This initiative was FHWA's focus for the next three years (2010 through 2012) and concentrated on shortening project delivery, accelerating technology and deployment, and going greener. After an extensive review of many leading technologies, the FHWA selected five technologies, two of which fall under ABC The five technologies are: PBES, geosynthetic reinforced soil (an ABC technology), adaptive signal control technology, safety edge, and warm-mix asphalt.

By 2011, FHWA's goal was to have 20 PBES projects designed or constructed. The 2012 goal was that 50% of single-span bridges that are authorized or receiving federal funding has at least one major PBES component.

Pooled-Fund Project: Multi-State ABC Decision Tool and ABC and FHWA's "Every Day Counts" Initiative. (Ref: A Planning Phase Decision Tool for Accelerated Bridge Construction ABC Links).

FHWA sponsored the pool-funded study, TPF 5(221); the Technical Advisory Committee has embarked on a joint project through the University of Nevada, Reno to look at ways to increase the resilience of transportation networks. FHWA's earthquake loss estimation software tool called REDARS (Risks from Earthquake Damage to Roadway System) will be updated to improve its accuracy in predicting bridge damage and associated costs, and increase its flexibility for wider application. REDARS may be used to identify the costs of bridge closure due to increased congestion and traffic delays, allowing transportation agencies to assess the costs and benefits of designing bridges with improved post-earthquake serviceability.

1.8.3 National cooperative highway research program

A recent useful publication is NCHRP Synthesis 324: Prefabricated Bridge Elements and Systems to Limit Traffic Disruption during Construction.

1.8.4 European best value construction selection method

It appears that the European countries have used design–build delivery on a much more extensive scale than the United States. There are certain types of projects using design–build based on the use of best-value selection. Direct design–build contracts are employed between highways agencies and design–builders.

US highway agencies can apply European design–build methods to many of their existing design–build contracting methods. The following concepts need to be considered:

- Speed the delivery of infrastructure,
- Increase the quality of construction,
- Reduce life-cycle maintenance costs,
- Capitalize on best-value selection processes to promote competition and innovation among design–builders.
- Promote appropriate use of performance specifications with low levels of design in design–build projects
- Issue request for proposals to promote innovation and accountability from the private-sector proposers.
- Ensure construction quality and cultivate a pool of qualified life-cycle service providers through the incorporation of maintenance and operation into design–build projects.
- Assign third-party risks to the party in the contract that can best control them.

1.9 Using advanced management techniques in ABC

This section deals with recent development in management techniques, which is an important aspect of implementing ABC.

1.9.1 Borrowing and applying new ideas

Management techniques for mass production such as those adopted by automobile or aircraft industries, such as robotics methods, should be introduced. Bridge technology and structural configurations are different for small, medium, and long spans. The planning approach should show flexibility to address major differences and implement ABC effectively.

Efficient structural planning aspects can minimize the impact of many of the constraints in meeting accelerated construction goals such as:

- Erection during wind and extreme weather conditions,
- Availability of labor, material, and equipment,
- Acquiring construction permits, construction easement, and site access.

Audits are used in practice to ensure actions from designers and project managers for road safety, infrastructure development/prefabricated technology, and operations for making work zones better.

In addition to gaining initial ABC time, an emphasis is on minimizing maintenance frequency, subsequent rehabilitation schedules, and adverse traffic impacts. Planning concepts include reducing long-term bridge costs through life-cycle cost analysis, optimization, enhancing the useful life of bridges, and providing rider safety and comfort. It is also important to establish low-cost design alternatives.

Various aspects of engineering management are presented, such as assets management (Chapters 2 and 10), disaster management (Chapter 3), design–build (Chapter 4), bridge failures and risk management (Chapter 6), and construction management (Chapter 9).

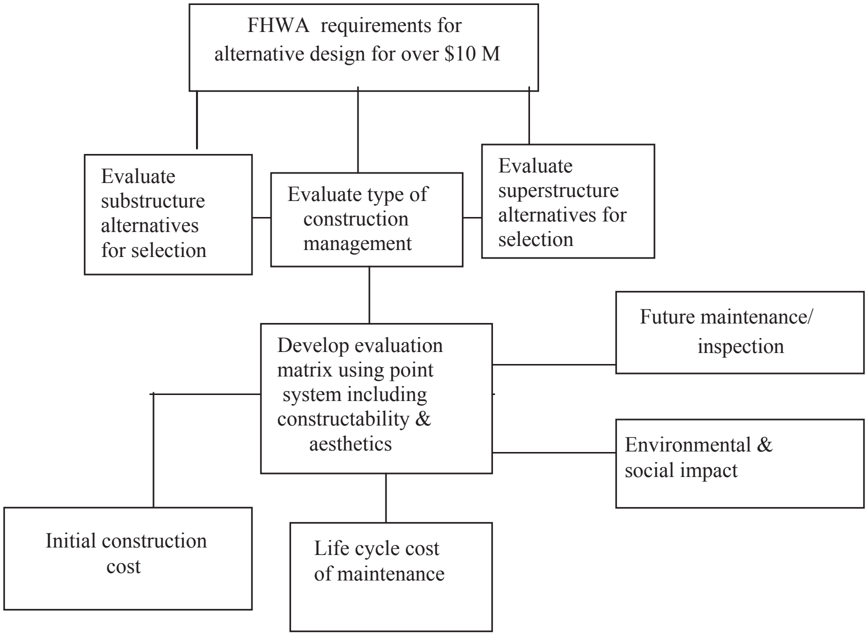

FIGURE 1.11

A flow diagram for bridge costs leading to ABC using FHWA concepts.

1.9.2 Value engineering as a planning tool for optimum cost

FHWA defines value engineering (VE) as "the systematic application of recognized techniques by a multi-disciplined team, which identifies the function of a product or service; establishes a worth for that function; generates alternatives through the use of creative thinking; and provides the needed functions, reliably, at the lowest overall cost." Constructability and MPT are considered.

VE is an organized application of common sense and technical knowledge directed at finding and eliminating unnecessary costs in a project. VE has many elements such as:

- Creativity,
- Cost worth,
- Team work,
- Functional analysis, and
- The systematic application of a recognized technique.
- Audits phase determines the amount of savings generated by the VE study based on the recommendations implemented in the construction project.

Figure 1.11 shows the selection of ABC for bridges whose cost exceeds $10 million, as recommended by FHWA.

A VE review can improve quality, save time, and save money. Contractors at the start of the project should perform a VE exercise to save money.

Figure 1.12 shows evaluation of projects for cost reductions in various construction activities.

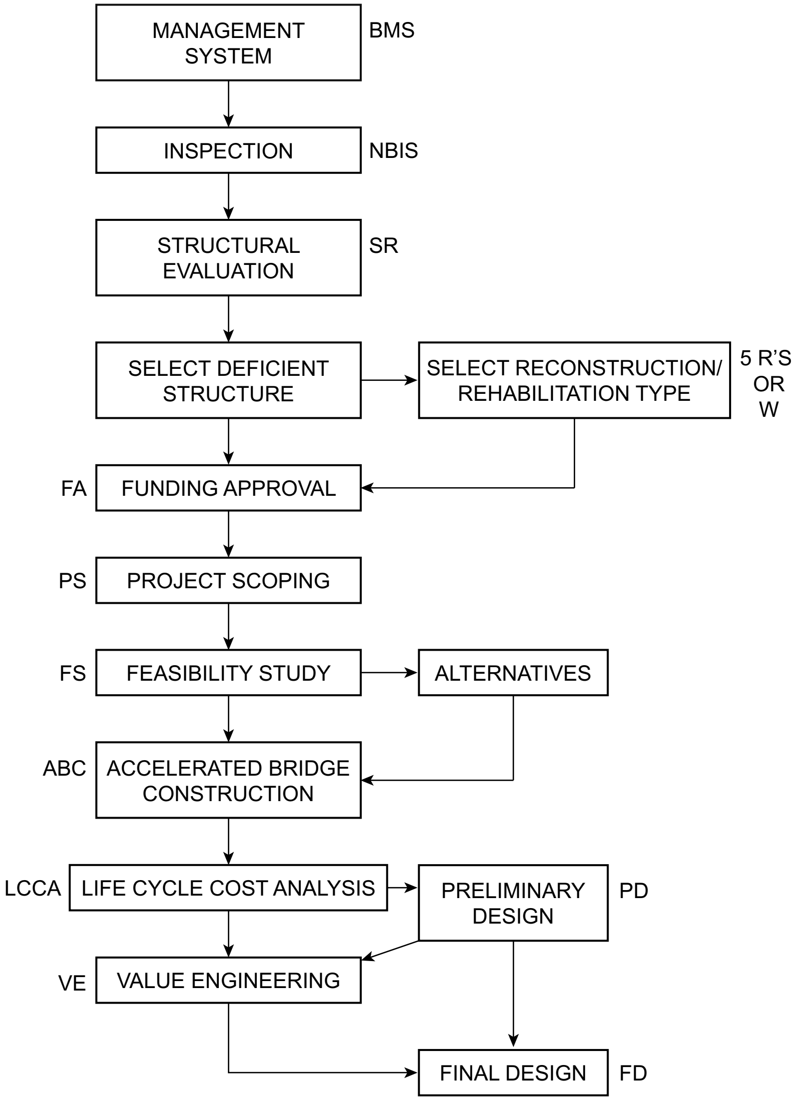

FIGURE 1.12

Flow diagram developed by author for Pre-construction VE review leading to ABC.

1.10 Conclusions for developing and promoting ABC

The two frequently used conventional construction methods are:

- Cast in place construction. Time of construction is much longer.
- Partially assembled components.

Modular building construction in timber has been successful in the United States.

ABC has its roots in rapid modern military engineering for quick assembly and in the floating bridges on rivers.

The conclusions addressed here are discussed in detail in the rest of the book. The references to many useful publications on ABC are listed in the bibliography, which is given at the end of the book as Appendix 1.

1.10.1 General conclusions for conventional cast in place bridge construction vs. ABC

Quality control in CBC is not as good as in factory construction, which uses temperature and humidity control.

Individual bridge construction is more expensive than mass production.

In CBC there are more sudden failures, casualties, and injuries during heavy construction and the use of temporary formwork.

Construction inspection time is reduced with ABC.

There are many differences between ABC techniques and conventional construction methods. ABC can acquire products made in other states and throughout the world.

ABP needs to be developed as a special management technique. Also, the principles of ABC apply to all types of bridge construction. The design–build type of construction management leads to faster completion.

Deterrents: These include administrative and planning bottlenecks such as construction easement and right of way, permit approvals, and utilities relocation. These need to be removed or minimized. Several issues are the timely specialized labor availability, weather problems, and large storage yard areas required at the site.

Reduced traffic impacts: Major outcomes of ABC are to reduce the adverse impacts on regular bridge traffic during construction and to implement cost savings through reduction in commuting distances.

Certification and training: Senior and junior construction personnel and designers need to be trained in rapid construction techniques.

Laboratory testing: To gain confidence in ABC methods, full-scale testing in structural behavior of additional field connections of sub-assemblies is required.

Mathematical modeling: Accurate methods of analysis applicable to model the discontinuities of components need to be developed. Integrated software should cover notes for rapid construction and detailed procedures.

Use of prefabricated bridge components: ABC requires finished components and sub-assemblies. Components made of high-performance steel, high-performance concrete, and aluminum seem to be the most popular outcome.

Chapter N in American Institute of Steel Construction (AISC)360-10 (AISC Specifications) and Chapter J in AISC 341-10 (for AISC Seismic Provisions) address AISC Quality Plans for quality control, quality assurance, and nondestructive testing. At the completion of fabrication or erection, the approved fabricator or erector must submit a certificate of compliance to the authority having jurisdiction stating that the materials supplied and work performed are in accordance with construction documents. To prevent poor performance, visit AISC quality certification programs (www.aisc.org/certification).

New materials and equipment: Applications of latest techniques in concrete manufacture such as use of fiber-reinforced polymer concrete, lightweight concrete, self-consolidating concrete, and HPS and hybrid materials will contribute more to durability, if not to early completion. Heavy cranes, erection equipment such as a trolley, and SPMT are required.

Design and construction codes: There is lack of a new comprehensive ABC code of practice and related construction specifications. Due to the initiatives taken by FHWA, TRB, and other agencies, there has been considerable progress made in promoting and implementing ABC concepts. For new code development, associated design approach and details such as construction load combinations need to be made part and parcel of AASHTO and state bridge design codes.

Continuous and rapid funding: Rapid construction requires rapid funding. Existing constraints include funding limitations. The Highway Trust Fund should each year invest more for bridge construction and maintenance projects because the returns will be high. It will also create more jobs.

Some of the steps being taken in several US states such as P3 have been cited and outstanding deterrents in rapid construction were identified.

Benefits over conventional construction: Applying the ABC methodology will result in 50% greater number of completed bridges each year. It will help the economy by reducing wasted hours due to traffic jams during construction, helping commuters to work, and also benefiting commerce by increasing faster delivery of goods. Much of the developments listed above are based on the growing number of publications on the practical subject.

Organizations like FHWA, TRB, NCHRP, AASHTO, DBIA etc. and universities like Florida International University etc. have been regularly contributing knowledge on practical design aspects leading to rapid construction. With further progress, some of the information may be refined but for the benefit of transportation industry.

References for Chapter 1 are listed in Appendix 1, Bibliography at the end of chapters.

Each chapter has separate list of references. There may be several captions in each chapter for the convenience of the reader.

A glossary of ABC terminology applicable to all the chapters is listed in Appendix 2, ABC Glossary.

The list of appendices is:

Appendix 1: Bibliography

The online supplementary material of this book are available in
http://booksite.elsevier.com/9780124072244/.

PART 1 REFERENCES TO LITERATURE
Appendix 2: Glossary of Terms
Appendix 3: PennDOT Bridge Inspection Terminology

PART 2 TRAINING IN ABC
Appendix 4: Proposed 3 Credits Course
Appendix 5: Training Courses and Workshops
Appendix 6: ASCE–Temple University College of Engineering

PART 3 ASCE REPORT CARD AND SURVEY FORM
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PART 4 LIGHTWEIGHT BRIDGES
Appendix 9: Rapid Construction of Timber, Aluminum and Lightweight Bridges
Appendix 10: Route 1 and 9 Bridge Replacement by Author
Appendix 11: Manufacturers of Prefabricated Bridges

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CHAPTER

Recent Developments in ABC Concepts

2

2.1 Application of ABC concepts

The construction world is geared to implementing the bridge design into practice. The sooner the construction is completed, the better, in the interests of the public. Implementation can be done in more than one way.

The main changes in ABC will be in the method of manufacture, construction sequence, and management method, whereas specifications, methods of measurements, and environmental requirements may change to a small extent. The ABC topics in this chapter further illustrate and expand upon those discussed in Chapter 1.

The trend of bridge failures exists, among other reasons, due to scour and erosion, use of outdated procedures and technology, and negligence. Management issues and variations in ABC applications, namely partial, full ABC, and super ABC, are addressed in this chapter. Associated topics include inspections to identify deficient bridges, accelerated bridge rehabilitation, conducting a survey on the use of scour countermeasures for bridges on rivers, and developing a field reconnaissance form. Sources of funding are discussed in detail.

Federal and state agencies and the supporting construction industry have done a great job in developing authentic publications and promoting ABC such as:

The FHWA (ABC manual) and
The AASHTO Technical Committee for Construction,
TRB,
Research at National Institute of Science & Technology (**NIST**),
T4 (grand challenges),
Actions recommended by the **Design-Build Institute of America** (**DBIA**),
The Construction Management General Contracting (CMGC) Institute and
The **Construction Industry Institute** (CII)

In addition to these are the continuing efforts by some universities such as **Florida International University (FIU)** and **University of Maine AEWC.** Research and technology development, in promoting the use of ABC, shows the awareness of American engineers and the construction industry in making life easier for many millions of road users, as well as indirect economic benefits to the community.

An accident during construction can alter traffic patterns on the highway, and reductions in reconstruction duration will help.

Conclusions summarize the state of the art, the progress being made in this technology, and recommendations for further work.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00002-2

2.1.1 Background

As discussed in Chapter 1, ABC is a relatively new subject. It is more of an art than a science. ABC requires a change in the construction management system. Early completion demands an emphasis on the refined design of bridge components. It requires a major change in the contractor's role from a passive member of the team (generally receiving instructions) to a more active role in an advisory capacity, with rapid construction being the primary objective. There are construction delays in the conventional system according to the size of the project, which adversely affect the travel time of the public using the road.

The change from conventional methods to ABC is happening gradually, however, allowing fewer contractors to switch over to this new role. The constraints in achieving earlier completion and project delivery need to be analyzed. These constraints are due in part to the management system and the method of construction, as no two bridges are exactly alike in geometry, remote locations, and component manufacturing for modular bridges.

2.1.2 Lengthy construction periods lead to significant waste of time and money

There is obviously a national loss when the public wastes man-hours and gasoline due to traffic jams, congestion, detours, or lane closures. The indirect loss is colossal and indeterminate, and that is why rapid construction has become the need of the day. Bridge reconstruction and maintenance need to utilize refinements in modern technology. Construction management techniques can play an important role in completing bridges as quickly as possible, without lowering the quality or durability of the bridge. To justify the changes in the construction management system, value engineering and alternative design approaches in planning can also be examined. The progress in the state of the art is receiving attention at the highest level of transportation agencies such as the FHWA and AASHTO, and is duly supported by universities such as Florida International University (FIU).

2.1.3 Review of ABC (manufactured or modular bridges)

A list of the bridge types to which ABC is fully applicable follows:

- Glulam bridges
- Precast concrete bridges with precast joint details
- Bridges using lightweight aggregate concrete
- High-performance steel (HPS) bridges for all spans
- Prefabricated, ready-made patented bridges in steel and precast concrete
- Bridges in a Backpack, developed by Advanced Infrastructures Technology (AIT)
- Aluminum bridges (which are light and easy to erect for quick, efficient transport)
- Variable-message sign (VMS) structures
- Mechanically stabilized earth (MSE) walls,
- Temporary steel bridges used in place of staged construction or detours

2.1.4 Meeting the owner's requirements

The basic requirements are quality construction, minimum cost, and a tight construction schedule. The secondary requirements are aesthetics, lowering long-term maintenance costs, and improved technology such as installing interactive touch-screens for traffic information and installing brighter lighting on bridge approaches by using less expensive solar panels.

The owner's requirements can be met by conventional methods as well, except for the following, which are possible only by using ABC:

- A rapid project delivery and construction schedule
- A more aggressive approach by the combined team of contractor and consultant, resulting in greater innovation
- Developing business aspects and team coordination
- Supporting a modified cost accounting system
- Exploring possible savings in very small items
- Repetitive use of construction equipment on several projects to utilize initial investments
- Diminishing friction between the consultant and contractor through communications
- Promoting modular construction like that used for the construction of tall buildings

2.2 A practical approach to solving ABC issues

The following steps are essential:

Funding allocation: Since huge costs for replacement or emergency repairs of every deficient bridge are required, adequate funds should be made available by bridge owners, as emphasized in Chapter 1.

Identification of deficient bridges and setting of priorities: Inspection reports are required. Every 2 years, inspectors perform inspections and prepare reports. Emergency inspections are held as required and according to the frequency of inspection policies. Relative rating for condition of bridges and safety considerations will determine assigning priorities for replacement and repairs.

Rapid Implementation: In most cases, earliest fixing is desirable. The obvious approach is to adopt ABC procedures using the latest technology.

2.2.1 Constraints and bottlenecks in ABC progress and their resolution

The author's personal experience as a project manager on a number of recent bridge projects in the northeastern United States has shown that fewer than one in five projects are using design-build teams or prefabrication.

Project management culture and increased costs with ABC seem to be the main reasons. Even the lowest bid is not low enough when selecting the ABC team. The highway agency therefore has to come up with more money, at least for the more complex bridges.

Currently, there are not enough contractors with ABC experience. In the design-build system, the risk factor is increased due to greater responsibilities and the fact that a loss on one project can run them out of business. Many contractors seem to be afraid of taking the lead on project management due to increased investments, and are content with taking instructions from the consultant.

ABC is being restricted to smaller spans (generally not exceeding 100 ft) where self-propelled modular transporters (SPMTs) are not used. The use of SPMTs is also restricted to smaller distances from the factory to the construction site (about 200 miles) because police escort arrangements and special permits are required. It increases the volume of administrative work for transporting the assembled units.

The older planned highways do not have large-diameter curves (for the exit and entry ramps), so long SPMTs are not able to negotiate the curves with ease. During the day or the rush hours, wide loads are not usually permitted for fear of accidents. Some older bridges on a long route do not have sufficient vertical under clearance. Currently 16 ft, 6 in. is required by the AASHTO Specifications. A reconnaissance of the proposed route would be required to remove the bottlenecks. However, alternate routes or detours are not always feasible.

Similar problems exist for transporting tall erection cranes to the site. Alternatively, there should be workshop facilities made available near the sites for assembling the huge cranes and dismantling them after the job is completed.

A greater investment by the contractor is required for introducing heavier lifting cranes and expensive SPMT, etc. The overhead would be higher. Also, due to increased involvement and responsibility in design aspects, the contractor may need to develop his own design cell, as an added precaution of checking the main consultant's design details.

2.2.2 Overcoming expertise limitations in the implementation of ABC

Even when the required infrastructure funding is readily available, for the fifty states there are a lesser number of certified ABC consultants and contractors with ABC experience than required the year around. In Appendix 6, an ENR List of 100 Design-Build Construction Companies is given.

In addition, there are specialized construction teams for ABC projects (such as FIGG construction of Florida). However, bridges come in all sizes and materials. Given the lack of expertise, not all the deficient bridges can be fixed in a given year.

The use of conventional methods has made the engineer availability issue more acute, and there is currently a glut or slowdown in the number of deficient bridges being disposed of. The lack of timely maintenance increases the risks of bridge failures. To overcome the problem, qualified consultants and contractors can be hired from developed countries such as like China, Korea, Japan, or India.

A similar problem existed in the nuclear industry during the 1970s and 1980s in the United States, and engineers in that specialized discipline were hired mainly from Europe. However, this approach is not likely to help in the transportation industry due to language barriers and the fact that US AASHTO and individual state codes for design and construction happen to be different. The training of foreign workers will not be easy or quick, due to possible gaps in science, technology, engineering, and mathematics (STEM) disciplines between the US curriculum and the curricula of engineers from foreign countries. There would then be a reliability issue, as complex projects can be mishandled, resulting in failure.

On the other hand, manufacturing tasks of various bridge components can be increased within the United States, by hiring foreign manufacturers to work locally and to train US workers by setting up subsidiaries.

ABC requires prefabrication of components and manufacture of SPMTs and other construction equipment on a significant scale. It is therefore a multibillion-dollar industry in which limited foreign expertise can be useful. This approach has helped in the multibillion-dollar car manufacturing industry when companies from Japan, Korea, Germany, Italy, and France set up their shops here.

A list of US and foreign manufacturers in the bridge industry is given at the end of this section. These manufacturers can team up and learn from each other.

Prefabricated bridge and component manufacturers: Presented below is the growing list of manufacturing companies who are successfully using bridge components and construction machinery worldwide (including the United States, Europe, and China).

United States

US Bridge (variety of proprietary bridges manufactured in Cambridge, Ohio).
Inverset Bridge (Fort Miller Company, New York)
Acrow Corporation, Parsippany, New Jersey
Mabey Bridge (UK)/Bailey Bridge
Conspan, West Chester, Ohio
Jersey Precast, New Jersey
Hi-Steel, Pennsylvania
Schuylkill Products, Pennsylvania
Cimolai, NY
American Bridge, Pennsylvania
Bright Bridge Construction Inc., California
D.S. BROWN, Ohio
MISTRAS, Princeton, NJ
Hayward Baker, Hanover, MD

In spite of all the constraints, ABC needs to continue to grow to further serve the public interest with more efficient and safe bridge construction and repair. Contractors need more training in the following areas to help them and their teams in the newer aspects of design-build contracts:

- Acquisition of the new type of business acumen required for ABC
- Learning to coordinate with the consultant, the client, and any subcontractor and subconsultant team members
- Identification of the sensitive activities to be performed in a timely manner using the critical path method (CPM)
- The logistics of transporting assembled bridges in regions with sharp curves and ramps
- Understanding of how to obtain permits for wide loads by getting familiar with the traffic laws of different states for haulage
- Optimization of design through selection of the appropriate types of abutments and piers; identifying the proper girder spacing, deck thickness, and deck drainage; use of lighter materials, etc.
- Training from ABC experts in how to reduce costs

ABC is being promoted worldwide and not just in the United States.

Manufacturers of Modular Bridges in Other Countries:

BBR International, Switzerland
DEAL Solutions, Italy
Mageba, Switzerland
Tensacciai, Italy
VSL International, California

Liuzhou OVM Machinery Co., China
Beijing Wowjoint Machinery Co., China
Redaelli Tecna, SPA, Italy
Freyssinet International, France
Dywidag-Systems International, Luxembourg
Bridon International GmbH, Germany
BERD S.A., Portugal

For governments, contractors, and consultants who invest in and/or train in ABC techniques, there are many benefits. Some of the benefits include the following:

- The completion and delivery time is cut by approximately half.
- The contractor is less involved in the fabrication and uses an outside contractor for the assembly of bridge components.
- Many of the contractor's quality control problems and disagreements with the consultant are greatly reduced as he is able to breathe more easily and use his intuition in making decisions.
- The contractor is able to learn from his own mistakes, which improves construction industry standards and leads to improved performance on future projects.
- Construction technology requires experimentation with calculated risks. It is sometimes better to try and fail than not to try at all. Stagnation in a multibillion-dollar industry is neither good nor desirable.
- In the long term, the life cycle costs may be lower. The returns are greater with ABC, as a result of avoiding discomfort and indirect costs to the public. This will likely indirectly compensate for any initial increase in costs.

2.3 Variations in ABC methods

There are several variations of ABC that were defined in Chapter 1. The FIU Website lists a wide variety of recently completed ABC projects. For example, bridge beam materials (HPS, prestressed concrete or composite), methods of construction (crane-installed manufactured bridges, roll-in roll-out or slide-in), and transportation of manufactured bridges (using highways or barges on rivers); state requirements and contractors with varying experience are listed. The subject is still developing, and it will be a while before one single bridge construction set of specifications is evolved.

It appears that there are glitches that may be holding up a more rapid switch-over to ABC. A slow but gradual shift from conventional methods to full ABC (with many projects utilizing a partial ABC approach) is observed, with each subsystem being used under different circumstances. ABC is being promoted and supervised by many state management agencies and also by some proprietary component manufacturing companies. For example, the project managers of the new long-span Tappan Zee Bridge in New York are in favor of using prefabricated deck elements.

2.3.1 Use of new ABC technologies

Bridge engineering, whether conventional or ABC, is linked to the needs of the public. Approximately one-fourth of the United States' 600,000 bridges require rehabilitation, repair, or total replacement.

Developing computer databases for rapid rehabilitation of identified deficient bridges will help in determining the scope of work.

The design-build (D-B) system serves as a benefit for the contractor in terms of making decisions and dealing with the owner. Both conventional and ABC bridges will be designed for identical long-term live load, as well as wind, snow and other environmental loads. With lighter-density materials, member cross sections would be smaller and dead load and thermal and seismic forces would be lower. The difference is in the magnitude and nature of construction loads.

The construction management system is different for ABC and conventional methods. Very few bridges are alike, with their geometry, materials, locations, live loads, and ownership being very different. The duration and type of on-site construction can have significant social impacts onto mobility and safety. Hence, management methods are expected to vary a great deal. The notable differences are summarized in the following sections.

2.3.2 Partial ABC utilizing prefabricated components

The only difference in this technique with conventional practice is the use of prefabricated components for the deck slab, girders, and substructure. Generally, no formwork is required. The completion time is quicker than for the conventional method of cast in place construction. Currently this method is generally being used on most projects, as a technical compromise between ABC and conventional construction.

2.3.3 Full ABC with prefabrication and a contractor-led contract

The consultant participates as a member of the contractor's team and performs detailed design. The contractor is involved in the planning decisions and has the upper hand in decision making. Prefabrication and other rapid construction methods are used. This results in the fastest completion and turnout for bridges.

Many of today's bridge construction and replacement projects take place in areas of heavy traffic, where detours and bridge closures severely impact the flow of people and goods on transportation corridors. One of the most common ways to accelerate bridge construction is to use prefabricated bridge elements and systems (PBES) to construct the bridge. These are prefabricated off-site or adjacent to the actual bridge site ahead of time, and then moved into place when needed, resulting in closure of the bridge for only a short duration. Very frequently, these PBES are constructed with concrete (reinforced, pretensioned, or post-tensioned or a combination thereof).

The contractor's ingenuity in streamlining construction procedures may be helpful in numerous scenarios, such as for bridges over wide rivers. Components may be prefabricated and partially assembled in a factory and transported by barges, and assembled on the site.

2.3.4 Contractors advising on design

Some contractors are able to hire structural designers to perform independent checks on the consultant's design. They can advise the consultant on erection procedures and construction loads. Attention to modern techniques such as optimization would result in economical design and cost savings to the owner. Full ABC consists of design and contracting practices which speed construction, improve safety, and minimize traffic disruption.

Super ABC or Full ABC with Bridge Components Assembled at Construction Site: Bridge components are fully assembled on-site by the proprietary bridge manufacturer. This method applies to small-span, timber, precast concrete, or steel bridges that are lightweight and have shallow foundations.

In many cases, the direct and indirect costs of traffic detours and temporary bridges that are used during construction can exceed the actual cost of the structure itself. For example, full-lane closures in large urban areas or on highways with heavy traffic volumes can have a significant economic impact on commercial and industrial activities in the region.

Partial lane closures and other bridge activities that occur alongside adjacent traffic can also lead to safety issues. Because of the potential economic and safety impacts, minimizing traffic disruptions is a goal that should be elevated to a higher priority when planning bridge-related construction projects. The super ABC concept as a supplement to full ABC should be an optimal solution.

2.3.5 Successful modular construction for tall buildings: a guide for ABC

There are parallel problems in the construction of tall buildings, where modular construction is on the rise. Spans in buildings are much smaller, and both dead and live loads are of smaller magnitude; in general, there are fewer construction problems. Sears Roebuck supplied components of simple modular timber buildings in the United States, which were assembled by purchasers using do-it-yourself (DIY) building plans and catalogs. There are suppliers of lightweight precast concrete segments for buildings and factories listed in the Yellow Pages.

Precast multistory car parks are now being successfully constructed. They are designed for vehicular loads that are similar to bridge live loads. The construction duration and delays of bridge projects likely affect the public to a greater extent than building construction; thus it is useful to look at techniques that can be carried over to bridges. Prefabricated structures seem to have merit, and the building industry is providing a lead to rapid bridge construction.

2.3.6 Widening the deck to provide additional lanes

A partial new bridge may be more economical when an existing bridge is not likely to be replaced in the near future. Additional lanes are constructed on one or both sides of the bridge. This helps in reducing traffic congestion. In the absence of a suitable detour route, staged construction would be required to maintain the flow of traffic during construction. During construction, the number of available traffic lanes may be reduced.

2.3.7 Staged construction

Due to the maintenance and protection of traffic (MPT) requirements, construction in stages is more difficult to implement than the unstaged construction of a new bridge. Fewer safety and traffic issues arise with unstaged construction.

2.3.8 Use of a temporary bridge instead of detour

On essential routes where detour is not feasible, a temporary bridge may be erected on either side of the existing bridge (along lines similar to those of a military bridge erection and demolition). An example is a Mabey- or Bailey-type bridge.

2.3.9 Replacing an existing bridge

After a useful (minimum) life of 75 years bridges are due for replacement. Common reasons are an increase in the volume of traffic, an increase in truck live loads, wear and tear, or low rating from structural deficiencies.

2.4 Advantages of ABC drawings and contract documents

In the following section, we review and compare the format and ABC drawings. Typically, using conventional methods, the volume of construction drawings is very large, especially for use in a temporary site office. Sometimes the number exceeds over 100 drawings.

Up to one-third of any drawing space (for a substructure or superstructure component construction) is occupied by dozens of construction notes and by quantity estimates. Notes are usually from the modified standard construction specifications or from the special provisions prepared for the project. Details of the notes shown on a construction drawing include:

- General notes pertaining to applicable codes of practice and for materials specifications
- Precautionary notes to prevent accidents or damage to equipment from negligence
- Special instructions for construction such as bolt tightening sequences

Sometimes it may be difficult for the site technicians to follow the notes on the drawings, as there is often too much information and it may be disorganized or difficult to interpret. In addition, the use of Computer Aided Design and Detailing (CADD), often an important aspect of conventional drawings, can be time consuming for developing ABC drawings by the CADD operators. With ABC, many construction notes will not be required, since the subcontractor or manufacturer of the prefabricated items will submit the quantity estimates.

Notes pertaining to technical specifications (about the method of manufacture) will not be required, as they are no longer a part of the fieldwork. The lengthy process of implementing drawings on-site will be simplified. With ABC, a greater emphasis can be placed on refined erection aspects, such as avoiding any lack of fit issues in relation to subassemblies.

2.4.1 Delays arising from request for information and drawing change notice

For certain items that are not clear, the contractor normally generates a request for information (RFI) for immediate action from the consultant. A copy is also sent to the client. This will delay the progress of the job, since the consultant's response is likely to be in the form of drawing change notice (DCN). An approval of the DCN will be required from the client, as the quantity estimates and total cost will change. Meetings are held to resolve the issues, the time for which was not originally provided in the schedule.

With ABC, the number of construction drawings required in the field will be fewer (dropping from, say, 100 to a few dozen), as some of them will be implemented in the factories or away from the site. Field supervision by the consultant becomes much easier.

2.4.2 Shop drawings

The present procedure does not help in expediting the production of shop drawings by the manufacturer. With ABC, the need for many of the shop drawings is greatly simplified, as prefabrication will be done in the factory. Also, the shop drawings review process will be greatly simplified, as the manufacturer also becomes an important member of the team and will usually have his own ready-made graphic presentations to supplement the concept based on past projects.

2.4.3 Simplified payment method

The field measurements for payment based on unit prices will not be required for the prefabrication work done in the factory, thus saving engineering man-hours on-site.

2.5 Accelerated management

A design-build system places the contractor in the driving seat. This is one example of accelerated management. Many of these bridges are in need of replacement or accelerated bridge rehabilitation. A great majority of bridge failures occur during the construction process, such as during the erection of girders, cranes, or formwork collapse during the pouring of castin-place (CIP) concrete decks. Not all failures during construction are reported. In some cases, they are hushed up to avoid bad publicity. These incidents add to overhead or to indirect construction costs.

Prefabricated and assembled bridges would minimize many construction failures. ABC methods were defined in Chapter 1. It is not recommended that conventional methods be abandoned altogether. They will continue to be used, when the benefits of experience acquired in the past is relied upon or when contractors with ABC experience are not available. Not all states have adopted ABC methods.

There are about 600,000 bridges on the public roads in the United States. These bridges represent a sizable investment of resources. Some states such as New Jersey are using ABC for vertical construction for tall buildings and for school and hospital projects only, rather than for bridge projects. Also, the majority of contractors do not feel comfortable with taking the lead on the more complex projects. This is partly due to high investment in SPMT, cranes with long booms, and other construction equipment. Non-repetitive geometry and span lengths or traffic loads result in unique bridges, which restrict the advantages gained from mass production of modular units. ABC can be deployed effectively:

- By recognizing that a rapid response is required to fix bridges damaged or destroyed by over-height vehicles, ship collisions, and natural disasters such as hurricanes, earthquakes, and floods. Methods including the use of advanced software that can analyze fragility, seismic activity, scour damage resulting from floods and tornadoes, and long-term fatigue will be required.
- By considering alternate structural solutions and value engineering, which makes cost reductions through planning and life-cycle cost analysis of bridges possible
- By using special methods for preservation of historic bridges other than routine ABC methods as part of new ABC code development
- By introducing security aspects in structural design against blast loads
- By planned coordination with utility companies for rapid utility relocation

The combined construction team of consultants, contractors, and subcontractors must be competent enough to provide all-around expertise in structural planning and design, as well as in construction planning and specifications. Since hundreds of millions of dollars are to be spent in a relatively short duration, bridge contracts require technical know-how combined with business acumen. A new ABC accounting system would be required from the contractors. The business side is always uncertain, delicate, and more difficult to manage than the more clear-cut technical side. The risk factors are higher when initiatives are more ambitious.

If a single construction planning decision by the contractor goes wrong, it will minimize his profits, and he may even have to pay from his own pocket. Huge investments in purchasing or leasing the equipment and in the relocation of work force are usually required. On the other hand, the consultant is not faced with similar risky investment problems in ABC.

On large projects for example, the primary contractor has to manage different subcontractors, the coordination of which is not easy. This adds to his many commitments and schedule worries. As a comparison, the bridge construction methodology in the United States and the role of consultants and contractors in the present system can be broadly classified as follows:

- The consultant makes planning decisions and prepares contract documents for the selection of the contractor.
- The team uses cast in place (CIP) construction for the substructure and superstructure.
- The consultant is responsible to the client or the owner mainly for the design of the bridge, preparation of construction drawings, and inspection in the conventional system (refer to Appendix 3 Bridge Inspection Terminologies).
- The consultant has the advantage from the beginning, usually serving as the advisor and right hand to the client. He is partly responsible for the selection of the contractor.
- The consultant's requirements may sometimes reflect "easier said than done" types of demands. On medium-sized and large projects, the difference of opinion on technical matters may cause friction and may not be in the best interest of the project completion.

Completion of the project takes longer with this method. On complex bridge projects and when funding is not readily available over a short period, the transportation agency may prefer to take more time to complete projects that have lower priority.

It has been observed that consultants can develop complacency in planning, to play it safe. They may take a conservative approach and may make choices in components that are unnecessary for the project. This results in overdesign and heavier slabs, beams, columns, and foundations. It costs the client much more and also increases construction difficulties in the transportation and erection of heavier pieces.

A good contractor understands structural performance and can provide a check on the consultant to reduce overdesign, provided that he is given the opportunity by the management system. Shortcomings in the management of the project for any reason may result in a lower quality of work. Hence, there is a need to review the present system and if possible, to improve it. With advancements in technology, it should be possible to evolve towards more effective teamwork.

On important projects, the client sometimes appoints a second consultant to review the design criteria and drawings prepared by the first consultant. This may complicate the situation and delay the project, since resolving the differences takes time.

Contractor's Role in Adapting to ABC Technology: A contractor can take over the role of second consultant in a more effective manner with ABC. The following contracting provisions are routinely encountered when setting up a bridge project:

- Best construction solutions based on various options and selections
- Lump sum cost or cost of materials plus labor
- The bidding process
- Incentives for a job completed ahead of schedule and disincentives if there are delays
- Warranties for a limited period

Project planning and scope must also be a part of the management process. For example, when determining appropriate ABC methods for a highway overpass, the team may notice:

- Heavy traffic on the overpass road (retail area)
- Relatively light traffic on the interstate highway

Based on this analysis, appropriate logistics and staging can be set up, among other scheduling and setup issues.

Incentives for Early Job Completion: Incentives are often part of contracting provision for construction. These will be in-built in implementing ABC procedures. The definition of ABC requires earliest completion. To minimize the duration of bridge construction, the development of contracting strategies such as realistic incentives/disincentives to encourage speed and quality is essential. Mass production management techniques leading to earliest completion as adopted by the automobile/aircraft industry may be considered.

2.6 Accelerated bridge rehabilitation

Once a bridge is constructed, it needs rehabilitation. The optimal life of well-maintained bridges is 75 years, but they can last longer with rehabilitation.

This is an extensive subject that is more diverse than bridge design and involves inspections, interpretation of data, selection of repair and rehabilitation methods, analysis, computer-aided design, and application of AASHTO and state Codes of Practice.

2.6.1 Maintenance problems of old and historic bridges

The present multiple interstate highways system in United States was initiated mainly during the Eisenhower administration in the 1950s and1960s. Many of the bridges that are now well over 50 years of age need to be rehabilitated or replaced. As bridges get older, highway agencies have on their agenda hundreds of bridges to reconstruct and open to the public in any given year.

- Rehabilitation tasks such as repairs or retrofits are much more common than replacements.
- The majority of rehabilitation tasks are applicable to superstructure repairs, retrofits, or widening, but with minor substructure rehabilitation work.
- Based on the inspection reports and ratings, if changes in the substructure are required, it will be classified as a replacement project.
- Bridge replacement may apply either to the use of existing foundation or to a new foundation (based on the old footprint or an entirely new footprint).
- Appendix 7 shows the criteria used for structural evaluation by ASCE Report Card and the need for innovations and new technology. Based on the grade awarded, policy decisions can be made for funding and prioritization.

2.6.2 Bridge widening using ABC

For widening projects, additional foundation design to support the new widened areas will be required. Soil properties will be known from past soil investigations and soil reports. Most DOTs will have databases on soil borings available. In case of doubt, new borings need to be driven and fresh soil data obtained. Soil tests in the laboratory need to be performed for a new soil report, since there may be changes in water table elevations with time.

Most contractors would prefer outright replacements rather than getting bogged down with messy rehabilitation work. A brief description of various aspects is given here. General considerations include the following:

ABC planning considerations and steps for bridges

- Funding and cost
- Functional requirements
- Aesthetic requirements
- Geometry, alignment, and profile
- Vertical and horizontal clearances
- Right of way availability
- Existing utilities relocation
- Soil conditions
- Constructability
- Staged construction
- Maintenance and protection of traffic
- Environmental permit requirements
- Public involvement
- New technologies and innovative methods
- Alternative design
- Value engineering
- Preliminary design
- Development of rehabilitation and replacement schemes
- Future maintenance and inspection access

Use of new construction materials

Progress is being made in more durable construction materials, which are:

- FRP concrete
- Lightweight concrete
- High-performance concrete
- Structural steel
- High-performance steel
- Glue-laminated timber
- Aluminum

Superstructure rehabilitation issues

Common problems are:

- Deck reconstruction and design
- Existing concrete deck repairs
- Deck protective system
- Deck replacement

- Concrete structure repairs
- Steel superstructure rehabilitation and design
- Deck joints
- Deck drainage
- Bridge railings and parapets
- Bearings retrofit and design
- Bridge widening

Substructure rehabilitation issues

These include:

- Geotechnical issues, soil report, and foundation design
- Foundation erosion
- Scour countermeasure design
- Abutment and wingwall repairs
- Pier repairs
- Seismic retrofit
- Integral abutment design
- Precast construction

Rehabilitation report

A rehabilitation report includes issues such as:

- Description of project area and structure
- Condition of structure and ratings
- General considerations and constraints
- Roadway and safety improvement
- Structural rehabilitation and reconstruction schemes
- Widening and/or vertical clearance improvements
- Maintenance of traffic
- Cost estimate for alternatives and cost analysis
- Recommendations

2.7 Asset management after identifying SD bridges

Bridge management is an essential part of overall, long-term asset management. It is applicable to all existing bridges, old or new. The purpose of management is maintenance of the bridge, by identifying deficiencies and ensuring the continued safety of traffic through rehabilitation. It is usually done by the state agencies and consists primarily of:

- Inspection: Inspection is the first step in asset management. First and foremost the deteriorating condition needs to be identified. It can visual inspection or by remote sensors.
- Structural health monitoring
- Rehabilitation

Each subject is covered by codes of practice from FHWA or the relevant state agency.

A list of Bridge Inspection Terminology and Sufficiency Ratings used by PennDOT is given in Appendix 3.

Transportation Equity Act: The design and construction of a new bridge or replacement are additional tasks outside the scope of the management system and are not part of rehabilitation or retrofit. Both structural expertise and major funding would be necessary to meet the objectives. In 1998, the Transportation Equity Act allocated over 200 billion dollars for resurfacing, restoring, and rehabilitating various programs every 6 years. Federal funding for stats infrastructure projects has increased in recent years.

2.7.1 Management systems

In 1985 FHWA initiated a two-phase demonstration project. Phase 1 called for a review of existing state Bridge Management System (BMS) practices for systematic inspection method of bridge analysis and rating.

Phase 2 required a microcomputer tool that any state could use to manage their bridge inventory. The phase 2 tool was named PONTIS.

The two highway bridge management systems deal with management of bridges on state and interstate highways.

In the United States, the responsible agencies for developing BMSs are the FHWA, AASHTO, and each state. An understanding of engineering concepts is an essential part of the qualifications for any inspector.

2.7.2 Bridge rating procedures and rating formulae

Details of rating procedure and formulae are presented here. Rating computation shows the structural health of the bridge and degree of deficiency of the bridge. Standard denominations of axle live load trucks will be used. A bridge rating is determined by the individual rating of its components, such as the deck slab, girders, and substructure. A bridge load rating decides the available live load capacity of a bridge in tons.

There are three methods of rating/structural evaluation of a bridge. Both theoretical and physical methods are being used:

- Live load rating based on LRFR methods
- Nondestructive static tests (such as placing sand bags with known loads)
- Moving load tests and field observations (using calibrated vehicles)

2.7.3 Rating criteria

Using the bridge inspection field data and reports, the next step is to evaluate the condition of the bridge by applying the rating criteria (sufficiency, load capacity, load factor, failure, vulnerability, seismic ranking, and prioritization). Individual ratings will identify the condition of the bridge.

Detailed procedures will be based on codes and textbooks related to inspection and ratings. A brief summary of several rating criteria is presented here.

Structure Inventory and Appraisal (SI&A) sheet ratings: The FHWA uses inventory data to rate the bridge as follows:

- Nondeficient (safely carries designed traffic loads)
- Structurally deficient (lighter load posting is required)
- Functionally obsolete (does not meet the highway criteria)

The SI&A sheet shows this rating at the end of the sheet.

Sufficiency rating (SR): SR is calculated from an AASHTO formula, which evaluates the factors indicative of bridge competence. A sufficient bridge has a 100 rating; an insufficient bridge is rated 0. When SR is >50 but <80, rehabilitation is required. When SR is <50, replacement is required. The SI&A sheet shows the SR value at the end of the sheet.

Load capacity rating: Although, in the original design, the bridge is designed for certain theoretical live loads at any given time, it needs to be rated for the actual live load that the bridge can support. This evaluation may show a reduction in strength due to factors such as fatigue, corrosion, or an increase in the magnitude of the truck load. Also, when the bridge is rated for a smaller live load than used in the original design, it may show a reserve of strength.

Vehicle rating categories: Examples of classified truck loads are

- H 20 (20 tons)
- HS 20 (36 tons)
- Type 3 (25 tons)
- Type 3-S2 (36 tons)
- Type 3-3 (40 tons)

Structural capacities and loadings are used to analyze the critical members and to determine the appropriate load rating. Live load vehicles vary in intensity, such as common or important routes in the United States, to ensure that no posted weight is exceeded and are issued for a limited number of crossings or for the whole year. Heavier vehicles need to be escorted.

2.7.4 Rating factor

In the past, a rating factor (RF) was based on the LFD method as follows:

RF for LFD is expanded as the general LRFR equation (refer to AASHTO Manual for Condition Evaluation and Load and Resistance Factor Rating of Highway Bridges, October 2003).

Usually axle loads are considered.

Load factor rating: This is computed as a rating of live load carrying capacity:

$$\frac{(\text{Allowable load} - \text{Dead load}) \times \text{Vehicle weight}}{(\text{Rating vehicle Live Load plus Impact})}$$

or

$RF = (C - D)/L\ (1 + I)$

C = Capacity of member

D = Dead weight effects

L = Live load effects

I = Impact factor
A_1 = Factor for dead load
A_2 = Factor for live load

For the allowable stress method, dead load (D) and live load (L) are unfactored:

$C = D + RF\ (L)\ (I + 1)$

For the load factor method, some inelastic behavior is assumed:

$C = 1.3D + A_2\ RF\ (L)\ (I+1)$

The BAR 7 (PennDOT) computer program is commonly used.

Using the equations below, a bridge is rated at two different levels: The inventory rating is set at 55% of the allowable yield stress of steel. The lower level allows for safe use of bridge for an indefinite period. $A_2 = 2.17$ for the load factor method. The operating rating is set at 75% of the allowable yield stress of steel and is the maximum permissible load. $A_2 = 1.3$ for the load factor method.

For compact sections	$M_u = f_y \times Z$
Noncompact braced section	$M_u = f_y \times S$
Noncompact unbraced section	$M_u = M_r \times R_b$

Conventional AASHTO Specifications terminology is used.

Use of the load resistance factor method (LRFD) for ABC: The LRFD method provides only one rating factor corresponding to the Strength Limit case, whereas the load factor method has both an inventory and operating rating to indicate a serviceability capacity and maximum strength capacity.

Failure rating: Failures of substructure will involve the tilting or settlement of a pier or abutment. Shear and flexure are another mode of failure. Failure types are defined as follows:

- Catastrophic failure rating, FR = 5
- Partial collapse, FR = 3
- Structural damage, FR = 1

The exposure parameter is a measure of the effect that a failure of structure will have on users of a bridge and highway network.

$$\text{Exposure} = \text{Traffic volume} + \text{Functional classification}$$

Seismic ranking and prioritization: Retrofit priorities are defined in the FHWA Seismic Retrofitting Manual for Highway Bridges and will depend upon:

- Structural vulnerability (some components are more vulnerable than others, such as girder connections, bearings, seat width, piers, abutments, and soils)
- Seismic and geotechnical hazards
- Importance factor

The rating system consists of the following: The quantitative part consists of seismic rating (bridge ranking) and is based on

- Structural vulnerability
- Seismic hazard

The screening of inventory data is required. AASHTO Specifications are limited to regular bridges. Their susceptibility grouping classifications as defined by some states are:

- High seismic vulnerability (HSV)
- Moderate-high vulnerability (MHV)
- Moderate-low vulnerability (MLV)
- Low seismic vulnerability (LSV)

Vulnerability Rating Scale (VRS): This rating scale can be summarized as follows:

- Safety Priority Action (immediate priority for remedial work)
- Safety Program Action (high priority for remedial work)
- Capital Program Action (priority for remedial work based on capital program)
- Inspection Program Action (low priority based on inspections and monitoring)
- No Action (likelihood of failure is remote)
- Not Applicable (no exposure to specific type of vulnerability)

The preliminary risk-based assessment of fracture critical members (FCMs) of major bridges shall include but not be limited to the following tasks:

Perform cursory site inspections: The intention is to become familiar with the physical layout, below-deck and above-deck features, and available access routes for each bridge. The cursory site inspections shall be limited in scope to visual inspections only, which do not require special inspection equipment or access methods.

Plans and documents: Assemble and review existing available plans and documents for each bridge, including the following:

- Original as-built plans
- Shop drawings
- Subsequent repair and rehabilitation plans
- Annual, biennial, and special bridge inspection reports
- SI&A form updates
- Load ratings
- Fatigue evaluations
- Structural models and computer analysis
- All other applicable reports and materials

2.7.5 Key components of rating research and studies

The following data and assessments should be part of any bridge rating study. These factors need close attention for successful implementation of ABC methods.

Traffic data: Compile and review current average annual daily traffic (AADT) data and average annual daily truck traffic (AADTT) data and associated peak occupancies for each bridge, which will be furnished by the owner. Compile and review current bridge replacement costs for each bridge, which will also be furnished by the owner.

Overload analysis: Compile and review available overload analyses performed for each bridge.

FCM: Identify all fracture critical and failure critical members, connections, and details for each bridge as part of a comprehensive assessment, including nonredundant members, members and connections with fatigue-sensitive details, welded connections, bearings, and other special details as applicable. The recognition and identification of the types of forces carried by the bridge member, together with its degree of load path, structural, and internal redundancy are essential. The identification of all fracture critical and failure critical members shall be based on the given below definitions.

Fracture critical members or member components: FCMs are steel tension members or steel tension components of members the failure of which would be expected to result in a partial or full collapse of the bridge. In order for a bridge member to be classified as fracture critical, it must satisfy two criteria. The first criterion is that the bridge member must be in tension or have a tension element. The second criterion is that its failure must cause a partial or full collapse of the structure.

Failure critical members: These are generally defined as members or member components whose failure would be expected to result in a partial or full collapse of the bridge. Failure critical members are not restricted to steel members in tension, and therefore may be constructed from any material and be designed to withstand nontensile loads. Some examples of failure critical members include a concrete compression member such as a single column pier or a compression member of a truss chord.

Prioritization: This shall be based on National Bridge Inspection (NBI) data, as well as specific operational and logistical features of each bridge. Following completion of the prior tasks, perform a prioritization of the fracture critical and failure critical members and member components on an individual bridge basis. These may include such features as:

- Potential for expected damage, loss of life, and functional use based on traffic volumes
- Criticality to emergency response and evacuation
- Military route designations
- Availability of alternative routes
- Bridge retrofit or replacement values
- Loss of use and associated toll revenue streams, and so on.
- Importance to regional infrastructure network and economy

The consequences of partial or full collapse may be based on vulnerability and importance.

Risk assessment: Identification of current best practices in the public transportation industry for risk management of critical infrastructure is required. Following prioritization of the major bridges, perform a risk assessment to determine the vulnerability of their fracture critical and failure critical elements. The AASHTO/TRB Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection, 2002, shall be used as the standard for conducting the risk assessment. The consultant may supplement this guide as deemed appropriate or required with prior written approval from the Authority.

The consultant shall evaluate the current best practice policies and procedures of other transportation agencies, and shall make specific recommendations for implementation as part of this study.

Summary reports and priority recommendations: The consultant must prepare a summary report of findings and recommendations based on the prioritization and risk assessment of all major bridges (including estimates of capital and operating costs where applicable). The summary report shall be presented with sections consistent with the scope of services. The priority recommendations for future engineering phases may include tasks such as:

- Additional special inspections
- Detailed structural modeling
- Redundancy and progressive failure analyses
- Fatigue analyses
- Conceptual retrofit design

An executive summary of a cost–benefit analysis and implementation timeline over a 10-year time frame is needed.

Unanticipated services: There may be certain services of a special nature that are necessary to advance the study that cannot be completely identified at this time.

2.7.6 History of the National Bridge Inventory Program

After the collapse of Silver Bridge in 1967 in West Virginia, in which 46 people died, the U.S. Congress passed the Federal Highway Act of 1968. As a result, a National Bridge Inspection Standard (NBIS) was introduced in 1971. NBIS established a national policy regarding important procedures for inspection including frequency of inspections, qualifications of inspectors, inspection reports, and maintaining databases of state bridge inventory for ensuring bridge safety.

The scope and types of inspections are visual and underwater inspections, and nondestructive testing (NDT). The role of inspection is therefore of paramount importance in safety evaluation and funding allocation. Inspectors can categorize bridges in various ways, with the two following categories indicating the immediate need for rehabilitation, retrofit, and/or repair.

Millions of people cross the aging or deteriorating bridges every day (Reference T+L Magazine dated July 2012, Report by Sarah L. Stewart).

The new system can therefore be used to identify:

- Maintenance needs
- Repair and rehabilitation strategies
- Functional improvements
- Bridge replacement requirements

A National Bridge Inspection Standard (NBIS) was introduced in 1971, which established national policy regarding:

- Inspection procedures
- Frequency of inspection,
- Qualifications of personnel
- Inspection reports
- Maintenance of state bridge inventory

Three manuals were developed as follows:

- "Bridge Inspector's Training Manual" (1970)
- "Manual for Maintenance Inspection of Bridges" (1970)
- "Recording and Coding Guide for the Inventory and Appraisal of the Nation's Bridges" (1972)

Nowadays, the inspection programs broadly consist of

- Fundamentals of inspection
- Inspection reporting
- Structural evaluation
- Advanced inspection techniques
- Identification of a **structurally deficient bridge:** The bridge has deterioration to one or more of its major components.
- Identification of a **functionally obsolete bridge:** The bridge has old features such as road widths and weight limits that are no longer used.

2.7.7 Summary of bridge components for inspection

- *Bridge decks*: Timber, concrete, steel, joints, drainage, lighting and signs, various deck repairs
- *Timber bridges*: Solid sawn and Glulam
- *Concrete bridges*: Slab bridge, T-beam, reinforced and prestressed concrete girders, box girders, precast segmental, box culverts
- *Steel bridges*: Fatigue and fracture design, nondestructive testing, rolled steel and fabricated plate girders, multigirder and through bridges, box girders, trusses, arches and rigid frames
- *Bridge bearings*: Rocker and roller types, elastomeric pads, sliding and multi-rotational
- *Common types of transverse restraint*: anchor bolts, keeper bars, shear keys

2.7.8 Selection of bearing types to resist earthquakes

The least transverse restraint is offered by roller bearings, rocker bearings, and elastomeric bearings. Rocker bearings are the most vulnerable.

High seismic forces are generated in the restraints during a seismic event. The following types of bearings may offer transverse restraint:

- Substructure: concrete shear key
- Elastomeric pad: bearing plates and anchor bolts
- Elastomeric pad: center pin
- Sliding or multirotational bearings: **guide bars** and with four or more girders.
- Sliding or multirotational bearings: **no guide bars** and with three or less girders.
- *Minimum seat width to support bearing*: Simply supported spans with high skew and inadequate seat width are the most vulnerable to overturning. Continuous superstructures with integral abutments are most stable.
  H = Height of column, pier, or abutment in feet; S = Skew angle at support; N = Seat width
  For Seismic Performance Category A and B:
  $$N = (8 + 0.02L + 0.08H)\ (1 + 0.000125\ S^2)\ \text{in.}$$
  For Seismic Performance Category C and D:
  $$N = (12 + 0.03L + 0.12H)\ (1 + 0.000125\ S^2)\ \text{in.}$$
- *Substructures:* Modular and cast in place types include abutments, wingwalls, piers, noise walls, and earth retaining walls.

2.7.9 Need to identify deficient bridges

In general, bridge deficiencies increase with time, with increased wear and tear and fatigue of members. It is important to identify the deficient bridges before a failure takes place. There is an old saying that "a stitch in time saves nine." Not removing the deficiency as soon as possible will cost much more. An inventory of deficient bridges needs to be prepared. Another saying is that "forewarned is forearmed." It applies to prediction of natural disasters as well as to the identification of bridges that are likely to fail in the near future.

2.7.10 Revisions to NBIS

The inspection and rating procedures have undergone further changes following subsequent bridge failures, such as:

- I-95 Mianus River Bridge in 1983
- Schoharie Creek Bridge in 1987 in New York and Cypress Viaduct due to the Loma Prieta earthquake in 1989 in California

In 1998, the FHWA estimated that nearly 30% of the nearly 600,000 bridges in the United States were considered structurally deficient. Over a quarter million bridges built between 1956 and 1975 would require major repairs or deck replacement in the near future. To ensure the best use of limited monies, wise engineering management is required. Bridge failures need to be avoided at a predetermined cost. Load posting requirements are a step in the right direction.

The following revisions were made to NBIS:

- *Inspection frequency*: Maintain an inspection frequency of 2 years for bridges exceeding 20 ft in length.
- *Fracture critical members (FCM)* must be identified.
- *Underwater inspection* procedures are required.
- *Team leader certification* requirements were revised.
- *Inventory data for state bridges* are to be updated within 90 days with any changes in load restriction.

2.7.11 Structural health monitoring

Knowledge of the condition of existing bridges through SHM will help in identifying the deficient bridges and evaluating them for the following actions. Selection of bridges on a priority basis for funding will ensure no failures:

- No action required, as bridge is in perfect condition
- Minor repairs required
- Major repairs and rehabilitation required
- Retrofit of components required
- Replacement of components required
- Replacement of entire bridge at existing location
- Construction of new bridge(s) in new location

Inspection methods do not change for the evaluation of bridges constructed using ABC methods. If anything, such bridges are likely to be in better shape than those built using conventional methods.

SHM consists of installing remote sensors and devices to reduce life cycle costs. Use of sensors was suggested before the sudden collapse of the I35W Bridge in Minneapolis.

Costs are based on selecting preferred alternatives for superstructure and substructure. An evaluation matrix would show the following:

- Initial construction cost
- Life cycle cost of maintenance
- Environmental and social impacts
- Constructability
- Future maintenance and inspection
- Aesthetics

2.8 Inspection programs

2.8.1 Safety inspection methods

The inspection methods are well established, since each and every bridge needs to be inspected at least once every 2 years. Methods of repair and retrofit require computer analysis and detailed design techniques and are only briefly addressed here. These include geotechnical investigation, hydraulic and scour analysis, dynamic analysis, and issues related to bridge geometry.

2.8.2 Types of inspections

Visual inspection, nondestructive testing, and underwater inspection are carried out. Examples of inspections are:

- Inventory/initial inspection with load capacity ratings from a Structural Inventory & Appraisal Sheet using AASHTO's Sufficiency Rating formula
- Evaluating structural deficiency
- Periodic/routine inspection
- Damage caused by accidents or environment
- In-depth inspection using nondestructive testing, etc.
- Interim or special inspection to monitor a deficiency

2.8.3 Use of the PONTIS system

Data are fed into a computerized database system. Besides bridge condition data, the system stores maintenance and traffic data, improvement and replacement costs, and available funding. Through optimization, a prioritized list of bridge needs (such as predicting and preventing any deterioration) can be produced, in keeping with the funds available.

The bridge engineer inputs the data into a computerized database system. This database contains bridge condition data, traffic needs, accident data, maintenance, improvement and replacement costs, available monies, and so on, from which a prioritized list of bridge needs can be produced that optimizes the limited funds available.

PONTIS consists primarily of:

- Commonly recognized (CoRe) elements and smart flags
- Sub elements
- Special non-CoRe elements

Examples of a sub element are exterior girders, girder ends, hinges, and other paint systems. Examples of smart flags are fatigue, rust, deck cracking, soffit, settlement, scour, and traffic impact.

Non-CoRe elements are unique items that a state can add to their PONTIS database. Examples include rigid frames, diaphragms, lateral bracing, splice plates, slope protection, and tunnels. In the PONTIS system, precise condition inspections are required.

An FHWA computer program calculates ratings. It converts PONTIS data elements to NBI condition (non-CoRe elements are not to be used).

PONTIS advantages: Using the inspection data, an engineer is able to accomplish the following:

- Predict deterioration
- Improve safety or serviceability
- Estimate savings and costs
- Optimize a program with limited funds
- Generate reports for state legislation

A good BMS is a comprehensive database of bridge, traffic, cost, and safety-related data and an ongoing program for data collection. ABC methods are better suited to make use of the Pontis system for implementing repair, rehabilitation, or replacement compared to conventional construction methods.

2.8.4 Performing inspection and writing an inspection report

Basic activities include:

- Visual and physical examination of bridge components
- Evaluation of bridge components
- Examination of approach roadway and evaluation of waterway

A sample copy of an inspection report is provided in Appendix 2.

2.8.5 Bridge inspector responsibilities

The inspector's responsibilities are also linked to the designer's role and supplement the designer's responsibilities of providing adequate safety factors and cost-effective designs. In particular, an inspector's role is to:

- Maintain public safety by identifying defects
- Protect public investment by initiating timely action
- Participate in bridge inspection programs by following inspection procedures, ensuring qualifications, and reporting and preparing inventory

- Provide accurate bridge records through high-quality inspection
- Fulfill legal responsibilities in preparing legal documents

2.8.6 Inspection man-hours for the inspection team

For 2-yearly inspection of thousands of bridges, a huge effort is required. Inspection time consists of the following duties:

- Office preparation
- Gathering tools and equipment
- Acquiring plans
- Accessing permits and previous reports
- Travel to multiple sites and fieldwork
- Report preparation

2.8.7 Duties of an inspection team

Much depends upon bridge engineer's field reports, in terms of the extent of repairs or replacements. Their engineering judgment dictates the need for funding allocation in hundreds of millions of dollars.

The inspection team must have a program manager and a team leader, whose qualifications and experience are laid down in the AASHTO Manual for evaluation of bridge conditions. Their duties are:

- Planning and preparing for inspection such as determining the type of inspection, selecting the team members, defining activities, developing a sequence and schedule, arranging for traffic control and method of access, organizing equipment and tools, and subcontracting and reviewing safety precautions
- Reviewing bridge files such as previous inspection reports, as-built plans, retrofit plans, and geotechnical, utility, and right-of-way plans
- Preparing forms and sketches
- Performing inspections, such as visual and physical examination and evaluation of bridge components by following procedures
- Preparing reports including completion of forms, objective written documentation, photos, references, evaluations, recommendations, and cost estimates
- Identifying items for repair and maintenance

2.8.8 Qualifications and training of inspectors

The objectives of any bridge inspection course include the review and study of:

- Bridge management
- Engineering concepts for inspectors
- Causes of failures
- Safety inspection and rating of in-service bridges
- Methods of repair and retrofit

2.8.9 Certification of bridge inspectors

With the advent of remote health monitoring and rating software, training in new techniques, leading to certification needs to be imparted to the bridge inspectors. The program manager shall be a registered professional engineer or have a minimum of 10 years experience in bridge inspection assignments and have completed a training course based on the Bridge Instructor's Reference Manual (BIRM).

The team leader in charge of an inspection team shall have the qualifications specified for program manager or have a minimum of 5 years experience in bridge inspection assignments and have completed a training course based on BIRM.

The qualification requirements would not change under the PONTIS system. The FHWA has developed a 3-week training program based on BIRM. The program consists of a 1-week course "Engineering Concepts for Bridge Inspectors" and a 2-week course "Safety Inspection of In-Service Bridges."

According to NHI, the following courses extending between 1 and 3 weeks are usually required for registration as a bridge inspector and adopted by majority of agencies:

- NHI "Bridge Inspector's Training Courses" Part I and Part II
- NHI "Stream Stability and Scour at Highway Bridges"
- NHI "Bridge Coatings Inspection"
- NHI "Fracture Critical Inspection Techniques for Steel Bridges"
- NHI "Bridge Inspector Refresher Training"

2.8.10 Summary of standard inspection procedures

- Inspection and diagnostic testing
- Maintenance policy principles
- Types of distress
- Load capacity evaluation
- Substructure and superstructure repair
- Bridge foundation rehabilitation
- Strengthening techniques for various bridge types

2.9 Bridges on waterways

2.9.1 Scour and soil erosion

Scour on critical bridges located on streams with high flood velocities have been the cause of major foundation settlements. Bridges with narrow waterway openings and erodible soils contribute to bridge collapse.

The levels of underwater inspection are as follows:

- Visual
- Detailed inspection with partial cleaning
- Detailed inspection with nondestructive testing

Special equipment such as fathometers may be required.

2.9.2 Underwater inspection

There are three methods commonly used:

- Wading inspection in shallow waters
- Scuba diving in deep water
- Hard-hat diving for rivers with high velocities

NBIS Criteria for selecting the type of substructure inspection:

The two inspection forms are a waterway/channel form and substructure scour form.

Inspection of piers and abutments is carried out with special emphasis on piles and pile bent inspection. Priority repair categories and repair methods are outlined by the NBIS as well.

2.9.3 Structural inventory & appraisal sheet

This well-known sheet is a summary sheet for data about each element of a bridge.

Each state must maintain an accurate and current inventory of the status and condition of all of its bridges. The inventory data is used by FHWA for its National Bridge Inventory, which is submitted to the Congress for funding purposes. It reflects the "condition" of a bridge by assigning condition codes. It has a section on "appraisal."

2.9.4 Personal and public safety during inspection

Hard hats, climbing boots, leather gloves, safety goggles and tool pouches, life jackets over waterways, etc. are required for safety. Established safety procedures must be followed. Traffic should be routed through work areas by trained personnel with traffic control devices, and approaching motorists should be guided in a clear and positive manner.

Field attire, including a reflecting safety vest, should be properly sized and suitable for the climate. Special equipment for underwater inspection, nondestructive testing, and surveying may be required. The federal Manual on Uniform Traffic Control Devices for Streets and Highways is generally used. OSHA regulations should be consulted. Access equipment and access vehicles include bucket trucks, cables, platforms, scaffolds, man lifts, and ladders.

2.9.5 Safety priorities

Comprehensive Strategic Highway Safety Plan will reduce roadway crashes, and injuries from accidents. The plan's goals include

- Top priority given to the installation of safety median barriers.
- Signage upgrades with reflective material for better visibility;
- Enhanced pavement markings for better nighttime and wet weather visibility;
- Improving design and operation of intersections,
- Increasing driver safety awareness
- Curbing aggressive driving leading to accidents
- Traffic signal timing improvements for both drivers and pedestrians
- Reducing pedestrian, bicycle, rail, and vehicular conflicts.

Congestion Relief and Driver Comfort.
Significant congestion results in the following:

- Decreased productivity
- Increased driver stress and reduced quality of life
- Wasted fuel
- Increased air pollution

Congestion reduction planning should address the bottleneck effect of intersections and interchanges. Old, outdated, or substandard geometries with increasing traffic have congested many locations.

2.10 Funding allocations for structurally deficient bridges

2.10.1 Author's survey of deficient bridges on rivers and design of scour countermeasures

The scour sufficiency rating needs to be evaluated. A scour analysis is carried out to evaluate scour depths based on FHWA Publication HEC-18.

Scour depths for long-term scour, contraction scour, and local scour are assumed to develop independently.

A scour report consists of a detailed field survey, substructure information, scour analysis results, hydraulics-related findings, and countermeasure recommendations.

Some of the common types of countermeasures are riprap, gabion baskets, concrete blocks, and sheet piling. Harnessing the river to reduce flood velocities may also be used.

2.10.2 Bridge rehabilitation linked to funding for infrastructure maintenance

The transportation network is an important engine driving the growth and prosperity of the state and regional economy. A robust capital program is required, one that spurs economic growth, improves mobility, and ensures the safety and reliability of the transportation system. It also delivers reforms that enhance the fiscal responsibility and public accountability of the transportation fund.

ABC requires using the funds at a rapid pace, unlike conventional funding, which may drag on for years. Also, except for emergencies, bridge funding cannot be done piecemeal. The public needs complete highway maintenance. This requires simultaneous and as-needed repairs to the infrastructure including banks of rivers, approaches to bridges, entry and exit ramps, retaining walls, culverts, lighting poles, and sign supports.

2.10.3 Sources of funding

For the success of rapid construction, readily available funds are the key factor. The transportation agencies do not have a magic wand to come up with huge funds for hundreds of projects simultaneously.

Continuing the Chapter 1 discussion on the availability of budgets, the four options that can be debated are:

- Transferring more money from the general fund to the Highway Trust Fund
- Raising the gasoline tax
- Charging drivers based on how much they drive using GPS devices
- Tapping oil and natural gas drilling royalties

The first two items have been commonly used, but last two need to be considered. The latest ASCE report card based on an in-depth study and submitted to the Congress has given the transportation industry a D+ grade. It recommended providing trillions of dollars to fix deficient bridges.

The federal government provides funding to each state. The Highway Trust Fund (HTF) and *Moving Ahead for Progress in the 21st Century* (MAP-21) are the main Congress-approved sources.

Every state has its own need-based criteria developed by transportation committees. Social reasons may also determine the sources and amount of funding such as in the case of protection of highways and bridges against floods, earthquakes, and other disasters.

The author worked in the planning and design of many bridges in the Northeast in states such as New York, Pennsylvania, New Jersey, Delaware, Maryland, Washington DC, and Virginia. Some of the more recent bridges had used the ABC technology. The author was selected as a member of ASCE Team to prepare the Pennsylvania State 2014 Report Card on the condition of bridges.

2.10.4 Congressional action for emergencies

The collapse of the portion of the Interstate 5 Bridge that runs over the Skagit River in Washington State in May 2013 made national headlines and prompted transportation advocates to call for immediate Congressional action. The bridge collapsed after a truck hit one of its overhead support structures, sending cars plunging into the river.

The Constitution mandates a federal role in roads, in contrast to many other programs for which the federal government is paying. Since 2008, Congress has shifted over $40 billion from the general fund, with over $12 billion authorized for 2014.

2.10.5 Funding of ABC projects each year

This section deals with the important aspect of funding huge costs of construction even though ABC methods help in minimizing the costs.

There is growing interest in alternative financing for major construction projects. In the short term, it is unlikely that elected officials will recommend, or that the public would accept, new gas or local infrastructure taxes or dramatically increased public spending.

- Public–private partnerships to invest in bridges, highways, and tunnels
- Bringing private money into transportation infrastructure, through outright sale of assets as well as private development of roads, bridges, and mass transit networks

It is important to ascertain the recurring costs at the time of structural planning, design, and construction details development. Funding for infrastructure usually has a high priority on federal and state governmental lists and is facilitated through congressional committees. The highway agency may come up with necessary funding allocations through the following:

- Sale of bonds
- Increasing tolls
- Loans
- State funding
- Federal aid

2.10.6 Funding constraints and resource allocation

Accelerated construction may not always be desirable. On large projects requiring huge investments, the availability of a lump sum within a limited duration of a few months only may not be possible, and rapid construction may be held up. In such cases, the funding allocation may spread over a longer period due to financial constraints.

Although certain construction aspects such as prefabrication and delivery may still be possible, the contractor may distribute his labor according to reduced demand. Some imported items and materials may take longer to arrive from abroad, and the schedule has to reflect such delays. The work may be done in phases over a much longer period, depending upon the release of funds. There cannot be one uniform construction duration for all bridge projects.

Projects may be classified as follows based on total cost:

Small projects with overall cost of 5 million dollars,
Medium-sized project not exceeding 50 million dollars,
Large projects not exceeding 250 million dollars,
Very large projects exceeding 250 million dollars.

All activities, whether technical, nontechnical, coordination, administrative, or accounting will increase in intensity and number, according to the size of project. If funding and resource allocation are the main considerations, rapid construction would suit smaller project delivery much better compared to full use of benefits on large size projects. Projects need to be planned for design and construction, taking into account financial constraints.

Funding and the Highway Trust Fund: The costs of maintenance work on large projects are usually very high. Bridges owned by state agencies need to be managed under a funding policy. Priorities in funding should generally be determined in light of maintenance principles. Transportation Trust Fund and Transportation Equity Act (TEA-21) have laid down certain criteria for the manner in which the funds should be spent.

If deficiencies are similar between those of interstate and local road bridges, funding requirement will be similar. However, important bridges have priority in funding. Bridges on interstate highways and highways for military vehicles, hospitals, and school routes would receive funding first. Those located on local routes or in rural areas, where traffic volume is far less, generally receive funding as routine projects. FHWA has developed computer software for evaluating life cycle cost analysis (LCCA). As a new tool, it facilitates the agency in the decision-making process.

Priority projects for replacement are generally identified for the Highway Trust Fund. Recommendations need to be made to highlight an innovative approach to achieving repairs and replacement of deteriorating bridges. Financial incentives need to be provided for developing and planning for the following:

- Tools and techniques to promote state-of-the-art technology
- Infrastructure development/prefabricated technology
- Higher planning, design, and construction standards and quality performance
- Public–private partnership projects, contract compliance, performance criteria, operational and warranty criteria, and long-term contractual commitments
- Additional costs of testing

2.10.7 Reforming the TTF

Restoring highway bridges to a state of good repair will be a top priority of all the highway agencies. Other major structures need to be programed for rolling programs of life-extending repairs or "right-sized" rehabilitation projects. It would be impossible to replace all identified deficient and functionally obsolete bridges in a short period of time, even with increased funding.

Highway agencies should use sophisticated engineering approaches such as ABC to manage these assets and to keep them serviceable in a timely manner.

Also, the movable bridges are in greater need of rehabilitation:

- Funding increases for programs that extend useful bridge life
- Emergency repair contracts
- Rehabilitation of bridge decks
- Bridge painting (especially in marine environments)
- Reconstruction of orphan bridges (such as highway bridges over railroads, without clear ownership).

2.10.8 P3 funding

Public–private partnership in recent years has eased the fund raising and resulted in huge allocations. Many states are now encouraging and promoting its adoption.

Future P3 Opportunities: Given the recent flurry of activity in Kentucky and neighboring states, it appears that there are excellent possibilities for future P3 opportunities, as reported by John Farris and Tom Howard in the Lane Report of University of Louisville. Some future applications for Kentucky are likely to include the replacement of the I-75 Brent Spence Bridge that crosses the Ohio River near Cincinnati, as well as the proposed I-69 bridge that would cross the Ohio River near Henderson, Kentucky. These two bridges are excellent candidates for a design-build approach, but the means of financing will likely be different, given the levels of traffic expected to cross each bridge.

Tax Increment financing projects: Tax increment financing (TIF) is a P3 method that has been used to help private developers to finance the public infrastructure needs of their projects. This program uses the increase in tax collections that a qualifying project will create as a mechanism to repay the developer for the costs of approved public infrastructure expenditures, such as road or utility upgrades. The state TIF program is being used by projects of all sizes in a variety of Kentucky cities, including Louisville, Lexington, Bowling Green, Covington, Georgetown, and Oak Grove.

2.10.9 New Jersey funding example applicable to ABC

The funding plan in New Jersey should provide a pathway to a long-term fix for the Transportation Trust Fund (TTF) while delivering needed congestion relief and transit capacity that will enhance the quality of life for residents. States should continue the long-standing commitment to "Fix-It-First" by repairing and rehabilitating deteriorating infrastructure, and make substantial progress toward maintaining a state of good repair and advancing critically needed capacity expansion projects.

In 2003, the Blue Ribbon Commission documented the resources needed to safely and reliably maintain New Jersey's transportation assets and to fund critical projects. The companion reform initiative includes the following:

- Recapturing of certain revenues intended for TTF
- Freezing capital maintenance at current levels
- Creating an independent Financial Policy Review Board
- Maintaining a core "pay as you go" program

Another substantial commitment of this program is to direct investments that encourage smart growth. An NJDOT study reviewed the following topics and suggestions.

- Generating new revenue
- Recapture turnpike toll contribution to the TTF
- Use of TTF funds for capitalized maintenance
- Maintain "pay as you go" in annual capital program
- Establish an independent financial policy review board

The board will review, advise, oversee, and hold accountable all relevant parties to ensure that funding for the state's transportation infrastructure is fiscally prudent.

2.10.10 Invest in smart growth projects

The capital programs of both NJDOT and NJ TRANSIT will adhere to the principles of smart growth, which will curb sprawl by incorporating land use into the transportation equation.

2.10.11 Additional funding for New Jersey and New York connecting bridges

Recently, the governors of New Jersey and New York have directed their bi-state port authority to upgrade three bridges that connect the two states. The Port Authority of New York and New Jersey will finance major construction projects on the Goethals, Outer, and Bayonne bridges, all of which connect New Jersey with Staten Island. The projects, which will cost billions of dollars, are expected to generate about 5000 construction jobs.

In addition to the 5000 jobs that the work will create, the projects are expected to generate more than $600 million in wages and more than $2.5 billion in other economic activity. The work will be completed by 2017.

Goethals Bridge: The Goethals Bridge, which connects I-278 between New Jersey and New York, will be replaced, as part of a public–private partnership (P3). Construction benchmarks must be met before payment is issued. The bridge is expected to open in 2016, with all work completed by 2017.

The Outer Bridge: This will be resurfaced, and the roadway of the Bayonne Bridge will be raised. The repaving of the Outer Bridge is the smallest of the three projects and is expected to be completed earliest.

Bayonne Bridge: The raising of the Bayonne Bridge roadway by 64 ft is needed to allow larger cargo ships using the Kill Van Kull waterway to pass beneath it.

Source: http://blogs.app.com/capitolquickies/2013/04/24/christie-cuomo-announce-bridge-construction-projects/.

With a substantial boost in federal, state and local highway funding, numerous projects to improve the condition and to expand the capacity of New York's roads, highways, and bridges will be able to proceed. This will not hamper the state's ability to improve the condition of its transportation system, and will enhance economic development opportunities.

2.10.12 Pennsylvania SD bridges

PA has received low grades for its bridges in the ASCE Report Card in recent years. It appears that, for 2014, funding allocation has gone up as a result.

In 2013, the PA State Senate approved a $2.5 billion transportation-funding bill aimed at repairing thousands of aging bridges and miles of roads while pumping more money into transit. Under the bill, the lion's share of money, about $1.9 billion per year, would go toward highways and bridges. Roughly $500 million per year would go to mass transit, including funding to help them convert their fleets to alternative fuels. About $115 million would be shared among airports, ports, rail freight, and walking and biking routes.

Source:http://articles.philly.com/2013-06-07/news/39791312_1_committee-chairman-john-rafferty-mass-transit-state-senate.

2.10.13 Maryland and Virginia SD bridges

Officials say 62% of roads in the Washington region need significant repair or replacement. Maryland and Virginia just passed tax increases to address transportation needs; high among them are deteriorating highways such as the Beltway. However, it will take time more than money to tackle the Beltway's worst sections, because simply closing several lanes for months would have nightmarish consequences.

Using the ABC technology discussed in this book will help in reducing reconstruction duration.

Source:http://articles.washingtonpost.com/2013-03-30/local/38144277_1_capital-beltway-asphalt-highway.

2.10.14 Conventional role of DOTs and design consultant

In the United States, the responsibility for design traditionally rests on the state DOTs or a design consultant who serves as an extension of the DOT. When a DOT hires a design consultant, there has been a rigorous approval of design. The trend in design-build is that DOTs no longer approve the design but, rather, stipulate a set of design standards.

2.10.15 Low-bid contracting method a disadvantage for ABC

US highway projects are generally awarded via unit price bids (using 100% complete construction drawings). Low-bid selection is difficult in design-build because design-builders must be hired before design is complete to take full advantage of time and cost savings. Perhaps the two biggest obstacles for design-build in the highway sector are:

- The statutory use of low-bid contracting in public highway construction
- The concern that the state should have full responsibility for design approval and construction administration.

Hiring the design-builder early in the process allows fast-track construction and more constructible designs.

2.10.16 FHWA sustainability requirements in accelerated bridge planning and accelerated bridge design

A sustainable development meets the needs of the present, without compromising the ability of future generations to meet their own needs. A "smart bridge" or a "green bridge" would always meet sustainability requirements.

2.10.17 Example of design-build for major bridges

On Interstate I-93 for an ADT of 200,000 vehicles per day, modular replacement superstructures on weekends reduced construction duration. Replacement of 14 superstructures in 12 weekends was possible. Use of incentives/disincentives was helpful.

2.10.18 Notable projects

There is no dearth of useful bridge and highway projects, which has made US highway network so extensive. The example given below is noteworthy.

The Everglades Project: On the Tamiami Trail in the Everglades in Florida, a 1-mile-long bridge, was recently completed. The design began healing the ecological wounds inflicted by a road that had blocked the life-giving flow of water through the Everglades for nearly 90 years. The bridge, which is part of an extensive plan that will increase water flow in the area, ranks among the most significant and visible Everglades projects to date. Often the biggest challenge in applying ABC is getting funding.

There was a 2-decade battle to get the project started and to get the funding approved. (Refer to March, 19, 2013 report in the Miami Herald by Curtis Morgan; http://www.miamiherald.com/2013/03/19/v-fullstory/3294968/a-bridge-to-help-heal-the-everglades.html).

Warranties: FHWA has specific rules governing the use of warranties. Agencies should coordinate with FHWA on the use of warranties on specific projects.

Lane Rental: Minnesota and Washington States already have lane rental policies and specifications in place. The contractor is charged for the amount of time that a lane is out of service. In the bidding process, the bid typically consists of a base bid for actual construction and a secondary bid for the lane rentals. This approach helps in completing the job in the least amount of time.

Every Day Counts (EDC) initiative: This is another approach that helps in completing the job in the least amount of time. All 50 states, Puerto Rico, the District of Columbia, and several territories were invited to these summit meetings, to do the following:

1. Learn about EDC
2. Provide comments and input
3. Start the process of implementing the new technologies

Information about the EDC Summit meetings can be found at the FHWA EDC website at www.fhwa.dot.gov/everydaycounts/index.cfm. The FHWA has summarized the process in a comprehensive flow diagram for all aspects of A to Z planning of ABC.

2.10.19 Accelerated construction technology transfer

This FHWA and AASHTO Technology Implementation Group (TIG) brainstorming process also help agencies with the implementation of ABC on specific projects. A workshop is held in which a group of experts brainstorm on how to build a project faster based on the site constraints of the particular project.

2.10.20 ABC decision making process

During project planning phase, the decision to use ABC on the project is made.

The FHWA Manual entitled "Decision-Making Framework for Prefabricated Bridge Elements and Systems (PBES)" (Publication Number FHWA-HIF-06-030, May 2006) is an excellent source of information on the process of planning a successful ABC project.

2.10.21 Development of the FHWA ABC manual

FHWA has published a comprehensive Accelerated Bridge Construction Manual. This pioneering work in ABC is a great contribution that can be utilized by bridge engineers both in the United States and abroad. ABC will inevitably lead to use of more innovative products and materials. Basic concepts of the subject and procedures are addressed. For details, consult the FHWA website. (Refer to FHWA–Accelerated Bridge Construction, Final Manual, and Publication No. HIF-12-013, November 2011) (Figure 2.1).

Pioneering Approach by Utah DOT: The Utah DOT has developed a new approach that involves measured responses to multiple decision measures as follows:

- ADT
- Detour time
- Evacuation route
- Economy of scale
- Applicability to standards
- Worker safety
- Environmental issues
- Railroad impact
- Weather limitations

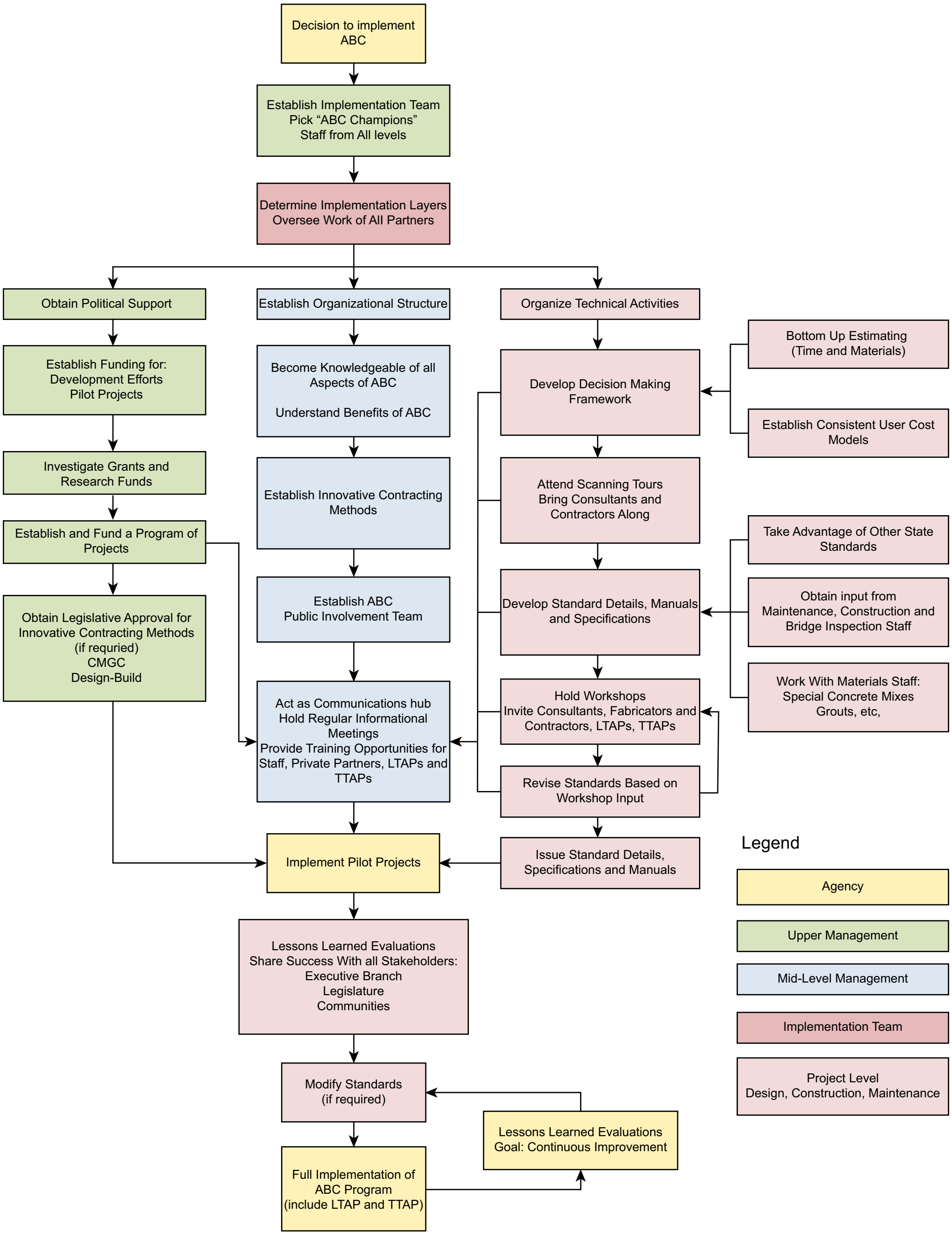

FIGURE 2.1

Typical flow diagram for construction sequence for ABC.

The individual measures are weighted so as to be consistent with Department policies (refer to INTELISUM, Accelerated Bridge Construction (ABC), UDOT and Federal Highways, August 2007, Volume 1, Number 3).

Pool Funded Study by Oregon DOT: The Oregon DOT, in collaboration with seven other states through a pooled fund study, has developed another decision-making process that will account for the characteristics of the project as follows:

- Project size
- Complexity
- Road user characteristics
- Environmental requirements
- Construction site attributes

Reference ODOT's ABC Program/FHWA EDC Initiative, Manager, Bridge Preservation, Bridge Engineering Section, Oregon DOT.

2.10.22 Decision and planning process for selection of appropriate ABC methods

The following components and parameters can be used to determine the appropriate types of ABC methods that are feasible for the project:

- Foundation and wall elements
- Rapid embankment construction
- Prefabricated bridge elements and systems (PBES)
- Structural placement methods
- Fast track contracting

The project site characteristics include:

- Site constraints
- Water crossings

One method of large-scale prefabrication is delivery of the prefabricated bridge system via barges.

Highway grade separations offer more flexibility in construction methods when compared to railroad crossings. It is possible to place a bridge over existing utilities, pipes, and small culverts.

Roadway parameters data needs to be prepared with the following considerations:

- Required clearances
- Available lane closures above or below the bridge
- Reasonable detours
- Available work zones at the ends of the bridge

2.10.23 Railroad crossings

Rail transport can accommodate larger and heavier elements when compared to roadway delivery methods. Railroad parameter data need to include the following:

- Required clearances
- Weight restrictions

- Nearby siding that can be used for storage and off loading of elements
- Available track closure periods; whether the line is electrified with catenary above the rails or by a third rail on the ground
- Signal equipment and/or signal lines in the area
- Temporary fill to place heavy prefabricated elements

2.10.24 Temporary bridges

The overall project construction time frame is increased when the use of construction staging or detours is not viable. Also, the cost of the temporary bridges and approaches is significant. These factors should be carefully weighed against the time savings and potential extra cost for ABC.

2.10.25 Traffic management

Short-term detours may be acceptable. Traffic management often leads to multistage construction processes with the shifting traffic.

The Massachusetts DOT used traffic management during the planning for a large ABC project on Interstate 93 in Medford, Massachusetts, by using prefabricated modular superstructure elements. The DOT developed an ABC approach that was able to replace up to six spans per weekend. It allowed for the complete closure of one direction of I-93 for a 55-h weekend period.

2.10.26 Construction staging

When no viable detours are available, construction staging becomes the only viable option. ABC can be used to reduce the duration of each stage and thereby the entire duration of the project.

2.10.27 Right-of-way issues

ABC projects may necessitate temporary right of way beyond the proposed transportation facility. Physical parameters need to be investigated as follows:

- Right of way for a staging yard near the bridge site
- Potential for a short-term lease of land
- Available right of way for crane locations near the bridge site
- Potential for short-term construction easements

2.10.28 Structure type options

For replacement projects, the most feasible structure types are those that can be installed on a different footprint, prior to removal of the existing bridge.

There are three potential ABC options:

- Constructing the superstructure on false work adjacent to the existing bridge and moving it into place using SPMTs

- Constructing the superstructure on false work adjacent to the existing bridge and moving it into place using lateral sliding/skidding equipment
- Constructing the superstructure in place using prefabricated elements (beams and precast deck); this option is always viable, since it most closely replicates conventional construction

2.10.29 Geotechnical constraints

The duration of loading can have an impact on the capacity of the soil to resist construction loads. The stability of the embankment should be checked to ensure that the soil will be stable during the use of the equipment.

2.10.30 Effects of utilities

Utilities both aboveground and underground may be present on bridge sites. Owners may consider relocation of utilities in a separate preconstruction contract. This will eliminate potential delays during construction caused by utility work.

2.10.31 Local government constraints

Hospital and school bus routes are cited by local governments as a point of concern. Even small detours can have a significant impact on bus routes and schedules.

2.10.32 Staging areas

There may be shipping limitations on the size and weight of the prefabricated elements for using the roadway. Allow the contractor to prefabricate elements in a near-site staging/fabrication yard.

Many methods of prefabrication can make use of staging areas. The design team needs to investigate the following issues:

- Providing ample room within the highway right of way to establish a staging yard
- Ensuring that the area is large enough for fabrication of the entire superstructure
- Making sure that overhead wires can be easily relocated or removed
- Ensuring that any sensitive underground utilities or structures along the travel path can be bridged and that there are available work zones at the ends of the bridge

2.10.33 Time and materials estimates

An accurate time and materials estimate is required. The contractor's experience usually helps in avoiding any errors of judgment.

2.10.34 Cost evaluation

All viable options should be explored to evaluate the cost impact of the project. Based on the cost analysis of eight bridge projects built under the Highways for Life (HfL) program, the additional cost premium for deploying ABC was found to be as high as 20%.

Standardization of details will help to reduce project costs. The investment in training and equipment will help. The following information shows different cost factors that are being used during the project planning process.

2.10.35 Road user costs

Several DOTs have developed spreadsheet-based tools for RUC computations. Examples include the New Jersey DOT's road user cost spreadsheets, Michigan DOT's CO3, and Maryland SHA's Loss of Public Benefit (LOPB) tool.

2.10.36 The Comprehensive 2010 Highway Capacity Manual by TRB

The Highway Capacity Manual (HCM) is a publication of the Transportation Research Board of the National Academies of Science It contains concepts, guidelines, and computational procedures for computing the capacity and quality of service of various highway facilities, such as:

- Freeways
- Highways
- Arterial roads
- Roundabouts
- Signalized intersections
- Nonsignalized intersections
- Highways
- Effects of mass transit, pedestrians, and bicycles on the performance of these systems.
  The manual provides an analytical basis for estimating work zone traffic impacts, a key component of the road user cost model.

ABC can be used to reduce the mobility, safety, and environmental impacts of work zone activities by reducing the overall duration of the project. The higher cost premium of using ABC is offset partially or fully by the gains in work zone road user costs.

2.10.37 Maintenance of traffic costs

These include traffic control (e.g., staged construction, detours, or temporary bridges), traffic control devices (e.g., signs and markings), public information campaigns, operations management, and law enforcement strategies.

2.10.38 Safety costs

In all cases, the reduction in construction time will inevitably reduce the exposure time and associated safety risks for both workers and motorists.

2.10.39 Agency construction engineering costs

In most cases, the construction management costs exceed the cost for design. Typical agency costs include labor costs for inspectors and resident engineers, rental of construction offices, and law enforcement costs. ABC can be used to reduce agency construction engineering costs by reducing the overall site construction time. With the use of prefabrication, there will be more costs for plant inspections; however these costs are intermittent and normally much less than full-time construction staffing.

2.10.40 Life-cycle costs

The FHWA has a website devoted to life-cycle cost analysis—(www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm). First, the quality of precast concrete can be better than site-cast concrete. The quality of plant-produced concrete mixes can also be controlled better, since the concrete does not need to be trucked to a construction site.

Precast elements and precast bridge deck panels are allowed to cure and shrink in an unrestrained condition, thereby reducing and, in most cases, eliminating shrinkage cracking. The increase in quality inevitably leads to an increase in service life. This leads to reduced life-cycle cost for the bridge.

2.10.41 Inflation costs

"The sooner, the better." ABC can be used to reduce the inflation effects on the bid and other inflation escalation factors.

2.10.42 Public involvement

Transparency about a project is often well received. Public involvement is critical to the success of an ABC project. An ABC project will create a short-term acute impact on travelers, businesses, and residents. Informing these stakeholders will ensure proper public support, and may reduce problems during construction through user cooperation in using narrower lanes and driving at slower speeds. The FHWA document entitled "Public Involvement Techniques for Transportation Decision-making" is recommended as a source for information.

2.11 Grand challenges by the AASHTO technical committee for construction (T-4)

Many of these grand challenges (refer to AASHTO Highway Sub-committee on Bridges and Structures, *Grand Challenges*: *A Strategic Plan for Bridge Engineering*, June 2005) are discussed in the FHWA ABC Manual.

The following topics were addressed by eight experts in the May 2011 Session. The identified challenges indicate milestones in the progress and implementation of ABC:

- ABC/PBES at FHWA
- FHWA ABC Manual
- ABC/PBES Research
- FIU ABC Center
- Update on NCHRP 20-07/Task 294

- National Steel Bridge Alliance
- Precast/Prestressed Concrete Institute
- American Segmental Bridge Institute

2.11.1 Grand challenge 1—The simplified AASHTO T-4 challenges can be summarized as the following Grand Challenges 1 to 7: strategies to extend the service life of existing inventory of bridges

One example is the application of de-icing agents to facilitate mobility, resulting in reduced service life.

(Please also see Chapter 4, which further discusses these important activities/areas for research, for additional information on all of these grand challenges.)

2.11.2 Grand challenge 2—*anticipated outcome*

Structural systems must utilize existing and new materials more efficiently in terms of safety, durability, and economy.

2.11.3 *Geotechnical*—improved and optimized systems and standards

Geotechnical constructions and foundations can reduce cost, increase standardization, accelerate construction, and result in longer-lasting low-maintenance bridge and highway structures.

2.11.4 Grand challenge 3—strategies to accelerate the construction of safe, durable, and economical bridges

Transportation and erection technology (including new ways of precasting/prefabricating component units) that allow complete bridges to be installed within hours.

2.11.5 Grand challenge 4—comprehensive *LRFD bridge design specifications* that addresses all applicable limit states

Greater understanding of the limit states is required for safe, serviceable, and economical bridges and highway structures, and for developing enhanced reliability-based provisions.

2.11.6 Grand challenge 5—project decisions affecting technical, cultural, and cost issues

Receiving adequate input from bridge engineers during the early decision process is required.

2.11.7 Grand challenges 6 and 7—strategies to cultivate and support a knowledgeable workforce and effective leaders in bridge engineering

Grand Challenge 3 is directly applicable to ABC, whereas other challenges are in supporting roles.

2.12 Design-build contracts and role played by the Design-Build Institute of America

Design–build (or ***design/build***, and abbreviated ***D–B*** or ***D/B*** accordingly) is a project delivery system used in the construction industry. It is a method to deliver a project in which the design and construction services are contracted by a single entity known as the ***design–builder*** or ***design–build contractor***. It is now commonly used in many countries and forms of contracts are widely available. Design–build is sometimes compared to the "master builder" approach, one of the oldest forms of construction.

The traditional approach for construction projects consists of the appointment of a designer on one side and the appointment of a contractor on the other side.

In contrast to "design–bid–build" (also known as design–tender),

- Design–build relies on a single point of responsibility contract.
- It is used to minimize risks for the project owner.
- It reduces the delivery schedule by overlapping the design phase and construction phase of a project.

The design–build procurement route answers the client's wishes for a single point of responsibility in an attempt to reduce risks and overall costs.

Master builder concept: Comparing design–build to the traditional method of procurement, the authors of the Design-build Contracting Handbook (2001, published by Construction Law Library), Robert F. Cushman and Michael C. Loulakis, noted that "from a historical perspective the so-called traditional approach is actually a very recent concept, only being in use approximately 150 years."

In contrast, the design–build concept–also known as the "master builder" concept, has been reported as being in use for over 4 millennia.

2.12.1 Growth of the design–build method

A study from the US Department of Transportation (reference Special Experimental Project 14, SEP-14) claims that

- Design–build delivery has been steadily increasing in the U.S. public building sector for more than 10 years, but it is still termed experimental in transportation. To date, under Special Experimental Project 14 (SEP-14), the FHWA has approved the use of design–build in more than 150 projects, representing just over half of the states.
- Proprietary manufacturing companies with many branches in USA and worldwide (as listed in Section 2.1 of this chapter) have boosted the manufacturing of bridges and the design–build system.

The European countries have used design–build delivery for longer than the United States and have provided the scan team with many valuable insights. The primary lessons of projects using design–build are:

- Use of best-value selection
- Percentage of design in the solicitation
- Design and construction administration
- Third-party risks

- Use of warranties
- Addition of maintenance and operation to design–build contracts

2.12.2 Debate on the merits of design–build versus design–bid–build

The results and cost associated with the two methods are not the same. Even if a fraction of 1% savings is possible, it is worthwhile to research the pros and cons of the new method. It will also help to develop comprehensive technical specifications and special provisions for year-around work on hundreds of projects.

It will be noted that not every project's administration is best suited for design–build. Construction technology is geared to the size and magnitude of projects as well as the difficulties of staged construction. The rise of design–build project delivery has threatened the traditional design hierarchies of the construction industry. As a result, a debate has emerged over the value of design–build as a method of project delivery. A recent example of this type of debate can be seen in the June 2011 issue of Construction Digital.

2.12.3 Difficulties in implementation of design–build

- Design–build limits clients' involvement in the design.
- Contractors are likely to make design decisions outside their areas of expertise.
- It is also suggested that a designer, rather than a construction professional, is a better advocate for the client or project owner.
- By representing different perspectives and remaining in their separate spheres, designers and builders ultimately create better buildings.
- The design–build procedure is poorly adapted to projects that require a complex and elaborate design for aesthetical or technical purposes.
- Design–build does not always make use of competitive bidding in which prospective builders bid on the same design.

2.12.4 Advantages of design–build

Proponents of design–build advocate the following:

- Design–build saves time and money for the owner, while providing the opportunity to achieve innovation in the delivered facility.
- Design–build allows owners to avoid being placed directly between the engineer and the contractor. Under design–bid–build, the owner takes on significant risks because of that position.
- Design–build places the responsibility for design errors and omissions on the design–builder, relieving the owner of major legal and managerial responsibilities. The burden for these costs and associated risks are transferred to the design–build team.

The decisions can be made by the owner or the agency based on their confidence in the performance and ability of contractors used in the past. The nature of the project and its size or emergency fixing requirement may decide the responsibilities shared by the contractor and designer.

A written General Contractor Agreement will prove invaluable in the event of disagreements, misunderstandings, or litigation. (For useful publications such as "Design–Build Manual of Practice" please, see DBIA Website.)

2.12.5 Performance of the Design–Build Institute of America

DBIA takes the position that design–build can be led by a contractor, a designer, a developer, or a joint venture, as long as the design–build entity holds a single contract for both design and construction.

The "design–builder" is often a general contractor but, in many cases, a project is led by a design professional (engineer or other professional designers). Some design–build firms employ professionals from both the design and construction sector.

Where the design–builder is a general contractor, the designers are typically retained directly by the contractor. A partnership or a joint venture between a design firm and a construction firm may be created on a long-term basis or for one project only.

There are incentives built into the payment clauses for early completion and disincentives if the project is not completed in time. Unit costs for certain items are subject to increase due to inflation. Payments are made as the job progresses. The quality of the work must be approved by the owner's engineers prior to payment.

2.12.6 Functions of design–build institutes

In 1993, the Design–Build Institute of America (DBIA) was formed. Its membership is composed of design and construction industry professionals as well as project owners. DBIA promotes the value of design–build project delivery and teaches the effective integration of design and construction services to ensure success for owners and design and construction practitioners. The Design-Build Institute of America is an organization that defines, teaches, and promotes best practices in design–build. The following includes some of the tenets of the Institute as currently reported by the Specialized Construction Institute.

DBIA will be the industry's preeminent resource for leadership, education, objective expertise, and best practices for the successful integrated delivery of capital projects. DBIA promotes the value of design–build project delivery and teaches the effective integration of design and construction services to ensure success for owners and design and construction practitioners.

Ethics and Values: Following these values should lead to quality performance and products. They should lead to professionalism, fairness, and the highest level of ethical behavior.

- Excellence in integrated design–build project delivery, producing high-value outcomes
- An environment of trust characterized by integrity and honest communication
- Mutual respect for and appreciation of diverse perspectives and ideas
- A commitment to innovation and creativity to drive quality, value, and sustainability

2.13 Types of contracts

There are alternative contracts between the owner and the construction team. However, a design–build contract is preferred for implementing ABC. Other contract types with modifications may be acceptable for partial ABC, as decided by the bridge owners and at their discretion, depending on the complexity of project. The common types of legal contracts are as follows:

- **Conventional Contract:** Owner-Engineer-Contractor
- **Design–Build Contract:** Owner-Contractor-Engineer

- **Lump-Sum Contract:** An old system seldom used nowadays due to inflation.
- **Cost Plus:** An old system seldom generally used on big projects. Labor and materials may be paid for separately.

2.13.1 Invitation for bids for conventional, partial ABC, and ABC projects

The highway agency has a standard format for the advertisement for bids for work (or material), which is used for conventional or design-bid-build projects. The advertisement date and the date for submission of bids with project description are given. A pre-bid meeting is held between the owner and the interested parties to answer any questions.

The advertisement usually addresses the following information:

- Time and place of the opening of bids
- Location of the work to be done
- Quantity of the work to be done
- Character and quantity of the material to be furnished.

However, for administration of partial or full ABC, certain modifications are required. Specialist contractors for performing innovative techniques and ABC may be required. Short listing or prequalification of prospective contractors may be required based on their specialist experience, which matches the complexity of project. In some cases, selection based on negotiations may not require advertisement.

2.13.2 Contract definition

The contract is a written agreement between the department and the contractor or the consultant for construction and design services. It is a legal package prepared by an attorney. DBIA has developed typical formats for the design-build contracts. Every state will have some differences within contracts to reflect local laws and regulations.

2.13.3 Bid documents

In general, the conventional contract includes the following bid documents in hard copies or electronic format:

1. **Proposal**
2. **Contract drawings/construction plans:** Using Micro Station or approved CAD software. The approved drawings should show the location, character, dimensions, approximate quantities, and details of the prescribed work, including layouts, profiles, and cross-sections
3. **Technical specifications/special provisions:** It is important to know the full specifications for the following items:
   a. All publications to which the contract refers
   b. Special provisions and bulletins referred to in, or bound with, the proposal
   c. All written agreements made or to be made, pertaining to the method and manner of performing the work
   d. The quantities or qualities of material to be furnished under the contract
4. **Estimate of quantities:** with unit prices, costs, and overheads

5. **Subsurface soil and geological data:** The Soil Survey Report and Profile and Core Borings are excluded from this definition
6. **The schedule with milestones shown:** A bar-chart format or CPM network showing activities on the critical path needs to be shown; Primavera software can be used
7. **Performance bond:** The approved form of security furnished by the contractor and the surety, as a guaranty on the part of the Contractor to execute the work, according to the terms of the contract
8. **Payment bond:** The approved form of security, furnished by the contractor and the surety, as a guaranty to pay promptly and the full amount. It will help to meet day to day expenses incurred in a timely manner and without any delays. Such sums as may be due for all material furnished, labor supplied or performed, rental of equipment used, and services rendered in connection with, the work under contract
9. **Insurance certificates**
10. **The signed agreement with Notice to Proceed**
11. **All work orders and supplemental agreements**

2.13.4 General and special provisions

General provisions shall address:

- Description and details of materials
- Construction methods
- Quantities

Technology changes or improvements occur every few years. Hence, more special provisions are required to suit.

- In the case of new materials, the sources of new information are provided by suppliers or manufacturers.
- Other factors are extreme temperature conditions and access to the site.
- Bridge foundations located on deep rivers may require added special provisions.
- There may be additions or revisions to the Standard Specifications covering conditions pertaining to an individual project. Examples are additions to administrative aspects, and use of alternative materials or construction methods.
- Special provisions should be included in cost estimates. They are usually noted in drawings as construction notes or referred to in the master specs.
- Special provisions should always be checked for any unusual items or surprises. No two projects are 100% alike.
- Different designers may use alternative methods or materials. Hence special provisions will vary and will need to be checked for unusual materials, details, or administrative aspects.
- **Contractor's responsibilities:** The contractor is most likely to be penalized if he deviates from standard specifications. The contractor is given the responsibility of developing certain construction details and getting them approved by the engineer. The contractor is encouraged to ask questions in writing to the engineer as Requests for Information (RFI) or discuss any issues at weekly progress meetings.

2.13.5 Method of measurement of quantities

Standard specifications for the state will be followed for the measurement units. For example, the units can be for a finished surface area or for a volume.

2.14 The Construction Management General Contractor Institute

The Construction Management General Contractor (CMGC) Institute of America is an association of leaders in transportation design, engineering, and construction who have gained broad, extensive knowledge of the CMGC project delivery method through its utilization on many horizontal transportation projects that were completed under budget and ahead of schedule.

They focus on making this knowledge and experience available to the skilled professionals in our field, who seek to lead the industry into the next decade.

CMGC is an innovative, accelerated form of design and construction work. The CMGC role has advantages in several areas:

- Completion ahead of schedule compared to conventional projects
- Finishing projects under budget by giving incentives to ABC teams
- Producing constructible designs
- Achieving better results in technologically advanced, innovative projects
- Providing learning opportunities to engineers
- Promoting environmental stewardship
- Increasing the benefit to the public

2.15 The Construction Industry Institute

A comparative study of project performance using alternative delivery systems for the building industry was published by the Construction Industry Institute (CII) as BMM2002-10. – "Measuring the Impacts of the Delivery System on Project Performance using Design-Build (D-B) and Design-Bid-Build (D-B-B)."

The study was sponsored by the National Institute for Standards and Technology (NIST). It has the following findings:

> The results of this study show that, on average, DB projects were about four times larger than DBB projects in terms of project cost. Contractor-submitted DB projects overall outperformed DBB projects in changes, rework, and practice use, but the difference was statistically significant only for change performance.
>
> Pre-project planning and project change management practice use had the greatest impacts on cost performance for owner-submitted DB and DBB projects. Research is being done at CII leading to improved construction practices.

(Refer to "Project Delivery Systems: CM at Risk, Design-Build, and Design-Bid-Build," Construction Industry Institute Research Report: 133–11. April 1998.)

The Associated General Contractors of America, 2004 discusses CMAR. For details of CMAR, also refer to Chapter 9, SEC. 9.8.1.

Most of the developments listed above are based on the growing number of publications on the practical subject.

Engineering organizations and universities like Florida International University etc. have been regularly contributing knowledge on practical design aspects leading to rapid construction. With further progress, some of the information may be refined but for the benefit of transportation industry.

2.16 Conclusions for ABC and design–build contracts

A new application of management using ABC has been presented in this chapter. It may be possible to reduce the number of failures with ABC by applying recent advancements in technology and innovative methods. The failed bridges that were built using old technology can be rebuilt on a fast track, using durable factory-style manufacture.

ABC-related design needs to be made part of AASHTO and state bridge design codes and specifications. Deterrents and bottlenecks such as MPT, construction easement, right-of-way, permit approvals, and utilities relocation need to be resolved and administrative procedures further simplified to facilitate ABC.

It appears that there are glitches that may be holding up a more rapid switch over to ABC. A slow but gradual shift from the conventional methods to full ABC (with many projects using a partial ABC approach) can be observed. Each management subsystem such as partial ABC can be used to accommodate different circumstances and physical conditions.

- By modular construction and by large factories manufacturing repeated identical structural solutions, leading to reduced costs and quality control, a surge has been seen in implementing ABC for dozens of similar projects in each agency. The list of proprietary manufacturing companies of bridge components and suppliers of construction machinery worldwide were shown. Proprietary manufacturing companies with many branches in USA and worldwide (as listed in this chapter) have boosted the manufacturing of bridges and the design–build system.
- The results and costs associated with the two methods are not the same. Even if a fraction of 1% savings is possible, it is worthwhile to research the pros and cons of the new method. It will also help to develop comprehensive technical specifications and special provisions for year-around work on hundreds of projects.
- It will be noted that not every project's administration is best suited for design–build. Construction technology is geared to the size and magnitude of projects and the difficulties of staged construction. The rise of design–build project delivery has threatened the traditional design hierarchies of the construction industry.
- FHWA has prepared a comprehensive ABC manual. AASHTO grand challenges by the AASHTO Technical Committee for Construction (T4) present additional goals to strive for.

Many initiatives taken by FHWA, AASHTO subcommittees, and the monthly webinars on ABC by Atorod Azizinamini at FIU have led to rapid progress in implementing the ABC concepts in spite of the many glitches.

Full-scale testing of joints in precast curved decks both for rectangular and for curved decks are required. Modifications to analytical methods applicable to discontinuities of components need to be developed.

There are many feasible applications of the latest techniques in concrete manufacture, composites, HPS, and hybrid materials that need to be promoted.

Integrated software that would cover all aspects of ABC design calculations and drawing preparation should be investigated and developed to save engineering man-hours.

For some bridge sites, lateral slide-in method of construction is feasible, whereas on other sites, factory-manufactured bridges can be brought to the site and erected using high-capacity cranes. Method of transportation can be by highways or by river barges. Similarly, the design–build method of management may have variations.

The reasons for adopting ABC include the daily rush hour difficulties faced by road users during construction periods, safety, and use of staged construction. It is expected that, by using innovative methods, fewer bridge failures will result. Inspection procedures need to be more rapid to keep pace with rapid identification and fixing of deficient bridges.

SHM is one approach by which, through use of remote sensor technology, emergency repairs can be implemented to prevent failures.

There are alternative contracts between the owner and the construction team. However, a design–build contract is preferred for implementing ABC. Other contract types with modifications may be acceptable for partial ABC, as decided by the bridge owners and at their discretion, depending on the complexity of project.

The subject is still developing, and it will be a while before a single bridge construction specifications manual is evolved. Also, rapid construction requires rapid funding for hundreds of simultaneous projects in hand. Hence, readily available funding in a few months may be the only deterrent.

All references are listed in Appendix 1 Bibliography at the end of the 11 chapters.

Each chapter has separate list of references. There may be several captions in each chapter for the convenience of the reader.

A glossary of ABC terminology applicable to all the chapters is listed in Appendix 2 ABC Glossary.

CHAPTER

Research and Training in ABC Structural Systems

3

3.1 Background

The first two chapters focused primarily on an introduction into the core aspects of ABC. Chapter 2 also addressed inspection procedures and acquiring inventory data on bridge conditions. This chapter reviews bridge rating procedures used to identify deficient bridges and assigning priorities to the identified problems. The innovative techniques of ABC need to continue to expand in usage and be adopted as routine for bridge construction. This chapter covers the important topics of research and for a developing topic like ABC; research in much needed topics such as new materials and method of construction is a priority:

- The many variations in bridge structural systems, leading to many diverse applications of ABC and additional impacts on accelerated bridge planning (ABP), analysis, design, and construction.
- The urgent need to train bridge engineers in ABC through continuing education programs and further research: besides FHWA and AASHTO, the lead taken in holding seminars by FIU is highlighted. FIU workshop themes and a list of webinars (organized around the recently and successfully completed ABC projects with steel and concrete bridges in the United States) are tabulated. The author has regularly attended the FIU webinars on ABC related projects.

Seminars at the Structural Engineering Institute of ASCE were conducted by the author to promote ABC. Due to the practical importance of the subject, in Appendix 4, a syllabus for three credits University Course in ABC is proposed. It will be of value to senior and graduate students. The duration of the course will be about 15 weeks.

Appendix 5 gives a summary of Training Courses and Workshops in ABC, mainly offered by FIU.

- The need to set up a national ABC Center to promote ABC.
- A review of research challenges from the AASHTO Subcommittee on Bridges and Substructures (T-4) on the developing subject.
- The author's presentation of a paper at the FHWA Baltimore Conference (with New Jersey State Bridge Engineer).

The latest information on ABC is provided through a bibliography compiled on the state of the art, the scope of the current work, and constraints for selecting ABC. A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2 ABC. Glossary.

Solutions to some of the conclusions are addressed in the chapters that follow. For example, Chapter 4 deals with innovative methods and projects, Chapter 5 with use of new materials and prefabrication, and Chapter 6 with design-build management methods.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00003-4

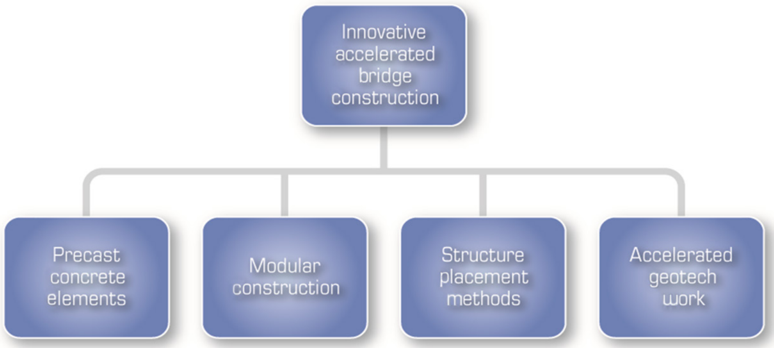

FIGURE 3.1

Flow diagram illustrating the major factors of ABC (Reference to UDOT).

3.1.1 Preparing an evaluation matrix

For construction purposes, the investment cost, life-cycle cost, environmental and social impact, constructability, future maintenance, inspection, and aesthetics need to be prepared at the planning stage. Planning must address differences in ABC for short, medium, and long spans. The salient features of ABC are graphically shown in Figure 3.1. As summarized, innovative techniques include structure placement methods and accelerated geotechnical work in addition to precast and modular construction. (Reference Accelerated Bridge Construction by Carmen Swanwick and by James McMinimee and Paul Blackham of UDOT).

3.1.2 Structural solutions

Inspection reports, structural health monitoring (SHM), and the rating calculations will suggest the structural solution, and one of the following will apply:

- No action required. The bridge meets all safety requirements.
- Repairs required.
- Retrofits required.
- Deck widening (adding lanes and side walk due to increase in average daily traffic (ADT)).
- Bridge replacement due to poor rating, using existing substructure, and existing footprint.
- Bridge replacement due to poor rating, using new substructure, and new footprint.

3.2 Variations in structural systems and scope of work

3.2.1 Additional justifications for using ABC

All of us cross bridges every day. We may only see a parapet railing, deck slab, or sign structures and light poles. But there is more to a bridge than meets the eye. The substructure foundation bearings and girders may not be visible. Bridges span over gaps in terrain or earth surface, such as gorges formed due to river valleys and natural cavities in topography. For through traffic in two normal directions, they form an elevated highway over an intersection. Jug-handle and cloverleaf intersections serve as multilevel changeovers and provide multiple paths for vehicles.

If a bridge is shut down, it would affect the sick going to hospitals and children going to school, and others may miss their plane flights, trains, or scheduled meetings, thereby adversely affecting commerce and industry. A great deal of planning and expense goes into the design, construction, and maintenance of both the structural and nonstructural (such as traffic signs, lighting, and utilities) of bridges.

Economic sense dictates that it may be less expensive to design and construct a new bridge than to continue maintaining a deficient or a very old bridge. Also, the life-cycle costs can become much higher than the initial investment.

3.2.2 Definition of the problem

For rapid construction, the three Ms are men, materials, and machinery.

- Men will require training to build faster. For the bridge engineers, training details are provided in Appendix 6 TEMPLE-ASCE One Day Course on Rapid Bridge Construction.
- Materials need to be more durable and be readily prefabricated, such as lightweight concrete girders.
- Machinery should be modern, such as self-propelled modular transporters (SPMTs), and offer greater mechanical advantages to save manual labor.

3.2.3 Appropriate structural systems for ABC

There is a huge variety of bridge structures. Each behaves differently, and structural analysis and design techniques vary. ABC methods are more applicable for some structural systems than for others.

There are basically six types of structural systems being used in practice, according to the span lengths (short, medium, long, and very long) and the choice of alternative construction materials for new bridges. Inspection reports, SHM, and rating results should identify the types of structural solutions for the maintenance of existing bridges. Short- and medium-span girder bridges in steel and prestressed concrete are the most common, and ABC is easier to apply to these structures. On the other hand, long-span cable-stayed or suspension-cable bridges are few and far between.

Moreover, the technology has changed dramatically in the past 200 years due to developments in construction materials. Older cast iron, mild steel materials have given way to high-performance steels of extremely high strength. Reinforced concrete girder bridges are limited to small spans, such as pedestrian bridges with smaller live loads, whereas prestressed concrete usage has become more common for larger-span bridges with more substantial live loads.

There has been a revolution in concrete manufacture for use with foundations, abutments, and piers. The switch over to precast segments for the deck slabs, abutments, and piers, and the use of composites and fiber-reinforced polymer (FRP) concrete, has changed construction methods.

Similarly, glue-laminated timber has replaced sawn lumber, resulting in much stronger small-span bridges. Chapters 4 and 5 will address innovative methods and prefabrication aspects in detail.

A review of the technical aspects shows that ABC is governed by the unique structural system for the type of bridge. ABP is the first step toward ABC. Hence, the span length, geometry, and aesthetics will dictate the material selection and shapes. Sizes will be based on allowable stress distribution. The six structural systems that are being used are:

1. Beams (for short spans)
2. Girders (for medium spans)
3. Trusses (for medium spans)
4. Arches (for short and medium spans)
5. Cable-stayed girders (for long spans)
6. Suspension cables with stiffened decks (for very long spans)

ABC is all about the method of manufacture and the erection of common types of bridge components. Superstructure and substructure components were described in earlier chapters. Here, their use in an innovative manner is discussed, and the need for training of engineers is emphasized.

3.2.4 Rapid design and construction challenges

It was pointed out earlier that tall buildings are being constructed at a faster pace than ever before by using ABC. This is possible by making bold management decisions and using innovative methods. The success in the vertical construction of multiple floors can be copied in the horizontal construction of bridges and highways. However, the scope of bridge work calls for heavier and more complex structural engineering, due to the large variety of bridges.

In conventional construction, there is a greater emphasis on minimum cost considerations and lesser emphasis on the duration to finish the job because of the availability of men and materials. The changeover to rapid construction places an increased pressure on the contractor's team and his/her limited resources. The sensitive issues include continued manpower availability, relocation of trained staff to new project locations, and introducing modern construction equipment and technology.

Further research in project management to achieve faster implementation and improved coordination and communication is necessary, so that ABC methods can be made more economical. The industry needs to develop a comprehensive construction code that spells out practical steps based on past experience for a refined and rapid type of construction. To make this all happen on a large scale, incentives need to be given to the staff in the form of a bonus. This approach will help encourage owners to select ABC teams for implementation on a greater number of projects instead of selected projects only.

3.2.5 Logistics and rapid production

Due to the short-term and long-term benefits of the design-build (D-B) method of construction management discussed in Chapter 2, federal organizations such as AASHTO and FHWA (with the help of certain universities like FIU) are looking into promoting important activities that influence ABC. Their training and research are critical. However, the problem does not just relate to science, technology, engineering, and mathematics (STEM).

Since no two bridges are alike, only ABC principles and limited guidelines can be given. For example, you cannot tell a painter or an artist exactly how to do his job, as those rules will not likely be followed. In the case of ABC, the contractor knows exactly "where the shoe pinches." His experience, intuition, and independent judgment in making day-to-day decisions need not be curtailed by imposing restrictions. To implement ABC, the contractor may be inclined, for example, to have his team work in the field in extreme weather conditions. The consultant also needs to play a more practical role by better appreciating what can be done in a given time length and by better coordinating drawings and details with the contractor's team, who are responsible for translating ideas into practice.

3.2.6 Rapid construction and associated needs

The owner's requirements are clear: reduction in schedule, wider decks, reduced seismic effects, increased bridge ratings, longer service life, cost savings, and lower maintenance. Many innovative concepts are presented below. Each concept is a subject in itself. Modern, prefabricated construction materials and methods are vastly different from traditional methods and require innovative ideas for making the system safe and efficient. ABC can be promoted through providing the owners with a better understanding of its benefits, as well as mathematical analysis.

In today's competitive construction market, there are many project delivery methods to match the variety of projects. However, tailoring your choice to the individual project's specifications and circumstances can help ensure success. The key factors dictating a particular type of delivery method include:

- Time restraints
- Risk
- Budget
- Level of quality

The method of choice for many owners is the D-B approach, which has become more popular in the last 10 years. Accelerated bridge construction through the precasting of bridge components helps to reduce greenhouse gas emissions caused by traffic delays and in simplifying long-term construction equipment operation.

Deck-plan shapes: The use of normal, skewed, or curved decks can make a big difference in construction duration. Bridges rectangular in plan are easier to construct and cost less than shaped bridges.

Cross-sectional types: Beams and girders will be rectangular, I-shaped, T-shaped, or hollow-box cross-sections. Steel cables are round. Piers have rectangular, square, or round columns. Piles may have a tubular cross-section. The moment of inertia of each shape will help in resisting bending moments.

Span types: Although there are no exact span lengths that can be classified as short, medium, and long, a broad range can be defined as follows:

- Short spans: 100 ft
- Medium spans: 101–300 ft
- Long spans: 301–500 ft and
- Very long spans: 501 ft and greater

Selection of modern materials for girders and beams: Modern construction materials available to satisfy the structural systems and span lengths are:

- Glue-laminated timber beams
- Reinforced concrete beams
- Prestressed concrete girders
- Mild steel beams of 50 ksi yield strength
- High-strength steel girders of 70 ksi yield strength

- High-performance steel girders of 100 ksi yield strength
- Steel ropes and cables of 270 ksi yield strength

Similarly, there are many variations in the substructures and the foundation types.

Abutment types:

- Cast-in-place wall abutments
- Precast mechanically stabilized earth (MSE) wall abutments
- Spill-through abutments
- Stub abutments
- Integral abutments without bearings

Pier types: These are generally reinforced concrete. Various types are as follows:

- Solid concrete wall
- Open or pier cap supported on columns
- Piers with piles extended to caps
- Integral piers without bearings

Foundation types: Shallow foundations are less expensive than deep foundations.

- Spread footings
- Piles
- Drilled shafts
- Combined footings
- Mats

Bearing types: These are made of steel alloys to transfer heavy reactions to the substructure. They need to allow thermal movements. A combination of fixed and free (sliding) bearings is used. Fixed bearings are restrained in all directions.

- Free or sliding bearings
- Multirotational bearings
- Isolation bearings

The above makes it clear that the permutations and combinations of structural systems, girders, and substructures (either composite or noncomposite) will result in dozens of unique bridge types. Each system will require an individual type of ABC. The behavior of each bridge type will be different and will require separate analysis and design.

ABC has become a more specialized subject in which engineers, technicians, field staff, manufacturer's factory staff, and even vendors need to be on board and give their very best. The majority of contractors and consultants only focus on selected types of applications. For example, among varied types of bridges, some contractors focus on segmental bridges and others on steel truss bridges. Examples are FIGG Engineering of Florida and Acrow of New Jersey.

It is expected that the sequence of rapid construction will fall in line with the behavior of the unique structural-system behavior, and this aspect must be kept in mind by both the designer and the constructor (refer to the latest version of the FHWA ABC Manual).

3.2.7 The owner's role in promoting ABC

In Chapter 2, the contractor's role in ABC was defined. The owner's decision-making and necessary funding are of paramount importance. Both the current bridge design manual and construction specifications of a given state are not geared toward ABC. New guidelines, details, and specifications for ABC need to be prepared by a team of leading contractors and consultants.

Like in the dynamic automobile industry, billions of dollars are up for grabs in the construction industry for maintaining the infrastructure. However, progress in technology is to some extent restricted by the flow of funds for maintaining the infrastructure. It makes economic sense to investigate ABC for easier implementation so that the reconstruction and rehabilitation of bridges can be done more efficiently and in less time. The end goal is to reduce inconvenience for the traveling public as much as possible by minimizing the duration of construction.

3.2.8 The role of consultants and subconsultants in ABC

In the present system, the consultant enjoys a privileged position by serving as an extension of the owner and his advisor. Sometimes the contractor is labeled as adhering to a "low-level mentality." However, the contractor plays an essential role in the "nitty-gritty" of erection and in ensuring that everyone pays close attention to detail; thus, the consultant's technical approach needs to align with the contractor's thinking. A flexibility of approach on the part of the consultant is required for success in the D-B system and to avoid friction with the contractor. The consultant can play the role of designer and checker in inspection and in certifying that the work is completed to the required quality in the scheduled amount of time. If for some reason the contractor is falling behind schedule, the consultant should warn the contractor of the delay and suggest ways and means to redress it.

For ABC project management, subconsultants also may be required and used as specialty consultants. For example, smaller firms can focus on specific issues such as seismic resistant design and flood scour–resisting foundations. Federal and certain state funding rules require the mandatory use of subconsultants:

- Who have qualified as disadvantaged business enterprises (DBEs),
- Small business enterprise (SBEs), and/or
- Women-owned business enterprises (WBEs).

The sub-consultants normally perform essential tasks such as field inspections, construction inspections, computer analysis, detailed design, or CAD support, etc. Due to the large sums of funding involved, this approach makes the expenditure more rational and economical and also helps in creating a selected team of engineers with a variety of technical know-how. Due to unified teamwork and better relations between the consultant and the contractor, there will be fewer claims or disputes in the ABC system. Increased communications through e-mails, meetings, and video conferencing will help in achieving quicker construction. There should be a provision in the contract for hiring specialist consultants and contractors from the industry, if so required, for solving any complex issues, rather than taking any risks that could arise from lack of proper knowledge about a situation.

3.2.9 Avoiding failure modes of steel and concrete

Common failures in engineering materials manifest themselves in the following forms:

- Yielding (crushing, tearing, or formation of ductile or brittle plastic hinges)
- Fracture (local cracking)
- Fatigue (reduced material resistance)
- Cracking (hairline cracks, minor or major cracks)
- Rupture (shearing)
- Large deformation (buckling)

Constructability issues: The above modes of failure must be avoided during various construction stages. These include transportation, lifting, erection, temporary support, equipment loading, and deck placement. The following conditions must be observed:

- No permanent inelastic deflection due to rotations at bearings shall be permitted.
- No yielding.
- No large deformation or web buckling.
- No lateral torsional buckling of compression flange due to wind (bracing is required).
- Formwork and temporary supports shall not be unstable.
- Quality control methods will be applied to obtain the required concrete strength.

Shoring and temporary support work is required. Paperless submission of documents (and electronic signatures) is useful for efficient communication between team members. For owner review and approval, accelerated submissions are necessary. Accelerated decision-making is required at all stages, including rapid fabrication, testing, resolution of erection issues, and field inspections. (Refer to Appendix 3 Bridge Inspection Terminologies).

The use of composite systems and composite structural action between components has been neglected in both design and construction. Deck slab is usually made composite with supporting girders or beams, by shear connectors. Girders are commonly made composite with the deck slab, but bearings serve as pinned connections between the girder ends and the supporting piers or abutments. Bearings allow translations and rotations due to lateral loads.

However, this results in a weaker structure due to the lack of frame action between horizontal and vertical members. Integral abutments, in this respect display, composite action and offer a much stronger bridge (refer to a paper by Mohiuddin Khan on modeling and seismic analysis of integral abutments published in ASCE Conference Proceedings, Nashville, 2004).

In buildings, the slab is cast integral with the beam, which is also cast integral with the columns. In most buildings, a unified or composite frame action is being utilized, which leads to the reduction of peak stresses both in the superstructure and substructure. In bridges, partial composite action can be achieved by grouted cast-in-place concrete joints between the precast deck panels. Integral abutments can be used in soft soils with exposed piles acting as columns. Full fixity at the end of girder will not allow any rotation. With integral abutments, rotation at beam ends is similar to the degree of freedom offered by the multirotational bearings. The partial fixity of girder ends with the integral abutments reduces deflections and the peak stresses.

3.2.10 Upgrading construction equipment

Most accidents on bridges occur during bridge construction. A recent example is the crane failure at Texas A&M, dated June 22, 2013. In College Station, Texas, workers were critically injured, after a barn frame collapsed at an $80-million Texas A&M University equestrian complex under construction. Twisted metal beams could be seen at the site, where the ground was broken last fall. The remainder of the structure that was still standing was stabilized, according to a statement from the College Station Fire Department. Gamma Construction, on its, described the A&M work as one of its 2013 projects. A lack of maintenance of equipment and training of operators can cause frequent breakdown and accidents.

- Many precautions are required to prevent accidents. Extreme weather conditions, such as heavy wind, need to be avoided.
- On the other hand, the success of ABC is due to powerful equipment. Different types of erection equipment are required for placing in-position the girders, box beams, trusses, arches, and cable-stayed and suspension-cable bridges. These include jib cranes, mobile cranes, truck mounted cranes, pallet trucks, forklifts, winches and cable pullers, and waste handlers. Not all of them are used in conventional construction.
- The erection contractor should invest and utilize modern robotics. The type of cranes to be used on a given project will depend upon the structural system and the dead weight of component to be safely lifted. It may initially increase the cost of the project, but the leasing period will be reduced due to ABC. Examples of cranes are:
- Tower cranes (for a maximum lightweight pick of 20 tons and heights greater than 400 ft)
- Lattice boom crawler cranes
- Mobile lattice boom cranes
- Mobile hydraulic cranes
- Lattice ringer cranes for varying heavyweight pickups and accessories

3.2.11 Field connection details

The manufacturers of timber, steel, precast-reinforced, and prestressed concrete components may consider refining the structural details for constructability reasons. The proprietary products are based on the details of previous productions through which the manufacturers usually develop a practical insight for the minutest detail. Any changes in contract drawings deemed necessary by the contractor, however minor, must be submitted to the D-B team for their approval and for making any necessary adjustments in analysis or design. Examples include connection details for seismic zones, slab-to-beam connections, or deck overhangs and parapets.

Special connections or hinges may be introduced for the transportation of long girders. Very long girders may be split into subgirders that are the maximum length permissible by traffic restrictions for wide loads or long loads (e.g., lengths of 100–150 ft) or for SPMT (refer to the FHWA Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges, 2007; UDOT Accelerated Bridge Construction SPMT Process Manual and Design Guide, 2009). Figure 3.2(a) shows use of twin SPMTs to synchronize the transport of a wide, precast T-beam bridge.

Figure 3.2(b) shows the use of single, long SPMT transporting long-span girders.

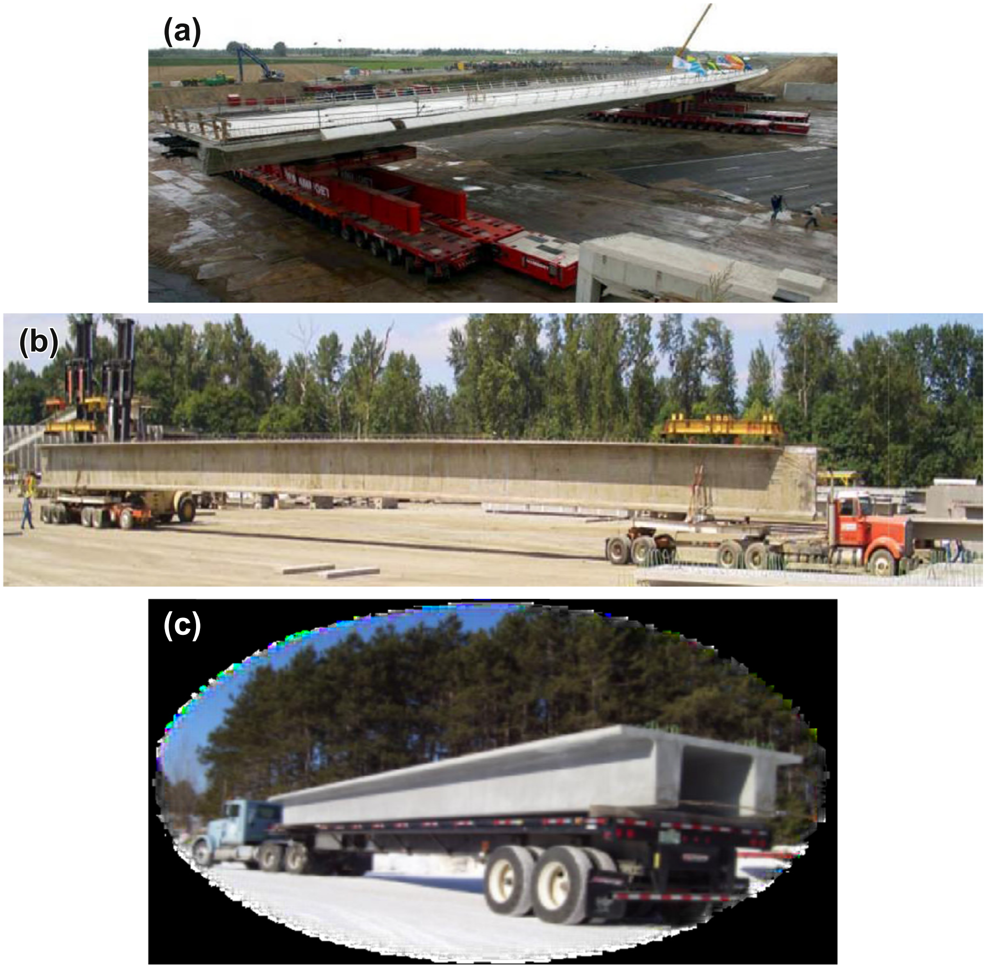

FIGURE 3.2

(a) Use of twin SPMTs for carrying a precast T-beam bridge (photo courtesy of FHWA). (b) Use of single, long SPMT for transporting long-span girders. (c) Use of SPMTs for transportation of long bridge components.

3.2.12 Self-propelled modular transporters

Figure 3.2(c) shows a very heavy, precast double T-beam being transported by an SPMT.

3.2.13 Assembling the transported components

These details may require high-strength bolts in the field for joining together the structural components during erection. These need to be made extra strong to account for secondary effects such as deck vibrations due to moving vehicles, fatigue and corrosion, etc. For example, precast deck panels need to be connected together by in situ or cast-in-place (CIP) concrete joints. Grouting and closure pours with nonshrink concrete or grout may be required to prevent any long-term cracking (refer to FHWA Connection Details for Prefabricated Bridge Elements and Systems, 2009).

3.2.14 Deck protection

Of all the structural members, the concrete deck is subjected most frequently to extraordinary forces. These include heavy rain, snow, frictional forces from the tires of heavy trucks, and other vehicle impacts. It is important that these effects be accounted for to ensure continued, long-term use. Latex modified concrete, corrosion inhibitor aggregate concrete, bituminous wearing surface, and a membrane waterproofing system should be considered for protection purposes.

3.3 SHM and prioritization of bridges for rehabilitation and replacement

In Chapter 2, the importance of SHM was discussed. Highway authorities utilize structural health monitoring systems to detect and monitor deficiencies on the major bridges. The structural health monitoring systems typically entail the installation of sensors at key locations on the structure being studied. The technologies vary among the systems; however, they possess the common feature of measuring desired physical properties. These may include loads, stresses, strains, and differential movements, as well as chemical composition of the concrete and steel structural components.

The consultant shall review and compare proprietary structural health monitoring systems offered by selected firms for their applicability, effectiveness, and installation and maintenance costs, and make recommendations for specific applications. For prioritization of bridges for repair and rehabilitation, the three methods are:

- Visual inspection reports
- SHM
- Ratings

Due to recent scientific advancements in measuring instrumentations technology, SHM is becoming popular. The modern concepts in SHM and integrated SHM (ISHM) reduce life-cycle costs and ensure long-term safety. Preserving the nation's infrastructure is of paramount importance. New technology for SHM helps in the following ways:

- Identification of deficiencies
- Quantitative measurements of displacements, rotations, and strains by sensors can be converted to peak stress distributions by using computer software.
- Ability to study the performance of new types of high-performance steel (HPS), high-performance concrete (HPC), hybrid materials, FRP, and structural plastics
- Making engineering decisions for repair, retrofit, or replacement.

SHM is a high-level application of advanced laboratory measurement techniques. This specialized subject will continue to grow and has great potential for condition monitoring and asset management of very expensive bridges. The measurements serve as a field laboratory and may eventually replace the visual inspection methods and life-cycle costs of inspections. It can be very useful as a diagnostic technology for identifying seriously deficient bridges. Recent progress in sensor technology has resulted in remote monitoring and the ability to study the history of slow deterioration of overstressed members in many structural systems.

After interpretation, the results of all measurements can be useful for condition assessments and safety evaluations of bridges.

Accurate deformations and displacement measurements are possible using inclinometers, tilt meters (for measuring rotations), electrical transducers, fiber optic sensors (FOS) and fiber-optic grating sensors, foil strain gauges, and frictional and vibrating wire strain gauges. Unlike the foil gauge, a frictional strain gauge can detect strains without bonding.

The next-generation sensors are micro–electro–mechanical systems (MEMS), which are integrated microdevices or systems combining electrical and mechanical components, whose size ranges from micrometers to millimeters. MEMS technology, combined with the miniaturization of electronics, has produced chip-based inertial sensors suitable for measuring accelerations and angular velocity.

Also, the unknown, dynamic characteristics of bridges can be determined from the vibration data. Teams are also using nondestructive evaluation (NDE) by guided acoustic waves for health monitoring of tendons and cables. It is commonly being used in the field to monitor cracks in FRP deck concrete. The use of carbon FRP (CFRP) wrapping for specimens reduces the corrosion rate in concrete by 50%. Selected, vulnerable members may be instrumented and studied rather than the entire bridge.

Use of vibration-based, damage-detection experimental methods in prestressed concrete girders: One can determine the longitudinal location of damage on a girder by applying the mode curvature and change in flexibility to accelerometer data. The transverse damage location on a prestressed concrete girder can be estimated by measuring mode shapes along each side of the girder before and after damage has occurred.

Improved bridge weigh-in-motion system: A Japanese technique has been developed to estimate the gross weight of a truck passing over a bridge by using a genetic algorithm (GA) and simulation analysis. With the proposed GA method, the calibration value (the ratio of measured value to computed value) can be estimated based on the traffic condition.

3.3.1 Security

ABC techniques can be utilized to maintain the security of important bridges against natural disasters and bomb threats from terrorists. The bridges most vulnerable to terrorist threat can be classified as follows:

- Bridges serving hospitals and school routes
- Bridges located on military routes
- Bridges located on interstate highways
- Historic bridges
- Long-span and landmark bridges whose photos often appear on postcards

A strategy should be in place for emergency management capability at the highway authority level, such as emergency funding and a readily available contractor–consultant team, to start and finish the required work in the minimum possible time. In a real emergency situation, inspection, rehabilitation, or replacement would require the use of ABC methods. These methods include accelerated bridge inspection (ABI) methods. The procedures would vary with the type of structural system, the bridge material, span length, etc. The use of remote sensors has been found to be a reliable tool in SHM and could be useful for rapid data acquisition in an emergency. Such procedures, however, require increased investments.

It is important that highway agency resource managers and operators (as well as emergency management and other relevant officials) develop, enhance, and implement effective security programs. For example, if the bridge is located on a waterway and the highway is inundated with floods, relevant knowledge of watershed management is needed.

3.3.2 Rehabilitation design procedures

For rehabilitation projects, type, size, and location (TS&L) plans shall have the normal TS&L plan complete details for construction, plus a complete review of the scope and extent of work. The anticipated bridge rating after the proposed work is incorporated shall be shown.

The following factors affect the selection and design of rehabilitation methods and influence the need for innovations:

- Site layout
- Bridge usage
- Deterrence and access control
- Specific bridge features (moving, suspension)
- Resiliency of bridge components
- Redundancy of the bridge system
- Other bridge-specific items

Criticality factor for assets: The criticality or vulnerability factor for assets can be expressed as a characterization of assets into regions of different levels of criticality and vulnerability:

- Preassessment: Resource identification
- Assessment: Vulnerability identification
- Postassessment: Decision making

Plan preparation and presentation: In plan preparation, actual field measurements should be considered more reliable than the drawings. Also, the detailed shop drawings should be considered more reliable than bridge plans. The contract plans should be sufficiently detailed to provide an overall view of the bridge, indicating the following:

- The existing and proposed geometric dimensions
- Limitations and restrictions
- Extent and type of work to be performed
- Construction stages
- Material information
- All related information needed to rehabilitate the bridge

Limitations of the nontraditional approach: Although cast-in-place construction is time tested, ABC applications are of recent origin. Although there are savings in construction time, design effort is sometimes increased due to numerous precast joints and components.

- The time required for borehole tests, pile driving, shop drawing review, and closure pour remains unchanged.
- Span lengths in concrete bridges are restricted to about 100 ft due to the transport restrictions of heavy components.

- Compared to a unified cast-in-place integral abutment bridge, a precast bridge with numerous deck joints is weaker during earthquakes.
- Transverse prestressing is required.
- Full-scale testing is required to develop confidence, especially for curved bridges.

Pay items and cash flow: All work shall be accounted for by specific pay items. Pay limits, quantities, and pay items should be adequately defined to eliminate ambiguity or confusion. Where applicable, the reasons for critical limitations and restrictions should be explained to assist the contractor and the field inspector in adjusting to the field conditions.

3.3.3 Preventive measures in design and construction to prevent failure

- Provide space for bearing inspection chambers.
- Greater vendor and construction engineer participation in revising and developing design codes should be implemented.
- Ensure seismic retrofit against minor and recurring earthquakes.
- Provide scour countermeasures.
- Ensure effective monitoring through remote sensors.
- Study the failure mechanisms of different types of structural systems.
- Codes for rehabilitation of mixed structural systems should be developed and made available.
- Codes for new materials, such as FRP decks, should be developed.
- New repair techniques need to be incorporated in the codes.

3.3.4 Research in arching action in deck slabs of integral abutment bridge

Modern design techniques will help with ABC as more economical or lighter structures can be designed. For example, planar stress has been neglected in deck slab design. AASHTO LRFD recommends incorporating arching action in the detailed design of deck slabs. Live load deflections are reduced. AASHTO C9.7.2.1 states that an arching action occurs in deck slab and an internal compressive dome is created. The membrane force would change the design of shear connectors due to the composite action. Deck slabs curved in plan and composite with curved beams would experience a greater effect of axial compressive membrane forces and compressive stresses in slab and equilibrium, balancing axial tensile force and tensile stress in a curved beam.

The biharmonic equation for planar stress needs to be applied simultaneously with the plate-bending equation to compute membrane forces. Using notations used by S. P. Timoshenko, (*Theory of Plates and Shells* by McGraw-Hill) membrane forces Nx, Ny, and Nxy can be represented by the standard equation:

$$\mathrm{Nx}\left(\partial^2 w/\partial x^2\right) - 2\mathrm{Nxy}\left(\partial^2 w/\partial x\,\partial y\right) + \mathrm{Ny}\left(\partial^2 w/\partial y^2\right) = 0$$

By using Airy's stress function, the field equation for deck slab analysis becomes

$$\left(\partial^4\varphi/\partial x^4\right) + 2\left(\partial^4\varphi/\partial x^2\,\partial y^2\right) + \left(\partial^4\varphi/\partial y^4\right) = 0 \qquad \text{where } \varphi = \psi/D$$

Arching action in slab with restrained boundaries from beam systems was studied by the author Mohiuddin Khan with K. O. Kemp at the University of London.

Canadian bridge design codes have also incorporated arching action in deck slab from stiff boundary conditions.

Arching or compressive membrane action (CMA) in reinforced concrete slabs occurs as a result of a migration of the neutral axis, which is accompanied by in-plane expansion of the slab at its boundaries. If this natural tendency to expand is restrained, the development of arching action enhances the strength of the slab. The term arching action is normally used to describe the arching phenomenon in one-way spanning slabs, and compressive membrane action is normally used to describe the arching phenomenon in two-way spanning slabs.

This has resulted in the reduction of deck reinforcement, the placing of which leads to increased construction effort and time. There will be an additional restraint to the edges of deck slab restrained at the abutments in integral abutment slabs, which needs to be investigated. (References: Khan, M.A., 1970. Elastic composite action in slab-frame systems, The Structural Engineer. London; Khan, M.A., Kemp, K.O., 1969. Elastic composite action in slab-beam systems, The Structural Engineer. London; Khan, M.A., 2004. Modeling and seismic analysis of integral abutments, ASCE Conference Proceedings, Nashville).

Correct distribution of reinforcement, both in precast or cast-in-place decks, is likely to reduce long-term cracking and minimize deck replacement.

3.4 ABP leads to ABC

3.4.1 Scope of the ABC approach

There is a need to cut down on inbuilt difficulties in the system. For example, design-build takes away slackness and red–tapism. ABC is useful for emergency replacement of bridges damaged by construction accidents such as crane collapse, vehicular accidents, ship collision, ice damage, flood, or earthquake, for which accelerated planning and design will also be necessary.

A bridge consists of superstructure, substructure, foundation, approaches, electronic signals, drainage pipes and a deicing system, and many utilities. Using accelerated planning principles for the selection of each type of component design, refinements can be made in optimum solutions.

Using ABC, formwork, or much of concrete placement and curing, is not required. For rapid construction, such as for busy highways and over rivers and waterways, there is no substitute for ABC. Activities such as borehole tests, pile driving, shop drawing review, and closure pour are unchanged. ABC has great potential for wider use, but many roadblocks need to be removed to pave the way for a much wider application. Some limitations include that an ABC design code based on ABP for alternatives and connections will be required: ABC is an entirely different method of construction. Fabrication, transportation of components, and erection methods are different.

ABP is the first step toward achieving ABC. Based on the inspection reports and ratings, ABP promotes durability and compliance with environmental preservation laws. ABP is the planning stage toward accelerated design and goes hand-in-hand with ABC.

As bridges get older, highway agencies have hundreds of bridges to reconstruct and open to the public in any given year. During lengthy construction periods, traffic problems are compounded at multiple bridge sites, which results in a loss of useful man-hours. Traffic jams have adverse effects on the air quality and health of users caused by idle fuel burning. Hence, as discussed earlier, ailing bridges need to be fixed on a priority-basis by using rapid construction with desirable functional improvements. To implement ABC with confidence, an applicable code for ABP and relevant specifications is needed. Additionally, we need to adopt innovative approaches to research in emerging construction technology in order to further advance ABP and ABC techniques.

3.4.2 Objectives of ABP

The primary objectives of ABP include constructability, erection, serviceability, durability, maintainability, inspectability, economy, and aesthetics. Detailed objectives are as follows:

- Develop modern codes and construction specifications: construction mistakes, ship collision, scour, design deficiency, overload, fatigue, and earthquake are the main causes of failure.
- Introduce specialized training of designers and field staff. Applied mathematical methods and the use of fracture mechanics in design need to be developed and promoted.
- Monitor construction activities on the "critical path" for saving time and long-term rehabilitation costs.
- Ensure safety during construction and a safe bridge for users following its completion.
- Obtain traffic counts for selecting full or partial detours and apply temporary construction staging.
- Optimize the size and number of girders and use modern material and equipment.
- Select pleasant bridge colors and aesthetics to maintain "America the Beautiful."

The original, successful decisions made by pioneer bridge builders need to be revisited. A return to the forgotten fundamentals, in some cases, may be desirable. For continuous bridges, for example, the use of double rows of bearings is a sign of added security against total bridge collapse. Fully covered bridges with canopies increase the life of the bridge deck, prevent accidents, have no drainage problems, and do not require deicing salts.

3.4.3 Impact of ABP on analysis and design

The following design issues need attention at an early stage:

- Distribution coefficients in LRFD method: Longitudinal joints alter the aspect ratio of deck panels. Although the span-to-girder spacing ratio may be unchanged, the transverse distribution of the live load is diminished. The percentage of longitudinal distribution is increased and needs to be evaluated.
- Load factors: AASHTO's use of load factors for CIP construction will change for precast construction.
- Changes in boundary conditions compared to conventional construction.
- The advantage of Poisson's ratio in transverse bending is no longer available due to discontinuity.
- The orthotropic behavior of the superstructure needs to be improved by providing diaphragms at closer longitudinal spacing.
- The advantage of arching action at supports will be lost since the deflection pattern has changed.
- Due to age differences in cast-in-place concrete for closure pour and precast panels, differential shrinkage is likely to take place. Longitudinal joints may crack or open up, requiring repairs and lane closures.
- Compared to CIP construction, a precast bridge with numerous deck joints is likely to be weaker during earthquakes.

- The trend in design is to eliminate transverse and longitudinal joints by adopting an integral-abutment and integral-pier approach for unified behavior. Segmental deck construction requires transverse prestressing.
- Span lengths in concrete bridges are restricted to about 100 ft due to transport restrictions of heavy components.
- Deck drainage provisions in transverse and longitudinal directions still require concrete topping with varying thickness in the field.
- Future widening is not easy if the design uses transverse prestressing of the deck slab.
- Full-scale testing is required to develop confidence, especially for curved bridges.
- Maintenance and protection of traffic (MPT), approach slab construction, permits and utility relocation, etc. are unavoidable constraints.
- Contractors, in general, have technicians trained in formwork and cast-in-place construction, and new training in ABC is required.
- Overemphasis of incentives/disincentives pressures the contractor into adopting unrealistic schedules at the expense of quality control.
- Also, the manufacturing nature of precast products creates a proprietary system and monopolistic environment, which may lead to unemployment of some number of construction workers.

Approach slab construction requires placing precast panels supported on grade. Separation from grade may happen due to a lack of compaction, and a raised water table leading to settlement of the approach slab.

3.4.4 Factors in acquiring a return on investment

Prefabrication: Proprietary manufacturers have now developed facilities for the prefabrication of bridge components in factory conditions on a massive scale.

Specialized training: Training in ABC beyond the college level is required, and workshops and webinars are being offered by FHWA, AASHTO, DBIA, state agencies, and universities like FIU. Appendix 4 provides details of a typical three-credit university course in ABC and Appendix 5 Training Courses and Workshops in ABC for details.

Equipment: The construction industry is fortunate to often have access to modern equipment, such as lifting cranes for every site and SMPTs for the transportation of subassemblies.

Early warning systems: Progress is being made on early warning systems for tornadoes, floods, and earthquakes, as these events can adversely affect construction activities. Such facilities were not available a generation ago.

3.4.5 Considerations of engineering ethics

It should be pointed out that in conventional contracts, the consultant approves the quality of the day-to-day work of the contractor and the quantities completed in the field. This invariably puts the contractor under undue pressure. There may be indirect payoffs leading to corruption, especially on large projects worth hundreds of millions of dollars. This situation adversely affects the quality of the work. With a single design-build (D-B) contract, this possibility is reduced since the contractor is likely to have the upper hand and cannot be blackmailed by the consultant.

3.4.6 FHWA flow diagram for feasibility study

Figure 3.3(a) and Figure 3.3(b) generalized flow diagrams proposed by FHWA show the planning considerations when selecting bridges for ABC.

3.4.7 Importance of deck overlays

The quality of the riding surface quality can be considerably improved by creating less friction between the rubber tires and the concrete surface. If bituminous concrete overlays are placed on bridge decks, they reduce roadway noise in urban residential environments, improve the riding surface, and protect the deck from deterioration. The bituminous overlay is porous and not waterproof. The overlay may

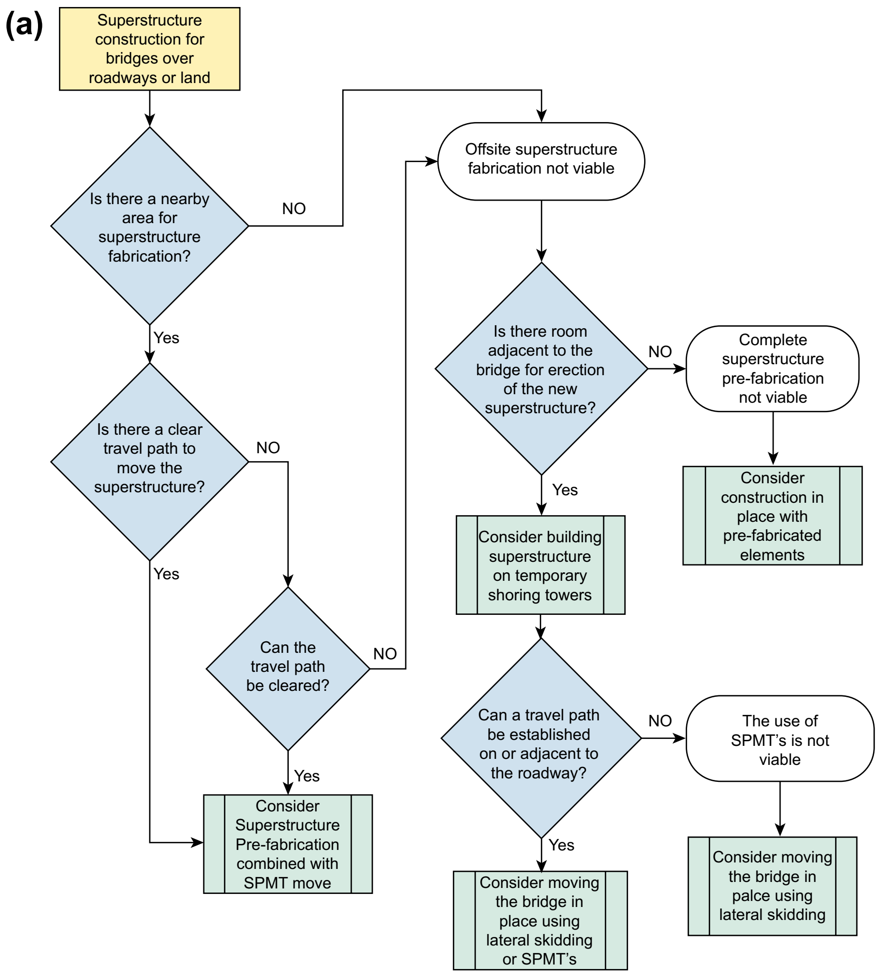

FIGURE 3.3

(a) Feasibility studies for superstructure fabrication and use of SPMT (developed by FHWA).

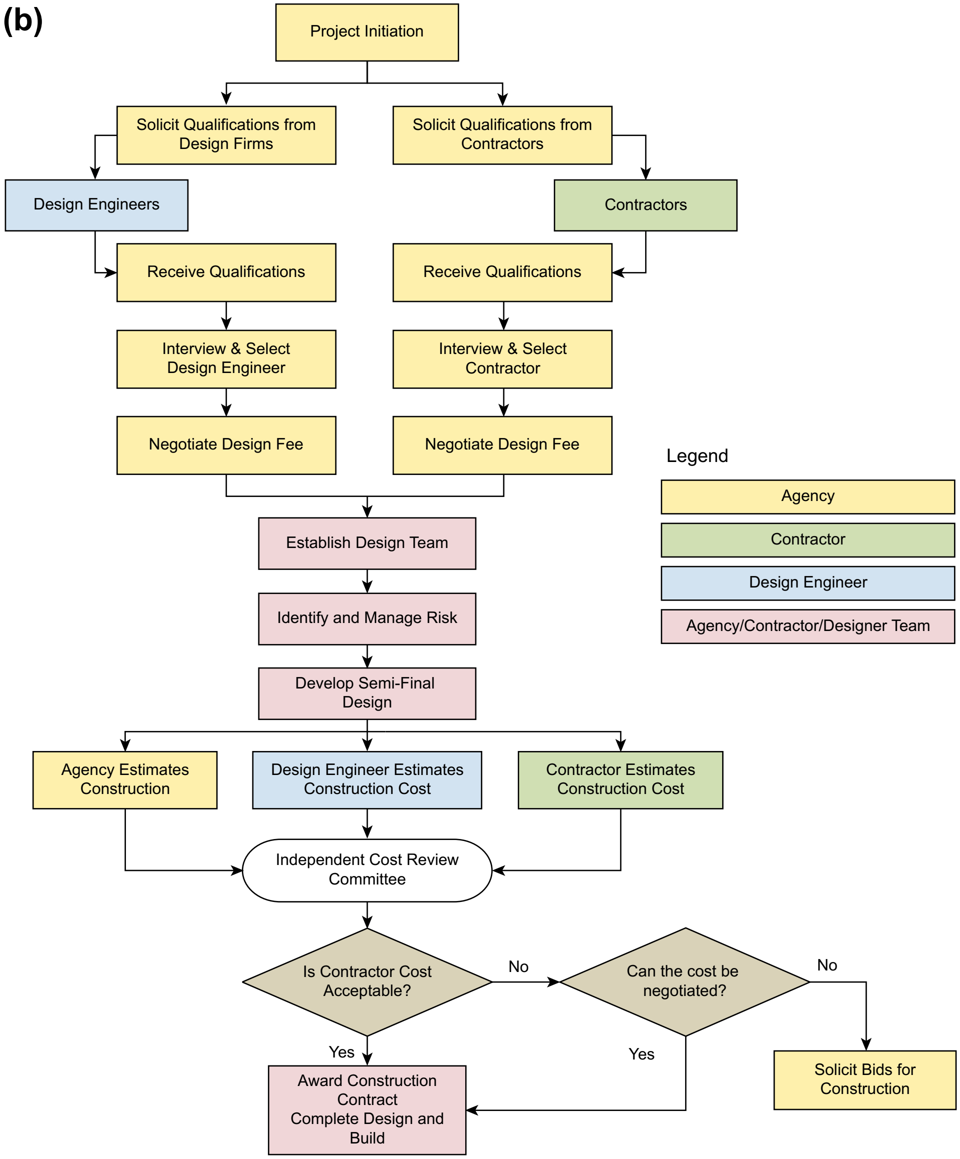

FIGURE 3.3 CONT'D

(b) Various phases in setting up an ABC team prior to construction (courtesy of FHWA ABC Manual).

trap moisture on top of the concrete deck. This can lead to accelerated deterioration of the deck due to the infiltration of water and deicing salts.

With the advent of low-permeability, high-performance concrete (HPC), many states are building bridges without supplemental wearing surfaces (bare concrete decks). The European approach to deck protection is to use bituminous overlays combined with high-quality waterproofing membranes. This approach has yielded long-lasting bridge decks that can meet the AASHTO goal of a 75-year service life. Several states have adopted this approach with similar results. Bridges built with bituminous overlays and waterproofing systems in Connecticut, in the 1960s, have performed very well over the last 50 years.

3.4.8 Diamond grinding

The use of prefabricated bridge-deck elements requires the use of joints between elements. Construction of the elements requires reasonable fabrication and erection tolerances. These issues will lead to an uneven riding surface. Several states have used diamond grinding to smooth out the deck after installation of the elements. The concrete cover in the elements must be thick enough to accommodate the grinding operation. Diamond grinding can improve the riding surface, but the finished product is not as smooth as a cast-in-place concrete deck.

The application of a concrete overlay will require additional time and/or bridge closures in order to place the overlay. For very fast construction projects, this can be accomplished on subsequent weekends after the bridge is reopened to traffic.

The Virginia DOT has developed a very-early-strength latex-modified concrete overlay. This material can be placed and cured in 3 h, and can provide low permeability and high-bond strength. Thin overlays will ensure a better-quality, final riding surface on the bridge deck. The overlay can serve as the last tolerance adjustment during the construction of the prefabricated structure.

3.4.9 Bridge deck expansion joints

Bridge deck expansion joints have long been the source of premature deterioration of bridge decks and supporting framing. Most states are designing bridges by using integral abutments and continuous superstructures in order to eliminate expansion joints. On larger bridges, it is inevitable that deck expansion joints will be required. Bridge deck expansion joints can be placed into two categories:

- *Joints placed within the deck overlay system*: These consist of various asphaltic plug materials and epoxy header systems combined with glands or seals.
- *Joints embedded into the deck or supported directly by the superstructure framing*: These systems tend to more elaborate and can accommodate larger movement. They typically consist of armored seals, finger joints, or modular expansion joint systems.

The effect of joint systems on ABC projects depends on the category. Joints that are placed within the overlay are typically not affected by ABC methods. The joint can be installed in the same manner as conventional construction.

3.4.10 Bridge bearings

During conventional bridge construction, bridge bearings are set during the erection of beam elements. Vertical adjustment for construction tolerances is normally accounted for in the gap between the top of the girder and the deck, which is the thickness of the deck haunch. On modular prefabricated ABC projects, the deck may be fabricated along with the girders, prior to installation. This is applicable to full superstructure bridge moves and for modular superstructure element bridges. For these bridges, the bearings can be used to adjust the elevation of the girders and the finished riding surface.

3.4.11 Drainage assemblies

It may be necessary to install drainage systems in following cases:

- Long-span bridges
- Bridges with flat grades where runoff widths are unacceptable
- Bridges built on sag vertical curves

It is possible to install drainage assemblies into prefabricated deck elements. Drainage assemblies have a tendency to clog and fail, thereby allowing roadway water to spill onto beams and substructures. The standard details may require minor adjustments in the prefabricated elements to facilitate the fabrication process.

3.4.12 Barriers and railings

The lack of crash-tested, prefabricated barrier systems may cause safety problems. Crash testing requirements are devised by the FHWA for all parapets and railings on the National Highway System (NHS). The AASHTO LRFD Bridge Design Specifications require that all barriers and railings be crash tested in accordance with the requirements outlined in NCHRP Report 350, entitled *Recommended Procedure for the Safety Performance Evaluation of Highway Features*. This document is published by the Transportation Research Board. These requirements have limited the number of prefabricated barrier systems that can be used. The FHWA Connections Manual contains more information on the issues with connecting barriers and railings to prefabricated elements.

3.4.13 Concrete barriers

The precast concrete barriers can be anchored to prefabricated decks through bolting to the deck. The bolt projects down below the deck and is secured with a nut and an anchor plate. This type of connection has been problematic. If this connection is used, it should be properly sealed. If the bolts are placed in preformed holes, water can migrate through the hole and corrode the anchor plate and the underlying framing. A longitudinal closure pour can be used to make up for casting and erection tolerances, as well as to provide a location to accommodate a roadway crown angle point.

3.4.14 Barriers on MSE and modular walls

Most states have developed standard details for precast concrete barriers that are set on top of the modular wall. The resistance of the barrier to vehicular impacts is normally accommodated through the use of a simple cast-in-place moment slab. Prefabricated MSE and modular block walls are very common. In some instances, the top of the wall is used to support a concrete barrier.

3.4.15 Metal railings

On ABC projects, prefabrication of metal railings is not normally an issue. Anchor rods can be installed in the deck panels in the fabrication shop.

3.5 Compliance with environmental permit regulations

The purpose of permits is to maintain the following during the months of construction:

- Air quality
- Water quality
- Health

Additionally, noise abatement is a critical issue for the local residents during construction and for the bridge users and residents over the long term.

The management of environmental permits is also critical in many bridge construction projects. Permits in this category can cover issues such as stream encroachment, navigation, Coast Guard issues, and tideland and riparian grants. The proposed construction should neither damage an existing wetland nor adversely affect the historical significance of the bridge itself or its surroundings, except as permitted through the environmental evaluation process. Engineering data and documentation are required for permit approval. As per regulations, reports or the filling-out of application forms are required for the following:

- EA (Environmental Assessment)
- EIS (Environmental Impact Statement)
- CE (Categorical Exclusions).

Stream encroachment permits will be required from the Environmental Protection Agency (EPA) and/or the state's Department of Environmental Protection (DEP) for construction purposes.

3.5.1 ABC team setup

Figure 3.3(b) shows a flow diagram with the various steps for the selection of a specialist team.

3.5.2 Construction permits

The contractor will be responsible for obtaining all applicable construction permits, including the use of quality assurance and quality control procedures.

3.6 Insurances against liabilities

Each type of insurance will be covered by state law and will be project-specific:

1. *Workers' Compensation and Employers Liability*: In the state in which the work is to be performed and elsewhere, as may be required and including:
   a. *Workers' Compensation Coverage*: In such amounts necessary to satisfy applicable statutory requirements
   b. Employers Liability Limits to cover Bodily Injury by Accident or by Disease.
   c. Waiver of Right to Recover from Others Endorsement where permitted by state law.
   d. U.S. Longshoremen's and Harbor Workers' and Maritime Coverage, where applicable.
2. *Commercial General Liability*: This includes Premises—Operations, Products/Completed Operations, Broad Form Property Damage, Contractual Liability (including Liability for Employee Injury Contract), Fire Damage and Explosion, Collapse and Underground Coverage.

3. *Automobile Liability including Physical Damage*.
4. *Commercial Umbrella Liability*.
5. *Pollution/Environmental Impairment Liability Coverage*: Required for contracts that involves the removal, transportation and/or disposal of hazardous materials. All insurance coverage shall survive until all hazardous materials are disposed of in an ultimate EPA licensed disposal facility, and until federal, state, and local environmental requirements have been complied with.
6. *Professional Liability Coverage*.
7. *Inland Marine Insurance*, where applicable.
8. *Watercraft Liability Insurance*, where applicable.
9. *Riggers Liability Insurance* for those contracts that involve rigging (furnishing the material hoist service).
10. *Railroad Protective Liability Insurance*: Where construction is to be conducted within 50 ft of the railroad, the Covered Party shall be responsible for this form of insurance.

3.7 Utility coordination prior to and during construction

One of the practical difficulties in ABC is interference with any existing utilities, located either below the bridge or overhead (e.g., lines for power or telephone). More utilities serving new technologies are being added to the bridge superstructure. In addition to the conventional water, sewer, and gas pipes, new cable and fiber optic conduits are being added.

The utility task is usually on a critical path; therefore, the project manager will begin coordinating with the utility owner's right after the notice to proceed, by following the utility relocation procedures and participating in all utility meetings, if applicable.

The ABC team will follow safe utility relocation procedures and address the following tasks: contacting and communicating with the utility owners, developing schemes for accommodation, preparing schedules and cost estimates in concert with the utility owner, and preparing the utility order for execution by the agency. The identified utilities will be shown on the construction plans, and any potential conflicts should be identified and resolved, with the revised plans forwarded to the utility company.

According to the FHWA ABC Training Manual, the best option for utilities is to remove and relocate them prior to the start of construction. This leaves the contractor unobstructed access to the site. In the case of a deck or superstructure replacement project, it may be possible to temporarily support the utilities and work around them during erection. Once in place, the utilities can be reattached to the new elements.

Underground utilities can also affect ABC methods. Placement of cranes on top of fragile underground utilities may be problematic. It is possible to span over these utilities through the use of steel plates and/or crane mats.

Utility companies may allow the temporary shutdown of service during short construction periods. Gas and water mains are sometimes designed with redundancy, thereby allowing short-term closure without significant impact to the utility network. ABC can be used to limit the length of time of these closures.

The ABC team must have state-of-the-art equipment and custom rigs to provide a full array of field services for assorted subsurface utility engineering assignments.

3.8 ABC for railway bridges

According to the University Transportation Research Committee (UTRC) at Rutgers University, the population and employment in the Northeast is expected to grow some 35% over the next 25 years, bringing the reality of even more traffic and congestion. It is the problem of mega cities everywhere.

For example, the Washington–Boston Northeast Corridor rail line does not have the ability to absorb the crush of new travelers in the coming decades. It will require a significant investment to grow capacity, improve reliability, and serve new markets. The Federal Railroad Administration (FRA), (an agency within the U.S. Department of Transportation) is leading the development of a Passenger Rail Corridor Investment Plan (NEC FUTURE) to define the investment required to keep the Northeast Corridor vibrant and to prepare the roadmap for federal, state, and private investment. Rebecca Reyes-Alicea (FRA's program manager for NEC FUTURE), is leading the effort for the planning process, the challenges in working on a corridor that crosses eight states and is served by commuter, intercity and freight railroads, and the steps NEC FUTURE is taking to develop a long-range investment program.

To expedite the construction of railroad bridges in a congested area, it is expected that ABC procedures will be applied. The requirements of repair and rehabilitation methods for railway bridges are based on the AREMA (American Railway Engineering and Maintenance-of-Way Association) Code. D-B management methods and prefabricated construction are applicable. Coordination with railway and transit authorities will be required for catenary construction and signaling, etc., to ensure the rapid availability of train service.

Infrastructure upgrades are central to ensuring safe and reliable performance, including the rehabilitation, expansion, and replacement of the bridges. The infrastructure upgrade program will also provide for track renewal, passenger communication upgrades, signal system upgrades, and improvements to overhead power lines and electric substations. Guidelines for rating railway bridges are given in the AREMA Manual. A variation of Cooper E loading is used. Maximum design live loads for replacement bridges are Cooper E80, but the bridges need to be rated for Silver liner, Bombardier, and other types of locomotives being used by the transit agencies. Unlike FHWA design methods, only the conservative allowable stress method is used. Inventory and inspection forms are different from the SI&A Sheet.

Railway bridges have several differences as compared to highway bridges, and are fewer in number:

- Deck slabs are not present since train wheels are supported on rails, sleepers, and ballast.
- Steel bridges are generally of the through-girder type with floor beams and require lateral bracing. Timber bridges are supported on timber-framed trestles or pile trestles.
- Stone arch and masonry bridges of smaller spans than highway bridges are common.

3.8.1 Storm-resilient grid for New Jersey transit system

(Reference Reuters Report by Selam Gebrekidan and Leslie Gevirtz).

New Jersey sustained a severe blow when Sandy made landfall. The storm also cost New Jersey Transit an estimated $400 million.

The Department of Energy and the state of New Jersey plan to design a small electric grid that will serve the state's transit system and withstand the onslaught of storms like Superstorm Sandy.

The microgrid will power the transit system's rail operations between Newark, Jersey City, and Hoboken in New Jersey. It will be designed by the energy department's Sandia National Laboratories, which has worked on such grids for the U.S. military.

The project will make a key part of the northeast energy infrastructure resilient to changes brought on by climate change.

3.9 Choosing the accelerated construction route in New Jersey

Since the author's work for ABC has mainly involved the New Jersey DOT, NJ Turnpike, and Port Authority of New York and New Jersey, progress made in ABC implementation is discussed here. Other states have similar administrative, design, and rapid construction issues. Northeast states such as New Jersey have been at the forefront of promoting and implementing innovative technologies to achieve improved work-zone safety, as well as motorist safety and comfort, by using jointless decks and integral abutments with minimal environmental disruption.

Audits are in practice at the New Jersey Department of Transportation (NJDOT) to ensure that designers and project managers are studying alternatives, new manufacture processes, connection details for prefabricated elements, management programs, and quality assurance. (Refer to the report on ABC presented by the author and New Jersey State Bridge Engineer at the FHWA Conference, Baltimore, MD, 2007.)

3.9.1 Superstructure work

Crews can cut the old bridge spans into segments and remove them, prepare the gaps for the new composite unit, and then set the new fabricated unit in place in an overnight operation. The quicker installation minimizes huge, daily, delay-related costs and daily traffic-control costs.

Construction is usually scheduled for the fall months, when the weather is more predictable. A single-course deck will save a minimum of 6 weeks in construction time compared to a two-course deck.

- On the Route 46 Bridge spanning Overpeck Creek in Bergen County, NJDOT decided to use prestressed, precast beams to prevent painting cost.
- Utilizing a precast superstructure (Inverset), NJDOT replaced a structure in South Jersey, Creek Road over Route I-295 SB.
- Prefabricated deck panels (Inverset, which is no longer proprietary) for three single-span Route 1 bridges over Olden Avenue and Mulberry Avenue in Trenton, NJ were constructed in 2005, over weekends.
- Besides exodermic and orthotropic decks, new materials used include High Performance Concrete (HPC) and corrosion inhibitor aggregate. Precast or steel diaphragms for prestressed beams have been allowed. Precasting has quality control and avoids reinforcement placement, concrete pouring, and weeks of curing of HPS: The author recently designed bridges with HPS 70W hybrid girders in New Jersey. It allowed for a longer span and lighter girders. Shallower girders improve vertical underclearance, reduce the number of girders to be constructed, and eliminate painting. Weathering steel provides enhanced resistance to fracture.

3.9.2 Parapets

A variety of parapets are used in New Jersey. NJDOT permits its contractors to use slip forms to increase the speed of construction, as done successfully with the Route I-195/I-295 Interchange.

3.9.3 Substructure work

Integral abutments with fewer piles have been successfully used in New Jersey. They can be constructed more quickly than conventional bridges. An example of an integral abutment bridge using prestressed concrete box beams on Route 46, over Packman's River, was designed by the author (Figure 3.4).

Currently, a design is in progress for lesser-used, semi-integral abutments for bridges on Nottingham Way over Assunpink Creek in Mercer County, and Garden State Parkway Bridges over Jakes Branch.

Lighter piers or precast concrete pile bents save costs and duration, as exemplified by the Albany Street Bascule Bridge carrying Routes 40 and 322 into Atlantic City. Precast, posttensioned pier caps were recently used on the Route 9 bridge over the Raritan River and by the author on at the interchange of US Route 322 and NJ Route 50.

Drilled shaft foundations and concrete cylinder piles of 36–66 in in diameter are in use. Precast sheeting has been used for retaining walls and abutment. MSE abutments have performed extremely well.

NJDOT has used RFP material for fender systems for two bridges along the Jersey coast, Route 9 over Nacote Creek, and Route 9 over Bass River. It is environmentally friendly and eliminates marine borers.

3.9.4 Installing scour countermeasures

Minimal marine life disruption and quick construction are achieved by using gabion baskets, articulated concrete, or cable-tied blocks in lieu of traditional sheet piles. The author has prepared a

FIGURE 3.4

Great attendance and rapt attention by senior engineers at the Philadelphia SEI meeting.

"Handbook for Scour Countermeasures" for NJDOT jointly with the City University of New York (CUNY), which was approved by the FHWA, and in addition helped developed relevant sections of the NJDOT Bridge Design Manual.

3.10 FHWA innovative techniques

As discussed in earlier chapters, the FHWA is promoting time and cost-saving techniques, as part of a new initiative to help state departments of transportation (DOTs) manage their road and bridge projects.

3.10.1 ABC goals

- Relentlessly pursue reducing traffic congestion during construction.
- Add value by furthering department themes and meeting project goals.
- Improve worker safety and safety to the traveling public.
- Improve quality.

In August of 2012, the FHWA unveiled the second round of the Every Day Counts (EDC) initiative in advance of a series of regional workshops in the fall to promote 13 cost- and time-saving measures to state and local transportation officials.

The FHWA hopes this second round of innovation initiatives will improve safety, streamline regulation, and quicken the delivery of projects.

The EDC initiative started in 2010. (It was inspired by the Senate confirmation process of the FHWA's administrator, Victor Mendez. Mendez met with senators in their offices, and many had stories about delayed project deliveries.)

The FHWA, working with state DOT officials and stakeholders such as AASHTO, developed an initial list of initiatives on which they have focused for 2 years. States chose which initiatives they wanted to pursue, and the FWHA provided access to technical expertise. The EDC is designed to provide evidence of innovations. Prefabricated bridge elements and systems and geosynthetic-reinforced soil are both accelerated bridge construction methods, and they were carried over from round 1 to 2 as the FWHA continues to champion the time savings provided by these techniques.

3.10.2 Emphasizing the advantages of ABC

- Reduced on-site construction time
- Minimized traffic disruption—*months to days*
- Reduced environmental impact
- Improved work zone and worker safety
- Provides positive cost-benefit ratios when user costs are considered
- Improved quality-controlled environment, cure times, easier access, etc.

3.10.3 List of FHWA initiatives

The **FHWA**, working with state department of transportation (DOT) officials and stakeholders such as the AASHTO, developed an initial list of initiatives on which they have focused for the past several years. States chose the initiatives they wanted to pursue, and the FWHA provided access to the technical expertise. It appears that some states are more aggressive in adopting initiatives because their circumstances allow it.

Safety Edge: One successful initiative was "Safety Edge." It is a paving process in which the edges of roads in primarily rural areas are compressed at a 30° taper angle rather than left at an unfinished 90°. Research indicates that 90° drop-offs are a factor in about 20% of rural traffic accidents.

EDC (Every Day Counts): Because of the challenging economic environment for infrastructure, state DOTs were pressured to find new ways to deliver projects in less time and for less money, and EDC has been well received. The success of EDC (discussed earlier in Chapters 1 and 3) is due to the collaborative nature of the initiative, combining input from the FHWA and participants such as state DOT officials, trade groups, and private industry stakeholders. The EDC is designed to provide evidence of proven innovations. However, the cautious nature of engineering perhaps delayed the application of the EDC approach. Construction industries, in order to remain in business, often prefer to rely on tested and proven techniques.

FWHA: continues to champion the ABC time savings provided by using prefabricated bridge elements and systems and geosynthetic-reinforced soil. The new initiatives list includes:

Alternative Technical Concepts: States can be presented with innovative ideas that save time and money. Contractors may be allowed to propose alternatives during the design phase, similar to value engineering.

Programmatic Agreements: This is a streamlined approach for environmental requirements that are often repeated on a project-by-project basis. An example is determining what mitigation actions are required when a particular endangered species is affected by rapid construction, and then repeating those actions on any project that impacts the species.

Locally Administered Federal-Aid Projects: This initiative is designed to reduce state oversight, by educating local agencies on the complexities of the processes and requirements of the Federal-Aid Highway Program.

Intersection and Interchange Geometrics: There is a need to explore any safety innovations to reduce possible conflict points between motorists, pedestrians, and bicyclists using the bridge.

High-Friction Surfaces: This safety measure adds a high-friction surface on curves, which account for 25% of fatalities. It does not impact the cost significantly, since curves comprise only about 5% of highway miles in the United States.

Geospatial Data Collaboration: This innovation allows data sharing between stakeholders, by exploring a cloud-based geographic information system platform.

Implementing Quality Environmental Documentation: The size of the National Environmental Policy Act documentation can be reduced to some extent, and innovation can accelerate project delivery.

National Traffic Incident Management Responder Training: This initiative offers a national training program for first responders. FHWA Strategic Highway Research Program 2 (SHRP2), discussed earlier, seeks to reduce the 4.2 billion hours and 2.8 billion gallons of gasoline motorists waste when frequently stuck in traffic on congested highways because of the following:

- Extreme weather
- Accidents
- Disabled vehicles
- Debris in the road

Market-ready technologies, vendor products, innovative techniques for the use of new construction materials, remote health monitoring, and recent developments in repairs and rehabilitation methods are addressed.

- Use of such efficient methods will cut down the life-cycle costs and the duration of maintenance.
- Some of the newer methods have not been fully tested, and precautions may be required in their applications.
- The latest ideas, ingenuity, and contributions from individual researchers and publications are listed.
- Recent developments in new materials and prefabricated concrete elements for rapid construction will be discussed.

3.10.4 Additional FHWA list of initiatives

Programmatic Agreements II: This is a streamlined approach for environmental requirements that are often repeated on a project-by-project basis. An example is determining what mitigation actions are required when a particular endangered species is affected, and then taking those actions on any project that impacts the species.

Locally Administered Federal-Aid Projects: This initiative is designed to reduce state oversight by educating local agencies on the complexities of the Federal-Aid Highway Program's process and requirements.

3-D Modeling for Construction Means and Methods: Combining construction equipment utilizing Global Positioning System (GPS) receivers with 3-D modeling of a project can deliver accurate grades on the first pass, increasing productivity by 50%.

Intelligent Compaction: Combining GPS with machines using vibrating compaction rollers and accelerometers to measure density improves the consistency of pavement.

Accelerated Bridge Construction (ABC): The FWHA is concentrating on Prefabricated bridge elements and systems.

3.10.5 Recent promotion of prefabrication by manuals and workshops

FHWA PBES Publications: Bridge substructure and superstructure systems are manufactured off-site. Bridge elements include decks, deck panels, girders, pier caps, columns, pile cap footings, and foundations. They are ready for installation when they are brought to the construction site. These elements can be evaluated through the use of an FHWA decision-making framework, or one developed specifically by a state. The following publications offer additional information on PBES and can be found at http://www.fhwa.dot.gov/bridge/prefab/pubs.cfm.

Prefabricated Bridge Technology: Get In, Get Out, and Stay Out
Prefabricated Bridges 2004
Prefabrication Minimizes Traffic Disruptions
Prefabricated Steel Bridge Systems: Final Report
Rapid Bridge Construction: How to Get There
Rapid Bridge Deck Replacement: A Field Demonstration and Load Test.

The following notable contributions are listed for further information on this new subject:

- TRB 87th Annual Meeting on Construction, Session Highlights, January 2008, Washington, DC.
- FHWA, "Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges," https://www.fhwa.dot.gov/bridge/pubs/07022/chap00.cfm.

A workshop organized by TRB, FHWA, and Caltrans and held in October of 2007 in San Diego, California, had representatives from several state DOTs, FHWA, TRB, researchers, and industry. The publication of the document "2007 FHWA Seismic Accelerated Bridge Construction Workshop Outcomes and Follow-up Activities" has useful suggestions in understanding the practical aspects of ABC.

A Seismic ABC Work Team was organized to focus application efforts by Caltrans. In July of 2008, the team published "Accelerated Bridge Construction Applications in California – A Lessons Learned Report." It documented the recent use of ABC techniques in California.

Statewide Transportation Improvement Program (STIP): The Statewide Transportation Improvement Program (STIP) is a federally required document that provides the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) a listing of all projects that are candidates for federal-aid, or regionally significant projects that are not using federal-aid.

This plan advanced the team's recommendations, detailed ongoing technology transfer activities, and compiled connection details.

The use of the FHWA decision-making matrix is promoted by the state.
Development of the MassDOT Prefabricated Bridge Manual and the 2011 LRFD Manual.
The goal is to create standard specifications for mechanically stabilized earth (MSE) walls, geosynthetic reinforced soil (GRS), continuous flight augering (CFA) piles, geofoam, and micropiles. Precast elements and hybrid bridge systems will become *standard practice.* (Reference Contech Construction Products, Inc.).

Design-Build: In this process, a team bids on and accepts responsibility for the design and construction of a project, streamlining the process.

Construction Manager/General Contractor: States are changing laws and regulations to allow a contractor to be hired during the design process, acting as a consultant to offer innovations and cost-reduction strategies.

Alternative Technical Concepts: By allowing contractors to propose alternatives during the design phase, states can be presented with innovative ideas that save time and money.

High-Friction Surfaces: This safety measure adds a high-friction surface to curves, which make up only 5% of highway miles in the United States, but account for 25% of the fatalities, according to the FWHA.

Intersection and Interchange Geometrics: This explores safety innovations to reduce conflict points between motorists, pedestrians, and bicyclists.

Geospatial Data Collaboration: This innovation explores a cloud-based geographic information system platform that allows data sharing between stakeholders.

Implementing Quality Environmental Documentation: This initiative reduces the size and increases the readability of the National Environmental Policy Act to accelerate project delivery.

Strategic Highway Research Program 2 (SHRP2) National Traffic Incident Management Responder Training: Seeking to reduce the 4.2 billion hours and 2.8 billion gallons of gasoline motorists waste stuck in traffic because of accidents, disabled vehicles, and debris in the road, this initiative offers a national training program for first responders.

3.11 Surges in transportation publications and workshops

The following new publications show an interest in the subject and the popularity of ABC in the United States. These offer a sampling of the many transportation newsletters and journals that have in the last few years featured accelerated construction techniques. The intended users are the decision makers, project managers, and designers.

The **FHWA ABC Manual** discusses the latest technology.
Experience in Design, Fabrication and Erection of Prefabricated Bridge Elements and Systems
2006: Decision-Making Framework for Prefabricated Bridge Elements and Systems
2007: Manual on the Use of Self-Propelled Modular Transporters to Remove and Replace
Bridges 2009: Connection Details for Prefabricated Bridge Elements and Systems

- This wide-ranging program focuses on the idea of:
  - Rapid renewal for highway infrastructure
- Three objectives have been identified to achieve renewal:
  - Perform construction rapidly
  - Cause minimal disruption
  - Produce long-lived facilities
- Project R04: Innovative Bridge Designs for Rapid Renewal
  - Project R04 documents innovative designs in more detail than this manual
  - FHWA manual will complement this work
  - Teams have been coordinating efforts
- Purpose of the Manual
- State of Practice in ABC

3.11.1 Caltrans workshop proposals

- Precast bridge components emulating the performance of cast-in-place structures
- Connection details and components capable of resisting seismic deformations
- Unbonded prestressed columns with recentering characteristics
- Precast segmental columns with energy-absorbing joints
- Seismic protection devices including bearings, dampers, and lock-up devices
- Rocking bridge foundations
- Replaceable bridge components including column plastic hinge regions, shear links, and link beams
- Concrete-filled tubes including steel and fiber-reinforced polymer (FRP) composites
- Disconnected spread footing foundations on poor soils by using piles or soil improvement techniques
- Advanced materials including high-strength concrete, rebar and steel, shape memory alloys, fiber-reinforced engineered cementitious concrete, fiber-reinforced polymer composites, etc.
- Use of fiber-reinforced polymer to rapidly repair column plastic hinge zones
- Rapid postearthquake bridge assessment by using seismic instrumentation

Whatever systems, devices, or components are developed in the upcoming workshop, each will have to be evaluated to consider:

- Postearthquake serviceability
- Postearthquake reparability
- Traffic impacts
- Life-cycle costs
- Constructability
- Maintenance requirements
- Durability
- Reliability
- Ease of future widening and other modifications
- Connection details for seismic regions

3.11.2 Newly developed glass fiber reinforcing bars

This technology could mean an end to damaged steel often caused by hot and humid climates. The glass fiber reinforcing bars, made by German company Schoeck Bauteile GmbH, may mean a longer life-span for concrete structures, in addition to lower maintenance costs. According to the manufacturers, the large fiber content and linear alignment of the fibers are achieved at the pultrusion stage, the manufacturing process that produces continuous lengths of reinforced polymer structural shapes. Helical ribs are also cut into the hardened bars to insure an optimal bond between the rebars and the surrounding concrete.

3.11.3 CASE Tool 5-3: promoting the use of computer software in the structural engineering office for transportation, erection, and assembling impact loads during ABC

The recently developed CASE Tool 5-3 is intended to assist the structural engineering office in the task of managing computers and software. This tool takes a two-level approach.

The first level is to outline concerns and issues related to the use of structural engineering software and computers. The principals and managers in firms can encourage action within each firm to develop management procedures.

Secondly, firms can thoughtfully address current computer/software use as well as issues that should be addressed for effective management. This tool is not intended to provide answers to all of the various related concerns or to be a template for a management policy, but is intended to be a tool for each firm to assess and address its specific needs.

3.12 Continuing education, training and research in ABC

One goal of ABC training and development is to implement standardization as follows:

- Develop guidelines for ABC project inclusion
- Develop typical details and manuals
- Include user costs in analysis

- Encourage innovation
- Provide training and obtain feedback

3.12.1 Trained personnel and training methodology

Training will be required to gradually adopt and grow ABC methods from experience. It is necessary that construction personnel be provided on-the-job training. Certification and training of construction personnel, continuing education of engineers in rapid construction techniques, and construction management will be required. ABC courses at universities are recommended.

Training should cover construction technology tasks such as understanding erection procedures, erection drawings, modern concrete technology, and the use of steel, timber, etc. in bridge construction. Just like engineers require professional engineering licenses to practice in different states, certification requirements need to be introduced for supervisory level of construction personnel. Experience has shown that better training leads to reductions in construction-related congestion and road-user costs, as well as improved work-zone safety and construction cost savings.

It is also necessary that construction personnel be given on-the-job training in the use of any new technology. Training costs at regular intervals need to be included in the overall project budget. FHWA (http://www.fhwa.dot.gov/) and AASHTO Website (info@aashto.org) on the subject serve as reference points for insight into current practices and future plans in accelerated construction. Workshops are being conducted to evaluate constructability. Topics include equipment locations, construction duration, access, and right-of-way and material availability. To resolve constructability issues and any misinterpretation of contract drawings, designers should be consulted before preparation.

3.12.2 Continuing education in design and construction

Rigorous certification requirements need to be introduced for certain levels of construction personnel. Specialized training needs to be provided to technicians, masons, and field labor. The websites made available by the FHWA (http://www.fhwa.dot.gov/bridge/prefab), Transportation Research Board (TRB), National Cooperative Highway Research Program (NCHRP), and others can be helpful in developing and providing training material.

This joint project between MnDOT and will replace the 80-year-old Stillwater Lift Bridge with a new four-lane bridge to connect expressways on both sides of the St. Croix River.

Other benefits are providing a safer, more reliable river crossing, improving traffic safety and easing congestion in the St. Croix Valley, creating jobs, and helping interstate commerce.

MnDOT is working with schools to develop a curriculum to teach students about the new St. Croix River bridge. The STEM (science, technology, engineering, and math) program will make engineers and materials available to classrooms in the St. Croix River Valley and surrounding communities. Other schools are expected to participate.

Awareness of the latest research and study of successful ABC projects will help the client finish the project quickly and allow the project manager and his team to be released from the day-to-day management duties so that the team can move on to another project. The ABC aspects and related implications for projects costing hundreds of millions of dollars are reviewed in the chapters to follow.

3.12.3 FHWA training initiatives and development of ABC provisions

The foremost site on accelerated construction methods and development, the FHWA's Accelerated Construction Technology Transfer Website, offers publications, case studies, and reports: http://www.fhwa.dot.gov/construction/accelerated/.

For a list of projects, refer to the FHWA Website at www.fhwa.dot.gov/bridge/prefab.

A summary of projects completed by selected states is reviewed in this chapter (Tables 5.1–5.7).

For projects constructed to date, see http://wwfhwa.dot.gov/bridge/prefab/projects.htm.

For research reports, see http://www.fhwa.dot.gov/bridge/prefab/research.htm.

For a calendar of upcoming events, see http://www.fhwa.dot.gov/bridge/prefab/research.htm. Highway for Life program: www.fhwa.dot.gov/hfl.

Accelerated Construction Technology Transfer (ACTT) General Information: This page, available at the FHWA Website, offers historic background, discusses workshops around the country, and describes projects and steps taken in several states, including New Jersey, Montana, and California (http://www.fhwa.dot.gov/construction/accelerated/index.cfm).

Workshop 109—Technologies and Connection Details for Accelerated Bridge Construction. This workshop covers technologies and connection details that are available for the development of accelerated bridge construction projects. It includes presentations on accelerated bridge techniques, equipment, and connection details.

New ideas are required to address the dual needs of faster construction and long service life. Some case studies from the United States and Canada offer new ideas on techniques and construction details to achieve the goal of "Get in. Get out. Stay out."

The Transportation Equity Act: Legacy for Users (SAFETEA-LU) establishes the "Highways for LIFE" pilot program with the purpose of promoting innovative technologies and practices for fast construction of efficient and safe highways and bridges.

An "Innovative Bridge Research and Deployment" program is introduced with the purpose of promoting innovative designs, materials, and construction methods in the construction, repair, and rehabilitation of bridges. To be eligible to participate in these two programs, states must submit applications to the United States Secretary of Transportation. For details on the application process, refer to the following websites: www.fhwa.dot.gov/hfl and www.fhwa.dot.gov/bridge.

In 1999, the Transportation Research Board formed Task Force A5T60 to promote accelerated construction in the highway infrastructure.

In 2002, the task force completed two very successful ACTT workshops. Since then, FHWA, in collaboration with the AASHTO Technology Implementation Group, continues the effort and conducts workshops in various states. The task force uses ACTT with the aim of reducing construction time, dramatically saving money, and improving safety and quality by minimizing delays and hazards associated with work zones.

By utilizing the FHWA Accelerated Bridge Construction Manual, the Utah DOT has designed and built several prefabricated bridge decks with concrete barriers cast onto the deck in the fabrication shop. This increases the composite behavior of the superstructure.

FHWA activities are shown on the FHWA ABC Website. For upcoming events, refer to http://www.fhwa.dot.gov/bridge/abc/events.cfm.

The following is a sampling of recent ABC events and conferences:

- International Bridge Conference, June 2011.
- SHRP2 Products and Outcomes Workshop (W-10).

- Missouri/Illinois ABC/PBES Workshop, June 2011.
- MASSDOT Fast 14 Showcase, July 2011.
- NHI *Innovations* Web Conferences.
- Field-Cast UHPC Connections for Prefabricated Bridge Elements and Systems, April 21, 2011.
- To Accelerate Bridge Construction or Not: A Planning Phase Decision Tool for ABC, May 19, 2011 (refer to http://www.nhi.fhwa.dot.gov/resources/webconference/).
- University of Nevada at Reno: FHWA has embarked on a multimillion dollar project through the University of Nevada at Reno to look at ways to increase the resilience of transportation networks.
- University of Nevada at Reno: Test Matrix and Next Generation Bridge Details for ABC. More information can be obtained at http://wolfweb.unr.edu/homepage/saiidi/caltrans/nextgen.html.
- FHWA Program: Risks from Earthquake Damage to Roadway System (REDARS): As part of this project, FHWA's earthquake loss estimation software tool called REDARS is being updated to improve its accuracy in predicting bridge damage and associated costs, and increase its flexibility for wider application. REDARS may be used to identify the costs of bridge closure due to increased congestion and traffic delays, allowing transportation agencies to assess the costs and benefits of designing bridges with improved postearthquake serviceability.
- Inaugural Webinar on the National Center for Accelerated Bridge Construction, March 11, 2011.
- The FHWA EDC Program emphasizes that each day lost is not acceptable, as every day counts.
  - EDC model leadership is required.
  - EDC requires both a top-down and bottom-up approach.
  - EDC partners and stakeholders: notable agencies that benefit from ABC are as follows:
    - AASHTO
    - American Council of Engineering Companies (ACEC)
    - Associated General Contractors of America (AGC)
    - American Public Works Association (APWA)
    - American Road & Transportation Builders Association (ARTBA)
    - Local Technical Assistance Programs (LTAPs) and
    - Tribal Technical Assistance Programs (TTAPs)
    - National Association of County Engineers (NACE)
  - Important topics by the FHWA for EDC:
    - "Agency leadership must prioritize initiatives"
    - "Project delivery personnel must be committed"
    - "Requires mid-level management champions"
    - "Frontlines of project delivery"
  - EDC Innovation Summits:
    - Ten regional summits
    - All State DOTs; Washington, DC; Guam; the U.S. Virgin Islands; and Puerto Rico participated.
- AASHTO Perspective on ABC by Malcolm T. Kerley, P.E., Chief Engineer, VDOT, Chair
- AASHTO Subcommittee on Bridges and Structures, ABC Center Webinar, March 11, 2011
- FHWA—Accelerated Bridge Construction, Final Manual, Publication No. HIF-12-013, November 2011
- Considerations for Durability and Cost of Precast Deck Panels: Bruce Johnson, Oregon DOT
- Accelerated Bridge Construction Research, Design and Practice, FIU, April 20, 2011: Presented by: Carmen Swanwick, SE, UDOT Chief Structural Engineer

3.12.4 Training of contractors and consultants in using PBES

PBES requires different skills and areas of experience, particularly from the construction superintendent. Using contractors with the proper training, equipment, and experience offers the best guarantee of a successful outcome. If such contractors are not locally available, training in PBES and advertising the project to a wider market to get enough qualified bids may be required. Following are some examples of workshops and seminars related to ABC:

- *MnDOT/FHWA Precast Slab System Workshop Summary Report*
  - Precast Post-Tensioned Abutment System and Precast Superstructure for Rapid On-Site Construction
  - A Precast Substructure Design for Standard Bridge Systems
  - Precast Technology and Bridge Design
  - Prefabricated Bridge Elements and Systems: A Winning Idea Fact Sheet
- *TxDOT/FHWA Workshop on Prefabricated Bridge Systems to Eliminate Traffic Disruptions*
  - The mission of this workshop was to advance the implementation of accelerated bridge construction technologies and facilitate the deployment of prefabricated bridge
- *FHWA/AASHTO/TxDOT Precast Concrete Bent Cap Demonstration Workshop*
  - Field Performance of Full Depth Precast Concrete Panels in Bridge Deck Reconstruction
  - Framework for Prefabricated Bridge Elements and Systems (PBES) Decision Making
  - Full-Depth Precast and Precast, Prestressed Concrete Bridge Deck Panels
  - Grouted Connection Tests in Development of Precast Bent Cap System
  - Innovative Prefabrication in Texas Bridges
  - Keep It Moving
  - Laying the Groundwork for Fast Bridge Construction
  - Main Attractions: Prefabricated Bridges
- Seminars at FIU organized by Dr Atorod Azizinamini

One-day workshop presented jointly by the ASCE Philadelphia Section and Temple University and organized by the author on November 22, 2013 on rapid construction and delivery. There was participation from FHWA's Benjamin Beerman and PennDOT in addition to leading fabricators such as Acrow, Hi-Steel, and Jersey Precast along with Temple University. Appendix 9 provides details of TEMPLE-ASCE One Day Course on Rapid Bridge Construction. Other useful references are as follows:

- *Prefabricated Bridge Elements and Systems in Japan and Europe Summary Report*
- *SHRP2 Project R04 Part 2—Everyday Solutions*: Application of SHRP2-Developed Tools in Case Studies by HNTB Corp (February 2012)
- *SHRP2 R04 ABC Demonstration Project #1*. Modular Construction (IADOT). October–November, 2011: 14-day ABC period.

3.12.5 Registration and licensing requirements for bridge engineers

The Structural Engineering Institute (SEI) of ASCE held four symposiums on training and separate licensing for structural engineers. Obviously, there is a direct link between the quality of the bridge products and the level of specialized knowledge in design and construction. Structural engineer qualifications will certainly help and improve report card grades. Several states have made it mandatory for bridge engineers to pass the SEI examination based on courses covering latest developments. All states should consider introducing such licensing regulations.

An interim step is to introduce temporary certifications for 5 years in bridge engineering based on 10 years experience in bridge engineering for engineers who have obtained E.IT, and the P.E. registration by passing NCAA exams. A special engineering examination may be arranged.

3.13 Training in emergency and disaster management

The following steps are recommended:

- Training in ABC methods for emergencies needs to be imparted to bridge engineers to conduct detailed vulnerability assessments and to develop effective security and emergency response plans to cover all eventualities.
- When facing a crisis, how it is handled in the first minutes and hours are crucial. There may not be enough time to write a feasibility report. It needs to be handled with ready-made solutions for the anticipated social and engineering issues. The purpose of the training is to assist engineers in that process.
- Assessment methods should develop immediate and long-term solutions to vulnerabilities and risks exposed during the assessment, as well as provide templates for writing and enacting the emergency response plans.

Future ABC design codes should incorporate and outline procedures to deal with emergencies and to determine what kind of rehabilitation would be needed, on a case-by-case basis (please see the textbook *Bridge and Highway Structure Rehabilitation and Repair* by the author). Roles and responsibilities and responses to both natural and man-made events including internal and external communications need to be defined (for example, when to go public, what to disclose, and what not to say).

The structure's vulnerabilities in a flash flood, earthquake, and tornado need to be identified, and what level of threat they pose needs to be determined. A plan to eliminate the threat or at least mitigate its impact should highlight any system-hardening options available, how and where they can be implemented, and what you should know about them.

Maintaining the most vital element of the nation's critical infrastructure and protecting these resources is a daunting challenge for bridge engineers tasked with protecting public safety and health. Therefore, ABC's innovative approach in resolving emergency situations should be a great help. The advanced methods of communicating, monitoring, and improving operations in transportation networks that are implemented in intelligent transportation systems (ITS) need to be utilized.

An easy-to-follow, five-step process that covers everything we need to know for successful crisis communications and issues management is as follows:

- Planning—why you need to plan, what you need to plan for and against, and how to develop a crisis communications plan and practice to make sure it works and is constantly kept up to date.
- Focus on the Crisis Communications Team: Including how to select team members, allocate responsibilities, and provide relief and construction supervision training.
- How to handle a crisis from the second you are alerted to it until the time it is over and it is safe to resume normal operations.
- Stakeholders, both internal and external, that need to be kept informed if you want to successfully manage the crisis.
- The crisis is over, but you now evaluate how things went. What worked, what didn't work, and what could be improved upon?

A review of case studies, best practices, useful tips and checklists, and real-life examples of critical Dos and Don'ts are normally required for crisis management and communications. Training is all about being ready and is the essential first step in being prepared. There are selected publications in which the following crisis management issues are addressed:

- Security (lessons learned from past disasters)
- Crisis Communications (short-term relief such as preparing evacuations methods, relief, food, and hospital facilities)
- Physical Security Planning and Response for Hospitals and Medical Facilities (includes detailed section on evacuation best practices)
- School Security Handbook (School security for K-12, colleges, and universities)
- Infrastructure Vulnerability Assessment (long-term solutions such as preparing and implementing ABC documents)

3.13.1 Training for design-build project delivery and functional/operational requirements

DBIA spent a year engaging in extensive research and development with owners and industry experts on a one-of-a-kind workshop to walk students through the writing of performance-based requirements.

Under the guidance of skilled facilitators in a brainstorming session, students determined functional/operational requirements, goals and restraints, and the correlation of goals to performance characteristics. At the end of the course, students were able to:

- Describe the role of performance-based requirements in the design-build model and explain the difference between performance-based and design requirements and the benefits of performance-based requirements.
- Employ a process to identify functional requirements and convert them into performance-based requirements.
- Complete a risk assessment based on functional requirements.
- Integrate the functional/performance-based and design requirements into a requirements document for the solicitation of new projects.

3.14 Webinars on ABC at FIU

The Center for Accelerated Bridge Construction (ABC Center), Department of Civil & Environmental Engineering at Florida International University (FIU), Miami, Florida has presented the following webinars. These webinars are organized almost every month by Atorod Azizinamini and are offered by experts and selected practitioners who recently and successfully implemented ABC. The well-designed webinars have the added advantage of offering professional development hours (PDHs) that are acceptable to licensing boards to permit professional practice. Each webinar discussed the latest happenings related to ABC in the United States and abroad (Table 3.1).

THE ABC Center at FIU presented the following webinars that contained the equivalent of 1.0 or more professional development hours (PDH). Each webinar informs attendees about the latest happenings related to ABC in the US and abroad for 10 min (see Table 3.2). For additional webinars not listed, please see FIU Website: www.abc.fiu.edu.

Table 3.1 Recent Webinars on ABC Organized by FIU Offering PDHs

ABC Topic	Speaker and Date	Description
ABC Replacement of a Bridge over Thanksgiving Weekend in Allegheny County, Pennsylvania	Michael Dillon, Allegheny County Department of Public Works, Pittsburgh, Pennsylvania (May 9, 2013)	This project required the superstructure replacement of a bridge over 4 days in November of 2012. The bridge was the only access to five businesses. The business owners agreed to shut down operations over Thanksgiving. This allowed Allegheny County to replace the existing adjacent box structure with a prefabricated steel structure with a grid deck. Other precast elements were used, such as back walls, moment slabs, and abutment caps. The presentation focus is on why ABC was selected for this project, and it includes a description of the project from planning through construction, including costs and lessons learned.
Economical Details over Piers Using Simple-for-Dead-Load and Continuous-for-Live-Load Design—Part 2: ABC Steel Girder Bridges—Simplified Details from Latest Research	Atorod Azizinamini, Professor and Chair, Department of Civil and Environmental Engineering, Florida International University (November 7, 2012)	Simple-for-dead-load and continuous-for-live-load (SDCL) design details at intermediate piers in ABC bridges should provide good long-term performance, be as simple as possible, and be economical. Various details have been used to connect steel girders over the pier using the SDCL system, with economy greatly influenced by those details. Some of the details reflect results of recent research studies and some do not. Recent research results and case studies show that very simple details can be used to apply SDCL in ABC applications. This presentation provides a description of simple SDCL details in ABC steel girder bridges, with supporting research data on the use of SDCL in ABC steel girder bridges. The next presentation will focus on ABC field applications, construction issues, and in-service performance of typical and simplified SDCL details with costs related to these exciting local bridge projects to be highlighted.
ABC Short-Span Low-Volume Bridge Types & Lessons Learned—Part 1: Steel	Bill McEleney, Director National Steel Bridge Alliance (May 26, 2012)	Across the country, the use of accelerated bridge construction (ABC) has proven beneficial for bridge types that range from short to long span, while maintaining traffic flows that range from low to high volume. These projects have provided many lessons. This presentation is the first in a series of three industry presentations on lessons learned from accelerated short-span low-volume bridge construction. It will discuss solutions that can meet the need to replace single- and multispan bridges with total bridge lengths in the 20–140 ft range, and to replace these bridges in a prefabricated and accelerated manner. It will describe details on various steel ABC projects and will focus on ways to further improve the accelerated construction of steel bridges.

Continued

Table 3.1 Recent Webinars on ABC Organized by FIU Offering PDHs—cont'd

ABC Topic	Speaker and Date	Description
ABC Short-Span Low-Volume Bridge Types & Lessons Learned—Part 2: Composites	John P. Busel, Dir. Composites, Growth Initiative, American Composites Manufacturers Association (ACMA) (August 21, 2012)	Across the country, the use of ABC has proven beneficial for bridge types that range from short to long span, while maintaining traffic flows that range from low to high volume. These projects have provided many lessons. This presentation is the second in a series of three industry presentations on lessons learned.
Construction Contractor Series#2: Experiences with ABC Projects in Utah	Eric Wells, Structures/Alternate Procurement Manager, Granite Construction Company, Salt Lake City, Utah (April 12, 2012)	This presentation is the second in the construction contractors series, to discuss what construction contractors really think about ABC. This presentation features a Utah bridge contractor's perspective on ABC, including past ABC projects in Utah. Discussion will include what made the projects attractive, and how they could have been improved.
Recent Durability Performance Results in Closure Joints of Modular Bridge Decks	Z. John Ma, Associate Professor, Department of Civil & Environmental Engineering, University of Tennessee, Knoxville (December 15, 2011)	Cast-in-place concrete closure joints are a potential weak link in prefabricated bridge decks, depending on the design of the reinforcement through the joint and the quality of the concrete mix materials, reinforcement and concrete placement, and concrete curing. This presentation describes research results from NCHRP 10-71, "Cast-in-Place Concrete Connections for Precast Deck Systems," completed last year. The presentation focus is on how to ensure long-term durability with minimum maintenance requirements for closure joints between full-depth precast deck panels and between decked-bulb-tee flanges. In addition to describing reinforcement requirements to ensure structural capacity, the presentation will discuss two concrete mix designs that were tested for durability—one for overnight cure and one for 7-day cure.
Field-Cast UHPC Connections in Full-Depth Precast Bridge Decks	Benjamin A. Graybeal, structural concrete research program manager, FHWA Turner–Fairbank Highway Research Center (October 11, 2011)	The need for robust, constructible connections has hindered the application of full-depth precast decks in spite of their many potential benefits. The use of ultra-high performance concrete (UHPC) simplifies these connection details while simultaneously producing a durable, robust system that eliminates the need for posttensioning. UHPC is a fiber-reinforced, cementitious composite material with mechanical and durability properties that far exceed those traditionally associated with structural concrete. To date, UHPC has been implemented in six bridge reconstruction projects in three states, and more are on the way. This session provides an in-depth discussion of the practical application of field-cast UHPC connections for full-depth precast decks, and will include a discussion on successful deployments and promising concepts now under testing and evaluation.

Table 3.2 Many Lunchtime FIU Webinars on ABC Topics Attended by the Author

Topic	Speaker and Date	Description
ABC and GRS bridge abutments in Ohio	Warren Schlatter, County Engineer, Defiance County, Ohio (April 17, 2013)	Defiance County was an early adopter of geosynthetic reinforced soil (GRS) for bridge abutments. GRS allows the construction of vertical load bearing walls at very reasonable cost and with very rapid construction. The vertical abutments provide an immediate cost savings in reduced superstructure length and cost. Defiance County has also experienced additional cost savings over time as the construction crew gained experience. There are 30 structures in service with GRS abutments and there has been success with construction with county crews and contractors. GRS abutments were used with a variety of superstructure types including adjacent box beams, spread box beams, steel beams, concrete slab, and even an FRP structure.
ABC and Innovative Bridge Construction for Minnesota Local Roads	Christopher Werner, Project Manager, HDR Engineering, Minneapolis-St. Paul, Minnesota (March 21, 2013)	In cooperation with the Minnesota DOT, the Minnesota County engineers Association, the Minnesota local road research board, and the FHWA Minnesota Division office, a number of counties in the state have built accelerated and innovative bridge construction projects on their local roads in the past few years. These projects have included side-by-side precast box beams on sheet pile abutments, mechanically-stabilized earth (MSE) walls with single-line pile abutments, precast inverted tee slab span bridges, large precast box culverts, and three-sided structures. The first two county precast inverted tee beam bridges have been recently constructed based on the groundbreaking work of the Minnesota DOT for this bridge type, and the first Minnesota county bridge with GRS abutments is scheduled to be built this year. Through many domestic local bridge scanning tours with federal, state, and local partners, the featured presentation describes the reasons that Minnesota counties have implemented ABC and innovative bridge construction techniques. The bridge elements, details, and costs related to these exciting local bridge projects are highlighted.
ABC Bridges from a County Perspective	Eugene Calvert, Engineering Supervisor & Marlene Messam, Project Manager, Collier County, Florida (Feb. 14, 2013)	Upgrading structurally deficient and functionally obsolete bridges while maintaining traffic continues to be a significant challenge as the nation's bridge inventory ages. Many of these substandard bridges are owned by local governments. But how do counties address the significant challenges they face in replacing their deficient inventory? Can ABC provide a means to address these challenges? This featured presentation discusses ABC bridges from a county perspective and includes examples of how counties are using ABC to replace their deficient bridges.

Continued

Table 3.2 Many Lunchtime FIU Webinars on ABC Topics Attended by the Author—cont'd

Topic	Speaker and Date	Description
Work-Zone Road User Costs—Comparison Between ABC and Conventional Construction	Nathaniel Coley, Engineer Office of Transportation Performance Management, FHWA, Washington, DC (January 10, 2013)	ABC offers many advantages over conventional bridge construction. Those advantages include reduced traffic impacts, onsite construction time, environmental impacts, and life-cycle costs; and improved work-zone safety, site constructability, material quality, and product durability. Most bridge owners are pursuing ABC to reduce onsite construction time and traffic impacts relative to conventional bridge construction. Although the reason for using ABC is typically to reduce traffic impacts, bridge owners in general don't currently include costs such as those related to how the construction is impacting motorists in their decision-making process on whether ABC is the best solution when considering bridge replacements. When mobility impacts are not quantified, direct cost comparisons between ABC and conventional construction are not apples-to-apples comparisons. The presentation compares work-zone road user costs for ABC and conventional bridge construction, and provides a simplified description of how to calculate them. Resources for in-depth evaluations will be provided.
Economical Details over Piers Using Simple-for-Dead-Load & Continuous for-Live-Load Design—Part 3: ABC Steel Girder Bridges Field Application of Simplified & Typical Details	Wayne J. Seger, State Bridge Engineer, Tennessee DOT and Mark J. Traynowicz, State Bridge Engineer, Nebraska Dept. of Roads (December 11, 2012)	Simple-for-dead-load and continuous-for-live-load (SDCL) design details at intermediate piers in ABC bridges should provide good long-term performance, be as simple as possible, and be economical. Various details have been used to connect steel girders over the pier using the SDCL system, with economy greatly influenced by those details. Recent research results and case studies show that those details can be simplified to provide optimum continuity for live load over piers. This presentation is on the use of SDCL design details over piers in ABC steel girder bridges. Last month's presentation described simplified details for continuity over piers based on the latest research. This presentation will focus on ABC field applications, construction issues, and in-service performance of simplified and typical SDCL details in Nebraska and Tennessee, respectively.
Economical Details over Piers Using Simple-for-Dead-Load & Continuous-for-Live-Load Design Part 1: ABC Concrete Girder Bridges	Francesco (Frank) M Russo, Senior Technical Manager, Bridges, Michael Baker Jr., Inc., Philadelphia, PA (October 18, 2012)	Simple-for-dead-load and continuous-for-live-load design details at intermediate piers in ABC bridges should provide good long-term performance, be as simple as possible, and be economical. This construction process has been used with prestressed concrete girder bridges built in a conventional manner for years. Various publications cover the technical aspects of designing for continuous behavior, yet there is little guidance on how these design and construction issues are integrated into an ABC project. This presentation discusses the advantages and disadvantages of achieving structural continuity in multispan ABC bridges, discusses continuous bridge continuity options that are nonstructural, and provides case studies of ABC continuity details adopted by various agencies in the recent past. Guidance on LRFD application to continuous beam design and sample details used in case study bridges will be provided.

ABC Short-Span Low-Volume Bridge Types & Lessons Learned—Part 3: Concrete	William Nickas, Managing Director, Transportation Services, Precast/Prestressed Concrete Institute (PCI) (September 13, 2012) Thursday, September 13, 2012	Across the country, the use of ABC has proven beneficial for bridge types that range from short to long span, while maintaining traffic flows that range from low to high volume. These projects have provided many lessons. This presentation is the third in a series of three industry presentations on lessons learned from accelerated short-span low-volume bridge construction. It will discuss solutions that can meet the need to replace single and multi-span bridges with total bridge lengths in the 20–140 ft range, and to replace these bridges in a prefabricated and accelerated manner. It will describe details on various concrete ABC projects and will focus on ways to further improve the accelerated construction of concrete bridges.
2012 Domestic Scan On ABC Connections: Findings & Recommendations	Alexander K. Bardow, State Bridge Engineer, Massachusetts DOT (June 14, 2012)	This presentation provides an overview of the recently completed ABC Domestic Scan 11-02, "Best Practices Regarding Performance of ABC Connections in Bridges Subjected To Multi-Hazard and Extreme Events," conducted as part of the NCHRP Project 20–68A, "U.S. Domestic Scan Program" for the National Academies. The purpose of the scan was to identify domestically used ABC connection details that perform well under extreme event loading, such as those experienced by bridges subjected to waves and tidal or storm-surges, seismic events, and other large lateral forces. On the East Coast, the scan team visited MassDOT and the Florida DOT, and also had web meetings with the Texas DOT, MCEER at SUNY Buffalo, and the South Carolina DOT. On the West Coast, the team visited the Washington State DOT and the Nevada DOT, with Nevada and California DOT jointly coordinating activities. Findings and recommendations will be discussed.
Construction Contractor Series#3: Experiences with ABC Projects in Massachusetts	Jack Harney, Director of Operations, J.F. White Contracting Co. Boston, Massachusetts (May 10, 2012)	This presentation is the third in the three-part Construction Contractors Series, to discuss what construction contractors really think about ABC. This presentation features a Massachusetts bridge contractor's perspective on ABC, including past ABC projects in Massachusetts. Discussion will include what made those projects attractive, and how they could have been improved.
Construction Contractor Series#1: Experiences with ABC Projects in Texas	William G. Duguay, Houston Area Manager, J.D. Abrams L.P., Houston, Texas (March 15, 2012)	So, what do construction contractors really think about ABC? This presentation features a Texas bridge contractor's perspective on ABC, including past ABC projects in Texas. Discussion will include what made those projects attractive, and how they could have been improved.

Continued

Table 3.2 Many Lunchtime FIU Webinars on ABC Topics Attended by the Author—cont'd

Topic	Speaker and Date	Description
Part 2: Everyday Solutions: Application of SHRP2-Developed Tools in Case Studies	Bala Sivakumar, Co-Principal Investigator, SHRP2 R04, HNTB, SHRP2 & FHWA Highways for LIFE (HfL) Program (Feb. 16, 2012)	The January 2012 presentation (Part 1) discussed the Strategic Highway Research Program 2 (SHRP2) ABC toolbox that was developed under R04, "Innovative Bridge Designs for Rapid Renewal." This presentation describes how the toolbox was used in two bridge construction pilot projects. The first project, built in 2011, was the U.S. 6 Bridge over Keg Creek in Iowa, in which the bridge was replaced with a 14-day closure using prefabricated elements. The second project, to be completed in 2012, is the I-84 Bridge over Dingle Ridge Road in New York, in which two adjacent bridges carrying I-84 will be laterally slid into place each over a weekend. Learn how the standard plans and details in the toolbox were used to ensure success on these projects.
Everyday Solutions: ABC Standard Designs from SHRP2	Bala Sivakumar, Co-Principal Investigator, SHRP2 R04 Vice President of Special Bridge Projects, HNTB (January 17, 2012)	The SHRP2 Renewal Area is developing ABC products that help bridge owners upgrade their aging bridges rapidly, with minimum disruption, to last longer, and to do so consistently throughout the nation. A major project to develop such products is R04, "Innovative Bridge Designs for Rapid Renewal." The presentation focus is on the ABC toolbox that has been developed in this project. The toolbox includes standard plans and details for designs that are as light, simple, and easy as possible to design, fabricate, transport, and erect. Spans range from 40 to 140 ft for one-piece installation, and up to 200 ft for multiple pieces to be assembled at the site. The standard plans and details for prefabricated modular abutments, piers, and superstructures will be discussed. These modular sections were developed for erection with conventional equipment, including above-deck carriers and launching systems. The presentation will also include a design example using these products.
Full-Depth Prefabricated Bridge Deck Options for Durability and Cost	Bruce Johnson, Oregon DOT, Chair, AASHTO Technical Committee for Bridge Preservation (Nov. 17, 2011)	Some states are replacing deteriorated bridge decks with full-depth prefabricated decks to accelerate on site construction and minimize traffic impacts. Because prefabricated decks are typically erected as segments that must be joined together, the connections are the critical factor for ensuring good, long-term performance and achieving an economical solution. This presentation describes design, construction, and maintenance details that have been developed to achieve good, long-term performance of full-depth prefabricated bridge decks. Comparisons are made between some of the various details considered for a project in Oregon, with advantages and disadvantages that were identified for each.

3.15 Seminar on ABC at Philadelphia Structural Engineering Institute of ASCE

The author made a presentation entitled *Modern Repair & Rehab Techniques for Steel & Concrete*, in December of 2010, on current practices, ongoing research, and future developments for bridge maintenance (Figures 3.4 and 3.5). A synthesis of bridge failures was presented to illustrate the points. The importance of live-load deflections and its impact on the design of girders and cross-frames was outlined, as a solid understanding of this aspect is critical to proper repairs. AASHTO LRFD procedures as modified by PennDOT DM-4, as well as inspection and rating procedures, were discussed in detail.

The author also led a discussion regarding methods to reduce important life-cycle costs through effective rehabilitation and repair strategies, and to extend the lifespan of these taxpayer investments. The meeting was well attended and there were thoughtful questions raised afterward that extended the discussion.

3.15.1 Training contractors in using innovative technology

Rather than just selecting contractors to perform the job only based on lowest bid amounts, contractors should also be prequalified based on their capacity to handle new technology and by their familiarity with new techniques. A written examination can be introduced for prequalification of contractors and consultants on special projects. To promote ABC further, training of engineers employed by both the consultants and contractors in this specialized discipline is needed.

3.15.2 One day ABC workshop at Temple University

ASCE Philadelphia Section sponsored a joint technical meeting in November of 2013. It was attended by practicing engineers and senior students. The full-day presentations were addressed by Benjamin

FIGURE 3.5

Author presents repair and rehab techniques for bridges at an SEI meeting.

Beerman, FHWA In charge of EDC Program, PennDOT expert of LRFD software, Chief Engineers of Acrow, High Steel and Jersey Precast in addition to Professors of Temple University. Appendix 6 lists the details of the program, which included the latest development in ABC.

3.16 Design-Build Institute of America's training programs in promoting design-build methods

These "core courses" are required of all candidates of the Designated Design-Build Professional certification program. By attending the courses, the team is now ready to move on with a clear understanding of managing the design-build process (Table 3.3).

3.17 The need for a national center devoted to ABC

A workshop was held on November 22, 2010, at Florida International University, to brainstorm the creation of a national center devoted for the promotion of ABC. A series of presentations were made by experts in the subject. Details are as follows:

- *Use of ABC by Counties*—Eugene Calvert, National Association of County Engineers (NACE)
- *FHWA Every Day Counts (EDC) ABC Initiatives*—Claude Napier, FHWA
- *Moving ABC Technology Forward*—Sandra Larson, Iowa DOT
- *SHRP2 and Upcoming Products, Helping the Bridge Industry*—Monica Starnes, TRB SHRP2
- *Bridge Construction Industry*—Bill Duguay, J.D. Abrams, L.P.
- *Prefabricators & Supplier Industry: Concrete*—Sue Lane, National Concrete Bridge Council (NCBC)
- *Prefabricators & Supplier Industry: Steel*—Bill McEleney, National Steel Bridge Alliance (NSBA)
- *Utah DOT ABC Program*—Carmen Swanwick, UDOT Chief Structural Engineer
- *Accelerated Bridge Construction*: A State Perspective—Paul Liles, Vice Chair, AASHTO
- *Use of ABC by the States*—Mal Kerley, Chair of the AASHTO Subcommittee on Bridges and Structures (SCOBS)

The list of potential activities was divided into immediate, short-term, and long-term categories.

3.18 Research challenges for developing ABC technology

Earlier chapters discussed the needs and role of research to overcome the constraints that are withholding a wider use of ABC. Research topics can be linked to the many innovative methods recently introduced by the joint efforts of research departments and construction management teams of contractors and consultants. This chapter reviews the innovative methods introduced in practice so that they can be explained by research. Research topics are identified and challenges are addressed in specific areas by the AASHTO Technical Committee (T-4) and at international conferences.

Table 3.3 Core Course Required for Designated Design-Build Professional Certification Program

Core Course No.	Title	Course Description
1	Fundamentals of Project Delivery	A general overview of the attributes of all the major project delivery systems, procurement methodologies, and contracting approaches. It sets the stage for a clear understanding of managing the design-build process.
2	Principles of Design-Build Project Delivery	The use of design-build focusing on essential concepts and characteristics, as well as critical elements of the RFQ/RFP process and overall project management. It is an interactive, problem-solving course where students can take part in a structured, team-learning environment.
3	Design-Build Contracts and Risk Management	Applying effective contracting language as well as insurance, bonding, and surety products and strategies to successful design-build project delivery. Key issues relevant to public and private sector owners and design-build entity teams are addressed for anyone utilizing integrated project delivery. The course emphasizes providing relevant legal, contracting, insurance and risk management knowledge, and risk mitigation measures.
4	Post-Award Design-Build	An overview of the construction and design-build contract management processes that are important as the construction phase ramps up. Discussion includes typical project schedules and possible risk areas and ways to avoid delays, the design–construction interface, and the responsibilities of each party (designer, builder, contract manager, and user) in a design-build contract. In addition, the course includes a basic overview of the commissioning, testing, and turnover phase of work.
5	Design Management Fundamentals	Effective integration of the distinctly different design and construction processes is a fundamental aspect associated with successful management of design within an integrated delivery framework, along with DBIA's *Design Management Guide*.
6	Super-Charged Source Selection	Where cost is not the sole criterion, the selection process varies dramatically from traditional design-bid-build practices. This course includes an overview of the two-phase design-build source selection process, to identify the most highly qualified firms, as well as the final down-select to choose the ultimate winner. It describes the key elements involved in qualifying a firm during phase one source selection and describes the steps involved in a two-phase selection and the key actions necessary to ensure success. It also discusses the identification of the typical components of a quest for qualifications documents, the selection of key members needed for an effective evaluation team, the determination of appropriate evaluation factors and processes for the project, and the assessment of the appropriate number of evaluation factors for a particular project. Additionally, the course also describes various methods for scoring proposals, including numerical, color scoring, or adjectival rating.

Continued

Table 3.3 Core Course Required for Designated Design-Build Professional Certification Program—cont'd

Core Course No.	Title	Course Description
7	Conceptual Estimating	The fundamentals of conceptual estimating, assessing risk, and calculating costs before the designs are complete. This course describes the role of the estimator in design-build, the various influences affecting building costs, the various types of estimates, how estimates are organized using standard estimating formats, how to use an estimating manual, how unit prices are developed, the fundamental concepts of value engineering, how to manage and control costs throughout the design process, and the various checks and balances needed to ensure the reliability of the estimate.
8	Design-Build Sustainability	Explains the interrelationship of the design-build delivery method and sustainability using the collaborative process, as well as how to define and document green (sustainable) project goals, understand contractual and risk management issues specifically related to sustainability and design-build, and set up measurable tracking tools to monitor the success of the design-build sustainable project.
9	Certification Exam Prep Course	Course content provides an overview of concepts learned in DBIA's four core courses, with an emphasis on the eight domain areas covered in the examination: • Project delivery • General attributes of design-build • Project team organization • Procurement • Estimating/specifying • Contracts and legal • Project management • Ethics/professionalism
10	Performance Requirements: The Key to Effective RFPs	
11	High Performance Contracting	Successful motivation requires a well-written contract that provides appropriate awards and incentives. In traditional design-bid-build, contracts often contemplate only failure, with provisions and clauses that address what the adverse consequences will be once failure occurs. This presumption of failure results in contracts that do not contemplate how the contracting parties might appropriately reward one another for success and excellent performance.

3.18.1 Important activities/areas of research

ABC technology is developing, and, due to its multiple applications research, will be needed to resolve outstanding issues. The following research areas are suggested:

- **Implementation and further development of innovative construction methods:** Development of prefabricated seismically resistant systems, including substructures
- **Maintenance Aspects:** Prescribing appropriate cost-effective, durable, preventive maintenance measures and rehabilitation methods for bridge components. It requires the development of maintenance needs, accessibility, repairability, and inspection criteria
- **Identification of transportation and erection issues** including loads and equipment, total bridge movement systems such as self-propelled modular transporter (SPMT), launching, etc.
- **Cost and risk analysis:** Implementation and further development of cost analysis and risk assessment
- **Quality Assurance:** Development of quality assurance measures for accelerated techniques for superstructure and substructure construction, development of more efficient modular sections, and implementation of and further development of contracting strategies that encourage speed and quality
- **Optimized structural systems:** Benefit/cost studies of these optimized structural systems (materials, details, components, structures, and foundations). Include assessment of real and perceived barriers to deployment of the various elements of optimized structural systems.
- Identification of technical and cultural barriers, both real and perceived, if any
- Establishment of a database to track accelerated bridge and highway structures and **s**ubstructures construction to demonstrate and document success, including costs
- **Connection details:** Implementation and further development of rapidly assembled connection details and joints that are constructible, durable, and repairable
- Implementation and further development of design considerations for the hardening of existing structures and rapid recovery after disasters (natural and man-made)
- **Monitoring:** Identification of the available technology for monitoring structures and evaluation of the sensitivity of techniques (including dynamic monitoring to assess condition). Also include methods to monitor foundations and detect scour, to protect and/or strengthen foundations against scour, earthquake, and impact damage; identification of the types of structures/parts of structures where enhanced monitoring is needed and is most promising
- Active and structured dissemination of information on available technologies and successful accelerated bridge construction projects to both decision-makers and designers; identification of the most useful data and information to be collected
- Deployment of the most promising technologies as demonstrations
- Development of recommended revisions to the AASHTO condition evaluation manuals
- Development of automated data collection and reporting
- Development of interpreting protocols and damage models using the data collected by the systems
- Evaluation of current visual methods and recommendation of improvements
- Evaluation of cost/benefit of monitoring/assessment systems

  Study of the implications of security and traffic management systems
  - *Bridge decks*: Including quantification of the impact of increased traffic volume and loads, nondestructive tests, methods for protection against and extraction of salt ion intrusion, and new materials and techniques for deck construction and repairs

- *Main load carrying members*: Including girder/main member repair and strengthening methods, methods to eliminate expansion joints and bearings, and corrosion mitigation techniques, including coatings
- *Substructures*: Including methods for corrosion protection and strengthening of piers and abutments
- *Foundations*: to modify soil (including liquefaction mitigation), to protect salt-water foundations against corrosion (including identification of aggressive environments), and to determine suitable existing foundations for proposed rehabilitation or widening in terms of geometry, integrity and response and soil-structure interaction,
- Identification of methods to accelerate construction of bridge foundations and earthwork and the demonstrated sources of construction delays.
- *New materials:* Structural systems must utilize existing and new materials more efficiently in terms of safety, durability, and economy. However, research is needed to better characterize their properties and optimize their use, and develop efficient design and construction systems, standards, and details. Characterization and optimization of material properties (including life-cycle performance) for both existing and newer materials include:
- Traditional, high, and ultrahigh performance concretes
- Traditional, high, and ultrahigh performance steels (including weld consumables and corrosion-resistant steels)
- FRP composite materials
- Geomaterials (including more accurate characterization on in situ soil conditions), geosynthetic products, and ground improvement techniques
- Other new (perhaps yet unidentified) materials
- Optimization of geotechnical and structural systems for safety, durability, and cost based on optimized materials and systems
- Development of appropriate limit-state criteria for the use of these materials, details, components, and structures for adoption into the LRFD Specifications
- Development of reliability-based engineering design properties for soil and rock
- Implementation of advanced materials and continuation of materials research, e.g., high-performance materials, materials durability, lightweight concrete to provide lower self-weight for larger components, etc.
- *Anticipated outcome*: In the short term, monitoring devices must be identified to determine the optimum time to apply the preservation methods. In the midterm, we should see the implementation of specifications, guidelines, and trial applications leading to deployment of the most effective existing methods, and development of the most promising emerging preservation methods. In the long term, the goal is deployment of the most promising emerging preservation methods.

3.18.2 Research issues

The following items need to be considered:

- Obtaining senior leadership involvement
- Evaluating project risks
- Defining the scope, schedule, and budget
- Identifying the procurement method

- Prescriptive projects: gaining experience
- Design-bid-build, construction manager/general contractor (CM/GC)
- Better project performance: innovations led by contractor
- Educating and communicating with industry
- Implementing standardization
- Improving based on lessons learned

Project evaluation: The factors that need to be addressed in planning are scope, schedule, budget, quality, risk, communications, and procurement.

Implementation of standards;

- Develop guidelines for ABC project inclusion
- Develop typical details and manuals
- Include user costs in analysis
- Encourage innovation
- Provide training and obtain feedback

Different types of bridges: For each of these bridge types, there are different techniques and research continues on the application of ABC for these scenarios:

- Precast deck replacement only on existing footprint
- Prefabricated superstructure replacement on existing footprint
- Complete bridge replacement on existing footprint using preassembled bridges
- Complete bridge replacement on a new footprint using preassembled bridges
- Widening of bridges using prefabricated techniques

3.18.3 Continued research on ABC

Based in Madison, Wisconsin, the Midwest Regional University Transportation Center began, in August, a study on accelerating bridge construction. A 1-year study by Sam Salem of the University of Cincinnati includes surveys of all 50 states and a close study of Ohio's efforts. See the project description at http://www.mrutc.org/research/0504/index.htm.

Research on seismic resistances: The National Earthquake Hazard Reduction Program (NEHRP) was initiated in 1977. The ground shaking maps produced by USGS are extensively used in infrastructure design and assessment. In addition to worldwide research in the countries affected by earthquakes, earthquake engineering centers and many universities in the United States are actively engaged in the development of models and technologies for their geographic regions. These institutions include:

- The Pacific Earthquake Engineering Research Center (PEER)
- The Multi-hazard Center on Earthquake Engineering Research (MCEER)
- The Mid-America Research Center (MAE)
- The Earthquake Engineering Research Institute (EERI) of California
- The federal- and state-funded research projects at many universities

Progress in technology: The traditional code-based approach is now transformed to a performance-based approach. The seismic design of infrastructure is expected to achieve performance goals geared toward life safety and toward functionality and rapid recovery after an earthquake event.

Component fit-up requirements: The fabricator and erector shall construct the bridge in keeping with the AASHTO Bridge Construction Specifications requirement that "fit-up shall be assumed to be performed under the no-load condition."

Selecting bolt splice locations: Some flexibility in splice locations and cross-frame length and unavoidable variations in span dimensions or member sizes may be permitted, for quick construction. Factory-made oversize holes are preferred.

Uplift at girder supports: Curved and skew bridges require special attention such as uplift at supports, achieving cambers, and reducing differential deflections between girders during erection.

3.18.4 Role of post-design activities prior to construction

To expedite the construction schedule, the designer or his representative should be available at all times during construction. The resident engineer at the site may answer requests for information (RFIs).

The shop drawing preparation and review process needs to be improved and made more efficient. To save review time and avoid resubmission and to improve the quality of shop drawings, the consultant/designer should be consulted before the preparation and submission of shop drawings. The contractor must hold meetings with the consultant/designer early to resolve any constructability issues and to avoid any misinterpretation of drawings.

The contractor should be familiar with AASHTO recommendations on preparation of shop drawings. The erector should develop an erection plan substantiated with a written description of each step, erection drawings and calculations of stability, erection stress, residual stress, and deflections. Calculations should be performed and checked by Registered Professional Engineers.

3.18.5 Constructability review

Fabrication and erection feasibility, construction sequencing, material availability and transport, site accessibility, and the construction schedule will be addressed. A constructability review will be done during design and quality assurance/quality control (QA/QC) review prior to approval of drawings and construction specifications.

3.18.6 Constructability planning

Each of the following items shall be evaluated to ensure constructability and to minimize or eliminate "surprises."

- Material availability at reasonable cost
- Fabrication and erection requirements
- Site accessibility and material transportability
- Erection feasibility
- Construction risk
- Effect of the selected construction alternate on the project
- Construction sequencing of different operations
- Environmental impact of proposed construction method (including lead-based paint issues)
- Impact on activities that are on the critical path in the construction schedule

3.18.7 Financial incentives

These will be provided for:

- Tools and techniques to promote state-of-the-art technology
- New manufacture processes
- Striving for higher standards and quality performance
- Improved safety
- Faster construction and temporary staging to reduce traffic

3.18.8 Further research topics

- Construction Schedules for ABC

  Reduction in the duration of construction schedule is the most important benefit of using ABC.
- On a given superstructure replacement project, a comparative study between conventional construction of the superstructure with the following ABC methods is required, to appreciate the differences in construction time:
  - Identify the construction season and months in a given year for the allowable field work window (for bridge sites that are subjected to extreme weather).
  - Identify activities on the critical path when using **prefabrication and SPMT** method and with Design-Build management. Compare overall duration of construction with Design-Bid-Build Method.
  - Identify activities on the critical path when using **lateral slide-in** method with temporary bents and with Design-Build management. Compare overall duration of construction with Design-Bid-Build Method.

    On a given **substructure and superstructure replacement** project, a comparative study between conventional construction of the substructure and superstructure with the following ABC methods is required, to appreciate the differences in construction time:
  - Identify activities on the critical path when using prefabricated abutment wall components and precast pier columns and caps. Can the new abutments be constructed prior to the demolition of old abutments?
  - Does the existing foundation need to be removed before constructing new foundations, if pile driving is required?

3.18.9 Contract clauses for ABC

A sample set of contract clauses between the owner and contractor for the prefabrication and SPMT method and lateral slide-in method for projects completed is required. What incentives are given for completion in time and penalties for any delay?

3.18.10 Need for special provisions in construction specifications

A sample set of special provisions (for detailed construction method) as approved by the owner for the prefabrication and SPMT method and **lateral slide-in method** for projects completed, is required.

3.19 Conclusions on identifying the ways and means to promote ABC structural systems

For rapid construction, the three main factors are men, materials, and machinery. Therefore training of engineers in ABC, research on new materials and introducing innovative construction techniques and machinery, will be necessary to achieve the goals.

Due to the practical importance of ABC, many suggestions and recommendations can be presented here:

Bridge rating procedures to identify deficient bridges and setting up priorities to fix them were reviewed. Structural health monitoring methods using remote sensors will help to prioritize bridges for rehabilitation.

ABC planning, analysis, and implementation methods vary for each of the structural systems and lead to many diverse applications for small, medium, and long spans, each of which has its own unique construction techniques. ABC should apply to the majority of construction scenarios.

The role of the transportation agency in patronizing and promoting ABC is critical. The roles of the ABC team (including the consultant and specialized subconsultants) come next for introducing innovations in design and field connections.

Preparing an evaluation matrix for selecting the type of fix or replacement is helpful.

The key factors dictating a particular type of delivery method include time restraints, risk, budget, and level of quality. Rapid constructability requirements (such as those for erection) need to be met, since most accidents occur during bridge construction.

Preventive measures in construction to prevent failures need to be introduced.

3.19.1 Important activities/areas of research are described

Innovative techniques need to be made more popular and adopted as routine bridge construction. Certain improvements for economical design include the following:

- An upgrading of most modern construction equipment is required.
- Current plan preparation and presentation should reflect ABC.
- Payment and accounting of pay items need to be accelerated.
- Utilization of arching action in deck slabs: There is reserve strength that is being neglected.
- Deck overlays for riding surface quality: Latex Modified Concrete, corrosion inhibitor aggregate concrete or Hi-friction Skid-resistant Polymer Overlay may be used.
- Bridge deck expansion joints for precast deck units.
- Compliance with permitting regulations: Environmental permits may hold up the start of construction.
- Insurance against risk and liabilities
- Utility coordination**:** Outside agencies can delay construction.

ABC applications to railway bridges: The scope of work is different from that of highway bridges and must be carefully considered.

FHWA initiatives: The listed items should lead to the development of more robust ABC provisions.

Training: Training normally follows research. Training programs are discussed in another chapter. There is an urgent need to train bridge engineers in ABC through continuing education programs. FIU and ASCE webinars have taken a lead in that direction. There is a need to set up a national ABC Center to promote ABC due to the economic benefits.

Web-based training modules for ABC and rapid delivery construction projects (such as using slide-in bridge construction) need to be promoted.

FHWA, TRB, ASCE, FIU, Iowa State University, and some other universities and states have taken the lead in this respect.

Research: A review of research challenges from the AASHTO Subcommittee (T-4) on the developing subject shows many emerging areas that need further development. The many initiatives taken by New Jersey were presented by the author at an FHWA Conference. Project management, improved coordination, and communication skills need to be researched, so that ABC methods can be made more economical. A comprehensive construction code that spells out practical steps based on past experience for a refined and rapid type of construction needs to be developed.

Research topics can best be sponsored by each state at universities and research departments with adequate facilities.

Innovative techniques in ABC that require research are described in Chapter 4.

The need exists both in new construction and structure rehabilitation for improved and optimized systems and standards for geotechnical constructions and foundations. Substructures and superstructures can reduce cost, increase standardization, accelerate construction, and result in longer-lasting, low-maintenance bridge and highway structures.

3.19.2 Constraints in implementing ABC

It is easier said than done. Experience is the best teacher. Following constraints need attention:

- MPT, approach slab construction, permits and utility relocation, etc. are unavoidable constraints and would be on a critical path for early completion.
- Contractors in general have trained technicians in formwork and cast-in-place construction and new training in ABC is required.
- The manufacturing nature of precast products creates a proprietary system and monopolistic environment, which may lead to unemployment of some number of construction workers.
- Overemphasis of incentives/disincentives can pressure the contractor into adopting unrealistic schedules at the expense of quality control.
- To make above recommendations to happen on a large scale, incentives may need to be given to the construction and design staff.

NOTE: Bibliography for this chapter is listed at the end of the chapters in Appendix 1. A list of Bridge Inspection Terminology and Sufficiency Ratings used by PennDOT are given in Appendix 3.

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CHAPTER

Innovative ABC Techniques

4

4.1 Maintaining the right-of-way philosophy with accelerated bridge construction

There has to be rewards to promote innovation and encourage the undertaking of some risk. This chapter addresses the philosophy of maintaining the right of way at all times and by providing reconstruction at the earliest as physically possible. The most recent initiatives and innovation techniques promoted by federal agencies and states are described. Progress made in the use of new construction materials and new deck overlays is discussed. Materials, prefabrication, training, construction equipment, and early warning systems can best meet the objectives of accelerated bridge construction (ABC). Teams need to carry out a feasibility study when selecting a bridge for ABC. A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2 ABC.

Chapter 3 has illustrated a network flow diagram (Figure 3.1) to help with conducting the study. The use of nanotechnology to reveal cracks and corrosion, provide photographic evidence of defects, and help with remote sensing technologies in rapid bridge inspection and structural health monitoring (SHM).

There seems to be a revolution in modern concrete technology and in the precasting industry. The new concrete materials are composed of high-strength materials, thereby minimizing the dependence on the diminishing steel supply. The long list of concretes includes high-performance concrete (HPC), ultra-HPC (UHPC), fiber-reinforced polymer (FRP) concrete, ultra high-performance fiber-reinforced concrete (HPFRC), carbon FRP (CFRP) concrete, and glass FRP (GFRP) concrete.

Examples of proprietary bridge systems include robotic steel beam assembly; robotics adds a new dimension of structural steel fabrication and erection.

4.1.1 The need to keep bridges and highways functional

Although public buildings are generally not owned by individuals, the road belongs to the users.

A local road or the street, which gives a house an address, has always been a basic necessity in everyone's life. It leads to your "castle" at all times and access should be easy enough and not restricted at any time.

The right of way is more than a privilege, it is a necessity. It connects your house through a network of highways to the rest of the country all the time. To reiterate, the simple daily needs served by roads and bridges can be defined as follows:

- Commuting to work
- Taking our children to school in school buses
- Using in case of emergencies by ambulances and fire engines
- Supplying water supply, power, and sewage disposal pipelines
- Shopping

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00004-6

- Delivering mail
- Providing for social needs and survival.

4.1.2 Responsibility of transportation engineers

Geographically, the street places your house on the world's map; without proper access, your house may not be of much use. Public transportation and the automobile industry rely on the right of way. Therefore the road is as important as the house itself. Both need to be maintained and kept in good condition. This need-based phenomenon is prevalent the world over. It is the transportation engineer's duty to keep it open.

In addition, one of our major investments is purchasing a car. Without full access to a highway, we lose our important investment. We pay taxes for using the transport facilities and always take it for granted that our taxes are at work. Hence, roads and bridges should be on the hot list to keep them open in a timely manner, which can only be done by adopting ABC options.

It appears that there are "too many fingers in the construction pie" in the process of making the use of bridges by the public possible. The following is the administrative breakdown of organizations and the many vested interests for construction and maintenance. They directly or indirectly call the shots:

1. Transportation secretary and congressional transportation committees, who make the policies
2. Federal organizations such as FHWA and AASHTO, who frame design codes and construction specifications
3. State departments of transportation, who also frame design codes and construction specifications
4. District and local governments, who are the local administrators
5. The Environmental Protection Agency (EPA), for issuing construction permits
6. Traffic police for night construction, long and wide load permits, and weight permits
7. Licensing boards of professional engineers authorizing the signing and sealing of construction drawings and documents
8. Consulting engineer organizations like American Society of Civil Engineers (ASCE) and Structural Engineering Institute (SEI) offering training
9. Research departments and universities for promoting research
10. Contractor's organizations such as the Design-Build Institute of America
11. Suppliers of construction materials and proprietary items
12. Construction equipment suppliers
13. Utility companies such as power supply, water boards, telephone, cable, etc., who use highways and bridges
14. Insurance companies, accountants, and lawyers who support the engineers

On a large construction project, for example, an inventory of accounts paid and payments made to individuals would show the wide variety of people involved in finishing the job either big or small.

The system and set up is not likely to change but we have to see how best we fit in, for the good of the community and by applying the best of our training. There is an old saying that "the rules of the game cannot be changed for you." ABC realizes that time is important and not to forget that "time and tide wait for no one."

4.1.3 Teamwork of engineering disciplines

Bridge engineering is not just the domain of structural engineers. There are many other disciplines involved, members of which serve on the team to make it happen, namely:

- Traffic engineering for traffic counts and road signs
- Geotechnical engineering for soil investigation
- Construction engineering for site staff and supplying the labor
- Mechanical engineering for cranes and construction equipment
- Electrical engineering for bridge lighting and sensors
- Other supporting disciplines like software engineering

Through their objective of "building a better world," engineers are supposed to manage, maneuver, manufacture, and bring together multiple disciplines (i.e., they have the capacity to bring together a host of other disciplines to achieve results). The construction industry provides jobs and livelihoods to millions of workers not just in America but worldwide.

Although the role played by some construction team members is not clearly defined, as "sleeping partners" their actions and contributions may also affect the quality of work and the finished products.

4.1.4 The good news

For centuries, engineering has been more of an art than science. The good news is that notable progress has been made in the recent years in the United States in several aspects of construction technology, such as in ABC. Rapid construction is primarily based on the availability of *men, materials,* and *machinery*, but the design codes for bridges and highways also play a role, and progress is being made in that area to help further the use of ABC.

The other good news is that there are international bridge and highway conferences held in America each year. Notable are the Pittsburgh and New York conferences, the ASCE annual conference in civil engineering, the SEI Structures Congress, and American Society of Highway Engineers conferences. FHWA and TRB have been holding conferences on ABC aspects at regular intervals. They are duly supported in their objectives by universities such as FIU. The state of the art, the progress made, and concerns are brought to light and recommendations are made for future research so that design codes and construction specifications can be made more practical and meaningful. As a member of the ASCE Methods of Analysis Committee, the Seismic Effects Committee, and the Scour Countermeasures Committee among others, the author has had the opportunity to organize and chair some of the sessions related to structures and bridges. Informal discussions with international experts have shown that more applied mathematical theorems need to be introduced for analysis and design and greater use needs to be made of probability and statistics, especially with the availability of super computers. It is a matter of getting engineers trained in applied mechanics and encouraging interested mathematicians to participate.

Some examples in the past are the applications of three-dimensional finite element methods in structural, geotechnical, and hydraulics engineering, the use of load resistance factor design (LRFD), and translating structural concepts via graphics and Micro Station CADD software into easy-to-understand construction drawings.

ABC is a component of accelerated highway construction (AHC). Both ABC and AHC are required simultaneously. For minimum disruption of traffic, bridge engineers therefore need to coordinate with highway engineers for the feasibility of field operations and with utility companies for temporary relocation of any utility pipes.

ABC concepts and advantages were discussed in previous chapters. However, the design codes and construction specifications are usually behind the practice. One difficulty has been that although very good revised codes of practice and guidelines are published as legal documents every four or five years, the users in the 50 states may know their local requirements in greater detail. Only they know "where the shoe pinches." Sometimes the shoes they are wearing may be one size too big or one size too small. For example, the construction duration windows for large highway and bridge projects in Alaska may be quite different from those in Hawaii because of the weather conditions. It is not just cold weather concreting and hot weather concreting but site access, storage facilities, transfer of equipment, and relocation of labor to the remote areas and job sites. A better appreciation of the specific issues through coordination between each state and the federal agencies.

Because credit may be given to the agencies for recent progress and refinements, for example in bridge inspection techniques, virtual design, the use of new materials such as recycled plastics, the use of FRP precast concrete girders and precast panels for decks in place of cast-in-place (CIP) construction. These methods are described in greater detail in this chapter.

Considerable information on important ABC aspects has been made available on a number of transportation research websites. Workshops and courses to train bridge engineers in innovative methods are now being organized by FHWA and FIU. Some university researchers have come up with nanotechnologies to reveal cracks and corrosion and have pioneered the usage of very high strength titanium metal in bridges.

In 2001 FHWA launched the ABC initiative. The ABC objectives were:

- "Get In, Get Out, and Stay Out"
- High construction speed
- Low maintenance cost

ABC is a method that is constantly changing with the new management methods of the labor teams, new materials, and new equipment for transport and erection. FHWA recommendations encourage using prefabricated bridge elements for foundations, columns, girders, and deck panels. With the required facilities now being available, it should be possible to construct or repair bridges and highways at a faster pace.

ABC objectives will not be achieved without implementing simultaneous AHC. This chapter explains further the philosophy and concepts discussed in the earlier chapters and addresses the most recent innovation techniques developed by federal agencies and states such as New Jersey (applying precasting techniques, e.g., with Jersey Precast of Trenton and Acrow of Parsippany) and California (with Caltrans promoting much needed seismic resistant details for bridges).

4.1.5 Continued research efforts

In resolving technical issues, the motto recommended by FHWA's "Highways for LIFE" initiative is, as noted previously, "Get In, Get Out, and Stay Out." In the context of rehabilitation, LIFE stands for the following:

- L—Long-lasting
- I—Innovative
- F—Fast construction
- E—Effective and safe

The kind of enthusiasm shown by FHWA for ABC is commendable and sometimes amazing. An alternative approach, in keeping with the "Highways for LIFE" motto is "where there is a will, there is a way."

To reduce traffic disruptions on bridge projects, FWHA is concentrating on three proven techniques, namely:

- Prefabricated bridge elements and systems (PBES)
- Slide-in bridge construction,
- Geo-synthetic reinforced soil (refer to *Civil Engineering*'s 2011 feature on ABC "Spanning the Nation").

Safety Edge: One successful initiative was "Safety Edge." It is a paving process in which the edges of roads in primarily rural areas are compressed at a 30-degree taper angle rather than left at an unfinished 90°. Research indicates that 90-degree drop-offs are a factor in about 20 percent of rural traffic accidents.

Effideck Bridge Deck System (EDC): Because of the challenging economic environment of infrastructure, it pushed state departments of transportation (DOTs) to find new ways to deliver projects in less time and for less money, and EDC has been well received. The success of EDC (discussed in Chapters 1 and 3) is due to the collaborative nature of the initiative, combining input from the FHWA and the participants such as state DOT officials, trade groups, and private industry stakeholders. The EDC is designed to provide evidence of innovations that are proven. However, the cautious nature of the engineering perhaps delayed the application of EDC approach. Construction industries, to remain in business, would prefer to rely on tested and proven techniques.

FWHA continues to champion the ABC time savings provided by using prefabricated bridge elements and systems and the geo-synthetic reinforced soil since the start. The new initiatives list includes:

Alternative technical concepts: States can be presented with innovative ideas that save time and money. Contractors may be allowed to propose alternatives during the design phase, similar to value engineering.

Programmatic agreements: This is a streamlined approach for environmental requirements that are often repeated on a project-by-project basis. An example is determining which mitigation actions are required when a particular endangered species is affected by rapid construction, and then repeating those actions on any project that impacts the species.

Locally administered federal aid projects: This initiative is designed to reduce state oversight, by educating local agencies on the complexities of the processes and requirements of the **Federal Aid Highway Program**.

Intersection and interchange geometrics: There is a need to explore any safety innovations to reduce possible conflict points between motorists, pedestrians, and bicyclists using the bridge.

High-friction surfaces: This safety measure adds a high-friction surface at the curves, which account for 25% of fatalities. It does not impact the cost significantly because curves comprise only about 5% of highway miles in the United States.

Geospatial data collaboration: This innovation allows data sharing between stakeholders by exploring a cloud-based geographic information system platform.

Implementing quality environmental documentation: The National Environmental Policy Act documentation size can be reduced to some extent and the innovation can accelerate the project delivery.

National Traffic Incident Management responder training: This initiative offers a national training program for first responders. FHWA Strategic Highway Research Program 2, discussed previously, seeks to reduce the wasted 4.2 billion hours and 2.8 billion gallons of gasoline motorists, when stuck in traffic frequently on congested highways because of the following:

- Extreme weather,
- Accidents,
- Disabled vehicles, and
- Debris in the road.

Market-ready technologies, vendor's products, innovative techniques for use of new construction materials, remote health monitoring, and recent developments in repairs and rehabilitation methods are addressed.

- Use of such efficient methods will cut down the lifecycle costs and the duration of maintenance.
- Some of the newer methods have not been fully tested and precautions may be required in their applications.
- The latest ideas, ingenuity, and contributions from individual researchers and publications are listed.
- Recent developments in new materials and prefabricated concrete elements for rapid construction will be discussed.

4.1.6 Changing bridge engineering and technology

- Rehabilitation of existing older bridges and construction of new bridges are a multibillion dollar industry. Table 4.1a–d show alternate uses of new methods and technology for new bridge construction or rehabilitation.

Table 4.1a Recent Changes in Bridge Technology

Type	Latest Methods	Older Methods
Construction method	ABC method with prefabrication; partial ABC	Conventional site construction
Conventional labor-material contract	Design-build or design-build-operate contract	Separate contracts for consultant and contractor
Complex bridge or on water	Hybrid girders; trusses	Tunnels; culverts

Table 4.1b Superstructure Alternates

Type	Latest Methods	Older Methods
Deck slab	Effideck, exodermic; precast panels, reinforced or prestressed; FRP/LWC etc.	Reinforced concrete deck slab; open steel grid deck or filled with concrete
Concrete girders	Precast prestressed; box girders; segmental	Reinforced or prestressed girders
Steel girders	HPS 70W; 100W; 50W	Grade A36; cast iron girders
Bearings	Multirotational; elastomeric pads; seismic isolation	Rocker and roller type

Table 4.1c Substructure Alternates

Type	Latest Methods	Older Methods
Piers	Frames; column bents; pie bents.	Reinforced concrete walls; steel frames
Abutments	Spill through; integral; semi-integral; MSE walls;	Gravity type reinforced concrete; full height; cantilever wall
Wing walls and retaining walls	Reinforced concrete; tie-back walls; splayed or at 90° return	Masonry or reinforced concrete walls

Table 4.1d Highway Structures and Deck Drainage Systems

Structures	Latest Methods	Older Methods
Sign structure	Variable message electronic boards	Bridge mounted; cantilever or overhead
Deck drainage	Scuppers	Holes in parapets
Deck overlays	LMC; CIA; asphalt concrete	Bitumen; asphalt layer

4.1.7 Recommendations for ABC

1. *Applications to steel bridges*: Use temporary bridges in place of detours using quick erection and demolition; there are several patented bridges in steel available; U.S. Bridge, Inverset, Acrow, and Mabey types are some examples.
2. *Applications to glulam and sawn lumber bridges, precast concrete bridges, precast joints details*: Use lightweight aggregate concrete, aluminum and high-performance steel (HPS) to reduce mass and ease transportation and erection; there are patented bridges available in concrete such as CONSPAN.
3. Connection details for seismic design; dismantle components and reuse at another site.
4. There are case studies discussing successful ABC, such as applications to glulam and sawn lumber bridges, precast concrete bridges, and precast joint details; there are also examples of the use of lightweight aggregate concrete, aluminum, and high-performance steel to reduce mass and ease transportation and erection.
5. *Training workshops on constructability*: Appendix 5 Training Courses And Workshops In ABC shows workshops and webinar topics conducted by FHWA and other agencies. Important topics may include but are not limited to, crane locations, maintenance and protection of traffic (MPT), construction duration, access and right-of-way, and material availability.

4.1.8 Awarding of contracts simultaneously for highways and bridges

Inspection reports are likely to show that on any given highway (exceeding a few miles, for example), there is more than one bridge that would need varying degrees of rehabilitation, repair, or even replacement. Each bridge is a bottleneck for the free flow of traffic and for the maximum utilization of the highway.

Piecemeal reconstruction of one bridge at a time followed by highway repairs does not help in maintaining traffic flow. The total completion time will be very long, with the repeated constraints and continued slowdown of traffic. Hence, ABC is most beneficial for fixing multiple bridges, the approaches and retaining walls, sign structures, and so on, simultaneously on a highway if conditions permit. This requires multiple design-build teams with ABC experience to be readily available at a given time. Good planning and training of personnel should help.

Asset management experience may show that when more than one contract is awarded to the same team, it gets difficult to discipline the team when it is not able to meet all the contractual obligations. With the available resources, it gets even more difficult in the middle of a contract to find a new team to replace an existing team that was engaged for the completion of multiple contracts. Obviously, ABC objectives will not be achievable if there is litigation over claims for payments made by the contractor. Hence, in the best interests of managing contracts for rapid construction and delivery, each construction team should be responsible for one contract only.

4.1.9 Accelerated highway construction to accompany accelerated bridge construction

Hundreds of miles of highway pavement may be subjected to intense rain, snow, floods, and earthquake tremors, thereby causing the embankment to settle and pavement to crack. The important aspects for AHC are as follows:

- Obtaining highway construction permits for night work (including for wide load haulage and self-propelled modular transporters (SPMTs)).
- Weigh stations to weigh and monitor overload vehicles in state or coming from out of state

Hence, ABC must preferably accompany AHC. Repairs to the highway embankment and pavement may be performed simultaneously with bridge construction. Schedules and milestones must be set for completion well in advance and approved by the highway agency, EPA, and traffic police departments.

A bridge may be fixed rapidly but a highway is not made of bridges alone. There are approaches on either side of the bridge, repairs for which are included in the bridge contract. Besides, as stated earlier, additional work may be required on sign structures, lighting poles, traffic signals, stop signs, zebra crossings, and roundabouts because they also get damaged. This simultaneous asset management approach would make it easier to reap the benefits of ABC.

4.1.10 Identifying and selecting of bridges for accelerated bridge construction

From traffic counts, it appears that ABC is most applicable to bridges that are located in urban areas. Most of the population in America continues to migrate to urban areas due to increased job prospects. As a result, average annual daily traffic on bridges located in urban areas is likely far more than those in rural areas. Urban bridges are generally much wider because of the median barriers, shoulders, zebra crossings, sidewalks, bicycle tracks, and the provision of acceleration and deceleration lanes.

Rural area bridges are subjected to a lighter traffic frequency. They may be less damaged and not have as frequent a need for repairs as urban area bridges. For urban bridges, detour options may be a cause of concern if nearby townships have narrow lanes and a dense population. Noise from highway traffic may not be acceptable to the residents.

Public meetings are normally held to explain alternate detour options available and obtain feedback. Temporary steel bridges may be erected adjacent to the bridges being repaired and temporary traffic lights may be installed, which may add to the cost of the project and slow down the speed of traffic.

For urban bridges, staged construction for the required deck and girder repairs with rapid construction would be far more difficult and would require a different method than for fixing bridges in rural areas with far less traffic. In selecting the bridges in a given county, need-based considerations rather than economics may govern. A public meeting of the residents of the area who use more than one bridge may be a good option. One way to prioritize selection is as follows:

1. Bridges located on military routes
2. Bridges serving hospitals and schools
3. Very expensive bridges whose replacement is not easy; examples are long-span suspension cable bridges
4. Historic bridges
5. Bridges promoting tourism spots
6. Bridges located on turnpikes and interstate highways carrying high traffic loads
7. Local bridges
8. Bridges in rural areas with low traffic volumes
9. Pedestrian bridges that are not being used for commute to work, etc.

Also, segments of highways connecting to the selected bridge selected are candidates for repairs.

4.1.11 Use of remote sensors and robotics

Asset management requires a free flow of traffic for optimum use of the billions of dollars invested in highways. Asset management can be improved by:

- The use of remote health monitoring methods
- The use of modern construction equipment and techniques
- The use of new construction materials and systems

4.1.12 Inspecting bridges by studying photographic evidence of defects

Bridges are scrutinized every 2 years and inspectors rely heavily on their eyes to find weak points. If they see red flags, they do more tests.

A new imaging program automatically detects irregularities in bridges. Research scientists at the Fraunhofer Institute for Industrial Mathematics (ITWM in Kaiserslautern) have developed this specialized software jointly with fellow scientists from the Italian company Infracom. The engineers have been using the new software successfully to inspect bridges in Italy.

The changing effects of weather and temperature, road salt, and the increasing volume of traffic all quickly cause damage such as

- Hairline cracks
- Flaking concrete
- Rust penetration

The imaging software can identify the above defects. The researchers have extracted metrics from photographs that include the characteristically elongated shape of a hairline crack, the typical discoloration in damp places, and the structures of the material, which are different for a concrete bridge than for a steel bridge. Even minor damage is identified and signaled.

No two bridges are alike and they differ in terms of their shape, construction material, and surface structure. The color depends on:

- The material,
- The dirt or fouling, and
- The degree of humidity

The information is stored in a database. When the researchers load a photo into the program, the software compares the features of the new image with those of the saved images. If it detects any irregularities, it marks the respective area on the photo. The bridge inspector can decide how serious the damage is and if something needs to be done. The earlier any damage is identified and clearly categorized, the simpler and less expensive it is to repair.

Robotics can save detailed inspection time on complex bridges. As in the automobile industry, simple type of robots can be used for performing routine but difficult tasks as under water construction and inspection.

4.1.13 Structural health monitoring using a self-powered monitor system

A team of University of Miami College of Engineering researchers is implementing a self-powered monitoring system for bridges that can continuously check their condition using wireless sensors. Sensors can harvest power from structural vibration and wind energy.

Thousands of bridges erected during the 1960s and 1970s, when much of the nation's infrastructure was built, do not have sensors installed. With a scarcity of inspectors and tens of thousands of bridges, the visual inspection process can be long and laborious. This team plans to place newly developed wireless sensors, some as small as a postage stamp, others no longer than a ballpoint pen, along strategic points on older bridges in Florida.

The joint venture is led by Physical Acoustics Corporation of New Jersey. The sensors are developed by project collaborators Virginia Tech University and record vibrations and stretching to acoustic waves and echoes emitted by flaws such as cracks. Even the alkaline levels in the concrete of bridge supports are being measured.

The work is part of the National Institute of Standards and Technology Innovation Program and is aimed at developing a more effective system to monitor the health and predict the longevity of bridges.

4.1.14 Use of nanotechnology to reveal cracks and corrosion

Carbon nanotubes are a fundamental building block of the nanotechnology revolution. According to an article published in the journal *Nanotechnology*, researchers at the Michigan State University (info@nanomsu.org) have recently developed a coating that could be painted or sprayed on structures. Any corrosion or fracturing that is too small for the human eyes to detect can be identified.

A new "skin" for bridges could be a sixth sense for inspectors looking for cracks and corrosion that could lead to a catastrophic failure such as the 2007 Minneapolis bridge collapse.

It would allow an inspector to check for damage without physically examining a structure. When it is time to examine the health of the structure, an inspector could push a button and in minutes the skin would generate an electrical resistance map and wirelessly send it to the inspector.

The sensing skin is an opaque, black material made of layers of polymers. Networks of carbon nanotubes run through the polymers.

One layer tests the pH level of the structure, which changes when corrosion occurs. Another layer registers cracks by actually cracking under the same conditions that the structure would. The skin could be a permanent veneer over strain- and corrosion-prone hot spots of joints in bridges.

4.1.15 Remote sensing technologies to replace highway inspections

The structural design of pavement that is supported on elastic grade should cater to the heaviest of truck loads. Wear and tear is caused by friction between the wheels and pavement surface.

In addition, AHC requires emergency management and timely assessment of traffic congestion and the impacts of environmental and recurring natural disasters. For condition assessment, modern remote sensing technologies for geospatial analysis and visualization applications (related to infrastructure inventory) are required. Efficient monitoring techniques involve the use of satellite imagery–based surface classification.

A geographic information system–based decision support system can be developed for assessing storm debris and erosion damages, by analyzing postdisaster imagery (refer to the University of Mississippi Research Center report by Professor Waheed Uddin).

4.1.16 Use of wireless data-acquisition system and falling-weight deflectometer

Drexel University evaluates concrete bridges lacking documentation. According to Professors Emir Aktan and Franklin Moon of Drexel University, 30% of aging U.S. bridges lack critical documentation about the bridge materials and reinforcement properties.

A *wireless data-acquisition system and a falling-weight deflectometer* have been tested to determine their effectiveness in producing rapid and cost-effective findings. The falling-weight deflectometer, which drops weights onto a grid marked on a bridge, could be a useful tool to complement visual inspections.

The researchers recommend that the bridges' foundations be inspected annually. The wireless system is not reliable for use during load testing but the researchers encourage the development of this technology because it could offer time and cost savings for bridge evaluators. Sensor-equipped bridges remain rare, but are growing more common.

4.1.17 Asset management using robotic devices

Every transportation agency is faced with management of its assets, which includes hundreds of bridges. No two bridges are alike and the varieties cover historic masonry arch bridges to the most modern segmental and cable-stayed suspension bridges.

Routine inspection and nondestructive testing (NDT) of bridges can be potentially performed by robotic devices using inertial navigation, odometer, and laser techniques. A "manipulator" device will fix the sensors on critical bridge locations.

4.1.18 Robotic steel beam assembly in the field

The Steel Beam Assembler by Zeman is a step into a new dimension of structural steel fabrication and erection at great heights and over rivers. The system is designed for fully automated assembling, tack-welding, and full welding of structural steel elements.

Bridges in a Backpack (developed by the Advanced Structures and Composites Center at the University of Maine and Advanced Infrastructure Technologies).

Advanced Infrastructure Technologies' innovative composite bridge system using arches is AASHTO-approved and lowers construction costs, extending structural lifespan up to 100 years. Designs are engineered to exceed AASHTO load standards for single span bridges from 25 ft to 70 ft and multispan designs exceeding 800 ft.

The Maine DOT has tested and supports the implementation of The Bridge in a Backpack stating its lightweight, easily transportable, and rapidly deployable features. The exact blend is engineered to optimize the efficiency of the bridge design.

- Arched carbon fiber tubes and a cast in place concrete provide a bridge superstructure as strong as steel.
- Lightweight and easily transportable design allows fewer workers and less equipment for bridge installations.
- It lasts two to three times longer than traditional concrete bridges with less maintenance.
- Reduced labor and construction costs, and fewer road closures and traffic diversions.

The benefits of the new technology are threefold.

- The arches are an instant framework.
- No steel reinforcing bars, or rebar, are needed because the tubes are stronger than steel.
- Third, the tubes protect the concrete from water and elements, extending the life of the concrete.
- The system uses a composite exoskeleton to fortify concrete superstructure to add significant strength, durability and protects the concrete from corrosion.

The fabrication of superstructure elements is a proprietary process that fuses several layers (including carbon fiber) with resin to create the composite material. Inexpensively transported to the job site, composite arches are placed in position, covered in composite decking and filled with an expansive concrete. Testing at the Advanced Structures and Composites Center included the following:

- Structural characterization and modeling,
- Fatigue testing for 50+ years of truck traffic,
- Environmental durability testing for ultraviolet, fire, freeze-thaw, and abrasion resistance, and
- Instrumentation and field load testing (http://innovativeproduct.org).

4.2 Ensuring adequate investment returns

There are several direct and indirect benefits of investments leading to rapid delivery. The average budget allocation for infrastructure for a state highway agency can easily run in the billions of dollars for a given year. Some states, such as California, New York, Florida, Texas, and Illinois, have more reconstruction work on their plate than less-populated states such as Alaska or Hawaii. Also, neighboring countries such as Canada that connect with the U.S. highways have extensive lengths of highways and the number of bridges, which are no less than those in the European countries. ABC is only one major factor to achieve efficiency in construction. Other factors related to infrastructure include AHC.

The engineering efforts required are substantial as can be seen in federal and state design codes. Hence, even small savings in the cost of materials, men, and machinery can lead to millions of dollars being made available for public needs. If implemented correctly, the returns from the investment will be high. This is only possible by running the industry as a business enterprise, and not just as an analytical and design exercise.

4.2.1 Enhancing the environment

The U.S. Congress passed the National Environmental Policy Act in 1969. Its objectives were to:

1. Formulate a national policy that will encourage productive and enjoyable harmony between people and the environment
2. Prevent damage to the environment and thereby maintain the health and welfare of people
3. Enrich our understanding of ecological systems.
4. Establish a council on environmental quality. This resulted in preserving important historic, cultural, and natural aspects of our national heritage. In addition, the quality of renewable resources was enhanced and recycling of resources was made possible. Some of the measures included:
   a. Using precast concrete elements with fewer environmental constraints
   b. Limiting construction activities to certain months of the year (May to August, for example) to minimize environmental impact
   c. Reducing wetlands disturbance by adopting an innovative top-down method of construction
   d. Preserving the natural habitat around the bridge such as providing deer and small animal crossings
   e. Minimizing damage to flora and fauna
   f. Minimizing side slope erosion of stream banks.

4.2.2 Developing and utilizing new construction materials

There is a quest for new construction materials to replace the dwindling resources of steel and rebar with recyclable materials, which are lightweight and cost less. Advancements in the use of new materials like titanium, concrete materials such as lightweight aggregate (LWA) concrete and FRP concrete and recyclable plastics are being used to develop structural design codes. The state of the art and the scope of new materials are discussed here.

There is significant research on many different materials for aggregate substitutes:

Granulated coal ash,

Blast furnace slag

Various solid wastes such as fiberglass waste materials, granulated plastics, paper and wood products/wastes, sintered sludge pellets, and others.

However, there is a growing interest in substituting alternative aggregate materials, largely as a potential use for recycled materials. The only two that have been significantly applied are glass cullet and crushed recycled concrete itself.

Modern and advanced materials include:

- High-strength concrete
- High-strength rebar
- High-performance weathering steel
- Fiber-reinforced engineered cement-concrete
- Fiber-reinforced polymer composites; use of fiber-reinforced polymer to rapidly repair column plastic hinge zones
- Elastomeric bearing pads

Research is being conducted concerning the use of FRP composite materials, geomaterials, geosynthetic products, and lightweight, high, and ultra-high-performance concretes and steels. It is important to develop appropriate limit state criteria for the use of these materials, details, components, and optimizing structures for adoption into LRFD specifications.

HPS should be considered for appropriate elements of a bridge. The author designed several HPS bridges recently for the New Jersey Department of Transportation (NJDOT) and the New Jersey Turnpike Authority. HPS allows for:

- Lighter girders
- Shallower superstructures
- Smaller overall project footprint
- Elimination of maintenance painting
- Enhanced resistance to fracture

Not all states have allowed the use of fiber-reinforced polymers and plastics. They are not currently adopted by NJDOT for main structural members, but NJDOT does encourage their use for ancillary components of a bridge. For example, NJDOT has used the material for the fender systems of two bridges along the Jersey coast: Route 9 over the Nacote Creek and Route 9 over the Bass River. The advantages of fiber-reinforced polymers and plastics include that they are very environmentally friends and they eliminate concerns regarding marine borers.

Deck and culvert overlays are described in detail in later sections. The use of silica fume and high early strength latex-modified concrete (LMC) will open a deck to traffic early (i.e., within 3 h of curing). Silica fume, pozzolans, fly ash, and slag may be used to reduce concrete permeability and the heat of hydration. Fly ash and cenospheres are preferred for HPC in bridge decks, piers, and footings. The following new construction techniques also provide significant cost savings and other benefits:

- Byproducts of coal fuel such as fly ash, flue gas desulfurization materials, and boiler slag provide extraordinary technical, commercial, and sustainable advantages.
- Development of preferred alternative structural solutions and optimization of girders using HPS 70 W, 100 W, and hybrid steel girders. The use of weathering steel minimizes painting cost.

It is anticipated that substantially increased life expectancy of bridges will occur with implementation of these new materials and techniques. The caveats are:

- Lack of design and analysis codes and techniques.
- Lack of history in the United States.
- Lightweight and high-strength materials are more suitable for girders.

4.3 Modern concrete technology and accelerated bridge construction

Strong and durable concrete is the backbone of bridge construction. This amazing material is essential for the construction of foundations, abutments, deck slabs, parapets, and median barriers. For piers and girders, alternate materials such as timber and steel may be suitable.

4.3.1 Environmental benefits of durable and corrosion resistant concrete

Longer-lasting concrete that can be used in most bridge construction is now available for the foundation, substructure, and superstructure. Concrete bridges are more commonly used for smaller spans as small steel spans have higher maintenance costs. Segmental prestressed concrete bridges have been used for longer spans.

Corrosion of concrete: In many structures, exposure to deicing chemicals and marine-sourced chloride is a significant cause of corrosion. The most common procedure for repairing deteriorated concrete involves the removal of the damaged material and replacement with new concrete or mortar. Differences in pH, porosity, and chloride content are a few of the factors that may result in corrosion activity. As a result, "chip and patch style" repairs may fail prematurely in chloride-exposed structures.

Reducing carbon dioxide emissions: The use of concrete in the harshest of environments is an achievement. Limestone, the primary raw material in concrete manufacture, is abundantly available in nature. Silica is available in the form of aggregates. Alumina and iron oxide are the other basic ingredients in the manufacture of cement. The concrete industry has recently reduced its CO_2 emissions.

4.3.2 Purdue University researchers create stronger, longer-lasting concrete (written by Jessica Contrera, in Purdue University Campus News, Feb 2, 2013)

The Indiana DOT will implement Professor Jason Weiss' research to build four bridges with HPC that can stay strong, resist cracks, and save money. The main concern is the deicing salt that everybody wants on the road during the wintertime. But part of that salt is chloride. When the chloride moves through the little holes in the concrete and get to the steel reinforcing bar, it starts to corrode.

In August 2010, two bridges were built for the country roads in Bloomington. The first was made out of regular concrete. The second was made of internally cured concrete. Today, the first has three cracks and the internally cured has none.

Water dissolves loose lime in the concrete, creating microscopic channels through which water can penetrate. In cold climates, the water freezes and expands, enlarging the cracks. The water also rusts reinforcing steel. New forms of concrete aim to eliminate these problems by making the concrete more waterproof.

4.3.3 Use of new concrete materials

Over the years, concrete mixtures are using admixtures with Portland cement powder as the binding agent of aggregates. Modern concrete technology has led to the following types of special concrete materials:

- Smart concrete
- Accelerators
- Air-entraining admixtures
- Water reducers
- Super plasticizers
- Pozzolans
- Emulsions
- Antiwashout admixture for underwater concrete
- *Spliced girders of varying depth*: Enables lightweight concrete to achieve spans of over 200 ft.
- *Self-consolidating concrete (SCC)*: Because vibration time is saved, SCC helps ABC; more workable concrete with lower permeability than conventional concretes.
- *Rapid setting concrete:* Nonshrink, multipurpose, high-strength repair mortar used for concrete repair, plaster repair, mortar bed, formed work, vertical, and overhead applications.
- *Blended cement concrete*: A blend of Portland cement and a combination of silica fume or fly ash used for enhanced strength and durability. Used in high-performance applications with materials such as slag cement.
- *Fibermesh concrete*: Microsynthetic fibers prevent all early age cracks during concrete's plastic state.
- FRP concrete
- *CFRP concrete*: For repair and retrofit of concrete structures with glass or FRP.
- GFRP concrete
- Glass cullet and autoclaved aerated concrete
- Concrete admixtures
- Fly ash concrete
- Pumice-Crete
- Cement substitutes
- HPC
- UHPC ultra-HPFRC
- Lightweight aggregate concrete
- Recycled concrete aggregate (RCA) concrete
- Accelerated cure cast-in-place concrete
- EDC
- Exodermic bridge deck
- Reactive powder concrete (RPC) bridge girders
- Full-depth precast concrete deck panels (FDDP)
- Cementitious materials concrete (fly ash, blast furnace slag, and silica fume)
- Deck overlays: Use of silica fume, pozzolans, fly ash, and slag and high early strength LMC

Trade names for these products include UHPFRC, RPC, Ductal, CoreTUFF, BSI, Densit, and Cemtec.

4.3.4 Use of high-performance concrete

UHPC is being used for PBES connections. (Refer to Ben Graybeal of FHWA on PBES Deck to girder UHPC connections use shortened height shear connectors or extended stirrup connections.)

The advantages of HPC include:

- Wider beam spacing and fewer beams
- Longer span lengths and fewer piers
- Increased vertical clearance
- Less permeable, stronger, and more durable concrete
- Lower initial and life cycle costs
- Fewer maintenance requirements

These properties are achieved by special mix design and improved curing. Field-cast UHPC simplifies fabrication of precast components and field construction operations and creates robust connections.

4.3.5 Ultra-high-performance concrete longitudinal joints in bridge decks

One technological development that is under way is the use of UHPC for bridge decks. This technique allows for full moment transfer. No post tensioning is required, and the joints are only 6 in wide with high strength and low permeability. Joints can be reinforced with hairpin bars or straight bars. The UHPC joint is reinforced to carry the full live load tensile force. UHPC has been used for transverse joints over piers.

In developing UHPC use and other technologies, laboratory testing of joints and connection have been used to assess the strength and serviceability of the transverse joint and determine the ultimate moment capacity. The tests show good correlation with design strength, but identified HPC deck cracking and bond issues.

Transverse joint serviceability design

1-in high-strength threaded bar posttensioned to 70 Kips
Prevent deck cracking under service loads
Keep bond between UHPC and HPC deck in compression

4.3.6 Ultra-high-performance concrete for prefabricated bridge elements and systems connections[1]

UHPC is an advanced cementitious material. It has high strength and high stiffness and exceptional durability. It is also self-consolidating and has internal steel fiber reinforcement for added ductility. Some benefits and challenges of using UHPC follow.

UHPC benefits

Reduced construction on critical path
Increased safety
Increased quality

[1] From a presentation by Ben Graybeal, Structural Concrete Research Program, Federal Highway Administration, Turner–Fairbank Highway Research Center.

Challenges

Transportation and assembly connections (significant hurdle)

Field-cast UHPC connections

Simplify fabrication of precast components
Simplify field construction operations
Create robust connections

Additional applications:

- Use of precast approach slab
- Precast sleeper slab for use with integral abutments is related to highway work.
- Precast parapets and median barriers.

Postconstruction review (lessons learned)

It is best to have two independent surveys because survey errors can lead to major delays during ABC period.
Longer pile lengths could be specified by contract to minimize schedule disruptions.
The designer should be present onsite during the ABC period for quick decision-making.
Set up a prepour meeting with UHPC supplier and follow procedures. The bond between UHPC and deck is critical.
UHPC reinforcement should allow joints to be more easily and quickly constructed. Straight bars are preferred.

4.3.7 High-performance concrete overlays

The benefits of a HPC composite overlay include:

- It addresses any spalling or cracking in the top of the existing deck.
- The composite action helps to strengthen the deck.

The disadvantages to the system include:

- The concrete curing time is longer than asphalt or polymer overlays, leading to possible MPT issues.
- It assumes the bottom half of the concrete is in an acceptable condition to be salvaged.
- Potential cracking of the HPC.

Field-Cast Noncontact Lap Splice Connection

- Compressive strength: 18–25 ksi
- Modulus of elasticity: 6200–7200 ksi
- Creep coefficient: 0.5–0.8
- Sustained tensile capacity: 0.9–1.3 ksi
- Rapid chloride permeability: 200–360 Coulombs
- Freeze/thaw resistance: RDM > 95%

4.3.8 Typical concrete strengths

Prestressed beams with HPC compressive strength = 8000–10,000 psi

- Deck slab with HPC = 5000–6000 psi
- The Route 106 Bridge over the Chickahominy River in Virginia used 84-ft-long AASHTO Type IV beams with minimum concrete design compressive stress $\left(f_c^{'}\right) = 8000$ psi.
- A very long structure of total length exceeding 1mile for Route 33 over the Pamunkey River in Virginia used $f_c^{'} = 8000$ psi.

4.3.9 Use of pervious concrete

Also called porous concrete, no fines, and permeable concrete, the material is increasingly being used in paving environments for concrete flatwork applications. Although pervious concrete was used as early as the nineteenth century, it has recently been rediscovered in the United States. It allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete slab. Pervious concrete is traditionally used in pedestrian walkways.

4.3.10 Ultra-high-performance concrete

UHPC is proposed as an innovative new material traced back to the 1980s, when the first big gains were made in increasing the resistance or strength of concrete. Developed in France during the 1990s, UHPC has seen limited use in North American bridge projects.

Consisting of fine sand, cement, and silica fume in a dense, low water-to-cement ratio mix, this highly moldable material offers a combination of superior properties including compressive strengths up to 30,000 psi and flexural strengths up to 6000 psi, ductility, durability, and a range of aesthetic design possibilities.

The high-tech versions of UHPC have different properties that make them more comparable to materials such as stainless steel or aluminum, which are often more expensive. These new types of UHPC concrete offer the following advantages:

- Intrinsically energy-efficient.
- Excellent insulation against wind and water.
- Its high density means it stores heat during the day and releases it at night, preventing bridge decks from freezing in winter.
- UHPC is denser than conventional concrete, which contributes to its remarkable imperviousness and durability.
- In addition, UHPC is extremely low in permeability and performs better in terms of abrasion and chemical resistance, freeze-thaw, carbonation, and chloride ion penetration.
- It sets much faster.
- Stronger concrete translates into significant gains for the environment. It can be used more thinly, consuming considerably fewer raw materials than regular concrete. The environmental advantage is clear: zero maintenance, zero painting, and a very long life.

Engineers and builders have far greater flexibility to use the material's long-lasting, thermal, and acoustic properties in pedestrian bridges and at bus stations and in turn, contribute to big energy and other environmental savings. White concrete contains titanium dioxide, which keeps the concrete clean while at the same time as destroying ambient pollutants such as car exhaust.

Sustainability: High-tech concrete is just one of the products that have emerged from the research and development laboratories of cement, steel, and chemical firms this decade, and it signals a growing commitment by heavy industry to the notion of "sustainability." UHPC mix designs typically include no aggregates larger than sand, and include steel fibers 0.2 mm in diameter and 13 mm in length. These steel fibers and the special mix design increase the strength and toughness of the UHPC significantly relative to more traditional concretes.

Disadvantages: The low water-to-cement ratios typically used result in difficult casting and curing conditions. There is a need to evaluate the strength and stiffness parameters of as-cast members. The potential for the development of practical quality control techniques for the future implementation of UHPC needs to be considered. Ultrasonic velocity measurements are used to estimate the bulk elastic modulus, shear modulus, and Poisson's ratio of UHPC; results are then compared with traditional destructive methods. The application of ultrasonic testing for the evaluation of early-age material properties and for nondestructive, in situ materials characterization is useful.

UHPC requires advanced cementitious composite material. It has high strength, high stiffness, exceptional durability, and added ductility when cast with internal steel fiber reinforcement.

4.4 Recent innovations leading to faster bridge delivery

Innovations help in upgrading the quality of construction and in completing the project in a timely manner. Advancements in ABC methods are discussed in the following section. Three of the core goals of innovation are the following:

Preventing bridge failures: By minimizing the identified deficiencies through maintenance.
Use of advanced methods: Using computer-aided analysis and design techniques.
Closer interaction: Between design documents and construction.

The following physical causes of deficiencies are omnipresent in bridge components:

- Deterioration
- Applied direct stress
- Thermal action
- Creep and shrinkage due to changes in atomic bonds between constituents

4.4.1 Innovative concepts leading to cost and time savings

Advanced infrastructure design will utilize ground-penetrating radar technology for evaluation of the bridge deck under the overlay. This is a high-speed nondestructive evaluation that does not require maintenance and protection of traffic. The estimated cost savings per bridge using this method is $0.1 million; the estimated time saved is 2 months.

Staged construction: The use of shoulders during staged construction is inevitable. To address this critical factor, an innovative approach consists of evaluating the integrity of the existing shoulders at the start of the design phase of the project. This approach would allow the identification of the exact locations where rehabilitation of the shoulders would be necessary. Substantial savings would be realized in terms of schedule and cost. *Estimated cost savings: approximately $0.25 million; estimated time saved: 2 months.*

Reduced construction staging: Investigate the possibility of eliminating the substages required for constructing temporary sidewalks carried by the structure. As an alternative, consider using a temporary bridge such as an ACROW or Mabey type. *Cost savings: $50,000; estimated time saved: 1 month.*

Overhead and utility lines: Advanced relocation of O/H utility lines to their permanent position without the use of temporary pole lines. *Cost savings: approximately $0.3 million; time saved: 3 months.*

Environmental permits: Early coordination with regulatory agencies such as the EPA and the U.S. Army Corps of Engineers should be performed to identify potential project permitting requirements (*estimated design schedule time saved: 3 months*). Early identification of issues that may be seasonally sensitive, such as presence of endangered and threatened species, will also help to reduce project delays (*estimated design schedule time saved: 1 month*).

Pedestrian/bicycle access during construction: To save costs, investigate the possibility of providing at-grade temporary pedestrian/bicycle access during construction using the existing service road adjacent to the bridge versus a temporary sidewalk carried on the structure. *Estimated cost savings: $100,000; estimated time saved: 1 month.*

Road closure versus staging: As an alternate to staging, investigate keeping the bridge open weekdays to accommodate the heavy weekday traffic and partially close the bridge over multiple weekends. Using precast deck/prefabricated superstructure construction will also accelerate the schedule. *Estimated time saved: 2 months.*

Precast and composite decks: The use of precast concrete modular deck sections in lieu of poured-in-place deck construction and Inverset type prefabricated superstructure sections for bridge structures may provide considerable cost savings and a reduction of a couple of months in construction time. Investigate increasing the strength and service life of the bridge by increasing the beam section properties through use of a composite new deck, and by making the existing simply supported beams continuous. *The potential increase in service life is 25 years.*

Inverset type composite girder fabrication: This is a precast concrete and steel composite bridge superstructure system that uses an "upside-down" casting method that takes advantage of the force of gravity to prestress the steel beams. The inverted casting process precompresses the concrete deck, yielding a crack-resistant deck with high durability. Inverset was formerly a proprietary system.

Use of stainless steel: Long-term corrosion can be prevented by using stainless steel reinforcement in place of mild steel or high strength rebar.

4.4.2 Recycled plastic lumber bridges

Axion International Holdings, of Basking Ridge, New Jersey, has developed a system in conjunction with researchers at Rutgers University to make bridges from recycled materials.

The engineers constructed a pair of bridges made entirely from recycled plastic products at Fort Bragg, North Carolina, and had M1 Abrams tanks driven across the spans. The M1 Abrams, manufactured by General Dynamics, weighs nearly 70 tons, making it too heavy to use on most standard bridges and roads.

The US Army Corps of Engineers Construction Engineering Research Laboratory designed and built the test structures. The tests indicated the structures held up well under both moving and static weight loads; the structures also withstood stresses caused when the M1 operator applied the vehicle brakes while on the bridge.

The two test thermoplastic spans were made from more than 170,000 pounds of recycled materials. The structures are less expensive to build than traditional wood timber bridges often used on U.S. military bases. The advantages of recycled structural plastic lumber bridges are:

- Speed of installation,
- Reduced costs for construction and maintenance
- Eco-friendliness

4.4.3 Lightweight titanium pedestrian bridges

A feasibility study to construct a pedestrian bridge at the University of Akron entirely of titanium investigates cost concerns. Titanium has the best strength-to-weight ratio of any metal. It is as strong and blast-resistant as steel but weighs 40% less. It is resistant to saltwater as well. It's in ample supply, mined in the southern and western United States and several other countries.

Corrosion-resistant bridges are critical to the defense and national security of the United States. The Defense Metals Technology Center in North Canton, Ohio, is coordinating with the military to solve metals-related technology problems. The high-profile venture demonstrates titanium's feasibility in commercial infrastructure projects, especially for corrosion-damaged steel bridges that require expensive painting and can spark greater demand and open new markets for titanium.

The study is a shot in the arm for Akron's metals industry and a boon to bridge builders searching for a rust-resistant alternative to steel.

4.4.4 Bridge construction using waste products

The U.S. Forest Service and the Montana Community Development Corp. helped to secure funding for a 90-ft-long, 8-ft-wide bridge. It was constructed with small-diameter "waste wood" and "waste plastic" as well as recycled tires.

It spans the Rattlesnake Creek in Missoula, Montana, and consists of lodge pole pine trees that were debarked and doweled to 6-in-diameter trusses. The structure is considered a showcase for innovation in the use of new construction materials. The decking material is a fiber-plastic composite (wood flour and polyvinyl chloride plastic).

4.4.5 Application of Life Dimensional 3D technique by InteliSum Inc

Life Dimensional 3D (LD3) camera and software provides digital photograph data.

HNTB worked with InteliSum Inc. to incorporate the results with their presentation and the bid.

A 2.8-mega pixel camera and true color/texture around each LIDAR point. Each pixel has the visual quality of a digital photograph.

The state of New Mexico is dealing with the environmental impact of increased traffic flow to the oldest capital city in North America (refer to INTELISUM, *Accelerated Bridge Construction (ABC), UDOT and Federal Highways*, August, 2007, Volume 1, No. 3).

HNTB were announced the winner of a bid for part of a railway track project in the City of Santa Fe, New Mexico, using the LD3 system.

4.4.6 University of Utah building information management program

The DIGIT Lab, at the University of Utah, provides a geospatial database to develop and provide analytical services to federal, state, and local agencies as well as private sector entities on a contract basis. At the request of the DIGIT Lab, InteliSum (IS) scanned the Union Building (located at the University of Utah) for a pilot project to demonstrate LD3's unique capability to capture the as-built conditions of their facilities.

The data collected has proven useful for building information management and emergency evacuation planning.

4.4.7 Introduction of new topics in rapid design

In the light of developments in numerical methods and computer techniques, a more accurate analysis and design approach can be used:

- AASHTO Load and Resistance Factor Rating procedures in place of the formerly used LFD method
- State codes of practice using the ultimate loads and probability approach
- Advanced methods of analysis and nonlinear finite element methods
- New software applications
- Design methods for accelerated bridge construction
- Plan review check list and quality assurance/quality control document (e.g., used by NJDOT and Wisconsin DOT)
- Use of context-sensitive design
- Field inspection
- Fabrication
- Accelerated testing
- Erection issues (erection sequences of column bents are shown in Figure 4.1)
- Grouting and closure pours.

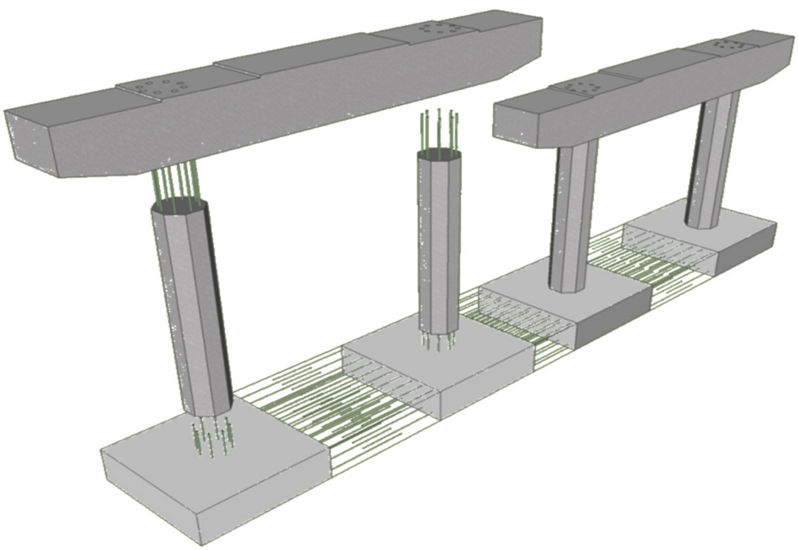

FIGURE 4.1

Precast components can be assembled into one bent.

4.4.8 Application of analytics and prediction software solutions

Construction companies need to be prepared to jump into new projects and programs focused on using ABC technology to drive sustainability and innovation. Technology providers continue to partner to delivery technology to both city officials and construction companies.

According to *Constructech* magazine 2014, published by Specialty Publishing Company, a strategic alliance between Cisco (www.cisco.com), San Jose, California, and AGT International (www.agtinternational.com) Zürich, Switzerland (a provider of analytics and prediction software solutions) aims to provide game-changing Internet-of-Everything solutions for smart cities.

Whereas today, the physical world is being connected to the Internet, many processes within a city center (from traffic and construction management to managing urban security) would benefit from the vision of a more connected world for rapid solutions, including in construction and management.

Associated tasks: Focus areas include transportation, health care, utilities infrastructure, disaster preparedness, and personal safety, among others. Accidents can damage bridges.

The companies will focus on two areas.

- Delivering a traffic management solution that will "identify, respond to, and resolve traffic incidents" by providing real-time situational awareness.
- Developing an urban safety solution by using software that uses city data determined from sensors, video feeds, and social media feeds to pinpoint suspicious activities and recommending an appropriate response.

Construction companies working on these types of infrastructure construction projects will need to understand the impact of the technology to help build the cities of tomorrow with transportation construction, which will be smarter, safer, and more connected.

4.4.9 Web resources for information on concrete by professional organizations

The billion-of-dollars concrete industry is shared by a large number of professional organizations in United States and abroad which are contributing to research and the development of design and construction specifications as listed below:

American Concrete Institute (ACI): A technical and educational society dedicated to improving the design, construction, maintenance and repair of concrete structures.

American Concrete Pavement Association: The association represents concrete pavement contractors, cement companies, and equipment and material manufacturers and suppliers, with a special focus on Portland cement concrete pavements. Approach slabs for bridges can use concrete pavements. (Refer to http://www.pavement.com/.)

Cement Sustainability Initiative: CSI was formed to help the cement industry to address the challenges of sustainable development. Research on recycling concrete and on reducing the CO_2 emissions is being conducted by CSI. (Refer to www.globalcement.com/news/itemlist/tag/Cement%20Sustainability%20Initiative.)

Concrete Foundations Association of North America: CFA is the resource for contractors, producers, engineers, and suppliers in the concrete foundation industry. CFA is an informational and networking tool for its members. The CFA carries out a multitude of educational and promotional efforts for the advancement of concrete foundation technology.

Concrete Materials Calculators: A resource from concrete.com to help estimate the amount of concrete needed for a pour or placement, or to fill a block or a column.

To use the concrete volume calculator, simply enter the width, length, and thickness of pour in feet or inches. The calculator will estimate the number of cubic yards of concrete. (Refer to http://www.concrete.com/calculators/concrete-materials-calculators.)

Concrete Network: This resource provides information for designing and building concrete foundations, decks, homes, and more.

Concrete Reinforcing Steel Institute: This institute strives to increase the use of reinforced concrete in the construction industry. Their site has several engineering data reports that are of interest to the homebuilding industry.

Environmental Council of Concrete Organizations: ECCO members are dedicated to improving the quality of the environment by working to increase awareness of the environmental aspects and benefits of concrete products.

ECCO promotes concrete as an environmentally preferable construction product, being made of materials that are abundant in supply, has modest energy needs during production, and is an ideal medium for recycling waste or industrial byproducts. The industry organization produces publications on the environmental impacts of concrete and concrete construction. Its Website includes a reference library that contains nearly 2000 bibliographic references and abstracts. (Refer to http://www.ecco.org.)

National Ready Mixed Concrete Association: NRMCA represents and serves the entire ready mixed concrete industry:

- Supports industry professionalism and quality by maintaining the national Plant Certification program and the Concrete Technologist Certification program.
- Provides technical advocacy in codes and standards for organizations such as ACI, ASTM, and TRB, helping ensure that ready-mixed concrete interests are advanced.
- Promotes the use of performance-based specifications helping to ensure quality results and increase the value-added qualities of ready mixed concrete production.
- Conducts concrete research at the NRMCA Research Laboratory, developing procedures that advance quality and reduce costs.
- Develops technical publications, including CIPs, the esteemed Concrete in Practice series of two-page briefs on important technical topics and TIPs, brief technical information topics packaged as Technology in Practice sheets.
- Coordinates technical education for the association's Seminar, Training & Education Programs.

NPCA—National Precast Concrete Association: NPCA is dedicated to expanding the use of quality precast concrete.

Precast concrete transportation products are used in the construction of deck panels, bridge girders, and railroad transportation systems. Products include: box culverts, three-sided culverts, bridge systems, railroad crossings, sound walls/barriers, Jersey barriers, tunnel segments, and other transportation products. (Refer to http://www.nrmca.org/research_engineering/default.htm.)

Portland Cement Association: The Portland Cement Association promotes cement and concrete for paving, residential, engineered structures, and public works. (Refer to http://www.cement.org/cement-concrete-basics.)

Precast/Prestressed Concrete Institute: This resource provides information on precast panels and includes a list of manufacturers. Prestressed concrete forms the backbone of bridge beams for all span lengths. More than half of the U.S. bridges are constructed from precast/prestressed concrete. High performance precast provides many benefits for all stakeholders from designers to users. PCI Design Handbook is widely used. (Refer to http://www.pci.org/project_resources/transportation_systems/bridges.)

Slag Cement Association: This association is a leading source of knowledge on blast furnace slag-based cementitious products.

Florida I-95 uses 60% slag cement. For bridges on rivers, the application of slag cement is useful. Seventy percent slag cement is used in tremie (underwater) concrete. The widening of I-95 from four to six lanes, between SR 528 and SR 519, comprises approximately 120,000 cubic yards of mainline paving. (Refer to http://slagcement.org.)

4.5 Development of diverse repair technologies

The following detailed recommendations are based on current practices and a literature review of a large number of publications, including those by FHWA, AASHTO, ASTM, and NCHRP (refer to Mohiuddin Ali Khan, *Bridge and Highway Structure Repair and Rehabilitation*, Chapter 11, Repair & Retrofit Methods). Accelerated decision making for the following disciplines is required:

The general procedures for repair of old bridges may be revised for a durable solution in the minimum possible time. These include:

- Field-verify applicable items from inspection reports.
- Conduct an in-depth evaluation inspection.
- Prepare a standard checklist of deficiencies.
- Investigate any mild defects for possible changes in physical conditions.
- Prepare cost-benefit analysis for rehabilitation versus replacement.
- Perform alternate analysis for selecting the most appropriate method of solution.
- Perform emergency repairs.

For each repair technique, the following approach is needed:

- The basic concept behind the technique
- Its successful application to specific engineering problems
- Procedure for field data acquisition
- Processing

The innovative techniques listed below are in early stages of development. They cover the use of:

1. Sample project-specific guidelines for final plans
2. Protective coating systems
3. Commercial products and services focused on mitigation technology for retrofit, restoration, and rehabilitation.

Other recent innovative developments are related to following detailed aspects:

- Methods to accelerate project completion
- Making accurate information available

- Automated generation of reports in multiple formats
- Team organization and collaboration with other disciplines

4.5.1 General repair procedures for deficient bridges

The following procedures may be applicable to any bridge repair project and need to be reviewed and adopted as necessary:

- Assessing damage and deterioration
- Load testing
- Identifying the causes of deterioration
- Developing reports
- NDT techniques
- Cementitious materials selection process
- Surface preparation
- Placement methods
- Crack and joint repairs
- Protective systems for concrete (using membranes)

4.5.2 Use of concrete repair materials

Available concrete repair materials include:

- Composites
- Polymers
- Polymer-modified cement
- Epoxy resins
- Polyurethane injection resins
- Shotcrete
- Carbon and glass fiber reinforcement

In selection of the type of repair concrete, the following factors must be considered:

- Initial and operational cost of the type of concrete
- Field evaluations
- Code acceptance

4.6 New materials and technology

Appendix 7 ASCE Report Card—Innovations and New Technology shows the emphasis in use of new materials and technology determined by ASCE for evaluating bridge performance and safety in each state. Innovative techniques include the availability of new repair materials:

- FRP composites to repair overhead sign structures
- SIKA CarboDur for general repairs
- SIKAWrap for shear strengthening

- Corporation A concrete admixture by Sika Corporation (called Sikament 686) can be used in cast-in-place or precast applications as a normal water reducer (ASTM C494 Type A) or as a high-range water reducer (ASTM C494 Type F). Increased workability is provided with no delay in normal set time.

Deicing overlays: The SafeLane surface overlay acts like a rigid sponge, storing the chemicals and automatically releasing them as conditions develop for the formation of ice or snow. This results in safer roads with better mobility and less maintenance because the overlay helps prevent frost or ice from forming on road or bridge surfaces. The final profile is about 3/8-in thick. The recommended method is outlined in *AASHTO Task Force 34*. The SafeLane surface overlay is expected to provide a robust surface for more than 15 years of service, plus the much-needed pavement seal to limit chemical and moisture penetration into the concrete bridge deck.

Smart paint: The National Science Foundation's ATLSS Engineering Research Center has developed "smart paint" with a special dye that outlines a fatigue crack in a bridge as it propagates. This paint sends out electrical signals, which are picked up by electrodes placed on either side of the paint's resin layer if the structure begins to vibrate. The electrical signal grows as vibration increases. This paint can evaluate fatigue in old bridges more accurately than strain gauges.

Corrosion protection: Certain AL water-based concrete admixtures, based on amino carboxylate technology, tolerate extreme cold and hot temperatures. The admixture forms a protective layer on embedded reinforcement that prevents corrosion caused by carbonation, chlorides, and atmospheric attacks. It provides corrosion protection for steel reinforcement, carbon steel, galvanized steel, and other metals embedded in concrete structures.

Corrosion prevention and maintenance painting of steel with protective coatings: Fluoroethylene vinyl ether resins were developed in the early 1980s in Japan. Fluoropolymers offer a number of desirable properties, among them excellent stability against ultraviolet light and the elements, corrosion resistance, and weather and chemical resistance.

Fluoropolymer topcoats now are required for use on all bridges in Japan, both for new construction and for repainting. On one of the longest Japanese bridges (a single span of the bridge is 6527 ft), the coating system was a four-coat system consisting of a number of coatings both field- and shop-applied.

Membrane waterproofing system: There are a number of proprietary products available for protecting decks, abutments, retaining walls, and foundations. Self-adhering sheet waterproofing membranes provide a simple peel-and-stick application.

Sika Corporation has sikalastic Base and Top coats.

New vendor products for rapid repairs: Hilti anchor and chemical bolts for connection details.

Seismic isolation bearings and retrofit: The seismic performance of a movable bridge requires some unique considerations, including the behavior of machinery elements and their tolerance for misalignment during earthquakes, and the issue of the requirement for seismic design when the bridge is in the open position. Surface conditions at the site are highly variable, making site-specific response analysis important.

Seismic retrofit design is based on the seismic deficiencies established through the performance evaluation. The isolation system consists of lead-core rubber seismic isolation bearings combined with semi-active viscous fluid dampers positioned between the bridge deck and end abutments. Semiactive dampers can offer an effective approach to response modification of seismically isolated highway bridge structures.

Fiberglass drains for bridges: New fiberglass drains for bridges and elevated highways are light, strong, and easy to install. Fiberglass requires fewer supports than other nonmetallic pipe, it resists corrosion, and it does not require painting.

Improved drainage manuals: Drainage system consists of scuppers installed in decks and approach slabs. Lack of rapid water disposal after rains is a recurring safety problem. A modern approach is shown in the *Ohio Drainage Guidelines* and *Tennessee Drainage Manual*.

Other modern developments include:

- Shoring and temporary works for lateral slide-in method
- Accelerated submissions and reviews (such as paperless submissions, electronic signatures)

Sample of special provisions for ABC: Refer to ToolBase Services, c/o NAHB Research Center, Upper Marlboro, MD 20774.

4.7 Modern equipment

Magnified remote cameras: The computer-based imaging system can provide spatial measurements and surface analysis. It can detect a surface flaw and determine its size, shape location, and defect details.

Developments in data recording: Examples include data loggers, data acquisition systems, and measurement and control products: data recording computer hardware devices include pen-based tablets, and notebook and desktop computers. There is often more rugged hardware available for field use. Techniques to extract data from laser-scan point clouds into 3-D Micro Station drawings have been successful.

Use of laser technology: To compute axial forces in cable-stayed bridges.

4.7.1 Construction equipment

The success of ABC is due to powerful equipment. Different erection equipment is required for girders, box beams, trusses, arches, and cable-stayed and suspension cable bridges. Timely availability, a leasing facility, and an experienced erection team will be necessary. Additionally, the contractor will need ready access to long-span freight vehicles to transport assembled bridge components, high-capacity cranes, excavation tractors, torque wrenches, etc. to efficiently transport the subassemblies of bridges and erect the bridge.

The erection contractor may also use robotics, cranes such as tower crane (for maximum lightweight pick of 20 tons and heights greater than 400 ft), lattice boom crawler cranes, mobile lattice boom cranes, mobile hydraulic cranes, and lattice ringer cranes for varying heavyweight pickups. In addition, specialized technologies for the superstructure roll-in and roll-out method using SPMTs have been provided in a recently published FHWA publication, “Manual on use of Self-Propelled Modular Transporters to Remove and Replace Bridges.”

4.8 Fiber-reinforced polymer concrete

The use of FRP bars with HPC is another development in the concrete industry. The first FRP bridge was built in Kansas in 1996. Construction followed in New York, West Virginia, Delaware, and Ohio. FRP bridge decks are used in bridge rehabilitation projects, often because of their relatively low weight and high durability. Related benefits of FRP include rapid construction and advantages in terms of lifecycle costs (e.g., corrosion resistance).

FRP is a strong material that is lightweight, durable, impervious to deicing salts, and weather resistant; it has a low lifecycle cost. There are a variety of fiber types and resins that can be used as composites. The fibers are glass, carbon, or aramid, which are brittle in solid form but have high strength in fiber form.

Some of the earliest composite materials were introduced in Egypt through the use of mud bricks with added straw to make a stronger material.

FRP is available in a variety of forms such as FRP bars, FRP grids, and tendons for prestressing. The combination of plastic and fibers produces great mechanical properties resulting in a lightweight, durable material. It is increasingly being used in strengthening applications and for deck replacements. Longer spans are now possible with lightweight aggregates and FRP, which replaces more expensive steel reinforcing bars.

Corrosion is the most common type of distress or deterioration in concrete bridges. Replacing a traditional steel bar with an FRP bar eliminates the expansion that comes with corrosion associated with steel embedded in concrete.

4.8.1 Modern rehabilitation methods with fiber-reinforced polymer

Examples of rehabilitation applications for FRP are:

- Column wraps to enhance seismic performance
- Beam wrapping to increase shear capacity.
- Bonded flange plates to increase bending capacity
- Epoxying FRP rods in grooves cut into the substrate to increase member strength
- Truss strengthening
- Wrapping aluminum columns of sign structures.

4.8.2 Federal highway administration recommendations for the use of fiber-reinforced polymer

Appropriate projects to consider include:

- A posted bridge that could benefit from a reduction in dead load and subsequent increase in live-load rating.
- A bridge that needs to be widened without imposing additional loads on the substructure.
- Superstructures less than 12 m in span (and longer spans as technology evolves).
- A historic structure that must be saved (i.e., rehabilitated instead of replaced) because of its cultural value.
- Moveable spans where the light weight can save operating expenses.

- A bridge that needs an improvement in load rating sooner than can be addressed through a capital improvement program. It is often unacceptable to program work for 5 years in the future when postings present an economic hardship.
- An accelerated schedule to installing decks or superstructures to reduce the cost of maintenance, reduces congestion, and protects traffic.

4.8.3 Advantages of fiber-reinforced polymer

- Noncorroding, unlike steel rebar
- Low maintenance
- Low fatigue
- Less dead load, high strength-to-weight ratio
- Flexural strengthening

For sign structure repairs, FRP:

- Costs less than full structural support replacement
- Allows repairs to be done quickly
- Causes less traffic disruption because only lanes beneath the repair need to be blocked off

The benefits of FRP composites have only recently been expanded to include the bridge construction industry. FRP composites have been providing practical solutions to structural problems in the aerospace, automotive, and manufacturing industries for many years. Research into FRP composites for bridge construction is still in the evolutionary stage. More information is required to provide confidence for the design of FRP bridges and for the development of design standards.

4.8.4 Disadvantages of fiber-reinforced polymer

- The cost of an FRP bridge is higher than a conventional bridge. The frequency of inspection is also greater also. Recommendations for inspection and maintenance are given in ACI 440.2R-02 "The Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures."
- Resistance to fiber is much lower than for steel rebar.

Visual inspection should record observations for:

- Changes in color
- Debonding
- Cracking
- Deflections
- Peeling
- Blistering
- Crazing

4.8.5 Fiber-reinforced polymer deck selection criteria

Span: A particular deck system is acceptable only up to the support span length at which it has been tested. There are several deck systems that can be used with steel supports spaced at 2.5 m.

Superstructures built thus far have been relatively short spans (less than 14 m). This is due to the cost of controlling deflection.

Longer spans will most likely require the use of high-performance carbon fiber or a hybrid system that utilizes concrete or another material with FRP.

Traffic volume: Though fatigue test data suggest that there is not a concern about using FRP decks on high-volume roads, the designer should be cautious about the application in an area that would be difficult to monitor or repair. Low-volume roads provide an opportunity for easy access so that more can be learned with little risk.

Cost considerations: Because an FRP deck or superstructure typically sells for a premium compared with steel and concrete, part of the scoping process must involve an evaluation of all costs associated with a project. A cost comparison should be made considering all available options. Past price ranges are:

- Decks: $65–$80/square foot of deck area
- Superstructure: $140–$150/square foot of deck area

Skew and grade: Deck manufacturers have been successful in the fabrication and installation of skewed superstructures and the use of FRP decks on skewed steel bridges. At the present time, there are no general restrictions on such use, but caution is advised in these circumstances. The same is true for percentage grade.

Depth: FRP decks are commonly available as a 200-mm (8-in)-deep section, although custom depths are available. During design, a rule of thumb can be used for the depth of an FRP superstructure: 1 in for each foot of span.

Specific design criteria for FRP are:

- To avoid long-term creep, predicted strains under design load shall be less than 20% of the FRP composite's minimum guaranteed ultimate strength. The ultimate strength is based on coupon testing and is noted in the approved plans.
- An environmental durability factor of 0.65 may be applied to the material properties, to account for degradation of properties over time.
- Because of the material's typical low modulus of elasticity, most designs will be driven by deflection limitations and not strength requirements. Although the criterion for deflection is somewhat arbitrary, it is typically kept at 1/800 of the supporting span length.

Research is required in the areas of long-term environmental effects on FRP:

- In identifying the various failure modes of FRP composites
- In developing design methodologies
- In developing efficient connections to utilize the advantageous properties of FRP composite sections

4.8.6 Fiber-reinforced polymer–retrofitted reinforced concrete beam-column joints

Researchers at the University of Queensland, Brisbane, Australia, along with researchers at Iranian universities, have investigated theoretical and experimental behavior of concrete beam-to-column joint specimens (unstrengthened and FRP-strengthened).

ANSYS finite element software was used for modeling reinforce concrete (RC) exterior joints. The specimens were loaded using a step-by-step load increment procedure to simulate the cyclic loading regime employed in testing.

The results show that the hysteretic simulation is satisfactory for both unstrengthened and FRP-strengthened specimens. Strengthening FRP sheets in the connection zone moves plastic hinges forward from the end of the beam to a reasonable distance, and decreases the maximum concrete strain in the joint region.

FRP sheets enhance the load carrying capacity, ductility, and energy dissipation of the joint and seismic performance of RC members after cracking, steel yielding, and concrete crushing during push and pull loading cycles.

4.8.7 Use of preimpregnated carbon fiber reinforced polymer and steel reinforced polymer sheets

For strengthening of decks, reinforcement of columns, and repairs of retaining walls, the use of carbon fiber sheets is gaining popularity (e.g., see those supplied by Mitsubishi Chemical Corporation).

Recently, a comparison of four techniques for strengthening concrete beams was performed by Richard Harrison et al. of Kansas University and Tarek Alkhrdaji. In addition to using externally bonded FRP as a successful technique for strengthening concrete members, other techniques like near-surface mounted (NSM) FRP bars have emerged as viable alternatives.

Four composite-based strengthening systems were designed to provide equivalent flexural performance. These systems are:

- Externally bonded CFRP sheets
- NSM prefabricated CFRP strips
- Externally bonded steel reinforced polymer sheets known as hardwire
- NSM stainless steel bars

4.8.8 Use of laminated fiber-reinforced rubber to reduce collision impacts

The energy absorption capacity of laminated fiber reinforced rubber installed at girder ends was studied at National Defense Academy by Japanese researchers and compared well with ordinary rubbers. It was concluded that during the collision, laminated fiber-reinforced rubber could reduce the impact force more than ordinary rubber. It was also concluded that the energy absorption could be estimated by using mass-spring systems for the impact force during the collision.

New York State installed its first FRP composite bridge in October 1998. Because FRPs are relatively new, a comprehensive test program, comprising load tests and visual inspections every 6 months and detailed finite-element analysis, is being carried out to monitor the structure and also to evaluate its long-term durability.

4.8.9 Use of fiber-reinforced polymer to repair sign structures

The problems cited most frequently with regard to sign and pole structures are weld defects and general fatigue cracking. Joint cracking between the internal trussing and the main chords of the sign structure is very common and other issues include the following:

- Improperly maintained aluminum overhead sign structures create hazards.
- Lack of inspection during fabrication can yield poor-quality joint welds.
- Insufficient construction supervision may result in internal stresses in an overhead sign structure before the sign is attached.

The greatest contributor may be that fatigue design was not a code requirement, when many trusses were designed in the 1960s. FRP composite materials have the potential to revolutionize the repair of sign structures with cracked secondary support members. Repair is accomplished with FRP by cleaning the damaged area of the sign support thoroughly and wrapping FRP around it. Repairs can be done in place, with only the lanes below the repair area blocked off.

Research shows FRP repairs are as strong as welded joints. The specification covers restoration of the tensile capacity of secondary sign structural members, such as internal truss diagonals, and not main members, such as longitudinal truss chords.

The benefits include:

- It costs less than full structural support replacement.
- It allows repairs to be done quickly.
- It causes less traffic disruption because only lanes beneath repair need to be blocked off.

4.8.10 Use of glass fiber–reinforced polymer for a lightweight emergency bridge

Experimental investigations performed on lightweight bridges made of high-performance materials have demonstrated a potential market. A single-lane bridge with a small span was using pultruded glass–fiber profiles has been shown to be cost-effective. This material is commonly available in the market in connection with bonded steel reinforcement for bolted joints. A testing program was executed to provide information on the failure criteria and temperature behavior of these bonded hybrid connections.

4.8.11 Use of glass fiber-reinforced polymer concrete

Research Program at Villanova University: Professor Yost gave a seminar sponsored by Structural Engineering Institute (when the author served as the founder chair of SEI in Philadelphia). Figure 4.2 shows a test in progress on scaled model. Glass Fiber Reinforced Polymer Concrete bridge decks seem to fail at higher loads than the conventional concrete decks and their use can be promoted.

Deck Pour (08 February 2012) – GFRP reinforced deck (Truck C)

FIGURE 4.2

Study of scale models of bridge decks using durable concrete.

4.8.12 Self-consolidating/compacting concrete

The ease of placement and reduced demand for skilled labor are the main advantages of using SCC. It can be used with high-range water reducers to achieve high early-strength concrete. Proper curing is critical.

SCC has very high slump and flowability properties without segregation. It uses specialty admixtures, which radically modify slump and flowability. Examples of such admixtures are viscous modifiers and high-performance polycarboxylate polymers. SCC is an improved version of HPC, with compressive and tensile strengths exceeding those of normal concrete.

Benefits are:

- It provides superior appearance and long-term durability.
- It eliminates the need for vibration.
- The resulting concrete is totally homogeneous with a uniform surface finish.
- To further enhance durability, a calcium-nitrite corrosion inhibitor may be added to the mix.
- It attains higher quality control resulting with f_c' values in excess of 9 ksi.
- The voids and honeycombing seen in many traditional concrete mixes are avoided.
- It can be used successfully in new construction projects with difficult placement or finishing.
- It is effective for repairs of concrete honeycombing.
- It is effective for strengthening projects when material must be placed under pressure into confined forms with highly congested reinforcement.
- The concrete is so flowable that instead of measuring the height of the slump cone, the diameter of the circular blob that pours out of a slump test cone is measured.
- Concrete pumping is easier. Forms do not have to be vibrated to consolidate concrete.
- There are labor savings because crews can pour large repair areas using a single pump.
- Because vibration time is saved, SCC helps ABC; it is a more workable concrete with lower permeability than conventional concretes.

SCC for use in drilled shaft applications: When conventional concrete is used in congested drilled shafts, coarse aggregates may bridge between reinforcing bars, which may lead to segregation of the concrete between the inside and outside of the reinforcing cage. SCC is feasible for use in congested drilled shaft applications.

4.8.13 Performance of blended cement in high-performance self-consolidating concrete

Rice husk is an agricultural waste generated in massive quantities from rice-processing units worldwide. With no worthwhile use, it is a waste material that creates disposal problems. Its high silica content makes it suitable for use with cement.

Tahir Kibriya of National University of Sciences and Technology, Pakistan, has investigated the use of blended cement with rice husk ash, in SCC, and the results suggest improved strength/durability. This experimental study aimed at evaluating the properties of high-strength SCC made from blended cements using rice husk ash, Portland cement, natural aggregates, and sand. Wide-ranging investigations covering most aspects of mechanical behavior and permeability were carried out for various mixes for compressive strengths of 60 N/mm^2, 80 N/mm^2, and 100 N/mm^2.

Compressive strengths of high-strength SCC specimen with blended cements were observed to be higher by about 4–9% than the control specimen, for concrete with 50% Portland cement blended with 50% rice husk ash.

Higher elastic moduli and reduced permeabilities were observed along with better sulfate and acid resistance. Better strengths and improved durability of such high-strength SCC make it a more acceptable material for construction.

4.8.14 Advantages of using shrinkage-compensating cement

The following influences both autogenous and total shrinkage of HPC when using shrinkage-compensating cement:

- Amount of binder
- Percentage of silica fume
- Water-to-binder ratio
- Type of super plasticizer, cement, and aggregate

Shrinkage can be measured under isothermal conditions and constant humidity of the environment. Shrinkage development in HPC can be reduced by using shrinkage-compensating cement in lieu of Type 1 cement, to help eliminate drying shrinkage cracking of bridge decks.

4.8.15 Materials specifications

- The cement shall be expansive hydraulic cement.
- Admixtures used in the concrete mixture must be compatible.
- Coarse aggregate stockpiles shall be saturated. Saturation shall be completed a minimum of 24 h before use; however, the application of water by sprinkling shall continue as directed by the engineer.
- The maximum water/cement ratio shall be between 0.4 and 0.45.
- Slump at the time and point of concrete placement shall be 3–6 in, except for concrete used to slipform bridge medians and parapets. The contractor may elect to slipform the bridge medians or parapets.
- The use of super plasticizers may be required to achieve a placeable concrete within the specified slump range and to meet the maximum water/cement ratio.
- Concrete shall contain 6 ± 2% of entrained air at the time and place of concrete placement.
- The maximum ambient temperature at the time of placement of concrete shall be 80 °F.
- Deck formwork beam flanges and reinforcing shall be thoroughly sprinkled with water before placement of the concrete.
- Sprinkled areas shall remain damp until placement of concrete; however, no excess standing water will be allowed.
- Concrete shall be placed when the rate of evaporation is less than 0.2 lb/ft^2/h. Atmospheric conditions shall be monitored throughout the pour. If the evaporation rate is exceeded the pour shall be stopped.

Curing: Storage tanks for curing water shall be onsite and filled before a pour will be permitted to start. Storage tanks shall remain onsite throughout the entire cure period. They shall be replenished, as required, with a shuttle tanker truck or a local water source such as a fire hydrant.

The finished surface shall be covered with a single layer of clean wet burlap. The fresh concrete surface shall receive a wet burlap cure for 7 days. For the entire curing period, the burlap shall be kept wet by the continuous application of water through soaker hoses. Either a white opaque polyethylene film or a wet burlap-white opaque polyethylene sheet shall be used to cover the wet burlap for the entire curing period.

4.8.16 Ultra high-performance fiber-reinforced concrete

Generally, concrete bridges are more commonly used for smaller spans since rust in steel members can increases corrosion and maintenance costs. When using UHPFRC, a compressive strength of 30 ksi is possible with flexural strength exceeding 7 ksi. The mixture of carbon nanotubes and polymer used in UHPFRC is very strong and has electrical properties that let it act as a sensor skin. This skin essentially provides a detailed multidimensional view of the behavior of a structure. Applied like paint or in prefabricated panels, it provides both protection and constant updates on a structure's condition from all over its surface rather than just a few spots.

Calcium silicate hydrate, a naturally occurring material in cement, is made up of particles little more than a nanometer in size. Carbon nanotubes have been incorporated in steel to give it added strength. The material also can be poured thinner than conventional concrete. UHPFRC also won't break off in chunks as reinforced concrete can. If microscopic steel fibers are embedded in the concrete, it provides more than 10 times the strength of conventional concrete.

Researchers in Britain have explored the behavior in of UHPFRC in explosions and studied its potential for use in security barriers and buildings where terrorist attacks could be a threat. Research studies were carried out by the following organizations:

- Ductal: Lafarge's trade name for UHPFRC (Vic Perry).
- University of Liverpool (Steve Millard).
- University of Michigan in Ann Arbor (Jerome Lynch).
- National Research Council's Institute for Research in Construction in Ottawa.
- Whitemud Resources Ltd. of Calgary promotes water-resistant concrete made with metakaolin.
- Remington Partners, Cambridge, Massachusetts (David Sykes), offers stronger steel that permits soaring, airy designs.

4.9 Lightweight concrete

In the early 1900s, Stephen Hayde discovered a method to manufacture lightweight aggregates (LWA) from shale, clay, and slate. Some bricks bloated during burning. Development of the rotary kiln process began in 1908. A patent for expanding LWA using a rotary kiln process was granted in 1918. The first use of LWC in a bridge project was on the San Francisco–Oakland Bay Bridge. The upper deck of suspension spans was constructed using all LWC in 1936. The lower deck was rebuilt with LWC for highway traffic in 1958. Both decks are still in service. As noted previously, the raw material is shale, clay, or slate. It expands in a kiln at 1900–2200 °F. Gas bubbles formed in softened material are trapped when cooled.

4.9.1 Benefits of LWC

Reduced weight of precast elements
Improves handling, shipping, and erection
Can also improve structural efficiency
Reduced permeability
Tighter quality control with a specified density
Can be used to achieve both accelerated construction and longer-life structures
Enhanced durability
Improved bond between aggregate and paste
Elastic compatibility
Internal curing
Reduced cracking tendency
Resistance to chloride intrusion
Fire resistance
Resistance to freezing and thawing
Wear and skid resistance
Alkali-silica reactivity resistance

The absorbed moisture within LWA is released over time into the concrete; this provides enhanced curing, which can give the following benefits:

Increased hydration of cement and SCMs
Especially helpful for HPC with low w/cm, which is often used for rapid construction or repairs
HPC impermeable to externally applied curing water
Improves tolerance of concrete to inadequate or improper curing, which can be an issue with ABC
Shown to reduce shrinkage and permeability.

The AASHTO LRFD specifications (Section 5.2) for LWC define it as “concrete containing lightweight aggregate and having an air-dry unit weight not exceeding 0.120 kcf.” Normal weight concrete is defined as “concrete having a weight between 0.135 and 0.155 kcf.”

NCHRP Report 380 “Transverse Cracking in Newly Constructed Bridge Decks” (1996) states that “Using low-elasticity aggregates should therefore reduce thermal and shrinkage stresses, and the risk or severity of transverse cracking.” It recommends using concretes with a low cracking tendency, which have a low early modulus of elasticity and are low early strength concrete. LWC has a lower modulus but retains strength.

With regard to the density of LWC, “equilibrium density” is defined in ASTM C 567 as density after moisture loss has occurred with time. This is often used for dead load calculations. “Fresh density” is used for quality control tests during casting. It must be used for precast member weight at early age.

- Concrete that falls between these definitions is often called specified density concrete.
- NCHRP Report 380, “Transverse Cracking in Newly Constructed Bridge Decks” (1996), states “using low-elasticity aggregates should therefore reduce thermal and shrinkage stresses, and the risk or severity of transverse cracking.”
- Different gradations are addressed in AASHTO M 195.

A seminar on low-density aggregates organized by TXI, producers of expanded shale and clay products, was held in Boulder, Colorado. Expanded shale is extracted from the mines and crushed and sized before being kiln fired at temperatures up to 2000 °F. The Expanded Shale, Clay and Slate Institute (ESCSI) of Salt Lake City, Utah, published a brochure (#4020) on structural lightweight concrete as incorporated by the American Concrete Institute (ACI) Code (section 318). The ACI Code covers all aspects of design. It will conform to ASTM C330, "Lightweight Aggregates for Structural Concrete." This type of concrete will be produced by the rotary kiln process (such as aggregate types Ridgelite, Hydrolite, Baypor, or Realite) for structural applications of concrete with compressive strengths of 2000–9000 psi or greater.

The following publications provide greater detail:

Kowalsky, M.J., Priestley, N., Seible, F., January–February 1999. Shear and flexural behavior of lightweight concrete bridge columns in seismic regions. ACI Structural Journal.

Sarkar, S.L., May 1999. Durability of lightweight aggregate pavement. Concrete International.

Holm, T.A., 1995. "Lightweight concrete and aggregates" – authorized reprint from *Standard Technical Publication* (STP 169C).

Harding, M.A., July 1995. Structural lightweight aggregate concrete. Concrete Construction.

Other references are listed in the Bibliography section at the end of the chapters in this book.

The many advantages of LWC may be summarized as follows:

- Reduced weight of precast elements.
- It has lower modulus but retains strength.
- LWA is just a lighter rock!
- A nonconcrete application for LWA is geotechnical fill.
- It can be used on ABC projects. LWC can be used to achieve both accelerated construction and longer-life structures.
- Enhanced durability because of:
  - Bond between aggregate and paste
  - Elastic compatibility
  - Internal curing
  - Reduced cracking tendency
  - Resistance to chloride intrusion
  - Fire resistance
  - Resistance to freezing and thawing
  - Wear and skid resistance
  - Alkali-silica reactivity resistance
- Tighter quality control with a specified density.
- It can be beneficial for substructures and decks.
- The time-dependent effects are creep, shrinkage, and losses.
- Improves handling, shipping, and erection.
- Can also improve structural efficiency.
- Reduces permeability.

Using high-performance lightweight aggregates: Lightweight HPC reduces deadweight, enables longer span lengths, and reduces the number of piers in a river thereby causing the least obstruction to fish travel. Spliced girders of varying depth enable lightweight concrete to achieve spans of more than 200 ft.

The advantage of using lightweight HPC in precast concrete is to reduce concrete density by more than 30%. Typical PBES applications are as follows:

- All LWC density 105 Pcf
- Sand LWC density120 Pcf
- Specified density concrete 135 Pcf

Research at Auburn University, Alabama, by Neill Allen Belk on the Evaluation of Lightweight Aggregate Concrete showed the feasibility of using LWC in precast, prestressed driven piles.

The ACI 318 (2011) correction factor for lightweight concrete (λ) of 0.85 was shown to be overly conservative when used to predict the 28-day splitting tensile strengths for lightweight concrete, prepared and cured according to the laboratory curing regime presented here. The tension and compressive stresses within all of the piles were less than the AASHTO (2010) stress limits.

Visit the ESCSI Website (http://www.escsi.org) for more info on the properties of LWA and LWC. In addition to stress reduction resulting from lower density during seismic conditions, the following advantages are possible leading to savings in a project:

- Comparisons often neglect other sources of savings in a project
- Reduced handling and transportation costs
- Reduced cost and time for substructure and foundations
- Reduced erection and rental costs
- Reduced structural modifications for bridge rehabilitation projects

4.10 Prefabricated bridge decks and overlays

Contractors must be knowledgeable about the latest technology and availability of new bridge components. It is important to develop typical connection details for precast deck panels, piers, and abutments and improve the quality of the superstructure by fabricating in a more controlled factory environment.

Technical service is being provided on websites for bridge products such as precast deck units, girders with welded shear connectors, diaphragms, bearings, parapets, precast pier units, etc. Quick assembly is possible by systems such as Conspan, Inverset, Effideck, drop-in deck panels, and posttensioning in both directions. Applying segmental construction for long spans is one method to use ABC. The balanced cantilever method eliminates the need of formwork.

4.10.1 Exodermic bridge deck

An Exodermic bridge deck is composed of a reinforced concrete slab on top of, and composite with, an unfilled steel grid. Exodermic decks are made composite with the steel superstructure by welding headed studs to stringers, floor beams, and main girders as applicable, and embedding these headed studs in full depth concrete.

This system maximizes the use of the compressive strength of concrete and the tensile strength of steel. Reducing the dead load of the deck with this system can increase the live load rating.

Precast Exodermic decks have the benefit of quick installation; they can be erected during short, nighttime work periods, allowing a bridge to be kept fully open to traffic during higher traffic volume hours. Exodermic decks require no field welding other than that required for the placement (with an automatic tool) of the headed shear studs.

The major advantage to the system, besides reduced dead load, is the installation time. Approximately 750–1000 ft^2 of the cast-in-place system can be installed in a standard 8-h period. Using a precast Exodermic system, 1900 ft^2 was installed on the Gowanus Expressway per overnight closing in 2001 and 2000 ft^2 per 7-h closing was installed on the Tappan Zee Bridge in 1997. Cracking is dependent on properly cured concrete and the relative stiffness of the superstructure.

The manufacturer suggests using an overlay system and prefers an asphalt overlay over LMC or other concrete overlays to increase the speed of construction. Overlays also allow for accommodating vertical geometric variations as opposed to a bare concrete deck.

Constraints: The cost of an Exodermic deck is approximately twice the initial construction cost of a cast-in-place deck (materials only). Bridges that do not have simple horizontal and vertical geometry and involve severe skews, small radii curves, or variable cross slopes should use the cast-in-place decks, negating the accelerated construction advantages of the system.

4.10.2 Corrosion protection for concrete

Bayer Material Science, a corrosion protection manufacturer, has designed thick film coatings for industrial waterproofing applications, such as concrete and metal bridge decks. Its physical and chemical properties include resistance to wear and abrasion, excellent tensile strength, a homogeneous seal on cracked, porous, and cellular substrates, corrosion resistance for metal substrates, good weather ability, resistance to microbes, and good chemical resistance. Baytec SPR spray systems can be pigmented to any color.

4.10.3 Deck overlays

With the advent of low-permeability HPC, many states are building bridges with bare concrete decks, without wearing surfaces. Highway agencies place bituminous concrete overlays on bridge decks to:

- Reduce roadway noise in urban residential environments
- Improve the riding surface
- Protect the deck from deterioration.

However, the bituminous overlay is porous and not waterproof. The overlay tends to trap moisture on the top of the concrete deck. This can lead to accelerated deterioration of the deck from the infiltration of water and deicing salts.

The European approach to deck protection is to use bituminous overlays combined with high-quality waterproofing membranes. This approach has yielded long-lasting bridge decks that can meet the AASHTO goal of a 75-year service life. Anecdotal information on bridges built with bituminous overlays and waterproofing systems in Connecticut in the 1960s indicated that they have performed well over the past 50 years.

The use of prefabricated bridge deck elements will inevitably require the use of joints between elements. Construction of the elements will also require reasonable fabrication and erection tolerances. These issues will lead to an uneven riding surface.

Several states have used “diamond grinding” to smooth out the deck after installation of the elements. The concrete cover in the elements should be thick enough to accommodate the grinding operation.

Overlays can therefore be used to eliminate the need for grinding. The application of a concrete overlay will require additional time and bridge closures to place the overlay. For very fast construction projects, this can be accomplished after the bridge is reopened to traffic. The Virginia DOT has developed a very-early-strength LMC overlay. Research has shown that this material can be placed and cured in as little as 3 h; it provides low permeability and high bond strength. The overlay can serve as a tolerance adjustment during the construction of the prefabricated structure.

4.10.4 Polymer concrete bridge deck overlay systems

After removal of an existing overlay, the underlying deck can be repaired. Placement of a new overlay will seal out moisture and chloride ions and prevent them from permeating into the deck. The overlay systems have a 10-y life span. These systems can be used in conjunction with a primer to fill cracks and patch partial depth bridge deck spalls in concrete, such as:

- Polyester polymers
- Epoxy-urethane polymers
- Other engineered polymers that are used to protect the existing deck and improve the riding surface

LMC and corrosion inhibitor aggregate concrete are also used.

Polyester polymer concrete overlay systems can achieve 4000 psi in compressive strength and 1600 psi in flexural strength within 24 h, and the bridge can accommodate traffic because of the fast curing system, which also allows traffic to be resumed within a few hours at temperatures lower than 40 °F.

Epoxy-urethane copolymer systems bridge existing cracks, yield an impervious barrier with chloride ion penetration resistance, and provide a high-skid and wear-resistant surface. The system remains flexible throughout its lifecycle and at low temperatures.

The polymer overlay systems have the following advantages:

- Rapid repair of shallow deck spalls and overlaying for quick return of traffic (overnight work)
- Superior adhesion to concrete surfaces
- Material is easily applied

The disadvantages to these systems include:

- Lower lifespan than deck replacement
- Requires a sound deck (all spalls repaired and no full depth spall repairs)

Manufacturers of polyester polymer concrete bridge deck systems include Kwik Bond, and manufacturers of epoxy-urethane co-polymer systems include Poly-Carb, Inc.

4.10.5 Bridge deck expansion joints

Bridge deck expansion joints have caused premature deterioration of bridge decks and supporting framing. Most states are therefore designing jointless bridges using integral abutments and continuous superstructures. But on larger bridges, deck expansion joints may be required.

Joints that are placed within the overlay are typically not affected by ABC methods. The joint can be installed in the same manner as with conventional construction. For embedded joint systems, it is difficult to install the joints within the prefabricated elements to the required tolerances. The best way is to install the joint system within small closure pours, after the installation of the prefabricated bridge deck.

4.10.6 Concrete barriers

Some projects have anchored precast concrete barriers to prefabricated decks by through bolting the parapet to the deck. The bolt projects down below the deck and is secured with a nut and an anchor plate. If this connection is used, it should be properly sealed.

The Use of Integral Utah DOT has designed and built several prefabricated bridge decks with the concrete barrier cast onto the deck in the fabrication shop. The dead load distribution of the parapet weight needs to be addressed, because it may not be the same as a conventional cast-in-place construction (refer to Utah DOT, Bridge Construction Manual, and Figure 6.5-1 Precast Deck Panel with Integral Barriers).

A longitudinal closure pour can be used to make up for casting and erection tolerances as well as provide a location to accommodate a roadway crown angle point.

4.10.7 Developing lightweight carbon-fiber arches filled with concrete

The innovative “bridge-in-a-backpack” technology (developed by the University of Maine Composites Center) has been discussed. It uses carbon-fiber tubes that are inflated, shaped into arches, and infused with resin before being moved into place. The tubes are then filled with concrete, producing arches that are harder than steel yet resistant to corrosion. Finally, the arches are overlaid with a fiber-reinforced decking.

The University of Maine researchers have estimated their bridge’s carbon footprint to be about one-third less than that of a standard concrete bridge and one-fourth less than a standard steel bridge. The technology has the potential for future use because of its light weight and the portability of its components.

4.10.8 Precast concrete steel composite superstructure units

The advantages of precast concrete steel composite superstructure (PCSCS) units are:

- Rapid installation: Erection times of 1 h per unit after deck removal is complete allow for overnight or weekend installation.
- Reduced beam depth.
- Year-round installation.
- Because of precompression in the concrete deck, deck cracking is minimized.

- Improved quality because of controlled environment construction. The primary disadvantages of this system include:
- The initial construction cost of a prefabricated system is approximately 50% more than that of a normal superstructure.
- Precompressed concrete cannot be replaced in the field. Any future redecking would require removal of the entire unit or a reduction in the capacity of the system.
- Repair of corrosion-related deterioration in concrete structures offers unique challenges. The "ring-anode" effect is a common cause of premature patch failure. It increases corrosion activity adjacent to a repair area. The ring-anode effect is caused by electrochemical incompatibility between reinforcing steel within a patch and steel embedded within surrounding concrete.

4.10.9 Example of panel-to-girder connection

A strong positive connection between the precast panels and the supporting girders is required to create a composite deck-girder system. Because of the use of ABC, the Utah DOT (UDOT) and Federal Highways Project at 4500 South and I-215 East replaced Structure F-156 on SR-266 over I-215 and reduced impacts to the traveling public by using ABC.

- The new superstructure was constructed offsite.
- The new substructure was constructed under the existing bridge.
- After the new structure was complete, the existing structure was removed and the new superstructure was moved into its final location using an SPMT system.

Schedule challenges included:

- Designing and constructing the bridge in 8 months.
- Removing and replacing the bridge in 58 h.
- Retaining the existing abutments (Figure 4.3).
- Excavating and constructing the new abutments in a confined work area and beneath the existing bridge.

Maintaining continuous traffic on 4500 South and on I-215 created a complicated substructure construction. Extensive height and width restrictions existed. Holes were created in the existing deck to pour the new foundation walls. The new girder seats actually touched the bottom of the existing girders.

The Construction Manager/General Contractor (CMGC) contracting method was used for this project. Benefits of the CMGC contracting process included:

- Ability to coordinate with the contractor's subcontractors upfront.
- Ability to coordinate with utility companies early in the project. Early contractor involvement in the project.
- Constant input and coordination on schedule and cost.
- Design focuses on contractor strengths.
- All the answers are not required upfront but can be developed throughout the project.
- Flexibility to provide early action items and early release packages (structural steel procurement and temporary site construction).
- Delivery of project within a tight schedule.

FIGURE 4.3

Construction of first abutment.

The areas of improvement include:

- Determining a method for improving construction cost estimates early in the design process since the cost of the project is determined as the design progresses. Providing more design time to investigate alternatives, optimizing design, and improving constructability.
- Defining clearly the roles and responsibilities of the team regarding the design engineer and the construction engineer.
- Setting up the UDOT Project Development Business System to handle CMGC projects more effectively or provide a different process for CMGC projects.

Benefits of the design process included:

- Designer and contractor working together as one team.
- Ability to visit the site constantly to ensure design requirements are met and design schedule is maintained.
- Early communication and coordination between the designer, contractor, and mover.

Areas of Improvement include:

- Knowing the design direction for the project upfront with owner-defined goals.
- Planning up front for more design associated with temporary works.
- Obtaining the contractor and subcontractors earlier in the process.

The benefits of the construction process included:

- Designer and contractor working together as one team.
- Ability to have a contingency plan in place due to unforeseen complications.
- Ability to have multiple pre-event meetings with the entire team to examine every step.

Areas of improvement include:

- Limiting the number of nonproject personnel on the job site to limit exposure, risk, and liability from the contractor.
- Coordinating more effectively between owner and contractor regarding site access.
- Developing a checklist for items to evaluate during construction.
- Providing a more detailed plan for the remaining tasks after the bridge move (grading plans, landscaping, staging area, and nonstructural items).
- Developing a protocol for site visitation for all individuals.
- Scheduling tour times if necessary.
- Investigating cheaper alternatives for temporary work.
- Scheduling adequate time for curing requirements of concrete work.
- Planning for adequate space at the staging area for the significant amount of SPMT equipment delivered to the site.

Benefits of the SPMT process included:

- Designer, contractor, and specialty contractor working together as one team.
- UDOT gained experience with the use of SPMTs.
- Ability to construct the new bridge and minimize traffic disruptions.

Areas of improvement include:

- Provide additional contingency in the conceptual cost estimate when a new technology is being implemented.
- Write specifications to promote accelerated bridge construction and the use of SPMTs (Figure 4.4).

Benefits of the public involvement process included:

- Printed information available to the public early in the project.
- Media and public informed throughout the project.

Areas of improvement include:

- Define clear expectations for the project and the timeline of the bridge move more clearly to the public.
- Provide more information in the public viewing area during the bridge move.
- Provide restroom facilities for all public viewers.

The department saved more than $4 million in user delay costs by using accelerated bridge construction techniques.

FIGURE 4.4

Assembled superstructure transported by SPMT.

4.11 Use of recycled concrete aggregate

RCA is not a cement substitute. Conventional concrete aggregate consists of sand (fine aggregate) and various sizes and shapes of gravel or stones. The coarse aggregate portion of RCA has no significant adverse effects on desirable mixture proportions or workability.

Recycled fines, when used, are generally limited to about 30% of the fine aggregate portion of the mixture. It is important to note the difference between aggregate and cement, because some materials are used as both a cementitious material and as aggregate (such as certain blast furnace slags).

4.11.1 Procedure for recycled concrete aggregate reuse

RCA is generally obtained as debris from defunct bridge structures/decks, retaining walls, sidewalks, and curbs that are being removed from service. Concrete can be crushed to a desired gradation. The material is cleaned of unwanted material such as bricks, wood, steel, ceramics, and glass. The aggregate must be "clean," without absorbed chemicals, clay coatings, and other fine materials in concentrations that could alter the hydration and bond of the cement paste.

4.11.2 Resource conservation

Several factors can be considered in this category:

- Reduced land disposal and dumping: The use of recycled concrete pavement eliminates the development of waste stockpiles of concrete.

- Recycled material can be used within the same metropolitan area, which can lead to a decrease in energy consumption from hauling and producing aggregate.
- It can help improve air quality through reduced transportation source emissions.
- Conservation of virgin aggregate: many European countries have placed a tax on the use of virgin aggregates. This process is being used as an incentive to recycle aggregates.

New concrete made with RCA typically has good workability, durability, and resistance to saturated freeze-thaw action. Aggregate composed of recycled concrete generally has a lower specific gravity and a higher absorption than conventional gravel aggregate. Lack of widespread reliable data on aggregate substitutes can hinder its use.

Aggregate typically accounts for 70–80% of concrete volume. Aggregates can have a significant effect on the cost of the concrete mixture. As the cost of quarrying for aggregates continues to rise, it makes engineering sense to preserve natural aggregate for future use.

Aggregate plays a substantial role in determining concrete's:

- Workability
- Strength
- Dimensional stability
- Durability

Concrete made with RCA has at least two-thirds the compressive strength and modulus of elasticity of natural aggregate concrete. The compressive strength varies with the compressive strength of the original concrete and the water-cement ratio of the new concrete.

The angularity of RCA helps to increase structural strength in the base, resulting in improved load carrying capacity.

- Residual cementation provides a strong, durable platform upon which to build. The inclusion of RCA in the concrete mix and a suitable fly ash has the potential to reduce the distress.
- RCA offers better control over gradation. It is able to meet gradation and angularity requirements.
- RCA has the potential to minimize D-cracking (which is caused by the freeze-thaw expansive pressures of certain types of aggregate) and the alkali silica reaction, which is caused by the detrimental reaction between silica found in certain aggregate and the alkali (cement) paste. Field-testing has shown that crushed and screened waste glass may be used as a sand substitute in concrete. Nearly all waste glass can be used in concrete applications, including glass that is unsuitable for uses such as glass bottle recycling.

4.11.3 State standards and participation by states

There are no standard regulations currently addressing the use of alternative concrete aggregate for engineered use or structural applications. Some states such as Washington and local codes specifically address the use of alternative aggregate.

In the United States, at least 140 million tons of concrete is recycled every year. Several states have high tipping fees for disposal of RCA; this is being done to control landfill usage, thus increasing the reuse of RCA. The Oregon DOT has already taken a lead in this respect on a large scale.

4.11.4 Benefits and costs of recycled materials

Use of any recycled material helps to keep that material out of landfills. Recycling practices also can decrease the environmental impact of obtaining and manufacturing the material from virgin resources.

4.11.5 Glass aggregate

Glass aggregate has the following advantages and benefits:

- Typically acts as a crack arrestor
- Benefits concrete durability (depending on the specific glass aggregate properties, the concrete, and its end use)
- Allows a greater range of aesthetic/decorative options for concrete
- Concrete unit cost decreases
- Lowering of freight cost
- Avoids landfill costs

4.11.6 Recommendations for recycled concrete aggregate use

It will be useful to include special provisions in construction contracts to track and implement waste management activities. There is a need to develop mix design and procedures for the reuse of chunks of aggregates with cement mortar coating salvaged from the debris. A sieve analysis and laboratory tests may be carried out.

4.12 Applications of innovative precast members

4.12.1 Full-depth precast concrete deck panels

A study of FDDP was prepared by the PCI Committee on Bridges and the PCI Bridge Producers Committee and cosponsored by FHWA. The cracking of FDDP is substantially controlled. The concrete used is mature. It has already undergone most of its cement hydration temperature change, shrinkage, and creep. The panels can be prestressed in the plant and posttensioned at the site, creating two-way precompression. For the properties of FDDP, see Table 4.2.

Table 4.2 Advantages of Full-Depth Precast Concrete Deck Panels

Criteria	Advantages
Construction speed	High
Shrinkage cracking	Eliminated
Hydration temperature cracking	Eliminated
Formwork	Eliminated
Maintenance cost	Low
Structural integrity	Maintained
Adaptability for continuous span bridges	Yes

Available resources on FDDP:
Refer to PCI (www.pci.org)

- State-of-the-Art Report on Full-Depth Precast Concrete Bridge Deck Panels, PCI Report No. SOA-01-1911 (2011)
- Full Depth Deck Panels Guidelines for Accelerated Bridge Deck Replacement or Construction, PCI Report No. PCINER-11-FDDP, 2nd edition (2011)
- PCI Journal papers (30+ papers, 1970s-2011). Citation for many of these papers is provided in the SOA report.

4.12.2 Effideck Bridge Deck System

The proprietary precast concrete deck replacement Effideck System can act compositely when the shear stud connectors are attached to the stringers through pockets in the deck. The system consists of modular deck panels of 5-in thickness supported by closely spaced hollow structural section steel tubes.

The panels can span either in the transverse direction between bridge stringers or in the longitudinal direction between floor beams. The panels are bolted to the existing bridge stringers from above the deck and the pockets are then grouted.

Advantages of the Effideck system include:

1. All installation work is performed from the top of the deck, resulting in faster installation without the cost of scaffolding.
2. A steel-on-steel load path ensures that the deck can support load even before the completion of the grouting process.
3. Typical panel weight is lighter that a conventional precast concrete deck panel.
4. Efficient connection details facilitate overnight installation.

4.13 Alternatives to concrete materials

4.13.1 Accelerated cure cast-in-place concrete

Accelerated cured cast-in-place concrete uses low-slump accelerated concrete in conjunction with the maturity method to obtain design compressive strengths in 12–15 h. Warmer concrete temperatures result in a higher rate of hydration, or more rapid strength gain, and colder concrete hydrates more slowly.

The use of accelerated cure cast-in-place concrete allows for deck replacements to be performed over a series of weekend work cycles or other 3-day cycles. The strengths and design life of this system are similar to conventional CIP concrete.

The disadvantage to this system is that high quality control, particularly in regard to the water content and concrete slump, is essential for concrete performance. Although the use of maturity loggers has been successful in New York State, it is not familiar to most contractors; it has a short history and for cast-in-place concrete it is more susceptible to cracking, especially during staged construction.

4.13.2 Reactive powder concrete bridge girders

The benefits of using RPC to carry bursting forces in prestressed bridge girders are significant. Tests are reported in literature on three RPC 150-MPa-deep beams. They have shown significant potential advantages to using RPC in bridge engineering.

4.13.3 Use of the cementitious materials fly ash, blast furnace slag, and silica fume

Concrete can be made more sustainable by use of cementitious materials such as fly ash, which is obtained from coal-fired power plants. About 70 million tons of fly ash is produced each year in the United States, but only about 15 million tons of it ends up in concrete products. It's a way to make roads, sidewalks, and bridges stronger and longer-lasting.

Fly ash from power plants and ground-up slag left over from the steelmaking process can replace some of that cement, and it can make the final product stronger. When mixed with cement, the kind of fly ash produced by burning anthracite and bituminous coal keeps reacting with water to strengthen the concrete nearly a month after pouring.

Silica fume is a key ingredient in high-performance concrete. It significantly increases the life of structures. It is a byproduct of silicon and Ferro-silicon metal production. It is a highly reactive pozzolan and its use decreases silica fume volume in the national waste stream. The *Silica Fume User's Manual* and a standard reference manual are available from the National Institute of Science & Technology, Gaithersburg, MD.

4.14 Use of other recyclable materials

4.14.1 Recyclable steel and waste products

Reinforcing steel and prestressing strands have always been recyclable. Steel used in old ships is salvaged and sold as scrap. The steel is removed and recycled.

Various solid wastes for use as construction materials include:

- Fiberglass waste materials,
- Granulated plastics,
- Paper and wood products wastes,
- Sintered sludge pellets, and others.
- The only two that have been significantly applied for recycling are glass cullet and crushed recycled concrete itself.

4.14.2 Use of recycled glass

Some of the specific glass waste materials that have found use as fine aggregate are "nonrecyclable" clear window glass and fluorescent bulbs with very small amounts of contaminants. Possible applications for such waste-glass concrete are bike paths, footpaths, gutters, and similar nonstructural work.

Field testing has shown that crushed and screened waste glass may be used as a sand substitute in concrete. Nearly all waste glass can be used in concrete applications, including glass unsuitable for uses such as glass bottle recycling.

Glass aggregate in concrete can be problematic because of the alkali silica reaction between the cement paste and the glass aggregate, which over time can lead to weakened concrete and decreased long-term durability. Further research is still needed before glass cullet can be used in structural concrete.

4.14.3 Use of new technology with glass fiber rebars[2]

Steel is often damaged by the hot and humid climate in the region. Newly developed glass fiber reinforcing bars could mean an end to corrosion, which is often a problem in reinforced concrete structures; the glass fiber reinforcing bars made by German company Schoeck Bauteile GmbH may mean a longer life span for concrete structures, in addition to lower maintenance costs, which may be required as early as 10 years after going into service.

The large fiber content and linear alignment of the fibers are achieved at the pultrusion stage, the manufacturing process that produces continuous lengths of reinforced polymer structural shapes. Helical ribs are also cut into the hardened bars to insure an optimal bond between the rebars and the surrounding concrete.

4.14.4 Use of recycled plastics

Recycled polymers have a range of uses from bridges, footpaths, and fences to even flood prevention. It will not chip or splinter and is even vandal-proof, and the environmental benefits are huge. Despite their versatility the manufacturer cannot use polyvinyl chloride or thermo-set plastics such as polyurethane in the production process.

Plastics that are often not usable by most plastic recyclers consequently end up in the waste stream. A vast amount of mixed plastic ends up in landfills. Innovative recycling technology can use plastic waste such that it outperforms the traditional alternatives of wood, steel, and concrete products.

4.15 Conclusions

This chapter addresses the philosophy of maintaining the right of way at all times for all the citizens. There has to be a reward to promote innovation and incur risk. The most recent initiatives and innovation techniques promoted by federal agencies such as FHWA and AASHTO and states, which are active in implementing ABC for faster bridge delivery are described.

Comparative study of conventional and innovative methods, new design methods, development of diverse repair technologies.

Modern Construction Equipment, list of FHWA and other ABC initiatives such as safety edge, ABC, Use of Recyclable Materials, examples of recent ABC applications in USA. The scope of D-B contracts and considerations of engineering ethics are addressed.

Progress has been made in the use of new construction materials and new deck overlays. Important issues of ensuring adequate returns of the hundreds of billions of dollars of yearly investments in infrastructure by rapid bridge delivery are discussed. To meet the objectives of ABC, materials, prefabrication, training, and construction equipment and early warning system are the prime factors.

[2]Adapted from Jimaa R, "An End to Corrosion with Glass Fiber Rebars," ConstructionWeekOnline.com, May 14, 2011, http://www.constructionweekonline.com/article-12336-an-end-to-corrosion-with-glass-fibre-rebars/1/print/#.Up-AY2RDsu4.

Innovations help in upgrading the quality of construction and in completing the project in a timely manner. A list of advancements in ABC methods are shown:

Preventing bridge failures—By minimizing the identified deficiencies by maintenance.

Use of advanced methods—Using the computer-aided analysis and design techniques.

Closer interaction between design documents and construction.

Continued research efforts in resolving technical issues.

Common examples of innovative concepts are ground-penetrating radar, staged construction, overhead and utility lines, environmental permits, road closures versus detours, precast and composite decks, and use of stainless steel need to be resolved.

On the administrative side, new procedures for asset management, award of simultaneous multiple contracts, AHC to accompany ABC are introduced.

Use of nanotechnology to reveal cracks and corrosion, studying photographic evidence of defects, remote sensing technologies would certainly help in rapid bridge inspection and SHM.

There has been a revolution in modern concrete technology and in precasting industry. The new concrete materials comprise of a variety of amazing high-strength materials, minimizing the dependence on diminishing steel.

The long list includes HPC, UHPC, FRP concrete, ultra HPFRC, CFRP concrete, and GFRP concrete.

In addition, there are developments in the use of SCC, lightweight aggregate concrete, RCA concrete, accelerated cure cast-in-place concrete, blended cement concrete, fiber mesh concrete, RPC, and rapid setting concrete.

Special repair materials have been developed by researchers. They include nonshrink, multipurpose, and high-strength repair mortar. Cementitious materials concrete use fly ash, blast furnace slag, and silica fume materials.

Examples of proprietary bridge systems are Robotic steel beam assembly by ZEMAN system adding a new dimension of structural steel fabrication and erection. The system is designed for fully automated assembling, tack-welding, and full welding of structural steel elements.

Recycled plastic lumber bridges, lightweight titanium pedestrian bridge, Inverset, Effideck bridge deck, Exodermic bridge deck, and FDDP.

Deck overlays use durable deck surfaces such as LMC and corrosion inhibitor aggregates concrete.

The following recommendations are made for future progress in the specialized subject of ABC:

Recommendations for ABC:

1. **Applications to steel bridges:** Use temporary bridges in place of detours using quick erection and demolition; availability of patented bridges in steel; US Bridge, Inverset, Acrow, and Mabey types and case studies.
2. Applications to glulam and sawn lumber bridges, precast concrete bridges, precast joints details; use of lightweight aggregate concrete, aluminum, and HPS to reduce mass and ease transportation and erection; availability of patented bridges in concrete such as Conspan.
3. Connection details for seismic design; dismantling components and reuse at another site.
4. There are case studies of successful ABC, such as applications to glulam and sawn lumber bridges, precast concrete bridges, precast joints details; use of lightweight aggregate concrete, aluminum, and high-performance steel to reduce mass and ease of transportation and erection.

5. **Training workshops on constructability:** The importance of training was discussed in Chapter 3. Appendix 2 shows workshops and webinar topics conducted by FHWA and FIU. Important topics may include but are not limited to, crane locations, maintenance and protection of traffic, construction duration, access and right-of-way, and material availability.
6. A feasibility study for selecting a bridge for ABC needs to be carried out. FHWA has prepared a network shown in Figure 4.1.
7. Performance requirements for successful design-build project delivery, application of LD3 Technique, greater role of post design activities prior to construction, emphasis on constructability Planning and review, fabrication and erection feasibility, construction sequencing, material availability and transport, site accessibility, and construction schedule will be addressed. A constructability review will be done during design.

Most of the topics discussed here are new and specialized ones, and explanations may require a chapter each, which is outside the scope of this book on ABC. Computer software and design details for pin-jointed assemblies and other practical aspects are addressed in later chapters.

For details on the numerous topics, whose references are not listed in the text, please see bibliography at the end of book.

For additional information on the above numerous topics, please see the bibliography at the end of book in Appendix 1.

A list of Bridge Inspection Terminology and Sufficiency Ratings used by PennDOT is given in Appendix 3.

SECTION 2

Recent Developments in ABC Concepts

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CHAPTER

Modular Bridge Construction Issues

5

5.1 Prefabricated bridge elements and systems

5.1.1 Introduction

In earlier chapters 2 and 4, the concepts of PBES were introduced. The prefabrication of bridge elements appears to have revolutionized the transportation industry, increasing efficiency through faster delivery. Prefabrication is an essential part of unlocking the benefits of ABC. Modern technology in construction techniques has provided new avenues of production. In this chapter the latest trends and the many advantages of purchasing ready-made bridges by using prefabrication methods are addressed.

A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2: ABC.

Examples of development of a wide range and variety of successful projects completed in the United States in recent years are presented in Tables 5.1–5.7. Full prefabrication for both superstructure and substructure components is shown. Superstructure applications adopted by various states include steel girders, trusses, and precast concrete I shape and box girders according to design requirements and availability for speedy construction.

In the past few years, a number of states have jumped on the ABC bandwagon and have been at the forefront of promoting and implementing innovative technologies. Like many other industries such as car manufacture, "the supply should always meet timely demand." Further details of interesting projects completed in selected states are provided in Chapter 8.

The following bridge construction methods can incorporate ABC and related prefabrication methods:

- A new bridge on a new highway.
- A replacement bridge on an existing footprint: this involves demolition and staged construction, and a temporary bridge or detour is required.
- A replacement bridge on a new footprint: deck widening and additional lanes may be required.
- Deck replacement only.
- Repairs to deck only.
- Deck and girder replacement only.
- Bearings retrofit and upgrades.
- Repairs to substructure only.

Details of repairs required for steel beams and connections are described. Ongoing research is focused on identifying and developing new bridge elements and systems for all materials that would help accelerate bridge construction.

Prefabricated bridge elements and systems (PBES) are manufactured off-site, ready for installation when they are brought to the construction site. Bridge elements are the basic building blocks of bridge construction, such as deck panels, girders, pier caps, columns, pile cap footings, and foundations.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00005-8

PBES offer costs savings in both small and large projects. Construction can be completed during limited-duration off-peak lane closings. Prefabricated systems allow bridges to be built in days or weeks rather than months or years, and the manufacture can be accomplished in a controlled environment without concern for job-site limitations; this increases quality and can lower costs.

Shipment of precast components to the job site reduces the impact on the environment. Finally, prefabricating takes elements and systems out of the critical path of a project schedule. Precast fabricators can produce quality components or systems in a controlled plant environment in much less time than is required on-site. Improved quality translates to lower life-cycle costs and longer service life.

The quicker installation of prefabricated bridges will minimize the huge daily delay-related user indirect costs. Also, daily traffic control costs from installing and maintaining traffic control devices, flagging, lighting, and detours will be a drain on DOT budget.

Minimize life-cycle costs: No bridge is designed to last forever. Bridges need repairs, rehabilitation, or replacement to deal with increased live load and widening. Maintenance expenses are recurring and the extent of work is based on yearly inspection reports. They may apply to over 50% of the inventory of bridges in a given state.

Substructure construction duration: Bridge construction and rehabilitation extending over several months has become a primary source of congestion. In cast-in-place construction, foundations for piers and abutments must be built first. Then pier columns and caps must be built before beams and decks are placed. However, off-site prefabrication technologies and processes help solve this problem.

5.1.2 Practical considerations for prefabrication

Prefabrication is a specialized subject for analysis and design. Connection details between components need to be safe. The contractor needs guidance on many issues of long-term performance. The consultant needs to perform research to come up with the right solutions. The conventional contracting system lacks focus on the new fabrication technology issues and feedback can only come from research results obtained during construction.

Achieving accelerated construction requires an experienced consultant, as well as experienced engineers and field staff. Other requirements and benefits of ABC and PBES include:

Training: Technicians need training in specialized manufacturing processes.

Equipment: Availability of high-capacity construction equipment.

Lighter material: Availability of stronger and lighter materials also contributes to the uniform quality of bridge components. Bridges installed using PBES have a life of 75–100 years.

Transportation of modular bridges: Availability of self-propelled modular transporters (SPMTs).

Leadership in the application of ABC: Updates and technical guidance to be provided by the federal agencies such as FHWA, AASHTO, TRB, etc.

Design-build: Simplified contract management procedures will lead to improved modern day communications between the contractor, the consultant, and the owner due to video conferencing and use of e-mails and cell phones, etc. helping to expedite construction.

Priority of bridges for accelerated repair: The buildup of inventory to fix, repair, and replace an increasing number of bridges as they get older and the capability of highway agencies to meet the challenges. Provision of much-needed social benefits to the public can be achieved through early completion and rehabilitation of highways and bridges.

Time and cost savings: The role of ABC in the multibillion dollar transportation industry is significant. Building upon the progress in prefabrication made in multistory building construction and car parks, stadiums, etc. will be helpful.
Labor availability: Relocation of large workforces to the construction sites for cast-in-place construction is no longer necessary with factory production.
Improved connection details and construction specifications: These are now available due to research in seismic design and flood-control measures at bridges. The construction of most bridge elements and systems can be done with controlled fabrication.

5.1.3 Types of modular prefabricated deck slabs

Innovative bridge designers and builders are finding ways to prefabricate entire segments of the superstructure. This may involve prefabricated truss spans and preconstructed composite units that are fabricated or assembled at or away from the project site and then lifted into place in one operation.

The maximum dead load in a bridge comes from the deck slab that gravitates to girders, bearings, substructure, and the foundations. If this weight can be reduced, there will be savings throughout as the supporting components will be lighter.

New materials being used for decks are high-performance concrete (HPC) and corrosion inhibitor aggregate concrete. Common precast deck shapes are rectangular, skew, or curved.

Precast construction has improved tolerances during manufacture and it helps control minimum sight distance in curved bridges and superelevation of concrete decks, thereby reducing accidents.

Precasting integrates quality control and avoids reinforcement steel placement, concrete pouring, and weeks of curing.

Partial-depth prefabricated deck panels act as stay-in-place forms that help accelerate and control construction for decks that are more durable than fully cast-in-place decks. Full-depth prefabricated bridge decks also facilitate construction; bridge designers are finding innovative ways to connect full-depth panels.

5.1.4 Precedence of prefabrication success in building structures

For a long time, prefabricated floor panels have been successfully used in buildings. Spans are generally less than 15 ft in length and have much smaller live load intensity than bridges. Special tractors are not generally required for the small spans. Slabs and beams are lighter in weight and low-capacity cranes are sufficient for erection. Initially, smaller-span bridges and pedestrian bridges (with live load similar to buildings) were selected for prefabrication.

Since the concepts of prefabrication for buildings and bridges are similar, there has been recent development in long-span prefabrication technology. In general, multistory parking garages and sports stadiums have now adopted prefabrication methods. This helps reduce congestion and traffic on the busy city streets.

5.1.4.1 Comparison of impact of modular construction in tall buildings to that for bridges

Accelerated construction is not just for expediting new bridges. There are techniques in which a building is manufactured piecemeal on a factory assembly line, trucked to the construction site, and erected much the way Legos are.

Modular construction is gaining popularity across New York City, as reported by an ASCE Smartbrief, dated March 11, 2013. It is taking 4 months to manufacture the modules, during which time the team has been building the foundation at the site.

5.2 General prefabrication criteria

The main benefits of using prefabrication as compared to conventional construction are time savings and cost savings.

5.2.1 Construction time savings

Bridge construction times can be reduced significantly by using precast columns. Columns can be segmented, post-tensioned, reinforced, hollow, or solid concrete. The quicker installation of prefabricated bridges will minimize the huge daily delay-related user indirect costs. With PBES, it has been possible to construct an assembled small-span bridge in a single weekend.

Conventional construction methods require many time-consuming on-site activities, which delay the project, such as formwork construction, rebar and concrete placement, concrete curing, and formwork removal. Other related tasks, including office planning, coordination, and scheduling of these tasks.

Many of these activities are weather-dependent. Savings from PBES installations are possible when the construction season is limited by weather and when many elements are required for a project.

Construction specifications are usually reviewed and approved by highway agency project managers. The documents are made available for use in future projects. Also, records of bid tabs and cost incurred for individual or new items can be used as guidelines in the planning of the future projects.

5.2.2 Construction cost savings

The cost savings with PBES are equally compelling. The approach of the Georgia Department of Transportation (GDOT) saved approximately $1.98 million, or 45% of what an interchange would have cost if it had been built with conventional construction practices.

Foundations for piers and abutments must be built first. Pier columns and caps must be built before beams and decks are placed. Because prefabrication technologies and processes were used, those elements could be constructed off-site and away from traffic, and brought to the project ready to erect.

Whereas conventional construction would have increased trip time by 25%, travel delays with PBES were rare. Scheduling deliveries for nonpeak traffic hours further minimized inconveniences to the traveling public. Lane closures were minimized.

5.2.3 Meeting sustainability: context-sensitive design and environmental requirements

Context-sensitive design (CSD) is a modern development that meets the needs of the present without compromising the ability of future generations to meet their own needs. CSD is a collaborative interdisciplinary approach that involves stakeholders in developing transportation facilities that utilize “smart bridge” or “green bridge” concepts while maintaining safety and mobility on bridges. This can deliver environmental, aesthetic, and scenic benefits, and also maintain some historic bridges.

CSD is a collaborative interdisciplinary approach that involves the preservation of environmental, historic, aesthetic, and scenic resources while maintaining safety and mobility on bridges.

FHWA initiatives in sustainability are being promoted by ASCE and many states. These include organizing training courses in CSD for engineers. Some of the steps are:

Safety and durability
Compliance with environmental and preservation laws
Application of CSD
Heat resistance
No painting
Use of the balanced cantilever method, which eliminates the need for formwork
Bio-retention ponds that collect and filter runoff from the bridge deck
Interactive touch-screens featuring bridge information
Solar roof panel at approaches for bridge lighting and signage.

HP sustainable concrete bridges: These bridges use coal combustion products. By-products of coal fuel such as fly ash, flue gas desulfurization materials, boiler slag, and bottom ash provide extraordinary technical, commercial, and sustainable advantages.

FHWA initiatives in sustainability examples are:

Compliance with the EPA environmental and preservation laws.
Heat and cold resistance.
Use of bio-retention ponds that collect and filter runoff from the bridge deck.
Use of interactive touch screens featuring bridge information for the drivers.
- Use of solar panels at approaches for bridge lighting and signage.
- Use of the balanced cantilever method to eliminate the need of formwork for segmental construction.

Prefabrication helps sustainability through healthy disposal of construction debris and avoiding any harm to the fauna and flora for bridges on rivers.

5.2.4 Constraints in historic bridge preservation

It must be pointed out that prefabrication for any unusual historic components of old bridges is a delicate operation. It is not easy to reproduce antique and artistic details associated with historic bridges, such as old parapets. The prefabrication of bridge components should be consistent with historic bridge requirements.

If bridge work needs to be done on historic bridges, coordination with the State Historic Preservation Officer (SHPO) is required during the preliminary planning stages. Appropriate pieces of the existing bridge can be incorporated into the modified or replacement bridge. Artistic parapets, stone work cladding, bridge monuments, or plaques can be salvaged and added on to the new bridge components in factory conditions. This approach may result in improved quality and cost savings.

5.2.5 Best candidates for PBES

According to the funding and legal requirements, it is necessary to follow the design guidelines given in the state design manual. If the physical conditions do not allow the use of the state manual, a modification needs to be requested from the chief bridge engineer of the state for using the new design details.

Where bridge construction poses unusual hazards to worker safety and traveler inconvenience, using PBES can alleviate those conditions. If the bridge is essential as an evacuation route, or if the bridge replaces an existing essential structure, the speed of PBES installation also makes it an obvious choice over traditional construction.

When several prefabrication projects have been completed, based on the experience gained, it should be possible to frame regulations similar to the AASHTO LRFD technical specifications. The best candidates for prefabrication are those projects when many similar bridges need to be constructed. In the future, it is expected that the practical details of similar bridge elements can be standardized.

Rapid on-site construction warrants acquiring data by addressing planning issues such as:

Emergency bridge replacement: These scenarios benefit from the use of prefabricated systems. The existing bridge must be replaced in the least time possible to minimize traffic disruption.
Sensitive bridges: Located on an evacuation route, or over a railroad or navigable waterway.
Public outreach: Feedback obtained from the users and the public, by holding town hall meetings, can be helpful. It should be explained to them that prefabricated bridges are being used in the interests of the public as they have a particular advantage over conventional bridges and they greatly expedite on-site installation.
Minimization of construction impacts on traffic: In terms of requiring lane closures or detours.
High average daily traffic (ADT) or high average daily truck traffic (ADTT): Safety concerns and costs may be reduced with the advance planning of PBES.
Critical path method (*CPM*): Bridge construction should be listed on the critical path of the complete project.
Bridge closure: During off-peak traffic periods such as nights and weekends preferred.
Decision-making guidance: Issues that must be addressed in deciding early on the use of PBES include the following:
Knowledge and experience of local bridge contractors and techniques that are needed to construct bridges with PBES components.
The lack of knowledge and experience in PBES design and detailing of new types of connections between precast components and the durability and performance of the connection details.
The ability of PBES to accommodate complex bridge geometry.
Limitations on component size and availability of equipment to erect components.
Availability of prefabricators who are capable of producing components.

5.2.5.1 Additional benefits for quick demolition and installation

PBES increases the speed of installation, reducing disruption. In just an overnight operation, crews can:

- Cut the old bridgespans into segments and remove them.
- Prepare the gaps/clear spans to match the new composite deck lengths.
- Lower and set the new fabricated unit to fit in place.

In addition, quick installation minimizes the huge delay-related costs and the daily traffic control costs. Construction, when scheduled for the fall months, has the benefit of more predictable weather. Also, when not using precast deck units, casting in place a single-course deck slab will save a minimum of 6 weeks in construction time compared to a two-course deck slab.

5.2.6 Superstructure installation methods

Prefabrication is successful with the advanced techniques developed for installation. These methods are discussed in detail in a later chapter, and consist of the following:

- Overhead large-capacity cranes
- Gantry cranes
- Lateral slide-in systems
- Roll-in roll-out method (using Hillman-type rollers)
- Longitudinal launching systems
- Installation using SPMTs.

Sometimes overhead wires can be problematic for crane operations. If overhead wires cannot be moved, one of the above installation methods can be used depending upon the cost and field constraints.

Summary of PBES: To reiterate, PBES methods offer significant advantages over on-site cast-in-place construction. As stated earlier, among these advantages is a substantial reduction in the on-site time that is required to construct or rehabilitate a bridge. The lowest costs result from off-site manufacturing through the use of standardized components, and in addition there is improved safety due to reduced exposure time in the work zone. The controlled environment of off-site fabrication also ensures quality components for long-term service.

Urban Traffic: As the U.S. interstate highway system approaches the end of its service life, urban congestion continues to grow. Traffic volume increases every year on the majority of highways in the United States. The projected freight tonnage is expected to increase considerably on some highways by 2020.

5.2.7 Maintenance and protection of traffic during ABC

Some work on the approaches and the bridge deck will require a detour taking into consideration the existing bridge width. The consultant will investigate the traffic detour alternatives: either to detour one direction of traffic or both directions. The team must evaluate pedestrian movement to provide safe passage to the pedestrians during construction. All bridgework involves managing the existing traffic during construction.

5.2.8 Feasible alternatives to manage traffic flow

The feasible alternatives are:

- Maintaining traffic on a temporary bridge
- Maintaining traffic on the existing structure while a new structure is constructed on a new alignment
- Maintaining traffic on a portion of the existing structure through staged construction.

This decision is based upon many conditions, including engineering feasibility, cost-effectiveness, ADT/truck traffic, impact on local economy and emergency services, environmental impact, and right-of-way. Adequate public coordination must exist in order to minimize adverse impact. Often there will be opposition to shutting down a bridge because it will result in unacceptable delays and detours. There is too much local opposition to shutting down the bridge. There are some temporary measures that can be enlisted to keep the bridge open:

- When the structure is in an advanced stage of deterioration, partial lane closure may be adopted by posting lower load limits
- Continue using the bridge on a temporary basis if there is high traffic volume
- Develop a traffic scheme using the standard procedures of the Manual on Uniform Traffic Control Devices (MUTCD) and other work zone guidelines.

5.2.9 Staging planning in lieu of lane closure or adopting a detour

The reasons for adopting ABC include the daily rush hour difficulties faced by road users during ®construction periods, safety, and using staged construction.

A traffic count needs to be performed to assess impact on traffic flow during construction. Warning signs must be placed weeks in advance so that the users may select an alternate route to avoid congestion.

Lane closures: Local authorities should be contacted to determine if they have any restrictions regarding lane closures.

Prior to developing staging plans, the agency's Traffic Operations Department will provide the maximum allowable lane closure hours in each direction and the maximum number of lanes that can be closed at one time. A night window of 8–10 h is required for the contractor to properly complete the work. Extra hours will be permitted for weekend work.

Construction staging plans shall include cross-sections of the bridge for each stage of construction. Fewer stages will give less time for completion. Two main stages are preferred over three or four, although there may be substages.

Traffic control plans: Structural drawings showing construction in each stage should conform to traffic control plans. A set of applicable standard traffic control plans is to be used as a basis for developing the final traffic control plans. These plans shall be customized to reflect site conditions and the ability of the shoulder to withstand traffic.

- Plans must comply with MUTCD and AASHTO LRFD regulations. All nonstandard signs shall be sized according to the MUTCD with letter heights and alphabet size given for each line.
- All traffic control schemes and detour plans on local roads, if applicable, must be approved by local authorities.

5.3 Promoting prefabrication by FHWA and others

Earlier chapters the progress in ABC by FHWA, other engineering organizations and universities. Modern prefabricated construction materials and methods are vastly different from traditional methods and require innovative ideas for making the system safe and efficient. There is a wealth of information being provided through manuals, workshops, and conferences. Since new construction methods cost hundreds of billion dollars each year, it is worthwhile studying the savings. Each technique may require a small brochure describing its many aspects.

5.3.1 Improvements in the manufacture of ready-made bridges

The FHWA, through its Innovative Bridge Research and Construction program and the Resource Center, strongly recommends prefabrication for accelerated construction. AASHTO and FHWA are encouraging prefabrication technology because of the many advantages for bridge owners, engineers, builders, and the traveling public.

Notable topics discussed include:

- Effective decision-making framework and guidelines
- SMPT manual and specifications
- Connection details
- Use of mechanical rollers
- ABC design manual and training
- Project data and workshop material
- Innovative contracting strategies.

FHWA has recently developed a program to promote accelerated construction through the use of precast bridge elements. Many initiatives taken by FHWA, AASHTO, and FIU in promoting fabrication are appreciated, as they are a step in the right direction. The following sensitive issues need consideration.

New bridge systems are needed that will allow components to be fabricated off-site and transported to the bridge site for quick assembly with minimal disruption to the traveling public.

Depending on the specific site conditions, the use of prefabricated bridge systems can minimize traffic disruption, improve work zone safety, reduce the impact on the environment, and improve constructability, increase quality, and lower life-cycle costs.

This technology is applicable and needed for both the rehabilitation of existing bridges and the construction of new bridges. Also, daily traffic control costs from installing and maintaining traffic control devices, flagging, lighting, and detours will be a drain on any DOT's budget.

- The dead load distribution of the parapet weight is not the same as in conventional cast-in-place construction. The fascia beam may end up carrying more dead load than what is normally assumed in design. The designers need to modify the design of the girders. It may be possible to mitigate this through the use of leveling bolts. There will be torsion due to eccentricity of the parapet shared by all interior girders, which needs to be computed. The AASHTO LRFD Bridge Design Specifications have requirements for barrier end zones that are different from interior span zones. This may require different reinforcing than what is used on conventional barrier designs.
- *Effect of joints in precast parapets*: This project details a higher level of mechanical interlocking capacity using a diamond shape (NCHRP 12-41). It promotes cost- and time-saving techniques.

5.4 Advancements in prefabrication technology by AASHTO and the prestressed concrete institute

5.4.1 Introduction

There are several types of rapid construction technologies currently used in the United States. One technology uses precast concrete bridge components that are fabricated off-site, allowed to cure, and then transported to the construction site for installation (shown in Figure 5.1). This technology

FIGURE 5.1

View of a semitrailer traveling to the site for erection by crane.

allows bridges to be constructed faster than traditional construction methods, reducing the amount of time the bridge and/or associated roads are closed to the public, and reducing the total construction time. For bridges above waterways, the construction time is also reduced; thus the amount of debris that falls from the construction site is reduced, which in turn reduces the environmental impact.

The widely used PCI Bridge Design Manual provides concrete girder shapes with standard dimensions and properties of typical sections. Examples of standard sections are as follows:

AASHTO solid and voided slab beam—For small spans
AASHTO box beams—For small and medium spans
ASHTO I-beam—For small and medium spans
AASHTO-PCI bulb-tee—For small and medium spans
Deck bulb-tees—For small spans
Double tee beam—For small and medium spans
AASHTO-PCI-ASBI standard segment for span-by-span construction—For long spans
AASHTO-PCI-ASBI standard segment for balanced cantilever construction segments—For long spans.

Their selection is based on the following design considerations:

- Live load intensity such as HS 20, HS 25 and H 20
- Other AASHTO-specified loads such as braking forces and earthquake, etc.
- Girder spacing of 5–12 ft (or using adjacent box beams)
- Boundary conditions such as partial continuity at supports provided by the deck slab
- Other special requirements such as transportation and erection

There are six different types of AASHTO I beams : Type I (28″ deep) to Type VI (72″ deep).

The precast prestressed units are available off the shelf from the manufacturing companies, and only a limited notice of delivery to the construction sites is required. However, it is not easy to connect I shapes with the precast deck slabs. Composite sections are possible with the cast-in-place deck slabs. To make composite sections with the deck slab, vertical rebar shear connectors are required. Transverse diaphragms provide stability for the longitudinal girders and help transfer the loads.

5.4.2 Ready-made technology for full-depth decks

Quick assembly of bridges has advanced in the recent years, in part through the use of superstructure proprietary systems for new bridges and bridge rehabilitation, such as:

CONSPAN: A complete assembled small-span reinforced concrete bridge.
Inverset: The method uses composite rolled steel joists and concrete deck panels. Prefabricated deck panels for three single-span Route 1 bridges over Olden Avenue and Mulberry Avenue in Trenton, New Jersey were constructed in 2005, over weekends.
Effideck precast systems: Prefabricated deck panels using "Effideck" were used for the replacement of a Route 1 Bridge in Trenton, New Jersey, paving the way for future rapid construction and minimal traffic impacts. Unique details are provided in the NJDOT Bridge Design Manual for reference.
SpaanSpan: A low-profile, precast concrete, through-girder bridge system that uses post-tensioned edge girders and precast drop-in deck panels in which after installation, the deck is post-tensioned in the longitudinal and transverse directions.
Exodermic bridge deck: This combines a reinforced concrete slab on top of, and composite with, a steel grid. Exodermic decks are made composite with the steel superstructure with headed studs welded to stringers, floor beams, and main girders through blackouts in the precast concrete.
Orthotropic decks: Rebars allow two-way bending and load transfer.
Open steel grid bridge flooring: A steel grid–reinforced concrete deck system, which can be precast prior to installation, for both temporary and permanent bridge decking applications.
Use of prefabricated trusses.
Low-cost design alternates, which include reducing the number of steel girders with HPS.

Figure 5.2 shows a full-depth slab-beam precast deck section. The voids allow selected utility pipes to pass through by concealing them against exposure to weather.

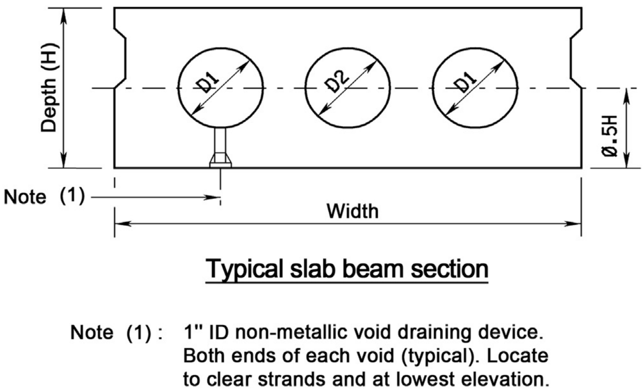

FIGURE 5.2

Precast prestressed slab beams used in New Jersey.

5.4.3 Partial-depth prefabricated deck panels

These act as stay-in-place forms that help accelerate and control construction for decks that are more durable than fully cast-in-place decks. Full-depth prefabricated bridge decks also facilitate construction; bridge designers are finding innovative ways to connect full-depth panels.

Partial ABC retains conventional design-bid-build construction management but uses precast and partly assembled superstructure and substructure components. For example, NJDOT uses precast, prestressed hollow adjacent girders for small spans, without an 8-in. thick structural slab. This may be regarded as achieving partial ABC. It reduces the dead loads on the substructure.

Full ABC requires design-build management of precast and assembled components. Conventional, partial ABC, and ABC-managed bridges will all be designed for the same live load, wind and snow loads, etc. In each case, lighter density materials can be used; therefore member cross-sections will be smaller and dead load, thermal, and seismic forces will be lower on the substructure and the foundations.

5.4.4 Deck replacement applications with prefabricated full-depth panels

Table 5.1 provides information from selected states (Kentucky, New York, and Virginia) on completed full-depth panel projects. For further details, see the FHWA ABC Website. Since there is no design code available, the listed design details can be used for guidance.

5.4.5 Partial prefabricated bridge elements and systems

Prefabrication technology in the United States is not new. When the deck slab and girders are prefabricated separately, partial advantages of composite behavior will result. Welded or rolled steel girders and precast, prestressed girders have been used in many of the older bridges, since AASHTO standardized the I-shaped girders a long time ago. Hawaii has successfully used partial-depth panels for their superstructures (as shown in Table 5.2).

Table 5.1 Examples of Successful Projects Completed in the United States for Prefabrication of Full-Depth Panels

Name	Location	Built	Description	Prefabrication
U.S. 27 over Pitman Creek	Somerset, KY	1993	700-foot bridge	Full-depth deck panels
Troy–Menands Bridge	Between City of Troy and Village of Menands, Rensselaer/Albany Counties, New York	1995	Six panels: 900 square feet of deck area per night	Exodermic precast concrete full-depth deck panels using lightweight concrete
Route 7 over Route 50	Route 7 over Route 50 bridges, Fairfax County, Virginia	1999	Replace approx. 14,000 square feet of bridge deck	Precast deck panels (lightweight); placement of rapid-setting concrete overlay supporting full traffic after only 3 h of curing

5.4.6 Prefabrication of full precast concrete superstructure components

Table 5.3 shows many U.S. states, such as New York, Pennsylvania, Texas, Virginia, Washington, and West Virginia, using a fully prefabricated superstructure. Design details may vary for each state, but Inverset applications are more popular. The units are brought to the site by SPMTs, lifted by high-capacity cranes, and placed into position on top of the bearings, to which they are anchored.

Table 5.2 Example of Successful Project Completed in the United States for Prefabrication of Partial-Depth Panels Only

Name	Location	Built	Description	Prefabrication
Keaiwa Stream Bridge	Route 11 near Pahala, Hawaii	2000	Seven-span, 230-ft long concrete bridge	Precast pretensioned partial-depth deck panels

Table 5.3 Examples of Successful Projects Completed in the United States for Full Prefabrication of Superstructure

Name	Location	Built	Description	Prefabrication
I-10 over Lake Pontchartrain		2002	Span 65 ft long and 46 ft wide	7.5-in. concrete slab cast on precast prestressed concrete girders
Tappan Zee Bridge	Hudson River, 13 miles north of New York City	1998	16,000-ft Tappan Zee Bridge carries 130,000 vehicles per day	Exodermic precast concrete, full-depth deck panels
Main Street over Metro North Railroad	Tuckahoe, New York	2000	Through-girder bridge	Precast prestressed concrete and steel composite superstructure
Norfolk Southern Railroad Bridge over I-76	I-76 east of U.S. Rte. 202 Interchange, Upper Merion Township, Montgomery County, Pennsylvania	2002	240-ft long, 42-ft high, 740-ton steel truss railroad bridge	Truss raised onto four 330-ton Hillman rollers and hydraulic winches used to pull it to its final position over the expressway
Lavaca Bay Causeway	Between Port Lavaca and Point Comfort, over Lavaca Bay, Texas	1961	Existing causeway	Precast monolithic beams, precast prestressed deck composite units
U.S. 59 under Dunlavy, Hazard, Mandel, and Woodhead Streets	Arch bridge on U.S. 59 (TxDOT)	1995	Attractive tied-arch bridges; structures suspend a thin slab from two tied arches 45 ft apart	Existing bridges used as work platforms for erecting arches. Prestressed deck panels precast in segments and bolted to erection beams to eliminate the need for falsework under the bridge.

Continued

Table 5.3 Examples of Successful Projects Completed in the United States for Full Prefabrication of Superstructure—cont'd

Name	Location	Built	Description	Prefabrication
Wesley Street Bridge	Ragsdale Creek in Jacksonville	2002		Precast prestressed slab beams
Dead Run and Turkey Run Bridges	George Washington Memorial Parkway, Virginia	1998	Dead Run Bridge has three spans, with two structures 305 ft long. Turkey Run has four spans, two structures 402 ft long	Full-depth noncomposite deck panels used for both the bridges
Richville Road Bridge	Manchester, Vermont	2001	Single-span bridge 69 ft long and 32 ft 8 in. wide	Three Inverset units consisted of two rolled beams with a precast reinforced concrete deck
Northeast 8th Street Bridge	NE 8th over IH 405 in Bellevue, Washington	2004	328 ft long and 121.5 ft wide	Totally prefabricated bridges
Lewis and Clark Bridge	SR 433 across Columbia River between Oregon and Washington state	2004	Steel truss bridge 5478 ft long and 34 ft wide, with 34 spans	Full-depth deck panels and precast approach slabs
I-5/South 38th Street Interchange	Tacoma, Washington	2001	Two-span, 325-ft replacement bridge	Precast post-tensioned box girder, tub girder segments, full-depth deck panels
Howell's Mill Bridge	County Road 1 over Mud River in Cabell County, West Virginia	2003	245-ft long bridge and 32.5 ft wide, with two spans.	Fiber-reinforced polymer (FRP) deck panels (8 by 32.5-ft) on weathering steel beams
Market Street Bridge	Wheeling, West Virginia	2001	180 ft 6 in. long with a single span 177 ft long	FRP deck and sidewalks replacement with half-inch wearing surface of polyurethane concrete and granite chips

5.4.7 Lightweight prefabricated trusses using timber and aluminum

For pedestrian, small-span bridges such as those required in public parks and for private gardens, prefabricated open parapets serve as longitudinal girders. Complete prefabricated bridges in lightweight timber and aluminum are being manufactured not on-site but under controlled conditions in a factory and are brought to the construction location, ready for installation.

5.4.8 Prefabricated glue-laminated wood sections or planks

An older method was to use sawn lumber. Smaller spans and small live loads are required. Wooden bridges are popular for pedestrian bridges. Timber planks are used as deck panels. Processed special-quality sawn wood is used. Wooden bridges are lighter in weight and are economical, especially in regions where tall timber trees grow abundantly.

5.4.9 Full prefabrication of bridge components off-site

Figure 5.3 shows typical prefabricated components commonly in use. Examples are precast box piers, pier caps, box beams, composite parapets, and deck wearing surfaces on the box beams. In most cases, the footing is cast in place; but for small spans and firm soils, precast footings are increasingly being used, subject to the geotechnical investigation and report. However, box beams are only one example. There are several types of full-depth or partial-depth precast girders that are also being used in lieu of the box beams, the details of which are provided in this chapter. For small and medium span bridges, prestressed concrete is more economical than steel.

AASHTO requirements are for a bridge life of 75 years, which can be accomplished with prestressed concrete.

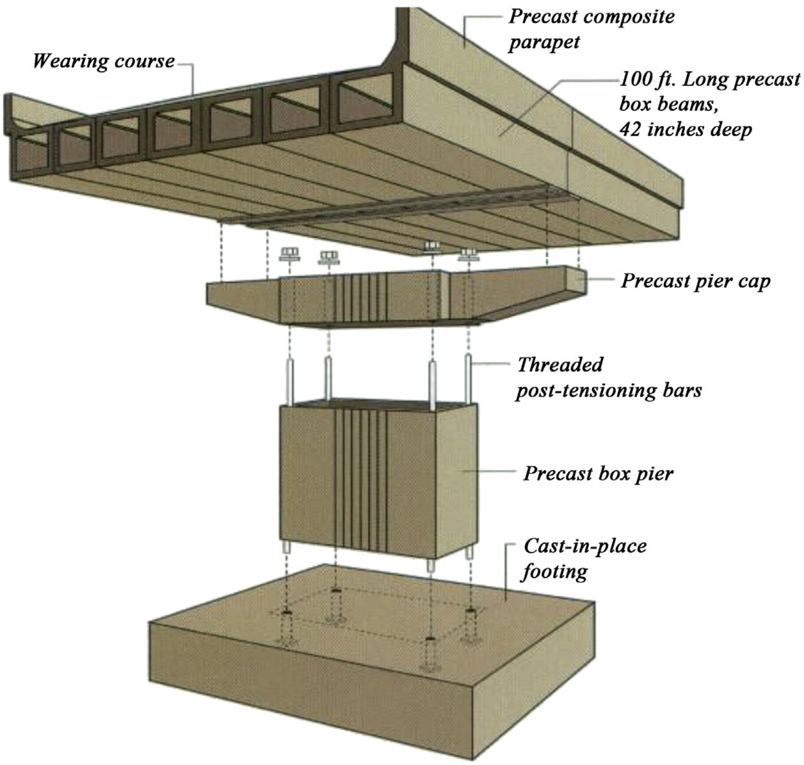

FIGURE 5.3

Typical prefabricated components.

(Photo courtesy of FHWA.)

5.4.10 Types of precast components for superstructures

The following components can be used:

- Precast prestressed deck panels
- Precast prestressed I-beams
- Precast diaphragm forms
- Precast pier cap forms
- Precast traffic barriers

The other components are precast parapets, cylinder piles, and precast approach slabs.

5.4.11 Use of precast concrete girders

Unlike building structures, where reinforced concrete beams of less than 20 ft are required, prestressed concrete girders are widely used for longer spans. Prestressing techniques have revolutionized the construction of bridge girders. Reducing tensile stress due to bending by inducing compressive stress has resulted in small-depth girders. Due to prestressing, girders can be of medium span lengths of 100 ft or even longer, but the longest lengths are unlikely to exceed 140 ft. The standard precast girders shapes are:

- Rectangular with depth exceeding the width
- I-shaped with bottom flange wider than top flange
- T-shaped
- Hollow or box girder.

Holes can be rectangular or round. Segmental construction is widely used for longer spans, and precast or steel diaphragms for connections in the transverse direction of prestressed beams have been allowed. Diaphragms help to distribute dead and live loads in both directions.

5.4.12 Use of prefabricated trusses

Increasingly, innovative bridge designers and builders are finding ways to prefabricate entire segments of the superstructure. This may involve prefabricated truss spans and pre-constructed composite units that are fabricated or assembled at or away from the project site and then lifted into place in one operation. Low-cost design alternates include reducing the number of girders with HPS.

5.4.13 Demolition first

In an overnight operation, crews can cut the old bridge spans into segments and remove them, prepare the gaps for the new composite unit, and then set the new unit in place.

5.5 Prefabricated steel girders

AISC standard steel sections to fabricate girders, arches, and trusses: These sections are manufactured in steel mills. Rolled steel joist (RSJ) is commonly used for the smaller spans. For medium spans, built-up sections are used with flange plates welded to the bottom flange. These are rolled in many sizes and depths that are selected according to the design requirements. Wide flanges are suitable for connections to the deck slab. Splices are easy to provide to allow continuity near the supports. Cambers can be provided to offset vertical deflections as per design and for deck drainage.

For long spans, new types of steel plates such as weathering steel and HPS 70W and 100W may need to be fabricated to the required girder shape. Painting to prevent corrosion may not be required except near the supports of girders.

These are the standard rolled sections listed in the American Institute of Steel Construction (AISC) Handbook. Plate components can be fabricated into plate girder shapes. Thin webs with stiffeners or deep beams are popular. Steel box beams are also used. Steel girders have the advantage that they can be bent into horizontally curved beams or vertically curved beams and steel sections are preferred for curved girders.

5.5.1 Prefabricated steel arches and pipes

This information comes from the Federal Highway Administration Accelerated Bridge Construction Manual (see http://www.fhwa.dot.gov/bridge/abc/docs/abcmanual.pdf).

Corrugated steel arches and pipes have been in use for many years. Steel plate arches can span significant distances in order to span rivers, roadways, or even railroads. The arches can be designed as a culvert or as a bottomless frame supported on concrete footings. Construction of typical steel plate arches can be accomplished in as little as one to three days depending on the water handling needs, the complexity of the shape, and the number of plates required to make up the structure.

Innovative concepts including use of high-performance materials can mitigate the frequent need for maintenance and the resulting traffic impacts.

HPS: The author designed bridges with HPS 70W hybrid girders in New Jersey recently. HPS should be considered for girder design. It allows for:

- Lighter girders
- Shallower girders, which improve vertical under-clearance
- Reduction in the number of elements to be constructed
- Reduction of the overall project footprint
- Elimination of maintenance painting
- Enhanced resistance to fracture.

5.5.2 Case studies of full prefabrication with combination of steel girders/arches with precast substructure

Table 5.4 shows examples of states (Alaska, California, and Wisconsin) that have completed superstructure projects with prefabricated steel girders and steel arches. For the precast substructure, bent pier caps were used, thereby achieving full prefabrication for the entire bridge and reaping the maximum benefit.

Table 5.4 Examples of Successful Projects Completed in the United States for Full Prefabrication of Both Superstructure and Substructure

Name	Location	Built	Description	Prefabrication
Kouwegok Slough Bridge	Unalakleet, Arkansas	2000	378 ft long and 25 ft wide with three spans	Pipe pile extensions support a precast concrete pile cap beam; rolled wide flange beams support prefabricated full-depth concrete deck panels.
Maritime off ramp at I-80 and I-880	Oakland, California	1997	Cofferdam system, precast bent caps	Curved welded steel orthogonal isotropic bridge.
Mississippi River Bridge	U.S. 14/61/ Wisconsin 16 over the Mississippi River, Wisconsin	2003	2573 ft long and 50 ft wide with 475-ft steel arch center span	Work on 475-ft long and 87-ft high center-span steel arch and river piers simultaneously. New bridge prefabricated segments were manageable for shipping and erection.

5.5.3 Case studies of prefabrication of superstructure only with steel girders and steel trusses

Table 5.5 shows Connecticut, Illinois, Ohio, Pennsylvania, Virginia, Vermont, and West Virginia using prefabricated steel superstructure.

Table 5.5 Examples of Successful Projects Completed in the United States for Full Prefabrication of Superstructure Only

Name	Location	Built	Description	Prefabrication
Church Street Bridge	New Haven Interlocking and Rail Yard, Connecticut	2003	1280 ft long with eight spans including 320-ft truss span	Prefabricated truss center span; 850-ton bridge lifted into place by world's largest mobile crane
Route 29 over Sugar Creek	Springfield, Sangamon County, Illinois	2001	Five-span bridge, 77.13 m long	Full-depth precast post-tensioned concrete deck panels, steel beams
Wells Street Bridge	Chicago, Illinois	2002	425-ton, 111 ft long and 25 ft high center span	Steel through truss
Fairgrounds Road Bridge	Between Xenia and Beaverbrook over the Little Miami River, Ohio	2002	226 ft long and 32 ft wide with three spans	Fiber-reinforced polymer (FRP) for deck panels, which were placed on the existing steel beams and grouted into place
Norfolk Southern Railroad Bridge over I-76	I-76 east of U.S. Route 202 Interchange, Upper Merion Township, Montgomery County, Pennsylvania	2002	240 ft long, 42 ft high, 740-ton steel truss railroad bridge	Truss raised onto four 330-ton Hillman rollers and hydraulic winches used to pull it to its final position over the expressway

Table 5.5 Examples of Successful Projects Completed in the United States for Full Prefabrication of Superstructure Only—cont'd

Name	Location	Built	Description	Prefabrication
I-95/James River Bridge	Richmond, Virginia	2002	Preconstructed concrete units include an 8¾-in. deck over steel plate girders	Preconstructed concrete units composite with steel plate girders were cast in a casting yard near the worksite
George P. Coleman Bridge	Yorktown, Virginia	1995	Largest double-swing bridge in United States with six spans replaced	Prefabricated steel truss spans units used
Richville Road Bridge	Manchester, Vermont	2001	Single-span bridge 69 ft long and 32 ft 8 in. wide	Three Inverset units consisted of two rolled beams with a precast reinforced concrete deck
Howell's Mill Bridge	County Road 1 over Mud River in Cabell County, West Virginia	2003	245 ft long and 32.5 ft wide bridge, with two spans	FRP 8 by 32.5 ft panels on weathering steel beams

5.5.4 Precast concrete steel composite superstructure units

The advantages to precast concrete steel composite superstructure (PCSCS) units include:

- Reduced beam depth.
- Rapid installation: Erection times of 1 h per unit (after deck removal is complete) allow overnight or weekend installation.
- Year-round installation.
- Due to pre-compression in the concrete deck, deck cracking is minimized.
- Improved quality due to controlled-environment construction.

The primary disadvantages of this system include:

- The initial construction cost of a prefabricated system is approximately 50 percent more than that of a normal superstructure.
- Pre-compressed concrete cannot be replaced in the field; any future re-decking would require the removal of the entire unit or a reduction in the capacity of the system, since the new deck would not be pre-compressed.

5.5.5 Accelerated rehabilitation of steel bridges

Structural steel replacement and/or strengthening: For each structural component, the following issues will be addressed:

- Existing steel beams with deck replacement shall be made composite in positive moment regions.
- In order to determine the remaining service life, a fatigue analysis of existing steel members to be reused or rehabilitated will be carried out in accordance with AASHTO Guide Specifications for Fatigue Evaluation of Existing Steel Bridge, the AASHTO LRFD Specifications for Bridge Highways, and the current state LRFD bridge design manual.

Investigate the use of high-performance steel: Use of HPS 70W for durability, weight, cost savings, and strengthening fractured floor beams will be considered.

Heat straightening: Steel can be bent from overload, collision, earthquake, or fire. This old technique is used to restore deformed steel members by gradual heating and cooling. Beams or girders that have been struck by trucks or are bent by other causes can often be repaired by heat straightening only, or in combination with field welding to install new sections for the damaged steel member portions. Steel has the capacity to restore to its original condition through heating. The performance of repaired steel does not change.

An accelerated repair procedure to straighten plastically deformed regions of damaged steel by applying repetitive heating and cooling cycles is generally used. Each cycle leads to a gradual straightening trend. Maximum temperature is controlled so that thermal stress from heat will not increase the yield stress of steel. If heat straightening is deemed to be practical, a detail showing the location of the repair and procedures needs to be prepared in the form of a report.

Use of Micro-composite reinforcing steel bars, corrosion inhibitors, and latex-modified concrete: Conventional 60 ksi rebars are known to corrode. Micro-composite steel is noncoated and is highly corrosion resistant. Corrosion inhibitors and latex-modified concrete can extend the life of bridge decks by more than 20 years.

The use of corrosion inhibitors with conventional reinforcement rods can mitigate the problem by chloride extraction. Corrosion of reinforcing bars is caused by salt penetrating concrete. The chemical corrosion inhibitor additive is designed to protect structural steel reinforcement by preventing oxidation after full or partial depth repairs of bridges. The corrosion inhibitor additive allows its products to chemically counteract the corrosion process that takes place at the interface between the iron and the concrete. ASTM has developed ASTM G109 corrosion inhibitor specifications.

Use of slip-critical connections: refer to "specifications for structural joints using ASTM A325 or A490 bolts" for the following four conditions:

Joints subjected to fatigue load
Joints with oversized holes
Joints with slotted holes with loads not perpendicular to slots
Joints in which slip will be detrimental to performance of the structure

Fatigue performance-based analysis: In order to determine the remaining service life, a fatigue analysis of existing steel members to be reused or rehabilitated will be carried out in accordance with AASHTO Guide Specifications for Fatigue Evaluation of Existing Steel Bridge, the AASHTO LRFD Specifications for Bridge Highways, and the current state bridge design manual. This will help to determine the logic of reuse or replacement.

Quality control inspection of welded joints: Rational quality control approaches to fabrication inspection and weld acceptance are required. It ensures that the structure has sufficient fatigue performance. In order to evaluate the effects of weld defects on fatigue performance, fatigue tests of butt-welded joint specimens of 25, 50, and 75 mm thick with various types of weld defects were performed in Japan by Miki and Nishikawa. Acceptable sizes of weld defects are established from these test results and fracture mechanics analysis. A computerized automatic ultrasonic inspection system has been developed and the applicability of these systems has been examined to be satisfactory.

Investigate the use of HPS 70W for durability, weight, and cost savings for strengthening fractured floor beams.

Removing floor beams with riveted connections to webs: To avoid instability to the structural system or local buckling, consider leaving fractured floor beams in place and strengthening with new channel beams.

5.5.6 Long-term issues with prefabrication

Joints, bearings, and devices (*JBDs*): A DOT study investigating joint failures listed "lack of designer's awareness" as a key concern. Topics of critical importance are theory and design of common types of JBDs; reliability-based design, installation, and maintenance; fatigue and corrosion; modeling; and finite element analysis. Increased awareness of JBDs can enhance the probability that critical components will perform their functions with intended structural control.

As-built plans and/or shop drawings should be reviewed followed by a thorough site inspection, making note of:

Material condition, Fatigue-prone details, Utilities, geometry, girder alignment, and possible paint removal and containment considerations.

Nondestructive testing should be performed on butt-welded top flange splices to ensure weld soundness.

Short-term crack sealing and joint repair in steel: Webs are fracture-critical members (FCMs). Fracture of thin webs is a dangerous scenario and needs to be fixed. Steels used in main members should be ordered to the correct level of strength and toughness. For main members, the material should specify Charpy V notch (CVN) requirements for the FCM zone and reference the direction of rolling.

Bond characteristics of carbon fiber reinforced plastics to structural steels: Fiber-reinforced plastics as a structural material can provide an opportunity for structural engineers to propose new structural systems instead of conventional steel or concrete.

Researchers in Japan studied the bond strength of carbon fiber–reinforced plastics to structural steels in order to develop the composite structure of steel and fiber-reinforced plastic. It was concluded that the strong anisotropy of fiber-reinforced plastics may cause local shear stress concentration, resulting in premature debonding.

Providing continuity at the hinge assemblies: Removing hinges and making the members continuous may be desirable. If the hinge cannot be removed, redundancy must be provided in the event of a hinge failure. If a pin and hanger assembly is to be rehabilitated, lubrication and nondestructive testing requirements are desirable.

5.5.7 Connection designs based on LRFD code

Connections and discontinuities usually have stress concentrations. It is important that the assembly of prefabricated components in rapid construction does not lead to a lower quality. Formulas for cross-frames and diaphragm connection designs based on the latest AASHTO LRFD code were programed by the author for application to an I-95 state road viaduct in Pennsylvania.

Fatigue stress evaluation method due to load reversal: The author developed a computer program in MathCAD to evaluate remaining useful fatigue life in connections and steel members. The method was based on American Railway Engineering and Maintenance-of-Way Association (AREMA) code (and was used for Cooper train loads for Southeastern Pennsylvania Transportation Authority (SEPTA) bridges in Philadelphia). Actual train live loads and impact were for Silver Liner, Bombardier, and diesel locomotives used by SEPTA. The yield stress of existing steel was less than 36 ksi. Allowable stress level was based on 2-million cycle capacity. The method can be applied to AASHTO HL-93 live loads for highway bridges.

Newly designed girders need to be safe and therefore require greater shear resistance than the cumulative shear force from dead and live load plus impact. Web depth at girder ends may need to be increased by using splayed webs.

Retrofit of steel beams: The bridge survey and evaluation report will be consulted if the superstructure is in serious condition due to cracks in the webs of numerous floor beams or at the truss connections. Drilling of holes at the tip of cracks may be required. The beams need to be retrofitted by installing splice plates at the bottom flange for easy access. Other applicable retrofit details shall be provided as per the AASHTO Guide Specifications for Fatigue Evaluation of Existing Steel Bridges.

Coupons: to evaluate the strength of old steel, a small sample of existing steel may be taken from a redundant location and tested for strength, depending on the available as-built plan and data.

5.5.8 New bridge bearings or replacing damaged bearings

For seismic-resistant construction, fixed- and expansion-type multirotational pot bearings or seismic isolation bearings are likely to be more suitable than other conventional types, such as disc or elastomeric pads. Bearings will be designed using the LRFD method.

Existing rocker and roller bearings have greater height than proposed pot or isolation bearings. The difference in height is handled by placing concrete pads or steel plates under the shallow bearings. The superstructure will be jacked to remove and replace bearings.

During stage construction, the existing deck slab may be temporarily supported by steel posts and beams prior to demolition. Any underpinning will be removed after the new deck is in position.

Replacement of dual bearing lines with a single bearing should be considered, particularly if replacement of the bearings is required.

5.5.9 Use of prefabrication for rehabilitation of steel through-girder bridges

When compared to a multi-girder system, through-girder systems with floor beams can save up to 2 ft in girder depth. With well-connected closely spaced floor beams acting as a rigid diaphragm between longitudinal girders, this system:

- Will have a shorter repair schedule, with only two longitudinal girders.
- Will provide much shallower structural depth that would benefit cost.
- Will improve sight distance.
- Is the least expensive alternative.

As a refinement of the two through-girder system, partial post-tensioning of the main through-girders will increase superstructure internal redundancy.

A study by the author shows that use of 70W steel in a multi-girder system can save 12 more inches in girder depth than using 50W steel. This provides the opportunity to utilize high-performance steel, reduce structural depth, and lower costs. The example of designing the Route 1 and 9 Magnolia Avenue Bridge using HPS 70W steel girders shows that reduction in structural depth will improve the profile of a bridge. The initial preferred alternative used a 50W multi-girder composite system.

5.6 Precast components for substructures

Cast-in-place reinforced concrete construction is predominantly being used for foundations and supporting elements, which are the columns and bearing support beams. Substructure construction technology is not changing as fast as superstructure technology. On replacement bridges, the existing abutments with wingwalls and piers are utilized if they are in good condition. This cuts down on the substantial cost of replacing the bridge.

Integral abutment bridges do not need bearings. Foundations are generally cast in place while the rest of the substructure can be precast.

A total substructure system consists of individual piers or prefabricated bent caps supported by precast columns. Cast-in-place bent and pier caps require extensive formwork and curing times, but if they are fabricated off-site, curing times are not a factor. For integral abutments, doing away with deck joints and bearings produces "maintenance-free" designs. An added benefit is quicker construction and no more inspections of the delicate bearings.

Precast caps provide the following benefits:

- For bridges over water, they reduce the amount of time workers need to complete their jobs.
- For bridges over existing roadways, they minimize the formwork required, which reduces traffic disruption on the lower roadway.
- For bridges with job site constraints, such as power lines that affect work zone safety, they limit the amount of time that workers are at risk.

Bent caps: Precast concrete pier caps were used by the author at the interchange of U.S. Route 322 and New Jersey Route 50. Precast pier caps are widely used.

Columns and piers: Bridge construction times can be reduced significantly by using precast columns. Columns can be segmented, post-tensioned, reinforced, hollow, or solid concrete. Lighter piers using precast concrete pile bents and integral abutments with fewer piles have been successful.

Precast concrete columns on spread footing or on pile cap: Round, square, or rectangular column sections may be used.

Precast pier cap on top of extended piles or extended drilled shafts on top of pier cap: Route 50 two-span bridge replacement project in New Jersey was designed by the author.

Steel columns on spread footing or on pile cap: HPS tubular or W sections should be used. Steel columns can be painted or precast and made composite with concrete.

Abutments and wingwalls: Types used include precast wall panels with tie-backs, steel cables used as anchors, and precast tapered wall panels with sloping heights.

Retaining walls: Include precast wall panels with uniform heights, MSE walls.

Barriers on MSE and modular walls: Prefabricated MSE and modular block walls are very common. In some instances, the top of the wall is used to support a concrete barrier. Most states have developed standard details for precast concrete barriers that are set on top of the modular wall. The resistance of the barrier to vehicular impacts is normally accommodated through the use of a simple cast-in-place moment slab.

Precast concrete barriers: Difficulties can arise on bridges with concrete curbing or concrete barriers. Some states have anchored precast concrete barriers to prefabricated decks by through bolting the parapet to the deck. If this connection is used, it should be properly sealed.

Barriers and railing connections: The FHWA Connections Manual contains more information on the issues with connecting barriers and railing to prefabricated elements. There are several ways given to address barrier and railing issues.

5.6.1 Crash testing requirements

The FHWA requires that all parapets and railings on the National Highway System (NHS) be crash tested in accordance with the requirements outlined in NCHRP Report 350 entitled *Recommended Procedure for the Safety Performance Evaluation of Highway Features*.

Some states have used non–crash-tested barriers and railings designed according to the AASHTO LRFD Bridge Design Specifications for non-NHS projects.

5.6.2 Prefabricated noise barriers

Prefabrication is a very useful application for various highway structures, including modular noise walls. A typical plan for a noise wall is shown in Figure 5.4. Prefabrication provides much faster wall construction compared to cast-in-place walls. Similarly, noise barriers located along a highway use precast panels even for conventional construction. Retaining walls are no longer being constructed as cast in place using formwork. Instead MSE walls are used both by partial ABC and full ABC.

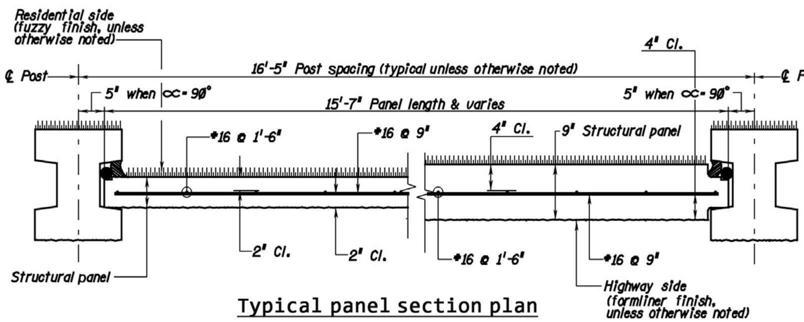

FIGURE 5.4

Use of precast panels for noise barriers in New Jersey.

5.6.3 Partial prefabrication of primary substructure only

Table 5.6 shows substructure unit prefabrication with cofferdams for a bridge across a river and the use of precast bent cap and segmental columns. For superstructure details, refer to the FHWA ABC Website.

Table 5.6 Examples of Successful Projects Completed in the United States for Prefabrication of the Substructure

Name	Location	Built	Description	Prefabrication
I-80 across Sacramento River between Crockett and Vallejo	Oakland, California	2003	Existing bridge	Cofferdam system, precast bent caps
US 290 ramp E-3	Austin, Texas	1996	Existing ramp	Precast pier and bent caps
Dallas/Fort Worth International Airport People Mover	Dallas/Fort Worth Metroplex, Texas	2004	Airport people-mover system	Precast post-tensioned segmental columns

5.6.4 Precast reinforced concrete box culverts

Culverts serve as alternatives to small-span river bridges. Either box shape or three-sided sections are used. Precast methods have been in use for a long time. They can be just a pipe of the desired length placed in the direction of flow of water.

The American Society of Testing and Materials (ASTM) Specification C1577, entitled Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains, and Sewers Designed According to AASHTO LRFD, can be used to design and detail these systems. This ASTM specification is for single-cell box culverts. For multi-cell box culverts, designers typically use single-cell units side by side.

Many state agencies have developed standard details for precast concrete box culvert systems. The use of precast concrete box culverts has become commonplace across the country; therefore, significant details are not presented here. The construction time for a precast concrete box culvert can vary depending on water-handling needs. For simple sites, the construction can be completed in three days.

5.7 Miscellaneous prefabricated bridge elements

Minor bridge elements can have an impact on the construction and long-term performance of a bridge built with ABC methods. The effects that these elements have on bridges built using ABC techniques are addressed here.

5.7.1 Bridge deck expansion joints

Bridge deck expansion joints are the source of premature deterioration of bridge decks and supporting framing. Most states are designing bridges using integral abutments and continuous superstructures in order to eliminate expansion joints. On larger bridges, deck expansion joints will still be required.

Bridge deck expansion joints can be placed into two categories:

- Joints placed within the deck overlay system: These consist of various asphaltic plug materials and epoxy header systems combined with glands or seals.
- Joints embedded into the deck or supported directly by the superstructure framing: These typically consist of armored seals, finger joints, or modular expansion joint systems.

Joints that are placed within the overlay are typically not affected by ABC methods. The joint can be installed in the same manner as with conventional construction. For embedded joint systems, it is difficult to install the joints within the prefabricated elements to the required tolerances. Details should be developed to allow for adjustment of the joint system in the field in order to accommodate the fabrication and erection tolerances of the prefabricated elements.

5.7.2 Drainage assemblies

Drainage assemblies have a tendency to clog and fail, thereby allowing roadway water to spill onto beams and substructures. It is possible to install drainage assemblies into prefabricated deck elements. The standard details that are used for conventional bridges can normally be applied to prefabricated elements. Minor adjustment may be required in order to facilitate the fabrication process.

5.7.3 Overhead and underground utilities

As discussed in the FHWA Accelerated Bridge Construction Manual, the accommodation of utilities on ABC projects can have an impact on the design and planning. Utilities can also have an adverse impact on the construction methods chosen.

The best option for utilities is to remove and relocate them prior to the start of construction. In the case of a deck or superstructure replacement project, it may be possible to temporarily support the utilities and work around them during erection. Once in place, the utilities can be reattached to the new elements.

Underground utilities can also affect ABC methods. Placement of cranes on top of fragile underground utilities may be problematic. It is possible to span over these utilities through the use of steel plates and/or crane mats. Concern has arisen over the use of SPMTs over underground utilities. Steel plating has been used to protect utilities; however it can become impractical for longer travel paths. SPMTs have the ability to distribute the load over a large area with many wheel sets.

In some cases, utility companies can temporarily shut down service during short construction periods. Gas and water mains are sometimes designed with redundancy, thereby allowing short-term closure without significant impact to the utility network. ABC can be used to limit the length of time of these closures.

5.7.4 Availability of bridge components

To facilitate one-time shopping for bridge construction products, "department stores" are being set up on similar lines to Home Depot and Walmart. Guidance may be provided by customer service on ready-made products such as precast deck units, girders with welded shear connectors and diaphragms, and a variety of bearings, parapets, precast pier units, etc. This way the contractor will have quick access to the latest technology.

5.8 Alternative use of hybrid-composite beam

The concept of the hybrid-composite beam (HCB) was originally conceived in 1996. Over the course of the next 10 years, substantial progress was made under the High Speed Rail–Ideas Deserving Exploratory Analysis (HSR-IDEA) program of the Transportation Research Board (TRB).

The HCB is an emerging structural technology that utilizes new materials such as lightweight concrete, steel, and fiber-reinforced polymer. This method makes use of the inherent advantages of each of these materials. The HCB combines the strength and stiffness of conventional concrete and steel with the lightweight and corrosion-resistant advantages of advanced composite materials. Laboratory tests have consistently confirmed bending and shear strength capacities well beyond the code-specified factored demand.

Lightweight: The girder is much lighter in weight than concrete or steel.
Safer: Internal redundancy and serviceability design result in capacities that greatly exceed code requirements. Reduced mass and resilient, energy absorbing materials offer excellent resistance and elastic response to seismic forces.
Reduced carbon footprint: The beams use 80% less cement, one of the largest contributors to the carbon footprint. They also require 75–80% fewer trucks for shipping, and smaller cranes for erection and reduced emissions.
Congestion relief: Lighter, modular bridge systems allows for ABC and reduced traffic congestion during construction.
Sustainability: No painting, rusting, cracking, spalling, or alkali–silica reactions (ASR) results in a sustainable technology that provides for projected 100+ year service life.

5.8.1 Hybrid-composite beam fabrication and construction

To fabricate the HCB system, the FRP box beam is laid up in a mold with the tension reinforcement in place. This lightweight beam is shipped to the bridge site, where it can be installed without the use of heavy cranes or lifting equipment. HCB provides a much safer working environment. The concrete arches and deck slabs of the HCB may also be precast prior to erection, resulting in an entirely prefabricated bridge element.

5.8.2 Design methodology

The applied loads as well as the load and resistance factors can easily be rationalized for assessing the response and structural capacity of the HCB.

The bending capacity of an HCB is calculated using strain compatibility and force equilibrium in the same manner as a reinforced concrete beam. The major difference is the additional contributions from the FRP box. The nominal moment capacity of the section is as shown in Eqn (5.1):

$$\Phi \text{ Mn} = C\,(d - a/2) \qquad (5.1)$$

where:

C = fc'ab (the compression force in Whitney's equivalent stress block)
d = the distance from the centerline of the steel reinforcement to the top of the beam
a = the depth of concrete in compression

5.8.3 HCB case studies

John R. Hillman of Chicago, founder of the HC Bridge Company, is a pioneer in the development of the HCB and has made efforts to bring the technology worldwide.

Colorado: In 2007, the first real demonstration of an HCB bridge took place on the test track at Transportation Technology Center, Inc. (TTCI) in Pueblo.

Illinois: The first installation of an HCB highway bridge began with the construction of the High Road Bridge in Illinois. This bridge comprises a 57-foot single-span bridge that carries two lanes of traffic over Long Run Creek. The HCBs are spaced at 7-foot, 4-in. centers. The bridge's six beams, each 58 ft long, weigh less than 4000 pounds, so all six beams could be shipped on one truck. The contractor was also able to erect the beams with a 30-ton utility crane instead of a 150–200 ton crane.

Maine: In the summer of 2011 another milestone in HCB technology took place with the completion of the Knickerbocker Bridge in Boothbay, Maine, which constitutes the longest composite bridge constructed to date anywhere in the world. The beams were also made continuous for live load with negative-moment reinforcing steel cast over the piers in the 7-in. concrete topping slab.

Missouri: In June 2009, the Missouri Department of Transportation (MoDOT) entered into a single design-build contract to replace 554 small bridges located in the rural areas throughout the State of Missouri. When completed in 2012, the Safe & Sound Bridge Improvement Program had replaced 554 deteriorating bridges that were no longer cost-effective to maintain and completed 248 bridge rehabilitation projects. As part of Highways for Life Award from the FHWA, MoDOT plans to use HCBs in place of the precast concrete box beams on three replacement bridges.

Currently, additional bridge installations are slated in Maryland, Virginia, Utah, and West Virginia, to name a few. With economies of scale and further advances in fabrication automation, it is now possible, with the HCB, to make sustainable structures using advanced composites a mainstream component for reconstruction of the world's deteriorating infrastructure. The supplier will provide a "cookie-cutter" design to satisfy the technical specifications.

Figure 5.5 shows use of a 100-ton capacity Hillman Roller that is bolted up to a load-bearing beam. After jacking the bridge up, the load beam is pushed into position and shims are added to take up the difference. Then the jacks are disengaged and the bridge rests upon the load beam and rollers.

FIGURE 5.5

Use of Hillman Rollers of New Jersey for lateral bridge roll-in Route 8 Bridge (on the Hudson River, New York), 2001.

5.9 Essential deck overlays for improving riding surface quality

Overlays on bridge decks should be preferably be prefabricated with the precast units and designed with the following objectives:

To reduce roadway noise in urban residential environments.
To improve the riding surface.
To protect the deck from deterioration.

There are several approaches to deck riding surfaces in the United States:

Bituminous concrete overlay: With the advent of low-permeability HPC, many states are building bridges without supplemental wearing surfaces, i.e., with bare concrete decks. The problem with this approach is that the bituminous overlay is porous and not waterproof. The overlay tends to trap moisture on top of the concrete deck. This can lead to accelerated deterioration of the deck due to the infiltration of water and deicing salts.

Bituminous overlays combined with high-quality waterproofing membranes: This European approach for deck protection has yielded long-lasting bridge decks that can meet the AASHTO goal of a 75-year service life. Several states have adopted this approach with satisfactory results.

Concrete overlays for precast decks with deck joints: Construction of the elements requires reasonable fabrication and erection tolerances. These issues will lead to an uneven riding surface. Several states have used diamond grinding to smooth out the deck after installation of the elements. This requires that the concrete cover in the elements be thick enough to accommodate the grinding operation.

According to the FHWA Accelerated Bridge Construction Manual, the overlays can be used to eliminate the need for grinding. For states that prefer smooth concrete riding surfaces, thin concrete overlays can be used. However, the application of a concrete overlay will require additional time due to bridge closures, in order to place the overlay. For very fast construction projects, this can be accomplished on subsequent weekends after the bridge is reopened to traffic.

LMC overlay: A very-early-strength latex-modified concrete overlay is used by the Virginia DOT and other states like Pennsylvania. This material can be placed and cured in as little as 3 h and provides low permeability and high bond strength. Thin overlays will ensure a better quality final riding surface on the bridge deck. The overlay serves as the last tolerance adjustment during the construction of the prefabricated structure.

Corrosion inhibitor aggregate concrete: This is more durable than bituminous overlays and is being used in New Jersey.

5.9.1 Polymer concrete bridge deck overlay systems

Polymer concrete bridge deck overlay systems repair the underlying deck after removal of an existing overlay and placement of a new overlay to seal out moisture and chloride ions and prevent them from permeating into the deck. Generally, these overlay systems have a 10-year life span.

The polymer overlay systems have the following advantages:

- Rapid repair of shallow deck spalls and overlaying for quick return of traffic (overnight work).
- Superior adhesion to concrete surfaces.
- Easily applied material.

The disadvantages to these systems include:

- Lower lifespan than deck replacement.
- Requires a sound deck (all spalls repaired and no full depth spall repairs).

These systems can be used in conjunction with a primer to fill cracks and patch partial depth bridge deck spalls in concrete, such as:

Polyester polymers: Polyester polymer concrete overlay systems can achieve 4000 psi in compressive strength and 1600 psi in flexural strength within 24 h, and the bridge can be opened to traffic due to the fast curing system. It also allows traffic to be resumed within a few hours at temperatures lower than 40 °F.

Epoxy-urethane polymers: This closes existing cracks, yields an impervious barrier with chloride ion penetration resistance, and provides a high-skid and wear-resistant surface. The system remains flexible at low temperatures and throughout its life-cycle of about 10 years.

Manufacturers of polyester polymer concrete bridge deck systems include Kwik Bond, and manufacturers of epoxy-urethane co-polymer systems include Poly-Carb.

5.10 Types of rapid bridge construction

The four major types of rapid construction are:

Factory-based manufacture of components: Precast contractors can perform time-consuming formwork assembly, concrete casting, and curing off-site in the controlled environment of a precast plant. Prefabricated bridge designs are more constructible because the factory work reduces time on-site. Constraints such as heavy traffic, extreme elevations, long stretches over water, and tight urban work zones are overcome through prefabrication. Safety improves, because prefabrication reduces the exposure time for workers and the public who travel through construction zones. Additional subcontractors can also be used for certain precast elements and products to help boost timely production.

Off-site manufacture of components: Subject to availability of space close to the site, temporary manufacturing facilities can be set up. This method will save transport time and cost when distances to the site are long.

Full construction on-site: This method was used over 50 years ago in the United States when prefabrication facilities were limited. It takes the longest amount of construction time, as formwork needs to be constructed and raw materials need to be delivered to distant sites. Relocation of a large workforce is usually required. Good weather is also required; otherwise completion will be further delayed.

Mixed construction: Both factory-based manufacture of elements and simultaneous on-site work can be combined. This practice is being used on the majority of bridge projects these days. For example, welded or rolled steel girders and precast concrete beams are supplied by local companies, while deck slab is cast on-site using permanent steel formwork left in place. Foundation and substructure construction is cast in place and is the construction that takes the most time.

5.10.1 Method of delivery to the site

The following methods are used:

Delivery by major roads: Reconnaissance is required to work out the logistics of travel for heavy and wide loads on exit ramps and narrow streets. SMPTs and hauling permits are required for preassembled bridges. Planning requires a site survey for impacted intersections, detours, allowable haul times, permit regulations, utility relocations, and easements.

Delivery by minor roads: Subassemblies of bridge components such as spliced girders are feasible with smaller trailers, which can use smaller-width highways. Full assembly of the bridge is carried out at the site.

Delivery by railroads: Open train bogies can be used for train travel to transport trusses and girders over longer distances. It will be a combination of road plus railroad transport.

Delivery by barges: For bridges located on large rivers and when rivers are navigable, long boats and barges can be used. Again, it will be a combination of road plus railroad transport.

5.10.2 Examples of full prefabrication (concrete girders and precast substructure)

Table 5.7 shows that many states prefer concrete girders over steel for the prefabricated superstructure. These states/territories include Alaska, California, Colorado, Florida, Missouri, North Carolina, New Hampshire, New York, Puerto Rico, Tennessee, Texas, and Wisconsin.

Bent pier caps were used to support the girders.

5.11 ABC presents challenging and technically sensitive issues

Bridge planning, design, construction, and maintenance have always been a conservative issue. The industry is based on centuries of long experience in developing codes of practice and construction specifications. Failure of a bridge and the resulting loss of life and property are not an option. The changeover from conventional methods to ABC is happening gradually, yet still the majority of bridges is being constructed or maintained using long-tried conventional methods.

There are many difficulties in the change to ABC, especially the following diverse technical reasons:

Variety of structural systems: Bridges are not just confined to the conventional slab-beam configuration. There are a wide variety of structural systems. Major systems are the alternative through-type bridges, truss-constructed bridges, arch bridges, cable-stayed bridges, suspension cable bridges, and the variations of these systems. The structural performance, methods of analysis, computer software, design details, and methods of construction in each case are very different. Each of the bridge types is a subject in itself. ABC changes are not minor refinements. Prefabrication and preassembled bridges generate different loads during transportation, lifting, erection, and construction. Introducing hinges and splices and the many connection details are new applications. There are design aspects that are based on guesswork, and research is required to obtain a clear solution.

Table 5.7 Examples of Successful Projects Completed in the United States for Full Prefabrication of Both Superstructure and Substructure Components

Name	Location	Built	Description	Prefabrication
Pelican Creek Bridge	Alaska	1992	178 ft long and 18 ft wide with three spans	Double-tee girders with precast caps and steel piles
Kouwegok Slough Bridge	Unalakleet, Arkansas	2000	378 ft long and 25 ft wide with three spans	Pipe pile extensions support a precast concrete pile cap beam; rolled wide flange beams support prefabricated full-depth concrete deck panels
Maritime off-ramp at I-80 and I-880	Oakland, California	1997	Cofferdam system, precast bent caps	Curved welded steel orthogonal isotropic bridge
Richmond–San Rafael Bridge	I-580 between Richmond and San Rafael, California	2004	2 bridges 3624 ft and 2843 ft long and 44 ft wide.	Precast cap shells and piles
SH 66 over Mitchell Gulch	Between Franktown and Castle Rock, Colorado	2002	Single span	Side-by-side precast slab girders welded onto precast abutments and wings welded to driven-steel H piles; precast railing, precast retaining walls
Reedy Creek Bridge	Main entrance to Walt Disney World Animal Kingdom Theme Park, Orlando, Florida	1997	1000-ft long bridge consisting of five structures, each 200 ft long	Precast components included pile caps and deck panels
I-70/Lake St. Louis Boulevard Bridge	St. Charles County, Missouri	2003	Two spans	Precast deck and beam sections and puzzle wall abutments
Linn Cove Viaduct	Grandfather Mountain on the Blue Ridge Parkway, milepost 304.6, North Carolina	1983	1243 ft long	153 superstructure segments, each weighing 50 tons, along with 40 substructure segments weighing up to 45 tons
Beaufort and Morehead railroad trestle bridge	Over Newport River between Morehead City and Radio Island, North Carolina	1999	2298 ft of trestle-span approaches	Precast prestressed T-girders spanning transverse, precast reinforced concrete caps, supported on composite piles
Epping 13940	Mill Street over Lamprey River, New Hampshire	2004	115 ft single span	Precast prestressed box beams and precast footing
Route 9/Metro North pedestrian bridge	Croton-on-the-Hudson, New York	1998	Ramps are 35 ft long precast concrete units	12 in. diameter precast piles support three-section precast box piers stacked vertically and post-tensioned to a cast-in-place concrete footing

Table 5.7 Examples of Successful Projects Completed in the United States for Full Prefabrication of Both Superstructure and Substructure Components—cont'd

Name	Location	Built	Description	Prefabrication
Cross Westchester Expressway viaducts	I-287 in Westchester County, 10 miles north of New York City	1999	Six-lane bridge	Precast segmental voided pier sections for each of the 42 piers
Baldorioty De Castro Avenue overpasses	San Juan, Puerto Rico	1992	Two 700-ft long overpasses and two 900-ft long overpasses	Precast bent caps; precast prestressed deck composite units; precast box piers
Route 57 over Wolf River	Fayette County, Tennessee	1999	20 span, 1408-ft long, 46-ft wide bridge	Precast bent caps; precast prestressed concrete stay-in-place deck forms; precast prestressed I beams; steel pipe piles, precast deck panels with topping slab
SH 361 over Redfish Bay and Morris–Cummings Cut	Aransas County, Texas	1994	Two bridges over Redfish Bay (2020 ft) and Morris Cummings Cut (415 ft) on the Texas Gulf Coast	Precast bent caps; precast piling, precast concrete piles/columns, precast partial-depth deck panels with topping slab
I-45/Pierce Elevated	Downtown Houston, Texas	1997	Twin structures, one northbound and one southbound, 113-ft span, section of I-45	Bent caps on the existing columns; precast prestressed I-beams, precast partial-depth deck panels with topping slab
NASA Road 1 over I-45	Houston, Texas	2002	Four-span, two-lane, freeway overpass	Precast concrete piles/columns, precast prestressed box beams
SH 249/Louetta Road overpass	Houston, Texas	1994	Two overpass structures at Louetta Road carry three lanes in each direction	Partial-depth deck panels, precast post-tensioned piers, pretensioned U-beams
SH 66 over Lake Ray Hubbard	Near Dallas, Texas	2002	Two prestressed concrete I-beam bridges 10,280 and 4360 ft long	Precast bent caps; precast prestressed I-beams, precast prestressed deck panels
SH 36 over Lake Belton	Near Waco, Texas	2004	Replacement of Lake Belton Bridge. Twin bridges 3840 ft long	Precast bent caps, precast prestressed U-beams, precast pretensioned partial-depth deck panels with topping slab
Mississippi River Bridge	US 14/61/WIS 16 over the Mississippi River, Wisconsin	2003	2573 ft long and 50 ft wide with 475 ft steel arch center span	Work on 475 ft long and 87 ft high center-span steel arch and river piers simultaneously. New bridge prefabricated segments were manageable for shipping and erection

Need for time-testing of ABC applications: ABC applications for the vast variety of structural systems are of recent origin. Long-term performance of bridges built by ABC techniques will not be fully known for quite some time. To build up confidence in the new methods and techniques, limited experience and quick solutions are not the best guidelines. Tables 5.1 to 5.7 show the number of projects successfully completed for each structural system in the United States, but this is only the beginning. As a result, ABC design codes and construction specifications are not finalized or available. However, no progress can be made unless a reasonable start is made. Research is required to obtain clear solutions.

Recent developments in new construction materials: When using ABC methods on new projects, selection of newer materials such as HPC, LWC, HPS, FRP, structural plastics, and other construction materials is desirable but not easy. Bridges are subjected to very heavy loads, and an incorrect assumption can be dangerous. Once again, further research is required to obtain clear solution.

Training requirements in ABC: Courses need to be introduced at the university level or through short courses for practicing engineers to prevent mishaps through incorrect decisions.

Liability insurance for the new system: Not all insurance companies may be inclined to offer the essential liability insurance, or it will be at a high cost. It will take time before insurance is made available at reasonable cost.

5.11.1 Constraints in implementing prefabrication technology

In the case of ABC, implementation is easier said than done. There is another saying that we are engineers, not magicians (although modern technology with the use of robots can be like magic).

Although a start has been made toward implementation of ABC, more work is required. New ideas are required to address the dual needs of faster construction and long service life. Audits are currently in practice in some of the states to ensure project managers and designers study alternatives including:

- Use of new manufacturing processes.
- Improved connection details for prefabricated elements.
- Long-term travel comfort such as no wear and tear of tires caused by wide deck joints.
- Encouraging use of joint-less decks/integral abutments.
- Management programs for effective ABC.
- Continued quality assurance.

Standards for design and construction specifications need to be developed. The construction industry is not geared for prefabrication due to lack of transport and erection equipment.

Also, the manufacturing nature of precast products creates a proprietary system and monopolistic environment, which may lead to unemployment of some number of construction workers. Modern prefabricated construction materials and methods are vastly different from traditional methods and require innovative ideas for making the system safe and efficient.

The bridge needs to be closed for the entire construction period, but lane and highway closures can be minimized. Deliveries of elements and systems can be planned for off-peak times, including weekends. For some deliveries, single-lane closures are sufficient.

Currently, it is difficult to find contractors with PBES experience. It requires different skills and areas of experience. Using contractors with the proper training, equipment, and experience offers the best guarantee of successful completion. If such contractors are not locally available, training needs to be offered. Contractors without experience in ABC may not be considered by some states for the award of a project.

Longer and heavier prefabricated components can require modification to conventional transportation and erection practices. For transportation over highways, sufficient headroom and clearance over the girder depth should be available when passing under a low intersection or through a tunnel. The loads must be within permit limits when transporting over bridges with low load limits. Hauling systems must have a sufficient number of axles and ample spacing to distribute the load. It may not be always possible to find a route that has adequate turning radii to get longer components to the bridge site.

5.11.2 Precautions during ABC

To prevent failures, engineering precautions are necessary during fabrication and erection. In a study on bridge failures carried out by author, it was concluded that most failures occurred due to:

Negligence during construction or erection: Failure of connections due to overstress from bolt tightening, failure of formwork, local buckling of scaffolding, crane collapse, and overload were some of the causes.

Component fit-up requirements: The fabricator and erector should construct the bridge in keeping with AASHTO bridge construction specifications requirements that “fit-up shall be assumed to be performed under the no-load condition.”

Staged construction: Stability of girders during stage construction and deck placement sequence need to be investigated and temporary bracing provided.

Expansion bearings: These may need to be temporarily restrained during erection.

Selecting bolt splice locations: Some flexibility in splice locations cross-frame length and unavoidable variations in span dimensions or member sizes may be permitted, for quick construction.

Uplift at supports: Curved and skew bridges require special attention such as uplift at supports, achieving cambers, and reducing differential deflections between girders during erection.

5.12 Use of new construction materials

On August 1, 2007, the bridge carrying Interstate 35W across the Mississippi River in Minneapolis collapsed. Thirteen died, and 145 were injured. On September 18, 2008, the fallen bridge’s replacement opened.

The new St. Anthony Falls Bridge contains 323 sensors to monitor for structural weaknesses, strained joints, and corroded concrete. Stronger concrete and steel makes structures more stable and permits innovative designs, while sensors warn before disaster strikes. Sensor-equipped bridges remain rare, but are growing more common. And while bridges are an obvious place to use sensors, highway structures and levees are also good candidates.

5.12.1 Recent advances in new materials

Meanwhile, researchers are working on stronger, more durable materials. A good deal of work has focused on concrete. Concrete is not completely impervious to water, which dissolves loose lime in the concrete, creating microscopic channels through which water can penetrate farther. In cold climates, the water freezes and expands, enlarging the cracks. The water also rusts reinforcing steel. New forms of concrete aim to eliminate these problems by making the concrete more waterproof.

The St. Anthony Falls Bridge is made of high-performance concrete containing coal-combustion byproducts fly ash and silica fume, making it denser and more waterproof. According to Florida-based FIGG Bridge Engineers, who built it, "materials like this mean bridges built today could last 100 years, versus 40 to 50 for older bridges."

Research in use of the following materials is still in progress:

- FRP composite materials
- Geomaterials and geosynthetic products,
- Lightweight, high, and ultra-high performance concretes and steels

There is a need to develop appropriate limit state criteria for the use of these materials, as well as details, components, and optimizing structures for adoption into the LRFD specifications.

5.12.2 Use of high-performance steel

Prefabricated steel bridges were discussed earlier. Progress in metallurgy has led to weathering steel and higher strengths. HPS should be considered for appropriate elements of a bridge. HPS allows:

- Lighter girders
- Shallower structures
- Reduction in the number of elements to be constructed
- Reduction in the overall project footprint
- Elimination of maintenance painting
- Enhanced resistance to fracture

Use of Fiber-Reinforced Polymers (FRP) and Plastics

- Not currently adopted by NJDOT for main structural members.
- NJDOT encourages their use for ancillary components of a bridge.
- NJDOT has used the material for the fender systems of two bridges along the New Jersey coast, Route 9 over Nacote Creek and Route 9 over the Bass River.
- Advantages:
  - Very environmentally friendly
  - Elimination of concerns regarding marine borers
  - Anticipated that substantially increased life expectancy will occur
- Cautions:
  - Lack of design and analysis codes and techniques
  - Lack of history in the United States

Lightweight and high-strength materials are more suitable for girders. Modern and advanced materials include:

1. High-strength concrete.
2. High-strength rebar.
3. High-performance weathering steel: Concrete bridges are more commonly used for the smaller spans, since rust in steel members increases corrosion and maintenance costs. Use of weathering

steel minimizes painting cost. Development of preferred alternative structural solutions and optimization of girders using HPS 70W, 100W, and hybrid steel girders is required.

4. Fiber-reinforced engineered cement-concrete.
5. Fiber-reinforced polymer composites: These can be used to rapidly repair column plastic hinge zones.
6. Elastomeric bearing pads.
7. Ultra HP FRC: A compressive strength reaching 30 ksi is possible along with a flexural strength of 7 ksi.

Using HP lightweight aggregates: Lightweight HPC reduces deadweight, enables longer span lengths, reduces the number of piers in a river, and reduces obstructions to fish travel. Spliced girders of varying depth enable lightweight concrete to achieve spans of over 200 ft.

8. Overlays: Use of silica fume and high-early-strength LMC will open the deck to traffic, within 3 h of curing. Silica fume, pozzolans, fly ash, and slag may be used to reduce concrete permeability and the heat of hydration. Fly ash and cenospheres are preferred for HPC in bridge decks, piers, and footings.
9. Self-consolidating concrete (SCC): Since vibration time is saved, SCC helps ABC; it is a more workable concrete with lower permeability than conventional concretes.

Byproducts of coal fuel such as fly ash, flue gas desulfurization materials, and boiler slag provide extraordinary technical, commercial, and sustainable advantages.

5.13 Proprietary manufacturing companies

In the United States there is a market economy that encourages both small and big entrepreneurs. The income tax system provides subsidies for genuine losses. This environment has helped large manufacturing companies to grow.

The following represents a list of some of the manufacturing companies for prefabricated products and components. The list of new companies is growing, both in the United States and abroad. Major factories are being supported by smaller manufacturing factories, resulting in a consortium.

There are many bridge companies, such as CONSPAN and Mabey-type temporary bridges. Since construction time is reduced with design-build applications, traffic jams are fewer and detours are avoided, and there are additional benefits to commerce and industry. Most industry observers predict a period of continued recovery, with new design innovations that will help bring about more diverse construction methods (see http://www.constructiondigital.com/innovations/where-is-the-construction-industry-headed-in-2013).

Modular design and prefabrication have a number of benefits with shorter production cycles and enhanced sustainability. This results in lower production costs, with savings to be passed on to the client. The use of eco-friendly materials and the prefabricated design also make these modular structures ideally suited to the changing demands of the transportation industry.

CONSPAN Modular Concrete Bridges: Clear spans range from 12 to 60 ft. The arch-box units can accommodate a wide range of fill heights together with AASHTO or AREMA loading. Headwalls are precast with the unit or separately. Footings may be precast or cast in place. Units may also be set on a slab bottom, pedestal walls, or pile caps.

Acrow Modular Steel Bridges (*located in Parsippany, New Jersey*): Acrow's bridges can be assembled in less than half the time of conventional bridges. They are compliant with AASHTO, ASQC (American Society of Quality Control), AWS (American Welding Society), AISC (American Institute of Steel Construction for small bridges), and ASTM (American Society of Testing Materials) guidelines. Acrow's bridges have been full-scale tested in the laboratory at Lehigh University, Pennsylvania for load-carrying capability and by military organizations.

Ready-made truss bridges are being manufactured by Acrow. USAID sponsored a project in Pakistan to replace flood-damaged bridges. Assembly was done near the sites. The ABC technique can be successfully utilized in the aftermath of flood and earthquake damage to restore highway links to cities. Examples are given below from Pakistan, where recurring floods and earthquakes have been a regular feature.

The more modern approach is to use modular or prefabricated bridges manufactured under improved quality control in supervised factory conditions. These may then be delivered to the site as preassembled bridges on special tractors. Acrow also has provided assembled prefabricated movable bridges on rivers that allow passage of vessels such as Bascule, vertical lift, and sliding bridge spans. After the Pakistan earthquake of October 2005, when bridges got damaged and paralyzed important highways, Acrow truss-type bridges provided immediate relief.

During manufacture, robots are extensively used to guarantee quality workmanship. All Acrow bridges are certified to be manufactured under the quality assurance standards of ISO9001 and American Institute of Steel Construction (AISC), thus assuring the highest level of quality.

Acrow bridges have similar characteristics to a type of bridge known as the Bailey bridge. Bridges have been used on roadways of all types. They have been used on interstate highways, motorways, state highways, provincial highways, primary and secondary roadways, rural feeder roads, and many more applications.

5.14 Further case studies of prefabricated bridges

Some case studies from the United States and Canada offer new ideas on techniques and construction details to achieve the goal of "Get in. Get out. Stay out." Prefabricated elements for the substructure and superstructure and complete bridge systems for rapid replacement are available and have been used for several years. Prefabricated systems allow bridges to be built in days or weeks rather than months or years.

- In 1995, the George P. Coleman Bridge in Virginia, the largest double-swing bridge in the United States, was dismantled and replaced in only 9 days using barges.
- In 2006, the Florida Department of Transportation used self-propelled modular transporters (SPMTs) to remove and replace a bridge superstructure in northeast Orlando.
- In March 2013, a new bridge in the Everglades was designed to heal environmental damage using the CONSPAN system (see Curtis Morgan, "A Bridge to Help Heal the Everglades," *Miami Herald*, March 19, 2013, http://www.miamiherald.com/2013/03/19/3294968/a-bridge-to-help-heal-the-everglades.html). The completion of a new one-mile-long bridge was described earlier. The bridge is the last major piece in the Modified Water Deliveries project, a series of projects originally approved by Congress in 1989 as part of plan to restore water flows to a newly acquired 107,000-acre section of Everglades National Park.

5.14.1 Accelerated girder/deck production

One girder/deck unit cast per day was precast at Pre-Con's Woodstock, Ontario precast plant using a reusable wood form.

- Units were prestressed and conventionally reinforced, but with a monolithically cast deck slab above. The girder deck was formed with a parabolic shape in elevation and cross-slope in section to account for girder camber and cross-fall.
- The deckside form was notched for projecting reinforcing steel to ensure proper alignment with steel in adjacent units. Focus was placed on the edge detail, girder-to-girder.
- High-performance concrete was required for production of these units, together with similar curing and temperature restrictions/monitoring procedures for the abutment and wingwall units. Center and surface thermocouples were cast into the unit: three wires/deck, two wires/girder, and three locations per deck and girder (15 thermocouples/unit total). A seven-day wet cure with burlap was maintained, including a layer of plastic vapor barrier.
- Temporary steel stands were required for stability after the girder/deck units were removed from the wood form.

Preventing shrinkage and micro-cracking: The concrete temperature was maintained between 100 and 700 °C and the temperature difference between any one set of the center and the surface thermocouples could not exceed 200 °C. All units were wet cured with burlap or filter cloth for a seven-day period. Soaker hoses were used to keep units continuously wet during the seven-day curing period. A moisture vapor barrier was used to prevent air flow between layers during the curing period.

The I-85 Bridge located in North Carolina was planned as a four-span concrete structure with eight columns per bent. Prefabricated elements were used for the substructure's columns, pier caps, and deck beams. The bridge components were cast off-site and shipped to the site on conventional semitrailers. Each component was carefully cast to within a 0.25-in. tolerance so connections made in the field would fit precisely. Using precast, prestressed columns and caps on the bridge expedited the work.

ABC heavy lift techniques have been used on the following projects in Massachusetts:

- Phillipston Bridge
- Craigie Bridge
- Wellesley
- I-93, Medford
- Morton St., Boston
- River St., Boston

Boone IBRC Bridge project (120th Street Bridge over Squaw Creek in Boone County, Iowa) (see Bowers et al., 2007):

> Through the FHWA Innovative Bridge Research and Construction program, a bridge in Boone County, Iowa was constructed using several different precast, high-performance concrete elements. Researchers from Iowa State University performed laboratory testing on the precast components that were used in the Boone County Bridge. Field instrumentation and testing were used to verify the post-tensioning operation and to verify several of the construction methods. Also, a comparison of the actual construction schedule with a theoretical schedule was completed.

Three deck panels could be cast in one casting operation. Panels could be fabricated every other day with a maximum of nine panels cast per week. The beams used were Iowa Standard “B” beams modified for wider spacing than the typical standard beam spacing.
Superstructure: The superstructure for the bridge utilized traditional PPC beams. Beams were modified from the standard design in order to eliminate a beam line. To modify the beams, additional prestressing strands were added and the concrete release and 28-day strengths were increased. Transverse joints were cast in place with a high early strength concrete mix. Due to the tight deck panel spacing, a small aggregate size was used with a maximum top size of 3/8 in. The maximum water cement ratio was 0.38 and the slump was increased using a high-range water reducer (HRWR) that allowed the slump to go to a maximum of 8 in. A retarding admixture was used as well that seemed to extend the life of the HRWR for workability.
The HRWR was very effective in aiding in the placement of the concrete. A cast-in-place concrete diaphragm and deck end-section was constructed to complete the integral abutment.
Superstructure testing: Laboratory tests were conducted to determine the flexural and punching shear capacity of the deck panels. Panels were designed for HS-20 loading.

5.14.2 Conclusions

The following conclusions were reached for this project:

- Placement of a single precast pier cap or abutment cap could be done in less than 30 min because piles were driven within tolerances.
- Deck panels for half the bridge could be erected in half a day. A theoretical work schedule predicted that the Boone IBRC Bridge could be assembled in 12 working days.
- The abutment connection capacity is at least 4.5 times greater than the unfactored service load.

5.15 Conclusions for prefabricated bridges

Initiatives taken by FHWA have led to considerable progress in implementing ABC concepts. ABC-related design needs to be made part of AASHTO and state bridge design codes and specifications. To gain confidence in structural behavior, full-scale testing of joints in precast curved deck is required.

Analytical methods applicable to discontinuities of components need to be developed. Application of the latest techniques in concrete manufacture, composites, HPS, and hybrid materials is feasible. Integrated software covering all aspects of ABC design and drawings should be developed.

Deterrents and bottlenecks such as MPT, construction easement, right-of-way, permit approvals, and utilities relocation need to be resolved and administrative procedures simplified to facilitate ABC. Certification and training of construction personnel, continuing education of engineers in rapid construction techniques, and construction management for ABC courses at universities are recommended.

Details of repairs required for steel beams and connections are described.

5.15.1 Improvements in the manufacture of ready-made bridges

There are many bridge companies such as CONSPAN and MABEY-type temporary bridges. Since construction time is reduced with design-build applications, traffic jams are fewer and detours are avoided in addition to benefits to commerce and industry. The use of eco-friendly materials and the prefabricated design also make these modular structures ideally suited to the changing demands of the transportation industry.

Prefabrication is a specialized subject for analysis and design. Connection details between components need to be made safe enough. The contractor needs guidance on many issues of long-term performance. The consultant needs to perform research to come up with the right solutions. The conventional contracting system lacks focus on the new fabrication technology issues and feedback can only come from research results obtained during construction. Achieving accelerated construction would also require training of both the consultant and the contractor's engineers.

Consider sample projects using the following bridge elements for guidance, in the absence of an ABC code of practice:

- Precast foundation elements
- Precast pile and pier caps
- Precast columns
- Precast full-depth deck slabs
- Cored slabs and box beams
- Next beams and deck girders
- Full-span bridge replacement units with precast deck
- Bridges installed with SPMTs
- Cost evaluations are important and should be accurate:
- Estimation of time and materials
- Roadway user costs
- Maintenance of traffic costs
- Safety costs
- Agency costs
- Life-cycle costs

If ABC cost <30% more than conventional cost, strongly consider ABC. For the small cost increase, the benefits are in early delivery, improved quality, and longer life of the bridge.

- Take advantage of existing technologies, such as:
  - Inverset
  - Precast elements
  - Prefabricated composite elements
  - Segmental construction
  - FRP deck

5.15.2 Extending the service life of bridges

ABC methods were evolved ahead of the design codes. Research is required in many areas, including:

- Developing strengthening methods and corrosion mitigation techniques; fabricating stronger girders by eliminating the need for shear stiffeners with the use of folded web plate in steel girders.
- New methods to monitor and strengthen foundations against scour, earthquake, and impact.

- Developing and reviving the concept of full canopy on bridges to facilitate mobility, improve drainage, prevent skidding, and eliminate the use of de-icing agents.
- Optimum use of construction materials: Research in the use of FRP composite materials, geomaterials, geosynthetic products, and lightweight, high-, and ultra-high-performance concretes and steels. We need to develop appropriate limit state criteria for the use of these materials, as well as details, components, and optimizing structures for adoption into the LRFD specifications.
- Reduced duration of bridge construction: We must develop contracting strategies such as realistic incentives/disincentives to encourage speed and quality. Mass production management techniques adopted by the automobile and aircraft industries may be considered.
- Mathematical methods, ABC codes, and technical specifications: We should further study and disseminate emerging technology knowledge and methods such as:
  - Strong mathematical technique, closed-form solutions, and formulas from mathematicians.
  - Identification and calibration of the service limit states for unusual construction conditions.
  - Beginning the transition to a performance-based specification, with an accompanying design manual.
  - Development and incorporation of security performance standards, especially for long spans.
  - Continued development of LRFR provisions is required. Integrate information from maintenance and operations into code development and vice versa. Promote automated data collection and reporting damage models using the data collected.

NOTE: The bibliography for this chapter is listed at the end of the chapters in Appendix 1.

CHAPTER

6 Rapid Bridge Insertions Following Failures

6.1 Introduction

All of us cross bridges every day. We may only see a parapet railing deck slab or sign structures and light poles. But there is more to a bridge than meets the eye. The bearings and girders may be hidden in addition to the substructure foundations. Bridges span gaps in terrain or other earth features such as gorges formed due to river valleys and natural cavities in topography.

Transportation bridges are an essential part of a network of highways and provide continuity to their use for rapid travel. If a bridge is shut down, it adversely affects the sick going to hospitals, children going to schools, and others missing important plane flights and the train departures, thereby adversely affecting essential progress in commerce and industry. It is time that new technology for alternative designs related to rapid construction is introduced.

A glossary of accelerated bridge construction (ABC) terminology applicable to all the chapters is listed for ready reference in Appendix 2 ABC.

This rapid construction technology is already being promoted by a number of federal and state organizations such as the Federal Highway Administration (FHWA) (reference PowerPoint presentation by Benjamin Beerman, Incharge, FHWA Every Day Counts Program), New Jersey (reference Mohiuddin Khan and State Bridge Engineer Richard Dunne's paper at ABC Conference in Baltimore, 2007). Reference seminars organized by the author at Temple University, the FHWA, and by Florida International University (FIU) are listed in Appendix 3. This chapter covers the following topics relating to bridge failure and rapid construction techniques:

1. Numerous incidences of recurring damage and failures in the conventional system of design and construction are demonstrated in this chapter, requiring a review of the design and construction philosophy.
2. An alternate ABC system (to that currently in vogue) with prefabrication and preassembly is proposed to overcome the difficulties. The difficulties are in transportation to the site and the availability of high-capacity cranes.
3. The use of prefabricated girders is on the rise and the conventional system has been modified to a partial ABC system. It is expected that due to the increased popularity and many advantages of ABC system, the partial ABC system will be a good place to start, leading eventually toward full ABC. The percentage of bridge projects using ABC will eventually increase to over 80% if not to 100%.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00006-X

6.1.1 Construction duration and impacts on maintenance and protection of traffic (MPT)

MPT requirements were addressed in Chapter 5. Inconvenience to the public will continue as long as the reconstruction is not complete. MPT will depend upon the following:

1. Staging of construction with no lane closure - Shoulder width or the sidewalk may be used with added widths obtained from converting 12 ft. to 10 ft.
2. Staging with one or more lanes closed.
3. Detour
4. Bridge shut down for traffic during construction duration.

Given infinite time, any structure can be built, replaced, or repaired. The highway agencies are more interested in fixing a bridge in a finite time. Their budgets are allocated from year to year and need to be used up within the given year and not linger on or overlap with the ongoing fresh allocations. Hence the purchases of bridges or sales of demolished bridges are for a limited time only (Figure 6.1).

According to Mammoet Europe B.V., the on-site construction of bridges and flyovers is often impossible, so complex, or has such a large impact on traffic flows, that off-site construction is required. These large and heavy elements need to be brought in and installed in a timely manner that minimizes interference with construction activities. Close coordination between these different activities is essential.

Thorough analyses and engineering help define the optimum dimensions and weights of the modules, taking the capacity of lifting and transport equipment into account. Route surveys are conducted to understand and counter any possible bottlenecks along the way that may restrict the size of modules or have an impact on the timing of the project. Also, knowledge of oversized load restrictions and regulatory issues helps determine the most efficient approach.

Modular construction challenges require a modern fleet of equipment, enabling lifting, transport, skidding, and push-up of modules of different dimensions and weights for ABC.

FIGURE 6.1

Any gap even in a wide river can be bridged with the right plan and construction equipment. (Reference Mammoet Europe B.V.)

6.1.2 Maintenance of old bridges

We are used to maintaining our cars on a regular basis, replacing essential parts every few years and replacing an old car every 10–15 years. The same approach applies to bridges. We replace the concrete or asphalt topping or the deck slab itself every 10–15 years. Most bridge superstructures are replaced every 50–75 years with or without the substructure.

Bridges are subjected to repeated wear and tear from heavier trucks and from extreme events such as flood and earthquakes. Maintenance requires timely rehabilitation, repair, and retrofit. There is an old saying that “a stitch in time saves nine.” If a bridge is neglected, an emergency replacement may result, and that is where ABC is particularly useful.

Life cycle costs are likely to be higher than the initial investment. It may be more economical and easier to design a new bridge than to maintain the same bridge over its remaining life.

Not counting railway and transit bridges, the three types of roads on which bridges are located are:

- Interstate: Due to heavy average daily traffic (ADT), not even a single lane can be shut down for maintenance. Already, there are traffic jams during rush hour. Time loss is a colossal waste at national scale.
- Collector: A lane can be closed for a short duration with nighttime work using ABC.
- Local: When ADT is low, ABC is not essential, and for small spans modular bridges can be used.

6.2 Bridge failures can be prevented by asset management methods of ABC

By analyzing the repetitive nature of bridge failures that involve conventional construction, it may be possible to reduce the number of failures with ABC. Scour and soil erosion with foundations not protected by scour countermeasures are responsible for the majority of failures. The Dee Bridge failure in 1847 is one example.

The major causes of bridge failures can be summed up as follows:

- *Foundation scour and soil erosion*: Examples are bridge failures such as the collapse of **Ovilla Road Bridge** over a flooded creek in Ovilla, Ellis County, Texas and Route 46 Peckman’s River Bridge after Hurricane Floyd in New Jersey. The **Peckman’s Bridge** replacement was designed by the author.
- *Corrosion of steel girders concrete deck and deck concrete cracking*: An example is the I-95 curved girder bridge.
- *Earthquake*: Bridge failures in California.
- *Overload and excessive magnitude of live load*: Numerous older bridges.
- *Excessive wind on suspension bridges without deck stiffening*: Tacoma Narrows Bridge.
- *Failure due to fatigue*: Numerous railway bridges.
- *Collision from trucks due to limited vertical under clearance*: An example is the North Jersey Bridge.
- *Collision from ships due to fog and heavy rain*: An example is collapse of the Sunshine Skyway Bridge in Florida.
- *Fire*: An example is the I-95 Bridge in northesast Philadelphia due to the burning of tires below.

Failures seem to occur worldwide for a variety of reasons. The inventory of bridges worldwide is in the millions and is gradually growing with the construction of new highways.

In the United States alone, there are 600,000 bridges. These are subjected to constant wear and tear and to natural disasters. Avoiding failures and keeping highways functional is the top priority of all highway agencies and they have access to the taxpayers' money to do that. The useful life of a bridge seldom exceeds 100 years with maintenance. Inventories of bridge failures are being maintained by owners as well as the media, as they are public knowledge.

According to a conservative estimate, even if 1% of the total number of bridges is estimated as deficient, 6000 bridges in the United States need to be fixed in the form of repairs, retrofit, and widening and replacement. Increased use is being made of the innovations in design and construction technology. For effective maintenance, inspection procedures are changing rapidly by way of remote health monitoring and use of sensors for crack detection.

In addition to the American Association of State Highway and Transportation Officials (AASHTO) and FHWA, the National Transportation Safety Board (NTSB) is responsible for overseeing bridge failures. However, unexpected failures like that of a steel truss bridge on I-35 West in Minneapolis in 2004 could be avoided. Similar truss bridges are standing elsewhere in the United States. A single-span nonredundant design is less safe as compared to a redundant design. The bridge that failed in Minneapolis was built in 1967 but had an alarming ADT rate of 144,000. An inquiry revealed that the gusset plates were under-designed and failed under the additional construction loads.

An in-depth survey of modern bridge failures by the author, based on available information, has revealed various modes of failure of highway structures and bridges, many of which are elaborated upon in this chapter. The overall objective of the study of such failures is to improve design codes and construction specifications and to reduce the duration of construction through techniques such as ABC.

6.2.1 Failure modes

Failure modes are different for steel, concrete, and timber bridges. For steel composite bridges, plastic hinges form at the midspan or at the ends of cover plates. Tension yielding occurs in the bottom flange and in the web to the underside of the top flange accompanied by cracking at the bottom surface of the slab. In prestressed concrete beams, collapse may occur due to breakage of the strands. These failures can be avoided by simultaneous adoption of ABC with modern design techniques.

A fascinating aspect of these failures is their regularity, a display of the mode of failure, which needs to be recognized and avoided by design and maintenance. It will be easier to avoid major failures when occurring approximately every 30 years: 1847, 1879, 1907 (Quebec Bridge failure), 1940, and c.1970.

A Sibly and Walker study (1977) is referred to as a point for discussion. Fitting the trend, two bridge failures are considered consistent by H. Petroski (1993). Petroski points to anecdotal evidence that suggests the theory has predictive merit. Also, the managing director of Brady Heywood, Sean Brady, has looked at the technical and human aspects of this unfortunate trend. Refer to http://bradyheywood.com.au/uploads/129.pdf.

It may be pointed out that many failures that occur during construction or demolition do not get reported. The present total number of bridges located in the U.S. highway system is extremely high. Lack of adequate maintenance and accidental failure can cause failures to occur sooner than 30 years, as recent failures in Minnesota and Washington State have shown. ABC prefabrication methods with better quality control should help in reducing the frequency of failures.

6.2.2 Importance of deck stiffening in suspension cable bridges

The importance of deck stiffness in suspension bridge design was recognized as far back as the 1850s. As a consequence, Roebling's generation utilized stiffening trusses and auxiliary ties to ensure deck stability, elements that are evident on the Brooklyn Bridge today. The gradual elimination of stiffening trusses and ties culminated in their absence from the Tacoma Narrows Bridge. Failure ensued, and the Tacoma Narrows Bridge was rebuilt with stiffening trusses included. These failures provide some insight into negligence and also the importance of innovative structural design.

6.3 Inspection and rating procedures as a starting point for maintenance

Monitoring of the structural health of bridges is required to identify any potential issues. Bridges that are fracture-critical or scour-critical are vulnerable to failure. The frequency of the two-year inspection timetable has been reduced to one year in such cases. In the case of extreme events such as floods and earthquakes, around-the-clock inspection may be necessary. A theoretical criterion such as sufficiency rating is used to identify deficiencies.

The objectives of inspection are as follows:

- Asset management
- Safety inspection and testing
- Structural evaluation
- Identification of deficiencies
- Suggestion of repair, retrofit, and/or rehabilitation solutions
- Prevention of failures

In the United States, the bridge management system (BMS) is formulated by the following agencies:

- AASHTO
- FHWA
- Each state where the bridges are located

An analytical tool is needed at the network level, rather than at the individual project level. It will use a systematic procedure for optimizing bridge inspection analysis data. This is achieved by the use of the Pontis System described earlier in Chapter 2. Ratings were defined in Chapter 2 under "Management System for Bridges NBIS."

6.3.1 Sufficiency rating

Sufficiency rating (SR) is a score that indicates a bridge's sufficiency to stay in service by meeting traffic demands and safety needs. It is a measure of the relative safety of bridges. SR is a percentage from 0 (worst) to 100 (best) based on an FHWA formula that includes four factors:

- Structural adequacy and safety, S_1 (Max. 55%)
- Serviceability for modern use, and functional obsolescence, S_2 (Max. 30%)
- Essentiality for public use, S_3 (Max. 15%)
- Special reductions, S_4 (Max. 13%).

$$SR = S_1 + S_2 + S_3 - S_4$$

If the SR value is $< 20\%$, the bridges are considered deficient and need to be fixed. However, FHWA defines a structural evaluation score "requiring high priority of replacement."

While a bad rating does not necessarily mean failure is imminent, when combined with high traffic volumes represented by traffic count and ADT, it signals possible trouble for a bridge. Based on visual inspections and low sufficiency ratings, those bridges that are found to be vulnerable to structural failure seem to require rehabilitation or replacement.

6.3.2 FHWA condition rating

The general structural health or condition of the bridge components can be defined by the physical observed field condition, defined as the condition rating. The NBIS Condition Rating uses the numbering system given in Table 6.1.

6.3.3 Visual inspection versus structural health monitoring

An alternate to visual inspection is to use a robotic system that can inspect bridges more frequently. Sensors, optical instrumentation, and digital cameras are some of the recent developments. Cracks, corrosion, and deformations can be measured by modern image processing (infrared imaging devices) and pattern recognition techniques. A detailed survey of nondestructive health monitoring methods was carried out by Jahanshahi and colleagues at the University of Southern California (2009).

6.3.4 Contract documents

After the project funding is approved, the consultant and contractor's team will be selected with the conventional system or the ABC design-build system through bids. For greater detail, the Design Build Institute of America (DBIA) may be consulted.

Table 6.1 NBIS Condition Ratings

Rating Number	Relative Rating
0	Failed
1	Imminent failure
2	Critical
3	Serious
4	Poor
5	Fair
6	Satisfactory
7	Good
8	Very good
9	Excellent
N	Not applicable

The set of minimum documents covering the technical, administrative, and legal aspects of conventional construction will consist of the following:

- Contract drawings
- Estimate of quantities
- Construction specifications
- Special provisions
- Construction schedule using bar charts or a Primavera network (showing milestones and the duration of each activity on the critical path)

Contract drawings are prepared to the required scale in CAD. They are used for construction and are required to show maintenance and protection of traffic (MPT) and erection details such as locations of cranes during lifting. These are not acceptable unless signed and sealed by a registered professional engineer in that state.

6.3.5 Legal signing of contracts

In general, notarized, signed agreements between the owner and the contractor and between the owner and the consultant are normally required. The consultant's expertise should be in civil engineering, structural engineering, or bridge engineering. For ABC contracts, agreements need to be signed between the contractor and the consultant. The subcontractors who get hired by the contractor will normally be approved by the owner.

After the contractor is selected, an attorney representing the owner will collect all the necessary signatures and notarize the legal document as necessary. The contract language will be in keeping with the federal and state laws, especially since they are responsible for providing the huge project funds. For example, there will be provisions for hiring minorities and women as an equal opportunity employer. Payments will be made according to accounting rules and are subject to audits.

The format for the above legal documents may change for ABC, depending upon the state requirements and the transportation agency within the state. For example, turnpike authority and river bridge commissions may deviate from the general format of other construction contracts as they may have developed their own construction specifications.

6.3.6 Shop drawings for structural components

All "shop drawings" normally required for fabrication will be in conformity with the contract drawings and will be prepared by the manufacturing company after the contract is awarded. The nitty-gritty details such as small additional holes or the location of lifting points of the component need to be shown and duly approved by the consultant. It is important that communication is maintained by weekly meetings at the site or the owner's office. There should be no secrets, and the right hand should know what the left hand is doing before it is too late and an accident happens.

6.3.7 Rehabilitation reports required for both conventional and ABC systems

A number of bridges located on the same highway can be conveniently included in the same report, since the rehabilitation can be performed simultaneously. Efforts will be made to use the same equipment and labor. The rehabilitation report should be comprehensive and often the following reports need to be included (the exact practice may vary from state to state and from project to project; see Textbook by Mohiuddin Khan, 2010. Repair of Highway Bridge Structures, McGraw-Hill):

- Field survey, topography, and drainage reports
- Visual inspection reports
- Underwater inspection reports
- Structural evaluation reports
- Rehabilitation or replacement options
- Geotechnical reports
- H and H (hydrology and hydraulic) reports
- Scour countermeasures report
- Seismic retrofit reports
- Estimate of quantities
- Cost estimates based on approved unit prices
- Special considerations or any other memorandums from the relevant highway agency

Each report will be site-specific and unique. There are often alternate options. Usually, cost will be the deciding factor for selecting the alternate option.

6.3.8 Implementation of drawings

During construction, if the original field data has changed (for example, the excavation shows a different type of soil than delineated in the geotechnical report, etc.), the drawings need to be immediately modified by the consultant. The procedure is to use a formal design change notice (DCN) with the approval of the owner.

Due diligence is required by the contractor, who is required to point out any discrepancy in the construction drawings in a timely manner. Usually the contractor generates a request for information (RFI), which is documented. The designer after investigation will clarify the query in writing without causing delay to the tight schedule. As an incentive, if the contractor finishes the job ahead of schedule, he or she is entitled to a bonus.

To meet or expedite the construction, a full-time “resident engineer” is posted by the consultant at the job site. The resident engineer performs quality assurance/quality control (QA/QC) of daily work at the site, certifies completed work for payment, and prepares a weekly progress report and submits it to the project manager at the head office with a copy to the owner. Some owners may insist that the resident engineer follows the designer for any DCN due to the engineer’s detailed knowledge of the design criteria, project data, and background of the construction drawings, which may run into several dozens, if not hundreds, in number.

6.4 Probability of failure and risk management

6.4.1 Hazard, vulnerability, and risk

A hazard can be defined as “a condition or changing set of circumstances that presents a potential for property damage, structural failure and injury.” Vulnerability analysis shows susceptibility to loss from hazard. It is opposite of resilience. Risk defines the likelihood of an event and its consequences.

6.4.2 Hazards and sources of hazards

By hazard analysis we identify threats to transportation and its users. Hazards can be the result of natural causes or man-made causes. Negligence, poor communication, and lack of teamwork or knowledge leading to planning and design errors can contribute to the creation of hazards. Both the application of preventive methods using preparedness methods and the provision of adequate cures using disaster management methods are needed after a hazard. For controlling hazards and preventing failures, it is important to recognize hazards, their probability of occurrence, and their past history. The principles of hazard control are:

- Identification and recognition
- Defining preparedness and selecting preventive actions
- Assigning responsibility for implementing preventive actions
- Providing means for measuring effectiveness and adjusting them
- Preparing a safety checklist related to the project

The goal in safety engineering is to prevent the fulfillment of Murphy's Law. According to the famous Murphy's Law, "whatever can possibly go wrong, will." Sometimes, the factor of safety used in design loads or material strengths may not be sufficient. They may also result from insufficient, delayed, or improper maintenance and repair.

In practice, the huge investment of funding for the infrastructure is safeguarded by taking out liability insurance against unforeseen circumstances and human errors. The failures or damage can happen in the short term or in the long term. For example, by federal law, you cannot drive a vehicle without insurance, even though unsafe driving resulting in damage or an injury may not be your fault.

In bridge construction, the failure may happen after, say, 20 years, when the contractors who built the bridge no longer exist. But insurance claims will be applicable and will be paid by the insurance company. Even if the insurance company is not there, there will be a guarantee from the government or the banking industry to pay the claims, so that the taxpayer is not penalized. The three considerations related to failure are the above-defined hazard, vulnerability, and risk.

In the United States, the federal Occupational Safety and Health Administration (OSHA) oversee failures or injuries during construction and develops and enforces related regulations. The three most frequently cited OSHA violations (2003) are construction related, as shown in Table 6.2. It will be noted that with ABC, use of scaffolding can be avoided.

The numbers are approximate as all construction accidents may not get reported. Most accidents or violations result in loss of life, equipment, or property. The owner may not pay for the related losses as per the provisions of the signed contract. The contractor may bear the loss or the liability insurance may approve the claims.

Table 6.2 OSHA Construction-Related Citations of Violations Leading to Damage and Injury

Rank	Topic	Number of Citations	Remarks	Method of Hazard Control
1	Scaffolding	8682	Construction related	Use prefabrication
2	Hazard communication	7318	Construction related	Use design-build management
3	Fall and injury protection	5680	Construction related	Implement OSHA regulations

There are a set of priorities in construction that will be helpful:

- Elimination of hazards
- Reducing the level of hazard
- Providing structural redundancy
- Installation of sensors and monitor stress levels
- Issuing warnings
- Introducing safety procedures in design
- Offering training to personnel

A good reference on this topic is *Safety and Health for Engineers,* by Roger L. Brauer (2006). The hazard control models proposed by Brauer in his book are the four M's: man, media, machine, and management. The nine general factors in the goal accomplishment model can be applied to ABC by making each factor specific. These are listed in Table 6.3.

Bridge engineering also complies with the general factors in Table 6.3 in its goal accomplishment model. It consists of preparing structural drawings, devising the construction process, project management, manufacturing components, selecting equipment, using self-propelled modular transporters (SPMTs) and high-capacity cranes, ensuring environmental protection, and reducing hazards that cause failures.

6.4.3 Risk analysis of river bridge failure

Risk is characterized as low, medium, high, or unacceptable. When risk is high, advanced risk assessment is required and risk management procedures should be implemented. Bridges located on rivers are subject to higher hazard assessment than those located at, for example, an intersection, due to factors such as:

- River instability
- Extraneous factors causing morphological change
- Fluvial hydraulics in the vicinity of the river crossing
- Structural integrity of the bridge

Table 6.3 Factors for Goal Accomplishment and their Applications to ABC

	Factors for Goal Accomplishments	Applications
1	People	Knowledge and training, culture and attitudes
2	Activities	Engineering decisions and actions taken
3	Equipment	Special vehicles, crane and construction equipment
4	Place	Highway, bridge, and waterway
5	Environment	Floods, earthquakes, and natural hazards
6	Management	Role performed by the owner, consultant, or contractor
7	Regulatory organization	Highway planning and bridge design and construction specifications
8	Time	Duration of contract (which cannot linger on forever)
9	Cost	Funds available, initial cost, and long-term maintenance costs

George Annandale, a consultant in Lakewood, Colorado, defines hazards as "potential sources of danger." Annandale proposes two levels of risk assessment and risk management:

- Level I: Hazard identification, exposure identification, and consequence assessment
- Level II: Risk assessment and risk characterization

The unique features of this proposal are a composite hazard rating system and a decision model to characterize the risk. The risk management module requires that risk management strategies be devised and implemented and decisions are made pertaining to whether reevaluation of risk is required.

6.4.4 A practical method of computing the composite hazard rating (R)

The data for computing the probability of failure, given in Tables 6.4 to 6.9, is based on bridge failures in South Africa, New Zealand, and the United States. The sources are as follows: For U.S. Bridges on rivers, FHWA published the book *Countermeasures* for hydraulic problems at bridges by Brice and Blodgett in 1978. An approximate method is proposed as:

$$\text{Hazarding Rating } R = f_1 \times f_2 \times f_3 \times f_4$$

where f_1 values are based on the classification of river channels described in Table 6.4 and listed in Table 6.5.

Table 6.4 Stability and Classification of River Channels

Channel Pattern	Suspended Load	Mixed Load	Bed Load
Straight	(1) Straight Banks, Flow Bars, and Islands	(2) Straight Banks, Single Meander Flow, with Bars and Islands	N/A
Meandering	(3A) Meandering banks, w/o bars, meander flow	N/A	(3B) Meandering banks and meander flow with bars
Braided	N/A	(5) Double loop, w/o bars, meander flow	(4) Doubly curved flow

Table 6.5 River Stability Base Factors to Compute (f_1)

Channel Type with patterns Straight, Meandering or Braided	River Stability Factor
1	1.0
2	2.1
3A	2.2
3B	2.4
4	2.9
5	3.0

f_2 values are given in Table 6.6. f_3 values are the product of bridge location, contraction scour, local scour, and aggradation or debris accumulation rating. Tables 6.6 and 6.7 show the comparative need for scour countermeasures based on river conditions and potential damage to bridge components.

f_4 values are the product of the structural integrity ratings of the foundation, substructure, bearings, and superstructure. Structural integrity values from a research study of bridge conditions in three countries are given in Table 6.8.

Table 6.9 gives a broad range of typical estimated hazard ratings. No action is required for lowest hazard rating, while those bridges with high hazard ratings need to be placed on the priority list for fixing the deficiencies (see also FHWA, 2007; National Safety Council, 2001; P. Delage, 2003).

Table 6.6 Extraneous Factors Affecting Changes in Morphology to Compute (f_2)

Type of Changes in Morphology	Potential for Change		
	Low	Moderate	High
Soil erosion or degradation—river migration or bank erosion	1.00–2.11	2.12–2.89	2.90–3.17
Aggradation or debris deposition—backfilling or berms construction	1.00–2.11	2.12–2.89	2.90–3.17

Table 6.7 Fluvial Hydraulics Values at Bridges to Compute (f_3)

Hydraulic Aspect	Potential for Damage		
	Low	Moderate	High
Potential for lateral scour	2.12–2.55	2.56–2.76	2.77–2.83
Local scour	1.06–1.27	1.28–1.38	1.39–1.42
Debris accumulation	1.06–1.27	1.28–1.38	1.39–1.42
Deck and bearings	0.42–0.51	0.52–0.55	0.56–0.57

Table 6.8 Relative Structural Integrity of Bridge Components Values to Compute (f_4)

Bridge Component	Structural Integrity		
	No Change	Minor Problems	Major Problems
Foundations	1.19–1.43	1.44–1.55	1.56–1.59
Abutments	1.19–1.43	1.44–1.55	1.56–1.59
Piers	1.19–1.43	1.44–1.55	1.56–1.59
Bearings and deck	0.39–0.72	0.73–0.77	0.78–0.79

Table 6.9 Composite Hazard Rating Classification

Category	Low	Moderate	High
Composite hazard rating	R < 20	20 < R < 70	R > 70

In this chapter, the most common types of bridge failures—although construction failures can be avoided by using modular bridges, the other types of failures are due to unrealistic design criteria and not resulting from ABC methods—are addressed:

- Bridges failing during construction
- Bridges failing due to floods, which cause erosion (floods causing erosion)
- Bridges failing due to earthquakes (earthquakes)
- Bridges failing due to hurricanes

Failures are pillars to success, but the number of failures can be kept to a minimum by utilizing advanced techniques available for design or for construction.

6.4.5 General civil/structural related failures

These failures may be described as pertaining to:

- Civil infrastructure analysis
- Structural collapse
- Embankment/excavating failures
- Under-bridge utilities
- Grading and deck drainage

6.4.6 Main reasons

The broad classification of the many types of failures is:

- Early failures that occur during construction
- Long-term failures due to high annual ADT, fatigue, corrosion, and lack of maintenance
- Unpredictable failures due to flash floods and seismic events
- Unexpected failures due to collisions
- Lack of bridge usage due to highway shutdown from subsidence of highway embankments

The focus is generally on modern bridges (using modern technology after 1940), the filmed Tacoma Narrows Bridge failure in Washington State due to wind and hurricane being the first one. This failure improved the design of suspension bridges, as it resulted in the provision of stiffening trusses to other long-span steel cable suspension bridges.

6.5 Failure studies of conventional bridges

A survey at the international level was conducted to identify the reasons for failure with conventional methods, especially when comprehensive bridge design codes exist and when the schedule for construction extends over several seasons. Usually, the owner will give allowance for the extreme weather conditions and for peak winter months when construction may come to a standstill. For example, cast-in-place concrete substructure and deck construction may delay the work, because it requires curing and the use of admixtures for cold-weather concreting.

6.5.1 Bridges failing during construction

The general reasons for failures during conventional construction are:

- Negligence in the field
- Improper planning
- Design deficiency

It will be noted that the construction of long-span and complex bridges has many difficulties, especially when it needs to be completed in a specified time. It is an area of weakness where required expertise in construction techniques is highly desirable. The difficulties relate to the following areas:

- Unrealistically quick construction schedule
- Staff not trained in the use of modern equipment
- Lack of quality control for materials testing
- Design errors and errors in reading drawings
- Lack of uniform and streamlined construction procedures for each bridge type

Difficulties in erection:

- Sequence of erection leading to instability
- Crane failures due to buckling
- Inadequate bracing of columns
- High temperatures and wind.

Examples of sloppy construction practices for concrete bridges:

- Design of formwork not adequate or removed prematurely
- Improper placement of reinforcing bars
- Improper sequence of concrete placement
- Incorrect profiles of post-tensioning tendons

Examples of sloppy construction practices for steel bridges:

- Welding deficiencies in steel connections
- Incorrect thickness of gusset plates
- Imperfections of the material

6.5.2 Role of National Transportation Safety Board (NTSB) in monitoring failures

The National Transportation Safety Board (NTSB) was established in 1967 as the federal government's primary accident investigation agency for all modes of transportation, namely aviation, highway, rail, marine, and pipeline.

The NTSB is normally the lead organization in the investigation of a transportation accident. The board has no legal authority to implement or impose its recommendations, but can assist federal or state agencies. The board's most important product is safety recommendations. The NTSB has issued about 13,000 safety recommendations in its history, the vast majority of which have been adopted in whole or in part by the entities to which they were directed. It maintains a training academy.

Significant investigations conducted by the NTSB in all modes of transportation in recent years include the collapse of the I-35 highway bridge in Minneapolis, Minnesota; the collision between two transit trains in Washington, D.C.; the sinking of an amphibious vessel in Philadelphia, Pennsylvania; and the crash of a regional airliner near Buffalo, New York.

Since 1990 the NTSB has maintained a preferred list of transportation safety improvements, in which it highlights those recommendations that would provide the most significant, and sometimes immediate, benefit to the traveling public.

6.5.3 American Society of Civil Engineers (ASCE) failure case studies

The publication *Failure Case Studies in Civil Engineering: Structures, Foundations, and the Geoenvironment*, second edition, by the American Society of Civil Engineers (ASCE), provides short descriptions of 50 real-world examples of constructed works that did not perform as intended. Each case study contains a brief summary, lessons learned, and references to key sources. This book is a valuable resource on typical failures for further research, and a demonstration of how each failure leads to improved engineering design and safety. Some examples of faulty construction are displayed in Figures 6.2 and 6.3. There is no scope for sloppy construction if ABC methods are used.

The kind of mistake shown in Figure 6.3 would perhaps be possible in an underground tunnel driven from opposite ends, but is hard to imagine for a bridge being constructed in broad daylight. Owners have made it mandatory to carry liability insurance against faulty construction for instances such as these where big replacement costs and loss of life are usually involved.

FIGURE 6.2

Example of nonstandard practice in supporting a river bridge.

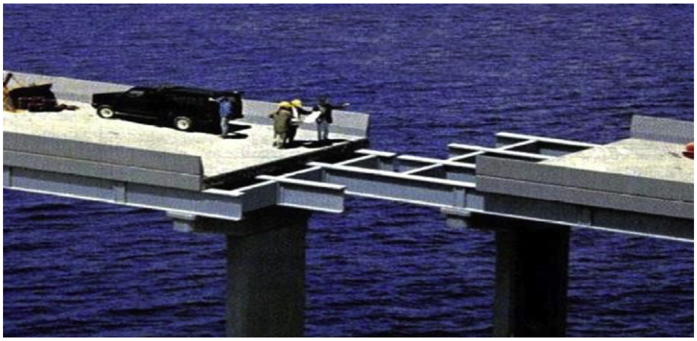

FIGURE 6.3

Example of alignment error when constructing from two opposite banks.

6.6 History of failures during construction and case studies

Major failures have occurred due to man-made and natural actions:

1. Construction failures: These are a frequent occurrence (refer to Tables 6.10–6.18)
2. Bridges located on rivers subjected to flood and scour
3. Poor maintenance
4. Use of substandard materials and manufacturing defects
5. Design errors
6. Earthquakes and liquefaction.

Secondary reasons. In addition, there are less frequent failures due to the following physical reasons:

- Accidents caused by trucks and ships
- Accidents caused by trains
- Fire
- Wind, hurricanes, extreme temperatures
- Vibrations and resonance
- Unforeseen reasons

6.6.1 Construction investigative services

The following investigation techniques are helpful in making engineering decisions:

- Materials failure analysis (plastics, rubber, metals, and concrete)
- 3D laser scanning and imaging technology in planning
- Computer graphics and modeling in design
- Fire code compliance, investigation of origin and cause
- Gas/propane explosion investigation
- Drainage and bridge freezing analysis

- Americans with Disabilities Act compliance for pedestrian bridges
- Construction site access
- Cranes and heavy equipment failures

The following lists of tables would provide a wealth of information into the background of failures as to what went wrong and what needs to be done to minimize such failures:

- List of bridges that failed during construction (not using ABC)
- List of bridges that failed for reasons other than during construction, such as floods and earthquakes (not using ABC)
- The avoidance of dangerous bridge failures (by using ABC)
- List of bridges completed (by using ABC)

Several types of construction failures were observed in our survey of bridge failures, resulting from the following conditions:

- Scaffolding collapse
- Failure of lifting equipment
- Insufficient design capacity of cantilevered arm for cantilevered construction
- Insufficient design capacity during incremental launching
- Girder and connection failures
- Design and detailing errors
- Incorrect construction sequence
- Negligence, accidents, and construction errors

These failures are summarized in Tables 6.10 to 6.17. The reasons for failures are mostly self-explanatory. Conclusions at the end of a table indicate planning methods to avoid failures and remedial measures. Based on the evidence of failures, these apply only to conventional construction and may not apply to ABC methods.

Table 6.10 List of Bridges that Failed during Construction when the *Scaffolding or Temporary Supports Collapsed*

Name of Bridge	Location	Year Failed	Reasons for Failure
Sullivan Square Viaduct, motorway bridge	Boston, Massachusetts	1952	Instability of scaffolding during construction.
Dawson Creek Suspension Bridge	Peace River, British Columbia, Canada	1957	Movement of anchorages on footings, which were not fixed properly—substandard construction.
Second Narrows Bridge	Between the Strait of Georgia and Fraser River, Vancouver, Canada	1958	A lower transverse beam of temporary truss that was located at falsework support collapsed; its purpose was to distribute the heavy superstructure load.
Barton Bridge	Lancashire, England	1959	Buckling of temporary props.
Continuous motorway bridge	Near Limburg, Germany	1961	Settlement of temporary foundations, load redistribution, scaffolding collapse.

Continued

Table 6.10 List of Bridges that Failed during construction when the *Scaffolding or Temporary Supports Collapsed*—cont'd

Name of Bridge	Location	Year Failed	Reasons for Failure
Motorway composite bridge	Heidingsfeld, Germany	1963	Temporary concrete support plates underdesigned.
Vorland Rees-Kalkar plate girder bridge	Between Rees and Kalkar, Germany	1966	Temporary supports underdesigned.
Arch bridge over Rideau River	Ottawa, Canada	1966	Scaffolding collapsed under weight of fresh concrete—construction failure.
Motorway bridge over Arroyo Seco River	Near Pasadena, California	1972	Scaffolding collapsed under weight of fresh concrete.
Bridge near Wennigsen	Niedersachsen, Germany	1971	Scaffolding collapsed under weight of fresh concrete.
Continuous suspension bridge over Laubachtal	Near Koblenz, Germany	1972	Scaffolding collapsed under weight of fresh concrete.
Loddon Bridge	Berkshire, England	1972	24 m span collapsed during placing of concrete due to failure of falsework.
Loddon River Bridge	Near Victoria, Australia	1972	Scaffolding collapsed under weight of fresh concrete; construction failure and OSHA standards.
Bridge over Leubas River	Near Kempten, Germany	1974	Scaffolding collapsed under weight of fresh concrete.
Multiple-span box girder bridge	East Chicago, Indiana	1982	Scaffolding collapsed under weight of fresh concrete.
Prestressed concrete precast box girder bridge	Saginaw, Michigan	1982	Temporary support elements too weak during construction.
Three-span arch bridge	Elwood, Canada	1982	Lateral buckling of scaffolding due to insufficient lateral supports—construction failure.
Simple span, steel truss road bridge	Germany	1982	Temporary support elements too weak.
Rheinbrucke Bridge over Rhine River	Near Hochst, Vorarlberg, Austria	1982	Scaffolding collapses under weight of fresh concrete.
Tokyo West Bridge over Tama River	Tokyo West, Japan	1984	Scaffolding removal sequence was not well thought out.
New (composite) Grosshesselohe Bridge	Munich, Germany	1985	Ignorance of load case "displacement of mobile scaffolding."
El Paso Bridge	El Paso, Texas	1987	Inadequate scaffolding during construction.
Box girder bridge	Los Angeles, California	1989	Collapsed when scaffolding was removed during construction.
Approach bridge (beam-and-slab)	Cologne-Wahn Airport, Germany	1995	Scaffolding collapsed under weight of fresh concrete.
Bridge near Pawnee City	Nebraska	2004	Failure of falsework caused bridge collapse during concrete pouring.

Conclusions: Temporary supports take time to erect and dismantle. Scaffolding or formwork is an unnecessary expense. Their instability is the most common reason leading to failure during construction. They need to be designed for the construction loads. With prefabricated, preassembled, or partly preassembled bridges, the need for scaffolding is avoided.

Table 6.11 List of Bridges that Failed during construction due to *Failure of Lifting Equipment*

Name of Bridge	Location	Year Failed	Reasons for Failure
Imola Avenue Bridge	Napa, California	2003	3–100-ton hydraulic jacks to raise falsework failed to support poured-in-place concrete deck slab.
Motorway bridge	Near Frankenthal, Germany	1940	Failure of lifting equipment during construction.
Nordbrucke Bridge over Rhine River	Dusseldorf, Germany	1956	Insufficient crane capacity to carry double load.
Bridge on DB Lohr-Wertheim, railway line	Near Kreuzwertheim, Germany	1984	Use of uncertified lifting bars and too weak bolt nuts.

Conclusions: High-capacity cranes are normally required. For lifting long members, three cranes placed on abutments or approaches would be needed rather than two cranes. Hydraulic jacks should be tested. Other lifting ropes should be high tensile. Special provisions are required. Also, the method of lifting and the lifting equipment to be used should be preapproved by the relevant agency.

Table 6.12 List of Bridges that Failed during Construction due to *Insufficient Design Capacity of Cantilevered Arm and Cantilevered Construction*

Name of Bridge	Location	Year Failed	Reasons for Failures
Hinton truss bridge	West Virginia	1949	Insufficient design capacity of cantilevered arm during construction phase.
Fourth Danube Bridge	Vienna, Austria	1969	Insufficient design capacity of cantilevered arm during construction phase; drop in nighttime temperature increased bending moment at the top of cantilever.
Cleddau Bridge	Milford Haven, Wales	1970	Cantilevered arm of second span buckled over the inner support due to inadequately stiffened diaphragm.
Soboth prestressed concrete bridge	Soboth, Austria	1970	Collapsed during cantilevered construction, prestressing bars badly put in place.
Rhine Bridge	Near Koblenz, Germany	1971	Center span was converted to two 100 m cantilevered arms during construction. Bottom flange of trapezoidal section buckled due to increased compressive stress.
Zeulenroda steel box girder bridge	Zeulenroda, near Leipzig, Germany	1973	Plate buckling of bottom chord, cantilevered construction.

Conclusions: This is a design issue related to construction. Long-span bridges involve construction in cantilever segments. Deformations and bending stresses are very high. Each girder segment needs to be designed for temporary construction conditions. Special provisions are required. Also, the method of construction should be preapproved by the relevant agency.

Table 6.13 List of Bridges that Failed during Construction from *Incremental Launching*

Name of Bridge	Location	Year Failed	Reasons for Failures
Brohltal Bridge segmental construction	Brohltal	1974	Incremental launch construction led to concrete crushing when low prestressing cable positions were over support, settlements.
13-span Rottachtal Bridge	Near Oy, Germany	1979	Incremental launch, large cracks, inversed position of gliding plate (top/bottom).
Cleddau Bridge	Milford Haven, Wales	1970	Incremental launch of long span, box girder plate buckling over support.
Prestressed concrete bridge	Avato, Japan	1979	Incremental launch, when cantilevers coming from two sides were to be joined, differences in length appear; temporary construction to correct it led to collapse of both cantilevers.
A3 Motorway Bridge (Main River)	Near Schaffenburg, Germany	1988	During incremental launch, critical load case not included; shear failure during construction.

Conclusions: When long-span box girders or heavy sections are launched in increments, precautions need to be taken. Design for construction loads is required. Calculations need to be checked and approved by the consultant. Long-span bridges involve incremental launching. Special provisions are required. Also, the method of incremental launching should be preapproved by the relevant agency.

Table 6.14 List of Bridges that Failed during Construction due to *Girder and Connection Failures*

Name of Bridge	Location	Year Failed	Reasons for Failures
West Gate Bridge	Melbourne, Australia	1970	Replacing the designed girder in two separate halves for lifting resulted in a hinge connection but hinge bolts were removed.
Motorway Bridge	Near Seattle, Washington	1988	Girders not tied together by diaphragms, domino effect during construction.
I-70 Bridge	Denver, Colorado	2004	Bracings, fastened to bridge with bolts, became loose as girder collapsed; construction failure.
Marcy Bridge (Utica–Rome Expressway	Marcy, New York	2002	Global torsional buckling during concreting, bridge not braced properly.
Bridge near Dedensen	Dedensen, Germany	1982	Lateral buckling of construction support girder during removing of lateral supports.
Hiroshima Bridge	Hiroshima, Japan	1991	Stability problem, sliding.
Prestressed bridge	Baltimore, Maryland	1989	Prestressing not in place, asymmetric loading during construction.

Continued

Table 6.14 List of Bridges that Failed during Construction due to *Girder and Connection Failures*—cont'd

Name of Bridge	Location	Year Failed	Reasons for Failures
Motorway composite bridge	Near Kaiserslautern, Germany	1954	Insufficient stiffness of top members about weak axis.
Composite Czerny Bridge	Heidelberg, Germany	1985	Use of wrong bolts.
Fourth Danube Bridge (plate box girder bridge)	Vienna, Austria	1969	Plate buckling of bottom chord in compression.

Conclusions: Design of girders and connections for the construction loads is required. Calculations need to be checked and approved by the consultant. Special provisions are required and need to be developed.

Table 6.15 List of Bridges that Failed during Construction due to *Incorrect Construction Sequence*

Name of Bridge	Location	Year Failed	Reasons for Failures
Three-span, three-girder composite bridge	Near Clifton, Tennessee	1995	Executed construction sequence different from the one planned.
Timber truss	Bad Cannstatt, Germany	1977	Construction sequence not thought out.
Westgate Bridge over Yarra River	Melbourne, Australia	1970	Plate buckling due to weak splicing of longitudinal stiffeners—construction sequence was not well thought out.

Conclusions: The sequence of construction and concrete pouring sequence should be finalized in the preconstruction meetings. Special provisions are required and need to be developed.

Table 6.16 List of Bridges that Failed during Construction from *Negligence, Accidents, and Errors of Judgment*

Name of Bridge	Location	Year Failed	Reasons for Failures
Buckman Bridge	Jacksonville, Florida	1970	Partial collapse of bridge due to voided pier filling with seawater during construction.
Concrete five-span box girder bridge	Near Rockford, Illinois	1979	Large cracks, failure of epoxy-filled joint (not hardened to take design shear force).
Walnut Street Viaduct over I-20	Denver, Colorado	1985	Failure of pier head during construction sent eight bridge girders onto road.
Truss bridge	Concord, New Hampshire	1993	Stiffener mounted at wrong place during construction.
Cologne Bridge	Cologne, Germany	1945	Collapse during refurbishment.
Highway bridge	Southern Spain	2005	Under construction.
Bihar District Bridge	Bihar, India	1978	Under construction.

Table 6.17 List of Bridges that Failed during Construction due to *Design and Detailing Errors*

Name of Bridge	Location	Year Failed	Reasons for Failures
Second Narrows Bridge	Gerber Hinge, Vancouver, Canada	1958	Bad construction details detected, but no action taken.
Composite bridge near Sept-Iles	Near Quebec, Canada	1984	Failure during construction from faulty calculations—design errors.
Hindenburg Bridge	Over Rhine River, Germany	1958	Bad construction details detected, but no action taken.
Prestressed concrete bridge over Tauern Motorway	Gmund, Austria	1975	Concrete resistance not yet achieved, construction not in accordance with design.

Conclusion: Design and detailing errors leading to failure (Table 6.17) are a serious matter. The QA/QC manager of the project and drawing checker should be held responsible. The consultant's calculations and use of computer software need to be checked by another consultant.

Table 6.18 Construction Failures of Conventional Bridges for Reasons Listed Below

Name of Bridge	Location	Year Failed	Reasons for Failures
Buckman Bridge	Jacksonville, Florida	1970	Partial collapse of bridge due to voided pier filling with seawater during construction.
Concrete five-span box girder bridge	Near Rockford	1979	Large cracks, failure of epoxy-filled joint (not hardened to take design shear force).
Walnut Street Viaduct over I-20	Denver, Colorado	1985	Failure of pier head during construction sent eight bridge girders onto road.
Truss bridge	Concord, New Hampshire	1993	Stiffener mounted at wrong place during construction.
Cologne Bridge	Cologne, Germany	1945	Collapse during refurbishment.
Highway bridge	Southern Spain	2005	Under construction.
Bihar district bridge	Bihar, India	1978	Under construction.

Truck carrying an oversize load hits I-5 Skagit River Bridge, Washington: In May 2013, when a truck carrying an oversize load hit Skagit River Bridge, a partial collapse of the 58-year-old steel truss bridge took place and sent three vehicles into the water below. While there were no casualties and repairs are under way, the incident has drawn attention to the condition of aging bridges across the nation.

Conclusions: Negligence can be avoided by teamwork and site supervision. The contractor must take out adequate life insurance for injuries and deaths. Preconstruction meetings should address any unusual features related to day-to-day work. There is little room for human errors when the project costs are in the millions of dollars.

6.6.2 Failure of bridges for reasons other than construction

There is a very long list of recorded failures that occurred for reasons other than the construction failures of the prior section (see Table 6.18 for some examples). By adopting ABC methods, these failures of bridges made with conventional construction can be minimized (Table 6.19).

Table 6.19 Examples of *Long-Term Performance Failures*

Name of Bridge	Location	Year Collapsed	Variety of Reasons of Failure Leading to Bridge Replacement
Tacoma Narrows Bridge	South of Seattle, Washington	1940	Suspension cable bridge with slender deck failed due to lack of stiffness; vibration and vortex shedding due to hurricane wind were neglected in design.
Peace River Bridge	Between Dawson Creek and Fort St. John, British Columbia	1957	Pier foundation scour; north abutment movement caused cable bent to deform. The bridge was closed in anticipation of failure.
King's Bridge	Over Yarra River, Melbourne, Australia	1962	Brittle fracture of steel girders; welds of flange plates were substandard; there were design flaws.
Movable point Pleasant/Silver Bridge	Rt. 35 Bridge over Ohio River at Point Pleasant, between Ohio and West Virginia	1967	Corrosion in the eyebar hanger joints caused stress concentrations; also lack of inspection procedures. Bridges with similar problems include the Hercilio Luz Bridge, which was converted to a pedestrian bridge and the St. Mary's Bridge over the Ohio River, which was demolished.
Reichsbrucke Bridge	Over Danube River, Vienna, Austria	1976	Temperature stresses caused creep, shrinkage, and concrete fracturing of the unreinforced concrete pier. Tower leg lost its footing.
Almo Bridge	North of Gothenburg, Sweden	1980	325 m long and 48 m wide steel arch bridge failed due to unstiffened rings in the tubular members. Tubes built of riveted curved plates were not joined longitudinally by stiffeners.
Sgt. Aubrey Cosens Memorial Bridge	Latchford, Northern Ontario	2003	Secondary bending induced fatigue cracks in hangers, which had two hinges. Hanger close to northwest abutment failed first. Deck over floor beam deformed first and collapsed due to very cold temperature.
Mianus river Bridge	I-95, Greenwich, Connecticut	1983	A span at the south end collapsed first and the failure propagated across the bridge to the other two spans in turn. Shortage of inspectors had deferred maintenance.
Schoharie Creek Bridge	Near Fort Hunter, New York State	1987	Soil erosion happened under the foundation after a record rainfall, which was combined with snow melt. As a result, FHWA publications HEC-18 and HEC-23 were published for the design of countermeasures.

Conclusions: Detailed analysis and descriptions of some of the failed bridges is reported by Bjorn Akesson in *Understanding Bridge Collapses* (2008). A failure is not just losing a bridge; it is also losing a highway, the loss of commerce, the daily added travel time for the thousands of users of the road, etc.

It appears that while short-term failures are related to construction difficulties, the majority of long-term failures result from peak floods, earthquakes, tornadoes, etc. Bruce Melville and Stephen Coleman of the University of Auckland, New Zealand (in their book *Bridge Scour* from 2000) cite the case studies of 31 bridges that exhibited scour damage in NZ due to flood erosion. In Table 6.19(a) and (b), a typical underwater inspection report for bridges located on rivers and typical case studies of pier failure, abutment failure, general degradation, and aggradation or debris for bridges on rivers in New Zealand are summarized.

Table 6.19(a) Sample of Defects and Alternate Solutions from an Underwater Inspection Report

S. No.	Repair Item	Proposed Construction Activity	Alternate Option
1	Debris accumulation	Clean debris	Dredging
2	Erosion or undermining	Plug concrete	Use grout bags
3	Spalls in foundation concrete	Pressure grouting	Drive micro-piles
4	Section loss of structural members	Strengthen member	Underpinning
5	Corrosion of rebars	Clean, paint, and provide adequate cover	Dowel anchor bars in concrete holes
6	Mortar loss in masonry joints	Repointing mortar	Provide apron wall
7	Missing or broken riprap	Replace by large stones	Use concrete blocks

Table 6.19(b) Examples of *Long-Term Failures* Due to *Scour in New Zealand*

Name of Bridge	Location	Year Collapsed	Reasons for Failure Leading to Bridge Replacement
Bulls Road Bridge	State Highway 1 over Rangitikei River, NZ	1973	One pier and span collapsed due to excessive scour resulting from failed skew angle of flow, steep gradient formed by mean river bed level falling several meters. Earlier an earthquake of magnitude 5.1 had struck.
Waitangitaona River Bridge	State Highway 6 over Waitangitaona River, NZ	1982	Pier failure from heavy rainfall of 500 mm and peak flow of 850 m^3/s. Debris accumulation at pier increased velocity of flow, causing pier foundation to scour and the collapse of two spans.
Waipaoa River Rail Bridge	Bridge 290 over Palmerston North, Gisborne line, NZ	1988	Approach and abutment erosion took place; three pier failures also resulted from peak flow of 5300 m^3/s, causing a combination of local and general scour.
Oreti River Bridge	State Highway 99 over Oreti River, NZ	1996	Gravel erosion upstream of bridge over a long distance resulted in progressive scour damage reducing pile depths supporting pier foundations.
Bullock Creek Bridge	State Highway 6 over Bullock Creek, NZ	1983	Level of aggradation and landslip-debris deposit material accumulation exceeded the deck elevation and blocked the opening and flood flow. The bridge had to be replaced.

6.6.3 Failure of bridges during earthquakes

Earthquake disasters are sudden and are in a different category from other mishaps. It is not easy to repair a bridge when the foundation has shaken or moved.

1. *The San Fernando earthquake, 1971*: Assessed at Richter magnitude 6.6, it occurred in the mountains behind Sylmar.

   Antelope Valley Freeway Collapse (1971/1994): This occurred at a highway interchange at Newhall Pass, north of Sylmar; Southern California The failure of the Interstate 5/14 interchange in 1971 represented a turning point in seismic design of freeway bridges and prompted a radical change in the seismic design provisions for such structures. However, these changes were not applied to the Interstate 5/14 interchange itself. The failure in 1994 reemphasized the dangers of procrastination in undertaking seismic retrofitting once the need for such action has been established.

   The overpass was in the final stage of construction; it was a prestressed concrete box girder design, 1349 ft long over nine spans. The interchange suffered horizontal accelerations that were estimated as high as 0.6 g. The 10–15 s of strong motion caused the superstructure of the 384 ft section of the overpass to jump out of the shear key seats and induced the column and bridge deck to act as an inverted pendulum. The capacity of the column was found inadequate and it failed in bending at the base. The freeway was reopened in 1993.
2. *The Northridge earthquake, 1994*: This Richter magnitude 6.4 earthquake again caused failure of portions of the Antelope Value Freeway Interchange. On this second occasion, some of the most severe damage occurred to sections that had been repaired following the 1971 earthquake and in other instances spans that had been under construction in 1971 failed. The fact that some spans were supported on columns of greatly dissimilar heights was thought to have contributed to the failures. Apparently the interchange had been scheduled for a seismic upgrade but the 1994 earthquake occurred before this had been started.

   One positive benefit was that Universal Building Code (UBC) seismic design provisions changed, followed by the latest International Building Code (IBC) (see Khan, 2013). Significant changes in bridge design criteria were made, such as:
   a. *Skew bridges*: Reduction was made to skew in overpass structures due to indeterminate behavior.
   b. *Seat width*: Large increases in the seat sizes to allow for much greater longitudinal and lateral horizontal movements.
   c. *Bearings*: The elimination of the use of rocker-type bearings, which were replaced by multi-rotational bearings. Currently, seismic isolation bearings are being used.
   d. *Distance to hinges from columns*: The requirement for placement of hinges changed so that there are a least two columns between adjacent hinges along the bridge.
   e. *Rebar detailing*: The incorporation of spiral reinforcement to confine longitudinal steel within the columns; elimination of lap slices at the base of the columns; and increase in the amount of reinforcement at the column to deck connection, to provide greater resistance to punching shear.
3. The Loma Prieta earthquake, 1989.

   Cypress Street Viaduct, *Interstate 880 in Oakland, California*: During the 1989 Loma Prieta earthquake, which measured 6.9 on the moment magnitude scale, much of the upper tier collapsed onto the lower tier due to ground movement and structural flaws. This collapse resulted in 42 fatalities.

Oakland Bay Bridge, Interstate 80 between San Francisco and Oakland: A 50-foot section of the upper deck of the eastern truss portion of the bridge at Pier E9 collapsed onto the deck below, indirectly causing one death. This pair of bridges spanning San Francisco Bay in California carries approximately 280,000 vehicles per day on their decks. In addition to the Loma Prieta earthquake failure, this famous bridge has had a history of construction failures. It has one of the longest spans in the world. On February 11, 1968, a U.S. Navy training aircraft crashed into the cantilever span of the bridge, killing both reserve officers aboard. The bridge was closed for just over a month, as construction crews repaired the section. It reopened on November 18 of that year.

Western span retrofitting: The western suspension span has undergone extensive seismic retrofitting. During the retrofit, much of the structural steel supporting the bridge deck was replaced while the bridge remained open to traffic. Engineers accomplished this by using methods similar to those employed on the Chicago Skyway reconstruction project.

The entire bridge was fabricated using hot steel rivets, which are impossible to heat-treat and so remain relatively soft. Analysis showed that these could fail by shearing under extreme stress, and so at most locations each rivet was removed by breaking off the head with a jack-hammer and punching out the old rivet, the hole precision reamed, and the old rivets replaced with heat-treated high-strength tension-control bolts and nuts. Most of the beams have all been reconstructed by replacing the riveted lattice elements with bolted steel plate, converting the lattice beams into box beams. This replacement included adding face plates to the large diagonal beams joining the faces of the main towers.

Diagonal box beams have been added to each bay of the upper and lower decks of the western spans. These add stiffness to reduce side-to-side motion during an earthquake and reduce the probability of damage to the decking surfaces. The western approaches have also been retrofitted in part, but mostly these have been replaced with new construction of reinforced concrete.

October 2009 eye bar crack, repair failure, and bridge closure: During the 2009 Labor Day weekend closure for a portion of the replacement, a major crack was found in an eyebar, significant enough to warrant bridge closure. Working in parallel with the retrofit, Caltrans and its contractors and subcontractors were able to design, engineer, fabricate, and install the pieces required to repair the bridge.

On October 27, 2009, a saddle, crossbars, and two tension rods broke off. The steel crossbeam and two steel tie rods repaired over Labor Day weekend snapped off the Bay Bridge's eastern span and fell to the upper deck. The cause may have been due to metal-on-metal vibration from bridge traffic and wind gusts of up to 55 miles per hour, causing failure of one rod, which broke off, which then led to the metal section crashing down. BART and the Golden Gate Ferry Systems added supplemental service to accommodate the increased passenger load during the bridge closure. The bridge reopened to traffic on November 2, 2009.

Eastern span replacement: The replacement span has undergone a number of design evolutions, both progressive and regressive, with increasing cost estimates and contractor bids. As of April 2011, the single-towered self-anchored suspension span (SAS) tower was structurally complete. This complex project was bid on and undertaken by American Bridge and Fluor Corp, with lifting and support assistance provided by Enerpac (for digitally controlled synchronous hoisting and strand jacking systems). Separated and protected bicycle lanes are a visually prominent feature on the south side of the new east span. The bikeway will carry recreational and commuter cyclists between Oakland and Yerba Buena Island. The opening date for the new span scheduled to be after Labor Day 2013.

6.6.4 Example of bridge failures in Minnesota

Please see reference in Appendix 1 (Bibliography) for Chapter 2 for details.

The May 2013 collapse of the Interstate 5 Bridge in Washington State, the Metro-North rail crash in Connecticut, and several other major recent failures have shown that further neglect would endanger the lives of traveling public.

Nearly one-third of the nation's major roads need significant repair or replacement, with a far higher percentage in the busiest urban areas. In Washington, DC and its suburbs, roads needing significant repair or replacement soar to 62 percent.

Forty-two percent of urban roadways suffer from congestion, costing an estimated $101 billion in wasted time and gasoline each year, according to a study released by the American Society of Civil Engineers. The best of roads might last 40 or 50 years, perhaps longer if located in a forgiving climate.

6.7 Vulnerability to failure of U.S. bridges

6.7.1 Danger and vulnerability to sudden failures

A recent report card prepared by ASCE has given a very low ranking to the U.S. infrastructure system. One of the reasons is that U.S. highway system initiated in 1956 by President Eisenhower is the largest in the world. It was developed on Germany's Autobahn system with plazas for fuel, rest, and food every few miles. With the high ADT, the highways are subjected to extensive wear and tear and some bridges are added to the danger list each year. Tolls being recovered daily still do not meet the maintenance and life-cycle costs.

Certain dangerous bridges are more vulnerable to sudden failures than most other bridges and need to be fixed before it is too late. The use of remote sensors for asset management of dangerous bridges is helpful, as they supplement the regular bridge inspections.

It is sometimes said that the loss of a bridge is an eventual gain by the contractor or the consultant. A failure is no doubt expensive and the burden always falls on the taxpayers' shoulders. There is a long list of bridges that have failed using conventional construction methods.

The most vulnerable stage is during construction, when critical items are inadvertently overlooked, thereby leading to unexpected failure in the field accompanied by loss of life. The ranking of dangerous bridges can be identified by applying rating procedures or by reports of visual inspections. Selected bridges listed in Table 6.20 are potential candidates for rehabilitation or even replacement, based on visual observations. They may continue to function, but probability theory indicates that it is better to be safe than sorry.

6.7.2 Promoting the latest ABC methods

Many failures seem to happen during conventional construction, rather than with ABC. ABC methods using prefabrication and preassembly are less likely to have construction failures. This is an important reason to avoid cast-in-place or in situ construction and use ABC methods.

There are other bridges with ADT greater than 50,000 vehicles that have been identified as vulnerable but have current SR values of 15% or greater and are not included in Table 6.20. A majority of the nation's dangerous bridges are found in the Northeast, including No. 2, Pulaski Skyway in New Jersey shown in Figure 6.4. Local conditions show that steel tends to corrode more quickly in humid climates,

Table 6.20 Examples of Major U.S. Bridges that are *Vulnerable to Failure if Not Fixed*

Name of Bridge	Location	ADT	SR	Deficiencies Observed
Storrow Drive westbound over Storrow Drive eastbound	Storrow Drive Tunnel, Boston	57,770	0%	Design flaws and corroding support beams; upper deck is too thick.
U.S. Rt. 1/9 over Passaic River/New Jersey Turnpike	Pulaski Skyway Newark, New Jersey (Figure 6.4)	61,500	2%	Deicing salts corrode steel. Rehab includes replacing deck, repairs to concrete and steel supports; enhanced ability to handle seismic events.
New York Route 907C Mill Basin Drawbridge	Belt Parkway, Brooklyn, New York (Figure 6.5)	142,600	3%	Maintenance problems; very old bridge is being replaced.
New York Route 987D over New York Route 907K	Saw Mill River Parkway over Cross-County Parkway, Yonkers, New York	73,000	5.3%	Bridge, built in 1940, has lowest possible rating.
SR 520 over Lake Washington	Seattle (Figure 6.6)	97,870	9%	Longest floating bridge in the world is an engineering marvel; crews repaired 30,000 ft of cracks in its concrete pontoons, and it is frequently closed during windstorms.
I-10 Calcasieu River Bridge	Lake Charles, Louisians	63,000	9.9%	Steep grades are a traffic concern; repairs to remove rust and replace damaged rivets are in progress.
New Jersey Route 21 southbound viaduct over New Jersey Route 21 northbound	Newark, New Jersey	53,300	11%	An aging concrete deck and steel beams are in need of repair.

FIGURE 6.4

Pulaski Skyway serving northern New Jersey requiring accelerated bridge repairs.

especially where salt is used to de-ice roads in the wintertime. All are more than 45 years old. FHWA data for 2012 for nearly 700,000 bridges was analyzed, focusing on the subset with an average daily traffic (ADT) of more than 50,000 vehicles.

Political Implications of Lane Closures: New Jersey highways that connect the Northeast have high ADT. As a result, even a single lane closure during rush hours can turn the connecting bridges like the George Washington Bridge into a parking lot. Recently, the Governor of New Jersey was dragged into any number of lawsuits due to lane closure. This predicament could be avoided by accelerated bridge planning and by implementing accelerated bridge rehabilitation. Use of new repair materials for durability and precast components can reduce construction time and the duration of lane closures.

Planning for Accelerated Bridge Retrofit helps to avoid congestion during construction. On busy and important bridges connecting two states for example, the adverse impacts on traffic can best be avoided by not having any lane closure during rush hours. Besides safety the comfort of the road user shall be of greatest importance. In traffic jams, there is a loss of productive effort which hurts both the persun trapped on the road and the national GNP. It also consumes expensive thousands of gallons of gasolene, the carbon fumes are an environmental hazard. The CO in the atmosphere is brought down to the soil by rain, adversely affecting the ground water quality and agriculture produce.

Undergoing major rehabilitation or replacement require years of work. As the nation's infrastructure continues to age, more large-scale projects will be necessary to keep our bridges in safe working order, according to a report by the advocacy group Transportation for America, claiming one in nine bridges is deficient, affecting more than 260 million Americans daily.

Drawbridge repairs (such as shown in Figure 6.5) can benefit from using prefabricated components and high-strength steel. Repairs to bridges over navigable waterways (Figures 6.5 and 6.6) can use the float-in method for transportation of prefabricated components.

6.7.3 Major bridge collapses in the United States and around the world

Table 6.21 shows the number of bridges for each category, with construction-related failures being the most common (McLinn 2009; Wardhana and Hadipriono 2003). These failures are unusually

FIGURE 6.5

Mill Basin Drawbridge, New York, requiring a special type of drawbridge ABC.

FIGURE 6.6

SR 520 over Lake Washington, Seattle.

Table 6.21 Categories of Estimated Number of Bridge Failures

Category	Minimum Number that Failed	Estimated Percent Failed
Major construction difficulties	Not always known	30.0%
Floods and overtopping	165	20.0%
Erosion, scour, and debris	78	15.0%
Collision	59	5%
Overload	44	10.0%
Deterioration	43	10%
Earthquake	43	10%
TOTAL	Not known	100%

large in numbers and recur all the time. They are expensive to replace and casualties are high. The reasons for failures need to be investigated; the majority of failures can be avoided by new technology.

The incidence of major bridge failures seems to have increased in the United States, as well as rest of the world, in the last 15 years. Examples are given in Table 6.22. In the United States, Canada, and Europe, bridge failures have increased by about a factor of four compared to the prior 10-year period of the 1990s.

The current National Bridge Inspection Standards (NBIS) definition for a fracture-critical member (FCM) is "a steel member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse." For an FCM, the FHWA requires specification of proper materials and testing for design and fabrication, and establishment of proper in-service inspection protocol.

Table 6.22 Examples of Major New York Bridges that have *Extraordinarily High ADT and are Vulnerable to Failure*

Name of Bridge	Location	ADT	Deficiencies Observed
NY Route 907L (FDR Drive) over 34th Street	New York	132,734	A fracture-critical bridge requiring inspection every 12 months; a July 2011 inspection recommended the bridge undergo deck rehabilitation.
NY Route 907L (FDR drive) over Avenue C Bridge	New York	130,500	A fracture-critical bridge requiring inspection every 12 months; an inspection recommended bridge widening and deck replacement.
NY Route 907P (Harlem River Drive) over ramp to northbound Harlem River Drive	New York	92,890	A fracture-critical bridge requiring inspection every 12 months; an inspection recommended bridge replacement of the six lanes.

FIGURE 6.7

Historic (NRHP) Ferry Street Bridge, Eugene, Oregon is in good shape due to regular maintenance.

Figure 6.7 shows the Historic (NRHP) Ferry Street Bridge located in Eugene, Oregon, which needs to be investigated as vulnerable to failure. Historic bridges require aesthetic appearance or ornamental features and an older technology to match the ancient bridge construction culture.

6.8 Rapid insertion/emergency replacement methods using ABC

As defined in an earlier chapter, ABC relates to a variety of functions, namely:

- Accelerated bridge demolition (ABD)
- Accelerated bridge planning (ABP)

- Accelerated bridge replacement (ABR)
- Accelerated bridge maintenance (ABM).

Projects can be limited or partial ABC or full ABC.

6.8.1 Partial ABC: Conventional bridges with prefabricated components

In Chapter 2, we noted that the trend to use prefabricated components is on the increase and many new bridges are likely to have some form of partial ABC, although a limited use of design-build contract management is in place.

Rolled steel joists with web and flange splices have been in use for a long time both in building frames and in bridges. Other examples are:

- Bearings (steel or elastomeric pads)
- Prefabricated parapets (like the Jersey barrier)
- Median barriers
- Railings (steel or precast)
- Utility pipes hung from the bridge deck on the underside
- The lighting poles.

Ancient drawbridges: One of the earliest examples of prefabrication can be seen in drawbridges that provide access to old forts. The prefabricated drawbridges located on trenches or on streams were once used to prevent the enemy forces from entering the heavily guarded fort.

Existing foot bridges: These are widely used for pedestrians and tend to be prefabricated.

Existing movable steel bridges: Located on navigable rivers, long-span cantilevers are prefabricated but were assembled on the bridge site. These are raised and lowered several times a day to allow the ships to pass underneath. Their long-term maintenance is a bigger problem than their construction (Figure 6.5).

6.8.2 Substructure of bridges built with ABC

The foundations and substructures of most modern bridges constructed using ABC parameters are cast in place. The precast deck panels also need longitudinal or transverse concrete pours. There is a gradual trend to switch over to ABC, especially for emergency replacements. Modern materials are being used that are durable with higher fatigue resistance and are less likely to corrode.

New foundation construction techniques: Many problems and the substandard performance of foundations observed in structures on expansive soils occur from faulty construction practices. The construction equipment and procedures that are used depend on the foundation soil characteristics and soil profiles. Construction techniques that promote a constant moisture regime in the foundation soils should be used during and following construction.

6.8.3 Factors affecting the selection of a bridge for ABC

There are many types of bridges of different geometry and modern materials. The basic parameters for their performance are span lengths, number of lanes in each direction, and the type of traffic (pedestrian, trucks/cars, or train). Geometry includes normal, skew, or curved decks in the plan. If a deck is curved in elevation, it acts like an arch. The use of shallow or deep foundations is based on soil conditions. A great deal of planning and expense goes into the design, construction, and maintenance of both the structural and nonstructural aspects.

For the uninterrupted flow of traffic in two normal directions, one would form an elevated highway over an intersection. Jug-handle and cloverleaf intersections serve as multilevel changeovers and provide multiple paths to the vehicles.

6.8.4 New materials for construction

Chapter 4 addresses research and developments in the new types of steel and in concrete technology. This development in new materials is especially helpful for implementing accelerated bridge construction.

In Chapter 5, Section 5.12, progress in new construction materials was described. It is important to try out better quality and more durable materials if available.

Materials are dependent upon structural system span length and curved geometry. New construction materials are increasingly being used in recent years. These include:

- High-performance concrete
- High-performance 70 and 100 W steel
- Fiber-reinforced polymer concrete (FRPC)
- Composites
- Aluminum girders
- Glulam, sawn timber
- Structural plastics

6.8.5 Bridges are more than one structural system

Once again, these are dependent upon span length. The common types are:

- Composite slab beam decks
- Hybrid girders
- Through trusses
- Arches
- Segmental cable-stayed bridges
- Suspension-cable bridges

ABC requires contractors and consultants with special insight and experience relevant to the type of structural system. In the past there have always been limited applications of ABC. Examples are the very small span bridges and the preassembled pedestrian bridges in timber or aluminum of less than 20 ft in length. Ready-made large-diameter pipes or culverts are used for constructing roads over a stream.

6.8.6 Essential features of full ABC

1. Application to steel bridges, temporary bridges in place of detours using quick erection and demolition; availability of patented bridges in steel, US Bridge, Inverset, Acrow, and Mabey types.
2. Applications to precast concrete bridges, precast joints details; use of lightweight aggregate concrete, aluminum, and high-performance steel to reduce mass and ease transportation and erection; availability of patented bridges in concrete; CONSPAN.

3. Availability of lifting cranes, transportation methods, and erection equipment
4. Connection details for seismic design; dismantling of components and reuse at another site.
5. Cost considerations; faster construction.
6. *Focus on seismic detailing*: In developing the next generation of California bridges, there is a focus on improved post-earthquake serviceability and the development of ABC techniques.

Prefabrication and precast technology is a world apart from traditional wet construction methods.

- Modern ABC technology seems to be pulling the train on design methods, unlike conventional construction.
- Site organization is based on the selection of one general contractor, who in turn selects several subcontractors. Each subcontractor should have experience and must specialize in a particular trade such as concreting, formwork, steel fabrication, bearings, reinforcing steel, etc.
- SPMTs have enabled the transportation of long-span assembled girders without the need for splices, resulting in increased factory production (Figure 6.8).
- The connection design used for precast construction is different than that used in traditional construction. Joint strength must be tested in a structures laboratory.
- Current specifications do not adequately cover construction-related design and temporary loads. Technical specifications may also be made comprehensive to give the minutest details of the construction loads and application procedure.

Utah DOT ABC measures and recommendations:

- Reduced construction time: reduce road closure periods to reduce traffic impacts and associated economic impact.
- Improved safety.
- Improved productivity: higher product quality and contractor productivity.

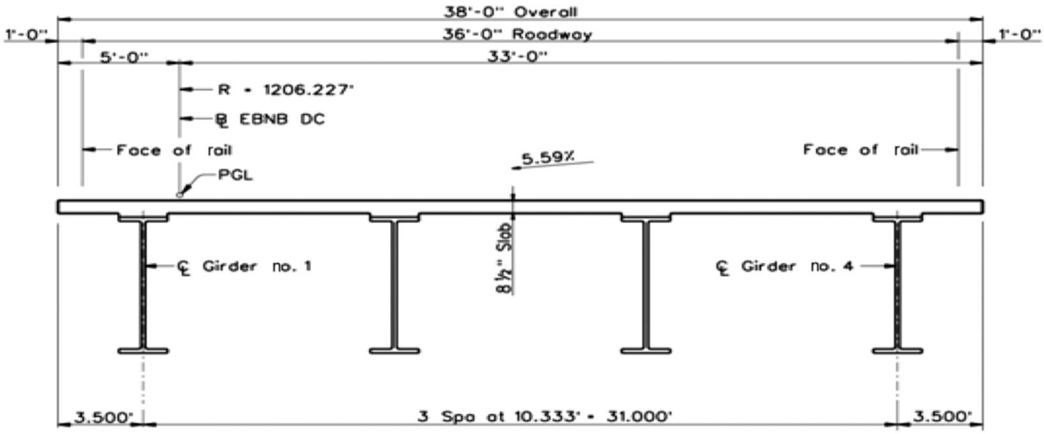

FIGURE 6.8

Typical cross-section of prefabricated composite section (parapets are not shown).

- Improved community relationships: reduce social impact to customers and neighbors. The general public is more demanding and public officials are taking notice.
- Increased awareness on motorist delay and environmental impact.
- Improved construction quality: higher product quality.
- Improved construction costs control project costs and keep project on schedule.

6.8.7 ABC and seismic issues

"Rapid insertion" bridge replacement is being practiced. Successful ABC requires detailed planning. At the annual Transportation Research Board (TRB) meeting in January of 2007, California representatives agreed to take the lead in developing ABC techniques that addressed seismic issues. A workshop was organized by TRB, FHWA, and Caltrans and held in October 2007 in San Diego, California. Representatives from several state DOTs, FHWA, TRB, researchers, and industry met, leading to the publication of the document, "2007 FHWA Seismic Accelerated Bridge Construction Workshop Outcomes and Follow-up Activities." The workshop resulted in the development of an action plan to guide future seismic ABC activities. A follow-up meeting was held at the January 2008 TRB meeting, resulting in the development of three seismic ABC-related research problem statements.

In California, a Seismic ABC Work Team was created to focus efforts for application by Caltrans. In July 2008 this team published "Accelerated Bridge Construction Applications in California–A Lessons Learned Report," documenting recent use of ABC techniques in California. The report also documents the use of precast concrete technology on several projects to reduce working days and traffic impacts. However, to fully implement ABC methods, remaining seismic issues must be resolved, particularly the development and testing of connection details capable of resisting seismic loads and deformations.

6.8.8 ABC rating procedure (Study of a hypothetical bridge project)

This procedure has been developed to calculate a hazard rating score that accounts for all of the project measures (f_1–f_4) defined in Section 6.4 (except environmental issues). In addition, weighting factors can be assigned to each measure to coincide with the current department themes.

The values assigned to each project decision measure are multiplied by the corresponding weighting factor. The ABC Rating Score is the ratio of the weighted score to the maximum score shown as a percentage. The ABC Rating Score has been categorized into three ranges.

The minimum score of 20 is intended to capture any project receiving a score of 5 in any one of the 4 most heavily weighted categories.

The higher threshold score of 50 is intended to capture any project receiving an average score of 3.5 in the 4 most heavily weighted categories.

Each of the three rating ranges lead to a different entry point on the corresponding ABC Decision Flowchart. Use the ABC Rating Score to enter the flowchart and work toward a conclusion.

6.8.9 ABC decision flowchart

The ABC Rating Procedure is the first step in the determination of whether ABC is appropriate for each project. The ABC Decision Flowchart uses the ABC Rating Score and then addresses yes/no factors that need to be considered prior to making a final decision on construction approach.

These factors include project schedule, environmental issues, total project cost, site conditions, and high-level indirect costs such as political capital, safety, or possible impacts to stakeholders. Together, the ABC Rating Procedure and ABC Decision Flowchart can be used to make a final determination on the appropriate construction methods for each project.

6.9 Accelerated bridge replacement (ABR)

To significantly reduce the time to construct or replace a bridge involves various methods during project planning, design, contracting, and construction. Nine measures of project constraints have been identified as being applicable to the ABC decision process. The following is a brief description of each measure and how they apply to the current department themes.

- Average daily traffic

ADT is a measure of the amount of traffic traversing the bridge site. Use a value equal to the total number of vehicles on the bridge and on the roadway under the bridge (if applicable). The value of maintaining the interstate highway network is accounted for in this measure by assigning the maximum score for this situation. This measure addresses the department theme of Decrease and Minimize Maintenance of Traffic (MOT).

- Delay/detour time

This is a measure of the time impact that a project has on vehicles passing through the construction site. Account for the construction time delays due to detours and congestion caused by construction. If delays are anticipated for both the roadway on and under the bridge, enter the worst-case scenario. This measure addresses the department theme of Decrease and Minimize MOT.

- Bridge classification

This measure is used to account for bridges that are on or over a designated evacuation route or part of a critical lifeline route that will be used in an emergency such as a major earthquake. ABC can be used to minimize time of impact for these important roadways. This measure addresses the department themes of Decrease and Minimize MOT and Accelerate Delivery.

- User costs

This is a measure of the financial impact of a construction project on the traveling public. The major contributing factors in calculating user costs are the delay time and ADT, but the duration of the impact to users is the key component in measuring the encumbrance to the traveling public. The department has instituted standard methods for calculating user costs. Calculate the user costs in coordination with the Structures Division Project Manager and the TOC and determine the total project cost for each construction option that is being evaluated (SPMT bridge move, prefabricated elements, conventional construction, etc.). This measure addresses the department themes of Decrease and Minimize MOT, Get a Good Price, and Encourage Innovation.

- Economy of scale

This measure accounts for the repetition of the elements and processes, and how they relate to the overall cost of a project, as well as the possible savings to future projects. The total number of spans is used in order to account for repetition of substructure elements as well as superstructure elements. This measure addresses the department theme of **Get a Good Price.**

- Use of typical details

This is a measure of the potential to make use of department-typical details that have been developed for ABC. Most bridges can be successfully built using ABC; however there are instances where the complexity of the bridge geometry makes the use of typical details impractical and costly. Contact the Structures Division Project Manager to evaluate the bridge site and determine the level of complexity as it relates to various ABC techniques. The use of typical details will lead to more repetition of elements, faster construction times, higher quality, and reduced prices. This measure addresses the department themes of Get a Good Price and Accelerate Delivery.

- Safety

This is a measure of the relative safety provided to the traveling public and the work force at the construction site. ABC and the use of prefabricated elements will reduce the exposure time of travelers and workers to these dangerous environments. Project sites that require complex MOT schemes for extended periods of time are undesirable. The goal of ABC is to minimize this exposure to both the traveling public and the workers on site. This measure addresses the department themes of Decrease and Minimize MOT and Accelerate Delivery.

- Environmental issues

This is a measure of the project's impact to the surrounding environment. The presence of endangered species or annual spawning seasons can lead to short construction windows. In other cases, projects may have limitations due to wetlands, air quality, extreme weather, or noise. ABC may be necessary to accomplish an acceptable level of impact on the surrounding environment. This measure does not specifically address a department theme and is not a weighted factor; rather, it is included in the ABC Decision Flowchart to evaluate if ABC can provide appropriate mitigation to an environmental commitment or requirement.

- Railroad impacts

This is a measure of the impact of the project on railroad traffic. The number of trains and type of train are used to measure this impact. This measure addresses the department themes of Decrease and Minimize MOT and Accelerate Delivery.

The ABC measures described above have been incorporated into the ABC Rating Procedure to help determine where the use of ABC is appropriate. The range of scores to be used with the ABC Decision Flowchart has been set to ensure that accelerated construction will be commonplace when the measured benefit is more significant than the measured cost with respect to accomplishing department themes and project goals.

6.9.1 Important features addressed by FHWA

Mobility impact time is the duration of the traffic flow of the transportation network that is reduced due to on-site construction activities. This includes the reduction or removal of the following items:

- Maintenance of traffic
- Materials
- Equipment
- Labor

Future of ABC: According to the FHWA, 40% of bridges were built over 40 years ago with a 50-year design life. 25% require rehabilitation, repair, or replacement.

Lessons learned:

- Team composition: involve contractors with ABC experience during the design process.
- Plan for unexpected problems: have extra equipment on standby.
- Do not be afraid to think outside the box.

Site constraints:

- Local ordinances and permits
- Construction easements
- Right-of-way

Utilities site constraints

- Temporary or permanent relocations
- Wetlands

Constructability/design:

- Meet with contractors to develop potential ABC techniques.
- Allow ABC techniques to be flexible in project specifications.
- Study transportation routes for bridge components and equipment to site.

Material procurement:

- Components of ABC
- Geotechnical solutions
- Soil-bearing capacity for heavy lifts
- Foundations and walls
- Advance pile driving

Abutment solutions:

- Tie-back anchors
- Abutment saw cutting
- Abutment modifications

Prefabricated bridge elements and systems:

- Abutment caps

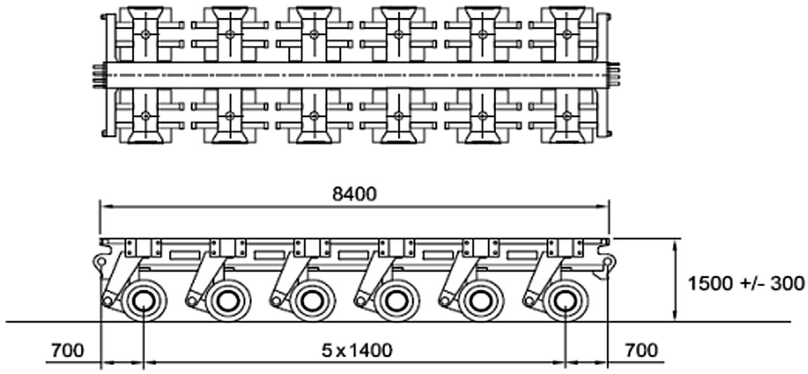

FIGURE 6.9

Axles of an SMPT their magnitude can be higher than HS-20 axle loads.

Precast bridge seat loading:

- Deck panels: concrete and steel

Structural placement:

- Skidding (roll-in)
- Use of SPMT: self-propelled modular transports (Figure 6.9) Chapter 3, Section 3.2 describes 3 types of SPMT. There is no standard length but more axles can be added as required.
- Peak bending moments need to be checked so that the bridge components are not overstressed.

6.10 Recent progress made with successful completion of ABC

Chapter 5 described examples of successful completion of prefabricated projects in a number of states. Projects completed by Kraemer Company are listed here.

Within a relative short period, progress has been made in the implementation of ABC. Successful examples are shown in Table 6.23 and those completed by Kraemer in Table 6.24 in the United States due to efforts from FHWA and others.

NICTD Train Crossing the New Structure

Friday, November 3, 2000: Start roll-in mobilization.
Sunday, November 5, 2000: Finished railroad opens for normal operation.

- Detailed planning

Checklist for go/no go meeting.
Detailed outage schedule.

Table 6.23 Recent Successful Project Examples using ABC

Name of Bridge	Application	ABC Details
4500 South over I-215 (2007)	Accelerated bridge construction using SPMTs	• Bridge needed immediate replacement due to rapid deterioration of bridge supports. • New bridge was constructed adjacent to the structure. • New bridge was moved using SPMTs during one weekend closure. • Existing bridge spans were removed using SPMTs. • Self-compacting backfill used to accommodate tight work area.
Riverdale Road over I-84 (2008)	Accelerated bridge construction using precast and prefabricated elements	• 90% precast elements. • Innovative noncomposite deck. • Innovative strategy for phasing. • Match-cast elements at on-site casting yard. • Noncomposite deck panels. • Longitudinally post-tensioned ABC strategy for phasing. • Phase I: Construct outside bridge quarters. • Phase II: Move traffic to outside, construct inside two quarters. • Phase III: Tie phases together and open entire bridge.
Payson deck replacements (2009)	Accelerated bridge construction using precast, prefabricated elements	• Accelerated phasing. • Longitudinally post-tensioned. • Predemo work.
I-80 over Echo Dam Road, Utah (2010)	Accelerated bridge construction using transverse sliding	• Replacement of EB and WB I-80 over Echo Rd. • Bridges replaced using horizontal skidding of the new bridge superstructures onto new abutments constructed under existing bridges while they remained in service. Final bridge placement in 7 h. Overnight detour on the ramps during slide. • Abutments and approach slabs on temporary supports. • Bridge slid onto new abutments and sleeper slabs. Daytime closures allowed on cross-street. Approach slabs construction with bridge.
I-80 bridges over 2300 East, Salt Lake City, Utah (2009)	Accelerated bridge construction using transverse sliding	• Replacement of EB and WB I-80 bridges. • Similar method as Echo Road bridges. • Vertical clearance challenge required bridge jacking.
I-15 south, Layton Interchange (2010)	Accelerated bridge construction using jacking/launching	• Single-point urban interchange (SPUI) over I-15. • Constructed each span on temporary steel frame supports above 12 feet of surcharge on approach embankments. • Surcharge was excavated from beneath the spans and they were lowered onto rail system. Two temporary bents used during launch process and then removed. Each bridge span was moved within 6-h nighttime closures. Bridge constructed on temporary supports. Surcharge removed underneath. • Jacked down onto slide rails. • Span launched out over I-15 during night closure.
I-15 CORE, Sam White Bridge (2011)	Accelerated bridge construction using jacking/launching	• First two-span bridge moved in North America. • Night closure. • Four SPMT rows.

Table 6.24 Kraemer's Recent Successful Project Examples Using ABC

Name of Bridge	Application	ABC Details
CNR Rainy River Bridge replacement (float-in)	Baudette, Minnesota Client: Canadian National Railway	The Rainy River Bridge replacement project included the replacement of five existing bridge spans, including a swing span with six new 176-foot through truss spans. Four trusses were erected on temporary platforms and floated into place and two trusses were erected on temporary bents. Once the new trusses were built and in place on the temporary bents adjacent to the existing bridge, the old spans were floated out and the new spans were rolled into place during three, two-day switch-outs.
CPR Bascule Bridge replacement (float-in)	La Crosse, Wisconsin Client: Canadian Pacific Railway	The Bascule Bridge replacement project involved the replacement of a 100-year-old swing span over the Black River in La Crosse, Wisconsin. The 307-foot structure was replaced with a 147-foot single-leaf bascule span weighing 500 tons and two 104-foot through-plate girder spans. Span replacements were completed in sections by floating-in and floating-out or rolling-in and rolling-out. The new bascule span was operational for marine craft less than 48 h after the bridge was opened to rail traffic.
RTD Fast Track West Corridor light rail transit over 6th Avenue (roll-in)	Lakewood, Colorado Regional Transportation Department	The RTD over 6th Avenue project was constructed as part of nine structures for the West Corridor, the first leg of a multicorridor rapid transit expansion in the Denver metro area, extending from Denver to Golden, Colorado. This ballasted light-rail bridge carries double track service over the 6th Avenue Freeway and is the signature bridge of the West Corridor. The basket-handled arch was constructed on falsework "off-line" and rolled into place utilizing pushing rams in the rear and heavy transports in front of the structure in a single 36-h period.
US-6 Clear Creek Canyon Bridge rehabilitation (full depth precast deck panels, Figure 6.10)	Clear Creek Canyon (between Denver, Black Hawk, and Central City, CO) Client: Colorado Department of Transportation	The US-6 project was the fast-track reconstruction of the superstructure, rehabilitation of the substructure, and full depth deck replacement of three bridges located in Clear Creek Canyon on US-6 in 12 days.
Powers North design-build (precast deck panels and abutments)	Colorado Springs, Colorado Client: Colorado Department of Transportation	The Powers North design-build project was the accelerated construction of six bridges and one mile of divided four-lane highway on SH 21 at Briargate Parkway, Union Boulevard, and Pine creek opening the road to traffic in 118 calendar days.
Page Avenue tied arch bridge (float-in)	St. Louis, Missouri Client: Missouri Department of Transportation	Construction of twin 17-span bridges across the Missouri River as part of the Page Avenue Extension Project relieving congestion on I-70 in St. Louis, Missouri. Kraemer constructed two, 600-foot-long tied arches for the main bridge spans. To expedite construction, each tied arch was floated into place above the Missouri River's navigational channel on a falsework tower custom designed by Kraemer.

FIGURE 6.10

Example of full-depth deck panels.

- Mobilization

  Start: Roll-in mobilization at 3 a.m. Friday, November 3, 2000.

  - Demolition operations Bridge jacking.
    Friday: Removal of the west panel of the existing truss bridge Saturday, lowering of the west end.
    Saturday: Nearly complete demolition.
    Sunday: Demolition of the existing east abutment cap.

- Precast abutment construction

  Heavy lifts.
  Setting of the new precast east abutment cap.
  Sunday: Trackwork required for the roll-in.
  New bridge rolled half distance.

Examples of other ABC Projects

1. NICTD Bridge over Torrence Avenue, Chicago 2013–Roll-in 65′ thru-girder span over Trail Creek, Michigan City. Build new abutments behind existing.
2. Case Study of Copano Bay Bridge, TX

   Carries SR 35-Gulf Intracoastal Waterway.
   11,010 ft long, 129 ft wide, 75 ft tall.
   Main navigational structure–CIP pile caps, tall columns, and bent caps.

   Kraemer's ABC experience includes:

- Innovative construction methods including
  - Incremental launching
  - Superstructure roll-in

FIGURE 6.11

CNR Rainy River Bridge Replacement, Baudette, Minnesota.

    - Superstructure slide-in
    - Superstructure float-in
- Prefabricated bridges and components including
    - Precast bent caps
    - Precast columns
    - Precast abutments
    - Full depth precast deck panels

Representative projects are listed in Table 6.24.

Figure 6.11 shows the use of floating platforms for Rainy River Bridge in Minnesota.

Construction over rivers is more difficult than over intersections. Elevation of floating platforms is governed by high tides and high winds.

Deep foundations like driving piles in the river bed may require cofferdams or river diversion.

6.11 Curved girders instability in unbraced erection conditions

Traditionally, design engineers and contractors work independently in the design and construction of most bridges. Design engineers are generally responsible for making sure the bridge is able to withstand all strength and service limit states in the end configuration while contractors are generally responsible for the stability of the bridge during erection and construction and to make sure the bridge is constructed as specified by the designer.

Curved girders are asymmetric in plan. Curved I-girders are subjected to various loading and support conditions throughout the different stages of construction. The lack of cross-bracings with unassembled curved girders causes warping stress from torsion even before the bridge is used. The torsionally induced warping stresses in horizontally curved girders can often equal or exceed the girder's bending stresses. Such girders are susceptible to both local and global buckling modes. Global buckling modes often control due to the limited availability of bracing during the early stages of construction.

Because of the limited bracing, the bridge system has significantly less torsional stiffness and will rotate more. The larger unbraced length also makes the bridge more susceptible to lateral-torsional buckling.

Highly curved bridges may experience relatively large warping stresses as a result of the large torsional moment. Overdesigned procedure can be avoided if prefabricated composite girders, either partially or fully assembled, are used to help overcome the erection stresses. For lifting, an optimum use of both holding cranes and shore towers needs to be investigated. Additional high-capacity cranes should be used, as the composite girder assembly will be heavier.

A study was sponsored by the Texas Department of Transportation at the University of Texas, at Austin, resulting in publication of "Guidance for Erection and Construction of Curved I-Girder Bridges" in 2010 by the researchers Jason Smith et al. The study showed the following deficiencies with the nonassembled erection and noncomposite stages of deck slab construction:

All erection stages should be analyzed for excessive deformations, stresses, and buckling considerations. The concrete deck placement produces a large load on the bridge before full composite action can be accounted for and the stabilizing effects of the hardened deck can be achieved. Thus, each concrete stage should be analyzed for excessive deformations, stresses, and buckling considerations.

Many contractors use rules of thumb and experience to ensure stability during erection. Rules of thumb differ from one contractor to another, and consistent erection methods are a rarity. Although some rules of thumb may be quite conservative, others may be much less so. Therefore, coming up with design guidelines based on parametric studies rather than rules of thumb are desirable to help allow the contractor and the designer to work together to prevent issues that may occur due to the lack of communication between the two professions.

Temporary supports are very expensive because they can require significant efforts to construct and often occupy valuable space that may interfere with traffic flow around the construction site. Cases where a holding crane may be satisfactory over a shore tower are also not well understood. To improve the understanding of temporary support requirements, the three-dimensional Finite Element Analysis (FEA) models must be validated using stress and rotation.

6.11.1 Use of commercial computer software to analyze erection stress

A comparative study of erection stresses (such as those due to warping) encountered during the different processes of erection can be made between the conventional and the ABC prefabricated and preassembled methods. The latter method is likely to show lower stresses. In addition to the theoretical analysis, strain gauges need to be mounted on the flanges and webs of curved girders to measure stress distributions. To compare different analysis programs, Nevling et al. (2006) utilized the results from a field study on a three-span curved bridge with five girders.

For manual analysis, a line girder method of analysis from the AASHTO (1993) *Guide Specification for Horizontally Curved Highway Bridges* and the V-load method are used.

V-load method: This is one of the first analytical methods used to design curved girders and was introduced by U.S. Steel in 1963 (Richardson, Gordon, and Associates 1963). This method was investigated by Fiechtl et al. (1987), and they presented a report on the development and evaluation of the method. The V-load method accounts for the girder curvature by applying self-equilibrating vertical loads on the girder. The report by Fiechtl et al. compares these results with refined finite element analysis for a variety of bridge configurations.

2D grillage models: The V-load method is accurate for noncomposite sections, but did not perform well for composite action due to the shear transfer by the deck. The following 2D grillage models are useful for design calculations of various load cases of the completed structure:

- MDX
- DESCUS
- SAP2000

However, the 2D models are not capable of analyzing the girders during construction and can miss critical information that can only be obtained from a full 3D analysis.

3D finite element programs: There are several programs available:

- ANSYS
- ABAQUS
- LUSAS
- ADINA
- BSDI

UT Bridge for construction loads: UT Bridge is a user-friendly 3D finite element program that can be used to analyze partially constructed bridges and to provide valuable information to engineers and contractors in the assessment of the safety of a bridge at various construction phases. These 3D packages do not include predefined load cases or the AASHTO checks.

6.11.2 Modeling methods

1. The finite-element method is one of the most general and accurate methods, but requires a significant amount of time to implement.
2. The finite-strip method divides the bridge into narrow strips with radial supports and provides some simplicity over the finite-element method, but does not offer the same flexibility as the finite-element method.
3. The finite-difference method superimposes a grid on the structure, and the governing differential equations are replaced by algebraic difference equations and solved at the grid points.
4. The slope-deflection method establishes partial differential equations in terms of the slope-deflection equations and is solved assuming a Fourier series.

The finite-element method is the most flexible with respect to configurations and boundary conditions. Computer FEM modeling can be completed with the incorporated graphical interfaces and can expedite the results. Lifting and erection should be avoided in windy conditions or when there is a high temperature change.

Lifting and erection loads analysis:

The computer analysis for temporary loads can be more complex than the regular analysis for long term live loads. Since the construction method used by each contractor is different, temporary load analysis cannot be laid down in advance.

The contractor needs to have the analysis method pre-approved by both the consultant and the owner to avoid any mishap in the field.

6.11.3 Stresses during girder lifting

Three of the critical issues that need to be addressed by the engineer when considering the lifting of girders are buckling, deformations, and stresses. Although local buckling of plate elements needs to be considered during construction, most I-girders with practical proportions are usually controlled by lateral-torsional buckling. A linear buckling analysis can be used to determine the critical buckling load, but the analysis is applicable for problems with small prebuckling deformations.

Except for extremely slender girders, yielding is not usually a problem unless the girders experience excessive deformations. However, the stress calculations should include both strong and weak axis bending as well as warping normal stresses from the torque applied. Descriptions of the spreadsheet calculations as well as the assumptions made during its development are incorporated into an Excel spreadsheet program named *UT Lift*.

6.11.4 Erection practices for lifting horizontally curved I-girder: Typical lifting scenario

Shore tower supporting curved girders with pier (spreader beam is being mounted for lifting of adjacent girder).

Construction issues: The length of a girder segment is most often controlled by the transportation hauling length. The maximum single girder segment lifted is 150 feet. The size of the pieces lifted depends on the lengths that can be transported to the site, the size of the crane available, and the bending stresses that can be tolerated without buckling. For continuous units, falsework must be used to support one girder as the other is lifted for splicing. The first lift should preferably be a pair of girders. Single or double crane lifts require cranes over 250-ton capacity, which would increase the cost of the erection.

Shore towers and holding cranes: The primary function of a shore tower or holding crane is to reduce deflections and stresses as well as provide stability to the girder prior to full assembly. A shore tower is a structure that is placed at a specific location along the girder to provide a reaction on the bottom flange. A shore tower can provide restraint to the system in all of the translational directions.

Use of spreader beams: The use of other lifting devices such as slings would not allow the beam clamps to hang vertical, which could cause them to slip or cause excessive flange deformation when the girder is lifted; the girder could also roll.

The use of adjustable spreader beams is preferred. The maximum reported spreader beam length is 150 feet. However, the length based on the lateral torsional bending stress limit is given by AASHTO.

Cranes: It is more desirable to use one crane only and a spreader bar for curved I-girder erection. Contractors typically prefer the use of one crane due to the high cost of renting this type of heavy construction equipment.

Determining lifting points: The lifting locations are determined through structural analysis. Unbraced flange length, compression flange stresses, and the ability of the top flange to sustain load transfer to the beam clamps are some of the engineered requirements. A two-point lift is preferable to eliminate the “roll.”

Shoring: The high cost of installing and designing temporary falsework to support curved I-girders during erection is important. The premature removal of temporary shore towers, improperly locating falsework, and lack of falsework adversely affects the structural system.

Erection: The effect of splice locations pertains to girder erection. The first girder that is in a set requires a holding crane or shore tower to temporarily support it until the adjacent girder is erected. Such an idea is ideal for design-build contracts, because the design engineer must know the methods and means that will be used to erect the girders while designing the superstructure of the bridge.

Unbraced length: Design specifications lack in-depth criteria for horizontally curved I-girder lifting. The equation in the AASHTO LRFD Bridge Design Specifications (2007) should be used.

Use of a parametric finite element model: To understand the behavior of curved girders during lifting, it is desirable to perform a series of analyses with a wide range of parameters to improve the understanding of the girders over a range of support and loading conditions. The parametric study can be carried out using the powerful finite element analysis software, ANSYS.

The variables in the parametric study include the radius of curvature (R), flange width to depth (bf/D), length to depth (L/D), and lift point location (a/L).

6.11.5 Review of AASHTO LRFD bridge design specification (2007) and other key specifications

There are several bridge design codes that specify requirements for curved I-girders during construction. The following paragraphs discuss the stated requirements of several codes and include the preferred practices for the state of Texas.

1. Section 2.5.3 discusses the design objectives during construction. “Constructibility issues should include, but not be limited to, consideration of deflection, strength of steel and concrete, and stability during critical stages of construction.”
2. Chapter 4 is dedicated to the structural analysis of bridges, and Section C 4.6.1.2.1 states: “Bracing members are considered primary members in curved bridges since they transmit forces necessary to provide equilibrium.”

   “Curved I-girders are prone to deflect laterally when the girders are insufficiently braced during erection. This behavior may not be well recognized by small-deflection theory. Classical methods of analysis usually are based on strength of materials assumptions that do not recognize cross-section deformation. Finite element analyses that model the actual cross-section shape of the I-girders can recognize cross-section distortion and its effect on structural behavior.”

   The recommendation of using finite-element analysis to model the bridge cross-section and bracing members is accomplished by the UT Bridge program.
3. Chapter 6 discusses the design of steel bridges. Section 6.5.1 states that the limit states should be investigated “for each stage that may be critical during construction, handling, transportation, and erection.” Section 6.7.4.2 discusses specific limitations on the unbraced length of curved I-girder bridges.
4. The AASHTO LRFD Bridge Construction Specifications (2004) provide the required construction practices as stated by AASHTO. Section 11.6 discusses the erection of steel structures, and states in Section 11.6.4.3 that “Cross frames and diagonal bracing shall be installed to provide

stability and ensure correct geometry. Temporary bracing, if necessary at any stage of erection, shall be provided by the Contractor."

5. The AASHTO/NSBA Steel Bridge Erection Guide Specification (2007) is published jointly by AASHTO and the National Steel Bridge Alliance (NSBA). Chapter 2 of this document specifically discusses erection procedure, and requires that a contractor provide a detailed erection procedure to the owner prior to the start of construction. Section 2.3(b) states that submitted procedures should contain "calculations to substantiate structural adequacy and stability of girders for each step of bridge assembly."
6. Chapter 6 discusses the lifting procedure and states that "crane and materials must be located such that the lift is safe and within the crane manufacture's capacity." Also, Section 6.3 states that "Girders shall be stabilized with falsework, temporary bracing, and/or holding cranes until a sufficient number of adjacent girders are erected with diaphragms and/or cross frames connected to provide the necessary lateral stability and to make the structure self-supporting." The commentary associated with Section 6.3 states that "Removal of falsework, temporary bracing, and holding cranes shall be in accordance with stability provided in the erection procedure."
7. Section 2.2.1 states that "for curved girders, flange width should be approximately one-third the web depth and no less than 30 percent of the web depth. The extra width for curved girders enhances handling stability and helps keep lateral bending stresses within reason." The Preferred Practices also state that "flange width affects girder stability during handling, erection, and deck placement. Keep the girder length (field section length) to flange width ratio below 85."
8. Section 2.2.4 provides additional cross-sectional proportioning recommendations and states that the recommended depth given in AASHTO 2.5.2.6.3 should be increased by 10–20% for curved girders. According to the TxDOT Preferred Practices, the total superstructure depth to span length ratio should be (1:0.033–1:0.04).
9. Section 2.6 states that for curved girders, TxDOT prefers that diaphragms or cross-frames be placed at 15–20 feet maximum to help limit flange-bending stresses and cross- frame/diaphragm member forces.
10. Another source of information about the current state of practice in construction and erection of curved I-girder is the NCHRP Synthesis 345 report (2005). This report, titled *Steel Bridge Erection Practices: A Synthesis of Highway Practices,* documents a survey sent to state departments of transportation, contractors, and fabricators.

Top flange bracing: Structural analysis should be performed to make sure that the girder does not translate a significant amount when the lifting crane is released.

Bridge Construction Equipment: NRS AS is a Norwegian company, which deals with advanced construction equipment for concrete bridges and modern techniques of construction (Reference Oslo, Norway, nrs@nrsas.com).

It provides exhaustive coverage of new and emerging bridge construction technology and modern construction methods for all bridge professionals looking to save time, labor, and costs, reduce risk, and increase the value and quality of bridge projects through mechanized construction. Bridge construction equipment is becoming increasingly more complex and sophisticated. The book explores configurations, operations, kinematics, performance, productivity, structure–equipment interaction, and industry trends for every family of special equipment. Each chapter also includes coverage of deck fabrication. Design-oriented chapters provide guidance on prevention of human error, design for robustness and redundancy, modeling and numerical analysis, instability and prevention of progressive collapse, and repairs and reconditioning of second-hand machines. Management-oriented chapters describe procurement, fabrication, and commissioning of special equipment.

6.12 Costs of bridge failures and funding allocations

6.12.1 Transportation funding and financing

The Federal Aid Highway Act of 1956 is responsible for highway funding. The official funding policy stated by Anthony Foxx, the 17th U.S. Secretary of Transportation, is as follows: "Governors and states have long recognized the importance of investing in surface transportation. When operated efficiently, the surface transportation system can enhance the economic competitiveness of states and the nation, as well as increase safety and the quality of life for users." However, the nation's transportation system faces many pressures, including a growing imbalance between system use and capacity, the erosion of traditional funding sources, increasing costs for the construction and maintenance of infrastructure, and shrinking sources of credit during difficult economic times. States are exploring a variety of new and innovative funding and financing methods, while at the same time looking to maximize the effectiveness of traditional sources.

NGA Center activities: To help states with transportation funding and financing issues and challenges, the NGA Center monitors and evaluates funding and financing challenges and policy responses across the states, and disseminates information through publications, conferences, and workshops to accelerate the adoption of the most effective policy tools and best practices. It provides governors and their policy advisors with targeted research and analysis on existing financial mechanisms as well as innovative new tools.

The NGA Center has also assisted states in exploring several funding and financing options, including debt financing (state infrastructure banks), a variety of user fees, public–private partnerships, and strategies specifically designed for freight. The available NGA Center Resources need to be consulted.

6.12.2 Essential costs of failures and the use of ABC

When the highway is shut down, it results in long detours, lowering of the speed limits, traffic jams, closing down of some local businesses, plus the loss of time for reconstruction. A projected cost estimate in millions of dollars may be made. In the ASCE Reston, Virgina Waterforum of 1992, Kenneth Young proposed guidelines of costs of sudden and unexpected requirements of each disaster. These may be modified as follows:

$$\text{Total direct costs} = \text{Demolition costs} + \text{New construction costs}$$
$$= C_1.L.W + C_2.L.W = (C1 + C2)\,L.W$$

where

C_1 = Unit cost of demolition and disposal of damaged bridge
L = Length of new bridge
W = Width of new bridge
C_2 = Unit cost of new bridge

An estimate of indirect costs should include any extreme weather conditions affecting construction, any unforeseen delays or shut-downs due to non-availability of materials, strike etc. These costs can be absorbed in insurances if it is in effect.

Total indirect costs during construction = Daily cost of detour length + Cost of time loss

$$= C_3 D \times A \times d + [C_4 \times O(1 - T/100) + C_5 T/100](D \times A \times d)/S$$
$$= C_3 + [C_4 \times O(1 - T/100) + C_5 T/100]/S\,(D \times A \times d)$$

where

C_3 = Unit cost of running a vehicle per mile ($0.50–$0.60)
D = Detour length in miles
A = ADT based on earlier traffic count
d = Duration of detour in days
C_4 = Value of time per adult ($10–$15 per hour)
O = Average occupancy rate per vehicle (1.25–1.5)
T = ADTT percentage
C_5 = Value of time per truck ($20–$30 per hour)
S = Average detour speed (30–50 mph)

Each item for each bridge requires an individual cost evaluation based upon bridge data, location, and unit cost of the type of construction, detour length, etc., and costs will vary for each state. An Excel spreadsheet is required, as some costs will be based on bid items submitted by the selected contractor.

By using ABC modular bridges and design-build contracts, the durations of demolition and new construction can be significantly reduced. It will lower the costs that are being incurred in conventional construction.

Funding for unforeseen failures is not easily available. FHWA has an Emergency Relief Fund while FEMA has a Disaster Assistance Program (DAP). The funds provided are never enough. For example, in the 1985 floods that struck the states of West Virginia, Virginia, Maryland, and Pennsylvania, nearly 50 bridges were lost. At an average, if $2 million are required to repair each damaged highway and the bridge, it will require $100 million. The DAP and ERF were able to provide $55 million. The deficit needs to come from the state funds, and usually are increased by raising gasoline taxes. Future maintenance costs are not included.

6.13 Conclusions

Failure studies: A survey at the international level was conducted to identify the reasons for failures in using conventional methods. Maintenance can avoid failures and at least warn of trouble in advance. Use of remote sensors to monitor structural health is desirable.

Early failures in conventional construction can be attributed to a variety of reasons, both administrative and technical. The study shows failures resulting from inadequate overseeing of projects, a lack of supervision at the site, design errors, lack of comprehensive codes, limited resources, and contractors' last-minute decisions to meet hasty schedules. For example, it is not easy to provide a large number of temporary supports in one construction phase, which may result in support settlement and collapse.

Most of the failures occurred during construction due to lack of redundancy in design, inadequate construction, and lack of contracting experience and knowhow.

Bridges on rivers failed more than on the intersections, due to soil erosion. Use of HEC-23 countermeasures is on the rise. Keeping the number of piers to a minimum will save costs. Balance cantilevers are required in segmental construction, as the use of temporary supports may not be possible.

Some progress has been made in making bridges seismic-resistant by using lightweight materials and isolation bearings.

Failures are not specific to any structural system. Steel girder bridges are as popular as trusses depending upon the span lengths. However, construction of curved girder bridges is more difficult than those of skew or straight bridges.

Use of modern technology: Bridge engineering is changing with time. New technology and innovative ideas developed in the last 20 years need to be adopted. In planning bridges, cost is still the main criterion. Much of the cost goes in the foundation and substructure concrete construction.

The use of new and stronger construction materials such as HPS, HPC, Ultra HPC, and FRP decks should be encouraged, as these are more durable. Shallow-depth girders will result, which are lighter in weight. Galvanizing will reduce corrosion. Currently, rolled sections in HPS 70 and 100 W are not available or expensive. Welded girders in HPS are being used.

Prestressed concrete box girders are stronger in torsion and cost-effective, especially with the use of lightweight concrete and lower maintenance costs. Also, composite construction such as using the inverse system is more economical and on the rise. Precast integral abutment construction requires greater attention.

Minimize cast-in-place concreting on-site: The closure joints on the deck between precast panels require wet concrete up to two feet wide. Ultra HPC and high early-strength admixtures may be used.

Project management and quality control: MPT is of critical importance. Quality control is another difficulty. Project managers at highway agencies may be encumbered with many bridge replacements at a given time and not have enough time to deal adequately with the contractor's claims and many change orders simultaneously. Consultants are supposed to serve as their right hand, but it may not always work that way. Adequate liability insurance needs to be taken out for unforeseen items so that the owner (and eventually the taxpayer) is not penalized by cost increases.

Modular transporters and construction devices: ABC prefabrication and preassembly of bridge components, and the use of SMPTs and high-capacity cranes, can and should prevent at least the construction failures. FHWA has published an informative manual on use of SMPTs to remove and replace bridges (refer to Publication No. FHWA-HIF-07-022, dated June 2007).

Similar manuals exist for lifting cranes, whether manufactured in United States or abroad, and include their effective boom lengths and related capacities. Girder supports need to be identified and also whether one or two cranes are being used. Peak stress and deformation can be checked prior to lifting. The location of cranes needs to be identified on contract drawings.

Improving team performance: It was observed that the professional relationship between the owners, contractors, and consultants needs improvement through increased communication. ABC design-build methods are a step in the right direction. Profit margins in contracting can vary in each state and in each country. Sometimes these relationships can turn sour when big money is involved. Fabricators need to come up with better details for connections and splices. Shop drawing standards are required.

Training in prefabrication and preassembled bridges and erection methods needs to be provided to design and construction engineers so that ABC can be implemented at a rapid pace.

Upgrading design specifications: New design codes and construction specifications related to precasting need to be developed. New AASHTO specifications using ABC methods are required. LRFD methods will still be required. These may include a finite-element 3D analysis for erection conditions. Existing computer software can include analysis and design based on construction load combinations.

Widening of highways in urban areas is not always an option. Right-of-way and legal issues are involved to acquire new land. Hence underpasses and/or double-deck highway will overcome the additional lanes problem and traffic congestion once and for all.

Bridges on rivers: Chapter 11 also addresses the issues linked to ABC. Deep foundations are preferred over shallow foundations for bridges that are scour-critical. Scour countermeasures need to be designed according to HEC-23 and provided to protect footings. When replacing an existing superstructure, deck elevation may be raised by one to two feet.

Training needs: Training of construction personnel in ABC techniques is therefore desirable as addressed in Chapter 3. A greater number of bridges are now being built using ABC. Websites such as FIU, FUWA, and the local Department of Transportation research library will be useful.

Safety checklists: Construction safety at sites requires the personnel to be safe and healthy. A checklist of do's and don'ts needs to be prepared and issued.

NOTE: Bibliography for this chapter is listed at the end of the chapters in Appendix 1.

A list of Bridge Inspection Terminology and Sufficiency Ratings used by PennDOT is given in Appendix 3.

CHAPTER

ABC Planning and Resolving ABC Issues

7

7.1 Our failing infrastructure and transportation problems

America's infrastructure is the backbone of its economy. Infrastructure projects have put thousands of people to work; thus, they are one of the key factors for the long-term health and prosperity of the people in any city or state. The important aspects are

1. Technical (planning, rating, design, and method of construction aspects)
2. Administrative (setting priorities on the basis of structural deficiencies and the necessary funding aspects)
3. Research leading to developing new techniques and economic solutions.

A sustainable infrastructure almost certainly requires planning, financing, design, construction, and operation. A bridge is a sensitive part of any highway system. Its importance is linked to

- The network of highways it serves. Major highways have priority.
- The volume of traffic it carries daily. Urban area bridges are more important for commerce, trade, and the overall economy.

A bridge's relative importance is considered to determine the funding allocation and its priority.

In Chapter 1, the need for rapid construction and delivery of bridges was discussed in detail. In Chapter 3 (Section 3.5), the important issue of accelerated bridge planning (ABP) leading to accelerated bridge construction (ABC) was addressed. A glossary of ABC terminology applicable to all of the chapters is listed for ready reference in Appendix 2 ABC. The administrative aspects for funding are addressed in Chapter 10.

In this chapter, the failing infrastructure, advanced concepts of planning, the need for rehabilitation or replacement, the use of ABC and associated financing aspects, and the scope of introducing new technology are addressed. Aspects of structural deficiencies and the need for a rapid replacement and delivery system and further benefits of ABC are presented.

7.1.1 Transportation problems can be resolved

Too many of our roads and bridges continue to be in a state of disrepair. In addition, with population in the cities increasing, more people use urban area highways and bridges every day. Heavier trucks make matters worse.

The lack of smart technology, growing traffic issues, and the lack of maintenance from limited funding are to blame. For example, the New York and New Jersey region transportation system is one of the largest arterial systems in the world and includes navigable rivers with many bridges and tunnels. It serves automobiles and many other modes of transportation. Examples are the ever-busy highways such as Interstate 95 running north to south and Interstate 80 running east to west; the multiple-lane

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00007-1

Pennsylvania, New Jersey, and Ohio turnpikes; and many others. Over 200 million trips are taken daily across deficient bridges in the nation's 102 largest metropolitan regions.

We come across undesirable rush hour traffic jams daily, with the rush hours generally extending to most of the day, up to 6 days a week, with lesser intensity of traffic on Sundays. It gets worse when we suddenly come across roadway warning signs such as

"BRIDGE IS OUT FOLLOW DETOUR."

Surely, we do not want to spend part of our useful lives on the highways and consuming expensive gasoline at the same time. It is not helping the environment either. There were probably less stressful days with fewer problems to deal with when there were fewer motor vehicles and trains in use.

7.1.2 Failure issues can be resolved with rapid delivery methods

As discussed in Chapter 6, there are numerous issues contributing to the failure of bridges, in particular those that are poorly maintained or neglected, and the failures can have an effect on the future approach to maintenance of existing structures.

In one case, an engineer improperly calculated the size of a plate that held various girders together, which failed when a large point load from construction materials stressed that joint. If anything, this points to the need for better checking of engineering calculations before construction as well as inclusion of an engineer on maintenance and repair contracts.

The **Quebec Bridge** is a road, rail, and pedestrian bridge across the lower Saint Lawrence River to the west of Quebec City, and Lévis, Quebec, Canada. The project has the unique disaster of failing twice (in 1907 and 1916), at the cost of 88 lives, and took over 30 years to complete.

In the Washington bridge failure case, a truck that was too tall for the lane in which it was traveling struck a steel element in a truss. The nature of a truss is that when you remove an element, the truss fails.

Recent collapses: Earlier, Chapter 6 showed a list of major failures in the past 10 years.

A recent failure showed the collapsed I-35W bridge in Minneapolis on August 4, 2007. We can expect more disasters like this at the current levels of infrastructure investment. In Chapter 5, the concept of hazard rating was introduced for bridges that are most vulnerable to failure from the extreme events. Scour and Seismic ratings can follow the computations of hazard rating for the purpose of priority and selection of repairs and replacement. There is an old saying that prevention is better than cure or that it is better to be safe than sorry.

7.1.3 Magnitude of failing infrastructure

The extent of failing infrastructure can be estimated solely by

- Functional obsolescence
- Structural deficiency (SD)
- Failing or near-fallen bridges

Functional obsolescence: The following parameters causing functional obsolescence need attention:

- The deck geometry, tangent, curved, or skew
- Load-carrying capacity, provision for new live loads

- Vertical and horizontal clearances in the light of innovations in the truck industry
- Sight distance and approach roadway alignment.

7.1.4 Bridge failures due to extreme events

An analysis of bridge failures due to construction difficulties and other common types of failures were addressed in Chapter 6. This chapter extends the analysis to extreme events and natural disasters, which are to a large extent outside of the control of human beings.

New Zealand and Haiti earthquakes: The recent earthquakes of 2011 in Christchurch, New Zealand and in Haiti present an unprecedented opportunity to study their effects on communities and potential exposure to earthquakes. Design practices need to be developed that are in line with current seismic design criteria that some areas in the United States have begun to implement.

Calamities from tsunamis: An earthquake is much more likely to become a disaster if it occurs in a populated area and when it generates a tsunami. The Tohoku, Japan earthquake of March 11, 2011 combined with the tsunami and damage to the Fukushima Daichi Nuclear Power Plant resulted in perhaps one of the worst natural disasters. The tsunami waves were estimated to range from 9 to 37.9 m in height, causing the majority of infrastructure destruction (with nearly 14,000 confirmed deaths, 5000 injuries, and nearly 15,000 missing). Structures built to meet current design criteria performed overall very well. Damage has been primarily to infrastructure that was built with much less stringent seismic design criteria, especially in those areas with structures that did not have tsunami resistance incorporated in the design codes.

Planning for tsunami resistance: It is likely that future structures including highways and bridges located close to the coastal areas will take into account the huge tsunami impact force. The extensive instrumentation placed by Japan before the earthquake to some extent has provided a wealth of new information that may help in planning for the future.

7.1.5 Avoiding bridge failures through diagnosis and design code provisions

In a study on bridge failures performed by the author, it was concluded that most failures occurred during construction or erection. To prevent failures, engineering precautions are necessary during fabrication and erection. Examples of the causes of failure are failure of connections due to overstress from bolt tightening, failure of formwork, local buckling of scaffolding, crane collapse, and overload. The stability of girders during staged construction and the deck placement sequence need to be investigated and temporary bracing provided. Expansion bearings need to be temporarily restrained during erection. Also, Occupational Health and Safety Administration rules need to be followed.

7.1.6 Independent watchdog societies for infrastructure health and quality

American Prosperity Consensus project: According to the findings of American Prosperity Consensus (in partnership with Slate), America's infrastructure is woefully underfunded. Its condition is severely degraded, despite continued efforts of local and state agencies to form private-public partnerships and to manage our infrastructure in a tight fiscal climate. The project details can be followed at america2040.com.

2013 Report Card by the American Society of Civil Engineers: On the basis of an inquiry from experts, every 4 years the American Society of Civil Engineers (ASCE) has been providing a report card that grades America's failing infrastructure on the basis of the acceptable and unacceptable criteria for each state. The grades A to D are based on the following criteria:

Capacity—Number of lanes versus smooth traffic flow
Condition—Drainage and cracks
Operations and maintenance—Road surface repairs
Public safety—Use of warning signs and lighting

Most structurally deficient bridges (SDBs) built during the 1950s and 1960s are very old and require maintenance on a regular basis. Newer bridges are performing better. This year the United States received a D+. Our infrastructure is crumbling with a mediocre C+ grade awarded for bridges. It may be a slight improvement from 4 years ago, but it is still pathetic. Shortfalls in investment will also lead to fewer jobs, gridlock, and an inevitable catastrophe.

However, the criteria used in the past report cards from ASCE do not seem to lay an emphasis on introducing any new technology or innovative methods. The evaluations in old report cards may not be directly applicable to the very important need for rapid bridge construction and delivery.

At the federal and state level, the economic and environmental well-being of our businesses and families are dependent on the public and political will. Our limited resources need to be mobilized against a host of challenges. By its detailed investigations, ASCE seems to recommend to its members and professional forums that they deliver a message to use the goodwill of the elected legislative. Public and private stakeholders need to encourage their elected representatives to revitalize transportation infrastructure and operations in the 50 states. This is possible only by outreach, newsletters, and editorial comments.

As a panel member of the ASCE 2014 Report Card Committee for Pennsylvania bridges, the author has investigated the following measures that would be applicable to most states. The reason that the bridge category is performing slightly better than the highways, etc., is due to the following:

1. New technology being introduced (e.g., integral abutments, higher concrete strengths, and high-performance steel [HPS] leading to longer spans).
2. Introduction of spliced P/S concrete I-shaped girder designs (longer spans from 225 to 270 ft possible, competitive with steel spans).
3. Use of hybrid and composite girders.
4. Introduction of geosynthetic reinforced soil (GRS) abutments similar to those used by the Ohio Department of Transportation (ODOT).
5. Introduction of the NEXT Beam (precast concrete beam system).
6. The "Spliced Prestressed Concrete Girder Standards" drawings developed by the Central Atlantic Bridge Associates (CABA) and Janssen & Spaans Engineering. The Spliced Prestressed Concrete Girder used in a continuous unit is currently only permitted for tangent structures. The minimum length of a continuous unit to use this product is 500 ft, and the maximum is limited to 1510 ft.
7. Introduction of precast substructure (CABA standards and guidelines).
8. The use of Load and Risk Factor Design (LRFD) software for substructure (such as ABLRFD, PAPIER) and for superstructure design (such as STLRFD, PSLRFD, etc.) has helped.
9. Pennsylvania passed legislation in September 2012 to allow the P3 type of contracting to provide funding. The Pennsylvania Department of Transportation (PennDOT) is developing an Asset

Management plan (required under MAP-21) and using a policy and data-driven, performance-based approach to resource allocation and utilization. The ability to predict asset needs and asset conditions for various funding levels and program policies (i.e., improvement vs. preservation vs. maintenance) will be essential for strategic and tactical decisions.

The ASCE documents the shortcomings of investments in its series of reports, *Failure to Act*. The investment shortfall is forecast to be $1.1 trillion by 2020, increasing to $4.7 trillion by 2040. The deterioration of infrastructure has direct and indirect costs, sometimes measured in human lives. A systemic failure naturally presents an incredible direct cost. There are plenty of infrastructure problems. The number of concrete structures put in place in the 1950s and 1960s that will need repair and upgrade in the near future is most likely to be gigantic.

Several fundamental guiding principles need to be developed:

- Exercising leadership and management in decision-making processes at all levels
- Using an integrated systems approach using modern technology
- Quantifying, communicating, and managing risks
- Adapting critical infrastructure in response to the dynamic conditions and practice.

SD: It is important to investigate the internal SD in the structure. Structural deficiencies include one or more of the following:

- Low structural capacities
- Lack of redundancy in the structural system
- Poor condition of superstructure and deck
- Poor condition of substructure
- Fatigue and fracture of beam connections
- Bearings malfunction
- Corrosion of steel and concrete
- Hydraulic inadequacy: Environmental or Coast Guard (CG) concerns may push the rehabilitation versus replacement decision in the direction of rehabilitation, whereas hydraulic inadequacies and poor stream alignment may push the decision toward replacement.
- Soil conditions: Any signs of foundation settlement may push the decision toward requiring the replacement of structure.
- Seismic vulnerability: If an existing bridge does not meet current American Association of State and Highway Transportation Officials (AASHTO) or state design specifications, then seismic retrofit needs to be considered.
- Substandard geometry: The factors to consider in planning and improving the substandard geometry are
    - Design speed
    - Clearances: vehicular/navigational
    - Substandard deck geometry
    - Lane and shoulder width
    - Maximum profile grade
    - Minimum horizontal radius
    - Super elevation rate and cross slopes
- Stopping sight distance to prevent accidents
- The level of service such as lighting, deck drainage, and variable message signs

A combination of the above factors as reported by inspection reports and rating studies can lead to weight restrictions; shutdown of the bridge; and, in some cases where detour is not feasible, shutting down the highway.

7.1.7 Status of SDBs in the United States

It will be noted that the different types of ratings help to identify SDBs. The data are used for establishing priority for fixing and fund allocations. Table 7.1 shows the highest percentages of deficient bridges in Pennsylvania and Oklahoma.

Among others, the following states are taking measures to resolve the deficiencies in their bridges and coming up with the required funding.

Maine: The condition of U.S. bridges has been monitored in recent years. Nationally, approximately 67,000 of the United States' 605,000 bridges are considered structurally deficient. The SAFE Bridges Act, introduced in the U.S. House of Representatives, would provide $5.5 billion to begin to reduce the backlog of the more than 150,000 structurally deficient and functionally obsolete bridges across the country. Transportation for America, a national safety advocacy group, found that Maine had the ninth highest percentage of SDBs in the county. Commercially available retrofitting technologies exist in the United States.

Although the nation as a whole received a C+, the 2013 Report Card for America's Infrastructure from ASCE gave Maine a C– for the condition of its bridges. The report found that the Maine Department of Transportation (Maine DOT) was responsible for 2772, or 70%, of known bridges in the state, only

Table 7.1 Increasing Number of SDBs in the United States

State	Approximate Percentage Deficient (Rounded)
Pennsylvania	26%
Oklahoma	24%
Iowa	19%
Missouri	18%
Ohio	10%
Mississippi	17%
California	15%
Nebraska	15%
North Carolina	13%
New York	12%
Indiana	11%
Alabama	11%
Kansas	11%
Illinois	10%
Virginia	8%
Texas	4%

205 of which were more than 80 years old. Transportation officials estimated that 288 bridges would be at risk of closure or weight restrictions within a decade.

- After the I-35 Bridge in Minneapolis, MN, collapsed into the Mississippi River in 2007, killing 13 people and injuring 145, Maine DOT assembled a panel that released a report *Keeping our Bridges Safe*.
- The older concrete slab bridges were not designed to carry new truck loads, and if reinforcement is not provided, more of them will need to be posted with weight limits.

Massachusetts: For details on Massachusetts bridge issues, refer to the following websites:

- http://www.massdot.state.ma.us/planning/Main/StatewidePlans/StateTransportationImprovementProgram.aspx
- http://www.boston.com/yourtown/news/downtown/2013/08/state_250m_project_will_let_drivers_travel_at_normal_highway.html

New York: New York bridges also have a high estimated cost of rehabilitation at nearly $9.4 billion.

Pennsylvania: The Pennsylvania Turnpike, our nation's first superhighway, has always had a toll. The Turnpike Commission has to pay the money they collect to PennDOT for other projects because of Act 44. Because of a lack of toll collection on other Pennsylvania roads, the Pennsylvania Turnpike Authority may have to cut funding on its own rehabilitation projects to maintain funding to other departments.

Ohio: ODOT has reduced the number of SDBs, but more and more bridges are aging into the "at-risk" category Â, the designator for bridges before they become "structurally deficient." Most structures and infrastructure systems were built before current design methods were developed. The structures, lifelines, and transportation systems are deteriorating.

Oregon and Washington: An earthquake of magnitude 9 on the Cascadia subduction zone will affect all communities along the Oregon and Washington coastline. Many earthquake-prone areas in the United States did not adopt seismic design until recently (e.g., Oregon adopted seismic requirements in 1994). Lack of seismic resistance is a common problem for all old bridges. It may be more economical to replace them to meet new seismic design criteria than to retrofit them.

In May, a bridge over the Skagit River in Washington collapsed, again raising concerns about the crumbling infrastructure in the state. The bridge was built in 1955 and is one of many aging bridges in the state.

Local governments: They perform periodic emergency response drills to identify gaps in their emergency plans. Where applicable, tsunami evacuation routes need to be identified and marked to aid in the event of a tsunami.

Plan of action: New technology and innovative methods such as ABC need to be introduced. Design software may be updated to include construction and erection loads. The benefits will be in improved quality, improved resilience, and overall cost reduction for the new bridges. The following are some of the actions that will help to attain these benefits:

- Use of structural health monitoring (SHM) by using remote sensors for bridge management.
- Bridge management systems (BMSs) can use laser techniques to evaluate scour depths at bridge foundations.
- Partial ABC can be upgraded to full ABC by prefabrication and design-build (DB) contracts. Construction will not be delayed because of bad weather with factory production. There will be reduced indirect costs resulting from fewer traffic jams and detours.

- Use of Federal Highway Administration (FHWA) software for life-cycle cost analysis will also help in reducing huge maintenance costs being incurred by the agencies.
- Bridges on rivers need to have protection against peak floods. Modern countermeasures designed using the latest standards for the Hydraulic Engineering Circular (specifically, HEC-18 and HEC-23) need to be installed.
- For hydrologic analysis, the use of U.S. Geological Survey (USGS) software such as StreamStats in place of the outdated TR-55 will greatly help in making the bridges safer and reduce costs of scour countermeasures. Also Army Corps of Engineers has replaced HEC-2 hydraulic analysis software with the more powerful HEC-RAS. Scour analysis can be performed by HEC-RAS.
- Introduction of long-span segmental construction on wide rivers (a recent example is the Edison Bridge segmental construction in New Jersey).
- Increasing the limits of splice locations in new precast girders.
- Introduction of WOLF-type precast girders.
- Repair of military bridges (existing bridges on military routes need to be checked for new military live loads).
- *Energy dissipation*: Technologies such as base isolation systems and various damping and energy dissipative devices are used to reduce seismic effects and the resulting structural damage to structures.
- *Wireless structural monitoring sensing systems*: For rapid information retrieval and damage assessment, new remote sensing techniques, including nanolevel and bioinspired sensing devices for more robust damage detection, are being developed.
- *Laboratory testing of models*: Over the past 10 years, the Network for Earthquake Engineering Simulation has performed the systematic testing of scaled structures and structural components enabling validation of theoretical models.
- *Shake maps*: Rapid mapping dissemination after an event is now available after every earthquake in California because the shake maps produced by USGS can be used by local and state governments in their planning for response and recovery operations.
- *Federal Emergency Management Association (FEMA) software*: The software tool HAZ-US developed by FEMA for multihazard loss estimation is also being used by state and local governments to estimate potential losses.
- There is a need to develop approaches to maintain or rehabilitate the resilience of the existing structures by managing extreme events. It is hoped that these approaches would be able to extend the service life of the existing inventory of bridges and highway structures.
- *Substructures*: They would require methods for strengthening the piers and abutments for extreme events. ABC will improve worker safety, quality, and constructability.

7.2 Planning bridges on new routes and replacements on existing routes

7.2.1 Functions of a bridge

Other than the complex, cable-stayed and long-span bridges, only the common types of bridges are considered and presented here. Bridges are located on one of the following networks and are classified as such:

> *Interstate*: Interstate bridges allow higher speeds. Interstates have express lanes but are thoroughfares with limited access and exits. Interstate and arterial bridges carry almost 90 percent of average daily traffic (ADT) for rural and urban areas.

Arterial: Thirty-three percent of bridges serve interstate or arterial highways.
Collector: Twenty-seven percent of bridges serve collectors. Collectors collect and distribute traffic between arterials and local roads. They are typically two-lane roads and provide for shorter trips at lower speeds.
Local: Forty percent of all bridges serve local roads.

7.2.2 Types of traffic

Each type has special requirements for varying live load impacts.

- Type 1: Highway bridges carrying vehicular traffic
- Type 2: Transit and railroad bridges carrying train traffic
- Type 3: Pedestrian bridges
- Type 4: Equestrian bridges
- Type 5: Airport bridges carrying aircraft

7.2.3 Feasibility studies

As part of planning of medium- and large-span bridge projects, it is customary to perform a feasibility study.

- It ensures constructability.
- It prevents a future change in design and thereby delay of the project.
- It leads to preliminary member sizes and accurate cost estimation.
- Feasibility study data and preliminary calculations can be used at the detailed design stage by another team.

This approach helps with removing any unexpected problems (e.g., unsafe soil conditions) before any funding can be approved.

7.2.4 Responsibility of asset ownership and the "whose baby?" issue

Ownership governs individual design criteria, and the owners develop procedures for maintenance or reconstruction. In the United States, bridge ownership breaks down in roughly the following way:

Local government owned: 51%
State government owned: 48%
Federal government owned: 1%

7.2.5 Geometry

Structural analysis is based on bridge geometry:

Type 1: Normal right angle plan
Type 2: Skew plan

Type 3: Horizontally curved plan
Type 4: Bridge on curved vertical alignment

Deck surfacing is made of timber, concrete, or steel deck.

Geometric configuration: The components of surface elements are lanes, shoulders, sidewalks, approaches, and ramps. A typical travel lane is 12 ft wide. For staged construction, it can be less than 12 ft (but not less than 10 ft). The minimum width of a vehicle is 4 ft between wheel centers and generally 6 ft overall. A vehicle with a wide load is required to display the warning sign “WIDE LOAD.”

The minimum width of a shoulder is 3 ft between the edge of the travel lane and the concrete barrier and less than 3 ft between the edge of the temporary lane and the concrete barrier during staged construction. Small shoulder widths serve as buffer zone to avoid accidents. The standard shoulder width is 10 ft, with a minimum width of 6 ft for emergency.

For safety reasons, a sidewalk is generally provided on both sides of the roadway. Even during staged construction a provision for temporary pedestrian bridge and utility support is usually required. Sidewalks are elevated by 8 in from the outer edge of the shoulder or the outer edge of the lane. For heavy traffic, a safety fence is required. The typical width of a sidewalk is 5 ft.

Entry or exit ramps connect two levels of traffic moving approximately at right angles. For safety reasons, entry and exit ramps are located adjacent to the right lane, which carries slower traffic. A ramp has traffic moving in a single curved direction whereas a bridge has traffic moving in both directions. An acceleration lane is for transition from a slow-speed entry ramp merging into fast-moving traffic. Likewise, a decelerating lane serves as a transition between a fast lane and a slow-speed exit ramp.

7.2.6 Structural systems

The design of a bridge is related to the structural system. Beam, truss, and arch configurations may be used for medium span lengths:

Type 1: Slab bridge
Type 2: Through bridge
Type 3: Slab-beam bridge
Type 4: Truss bridge
Type 5: Arch bridge
Type 6: Cable-stayed bridge
Type 7: Segmental bridge
Type 8: Suspension bridge

7.2.7 Parameters for the selection of bridges and span classification

The minimum single span for a bridge is 20 ft, below which a culvert is normally used.

Pedestrian bridges with lighter live loads can be smaller in length than 20 ft.

Single spans: In practice, most bridges are a single span over narrow rivers or narrow roads with two or three lanes.

Continuous spans: Piers are needed over wide rivers, highways, or valleys. Continuous bridges have the added advantages of redundancy, which generates increased resiliency against failure.

Span length: Construction issues are based primarily on span lengths. For practical considerations, the selection of bridge types may be governed by the span length. The earlier rule of thumb was short span is less than 50 ft, medium span is 50–200 ft, and long span is greater than 200 ft.

On close examination for planning purposes, span lengths can be reclassified as follows:

Small span (20–40 ft): Examples of the types of superstructure used are

- Bridges with steel stringers (*Note*: They have relatively higher life-cycle costs for small spans when compared with using timber or modern precast concrete bridges.)
- Reinforced concrete slab and T-beams
- Precast prestressed cellular decks
- Timber bridges using glulam or sawn timber
- Prestressed concrete adjacent and spread box beam bridges

Medium span (40–120 ft): Examples of the types of superstructure used are

- Prestressed concrete adjacent box beams
- Spread box beams
- Steel girder bridges

Long span (120–240 ft): Examples of the types of superstructure used are

- Steel girder bridges (50W or hybrid 70W and 50W grades)
- Steel deck and through trusses
- Prestressed concrete arches

Very long span (over 240 ft): Examples include

- Steel arches
- Prestressed concrete segmental boxes
- Cable-stayed bridges
- Suspension cable bridges

Girder shapes: The most commonly used girder shapes are

- I-shaped girders
- Adjacent or spread box beams
- Composite beams
- Through girders

Abutment types

- Cantilever wall:
  - Full-height abutment
  - Mid-height abutment
  - Stub and semistub abutments
- Spill-through abutment
- Modern types include
  - Integral abutments
  - Semi-integral abutments
  - Mechanically stabilized earth (MSE) wall abutments

Pier types

Multiple bents and flared caps are aesthetically pleasing. Common shapes include

- Solid wall
- Hammerhead
- Multiple column bent
- Modern types are
  - Multiple pile bent
  - Integral pier

Foundation types

- Spread footing
- Drilled shaft or caisson wall
- Pile foundation (end bearing or friction piles)
- Steel H pile or W sections
- Steel pipe pile
- Concrete pile or steel-encased concrete pile
- Prestressed concrete pipe
- Steel sheet piles

For the selection of the foundation, the expertise of a geotechnical engineer will be used.

The Geodesign concept incorporates the latest technologies, such as geographic information systems Model Builder, building information modeling, robotics, and gaming, to capture, manage, analyze, and display detailed geographic information. These technologies and applications allow professionals to come up with master plans and designs that more closely adhere to sustainable principles (see http://www.montgomerynews.com/articles/2013/10/07/roxborough_review/news/doc5252d98f0ac5b060829910.txt for more information).

An example of widely used partial ABC using conventional design-bid-build (DBB) is shown in Figure 7.1.

FIGURE 7.1

Single-crane lifting of precast, prestressed concrete box beam (designed by author for Lumberton bridge).

7.3 Role of government agencies in maintaining infrastructure

7.3.1 The administration of infrastructure and asset management

Administrative responsibilities: If correctly diagnosed, failures lead to improvements in design and maintenance procedures. In addition to the regular update of design codes, it is also important to understand the role of oversight and to ensure that adequate funding is provided by the federal and state agencies. Because potential failures are a hazard to public safety, they fall under the jurisdiction of federal government agencies such as

FHWA: FHWA is the main agency for oversight of highways with regard to maintenance, safety, reestablishing mobility, and reconstructing bridges after a catastrophic failure.

The National Transportation Safety Board (NTSB): NTSB is the entity that usually investigates the causes of bridge failures. It has the general authority under 49 U.S.C. §1131 to investigate selected highway accidents in cooperation with state authorities.

FEMA: An agency of the U.S. Department of Homeland Security, FEMA oversees disaster mitigation, preparedness, response, recovery, and education of engineers. Federal highway funding programs are the main source for funding of bridge repairs. FHWA's Emergency Relief (ER) program is also administered through the state departments of transportation. The ER program provides funding for bridges damaged in natural disasters or that were subject to catastrophic failures. The program provides funds for emergency repairs immediately after the failure to restore essential traffic and for long-term permanent repairs. It also uses innovative contracting to accelerate the rebuilding of any damaged federal-aid highway facilities.

Interstate preventive maintenance: These projects cater to

- Accidents caused by deficiencies
- Corrosion prevention by painting
- Sealing of cracks
- Deck joint repairs
- Highway capacity improvement

The CG and the Army Corps of Engineers (COE): They have the responsibility of clearing and reopening the waterways after floods or a vessel collision. The CG is the authority that will declare the river safe for navigation once river debris has been removed. The COE is the agency responsible for clearing federal navigation channels and assisting in the removal of river debris with a barge-based crane operation.

Examples of special situations for funding are

- The need for providing scour countermeasures.
- Seismic retrofit of bearings and connections.
- Condition of the bridge, according to the *Bridge Management System Coding Manual, Publication 100A*. For example, in Pennsylvania, a condition rating of 6 or less would require the need for rehabilitation.
- If a bridge is structurally deficient or functionally obsolete, with a sufficiency rating of 50, then it may receive Federal Critical Bridge (FCB) funds for replacement or rehabilitation.
- If a bridge is structurally deficient or functionally obsolete, with a sufficiency rating between 50 and 80, then it may only receive FCB funds for rehabilitation.
- All of the deficiencies and problems listed in inspection reports must be addressed and resolved.

The Federal-Aid Highway Program is funded by the Highway Account of the Highway Trust Fund (HTF). These are several large “core” formula-driven programs through which highway funds are apportioned to the state departments of transportation, including the

- Interstate Maintenance Program
- National Highway System
- Surface Transportation Program
- Congestion Mitigation and Air Quality Improvement Program
- Highway Bridge Replacement and Rehabilitation Program (HBRR)
- Discretionary programs under the control of FHWA or earmarked directly by the U.S. Congress, such as the Safe, Accountable, Flexible, and Efficient Transportation Equity Act, a Legacy for Users.

States can “flex” funds from other Federal-Aid Highway Programs to increase spending on bridges. In addition, there is nothing to prevent a state from spending its own funds on bridge projects beyond the minimum local matching share.

The Highway Bridge Program (HBP): This is the primary federal program to fund the replacement or rehabilitation of structurally deficient or functionally obsolete bridges. HBP is also referred to as the HBRR. HBRR is the primary source of federal funds for replacement, reconstruction, and capital maintenance. HBRR funds are apportioned to the states by a formula based on each state’s relative share of the total cost to repair or replace deficient highway bridges. Plans for the spending of these funds are under the control of the state departments of transportation. These funds are usually not spent on new bridges, but they are available for the following:

- Systematic preventative maintenance
- Rehabilitation to restore structural integrity or to correct major safety defects
- Replacement of low-water crossings, and bridges made obsolete by certain COE projects and not rebuilt with COE funds
- Painting, seismic retrofitting, antiscour measures, and deicing applications
- Total replacement of a structurally deficient or functionally obsolete highway bridge with a new facility constructed in the same general traffic corridor

A funding application report will address the following issues:

- Geometry, number of lanes, horizontal and vertical clearance
- Deck condition: Concrete strength, cracking, corrosion detection by half-cell method, delaminations, spalls, salt content above and below reinforcement layers, and air content
- Deck drainage, substructure drainage, and drainage disposal
- Safety railings

7.3.2 The role of state departments of transportation

Although the Federal-Aid Highway Program provides federal money to highways and bridges, the money itself is normally under the control of the states. The state departments of transportation (DOTs) have to comply with detailed federal planning guidelines on where and how the money will be spent.

The options available to each state are as follows:

- Increase funding to perform immediate repairs
- Implement weight restrictions
- Install high-tech sensors and train additional inspectors
- Close down some lanes, if feasible
- Close down the bridge adversely affecting travel, trade, and commerce

Funding can be increased by

- Increases in HTFs
- Issuing bonds and taking out debts
- Raising gasoline taxes
- Hiking tolls on roads and bridges
- Shifting funds from other nontransportation allocations

7.3.3 Project production process

Scoping is the first major stage of the project in which most important decisions are made. The end products of this stage are

- Project objectives
- Design criteria
- Feasible alternatives
- A reasonable cost estimate
- To identify key environmental issues (e.g., wetlands, endangered species, protected streams, contaminated soil, asbestos, lead-based paint, noise, etc.)

The information needs to be assembled and analyzed in this stage. It must be of sufficient detail to demonstrate that the project is defined by these "scoping products." Analysis should show that the scope of the project is appropriate. Only then should the next stage of project production be undertaken.

The scope of work: This applies to the following aspects:

- Life-cycle cost evaluation
- Maintenance and protection of traffic (MPT)
- Hydraulic and scour studies
- Seismic retrofits
- Environmental considerations and acquiring permits
- Performing value engineering for optimum project cost

The following outlines some of the major steps in scoping for a rehabilitation project:

Addressing specific deficiencies: The scoping document may also serve as a design approval document. It should include the following information:

- Obtain and examine bridge inventory, load rating data, and the latest inspection report (considering the overall condition of the bridge and the specific condition of the major structural elements,

the year constructed, design loading, etc.); this can provide clues to the potential serviceability of a rehabilitated structure.
- Identify geometry, materials used, and details that may limit potential alternatives.
- Obtain and examine record plans; structure width; and type of construction, materials used, and fabrication methods used.

Verifying documented information includes the following steps:

- Verifying data to ensure that the information in the bridge inventory and inspection system and on the record plans is accurate.
- *Visiting the project site:* This is not meant to be an in-depth bridge inspection, but rather a verification visit to assist in a feasibility assessment.

If applicable, evaluating the hydraulic adequacy of the structure includes the following steps:

- Identifying susceptibility to flooding, scour, and damage from floating ice and debris.
- Performing a hydraulic assessment.
- Performing some preliminary engineering activities before closure of scoping activities.
- The technical activities for this phase are focused on feasibility, including a list of reasonable alternatives and their cost estimates.
- General considerations that help define the feasibility of each alternative are required.

Determining reasonable costs and a schedule for the most feasible alternate includes the following steps:

- Providing project-specific programing information.
- Comparing general requirements of work to other projects of similar size and type and estimating a reasonable cost for work.
- Preparing an approximate schedule.

Summarizing recommendations of scoping activities includes the following steps:

- The information gathered and the conclusions reached through these activities should be presented in the project's scoping document.
- Any unfeasible alternatives should be eliminated.

7.4 Engineers meeting the need to replace or rehabilitate bridges

7.4.1 Assessment of the condition of a structure

The following documents are required for condition evaluation:

- In-Depth Inspection Report
- Rehabilitation Report
- Sufficiency Rating
- Underwater Inspection Report
- Scour Rating
- Seismic Rating
- *FHWA Recording and Coding Guide for the Structure Inventory:* The old Structure Inventory and Appraisal sheet codes for condition evaluation or shutdown of the bridge have now been replaced by the Pontis data sheet.

7.4.1.1 Use of AASHTOware program

The AASHTOware Bridge Rating replaces the former Virtis program. The analytical software allows users to perform bridge load ratings that are indispensable for determining maintenance needs, ensuring public safety, scheduling retrofit or replacement elements, and for assessing overload permits. Bridge Rating provides highly accurate load rating techniques and calculations.

Pontis (now known as AASHTOware Bridge Management) is a bridge management software tool. It is a data application, relying on collected cost data and condition data of bridge elements (beams, piers, railings, etc.).

AASHTOware Bridge Management was developed during the early 1990s. AASHTO incorporated the Pontis program into the AASHTOware program and Pontis 4.2 and 4.3 were issued to the licensees in 2003. These data are analyzed to arrive at the optimal long-term preservation and improvement policies for a network of bridges.

The software now includes multimedia capability, supports links to photos and drawings, the entering of data in metric or English units, and enhanced security. Pontis 5.1.2 improved the utility of agencies' bridge inspection data and laid the groundwork for the next generation of AASHTO's Bridge Management software requirements by ensuring data are in the correct format. It prepares agencies' inventory data for multiobjective risk assessment, tradeoff analysis, and deterioration modeling tools in Pontis 5.2 (which is currently under development).

AASHTOware Bridge Management information is available at

- http://www.aashtoware.org/Bridge/Pages/Management.aspx?PID=2
- http://www.pontisusergroup.org/
- http://www.aashtoware.org/Bridge/Pages/Rating.aspx?PID=3

7.4.2 Management-related issues

Simplified structural options: A well-maintained bridge is the goal of the engineer. To a certain extent, the choice of the type of maintenance is between the five Rs—repair, retrofit, restore, rehabilitate, or replace—with a further option to widen or demolish.

The rehabilitation of highway structures other than bridges is also considered equally important. These include bridge approaches, sign structures, railings, parapets, fences, noise barriers, and culverts; each is a subject in itself.

Rehabilitation process: FHWA rating criteria are generally used. However, newer monitoring methods have emerged using remote sensors and robotics. Twice yearly, yearly, or as needed, inspection reports serve as the eyes and ears of the design engineer. Recommendations coming from the field assessment are evaluated by rating analysis programs. Alternatives based on repair methods and cost consideration are studied before preparing rehabilitation designs and drawings.

7.4.2.1 Steps required for rehabilitation

As discussed in earlier chapters, necessary steps for rehabilitation are emphasized.

- Field inspection and SHM followed by preparing an inspection report.
- *Condition and sufficiency ratings:* Compute the condition rating and sufficiency rating for funding approval.
- Analysis and load rating (inventory and operating ratings). Additional ratings for extreme loads such as scour and seismic vulnerability may be required.

- Preparation of a rehabilitation report.
- Implementing diagnostic design procedures.
- Selecting methods of retrofit, rehabilitation, or replacement.
- *Contract documents:* Preparation of contract documents and selective reconstruction.

7.4.2.2 Components of bridge to rehabilitate

- Decks, deck joints, or bearings are subjected to deicing salts and constant wear and tear and need the greatest attention.
- Usually the substructure is to some extent overdesigned and is less likely to need repairs, except for repairs resulting from erosion or earthquakes.

Choice between rehabilitation and replacement: With thousands of bridges to be fixed, the criteria are

- *Economics:* Replacement is expensive.
- *Inconvenience to the public during reconstruction:* It causes interruption in service during the construction period.
- Sentimental/historical reasons can discourage replacement.
- Environmental concerns and permit requirements will be greater for new bridges, especially those with four or more lanes.
- A sufficiency rating, diagnosis of deficiencies, and cost-benefit analysis need to be performed to determine the course of action.

7.4.3 Improving bridge management

When starting a bridge rehabilitation/replacement project, identifying the causes for existing structural deficiencies, functional obsolescence, and bridge failures is an important step. A review of the issues addressed in previous report cards and any implementations completed or underway so far also need to be discussed. Priorities in selection criteria for rehabilitation/replacement also need to be examined.

Monitoring using nondestructive testing (NDT), SHM, and remote sensors: The potential exists for the development of early problem detection and warning systems and the use of NDT facilities. Implementation of effective monitoring systems results in reduction of manhours and development of optimal inspection and repair schedules.

Effective monitoring systems can

- Assess long-term performance and increase system reliability
- Improve the credibility of inspections and subsequent ratings through less subjective data
- Improve uniformity of data, enabling the development of better decision-making tools
- Improve and augment visual assessment and provide early detection and warning

Inspection reports and planning issues: Recommendations are given in inspection and rehabilitation reports for emergency repairs, which should be implemented as soon as possible. The following course of action is adopted:

1. No reconstruction option should be dismissed without good reason. The scope of work, type of design, construction effort, and cost should be evaluated before a decision is made.

2. In extreme cases, the bridge may be shut down indefinitely. A temporary detour is followed.
3. In other cases, some lanes may be closed down to reduce risk of failure by reducing live loads.
4. A partial detour in one direction only may be used.
5. The client may have emergency repair funds through which immediate repairs are possible. Design exceptions as required need to be approved by the state.

Inspection classification: NBIS and live load and sufficiency ratings serve as the criteria for selecting bridges for replacement or rehabilitation. This requires inspection data. For inspection purposes, many highway agencies have the following classifications:

- *Abandoned*: A bridge that once satisfied the bridge inventory definition, but it is now permanently closed.
- *Closed*: A closed bridge that once satisfied the bridge inventory definition, but it is now temporarily closed for any reason except collapse. Secondary uses such as pedestrian traffic may be allowed.
- *Collapsed*: A bridge that once satisfied the bridge inventory definition, but it is now closed because of collapse.
- *Deleted*: A bridge that has been deleted from the inventory.
- *Inventory*: A bridge included in an inventory file when it carries moving loads.
- *Temporary*: A bridge that is used to maintain traffic during a modification or replacement.

Results from a study on infrastructure health conducted by FHWA, in coordination with AASHTO, are now available online in a series of four reports.

"The study's goal was to define a consistent and reliable method to document infrastructure health, focusing on bridges and pavements on the Interstate Highway System," according to FHWA. The goal was to develop tools to provide FHWA and state transportation agencies with key data that will produce better and more complete assessments of infrastructure health nationally.

For this study, definitions of good, fair, or, poor relate solely to the condition of a bridge or pavement and do not consider other factors such as safety or capacity. Separate tiers of performance measures that can be used to categorize bridges and pavements were then evaluated. Tier 1 measures are considered ready for use at the national level whereas Tier 2 measures require further work before being ready for deployment.

Performance measures for bridges included SD ratings (Tier 1) and structural adequacy based on National Bridge Inventory (NBI) ratings (Tier 2):

These measures were evaluated on I-90 in Wisconsin, Minnesota, and South Dakota. The I-90 corridor runs for 874 mi, with average annual daily traffic ranging from approximately 5000 vehicles to 90,000 vehicles. Evaluations were done using Highway Performance Monitoring System and NBI data as well as data collected by the FHWA project team and provided by the participating state highway agencies. State information included documentation of their systems, processes, and corridor inventory.

The good, fair, and poor analysis for bridges proved to be a viable approach, with NBI data sufficient for the performance management assessment. However, a bridge's SD status was not as easily incorporated into the analysis. The study report notes that a measure of structural adequacy that is based on NBI ratings would be a viable supplement to SD status as a national measure of bridge condition, although "implementation would require developing a general consensus on its definition."

As part of the study, a sample health report was prepared for the pilot corridor. This report uses several metrics to assess the overall health of a corridor, including the good/fair/poor measures, age, remaining service life for pavements, and traffic volumes. The assessment would enable FHWA to examine corridor health across multiple states in a consistent manner. To download the pilot study report, *Improving FHWA's Ability to Assess Highway Infrastructure Health* (Pub. No. FHWA-HIF-12-049), go to www.fhwa.dot.gov/asset/pubs/hif12049/hif12049.pdf.

FHWA and AASHTO presented the study results to senior-level state transportation agency representatives at a national meeting held October 13, 2011, in Detroit, Michigan. To view the national meeting report, which summarizes discussion about the recommended condition ratings and health reporting, visit www.fhwa.dot.gov/asset/health/workshopreport.pdf.

7.4 4 Structural options

Planning and design procedures for replacement are covered by LRFD Design Specifications and will only be briefly discussed in this book. General considerations include various interdisciplinary approaches, including extensive planning considerations, such as:

- Funding and cost
- Relocation of utilities
- Functional requirements
- Right of way
- MPT and staged construction
- Improving soil conditions.

Other considerations are as follows:

- Use of standard geometry, alignment, and profile
- Vertical and horizontal clearances
- Constructability
- Use of alternative analyses
- Aesthetic requirements
- Environmental permits
- Public involvement
- New technology and innovative methods
- Future maintenance and inspection access
- Development of rehabilitation and replacement schemes by performing value engineering

The AASHTO Standard 16th Edition and AASHTO LRFD specifications address the following standard issues for bridges to remain functional:

1. Design speed limit
2. Standard lane and shoulder width
3. Maximum profile grade
4. Minimum horizontal radius
5. Super-elevation rate and cross slope limits
6. Stopping sight distance and K value

7. Clearances, vehicular/navigational
8. Level of service

7.4.5 Maintenance versus replacement

The life-cycle costs and rehabilitation efforts are greater for the superstructure components because they are subject to greater wear and tear from traffic whereas the substructure is less affected by this. Replacement can apply to a component or to the entire superstructure:

- Parapet replacement
- Deck overlay replacement
- Deck joint replacement
- Deck and parapet replacement
- Deck, parapet, and girder replacement
- Deck drainage replacement
- Bearing replacement
- Entire superstructure replacement

Need to rehabilitate: The primary reasons are safety, continuity of use, and failure prevention. The following considerations are of paramount importance:

- Correcting deficiencies
- Improving traffic conditions, geometry, sight distance, and clearances
- Increasing load-carrying capacity
- Providing for possible future widening
- Minimizing the costs to be incurred
- Addressing environmental concerns

Various types of failures, their causes, and methods of preventing failures need to be analyzed. Repairs should directly follow the recommendations presented in inspection reports. Emergency repairs are generally required immediately after an emergency or after extreme events, such as vessel collision, flood scour, or earthquake.

Figure 7.2 shows a possible method for implementing ABC, including the project-level activities.

Eligibility to rehabilitate: An experienced or licensed professional engineer is qualified to oversee the delicate tasks.

Foundation failures: The following causes of failures need to be rectified. For widened structures, differential settling of new and old components in widening shall be considered. It is possible that the existing foundation has settled. New footings may need to be placed on piling or drilled shafts in an attempt to prevent differential settlement. The widened section should be designed so that superstructure deflection for the new and old deck is identical.

Scour analysis: Foundations need to be investigated for scour. The investigation consists of determining on what the substructures are founded and the foundation depth as well as deciding whether potential scour will endanger the substructure's integrity. Local scour and stream meander need to be considered.

Table 7.2 shows notable differences in using old and new materials and methods for live loads. There are notable differences in the construction steps between replacement and rehabilitation options when only the truck live loads govern.

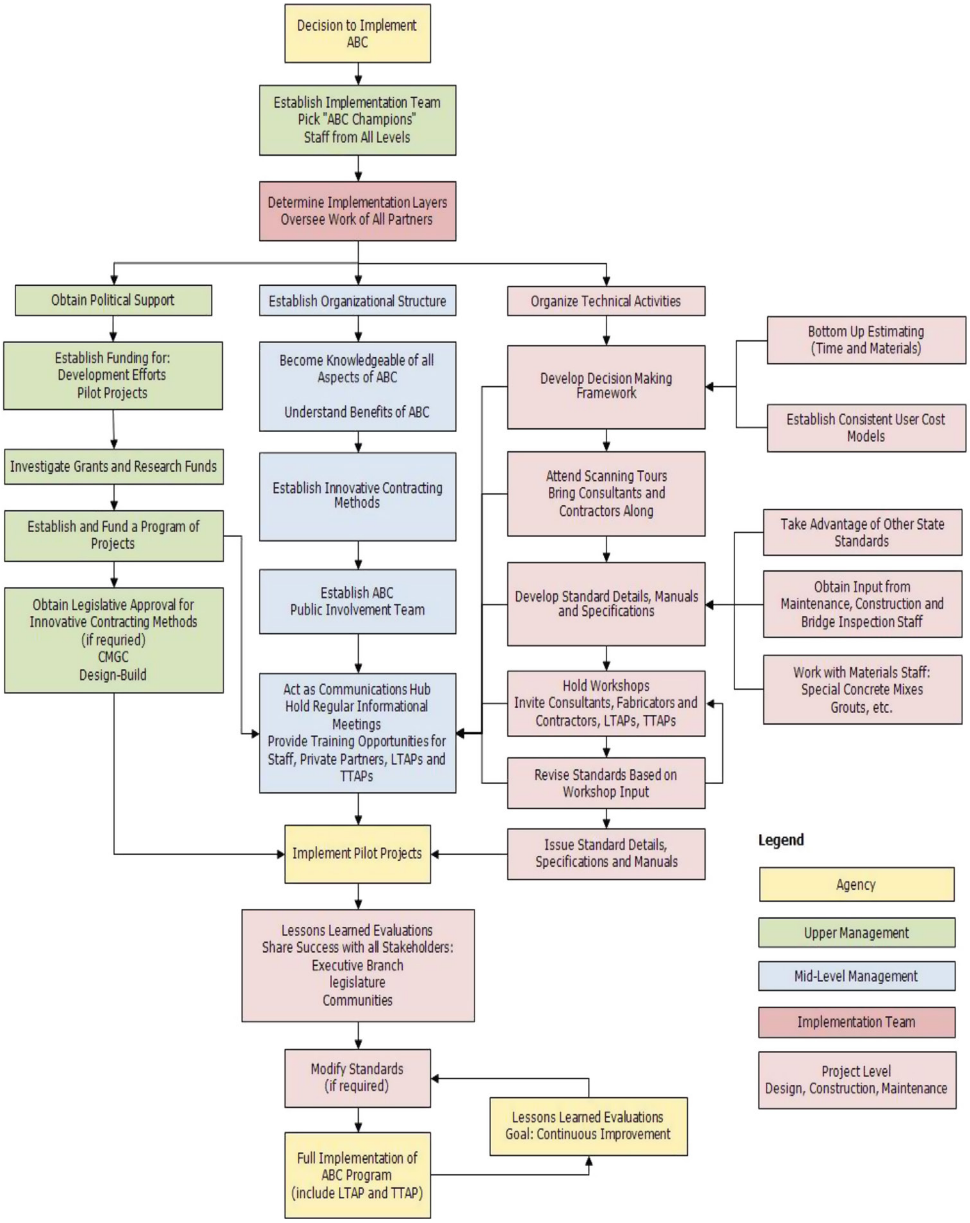

FIGURE 7.2

Flow diagram for promoting implementation of ABC on projects by management teams (Source: FHWA).

Table 7.3 shows the construction steps when extreme events of earthquakes and flood scour govern. As in conventional construction projects, the ABC projects will be run by licensed engineers at the contractor and consultant offices so that all work is done according to design and construction standards and the quality of work is of a high standard.

The importance of using new construction materials and innovative methods were emphasized in earlier chapters. In Tables 7.2 and 7.3 the differences are highlighted.

Table 7.2 Notable Differences in Using Old and New Materials and Methods for Live Loads

Selecting Method of DB	Old or Existing Construction	Replacement	Rehabilitation
Inspection and structural evaluation	Not applicable for original construction	Deficiencies must be established	Modern inspection methods with ultra-high speed 3D laser techniques
Use of materials	Traditional materials used	Modern materials used	Special materials used
Construction techniques	Traditional construction used	Formwork, pile bent, precast components	Modern techniques use
Geometry and vertical clearance under bridge	Substandard	16 ft 6 in, standard cross slope and grade	Limited changes
Structural system	Nonredundant through girders	Redundant system	Nonredundant through girders
Live loads	Live load to be checked by rating (bridge may be posted)	HL-93	Live load to be checked by rating
Environmental issues	Monitoring agencies such as EPA were not required	Stream encroachment and other construction permits required	Some air, water, and noise control requirements need to be complied with

Table 7.3 Notable Differences in Using Old and New Materials and Methods for Extreme Events

Design Issue	Old or Existing Construction	Replacement	Rehabilitation
Seismic design	Not applicable	Seismic zone and multiple spans to be considered in design	Seismic retrofits may be required
Scour analysis/countermeasures design	River characteristics have changed	Based on hydraulic studies	River maintenance is required for bridges over scour-critical rivers
Foundation scour	Riprap	Gabions, grout bags, sheet piles	Gabions, grout bags
Bridge security	Not applicable	Full security	Limited security

Substructure replacement: In the past, there has often been overdesign by using gravity and massive wall-type abutments, piers, and their foundations. This had a built-in advantage in that when it came to replacement, only the superstructure was replaced. It is an unusual situation if the substructure needs to be replaced while the superstructure is in satisfactory condition. In some cases, superstructures can be lifted off of the bearings and reused. In most cases, the entire bridge is replaced, except when using the roll in-roll out technique, which can preserve the superstructure.

Projects requiring painting: Repainting of steel bridges is required at regular intervals of 15–20 years, especially for structures located over rivers. To remove and dispose of existing lead-based paints, repainting costs have escalated in recent years and in some cases have become nearly comparable to the cost of a new bridge. Painting may require lane closures and needs to be planned for minimal traffic effect. However, the quality of painting and on-site painting methods have improved. New types of girders promoted by ABC will minimize or eliminate the need for painting.

7.5 Progress in design build, prefabrication, and the role of the construction manager/general contractor

7.5.1 D-B philosophy

With D-B project delivery, the designer-builder assumes responsibility for most of the design work and all construction activities. This provides the designer-builder with increased flexibility to be innovative, along with greater responsibility and risk.

7.5.2 ABC goals

- Relentlessly pursue reducing traffic congestion during construction
- Add value by furthering department themes and meeting project goals
- Improve worker safety and safety to the traveling public
- Improve quality

ABC techniques are applicable to all the major types of construction aspects such as:

- Rehabilitation
- Deck replacement
- Superstructure replacement
- Full bridge replacement
- Fast track contracting using DB, construction manager (CM)/general contractor (GC) contracting provisions
- Corrosion mitigation techniques including coatings at the fabrication stage
- Bidding options and incentives/disincentives

7.5.3 Advantages of ABC for extending service life

As discussed in Chapters 1 and 2, ABC technology (with prefabrication) will help in cutting the time of construction and improving the quality of construction. In addition, the life-cycle costs for bridges will be lower and it can solve traffic problems caused by long construction durations, which can extend months and sometimes years with traditional construction techniques. The costs of bridge reconstruction are considerably reduced by factory production and field assembly. Other aspects of ABC that are improving bridge construction are the following:

- Methods to eliminate expansion joints and bearings by modernizing structural details such as using jointless decks increase the service life of a bridge.

- Integral and semi-integral abutment bridges are being used extensively to eliminate the problematic deck joint.
- Jointless bridge systems result in more durable bridges because combined longitudinal frame behavior is offered by moment connections between the ends of beams and pinned connections with the structural approach slab resting on grade.

The main load-carrying members are the core of any bridge. They require strengthening methods, improved retrofit, and replacement of bearings. Most retrofits are in the form of upgrading the bearings, scour countermeasures, and use of crash-tested parapets.

Key areas that need extensive investigation include

- Development of performance-based earthquake engineering design tools to enable rapid and widespread adaptation of advanced design methods
- Development of new technologies and adaptation of existing technologies for predisaster assessment and for rapid response and postdisaster evaluation
- Instrumentation of infrastructure components
- Methods and tools for data assessment and interpretation leading to useful information and instrumentation for assessing the energy release and variation of intensity of the strong shaking of earthquakes

Considerable time savings over the traditional process of DBB allows design to be tailored to a contractor's resources and promotes the use of quality evaluation factors and best-value selection criteria when selecting contractors. By using ABC, we will achieve

- Reduced overall project costs in many cases
- Reduced inspection, police, and flagging
- Reduced field office rentals
- Reduced inflationary bid costs

The cost to society (user costs and/or project costs) can be reduced by

- Reduced on-site construction time
- Minimized traffic disruption: months to days
- Reduced environmental effect
- Improved work zone and worker safety
- Positive cost-benefit ratios when user costs are considered
- Improved product quality: controlled environment, cure times, easier access, etc.

For owners, using a single DB contractor provides multiple benefits, including

- Expediting delivery times
- Eliminating extensive procurement times
- Minimizing risk through a single accountable entity
- Reducing the hassle of multiple contracts and contractors

The CM/GC occupies the middle ground between the traditional DBB and DB. The CM/GC provides for project acceleration by allowing the owner to contract with a CM early in the design process and agree to a negotiated price for construction later before design is complete.

7.5.4 Selected D-B initiatives

The objectives of the D-B team are to play a dynamic role in the management of the project and take certain initiatives. The following are some examples:

- Planning and environmental legal sufficiency enhancements
- Clarifying the scope of preliminary design
- Flexibility in right of way and flexibility in utility relocation
- Prefabricated bridge elements
- GRS
- Duties of CM/GC

7.5.5 Compliance with codes and standards

When a bridge is being considered for rehabilitation, it should be reviewed for compliance with current LRFD standards. Existing vertical clearance, horizontal clearance, load capacity, free board, seismic capacity, lane width, and shoulder width should be compared to current standards. Hydraulic and seismic history should also be reviewed. If the existing features are nonstandard, consideration should be given to improving them under rehabilitation or by replacing the bridge.

- Prestressed concrete trapezoidal box and tub sections/comparison with bulb T sections
- Composite timber and concrete decks

The girders commonly used for small or medium spans are made of timber, steel I beam, reinforced concrete, prestressed concrete I shapes, or box sections. Arches have been constructed in masonry, timber, steel, and concrete. Steel cables and trusses are used for long spans. Aluminum and composites used for pedestrian bridges result in lightweight decks.

7.5.6 Notable increase and popularity in ABC

Forty percent of U.S. bridges were built over 40 years ago, with a design life of 50 years. With increased traffic volumes on our nation's aging roadways and bridges, there is a growing need to repair the most vital bridges in the highway system in an accelerated fashion to limit safety and mobility effects. Because of this, ABC is growing in popularity across the country.

As discussed in earlier chapters, ABC involves using various methods during project planning, design, contracting, and construction to significantly reduce the time to construct/replace a bridge as compared with traditional cast-in-place methods. With ABC, a bridge can be removed and replaced in a matter of days rather than months or even years.

ABC includes a range of methods, used individually or in combination. The primary methods for ABC are using prefabricated components that are built offsite and can be quickly put in place once onsite or building the entire structure offsite and moving it into place using a self-propelled modular transporter (SPMT). Other ABC methods include working with stakeholders to innovate during planning; doing certain activities (e.g., right-of-way acquisition, utility relocation, materials procurement) sooner, before project advertisement; and accelerating schedules to reduce project delivery time.

ABC can improve safety, productivity, and quality while reducing effects on traffic and the environment. With ABC, traffic disruptions to motorists are significantly reduced because roadwork is done in a fraction of the time and long-term work zones can be avoided. Because exposure to work zones is reduced, safety for the traveling public and construction workers is improved. Safety and efficiency can also increase because traffic control installation and removal happen less frequently.

By limiting the time spent at the site reconstructing the bridge, construction effects on the surrounding environment are reduced. Because ABC often involves building part or all of a bridge in a controlled environment away from live traffic, the end product is generally of higher quality and productivity is often greater as workers can focus on their work with less distraction from traffic. These benefits are particularly evident when a bridge is built offsite and moved into place using an SPMT because the existing bridge can remain open until the new bridge section is transported into position and the existing bridge is replaced.

7.6 MPT during construction

7.6.1 Traffic control and projected traffic count

The importance of maintenance and protection of traffic was emphasized in earlier chapters as basic requirement. Traffic counts are required for ADT volume. A traffic count needs to be performed to assess the effect on traffic flow during construction. Warning signs must be placed weeks in advance so that the users may select an alternative route to avoid congestion. Local authorities should be contacted to determine if they have any restrictions regarding lane closures. Before developing staging plans, the agency's traffic operations department will provide the maximum allowable lane closure hours in each direction and the maximum number of lanes that can be closed at one time. An 8- to 10-h night window is required for the contractor to properly complete his work. Extra hours are permitted for weekend work.

Traffic count is needed for

- Planning the number of lanes to close.
- Fatigue analysis of girders.
- Detour purposes.
- Posting any weight or speed restrictions. Widening may be required because of high ADT, congestion, and traffic jams. Plans must comply with the MUTCD (*Manual on Uniform Traffic Control Devices*).

Traffic control guidelines and AASHTO LRFD specifications: All nonstandard signs shall be sized according to MUTCD with letter heights and alphabet size given for each line. If shutting down will result in unacceptable delays from detours and/or if there is too much local opposition to shutting down, construction needs to be performed in more than one stage.

7.6.2 Planning for the MPT

MPT will be based on a hierarchy of options:

- Half-width staged construction
- Scheduling nighttime work hours to expedite construction
- Construction of a new bridge adjoining the existing bridge (use existing bridge for traffic maintenance)
- Prescribe temporary stream crossing and approaches (e.g., stream crossing made of multiple pipes/fill material)

- Prescribe temporary bridge and approaches for bridges carrying high traffic volume
- Provide bridge on new alignment
- Temporary measures to keep bridge open:
  - If structure is in advanced stage of deterioration, then partial lane closure may be adopted by posting lower load limits
  - Continue using on a temporary basis if there is high traffic volume and/or there is no money immediately available for full replacement
  - Two lanes closed during construction
  - Temporary roadway detour
  - Temporary construction access

7.7 Action required by environmental engineer

In addition to MPT, another basic requirement is to comply with environmental regulations.

Federal and State agencies review and approve construction impacts on environment and issue construction permits. With the reduction in the duration of construction from ABC, any adverse effects on the environment will be reduced compared with conventional methods. However, to further minimize any adverse environmental effects, these environmental concerns should be addressed:

- Develop a baseline survey to define current environmental issues
- Develop an assessment of the effect of proposed repairs on air pollution or on the water environment
- Develop considerations or measures to avoid or mitigate adverse effects
- Eliminate effects on wetlands by using top-to-bottom construction and temporary bridges
- Develop alternatives to minimize effects
- Issues related to ecology:
  - Preservation of vegetative species: Ecology (flora and fauna), minimizing effects on natural vegetation by controlling construction access points (revegetation of disturbed areas may be required)
  - Landscape preservation
  - Preservation of endangered species
  - Maintaining air and water quality
  - Relocation hazards of underground and bridge supported utilities
  - Reactions with acid-producing soils

7.7.1 Advance permit approvals and meeting EPA requirements

The proposed construction should neither damage an existing wetland nor adversely affect the historical significance of the bridge itself or its surroundings, except as permitted through the environmental evaluation process. For bridges located on streams, a flood hazard area general permit is required. Engineering data and documentation are required for permit approval. As per regulations, the following reports/proforma need to be submitted:

- EA (Environmental Assessment): An EA is required when the significance of the environmental effect is not clearly established.

- EIS (Environmental Impact Statement): EIS documents need to be prepared when a replacement or new bridge (usually with four or more lanes) has a significant effect on natural, ecological, or cultural resources including endangered species, wetlands, flood plains, groundwater, fauna, and flora. An EIS is required when there are effects on properties protected by the Department of Transportation (DOT) Act or the Historic Preservation Act. Significant effects on noise and air quality need to be avoided.
- CE (Categorical Exclusions): An action that does not have a significant effect on the environment falls under CE. Examples provided by FHWA are reconstruction or modification of two-lane bridges, adding pedestrian or bicycle lanes, widening for shoulders, installation of signs, etc.

7.8 Improved aesthetics

ABC shall not be at the expense of aesthetics. Factory manufacture of prefabricated bridges is expected to improve quality control and also improve aesthetics.

Examples of aesthetics can be seen in the elegant patterns engraved on precast concrete walls retaining and noise walls, which is a source of delight for road users.

The famous structural engineer Hardy Cross laid down the criteria of a beautiful bridge: “The first requirement of a beautiful bridge is that it must stand up long enough for us to look at it.”

A bridge should have a pleasant appearance. As the old saying goes, “A thing of beauty is a joy forever.” It should have a visual relationship with the surrounding area and have visual effect. New bridge façades should preferably blend with the appearance of existing bridges in the vicinity. Prefabrication in factory conditions can create artistic and attractive patterns on the girders.

- Bridges should have an open appearance and avoid abrupt changes in elevation or curvature.
- Abrupt changes in beam depth should be avoided when possible. Whenever sudden changes in the depth of the beams in adjacent spans are required, care should be taken in the development of details at the pier.
- Avoid mixing structural elements (e.g., concrete slab and steel beam superstructures or cap and column piers with wall-type piers). In general, continuous superstructures shall be provided for multiple span bridges. Where construction joints cannot be avoided, the depth of spans adjacent to the joints preferably should be the same. The use of very slender superstructures over massive piers needs to be avoided.
- Lighting can make a big difference in the aesthetics of a bridge.
- For abutment, wing wall, and retaining walls, MSE walls are gaining popularity because of their elegant styles, low cost, and quick construction.
- Normally it is not practical to provide aesthetic treatments at a cost premium without specific demands; however, careful attention to the details of structure lines and forms will generally result in a pleasing structure appearance.
- Patchwork in concrete or dissimilar steel painting should be avoided.

One of the most significant design factors contributing to the aesthetic quality of the structure is unity, consistency, or continuity. These qualities will give the structure an appearance of a design process that was carefully thought out. Sound planning also leads to safety and effective operation at intersections.

Use of innovative ideas and new technology: Lightweight and weather-resistant transparent noise barrier sheets incorporate polyamide filaments that hold broken sheet in place in the event of impact by a car or truck.

Other cost considerations related to aesthetics include the following:

- The aesthetics of the structure can generally be accomplished within the guidelines of design and require only minor project cost increases. If form liners are being considered, then the depth of the projections should be as deep as possible to have the desired visual effect.
- Using shallow depths provides very little visual effect or relief when viewed from a distance.
- The depth of the form liner shall not be included in the measurement of the concrete clear cover.

7.8.1 Site drainage issues

Effective deck drainage:

- Use of deck waterproofing membranes
- Extension of deck drains below bottom of girder flanges
- Prevention of clogging of deck drains
- Construction effect on flood plain
- Soil erosion and sediment transport: minimizing the erosion of native substrate due to sediment transport after installation

For flood conditions, only 1 ft of free board is usually provided under the bridge. Site drainage will ensure that the bridge deck is not submerged and the traffic flow is maintained.

For bridges located in flood plains and on rivers that can flood, retention and detention basins are required.

A retention basin is used to manage storm water runoff; to prevent flooding and downstream erosion; and to improve water quality in an adjacent river, stream, lake, or bay. It prevents soil subbase deterioration.

A retention basin is a storage site similar to a detention basin, but the water in storage is permanently obstructed from flowing downstream.

Detention basin/retarding basin: It is an excavated area installed on, or adjacent to, tributaries of rivers, streams, lakes, or bays to protect against flooding. It can be built close to the bridge location. These objects exist for flood control when large amounts of rain could cause flash flooding if not dealt with properly.

Water detention pond: It detains water. A detention pond is a low-lying area that is designed to temporarily hold a set amount of water while slowly draining to another location. In a detention pond, all of the drainage from higher areas runs into it. It is normally a grassy field with a couple of concrete culverts running toward a drainage pipe. It may have pipes, headworks, and a vortex chamber. A soil survey may be required.

Water retention pond: It retains water all of the time. A retention pond is designed to hold a specific amount of water indefinitely. The pond is usually designed to have drainage leading to another location when the water level gets above the pond capacity, but it still maintains a certain capacity.

7.9 Design-related issues

The introduction of new technology and innovative structural systems such as the following can introduce a host of issues that the construction team must be ready to handle:

- Integral abutment bridges with prestressed girders, eliminating deck joints
- Semi-integral abutment bridges

- Bridges with integral piers
- Simplified seismic detailing procedures and warning systems
- New erosion protection countermeasures for foundations in rivers
- Providing limits of splice locations in girders

FHWA's "Bridge of the Future" initiative was the GRS Integrated Bridge System (IBS). Its combined cutting-edge geosynthetics is a simple construction method. It can lower costs, slash construction time, improve durability, and increase worker safety.

GRS abutments are similar to those used by ODOT. Geosynthetic soil is a fast, cost-effective bridge support method using alternating layers of compacted fill and layers of geosynthetic reinforcement to provide bridge support.

7.9.1 Use of specialized construction

For ABC, SPMT and heavy cranes are required. For conventional field construction, bridge construction equipment is becoming increasingly more complex and sophisticated. Knowledge of configurations, operations, kinematics, performance, productivity, structure-equipment interaction, and industry trends for every family of special equipment, including the following, are required:

- Beam launchers and shifters
- Overhead and underslung self-launching gantries for span-by-span erection of precast segments
- Lifting frames and self-launching gantries for balanced-cantilever erection of precast segments
- Form travelers and suspension girder for balanced-cantilever in-place casting
- Underslung travelers for in-place casting of arches and cable-stayed decks
- Self-launching gantries and movable casting cells for span-by-span macrosegmental construction of adjacent bridges
- SPMTs, tire trolleys, telescopic launchers, and portal carriers with underbridge for full-span precasting

7.9.2 Precast Wolf girders

Another improvement in aesthetics can be achieved by the elegant shape of Wolf Girders. The following is from "Wolf Girders—A Function Driven Solution" by John A. Lobo and David A. Burrows, available at http://www.structuremag.org/Archives/2013-9/SF-PHX-Sept13.pdf. Wolf girders were used as components of the new PHX Sky Train in Phoenix, Arizona.

Comparison with AASHTO I-Girders: The Wolf girder is comparable to AASHTO Type IV and Type V girders.

The Wolf girder is approximately 25% heavier than an AASHTO Type IV, but it offers approximately 50% more capacity for an overall 25% better strength to weight capacity.

AASHTO Type V girders are approximately 15% more efficient than Wolf girders. However, the alignment and column arrangement dictated by existing ground conditions did not allow for optimal span arrangement, and the Type V girders did not provide savings over the Wolf girder.

A preliminary estimate showed that that the elevated guideway would contain 19,000 LF of Type IV girders or 15,000 LF of Type V girders, but only 11,000 LF of Wolf girders.

7.9.3 Improvements in construction to meet horizontal and vertical clearances

There is an ever increasing trend in freight trucks is to increase the truck capacity.

Wide loads are restricted by the lane width. Hence the only option is to increase the height of track. This causes many practical issues. The older bridges have only 14 ft. clearance which is inadequate for currently used trucks. If existing horizontal or vertical clearances are not adequate, then the existing bridge needs to be replaced with a new bridge that has higher clearances. As an alternative, posting for vertical clearances over and under a bridge is required in keeping with agency requirements.

AASHTO specifications have defined minimum horizontal and vertical clearances for bridge substructures and superstructures. These may be modified by state and local codes. The minimum vertical clearance from the top of the road surface is 16 ft 6 in and a minimum of 23 ft from the top of the rail. Older bridges were often designed for lower clearances.

Vertical clearance requirements: Minimum vertical requirements are based on the importance of the highway. It would be uneconomical to design all bridges to a single horizontal or vertical clearance requirement rather than based on their importance and frequency of use. Some bridges may have additional levels for carrying traffic (e.g., the George Washington Bridge, New Jersey). In such cases there might be a top level, bridge deck level, and lower level. AASHTO specifications lay out the following minimum vertical clearances:

- Interstate highway, 16′6″ (5.03 m): freight trucks with unusual height use selected routes
- State highway, 15′6″ (4.72 m): height caters to most trucks
- Local street, 14′6″ (4.42 m): minimum truck traffic required on local streets.
- Pedestrian, 17′6″: comfort of walking with the least noise from traffic above
- Waterway: usually determined by CG; applicable only for navigable rivers
- Over railroad 23′0″: trains with special freight height

Horizontal clearance requirements: The minimum horizontal clearance between the edge of the lane and the concrete face of the abutment or pier is applicable.

Commonly used clearances include a minimum horizontal clearance of 30 ft to the abutment face from the edge of the travel lane.

Agencies can modify clearances to a certain extent, but these variations must be approved by AASHTO before the state highway code is implemented. The changes can be either less or more on the basis of experience, judgment, and special conditions present in that state.

For projects funded by federal programs, AASHTO specifications for ABC need to be modified for erection and assembly conditions and loads. The highway agency can approve design modifications when planning a new bridge on the basis of prevailing clearances of bridges located on that highway.

7.9.4 Corrosion protection strategies for increased life

These can best be achieved in factory conditions as compared with cast-in-place construction:

- Epoxy rebar, top mat only or top and bottom mats
- Low permeability concrete
- Use of corrosion inhibitors
- Use of surface sealer
- Use of weathering steel is on the increase since painting cost is minimum

7.9.5 Reducing deck cracking and efflorescence

The following issues should be avoided to prevent deck cracking:

- High negative moment over piers
- Deficient rebars detailing
- Shrinkage cracks due to high water/cement ratio during curing
- Excess cement paste in concrete
- Excess number of shear connectors
- Small aggregate sizes
- Inadequate bar cover

7.10 States across the country implementing ABC

Further progress in the United States on ABC was reported by the *Journal on Roads and Bridges*, April 2003. This offers a wide-ranging introduction to accelerated construction efforts around the country, and several states are cited (see http://www.roadsbridges.com/rb/index.cfm/powergrid/rfah=lcfap=/fuseaction/showArticle/articleID/4010). For an infrastructure report card that may indicate the need for introducing ABC techniques, please visit Roads and Bridges website for more information. The following states have gained recent attention for successes in accelerated construction.

7.10.1 California

Caltrans has made accelerated construction a key component of its highway rehabilitation efforts (see http://www.dot.ca.gov/research/roadway/llprs/llprs.htm). Caltrans strategies for state infrastructure improvements see accelerated construction as an integral technique. An overview, with a description of funding and projects is at http://www.dot.ca.gov/hq/transprog/stip/2004%20ITIP/proposal5.htm. This program is funded through an innovative financing method (see http://www.dot.ca.gov/hq/innovfinance/garvee_bond/garvee_highlights.htm).

Deep soil stabilization: Caltrans worked with the Swedish Geotechnical Institute to obtain translations of Swedish research that developed deep soil mixing techniques for subbase stabilization. Although expensive, the methods work particularly well as a component of accelerated construction (see http://www.dot.ca.gov/research/researchreports/twopage_ summaries/resnotes_swedish_rpts.pdf).

7.10.2 Florida

Accelerated construction was a component of a mid-1990s innovative contracting law passed in Florida (Please visit their website for more information).

Hot in-place recycling: Road builders have worked with hot in-place recycling, a method emerging from emphasis on accelerated construction.

Palm Beach County I-95: Achieved mostly through careful scheduling of roadwork, accelerated construction is cited as a significant component of reconstruction plans that will continue through 2008 (see http://www.bdb.org/clientuploads/Research/road_construc_PBC.pdf).

7.10.3 Indiana

The Indiana Department of Transportation (InDOT) has been using accelerated construction practices since the mid-1980s. By improving streets and intersections in Indianapolis, InDOT paved the way for successful traffic diversion off I-65 and I-70 to accelerate mainline construction in its Hyperfix project (see the article in the May/June 2004 *Public Roads* at http://www.tfhrc.gov/pubrds/04may/06.htm).

7.10.4 Kentucky

An article in *Roads and Bridges*, June 2004, reports on how the state of Kentucky has used improved mapping and surveying techniques to accelerate preconstruction. To read the three key steps the agency believes as central to the success in accelerated preconstruction, please visit http://www.roadsbridges.com/rb/index.cfm/powergrid/rfah=lcfap=/fuseaction/showArticle/articleID/5232.

7.10.5 Michigan

The Michigan DOT strategic vision leads to

- Safety: reduce work zone accidents
- Mobility: reduce congestion; improve flow
- Innovation: new equipment and procedures
- Leadership: new standards, use by local agencies
- Transparency: public discussion of cost/benefit

Prefabricated Bridge Elements and Systems, structural placement methods, SPMTs, launching, sliding, and heavy lifting are also being used.

7.10.6 Minnesota

Accelerated construction became a cornerstone of the Minnesota DOT 2003 strategic plan (see “Building Faster” at their website for more details. In June 2003, Minnesota designated up to $900 million over 5 years toward accelerating highway construction efforts.

Highway 14: One of the 12 projects designated for acceleration is this expansion; originally scheduled for 2005–2009, accelerated construction commitments moved the schedule up to 2004 to 2006 (http://www.newsline.dot.state.mn.us/archive/04/aug/11.html#3).

I-494: The I-494 DB project is another of the 12, and it featured a 2004–2006 timeline (http://www.dot.state.mn.us/metro/news/04/08/03i494.html).

7.10.7 Montana

Accelerated construction was seen as an important component of the Montana Department of Transportation (MDT)’s U.S. 93 wildlife fencing efforts (Please visit their website for more details).

7.10.8 New Jersey

New Jersey used an Accelerated Construction Technology Transfer (ACTT) workshop to develop accelerated construction plans for a bridge on the New Jersey turnpike (see the article in the January/February 2004 issue of *Focus* http://www.tfhrc.gov/focus/jan04/03.htm).

7.10.9 Oklahoma

Several articles in the *Focus* August 2002 issue discuss accelerated construction. Two not yet mentioned previously include one advocating the technique ("The Time for Accelerated Construction is Now") and another on the Oklahoma DOT's success in quickly responding to a bridge problem ("Accelerated Bridge Repairs: Meeting the Challenge in Oklahoma") (see http://www.tfhrc.gov/focus/aug02/index.htm).

7.10.10 Pennsylvania

In elevating, widening, and improving the intersections and interchanges of Route 28 in Pittsburgh, a busy four-lane highway running tightly along the Allegheny River, PennDOT used accelerated construction methods. (*Roads and Bridges*, June 2003; see http://www.roadsbridges.com/rb/index.cfm/powergrid/rfah=cfap=/fuseaction/showArticle/articleID/4216).

7.10.11 South Carolina

The South Carolina DOT's accelerated construction page offers a brief description of the practice and links to websites devoted to descriptions, images, and documents for 11 construction projects that used the building technique.

7.10.12 Texas

Project Pegasus, the reconstruction of two interstates in Dallas, is something of a poster child for major accelerated construction projects. Visit the project on internet. The October 2003 issue of *Focus* reported on the project. Project Pegasus was the focus of an ACTT workshop in 2003.

7.10.13 Utah

The Utah Department of Transportation (UDOT) is one of the forerunners in embracing ABC techniques. In Utah, ABC is considered for inclusion on all projects involving structures. UDOT started using ABC elements in 1997 and has now used ABC methods and elements in over 200 settings.

For Utah, ABC is a means to meet the goal of providing the best value to roadway users and the general public. The UDOT has details that are based on connections that are used in buildings that are acceptable for high seismic zones in the ACI Building Code. Caltrans is currently completing more testing on these connections.

7.10.14 Washington

http://www.wsdot.wa.gov/commission/AgendasMinutes/agendas/2004/May19/Item10.pdf; and a project team meeting summary at http://www.wsdot.wa.gov/projects/SR520Bridge/LibraryFiles/2004/04-04-WSDOT recently diverted $10 million from right-of-way funding to design to accelerate construction. http://www.wsdot.wa.gov/projects/viaduct/qpr/dec2003.htm.

Alaskan Way Viaduct: Another critical Seattle arterial, the Alaskan Way Viaduct carries traffic through Seattle on State Route 99, the main alternative highway to I-5. The viaduct runs along Elliot Bay on the city's western shore and faces extensive seawall and highway reconstruction.

7.11 Overview of maintenance procedures

7.11.1 ABC and D-B construction

Many states have legislation that mandates minimizing any traffic disruptions during construction. Accelerated bridge design and construction research will advance technology by developing improved prefabricated structural systems using enhanced details, materials, and foundation systems.

The organization of a combined contractor-consultant team seems to have reduced some of the friction and any earlier lack of coordination between contractors and consultants. Traditional systems have been refined for contractors playing a greater role as team members, which have resulted in more realistic construction-related design and better use of contractor's resources, leading to a faster turnout in construction.

7.11.2 Risk assessment and improving the security of bridges

Modern technology can provide a reliable approach to security such as the use of wideband Internet networks for all security systems, digital closed-circuit television surveillance systems, access control systems, and biometric devices. Recent natural disasters and the threat of terrorism highlight the need for effective monitoring and for rapid reconstruction and recovery of our bridges and highway structures.

7.11.3 FHWA national policy on ABC and everyday counts

The enhanced contributions of bridge engineers to transportation policy decisions can result in

- More practical input to context-sensitive design approaches
- Enhanced utilization of transportation systems through nationwide uniformity in size and weight restrictions

The national policy objectives as defined by FHWA are

- To develop strategies in which bridge engineers more effectively contribute to transportation-policy decisions
- To develop recommendations to AASHTO on oversize/overweight vehicles and the long-term effect of construction on the environment

7.12 Increasing the service life of bridges

The following issues listed below are common to many states.

7.12.1 Design aspects to minimize maintenance

- Elimination of deck joints by using integral and semi-integral abutments
- Fiber wrapping columns to increase seismic resistance
- Transverse post-tensioning of precast deck slab
- Use of grade beams under approach slab to prevent settlement

7.12.2 Materials selection

Concrete: The following methods of construction may be considered.

- Latex-modified and microsilica-modified concrete overlays can be used. The use of precast concrete approach slabs will expedite construction.
- Improved concrete mix design for extreme hot weather.
- Use of ultra-high-performance concrete, fiber-reinforced polymer, or carbon-fiber reinforced polymer needs to be investigated for the superstructure.
- Use of precast concrete railings in place of steel railings.
- Improved concrete deck curing techniques.
- Use of concrete inhibitor aggregates.

Steel:

- Use of stainless steel
- Use of weathering steel with painted beam ends, HPS 70W, and 100W
- Use of epoxy-coated rebars and thicker epoxy coats

7.12.3 Cost-effective preventive strategies

- Avoid field welding for fracture critical tension members
- Resolve MPT issues before reconstruction using detours or temporary bridges or by staging
- Train bridge engineers and technicians through bridge management training courses.

7.12.4 Potential of new applications

Further information needs to be developed for the following:

- Deck crack sealing with high-molecular-weight methacrylate or with silane/siloxanes
- Approach slab patching
- Deck surface sealing with boiled linseed oil
- Substructure concrete sealers and composite wrapping of substructure caps and piers

7.12.5 Structural solutions

Although rehabilitation is usually associated with the older bridges, it may be required for newer bridges when planning, design, or construction mistakes are present. The capacity of existing bridges built for a lighter live load may damage the deck slab or the girders when heavier vehicles are permitted. Weight restrictions need to be implemented. In general, most recurring maintenance problems would require unique structural solutions.

The rehabilitation of bridges is far more challenging than a new design that is based merely on code compliance. For maintenance of an existing bridge, there are fewer alternatives available to the designer than when designing a new bridge.

Some of the common rehabilitation examples are

- *Repairing cracks in concrete*: Concrete deck slab or an earthquake-damaged concrete pier can be repaired by new materials technology. Several products are now available in the market.

- *Underpinning*: Strengthening of the unknown foundation by underpinning with mini piles to increase the load-carrying capacity is possible.
- *Retrofits and widening*: Bridge performance can be upgraded by seismic retrofit or scour countermeasures and by widening using precast slab panels to provide additional lanes, shoulders, or sidewalks.
- *Partial ABC*: For rehabilitation of an existing bridge, an engineer's options are restricted as compared with the options available for design of a new or replacement bridge. However, partial ABC is still possible.

7.12.6 Basic maintenance activities

Keeping bridges in perfect condition: This involves diagnostic design and selective reconstruction. Design-related activities are based on

- NBIS inspections
- Interpretation of data
- Selection of repair and rehabilitation methods
- Analysis
- Computer-aided design
- Application of AASHTO and state Codes of Practice

7.12.6.1 Designing for blast loads

For important bridges carrying high ADT, the design criteria need to consider structural response to applicable blast loads similar to subjecting the bridge to a high-magnitude (safe shutdown) earthquake. Development of a performance-based specification and accompanying design manual for blast loads is required.

7.12.6.1.1 Superstructure rehabilitation issues

- Deck reconstruction and design
- Deck protective systems
- Steel superstructure rehabilitation
- *Deck joints*: joint types, compression seals, strip seals, modular and expansion joints, joint replacement, deck joint rehabilitation, joint design
- *Deck drainage*: scuppers, inlets
- *Bridge railings*: bridge railing rehabilitation
- *Barrier design*: median barrier and parapets
- *Bearings retrofit and design*: evaluation and strengthening of rocker and roller types, elastomeric pads, sliding, multirotational, dampers, and seismic isolation bearings
- *Girder retrofit*: composite sections, shear connectors, web stiffeners, cross-frame design and splice design
- *Bearings retrofit and replacement*: restrainers, seat width improvement
- *Utilities relocation*: design of hangers and pipe supports

7.12.6.1.2 Substructure rehabilitation issues

- Geotechnical issues and foundation design: foundation types, underpinning and rehabilitation, mini piles, pin piles, pile groups, caissons
- MSE walls, modular walls, restoring abutments and piers, underpinning methods
- Abutment and wingwall repairs
- Pier jacketing
- Column strengthening
- Seismic retrofit
- Scour countermeasures retrofit

7.12.7 Award of D-B contracts

Figure 7.3 shows various steps of a flow diagram (as recommended by FHWA) for building up a D-B team and its selection on the basis of contractor's negotiated cost.

FHWA was represented by Mr. Benjamin Beerman in the one day workshop held in 2013 at Temple University.

7.12.8 University of Buffalo experiment: Seismic response of ABC system (Chapter 3)

The specific objective of this research is to design, construct, and perform multidirectional seismic testing of a complete bridge system using the two adjacent 7- by 7-m triaxial shake tables of the Structural Engineering and Earthquake Simulation Laboratory at the University at Buffalo.

The general objective of this task is to experimentally evaluate the dynamic/seismic response of a reinforced concrete bridge system constructed with accelerated techniques. The multidirectional seismic/dynamic behavior of these innovative bridge systems have never been evaluated in the past. The ABC techniques considered by the research team centered on segmental hollow bridge pier construction with self-centering and energy-dissipating capabilities.

7.13 Practical examples of Pennsylvania and New Jersey bridges

Tall piers for Monfayette Expressway: Photos of the Monfayette Bridge project located near Pittsburgh with long spans (nearly 300 ft) and tall columns (nearly 200 ft high) are shown in Chapter 1 (see Figure 7.4 for a refresher). In place of bar splices, which were congesting the hammerhead pier cross section and making concreting difficult, bar splice threaded sleeve connections were used.

An innovative method was used for casting of concrete for the tall piers. The 200-ft tall piers were constructed in seven or eight concrete pours, each pour not exceeding 25 ft in height, to be poured in one day, which avoids too many construction joints. A special concrete mix design was tested with a new type of admixtures. These improved techniques if used in similar situations will prevent major losses. The contractor may also be eligible for a bonus because of early completion.

New bridge over Schuylkill River: In 1996, Philadelphia's famous Schuylkill Bridge was retrofitted with scour countermeasures to prevent erosion. In addition, a new composite steel bridge was constructed adjacent to the existing bridge.

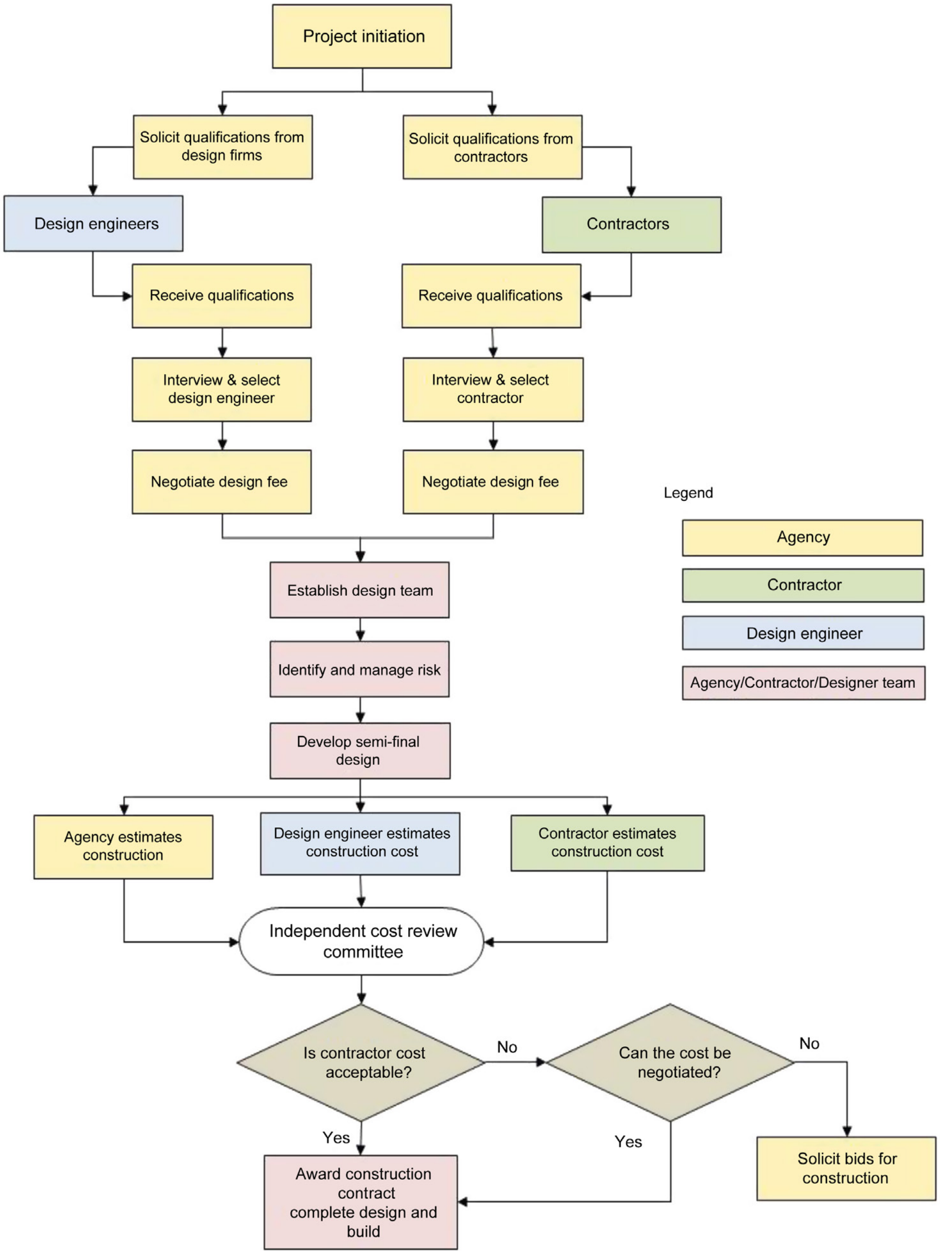

FIGURE 7.3

Flow diagram for project management using agency/contractor/designer team (source FHWA).

FIGURE 7.4

Monfayette Expressway six-span bridge with tall columns.

Special provisions were developed for their substructure construction under water. There was no HEC-23 available then for the design of countermeasures. The life of the bridge was increased as foundations were shielded from flood water. Other personal examples relate to seismic retrofit, ductility detailing of beam column joints, and structural countermeasures. ABC or partial ABC projects on which the author has worked have created interest in this growing topic.

Route 50 precast bridge in South Jersey: A two-span precast slab bridge with precast pier on concrete piles/columns on Route 50 in New Jersey was designed by the author. The innovative approach of full-length precast piles extended to the deck level was reported jointly with the co-author (New Jersey State Bridge Engineer), Richard W. Dunne, at the FHWA Conference in Baltimore.

(Reference Khan, Mohiuddin Ali & Richard W. Dunne, "Application of Accelerated Bridge Construction Concepts", FHWA Conference, Baltimore, 2007).

7.14 Conclusions

Before launching on a multimillion dollar project, it is a professional responsibility of the engineers to indulge in an effective planning exercise. This chapter investigated the following issues:

The continued and ever-increasing infrastructure difficulties faced by the public are highlighted. Economic and public comfort benefits derived from early completion of projects are reviewed. The various steps in the methodology of ABC are addressed.

Promotion by federal and research organizations has resulted in seminars, continuing education, and useful publications leading to adoption of ABC to some extent in design.

A survey of ABC projects successfully completed by many states has shown an increased interest in adopting the new technology.

Major contractors and fabricators have welcomed the increased responsibility of the DB system in which their decision-making is appreciated.

In the United States, the facilities exist to implement ABC because of the availability of SPMT, wide roads with exits for their plying, and heavy cranes for their erection.

Partial ABC: For rehabilitation of an existing bridge, an engineer's options are restricted as compared with the options available for design of a new or replacement bridge. However, partial ABC is still possible.

It is encouraging to see new publications and workshops promoting ABC.

NOTE: A bibliography for this chapter is listed at the end of the chapters in Appendix 1.

A list of Bridge Inspection Terminology and Sufficiency Ratings used by PennDOT is given in Appendix 3.

SECTION

Modular Bridges

3

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CHAPTER

Prefabrication of the Superstructure

8

8.1 Introduction

Prefabrication of the bridge superstructure is the most important aspect of the ABC method. It is more of a reconstruction than a first-time construction. The use of prefabrication for the superstructure is more common than for the substructure. The two main options available to engineers for the accelerated bridge construction (ABC) method are (1) factory manufacture and transportation of prefabricated components to the site, or (2) fabrication at the site adjacent to bridge and lateral slide-in construction.

> All new construction is linked to maintenance, such as replacement and repairs, unless it is an entirely new highway bridge. The condition of U.S. bridges dictates the construction for which funding needs to be made available. This chapter addresses the prefabrication and assembly of superstructure components, the transportation of assembled bridges using self-propelled modular transporters (SPMTs) for incremental launching, and the successful use of rapid construction in many states. The design-build contract system is an essential part of ABC and leads to prefabrication. According to SHRP2 Project R04, ABC is the clear choice. Lifecycle costs are significantly reduced.
>
> Chapter 8 presents prefabrication of the superstructure, whereas Chapter 9 addresses prefabrication of the substructure prior to erecting the superstructure. A discussion of successful projects completed in recent years in different states (Section 8.7) supplement those given earlier in Chapter 5 (Tables 5.1–5.7). Other issues covered in Chapter 8 include a wider use of the P3 system and high friction deck surface to prevent rusting of rebars.

A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2.

8.1.1 On-site construction and the ABC use of prefabrication

A typical sequence of the ABC construction-related activities are:

- Accelerated submissions and reviews
- Paperless submissions and electronic signatures
- Fabrication
- Accelerated testing
- Shoring and temporary works
- Erection issues
- Field inspection
- Accelerated decision making
- Grouting and closure pours

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00008-3

According to the conditions available, onsite construction can also be part prefabricated and part cast-in-place (CIP).

Today, CIP is like manufacturing the isolated bridge in a forest or in wilderness. On-site construction under open sky is far more difficult than factory manufacture due to the location of distant sites and inclement weather. New bridges have become more complex compared to bridge practices of the past, when CIP construction was the only option. Today, a factory has the necessary facilities for quick fabrication and has trained workers who do not need to travel, thereby saving travel costs. As stated in Chapter 1, advantages of prefabrication include the following:

Extreme events and climatic hazards: Dodging the weather by indoor factory manufacture of components has made a big difference. Much of North America has a cold climate for four months of the year, which slows down the speed of outdoor work. In large factories that are covered and centrally heated, the temperature change does not affect the schedule. Also, the activities on the critical path are not affected.

Labor availability at remote locations: Most bridge sites are located on distant highways. It can be very expensive and difficult to relocate hundreds of workers. A factory that prefabricates bridge components can serve as a regular workplace.

Storage of construction materials: A special building is required onsite to store construction materials such as aggregates, cement bags, ladders, machinery, and dozens of other appliances. Temporary pathways need to be constructed. This can lengthen the schedule.

Formwork: This is an expensive aspect of CIP construction. It needs to be erected for the deck slab and for the CIP girders. It adds to the cost of work and affects the schedule.

Exposure to rain and sunlight: Due to the exposure of steel and cement to the elements, corrosion of steel and wetting of cement, etc., occurs, which lowers the quality of work and is not desirable.

Mobilization: For CIP, a temporary administration building needs to be set up. This adds to the overhead.

Quality control: This is affected due to the limited number of senior engineers that are available during the entire construction period for construction inspection, unlike in a factory where they are hired full time. Because ABC often involves building part or all of a bridge in a controlled environment away from live traffic, the end product is generally of higher quality and productivity is often greater because workers can focus on their work with less distraction from the traffic.

These benefits are particularly evident when a bridge is built off-site and moved into place using an SPMT. The existing bridge can remain open until the new bridge section is transported into position and the existing bridge is replaced.

Promote modular construction: The European practice is to standardize the design of bridges on typical intersections (limiting it preferably to two spans) and wherever possible on the river bridges also. The location of abutments can be adjusted to utilize standard precast girder lengths. The locations of field connections are also kept unchanged, as determined from analysis.

Winding up: After completion of the project, there are fewer activities required on the site and winding up is much quicker.

Hidden benefits: There are hidden benefits to using prefabrication. One benefit is that it is easier to supplement any unforeseen shortage of materials to complete the project. Another is the ready availability of emergency medical treatment in case of injuries.

Associated costs: There are extra costs for the use of SPMTs and heavy lift cranes, which are offset by early completion and use of the bridge.

Overall, the use of prefabrication leads to higher quality, a reduction in lifecycle costs, and longer life for the bridge.

8.1.2 The importance of prefabrication

Prefabrication is the backbone of ABC. As stated in earlier chapters, there are many advantages with this approach in significantly reducing the time of construction of bridges onsite. The major advantages are:

- Preventing delays through the indoor factory production of many components, which can avoid delays caused by extreme weather conditions, such as wind, rain, and snow.
- Doing away with relocation of bridge workers and their families to remote bridge construction sites.

This topic was discussed and emphasized in earlier chapters. The advantages are the sum of the individual aspects described in each chapter; they are emphasized separately, such as the prefabrication aspects of the current chapter. Some duplication may occur, but reiteration is of great importance to underline the practical importance of the subject of ABC and its various aspects. ABC can improve safety, productivity, and quality while reducing impacts to traffic and the environment.

With ABC, traffic disruptions to motorists are significantly reduced, as roadwork is done in a fraction of the time and long-term work zones can be avoided. One of the key benefits of ABC is increased safety. Because exposure to work zones is reduced, safety for the traveling public and construction workers is improved. Safety and efficiency can also increase because traffic control installation and removal happen less frequently. By limiting the time spent at the site reconstructing the bridge, the impact of construction on safety is reduced.

With increased traffic volume on our nation's aging roadways and bridges, there is a growing need to repair the most vital bridges in the highway system in an accelerated fashion to limit safety and mobility impacts. Because of this, ABC is growing in popularity across the country.

ABC involves using various methods during project planning, design, contracting, and construction to significantly reduce the time to construct/replace a bridge, as compared to traditional cast-in-place methods. With ABC, a bridge can be removed in a matter of days rather than weeks. ABC includes a range of methods, used individually or in combination. The primary method for ABC uses prefabricated components that are built off-site and can be quickly put in place once onsite. Building the entire structure offsite and moving it into place using an SPMT is therefore becoming popular. Other ABC methods include working with stakeholders to innovate during planning; doing certain activities (e.g., right-of-way acquisition, utility relocation, materials procurement) sooner, before project advertisement; and accelerating schedules to reduce project delivery time.

Case studies of the construction of a bridge on I-85 in Georgia and other innovative projects have confirmed the benefits of ABC.[1] The use of prefabrication in a bridge project is illustrated in Figure 8.1.

8.1.3 Parameters in planning bridges

The major parameters in planning bridges are span length, width, and live load intensity. For new bridges, only span length can be adjusted by coordinating with highway engineer, which may result in the change of alignment.

[1] See http://www.fhwa.dot.gov/everydaycounts/technology/bridges/casestudies.cfm.

FIGURE 8.1

Prefabricated girders being placed in position using two cranes.

The width depends upon the number of lanes, as evaluated by the traffic engineer. For live load intensity, both the American Association of State Highway and Transportation Officials (AASHTO) code and the state codes will govern. However, note that HS 20 trucks may not meet the special axle loads of heavier trucks, such as the SPMTs that are used for ABC.

8.2 Continuous reconstruction of nationwide bridges

One in four of the nation's bridges are either structurally deficient or functionally obsolete. About 67,000 of the United States' 605,000 bridges are considered to be structurally deficient. The SAFE Bridges Act, introduced in the U.S. House in June 2013, would provide $5.5 billion to start to reduce the backlog of the more than 150,000 structural deficient and functionally obsolete bridges across the country.

It appears from American Society of Civil Engineers (ASCE) report cards that there is a need for the continuous reconstruction of bridges and infrastructure nationwide. The inspection reports indicate that too many U.S. roads and bridges are in a state of disrepair. All infrastructure, including bridges and highway structures, has fallen under the microscope in recent years.

Maintaining safe bridges requires consideration of bridge capacity and condition, lifecycle costs, available funding, operation, public safety, resilience, and the adoption of innovative methods, and new technology for construction as well as for the analysis and design process. With the population increasing, more people will use bridges every day.

Although some progress has been made in recent years to reduce the number of deficient and obsolete bridges in rural areas, the number in urban areas is on the rise. According to investigations by the ASCE for past report cards, $17 billion in annual investment is needed in the United States to substantially improve current bridge conditions. Currently, only about half of the required amount is spent annually on the construction and maintenance of bridges. Many of these bridges will continue to deteriorate over time without maintenance. Some of the older concrete bridges were not designed to carry today's truck loads. If reinforcement is not provided, more of them will need to be posted with weight limits to prevent degradation.

ASCE's 2013 *Report Card for America's Infrastructure* includes evaluations of bridges. The report card's constructive criticism can form the basis of a blueprint for modernizing infrastructure with sustainable technology. Much reconstruction is needed, and applying sustainable technology and modular construction will provide more reliable and long-term solutions. In the United States, approximately 67,000 bridges are deficient; the number is increasing with time due to continued wear and tear, so this is a cause for concern. It appears that the United States is not alone in suffering from poor structural conditions, bridge planning, and road conditions, as other large population countries such as China (about 9% deficiency) and India (about 7% deficiency) have this issue as well.

Deficiency does not indicate imminent failure, but occasional shutdowns for maintenance and increases in lifecycle costs, with possible earlier bridge replacements, are likely.

8.2.1 Examples of actual failure or near-failure conditions

There have been recent examples of actual bridge failures or near-failure conditions. A bridge in Washington State collapsed, sending three people to the hospital.[2] The I-35 Bridge in Minneapolis, Minnesota collapsed into the Mississippi River in 2007, killing 13 people and injuring 145.

The Maine Department of Transportation (MaineDOT) assembled a panel that released a report in 2007, "Keeping Our Bridges Safe."[3] That report found MaineDOT was responsible for 70% of known bridges in the state, 205 of which were more than 80 years old. Transportation officials estimated that 288 bridges would be at risk of closure or weight restrictions within a decade.

Transportation for America[4] (a national safety advocacy group) found Maine had the ninth highest percentage of structurally deficient bridges in the county. The University of Maine has been involved with load testing several Maine bridges. Recently, the I-95 Bridge that crosses Kenduskeag Stream was shut down for a few hours and heavily loaded dump trucks were used to test the effects the loads had on the bridge.

8.2.2 Introducing sustainability

Redesigning and modernizing our bridges to be sustainable is of critical importance. It will not only revive the economy and environment, but it will make our infrastructure more resilient to challenges from climate change and population growth, among other issues. The author has served as a panel member for the ASCE team preparing the 2014 report card for Pennsylvania's bridges. The following addresses the most relevant issues from this report.

The lack of coordination with other engineering disciplines that involve the location of traffic sign structures, the various utility pipelines supported by bridges, and effective deck drainage from heavy rainfall or the use of nonslippery road surfaces is adversely affecting the public.

Bridges with higher redundancy and with fewer fracture critical members should be preferred as insurance against failure. Fracture-critical members are those that will cause simultaneous failure of other members when they fail. Implementing these features may mean a return to the forgotten

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[2] See, e.g., http://bangordailynews.com/2013/05/24/news/nation/truck-crash-may-have-caused-washington-state-bridge collapse/?ref=inline.

[3] See http://www.maine.gov/mdot/pdf/Keeping%20Our%20Bridges%20Safe.1107.pdf.

[4] http://t4america.org/.

fundamentals, when bridges were overdesigned on purpose with higher safety factors for material strength and live load.

With new materials, such as high-performance concrete (HPC), high-performance steel (HPS), lightweight concrete (LWC), there is a hidden benefit of an increased factor of safety. Using higher live loads in design will prevent the common practice of limiting bridges to lower live loads; this bars heavier trucks from using the highways, thereby leading to economic losses and delay in case of detours. Other key issues and elements of the report include the following:

Existing capacity as well as future capacity: Current roads and bridges should be able to sustain the current population and future growth. For sustainability, master plans, funding plans, and capital improvement programs serve as guidelines.

Existing as well as future conditions: Future projects in the pipeline that are either likely to be funded or where design is already under way will improve structural conditions.

Operation and maintenance: There should be consideration of infrastructure failures related to noncompliance with regulatory requirements. What may be evaluated is the ways the public agencies run and maintain the infrastructure compared to a set of best practices.

Public safety: The extent to which the public's safety is jeopardized by the condition of the infrastructure is a priority consideration. The likelihood of a major failure and consequences of a failure will require understanding what needs to be repaired, rehabilitated, or replaced urgently.

Resilience: When considering resilience, the capability to prevent or protect against significant multihazard threats and incidents with minimum damage to public safety and health need consideration. Resilience can to some extent depend on the economy, national security, and the ability to expeditiously recover and reconstitute critical services.

Use of innovations and modern technology: It is important to make use of the latest technology for safety, economy, and reductions in life cycle costs. For example, ABC and prefabrication can help in many ways toward these stated objectives.

Weighting factor: The fundamental components are not weighted. The experts in the subject areas may have determined grades based on a particular plus or minus in any of the components.

8.2.3 Research and grading process

Existing available data or surveys for new data should be reviewed where applicable to a category. Data collected will be used as follows:

- Assessment of infrastructure using the existing reported grades
- Identify dollars needed to replace existing infrastructure in current dollars and current amount being spent
- Identify dollars needed to upgrade infrastructure to meet future needs
- Percent capacity of problem
- Quantity of infrastructure, number of bridges, miles of road, pipe, etc.
- Consequences of doing nothing

The data should be compiled and analyzed, resulting in the development of a summary report. The following criteria should be used in presenting the data:

- Total need defined by the dollars needed
- Identify existing and future needs and current funding levels
- Percent of capacity represented by the problem

Quantity that the problem represents
Progress made in category from previous report card, including condition, funding, etc.
Determine an initial grade
Subject matter experts should then complete an analysis and final determination of the grade.

8.3 Developments in ABC technology

8.3.1 Innovations in superstructure fabrication

A list of recent innovations is presented here to illustrate the various technologies and advancements that can be used with ABC to improve bridge construction:

Prefabricated bridge elements and systems (PBES)
Half-depth and full-depth precast deck panels
Connection details for PBES[5]
Precast voided slab
Approach slab panels
Inverset
Precast NEXT beam
Spliced girders
Bulb tee and Wolf girders
Precast box culverts
Patented bridges in steel; proprietary bridges such as US Bridge, Inverset, Acrow and Mabey types
Use of aluminum and high-performance steel 70 and 100W to reduce mass for ease of transportation and erection
Patented precast bridges in concrete
Small span bridges such as Conspan
Use of fiber-reinforced polymer (FRP) concrete and composites
Use of lightweight aggregate concrete

The associated ABC method for rapid delivery requires the use of SPMT for site delivery. Structural placement methods are easier due to availability of structural components or even bridges without the conventional expensive formwork. Launching can be accompanied by sliding and heavy lifting techniques.

8.4 The stakeholders in promoting rapid construction

Federal and state management agencies have a vested interest in promoting technologies that can redress some of the burning issues discussed in this chapter and earlier chapters. Stakeholders evaluate various alternative construction strategies by considering both quantitative and qualitative criteria, and

[5] See http://www.fhwa.dot.gov/bridge/prefab/if09010/index.cfm.

create and analyze comparisons of various strategies, considering tangible and intangible factors. User guides and training materials are being developed. Notable stakeholders include the following:

AASHTO Technical Committee for Construction, T-4
Federal Highway Administration (FHWA) projects: Prefabricated bridges and Every Day Counts
ABC websites; manuals and other resources, including a manual on the use of SPMTs[6]
Highways for LIFE (HfL)
Innovative Bridge Research and Deployment Program (IBRD)[7]
Strategic Highway Research Program (SHRP 2)[8]
Transportation Research Board (TRB)/National Cooperative Highway Research Program (NCHRP) publications and PCI publications
ASCE webinars on related subjects and monitoring by their report card committees
ABC Center at Florida International University and their specialist seminars
Oregon DOT–led pooled fund study, TPF-5(221), regarding an ABC decision making and economic modeling tool
Active participation in promoting ABC by states (such as Ohio and Utah) through introducing decision trees and economic modeling tools for ABC, and continuing research on ABC at participating universities.
Prefabrication needs to be addressed in AASHTO design and construction specifications: it is good engineering and it minimizes traffic delays. The public expects it, and the public demands it.

8.4.1 TRB/NCHRP projects

Table 8.1 includes a list of projects related to ABC from the Transportation Research Board and the National Cooperative Highway Research Program.

For information on other NCHRP projects, refer latest information on NCHRP website.

Guidebook on Accelerated Construction (AC) by TRB: In January 2014, TRB embarked on developing the "Guidebook on Accelerated Construction Methods and Technologies for Transportation Infrastructures." The objective of this research is to develop a guide to effectively evaluate the various AC techniques for transportation infrastructure elements such as roads, bridges, tunnels, and culverts. The guidebook will include examples of AC procedures, policies, flowcharts, checklist, and other resources.

Syracuse University Survey: Many states are making considerable progress in AC, which is confirmed from a survey conducted by Syracuse University in 2012.

Specifically, the new guide will be a welcome edition and is expected to include the following:

1. A review and synthesis of recent experience of state departments of transportation on the use of AC,
2. Identifying the current state-of-practice, best practices, and specific challenges facing state DOTs and contractors on the use of AC, and
3. Documenting the results of this research in a report.

[6] http://www.fhwa.dot.gov/bridge/pubs/07022/chap00.cfm.
[7] http://www.fhwa.dot.gov/bridge/ibrd/index.cfm.
[8] http://www.trb.org/StrategicHighwayResearchProgram2SHRP2/Public/Blank2.aspx.

Table 8.1 List of TRB/NCHRP Projects Related to ABC

No	Title	Status
10–71	Evaluation of CIP reinforced joints for full-depth precast concrete bridge decks (research at University of Minnesota)—the *NCHRP Web-Only Document 173* covers two very different systems: (1) the precast composite slab-span system (PCSSS), which is an entire bridge system, and (2) transverse and longitudinal cast-in-place connection concepts to transfer moment and shear between precast deck panels and the flanges of precast decked bulb-Ts.	Completed
12-65	Full-depth, precast-concrete bridge deck panel systems	Completed report 584
12-74	Development of a precast bent cap system for seismic regions	Report 681
18-12	Self-consolidating concrete for precast prestressed concrete bridge elements	Report 628
18-14	Evaluation and repair procedures for precast/prestressed concrete girders with longitudinal cracking in the web	Report 654
18-15	High-performance/high-strength lightweight concrete for bridge girders and decks	Research in progress
24-31	LRFD design specifications for shallow foundations	Report 651

8.5 Environmental impact, guidelines, historic sites, and transportation

This section covers some additional topics related to ABC that must be considered when implementing any ABC features, including superstructure prefabrication.

8.5.1 Environmental impact

Because PBES offers rapid onsite installation, the environmental impact of construction is reduced. Environmentally sensitive areas, such as wetlands or urban areas in which air and water quality and noise pollution are issues, can limit the amount of construction work that can be done onsite. Environmental issues can also limit construction scheduling during seasons when wildlife and plant life are particularly vulnerable.

8.5.2 Impact of climate change on bridge performance

The ASCE Committee on Adaptation to Changing Climate (CACC) recommends initiatives related to:

1. Climate change and its effect on the safety, health, and the welfare of public
2. Appropriate standards, loading criteria, and design procedures.

The evaluation of the natural environment and related research and monitoring needs need to be investigated. The evolution of structural standards and practices will occur based on the changing nature of hazards, risks, and benefits. However, cast-in-place construction will be more susceptible to climate change than factory production. ABC will help limit the duration of construction.

Extreme events are likely to be impacted by climate change. The International Panel on Climate Change (IPCC) assesses climate change. The physical impacts will be seen in temperature, precipitation, winds, tropical cyclones, extratropical cyclones, droughts, floods, coastal events, extreme sea level events, landslides, and cold regions (see White et al., 2013).

According to IPCC (2012), there will be observed and projected changes on extreme events. "Long life, loose fit, and low energy" are recommended as useful concepts for the safety, health, and welfare of public. Long life contributes to sustainability and reduction of greenhouse gas emissions. Loose fit can make structures adaptable to conditions that could not be foreseen during original design. Low energy provides both economic benefits and reductions in greenhouse gas emissions driving climate change.

8.5.3 Developing guidelines

The PCI Northeast Bridge Technical Committee has developed useful guidelines for accelerated bridge construction using precast/prestressed concrete components.

1. Refer to PCI Northeast (A Chapter of Precast/Prestressed Concrete Institute), Accelerated Bridge Construction, Bridge Guideline: June 2012, Guideline Details for Precast Concrete Substructures. (November 2012, Guideline for Precast Approach Slabs).

This guide will assist designers in determining which means and methods would be appropriate for considering accelerated construction techniques. This guide offers solutions from deck replacement to total reconstruction of a bridge.

8.5.4 Use of ABC for historic bridges

The prefabrication of bridge components should help if consistent with historic bridge requirements. The owner will need to determine if appropriate pieces of the existing bridge can be incorporated into the new bridge. In some cases, monuments, parapets, stone work cladding, plaques, or other significant features can be salvaged and added on after the new bridge is in place. Communications with the state's Historic Preservation Officer (SHPO) are crucial during the preliminary planning stages.

8.5.5 Transporting the assemblies to the site

Existing roads: Permits are required and wide loads often need a police escort. For transportation over highways, the hauling systems must have axle numbers and spacing such that the loads are within permit limits. The transporter must find a route that has adequate turning radii to get longer components to the bridge site.

Existing railways: Fabricated heights need to be able to pass through tunnels. Consider the use of waterways, especially when the bridge is located on a river.

Preliminary planning requires a site survey for impacted intersections, allowable haul times, permit regulations, utility relocations, second-party easements (municipal, railroad, airport), and ease of movement throughout congested areas, including job site detours. In some cases, parts can be shipped by barges without requiring any rehandling on land.

8.6 Case studies of a variety of bridges using PBES in the United States

8.6.1 Further advantages of PBES

Some key advantages of PBES are in the following areas:

Traffic count: If average daily traffic and/or average daily truck traffic in the work zone is high, PBES is recommended for rapid construction.
Military bridges and essential bridges: If the bridge is essential as an evacuation route, or if the bridge replaces an existing essential structure, the speed of PBES makes it an obvious choice over traditional construction, which is slower.
Worker safety: Where bridge construction poses unusual hazards to worker safety and/or traveler inconvenience, using PBES can alleviate those conditions.
Lane and highway closures: Deliveries of elements and systems can be planned for off-peak times, including weekends. For some deliveries, single-lane closures are sufficient. Prefabrication allows faster partial or total repair of bridges and bridge parts. If standardized bridge elements are used, the use of PBES can offer costs savings in both small and large projects.

Many job sites impose difficult constraints on the constructability of bridge designs: heavy traffic on a provincial highway that runs under a neighborhood bridge:

- Difficult elevations,
- Long stretches over water,
- Restricted work areas due to adjacent stores or other facilities, etc.

Using prefabricated bridge elements and systems relieves such constructability pressures.

As can be seen, the benefits of precast, prestressed concrete for bridge construction include speed, durability, minimum traffic interruption, assured plant quality, minimum maintenance, and attractive designs.

Prefabricated bridge elements and systems offer bridge designers and contractors significant advantages in terms of construction time, safety, environmental impact, constructability, and cost. Using prefabricated bridge elements and systems means that time-consuming formwork construction, curing, and other tasks associated with fabrication can be done offsite in a controlled environment without affecting traffic.

Because prefabrication moves so much of the preparation work for bridge construction offsite, the amount of time that workers are required to operate onsite, frequently in traffic or at elevations or over water, is greatly diminished. Job site constraints, such as nearby power lines, are minimized when contractors can complete most of their construction offsite. Construction is less disruptive for the environment.

Increased quality and lower life costs: Prefabricating elements and systems removes them from the critical path of a project schedule: work can be done ahead of time, using as much time as necessary, in a controlled environment. This reduces dependence on weather and increases the control of quality of the resulting elements and systems. All projects that use prefabricated bridge elements and systems increase the quality of their structures; most also lower lifecycle costs.

Traffic and environmental impacts are reduced, constructability is increased, and safety is improved because work is moved out of the right of way to a remote site, minimizing the need for lane closures, detours, and the use of narrow lanes. Prefabrication of bridge elements and systems can be accomplished in a controlled environment without concern for job-site limitations that increase quality and can lower costs. Prefabricated bridge elements tend to reduce costs where use of sophisticated techniques would be needed for cast-in-place construction, such as in long water crossings or higher structures (e.g., multilevel interchanges).

8.7 Notable progress in the United States

A listing of successful ABC projects completed in the last 10–15 years by various states is presented below. Other projects are in progress. Completed projects provide valuable experience for other similar projects. For details, project managers of selected projects may be contacted at the official level. Access to the details of many of these projects can be gained through the FHWA at http://www.fhwa.dot.gov/bridge/prefab/projects.cfm.

8.7.1 Arizona

The Wolf girder, the first major use of a precast open box girder in Arizona, was developed to meet a specific need on the Sky Train project and has performed as well as expected, blending structural efficiency and stability with an aesthetically pleasing form. This girder will be used not only on the upcoming stage 2 of the Sky Train but, having proved its worth, will hopefully be adopted for local projects in Phoenix and elsewhere in Arizona.

Comparison with AASHTO I-Girders: The Wolf girder is comparable to AASHTO Type IV and Type V girders. The Wolf girder is about 25% heavier than an AASHTO Type IV but offers approximately 50% more capacity, for an overall 25% better strength-to-weight capacity. AASHTO Type V girders are approximately 15% more efficient than Wolf girders. However, the alignment and column arrangement dictated by existing ground conditions did not allow for optimum span arrangement and the Type V girders did not provide a saving over Wolf girder.

On one major project of elevated guideway, a comparative estimate showed that it would contain 19,000 LF of Type IV girders or 15,000 LF of Type V girders, but only 11,000 LF of Wolf girders. The advantages of using Wolf girder were described in Chapter 7.

It was the first major use of a precast open box girder in Arizona. It was developed to meet a specific need on the Sky Train project and has performed as well as expected, blending structural efficiency and stability with an aesthetically pleasing form.

Although the design used some standard geometry from Texas tub girders, the difference in depth and width of the Wolf girder precluded use of existing forms. US Concrete Precast Group, who won the contract to provide the 11,000 linear feet of Stage 1 girders, opted to use a custom built girder form. The Wolf girder used only straight strands, with debonding at the ends to control initial stresses; hence, both precasters did not require hold-downs or a structural slab beneath the girder.

Use of self-consolidating concrete: The precaster used a high workability mix that facilitated placement of concrete. For Stage 1A, the project team allowed the use of self-consolidating concrete that had been recently approved for bridge girders by the Arizona Department of Transportation. In both cases, the result was a high-quality surface finish with minimal blemishes.

8.8 Selecting and optimizing the girder shape

The designer decided, with the agreement of both the owner and CMAR, to design a simple trapezoidal precast concrete box girder that would be easy and economical to build locally.

Although Arizona has not used precast trapezoidal box girders and has no standard shape, several states have standardized these types of girders, including Colorado, Florida, and Texas, with the Texas "tub-girders" being perhaps the most widely known.

This established the need for top flanges and the rabbit ears option followed, with greater success. The top width of the section was driven by the minimum width of the guideway deck, and depth of the section and thickness of the flanges was optimized though iteration.

The designers noted the details of the Texas U54 beam and decided to incorporate some of the details into the final custom shape, thus creating the final version of the girder that was subsequently nicknamed the "Wolf girder." A key detail adopted from standardized sections was the chamfers in the top flange that facilitate stripping of the forms without damaging the concrete girder. The designers also drew on detailing mild steel reinforcement, skewed ends, and spacing of internal diaphragms.

A preliminary estimate showed that the elevated guideway would contain 19,000 LF of Type IV girders or 15,000 LF of Type V girders, but only 11,000 LF of Wolf girders.

Arkansas

Examples are:
Kouwegok Slough Bridge
Pelican Creek Bridge

California

Examples are:
IH80/Carquinez Strait Bridge
Maritime Off-Ramp at I-80 and I-880

8.8.1 Caltrans workshop proposals

The following is a list of ideas proposed by Caltrans in order to build the next generation of California bridges:

Precast bridge components emulating the performance of cast-in-place structures
Connection details and components capable of resisting seismic deformations
Unbonded prestressed columns with re-centering characteristics
Precast segmental columns with energy-absorbing joints
Seismic protection devices including bearings, dampers, and lock-up devices
Rocking bridge foundations
Replaceable bridge components including column plastic hinge regions, shear links, and link beams
Concrete-filled tubes including steel and FRP composites
Disconnected spread footing foundations on poor soils using piles or soil improvement techniques

Advanced materials including high-strength concrete, rebar and steel, shape memory alloys, fiber-reinforced engineered cementitious concrete, fiber-reinforced polymer composites, etc.
Use of fiber-reinforced polymer to rapidly repair column plastic hinge zones
Rapid post-earthquake bridge assessment using seismic instrumentation

Whatever systems, devices, or components are developed in the workshop, each will have be evaluated to consider the following:

Post-earthquake serviceability and post-earthquake reparability
Traffic impacts
Lifecycle costs
Constructability
Maintenance requirements
Durability
Reliability
Ease of future widening and other modifications

Colorado

The example is:
Mitchell Gulch Bridge in Denver

Project description

SH 86, South of Denver
Owner: Colorado Department of Transportation – Region 1
1200 vehicles/day
40 ft long single span bridge
Redesigned per CDOT value engineering process

Schedule

Single weekend
Started construction Friday at 7 PM; Opened for traffic Sunday at 5 PM
Less than 48 h to complete!

Connecticut

The example is:
Church Street Bridge

8.8.2 Long-term monitoring of two polymer composite bridges

At University of Delaware (UD), Harry W. Shenton III Michael J. Chajes, William L. Johnson, Dennis R. Mertz, Jack W. Gillespie, and their team designed continuous, long-term monitoring systems for two polymer composite bridges recently built in Delaware. The Magazine Ditch Bridge has been continuously monitored for more than a year.

(Presented in their paper is a brief overview of the systems and sample results from the data collected for the Magazine Ditch Bridge).

The monitoring system provides data to investigate the effects of sustained load, environmental factors, and live load on the bridge. Early results show that daily and seasonal temperature changes can induce strains in the bridge that are equal in magnitude to the maximum live load strains.

A similar system has been designed for the first state-owned composite bridge in Delaware. Research related to Bridge 1-351, its design, materials, fabrication, construction, and monitoring of the FRP deck system was performed at UD.

Florida

The example is:
Reedy Creek Bridge

Florida successfully used SPMTs in moving I-4 bridges. Videos showing the moving of a complete bridge superstructure carrying Graves Avenue over I-4 near DeLand, Florida illustrate the process.[9] The bridge was moved into place in less than an hour while traffic was temporary slowed using a gang of highway patrol "rolling road blocks" to interrupt traffic flow for less than 30 min. Table 8.2 outlines the project.

This bridge is in Disney World, Orlando, Florida, in the Reedy Creek Wetlands. The need was to provide vehicular access to the new Animal Kingdom theme park.

8.8.2.1 The solution

A precast prestressed concrete slab
Bridge constructed using top-down construction
Five continuous segments at 200 ft = 1000 ft, each segment = 5 spans at 40 ft.

8.8.2.2 Original design

Cast-in-place construction
Value engineering proposal selected the use of precast components in the same configuration

Table 8.2 Use of SPMTs in Florida

Location	Pros	Construction Method	Remarks
Graves Avenue Bridge was moved from its current position across I-4 in 2006.	Limited the impact on motorists to only two weekend nights of detours/closures along the corridor.	SPMTs were used to move the new spans from their fabrication site along I-4 to the bridge location.	This was the first use of SPMTs in the United States to replace a bridge across an interstate.

Conclusion: The precast alternate saved both cost and time. The deck construction used 405 haunched slabs in two sizes.

Hawaii

The example is:
Keaiwa Stream Bridge

[9] These videos are available at http://www.fhwa.dot.gov/bridge/prefab/gravesave.cfm.

Illinois

The examples are:
Illinois Route 29 over Sugar Creek
Wells Street Bridge

8.8.3 Concrete recycling cuts highway construction cost by landfill use[10]

Purdue University civil engineers worked with the Indiana Department of Transportation (INDOT) to perfect the use of recycled concrete for highway construction, a strategy that could reduce material costs by as much as 20 percent. Concrete pavements were made by mixing cement with water, sand, and “virgin aggregates” obtained from rock quarries located in the proximity of the construction site. In Indiana, most of these aggregates are quarried limestone.

Whiting is leading the concrete recycling project funded by INDOT through the Joint Transportation Research Program with Jan Olek, a Purdue professor of civil engineering; the researchers are testing concrete mixtures that contain varying percentages of recycled concrete. They also are developing cost-analysis software that will enable the state and construction contractors to estimate how much they could save by using recycled concrete. Crushing old concrete pavements into aggregate that can be recycled in new concrete can potentially reduce materials costs by 10–20%, depending on whether any quarries are located near construction sites.

The team will finalize a report providing guidelines and recommendations to help create design and material standards. Standards are needed to control the quality of RCA and its proper use in creating the new concrete. The focus of the standards will be on test methods for freeze-thaw durability and absorption of water and deicing chemicals.

Concrete taken from State Route 26 when it was recently repaved in Lafayette has been crushed for use as RCA for the project. A commercial concrete plant in Lafayette operated by Irving Materials is mixing the material. In addition, Jay Snider and Calvin Kingery of Irving Materials as well as Dick Newell of Milestone Contractors are working alongside the researchers, helping with issues ranging from adjusting mixture proportions to placement of trial slabs in the field.

Industry partners helped found the Applied Concrete Research Initiative in 2008 along with INDOT and academia, and are providing their services free of charge.

A case study using fiber-reinforced polymer decks for bridge rehabilitation: A bridge in Tippecanoe County is the first in Indiana to be rehabilitated with an FRP deck. Among the bridges evaluated, County Road 900E over Wildcat Creek is a three-span continuous steel stringer bridge with two concrete approach spans. The FRP deck replacement would only take place on the three main spans.

8.8.4 INDOT typical ABC design for new bridges

Single span 80′; three lanes at 12′
Left shoulder 6′, right shoulder 12′
Bridge width 33′-4″ 57′-0″

[10] From http://www.purdue.edu/newsroom/research/2011/110421OlekConcrete.html.

Provides room for future traffic control
Use 2″ asphalt wearing surface; eliminates grinding.

Iowa

An ABC project in Boone County was presented at the 2007 Mid-Continent Transportation Research Symposium in Ames, Iowa, in August 2007 (Bowers et al., 2007). Three deck panels could be cast in one casting operation. Panels could be fabricated every other day with a maximum of nine panels cast per week. Panel forms and spiral reinforcing were used to reinforce the bursting zone. Longitudinal joint reinforcing was also used. The panels were cast on a steel casting bed in the open.

The new Jakway Park Bridge in Buchanan County, Iowa is one of the first highway bridges in North America to be built with a new generation of ultra-high performance concrete (UHPC) pi-girders. The bridge is 24 ft, 3 in. wide by 112 ft, 4 in. long. The UHPC center span is 51 ft, 2 in. It is one of the first North American highway bridge projects to incorporate batching of UHPC in a ready-mix truck.

The Iowa DOT and the Bridge Engineering Center at Iowa State University designed the bridge, a combination of cast-in-place, simple span slabs with a center span consisting of a series of precast UHPC pi-girders. The Jakway Park Bridge has a clean, balanced, and symmetrical appearance. It can certainly be considered an important technological advancement in the bridge building industry.

Testing of the section by Turner–Fairbank validated the FEM analysis for flexural and shear capacity in the longitudinal direction. The testing also confirmed that the stress in the transverse direction of the deck was unacceptable for service loading and a low transverse, live load distribution between adjacent pi-girders would require stiffening. Future research will address current design and production concerns and develop more efficient beam designs to maximize UHPC's unique structural properties.

Keg Creek Bridge

US-6 Bridge over Keg Creek, Council Bluffs, Iowa
Three-span bridge; spans: 67′-3″, 70′-0″, 67′-3″
IADOT design–conventional construction required 6-month closure
ADT = 4000; 14-mile detour
Redesigned for ABC by SHRP2 R04 Team
Modular construction
14-day ABC period (road closure)
Selected by IADOT as ABC candidate
Project needed to fit timing for R04 project
Highway/civil design by IADOT

ABC design

Entire bridge built with prefabricated elements and modular systems.
Decked steel beam modules: simple for DL; continuous for LL.
Only the 6′ diameter drilled shafts were cast in place prior to closing the existing bridge.
Contractor could self-perform concrete precasting or have it done by a precasting plant.
Size and weight to allow erection with conventional cranes (<200 Kips)

Three typical construction stages
Stage 1 work (pre-ABC period):

Construct drilled shafts to ground level
Prefabricate modules in staging area.

Stage 2 work (during 14-day ABC period):

Detour traffic and demolish existing bridge
Assemble precast piers and abutments
Assemble modular superstructure and precast approach pavement
UHPC closure joints/grind deck/reopen bridge

Stage 3: Post-ABC complete channel works/slope protection (20 days)
Kentucky

The example is:
US-27 over Pitman Creek

Louisiana

The examples are:
I-10 over Lake Pontchartrain

Bridges can be damaged or destroyed by:

- Overheight vehicles,
- Ship collisions, and
- Natural disasters, such as hurricanes, earthquakes, and floods,

The Louisiana Department of Transportation and Development in 2006 removed and replaced the superstructure of the eastbound and westbound I-10 bridges in Rayne in a few hours using SPMTs. The bridge damage was caused by an overheight truck (see Merwin, 2007).

Maine

Fiber-reinforced polymer flexural retrofit system was developed in Maine.

It is estimated that a few hundred of Maine's more than 2400 bridges are concrete flat-slab bridges. They are typically short spans built along two-lane state routes and secondary roads. Most were built between the 1920 and 1950s.

A typical flat-slab bridge could cost an estimated $420,000 to replace or $120,000 to replace just the deck. A new type of bridge called a fiber-reinforced polymer flexural retrofit system could increase the strength of a bridge by 30% and cost closer to $70,000. The system is easy and inexpensive to install.

The lightweight carbon-glass strips, about a foot wide and made to length, are placed under the bridge with adhesive and then screwed into place. A two-person crew could do the job in a matter of days, whereas a bridge replacement or renovation would take weeks or months. "The strips have strength comparable to steel, but are light enough to be handled by a single person," according to

Hannah Breton Loring, the graduate student who created the system at the University of Maine. The strips have held up well in testing for the effects of saltwater and freezing and thawing.

The strips were tested on large concrete beams by Loring at the university's Advanced Structures and Composites Center. Without the composite strips, the beams failed under 15,000 pounds of force. With the strip's support, they failed under 22,000 pounds.

Massachusetts bridges

Heavy lifts/ABC were used at the following bridges:
Morton St. and River Street Boston Bridges[11]
I-93 Rapid Bridge Replacement Project
Replace 14 superstructures in 12 weekends
ADT 200,000 vehicles/day
All bridges carry I-93 over other features
Erected modular replacement superstructures on weekends.

8.8.5 MassDOT's Uxbridge replacement project

Modular Decked Steel Folded-Plate Beams for ABC Applications. For details and guidance please contact the state DOT.

The webinar by Maury Tayarani, Bridge Project Manager, Highway Division, MassDOT discussed design, fabrication and construction issues related to the use of modular decked steel folded-plate beam, using Uxbridge, in Massachusetts as a case study.

The steel folded-plate girder, with its more efficient cross-section, is an alternative to traditional I-shaped or closed steel box steel beams in modular decked beam elements, Elimination of the internal or external cross-frames, coupled with open bottom side for easy inspection, makes folded plate beams—an economical system with long service life for short span bridges with lengths less than 60 ft.

Wellesley Cedar Street Bridge

This bridge required accelerated bridge construction using SPMTs (Joseph P.G. Gill Engineering, Needham, MA).

Description: Due to the increased interest in ABC, the use of SPMTs continues to grow throughout the United States. MassDOT's Wellesley Cedar road bridge project. a two-span continuous superstructure rehabilitation project, used SPMTs along with prefabricated pier and abutment details to meet ABC objectives that minimized site disruptions and limited mobility impacts to just 4 days.

Prefabricated/modular bridges
Examples are:

Holyoke, Route 202 over B&M RR
Hopkinton, Route 85 over Subury River

[11] For more information on the River Street Bridge project and the use of ABC, see the April 17, 2012 article "Did Someone Order an Instant Bridge?" by John Schwartz at http://www.nytimes.com/2012/04/18/us/rapid-construction-techniques-transform-infrastructure-repair.html?pagewanted=all&_r=0.

Taunton, Holloway St. over Route 140 NB
Long Hill Rd. over CSX RR, West Brookfield
Northbridge Route 122 over the Blackstone River (fully precast through girder bridge with prefabricated deck, micro piles, abutments, etc.)

Precast arch bridges
Examples are:

Polly Harwood Bridge, Hill Street High Rd. over Westfield Brook, Windsor
Route 202/Route 10 over Johnson Brook, Southwick
Willow Street over Charles River, Dover–Needham
Phillipston Bridge Replacement, Route 2 over Route 2A[12]
Location: Phillipston, MA
Precaster: J.P. Carrarra & Sons, Inc., Middlebury, VT
Owner: MassDOT
Designer: TranSystems Corporation, Boston, MA
Contractor: SPS New England, Inc., Salisbury, MA
Total length: 60 ft, 8-inch span between abutments

Minnesota
State-of-the-art report on full-depth precast concrete bridge deck panels (SOA-01-1911).
Use of full-depth precast concrete deck panels by MNDOT is outlined in Table 8.3.
The use of inverted tee beams by MNDOT is outlined in Table 8.4
The use of precast concrete segmental box girders by MNDOT is outlined in Table 8.5.
Table 8.6 describes the use of slide-in construction by MNDOT.
Table 8.7 outlines the use of SPMT by MNDOT.
MNDOT Br. No. 62626 (Maryland over 35E)
Another example of construction method: using SPMT.
Design-build, move was scheduled for summer 2012.
Hastings design-build (arch installation). For details and guidance please contact the state DOT.

The in-depth investigations of MnDOT have confirmed the recommendation of the FHWA on the use of ABC technology (as reported in the latest ABC Manual and their *Every Day Counts Program*): The benefits include the following:

Innovation: new equipment and procedures
Leadership: new standards, use by local agencies
Mobility: reduce congestion, improve flow
Safety: reduce work zone accidents
Transparency: public discussion of cost/benefit.

Maintenance and protection of traffic (MPT) is improved considerably by adopting procedures such as post-tensioning, precasting, and temporary works and by the use of materials such as high-strength concrete and steel and modern equipment such as SPMT and cranes.

[12] Based on information from http://www.pcine.org/projects/project.cfm?articleID=5C01EB98-92F8-CF77-578CC3A6B3606E99&categoryIDs=.

Table 8.3 Description of FDDP by MNDOT

Nationwide Applications	Pros	Cons	Use by MNDOT	Remarks
Tried by about half the states; use dates back to 1970s	Any size bridge (new or rehabilitation) Quality/durability faster construction	Requires post-tensioning Roadway crown logistics Grouting (shear pockets, haunches) Skewed supports Existing shear connectors on rehab bridges	FDDP used on Br. 69071, SB T.H. 53 over Paleface River	25% reduction for ABC time compared to conventional construction

Table 8.4 Description of Inverted Tee Beams (by MNDOT)

Nationwide Applications	Pros	Cons	Remarks
Research at University of Minnesota	History/development: Based on French system developed in U.S. by MnDOT. First bridges let in 2005; 11 bridges let to date	Inverted tee beam design still evolving (standards being developed)	25% reduction for ABC time compared to conventional construction

Table 8.5 Description of Precast Concrete Segmental Box Girder (by MNDOT)

Nationwide Applications	Pros	Cons	Use by MNDOT	Remarks
First used in U.S. in early 1970s hundreds of bridges nationwide used in all regions	Suitable for long spans	Requires specialized contractors	35W/62 Crosstown (four bridges) Center span of new 35W Bridge Potential use on St. Croix	35% reduction for ABC time compared to conventional construction

Table 8.6 Description of Slide-In Construction Method (by MNDOT)

Nationwide Applications	Pros	Cons	Construction Method	Remarks
Not as common as SPMT Showcase/demonstration projects More variability (contractor methods)	Very minimal traffic disruption Work separated from traffic Higher quality (not on critical path)	Need right site conditions New foundations	MNDOT staged removals/temporary crossings. Slide-in used on Br. 25028, T.H. 61 Red Wing, Jan. 2013 let potential site in district 3	In place bridge nonstandard/dynamic loads 80% reduction for ABC time compared to conventional construction

Table 8.7 Description of SPMT Use by MNDOT

Nationwide Applications	Pros	Cons	Remarks
Tried by at least a dozen states (25+ in Utah) Detail and spec resources available More options for heavy lifter	Very minimal traffic disruption No work over traffic Higher quality (not on critical path)	Need right highway conditions for transport Initial investments are higher	In-place bridge High mobilization Costs 90% reduction for ABC time compared to conventional construction

8.8.6 Sensors installed on the new I-35W bridge

On August 1, 2007, the bridge carrying Interstate 35W across the Mississippi River at Minneapolis collapsed. Thirteen died and 145 were injured. On September 18, 2008, the fallen bridge's replacement opened. The new St. Anthony Falls Bridge contains 323 sensors to monitor for structural weaknesses, strained joints, and corroded concrete.

The St. Anthony Falls Bridge is made of high-performance concrete containing the coal-combustion byproducts fly ash and silica fume, making it denser and more waterproof (according to Alan Phipps, senior vice-president and director of operations at Tallahassee, Florida-based FIGG Bridge Engineers, which built it). Materials like this mean bridges built today could last 100 years, versus 40–50 for older bridges.

Missouri

The example is:
IH70/Lake St. Louis Boulevard Bridge

New Hampshire

The example is:
Epping 13940

New Jersey

The author was associated with a highway embankment project in North Jersey utilizing RCA for structural fill, which is made abundantly available from demolition of debris. This resulted in cost savings from the transportation of tons of wasted but good quality aggregates.

New Jersey DOT has been promoting and implementing innovative technologies to achieve improved work zone safety and motorist safety and comfort by using jointless decks and integral abutments that cause minimal environmental disruption. Audits are in practice at NJDOT to ensure designers and project managers study alternatives; new manufacture processes; connection details for prefabricated elements; management programs; and quality assurance.

Superstructure: Crews can cut old bridge spans into segments and remove them, prepare the gaps for the new composite unit, and then set the new fabricated unit in place in an overnight operation. The quicker installation minimizes huge daily delay-related costs and daily traffic control costs. Construction is usually scheduled for the fall months, when the weather is more predictable. A single course deck will save a minimum of 6 weeks in construction time compared to a two-course deck.

On the Route 46 Bridge spanning the Overpeck Creek in Bergen County, New Jersey, NJDOT decided to use prestressed, precast beams to avoid painting costs. Utilizing a precast superstructure

(Inverset), NJDOT replaced a structure in South Jersey, Creek Road over Route I-295 SB. Prefabricated deck panels (Inverset, which is no longer proprietary) for three single-span Route 1 bridges over Olden Avenue and Mulberry Avenue in Trenton, New Jersey were constructed in 2005, over weekends.

Besides exodermic and orthotropic decks, other new materials being used are HPC and corrosion inhibitor aggregate. Precast or steel diaphragms for prestressed beams have been allowed. Precasting allows for quality control and avoids reinforcement steel placement, concrete pouring, and weeks of curing.

Use of High-Performance Steel: The author has recently designed bridges with HPS 70W hybrid girders in New Jersey. It allows for longer spans and lighter girders. Shallower girders improve vertical underclearance, reduce the number of girders that must be constructed, and eliminate painting; weathering steel provides enhanced resistance to fracture.

Parapets: A variety of parapets are used in New Jersey. NJDOT permits its contractors to use slip forms to increase the speed of construction, as done successfully at the interchange of Routes I-195 and I-295.

Figure 8.2 shows an example of partial ABC using adjacent precast box beams in New Jersey.

New York

Aref and Alampalli studied the dynamic response of a fiber-reinforced plastic bridge recently constructed in New York State. The dynamic behavior of the bridge was studied using detailed finite element analysis. These models were then compared with field tests performed on the bridge to validate finite element models.

Examples are:

I-84 Bridges
Existing Bridges
Three simple spans: 37 ft: 55 ft: 42 ft
Two lanes at 12 ft
Two shoulders at 2 ft

NYSDOT was planning to use a temporary bridge in the median at a cost of $2.0 M to maintain traffic. It would take one construction season for each bridge. Alternatively, an overnight lateral slide was proposed:

Eliminates need for a temporary bridge and cross-overs
Traffic disruption on I-84 reduced from 2 years to two weekend nights (16–18 h closures)

FIGURE 8.2

Replacement of the scoured Lumberton–Vincentown Bridge in New Jersey in 1991.

Designed by the author.

Slide-in new single span concrete superstructure and approach slabs at the same time for faster construction.
Bid opening were due in November 2012. The available HFL funds were $2.0 M and SHRP2 funds were $300,000.

New Bridges: ABC Design

Single span 80′, three lanes at 12′, left shoulder 6′, right shoulder 12′
Bridge width 33′-4″ 57′-0″
Provides room for future traffic control
Uses 2″ asphalt wearing surface; eliminates grinding
New bridges will be about 2 feet higher than the existing to provide underclearance
Need to minimize new structure depth
New bridge is wider
Construct abutment drilled shafts outside footprint
NEXT beam (double T-beam) superstructure
Precast approach slabs

Impacts to the New York City watershed
Impact on construction time will be substantially reduced; at least 5 acres of land will not have to be disturbed with the ABC.
ABC benefits for New York

Construction duration will be significantly reduced from two construction seasons to two weekends.
Safety within the work zone will be improved.
Reduced costs: primarily by not building the crossovers and temporary bridge in the median ($2.0 M savings).

(Reference Jerry A. DiMaggio of Transportation Research Board and Bala Sivakumar of HNTB Corporation)
Description: In 2011, as part of an ongoing Strategic Highway Research Program, the SHRP2 R04 project, the Transportation Research Board and FHWA's Highways for LIFE program identified the I-84 Eastbound and Westbound Bridges over Dingle Ridge Road, owned by New York State Department of Transportation Region 8, as a viable candidate to demonstrate accelerated bridge construction methods for replacing an existing structure via the lateral slide method while making use of a concrete superstructure.

- This project was completed over two weekend periods (20 h closure each).
- Raising I-84 approaches by as much as 2 feet was required during ABC window, to satisfy underclearance.
- Removal of asbestos was required from existing abutment backwalls.
- Existing abutments on fill with spread footings needed minimizing disturbance during substructure construction.

During transportation, lifting, erection, temporary support, equipment loads, and deck placement, the following conditions will be observed:

No permanent inelastic deflection: rotations at bearings shall not be excessive,
No web buckling,
No yielding,
No lateral torsional buckling of compression flange due to wind (bracing is required),
Formwork and temporary supports shall not be unstable,
Quality control methods will be applied to obtain required strength of concrete.

8.8.7 Summary of rapid construction procedure

- During the pre-ABC period, construct abutments and new superstructure.
- During the ABC period, allow detour and demolish existing bridge.

In the final ABC phase, slide in the new bridge, raise the approaches to the required grade, and reopen the bridge to traffic.

Major truck route and existing bridges are too narrow for two-way traffic with cross-overs (28 ft wide roadway)
Pre-ABC period: construct abutments, new superstructure
ABC period: detour, demolish existing bridge, slide in new bridge, and raise approaches, reopen.
Both bridges completed over two weekends,
Three simple spans: 37′: 55′: 42′,
Two lanes at 12 ft; two shoulders at 2 ft.

Savings: NYSDOT was planning to use a temporary bridge in the median at a cost of $2.0 million to maintain traffic; this eliminates the need for a temporary bridge and cross-overs.

Overnight lateral slide: Slide-in new single span concrete superstructure and approach slabs at the same time for faster construction.

Traffic disruption on I-84 reduced from 2 years to two weekend nights (16–18 h closures).
Highway for Life (HfL) funds: $2.0 million.
SHRP2 funds: $300,000.

8.8.8 NY Alexander Hamilton Bridge

The technical presentation by Tariq M. Bashir, Supervisor Design, focused on the design and construction challenges faced during the rehabilitation of the Alexander Hamilton Bridge, and the interchange between Interstate Highways 87 (Major Deegan Expressway) and Interstate Highway 95 (Cross-Bronx Expressway), with particular emphasis on maintaining the traffic flow during construction. This complex infrastructure rehabilitation project required extensive interagency coordination and public outreach. With a construction cost of $407 million, the project used rapid construction principles, thereby reducing congestion of traffic during rush hour on one of the busiest bridges in New York. Figure 8.3 (a) shows a view of Alexander Hamilton Bridge in New York keeping construction time for rehabilitation to a minimum. Project Manager gave a technical presentation to ASCE Section in Philadelphia, which was organized by the author.

FIGURE 8.3A

View of Alexander Hamilton Bridge in New York utilizing some of the ABC concepts for rehabilitation.

8.8.9 Lightweight truss bridge rehabilitation using composites and FRP deck

According to FHWA, there are over 93,000 weight-restricted bridges in the United States. As reported, the 140-ft span Warren truss bridge carrying New York State's Route 367 over Bentley Creek in Chemung County built in 1940 found new life in 1999 after the installation of a 13-in. thick, E-glass reinforced vinyl ester resin deck weighing only 32 psf. This reduced the dead load by 80 percent and almost doubled the live load carrying capacity of the bridge.

A 14-ton weight restriction was removed and the bridge reopened to all legal loads. The deck itself rates much higher than the bridge. It meets L/800 deflection requirement with an inventory load rating of HS85 (154 tons).

Prestressing with CFRP tendons: Balazs and Borosnyoi carried out an experimental study on prestressed concrete beams pretensioned either with CFRP or steel wires. Load-deflection responses were analyzed and the pivot point of loading-unloading moduli under repeated loading was defined.

(Reference Balazs G.L., Borosnyoi A., 2001. *American Society of Civil Engineers*, High Performance Materials in Bridges, Proceedings of the International Conference, *Hawaii.*)

This paper describes a comparative experimental study that was performed on prestressed concrete beams pretensioned with carbon-FRP or steel wires. Load-deflection responses are analyzed and pivot point of loading-unloading moduli under repeated loading is defined. Practical details are given on the prestressing technique and heat curing.

Considerable corrosion of reinforced concrete members accelerated the research on nonmetallic materials like fiber-reinforced polymers (FRP) for structural application as noncorrosive reinforcement.

Under pass of Dingle Ridge Road is on a steep 15.7% grade which exceeds AASHTO 8% maximum grade limit.

As a result, new bridge will be about two feet higher than existing bridges to provide minimum vertical underclearance. In addition, there is a need to minimize new structure depth. Also, the new bridge is wider.

Table 8.8 Description of SPMTs in New York

Location	Pros	Construction Method	Remarks
Belt Parkway Bridge in Brooklyn	Using ABC techniques, the entire project was completed in 14 months at a final cost of 8% less than originally estimated.	Used prefabricated components to replace the bridge	Using traditional construction techniques, this replacement was scheduled to take 3–4 years to complete.

FIGURE 8.3B

Roll in of the fabricated bridge and roll out of deficient bridge.

8.8.10 NEXT beam (double T beam) superstructure

ABC benefits

Safety within the work zone will be improved.
Impacts to the New York City watershed will be substantially reduced; at least 5 acres of land will not have to be disturbed with ABC.

Table 8.8 describes the use of SPMTs in New York.

Figure 8.3(b) shows the use of roll in-roll out method on a busy street in New York as reported by Project Manager Tariq Bashir of NY State DOT (designed by HNTB).

Other New York bridges using ABC include:

Troy-Menands Bridge
Route 9/Metro North Pedestrian Bridge
Cross Westchester Expressway Viaducts
Governor Malcolm E. Wilson Tappan Zee Bridge (Tappan Zee Bridge)
Main Street over Metro North Railroad

8.8.11 Strengthening of a concrete T-beam bridge using FRP composite laminates

Osman Hag-Elsafi, Sreenivas Alampalli, and their team studied the application of fiber-reinforced polymer (FRP) composite laminates to strengthen a 70-year-old reinforced concrete T-beam bridge in New York.

Leakage at the joints of this single-span bridge led to substantial moisture and salt infiltration in the superstructure as manifested in efflorescence, freeze-thaw cracking, and delamination at some locations.

The bridge was strengthened using bonded FRP laminates. Load tests were conducted before and after the FRP laminates were installed to assess the effectiveness of the strengthening system. Test results are compared with those obtained analytically using classic approaches.

8.8.12 Robert Moses Causeway over Great South Bay, Long Island, NY

Southbound bridge length: Approximately 2 miles, two lanes wide, 153 spans.

8.8.12.1 Original contract

Rehabilitate superstructure girder and truss spans
Replace 122 stringer spans with spread P/S box beams
Replace deck.

8.8.12.2 Value engineering proposal

- Substitute full-width quad-tee span segments for spread box-girder spans

NYC watershed area
Over 75,000–100,000 ADT
Major truck route
Existing bridges are too narrow for two-way traffic with crossovers (28-ft wide roadway)

Roll-in roll-out method used on NYSDOT Hillside Avenue and Jamaica Avenue Bridges over Van Wyck Expresssway: New abutments and center pier were constructed in stages performed at night. Temporary support bents were placed adjacent to the existing structure and new superstructure was built. The existing bridge in each direction was moved on temporary bents and the new bridge was moved in place of the existing bridge.

For a deck panel project in New York, the square-foot bid cost for the panels was $46 per square foot, including a 2″ high performance concrete overlay. UHPC joint fill was $23 per square foot. UHPC joint fill for bulb-T bridges was up to $28 per square foot (Route 23 over Otego Creek, January 2009).

North Carolina

Examples are:
Linn Cove Viaduct
Beaufort and Morehead Railroad Trestle Bridge

Ohio

Geosynthetic reinforced soil (GRS) abutments, similar to those used by Ohio DOT.
Limits for splice locations in prestressed concrete I-shaped girder designs will provide longer spans when using concrete.

Oregon

Solution using new casting bed: The span length of 183 ft, 3 in. for a recent bridge was the longest ever used in Oregon bridge construction. Each beam has a top flange width of 5 ft, a bottom flange width of 2 ft, 6 in. and contains 56 0.6-in.-diameter strands. Beam spacing was at 6 ft, 10 in.

Fortunately, the precast manufacturer, Morse Bros. Inc. of Harrisburg, Oregon, had just installed a new casting bed that could fabricate bulb-tee beams up to 96 in. deep and 190 ft long very similar to what was needed for the Oregon project. The final design required seven precast, prestressed concrete bulb-tee beams, each with a 90 in. depth. The contractor's past experience with casting beds helped with the rapid construction.

Oregon Department of Transportation (ODOT) Deck Mix Design Research, September 2010

Mix design provides significantly increased durability and abrasion resistance,
Pretensioned transverse versus mild steel reinforcement,
Eliminates tension cracking,
Improves the durability of the concrete,
Panels are also more resistant to damage from lifting and transport,
Very high chloride environments may need additional protection,
Post-tensioned longitudinal versus mild steel,
Longitudinal post-tensioning provides compressive stress over narrow transverse joints, which results in good durability by preventing tension cracking under live load.
The use of mild steel and nonshrink grout or UHPC concrete in wider joints eliminates the need for post-tensioning work.
With UHPC, this type of deck joint also results in good durability due to the tensile strength, bond strength, and high compressive strength of the UHPC.
With UHPC, the closure pour area will also more closely match the abrasion resistance of the ODOT deck panels.

Oregon Department of Transportation deck mix design research: Silica fume content strongly influenced compressive strength, the wear rate, and chloride ion penetration resistance, which increased from 4% to 7%. Fly ash versus slag also strongly influenced the 30-min wear rate, chloride ion penetration resistance, and compressive strength. A curing regime was also found to be significant for wear rate and compressive strength (steam cure and curing compound). The recommended mix design and curing regime has 20% of the wear and 35% of the chloride ion permeability.

Composite action options: Composite action is achieved by forming oval-shaped voids in the panels over the girders and filling the voids with concrete to encase rebar or studs. The studs or vertical rebar provide horizontal shear transfer from the girder to the panel. Longitudinal joints could be used if bridge is too wide for a single panel. This would result in more closure concrete in the joints, and more panels because the panels would not be continuous over a girder.

8.8.12.3 Concrete panel mix design

HPC 8000 psi (recommended in the ODOT abrasion-resistance research report).
PCI state-of-the-art report also recommends 8000 psi in severe environmental conditions.
Plant curing results in less cracking because shortening is not restricted by constraint from the girder connections.
ODOT mix: 0.30 w/c ratio, 7% silica fume, steam cure, curing compound.

8.8.12.4 Certified plant fabrication versus contractor on-site fabrication

Certified plant fabricators has both cost and quality advantages.
Plant fabricators have forming, prestressing, testing, and transport equipment available in the plant.
Past experience in producing precast products results in improved quality, efficiency, and sequencing flexibility with fieldwork.

8.8.12.5 Concrete and grout joint material

UHPC concrete in the transverse and longitudinal joints reduces the width of the joints by increasing the bond strength and reducing the required splice lengths.
Durability is improved.
UHPC is used in the connection voids since it is more efficient to use UHPC
Thin grouted joints are used in post-tensioned deck panel systems, which are less costly, but the savings need to be weighed against the cost and time required for post-tensioning.

8.8.12.6 Panel dimensions, configuration

Panel thickness is controlled by live load design, and the allowance for wear and possible grinding for smoothness.
A thickness of 8½″ was selected to provide the required strength and ½″ of sacrificial concrete at the top of the panel.
The width and the length of the panel are controlled by transport restrictions from a fabricator.
Oregon limits: 55 kips and 10 foot width. These limits resulted in a maximum length of 50 feet.
On the first project in Oregon, the average bid price of the low three bidders for the precast deck panels was $50 per square foot. UHPC was $42 per square foot (US 30 over Burnt River, 2011). The second low bid on Burnt River was $45 per square foot for panels and $27 per square foot for UHPC.

8.8.13 US 97 over Union Pacific Railroad tracks, Chemult, Oregon

A single-span design of nearly 182 ft on a 60-degree skew replaced a bridge on a major Oregon highway over railroad tracks in less than 7 months. Faced with twin challenges of a long span and short construction time to design and build a replacement bridge to carry a busy highway over an active railroad in Chemult, Oregon, project engineers turned to precast, prestressed concrete girders to create the best solution.

One of 11 bridges in a design-build project for the Oregon Department of Transportation, the structure features a single-span precast, prestressed concrete design. That approach avoided activity near the main line of the Union Pacific Railroad and sped up construction as well (according to Terry Stones, lead engineer from David Evans and Associates Inc. of Salem, Oregon, the design build engineering firm).

The precast design eliminated any need for intermediate bents, allowing the contractor, Hamilton Construction Company of Springfield, Oregon, to stay clear of the railroad track, which carries both freight and passenger trains and remained operational during construction. The old three-span bridge was considered structurally deficient and too narrow, with practically no shoulders. The final design called for seven precast, prestressed concrete bulb-tee beams, each with a 90 in. depth and a length of 183 ft, 3 in., the longest ever used in Oregon bridge construction. Each beam has a top flange width of 5 ft, a bottom flange width of 2 ft 6 in. and contains 56 0.6-in.-diameter strands. Beam spacing was at 6 ft 10 in.

The beams were cast with concrete having a specified compressive strength of 9000 psi at 28 days and 7000 psi at prestress transfer.

SPMT use: The beams, each weighing 93 tons and two-thirds the length of a football field, were delivered one at a time on a transporter with 13 axles with the rear units steered remotely by an operator in the truck. The spans were transported from the Morse facility in Harrisburg, near Eugene in the western part of the state, along the 125-mile delivery route over the Cascade Mountains to the bridge site on U.S. 97 midway between Bend and Klamath Falls near the center of the state.

8.8.13.1 Oregon DOT research

Considerations for Durability and Cost of Precast Deck Panels, (reference Bruce Johnson, of Oregon DOT, November 2011). For details and guidance please contact the state DOT.

Durability considerations,
Pretensioned transverse versus mild steel reinforcement,
Post-tensioned longitudinal versus mild steel,
Deck joint configurations,
Overlay versus additional cover and grinding,
Composite action options,
Continuous longitudinal joints versus pockets,
Concrete panel mix design,
Abrasion resistance, strength, permeability, and curing.

Pennsylvania

For Pennsylvania, a Northeast Extreme Tee Beam (NEXT) beam standard is available, with a double tee beam where the top flange provides the form for casting the deck. (Source: FHWA PA Division Bridge Engineer, derek.constable@dot.gov, *Prefabricated Bridges*, AASHTO and QuikBeam AASHTO Version 5.02).

Example is:

Norfolk Southern Railroad Bridge over I-76

Tennessee

The example is:
Route 57 over Wolf River

Texas

8.8.13.2 Use of half-depth and full-depth deck panels

Videos highlighting the use of partial depth deck panels, including SH 249/Louetta Road Overpass and the Pierce Elevated Bridge, are available at https://www.fhwa.dot.gov/bridge/prefab/videos.cfm.

Table 8.9 outlines some of the benefits of using FDDP.

Other reports on the use of FDDP include the following:

State-of-the-Art Report on Full-depth Precast Concrete Bridge Deck Panels, PCI Report No. SOA -01-1911 (2011).
Full Depth Deck Panels Guidelines for Accelerated Bridge Deck Replacement or Construction, PCI Report No. PCINER-11-FDDP, 2nd edition (2011).
PCI Journal Papers (30+papers, 1970s–2011).

Table 8.9 Benefits of Using FDDP

Item	Effect of FDDP
Construction speed	High
Shrinkage cracking	Eliminated
Hydration temperature cracking	Eliminated
Formwork	Eliminated
Maintenance cost	Low
Structural integrity	Maintained
Adaptability for continuous span bridges	Yes
Initial cost	Relatively high
Service life	Long

Citation of many of these papers is provided in the SOA report. Additional available resources include:

Publication No. FHWA-HOP-11-006
NCHRP reports (http://www.trb.org/NCHRP/NCHRPProjects.aspx)
Tadros M. et al., 1998. Rapid Replacement of Bridge Decks. NCHRP 12-41, Report # 407.
Badie S., Tadros M., 2008. Full-Depth, Precast-Concrete Bridge Deck Panel Systems. NCHRP 12-65, Report # 584.
French C. et al., 2011. Evaluation of CIP Reinforced Joints for Full-Depth Precast Concrete Bridge Decks. NCHRP 10-71, Web only document 173.

Other Texas projects include the following:

Dallas/Fort Worth International Airport People Mover
Examples are:
I-45/Pierce Elevated
Lavaca Bay Causeway
NASA Road 1 over I-45
SH 36 over Lake Belton
SH 361 over Redfish Bay and Morris–Cummings Cut
SH 66 over Lake Ray Hubbard
US 290 Ramp E-3
US 59 under Dunlavy, Hazard, Mandel and Woodhead Streets
Wesley Street Bridge.

Live Oak Creek Bridge, Texas
Erection of deck panels over shear studs on beams in 2007,
86 full-depth, full-width deck panels, totaling 22,400 sq ft,
Panels designed per NCHRP 12-65, "Full-Depth, Precast-Concrete Deck Panel Systems": no post-tensioning or overlay.
Utah
See below.
For details and guidance please contact the state DOT.

8.8.13.3 UDOT's ABC approach

The Utah Department of Transportation (UDOT) is one of the forerunners in embracing ABC techniques. In Utah, ABC is considered for inclusion on all projects involving structures. UDOT started using ABC elements in 1997 and has now employed ABC methods and elements in more than 200 settings. UDOT strives to accelerate project delivery by minimizing impacts to the public and encouraging innovation.

By accelerating project delivery, UDOT has gained trust from political representatives and praise from the community. For Utah, ABC is a means to meet the goal of providing the best value to both roadway users and the general public.

8.8.13.4 Case studies of ABC techniques in Utah

The Utah DOT has details that are based on connections that are used in buildings that are acceptable for high seismic zones in the ACI Building Code. Caltrans is currently completing more testing on these connections.

The Utah Department of Transportation is using an innovative method in bridge building to replace an I-84 overpass bridge near Echo Junction.

According to Tim Rose, UDOT Region 2 deputy director, the real advantage here is ease of construction and quickness of construction. The geosynthetic reinforcement, soil-integrated bridge system uses tons of soil and will save taxpayers time and money. UDOT is the first in the country to use the reinforced soil technique at the abutment of an interstate bridge.

Typically, massive steel pylons driven into ground surrounded by concrete form the bridge abutment. At Echo Junction, crews are building the footing for a 58-foot-wide span of multiple layers of compressed dirt separated by tarp-like fabric.

The abutment can be done in three steps: first, laying the block; second, placing and compacting the backfill; and third, laying a sheet of the geosynthetic reinforcement. The process is repeated to the specified height of the bridge abutment. The technique will save about $200,000 on the project's $3.2 million price tag because concrete is more expensive and takes 28 days to cure.

Dozens of geosynthetic reinforcement, non-interstate bridges have been built for 30–60% less than traditional bridges because fewer materials are used, construction is faster, and less equipment is needed, according to FHWA.

The real advantage here is ease of construction and quickness of construction. There is also no staging of equipment or material delivery to get in the way of traffic, construction can be done in any type of weather, and only a small crew is needed. Only one temporary closure on the interstate will take place when builders slide the bridge deck into place when the abutment is finished. The project also requires less maintenance because it is not affected by weather changes, has fewer parts, and has a jointless bridge.

Some key projects in Utah include:

4500 South Bridge over I-215E (2007): prefabricated superstructure driven into position with SPMTs. I-215 was closed over a weekend; 4500 South closed only 10 days. For details and guidance please contact the state DOT.

I-80 State Street to 1300 East, Multiple Structures (2008)

I-80W over Highland Drive

I-80W over 900 East St.

I-80W over 700 East St.
I-80W over 600 East St.
I-80W over 500 East St.
I-80W over 300 East St.
I-80W 600 East Ramp Bridge.

For precast deck panel projects in Utah, the bid cost for the panels started at about $70 per square foot 4 years ago; now, the average is about $40 per square foot (estimated bid cost from design-build and CMGC projects).

8.8.13.5 Case study of SPMTs by UDOT

On I-80 at Mountain Dell and Lambs Canyon near Salt Lake City, UDOT replaced four bridge superstructures in 37 h over two weekends. The bridges were built adjacent to the existing structures in the median of I-80 over a 4-month period. They were then transported using SPMTs to their final location. This project was the first in the country to demolish, move, and replace two bridge superstructures in 16 h, and was the first total closure (except for emergency access) of a major interstate trucking route for bridge replacement.

UDOT was able to mitigate construction impacts and meet the needs of the local community with regard to mobility and safety by:

Implementing public outreach strategies
Coordinating with local media for construction updates
Meeting with the local community early and often throughout the construction process
Posting information in common areas that travelers frequent

Using off-site construction and SPMTs, UDOT estimated that motorist delay was decreased by 180,000 h, equating to a savings of over $2.5 million. Table 8.10 outlines the Lambs Canyon project.

Examples of bridges set with SPMTs in Utah are:

- *3300 South over I-215* – Built in 2008
  - Sand LWC used for deck
  - Less deck cracking than bridges with NWC decks
- Three bridges moved in 2011
  - Steel girder bridges with sand LWC decks

Table 8.10 Use of SPMTs in Utah Bridge Construction at Lambs Canyon

Location	Pros	Construction Method	Remarks
On I-80 at Mountain Dell and Lambs Canyon near Salt Lake City, UDOT. UDOT was able to mitigate construction impacts and meet the needs of the local community with regard to mobility and safety.	Replaced four bridge superstructures in 37 h over two weekends. This project demolished, moved, and replaced two bridge superstructures in 16 h for bridge replacement.	The bridges were built adjacent to the existing structures in the median of I-80 over a four month period. They were then transported using SPMTs to their final location.	Using off-site construction and SPMTs, UDOT estimated that motorist delay was decreased by 180,000 h, equating to a savings of over $2.5 million.

- 200 *South over I-15 – 2* spans at 3.1 million lbs
- *Sam White Lane over I-15 – 2* spans at 3.8 million lbs
- *I-15 Southbound over Provo Center Street*- Two moves of 1.5 and 1.4 million lbs

UDOT Bridges Using Precast Concrete Elements[13]. For details and guidance please contact the state DOT.

I-80, Wanship Bridge: precast concrete elements
I-215 over 3670 South: modular construction
800 North over I-15: precast deck panels
Riverdale Road over I-84: Lego Bridge
4500 South over I-215: SPMT
I-80; Lambs Canyon Bridge: SPMT, design-build
I-80; State Street to 1300 East: SPMT
I-70; Eagle Canyon Bridge: precast deck panels
SR-66 over Weber River: slide-in, design-bid-build
I-80, two bridges near Echo Junction: slide-in, design-build
I-80 over 2300 East: slide-in, design-build
South Layton Interchange: launch, design-build
U.S. 89 over I-15: SPMT, design-build
I-15 CORE Proctor Lane over I-15: SPMT, design-build
I-15 CORE 200 South over I-15: SPMT, design-build
I-15 CORE Sam White Lane over I-15: SPMT, design-build

Additional slide-in examples:

I-80 over Weber River, spring 2011
I-80 at Atkinson, summer 2011
I-80 at Summit Park, summer 2011

8.8.13.6 Prefabricated bridge elements

SR-193 over UPRR and UTA; spring 2012

Vermont

Use of Integral Abutments for ABC Bridges in Vermont: Source presentation by Wayne B. Symonds and Bill Lammer, Accelerated Bridge Program, Vermont Agency of Transportation.

Description: In integral abutment bridges, continuity between the superstructure and substructure is created by making the deck and substructure monolithic. A jointless integral bridge has a continuous deck with no expansion joints over the superstructure, piers, and abutments.

Leaking deck joints have been a major cause of bridge deterioration and reduced service life, especially where roadway drainage carrying deicing chemicals can spill onto bridge elements below. One solution is to eliminate all expansion joints and use jointless bridges. For ABC applications, this approach could lead to a delay in construction if appropriate details are not used. Vermont has developed details and design approaches that are being used for integral abutments in Vermont's ABC bridges.

[13] From presentation "Accelerated Bridge Construction: Research, Design, and Practice," Carmen Swanwick, UDOT Chief Structural Engineer, University of Buffalo, April 2011.

Richville Road Bridge was also completed using ABC.

Virginia

The Virginia Department of Transportation (VDOT) planned 11 bridge superstructure replacements on the I-95 corridor. These were advertised in spring 2010 with an estimated completion in September 2014. Most construction is scheduled overnight and the plan was to have all lanes open during weekdays.

An example of a total superstructure system with preconstructed composite units (*Virginia's I-95/ James River Bridge*) can be viewed at http://www.fhwa.dot.gov/download/preconst.wmv.

8.8.13.7 Other new technology case studies

Fiber-reinforced polymer matrix composites (PMCs) are very effective for concrete rehabilitation and deck slab construction. VDOT used them successfully for superstructure replacement of *Tom's Creek Bridge*.

For injecting hairline and wide cracks in concrete, epoxy injection resins are being effectively used. For waterproofing joints and cracks, sealing leaks, and conducting underwater repairs to concrete, polyurethane injection resins are being effectively used.

ABC projects in Virginia include:

Dead Run and Turkey Run Bridges
Route 7 over Route 50
George P. Coleman Bridge
I-95/James River Bridge

An example of the use of SPMTs in Virginia is given in Table 8.11.

Washington

Skagit River Bridge emergency slide - replacement for collapsed Washington span (Moves into Place, September 17, 2013) by Bijan Khaleghi, Bridge and Structures Office, Washington State Department of Transportation).

Description: One span of the *Skagit River Bridge on Interstate 5* in Burlington, Washington was struck by an over height vehicle and a portion of the truss bridge collapsed into the river. The WSDOT recovery plan to reconstruct the Skagit River Bridge included three contracts:

Install a temporary bridge to reconnect I-5,
Replace the permanent span using ABC techniques,
Rehabilitate the remaining trusses to the current functionality standards.

This presentation focused on the second contract, the ABC replacement. The replacement span is composed of deck bulb tee girders made of lightweight aggregate. It was built adjacent to the temporary

Table 8.11 Use of SPMTs in Virginia

Location	Pros	Construction Method	Remarks
Coleman Bridge along Highway 17	Replacement was completed in a period of 9 days, 3 days earlier than was anticipated.	The truss and swing spans were constructed off-site at a nearby manufacturing facility then floated to the construction site on barges.	Originally, the contractor estimated the entire process to take 12 days.

bridge. On Saturday night, September 14, 2013, the roadway was closed to traffic for a period of 19 h while the temporary span was laterally slid out and the permanent span was laterally slid into its final position.

Time was of the essence: it was even built into the bidding process as a key factor in the $8.5-million project to replace the collapsed I-5 Bridge over the Skagit River in northwest Washington State. On Sunday, September 15, crews from winning contractor Max J. Kuney Co., Spokane, made good on the firm's bidding commitment by sliding into place the state's first lightweight concrete bridge, with a 19-h closure of the four-lane interstate connecting Seattle to Vancouver, BC.

According to PB Northwest regional manager, with time being such a driving factor, settling on a lightweight concrete design (the girders were constructed by Concrete Technology Co., Tacoma) emerged as the clear favorite.

The Skagit's fluctuating water levels presented too many risks to floating the bridge into place. High-strength lightweight concrete, an 8500-psi mix, was needed to keep the entire 165-ft girder span under the state DOT's 950-ton limit. Each of the eight girders were lifted offshore, handed to a barge crane in midair, and then placed into the integrated girder structure—also a first-time approach for the state. Accounting for space issues related to the existing bridge and roadway, designers configured the bridge-deck jack-and-slide sequence so that lifting occurred 20 ft from the ends.

Use of laser beam for alignment: The bridge was shifted about one inch to the south, based on that laser beam knifing through the air. The four hydraulic jacks, each with two pistons, then began to slide in the permanent span at close to sunrise on September 15. The process to get the bridge poised over its final resting place took about 45 min, which is a great achievement of applying ABC.

Formal probe needed into 520 bridge dangers (by Tracy Vedder, KOMO News Problem Solvers. Published: Feb 17, 2013).

When the Problem Solvers toured the Aberdeen pontoon construction site, there were already significant signs of concrete cracks in the second group of pontoons.

At $4.1 billion, construction of Seattle's *520 Floating Bridge* is the most expensive taxpayer-funded project in Washington state history. Construction on the bridge is expected to last another two years. It's an issue that requires the safety of every single driver, who will cross the largest floating bridge in the world.

The Washington DOT continues to complete significant research on seismic connections. Washington ABC project include:

I-5/South 38th Street Interchange
Lewis and Clark Bridge
Northeast 8th Street Bridge

The use of SPMTs in Washington is outlined in Table 8.12.

Table 8.12 Use of SPMTs in Washington State

Location	Pros	Construction Method	Remarks
Replacement of the deck of the Lewis and Clark Bridge across the Columbia River	Deck replacement was completed in a period of 4 months.	More than 3900 feet of concrete deck paneling was installed by using SPMTs to bring in prefabricated elements.	Completion time reduced from 4 years to 4 months of nighttime closures and three weekend closures

West Virginia

Exodermic deck panels were placed on the Robert C. Beach Memorial Bridge near Morgantown, WV. Other bridges using ABC in West Virginia are:

Howell's Mill Bridge
Market Street Bridge

Wisconsin

The example is:
Mississippi River Bridge

8.9 Selected examples of successful application of precast construction

In addition to the above examples, various forms of ABC have been successfully used by a number of states—and the list is growing. Both partial and full ABC methods were used including prefabrication, use of SPMT, and the lateral slide-in method. For details and guidance please contact the state DOT.

- *Mathews Bridge, Jacksonville, FL*
- *Royal Park Bridge, Palm Beach, FL*
- *17th Street Bascule Bridge, Ft Lauderdale, FL*
- *Soldiers Field Bridges, Chicago, IL*
- *US 27 Bridge over Pitman Creek, KY*
- *Eads Bridge over the Mississippi, St Louis, MO*
- *Veterans Home Bridge, Minneapolis, MN*
- *I-280 Stickel Bridge, Newark, NJ*
- *Rt. 61 over Mohawk River, St. Johnsville, NY*
- *Tappan Zee Bridge, Tarrytown, NY*
- *Kingston–Rhinecliff Bridge, NY*
- *Troy-Menands Bridge over Hudson River*, NY
- *Goat Island Bridge at Niagara Falls, NY*
- *South Grand Island Bridges, Grand Island, NY*
- *Ben Sawyer Swing Bridge, Charleston, SC*
- *Robert C. Beach Memorial Bridge, Morgantown, WV*

8.9.1 Selected examples of bridges with precast panels

The following states are using precast panels that are well connected to the supporting girders. For details and guidance please contact the state DOT:

Bloomington Bridge, Indiana State Highway Commission
Bill Emerson Memorial Bridge, Missouri DOT
Skyline Bridge (NUDECK System), Omaha, Nebraska

Live Oak Bridge, Texas
Woodrow Wilson Bridge, Washington D.C.
I-39/90 Bridge over Door Creek, McFarland, Wisconsin

8.9.2 Panel-to-girder connections

A positive connection between the precast panels and the supporting girders is required to create a composite deck-girder system. A shear key must be designed to eliminate relative vertical movement between adjacent panels and transfer live load from one panel to the next.

When subjected to live loads, a vertical shear force tries to break the bond between the panel and the grout filling of the joint and a bending moment puts the top half of the joint in compression and the bottom half of the joint in tension.

8.10 Use of lightweight concrete for girders (a win–win situation)

LWC Project for CONRAC Automated People Mover (Atlanta, GA):

This example of the use of LWC carries tracks for automated people mover (APM) between a terminal and a new rental car facility.

Pretensioned tub girders were erected in 2007. They are very heavy girders with maximum spans of 143 ft.
5 ft deep precast pretensioned box girder. 12–16 ft wide slab cast on tub before detensioning.
Case Studies of LWA

The premium depends on the cost of LWA, the cost of the NWA being replaced, and aggregate shipping cost: For details and guidance please contact the state DOT.

Okracoke Island, NC
Lake Ray Hubbard, TX
Edison Bridges, FL
Woodrow Wilson Bridge, VA/DC/MD
NEXT 36 F precast beams unit weights
LWC from 1162 to 1336 lbs/ft
LWC from 1504 to 1851 lbs/ft
NEXT 36 D beams
16% reduction from NWC in weight for same width sections
12 ft wide LWC is lighter than 10 ft wide NWC

Table 8.13 includes some additional details on LWC precast decks.
Utah has set several bridges with SPMTs and LWC:

3300 South over I-215 (2008): Sand LWC was used for the deck; less deck cracking than bridges with NWC decks; three bridges being moved in 2011; steel girder bridges with sand LWC decks
200 South over I-15: two spans at 3.1 million lbs

Table 8.13 Details of LWC Precast Decks

Name of Bridge	Style	Length of Girder	Details
I-95 in Richmond, VA	Prefabricated full-span units.	Steel girders and sand LWC deck.	Specified concrete compressive strength = 10,000 psi.
Coleman Bridge, Yorktown, VA	26 ft wide with 2 lanes to 74 ft wide with 4 lanes and shoulders. Piers were reused and caps only had to be widened.	Sand LWC deck was used based on cost savings.	Bridge replaced in 1996. Spans floated into place during a 9-day closure. Reduced the steel required in new trusses.
Lewis & Clark Bridge, OR/WA	Deck replacement on existing truss.	Sand LWC precast deck units with steel floor beams.	Max. deck unit weight = 92 t. sand LWC saved about 14 t.

Sam White Lane over I-15: two spans at 3.8 million lbs
I-15 Southbound over Provo Center Street: two moves of 1.5 and 1.4 million lbs.

8.10.1 Design using LWC

US bridge design specifications address LWC,
Modifiers for tensile strength, shear, etc.
Special shear resistance factor, f
Reduced modulus of elasticity, Ec
Increases elastic shortening loss and cambers,
Time-dependent effects: Creep (CR), Shrinkage (SH), and losses,
For HS LWC, these quantities are very similar to NWC; US bridge design specs do not address specified density concrete (SDC).

In a complex structural system, such as a bridge made of laminated fiber-reinforced plastic materials, several sources of structural degradation may occur during the life span of a bridge. For example, damage due to delamination, cracks, and loss of bond between components, and change in material properties may often take place in various parts of the structure and cannot be detected by visual inspection. Thus, a finite element model validated by field testing can be used to foresee damage scenarios.

The correlation of dynamic testing on the bridge with dynamic analyses of the bridge using finite elements was used to give an indication of the degree and possible location of the damage within the bridge.

Smith and Bright from University of Bristol in UK investigated the use of fiber-reinforced composites for upgrading orthotropic bridge decks. Poor durability of paving materials and fatigue failure of welds has contributed to high costs of repair including road user delay costs due to traffic disruption.

In the ASCE Conference Proceedings, it is proposed by the authors using a layered surfacing system by combining lightweight asphalt, conventional asphalt, and a layer of glass fiber mesh embedded just beneath the chip-sealed surface. Fatigue tests indicate that glass fiber reinforcement increases the durability by a very high factor of at least 10.

8.11 Deck overlay options

8.11.1 Comparative study of useful life of an overlay

The overlay thickness is 1.25–2.5 inches with a corresponding scarification depth of 0.25–1 inch.
Latex modified concrete (LMC), 19 years (maximum life),
Low slump dense concrete, 18 years,
Asphalt with membrane, 17 years,
Fly ash concrete, 17 years,
Silica fume concrete, 16 years,
Standard concrete mix, 14 years,
Asphalt without membrane, 12 years,
Plasticized dense concrete, 11 years,
Thin bonded epoxy, 10 years (maximum life),

The wearing and protection systems include:

Typical CIP deck,
Bonded concrete overlay,
Waterproof membrane overlaid with asphalt,
Epoxy overlay,
Monolithic concrete overlay,
Low permeability panel with no overlay.

The least expensive option is option for low permeability panel. It is advisable to provide an extra "wearing surface" thickness and to use standard roadway profiling grinders to smooth out the surface. Also, provide extra protection of the reinforcement. Discoloration due at grouted joints and pockets may be objectionable to some owners.

Use of high early strength LMC will open the deck to traffic within 3 h of curing. Silica fume, pozzolans, fly ash, and slag may be used to reduce concrete permeability and heat of hydration. Fly ash and cenospheres are preferred for HPC in bridge decks, piers, and footings. Byproducts of coal fuel such as fly ash, flue gas de-sulfurization materials, and boiler slag provide extraordinary sustainable advantages.

8.12 Use of ABC outside USA

It appears that modified ABC methods were in use for a long time. Their successful contributions were partly responsible for the introduction and current widescale use in the United States.

Mosquito Creek Bridge, Vancouver

Built in North Vancouver in 1952, this has the distinction of being the first prestressed concrete bridge built in Canada. The bridge used precast pretensioned slab girders. The bridge is still in service, having been widened on both sides over the years.

Construction management contracts in Canada

These should be used, initially on a trial basis, to team all trades including the precast contractors with forward-looking engineers to find new ways to accelerate the construction without sacrificing the design life of structures. The quality control in certified precast plants can be used to everyone's advantage. Scope and contracts should be performance related and clearly outline all functional requirements of a structure.

Standard tender methods: Conventional tender methods are not conducive to innovative solutions. In many cases, precast manufacturers are reluctant to share their expertise and ideas with others prior to bidding.

Certification: One should require that precast concrete elements manufactured in precast plants be certified in accordance with Canadian Standards Association (CSA) Standard A23.4 or provincial standards prior to tenders being issued. This will prevent the possibility of poor or unacceptable results due to unqualified fabricators. Canadian Precast/Prestressed Concrete Institute (CPCI) members have access to the latest bridge design and technology throughout North America. Because voluntary alternates are not considered unless the contractor is the low bidder, new ideas and value engineering may not be worth the risk or effort. The precaster generally has no access to the designer during the tender period to answer technical questions.

Need for innovation: Standard bridge details should be revised or relaxed if they become a barrier to innovation and new ways of construction.

Use of large precast components: To speed up the construction, precast manufacturers need to be consulted regarding constructability, shippable sizes and weights, and erection equipment required to install the large pieces at the job site.

The paper by John R. Fowler on ABC (Canadian Precast/Prestressed Concrete Institute, Bridges for the twenty-first century session of the 2006 Annual Conference of the Transportation Association of Canada, Charlottetown, Prince Edward Island) includes a background on precast concrete bridge construction, including an overview of fabrication, transportation, and erection, and a look at sustainability issues.

8.12.1 Girder with deck production method

Pre-Con's Woodstock, Ontario precast plant can precast girders with the deck using a reusable wood form. Units are prestressed and conventionally reinforced (similar to typical CPCI girder units), but with a monolithically cast deck slab above. The girder deck is formed with a parabolic shape in elevation, and is cross-slope in section to account for girder camber and cross-fall for drainage.

High-performance concrete is required for production of these units, together with similar curing and temperature restrictions/monitoring procedures used for the abutment and wingwall units. A 7-day wet cure with burlap is maintained, including a layer of plastic vapor barrier. Temporary steel stands are required for stability after the girder/deck units are removed from the wood form. This system allows for a high degree of design flexibility.

Industry standard tolerances: These are given in CSA Standard A23.4.

Design details shown on drawings need to include fabrication notes about acceptable tolerances that can accommodate the length and out-of-square tolerances in large precast members. New sections, if developed, need standard tolerances because their camber behavior is only theoretical. This approach will prevent any lack of fit on the field.

Baldorioty Bridges, San Juan, Puerto Rico

Create expressway,
Separate at-grade intersections,
Two intersections, four bridges,
100,000 average daily traffic.

The challenge was to:

Design and build four urban grade separations.
Two bridges – 900 ft long × 30′- 4″ wide,
Two bridges – 700 ft long × 30′- 4″ wide,
Maintain continuous traffic,
Complete each bridge in less than 72 h

8.12.2 Report

700-ft bridge (January 1992): open to traffic in 36 h,
900-ft bridge (March 1992): open to traffic in 21 h,
900-ft bridge (May 1992): open to traffic in 23 h (rain),
700-ft bridge (July 1992): open to traffic in 22 h,
This project was ahead of its time; there has been little interest in it since 1992.

U.K.'s Humber Suspension Bridge Bearing Replacement under Traffic.

Traffic on one of the longest suspension bridges (with a 1410-m long main span), Humber Bridge located in eastern England, will be allowed during a major structural intervention.[14]

The bearings that control the vertical and lateral position of the deck box girder at the towers are to be replaced under traffic. A new system of pendels and bearings, combined with wind shoes, will replace the A-frame rocker bearings at the ends of the deck box of the span.

8.13 Publications

Selected publications in addition to those listed by the stakeholders are listed here.

8.13.1 FHWA publications

Conditions and Performance Report 2010
National Bridge Inventory 2012
Bridge Preservation Guide 2011
Prefabricated Bridge Elements and Systems Cost Study: Accelerated Bridge Construction Success Stories
Connection Details for Prefabricated Bridge Elements and Systems
The Bridges That Good Planning and Execution Rebuilt

[14] From a report by John Collins, Richard Hornby, Peter Hill, and John Cooper in *Bridge Design and Construction*, December 2013. http://www.bridgeweb.com/MemberPages/article.aspx?id=3181&typeid=3.

Construction Procedures for Rapid Replacement of Bridge Decks
Development of a Precast Bent Cap System
Comprehensive Bridge Design Manual:

1. Prefabricated Bridge Elements and Systems, Federal Highway Administration: www.fhwa.dot.gov/bridge/prefab
2. Precast/Prestressed Concrete Institute (PCI), Chicago, IL: www.pci.org
3. Canadian Precast/Prestressed Concrete Institute (CPCI), Ottawa, ON: www.cpci.ca

National Bridge Investment Analysis Methodology.
Transportation for America – The Fix we are in for; the state of our Nation's Busiest Bridges.

For additional information on the above numerous topics, please see the bibliography at the end of book in Appendix 1.

8.14 Conclusions

Historically, the prefabricated elements used most often to reduce on–site construction time are superstructure deck beams, rather than substructure components, which may take more time to construct. Occasionally, owners have used prefabricated deck panels to replace decks on high traffic corridors.

Adjacent concrete box beams, plank beams, tee beams, and modular sections of steel beams (with pre–topped deck) have been the most common types for these projects. Today, there is a focus on researching and developing new and improved standardized beam sections, including proprietary NEXT beams, Inverset, Wolf girders, decked double tees, deck bulb tees, etc.

It is seen that considerable progress has been made in the United States toward implementing modern prefabrication techniques for the superstructures. It is a revolutionary approach compared to the bridges built 50 years ago. Case studies of successful projects by many states have been presented. Other projects are in progress.

The reasons for success are as follows: The contracting industry is not afraid of taking the lead in the management of small- and medium-sized projects and not afraid of taking risks and meeting challenges. There have been developments in special transportation methods for long and wide loads using SPMT. In addition, heavy capacity cranes for lifting and erection are now available. Organizations such as FHWA (with their Every Day Counts Program and ABC Handbook), TRB, and AASHTO have been a motivating factor. The design-build contract system helps to adopt prefabrication. According to SHRP2 Project R04, ABC is the clear choice. Lifecycle costs are significantly reduced.

A list of recent innovations has been presented for selection and for further action and implementation, such as:

Connection details for PBES,
NEXT beam, spliced girders, bulb tee, and Wolf girders,
Use of SPMT,
Structural placement methods,
Launching, sliding, and heavy lifting.

On-site construction under open sky is far more difficult than factory manufacture. New bridges have become more complex since the bridge practice of a century ago, when CIP construction was the only option. On the contrary, a medium-size factory would have the necessary facilities for indoor fabrication. Other advantages of the latter are as follows:

Extreme events and climatic hazards: Most of North America has a cold climate for four months in the year and southern states have high temperatures in summer, which slows down the speed of outdoor work. In large air-conditioned factories, the temperature change does not affect the schedule for construction. Also, the activities on the critical path are not affected.

Minimum labor availability (usually difficult at remote locations),
Storage of construction materials avoided,
Limited use of formwork.
Accelerated schedule,
Minimum exposure to rain and sunlight during construction,
Minimum mobilization,
Quality control is easier,
Promotion of modular construction,
Hidden benefits such as winding up are easier.

Associated costs: There will, however, be extra costs for the use of SPMT and heavy-lift cranes, which are offset by early completion and use of the bridge.

Overall, the use of prefabrication leads to higher quality, reduction in lifecycle costs, and longer life for the bridge.

Encouraging the Use of Approved Innovations: Some innovations and procedures that should be investigated include the following:

Introduction of precast concrete NEXT Beam systems of varying depths.
Improving sight distance and super elevation standards in curved deck bridges.
The causes of structural deficiencies, functional obsoleteness, and causes of bridge failures need to be investigated.
Priorities in planning of structural system and rapid construction need to be introduced.
Introduction of precast concrete Wolf girders.
Use of new concrete technology: Introducing LWC, FRP concrete/CFRP concrete, UHPC for superstructure, and HPS 100W.

Overload prevention and review of live loads: In the light of latest advancements in the truck manufacturing industry, it has become important to assess the magnitude of axle loads on highway bridges and also update the military live loads on military routes due to new tanks. ASME design codes need to be reviewed.

Unknown foundations: Using modern technology, the process of assessing the sizes and depths of foundations can be updated.

Introducing blast loads in design: For the security of important bridges, optional analysis for blast loads needs to be introduced. CUNY and University of Missouri–Columbia (UMC) have been carrying out research and experimental studies and have developed a type of impact load design (similar to a partial seismic design).

Maintenance of bridges on waterways: Due to increased corrosion of steel bridges due to daily evaporation, the life of bridges is adversely affected. During floods, countermeasures should not get displaced. Sediment deposits in some rivers require dredging and clearing stones under the bridges before it is too late. Hence, frequent inspections may be required.

Integral pier bridges: Besides integral abutment bridges, use of semi-integral abutment bridges and integral pier bridges is recommended.

Use of high-friction surface: Introducing the British-invented surface treatment on asphalt pavements to create high-friction between vehicle tires and the bridge deck surface will help in braking and prevent skidding. Binders such as thermo-setting epoxies are used. Maryland has successfully introduced plates on their intersections. The cost of accidents in terms of fatalities can be considerable.

Structural health monitoring (SHM): The new advanced technology uses lasers and remote sensors for bridge inspections. Bridge inspectors need to be trained in the use of computer software of remote sensors, radar technology, and Lidar techniques to obtain quick information regarding the fatigue-based stress-strain history. This approach will make bridges safer and reduce lifecycle costs. For bridge details and guidance on implementing successful ABC projects, please contact the state DOT.

Note: Appendices 1 to 11 are provided at the end of the book for ready reference.

CHAPTER

Prefabrication of the Substructure and Construction Issues

9

9.1 Rapid substructure construction a greater challenge than that of rapid superstructure

In Chapter 8, superstructure prefabrication techniques and modular construction methods, such as using special girders (Inverset, NEXT beams, and Wolf girders), the need for precast connections, and case studies of successful deck components in many states were discussed. This chapter deals with rapid construction applications for the equally important bridge substructure and foundations. A list of successful substructure projects that were completed in recent years in different states was given in Chapter 5 (Tables 5.4, 5.6, and 5.7). Case studies and detailed discussions on substructure construction are given in Sections 9.7 and 9.8.

In this chapter, the substructure, totally prefabricated bridges, and emergency replacement of the existing substructure (when the superstructure is lifted off the top of bearings and reused) using precast units are addressed. The methods of construction management for rapid delivery are equally (and simultaneously) applicable to both the substructure and superstructure components.

It is important to understand that prefabricated bridge elements and systems (PBES) focus not only on the conventional prefabricated bridge beams and decks but on the prefabrication of all bridge elements, including abutments, piers, footings, walls, parapets, and approach slabs. A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2.

Maintaining minimum clearances to prevent accidents: For ABC substructure design and construction, the AASHTO requirements for vertical clearance over an interstate (16 ft, 6 in minimum) and over a railroad (23 ft) dictate the clear height of the abutments and piers. Some existing bridges do not meet this important requirement; such bridges have therefore become functionally obsolete and are candidates for replacement.

Prefabrication construction of substructure will control and achieve the required clearances. To raise the bridge deck elevation, the elevations of the approaches and the highway need to be raised. There are difficulties with raising the highway elevation, and lowering of the underpass may be required. For bridges on rivers with navigable traffic, movable bridges are more expensive for daily operations and long-term maintenance.

In addition, a number of states have approved legislation that mandates minimizing traffic disruption during replacements. Early construction and delivery of the substructure is therefore a step in the right direction. Innovative construction methods, materials, and systems are needed for reducing on-site construction time.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00009-5

Advantages: The advantages of using ABC for the superstructure have been discussed. For the substructure, when compared to conventional construction, the advantages include the following:

- Nighttime work hours are not required for lifting bridges into the existing footprint.
- Rapid construction has the ability to provide a bridge on the same alignment.
- Construction of a new bridge adjoining the existing bridge is not required.
- Partial lane closure is not required.

Historically, bridge deck, girders, and parapets have been replaced with prefabricated construction using the existing substructure. This practice will continue until all existing bridges of the older generation are completely replaced, when entirely new substructure will be required.

In the distant past, the LRFD method was not in vogue. The design requirements for substructure components have generally been more conservative (with higher factors of safety on loads and materials) than for the supported superstructure components. Also, the structural behavior of the superstructure is generally better understood than that of the substructure, which is subjected to soil interaction.

As a result, substructure design criteria based on load combinations for flood design, which has a probability of peak flood occurring once in 100 or 500 years, is more conservative. For example, higher bending moments from lateral loads result in vertical members such as piers, abutments, and wingwalls and their foundations than in the horizontal deck elements. The brunt of lateral forces from floods, winds, earthquakes, etc., and resulting bending stress is borne to a far greater extent by the substructure than by the superstructure.

Foundations: For stability and geotechnical considerations, the footing sizes are kept larger. Deep foundations (when used) would last much longer than the superstructure and are not replaced as often as the superstructure components. Therefore, during the life of a bridge, the deck and the girders take more repeated impact loads than the distant substructure components. Bearing retrofits are used with modern bearings (such as seismic isolation bearings) and for replacing rusted rocker and roller bearings. The deck or the bearings are likely to be replaced more than once, while the abutments and the piers remain unchanged or undergo minimal changes. However, in the case of floods causing erosion or for earthquakes, the substructure fails first, causing the superstructure to fail next.

The use of prefabrication for the substructure components (such as footings and the deep foundation) is comparatively limited and required only for substructure repairs and retrofit. Only small span prefabricated piers and arch bridges (such as CON/SPAN) have used ABC techniques for the substructure. Reinforced concrete has traditionally been used for pier bents and abutment walls for conventional construction. Precast abutment and pier walls, with vertical cast-in-place joints, need to be posttensioned for stability and water tightness.

Summary: Hence, the percentage of prefabricated piers and abutments being transported using self-propelled modular transporters (SPMTs) and erected at the site is comparatively lower than the prefabricated superstructure components, and the substructure prefabrication technology is still in the development stage for replacing an existing bridge.

The substructure work we discuss here is generally applicable to the following conditions:

- Emergency repairs and retrofit of a substructure on an existing footprint (such as the aftermath of floods or an earthquake)
- Total replacement of bridges on an existing or a new footprint
- Extending the widths of abutments and piers for deck widening
- Planning of an entirely new bridge on a new highway

Avoiding lane closure: The staging of construction is possible by closing down lanes, but staged construction may lead to less rapid delivery. An assembled single-lane bridge (with traffic in each direction) can be transported using an SPMT. If not, a lateral slide-in or roll-in roll-out method can be used if feasible.

Climatic hold-ups: The construction season is dependent upon weather conditions and may not be the same for every state in the United States. Nationally and locally, the use of ABC for substructure continues to grow. In peak winter months, for example, factory manufacture is possible but erection may take longer. There is a learning curve associated with using some ABC technologies, which will take a concerted and coordinated effort by owners, designers, and constructors alike.

9.1.1 Prefabrication of substructures in Europe and Japan

The SPER system is a method of rapid construction of piers using precast concrete panels as both structural elements and as formwork for cast-in-place concrete. Tall hollow piers use panels for inner and outer formwork, while shorter solid piers use panels for the outer formwork only. The system provides similar seismic resistance as a conventional cast-in-place system.

9.2 An overview of rapid substructure construction

In the United States, bridges are located on one of the following networks and are classified as such:

- Interstate
- Arterial
- Collector
- Local

ABC and rapid substructure construction will be especially helpful for the replacement of bridges located on the more important interstate and arterial roads carrying high average daily traffic (ADT). It is an unusual situation if the substructure needs to be replaced while the superstructure is in satisfactory condition. In some cases, superstructures can be lifted off the bearings and reused. In most cases, the entire bridge is replaced, except when using the lateral slide-in or roll in–roll out technique, which can preserve the superstructure.

The main substructure components are the following:

Precast cantilever wall abutment types

- Full-height abutment
- Mid-height abutment
- Stub and semi-stub abutments
- Spill-through abutment

Modern types include:

- Integral abutments (Figure 9.1)
- Semi-integral abutments
- Mechanically stabilized earth (MSE) wall abutments (Figure 9.2)

Precast retaining walls can be constructed in place of conventional cast-in-place construction (Figure 9.2).

FIGURE 9.1

Author-designed integral abutment on Route 46 on Peckman's River in New Jersey.

FIGURE 9.2

Mechanically stabilized earth wall under construction with precast segments.

Precast pier types

Multiple bents and flared caps are aesthetically pleasing. Some common shapes are:

- Solid wall
- Hammerhead
- Multiple column bents (hollow or solid concrete, segmented, post-tensioned, and reinforced) (Figure 9.3)

Modern types include:

- Multiple pile bents
- Integral pier

The author designed precast multicolumn pier bent for a U.S. Route 50 bridge located in southern New Jersey (Figure 9.3).

FIGURE 9.3

Use of precast multicolumn pier bent by the author for a U.S. Route 50 bridge located in southern New Jersey.

The use of precast abutment and pier elements may require posttensioning in order to provide a composite and watertight connection. More recently, grouted rebar couplers, which have been used in building construction for about 40 years, are being specified as a more rapid and less costly alternative for component connections.

The height of bridges seldom exceeds 20 ft and the width for a two-lane bridge is less than 40 ft, compared to the much longer span lengths of girders carried by SPMTs. The transportation of precast substructure components for assembled pier bents is therefore not as common as that for superstructure components.

Foundation types

- *Shallow footings*: Precast footing slabs
- *Deep foundations*: Piles, pile caps, and drilled shafts or caisson wall

Pile foundation is designed as end bearing or friction piles. The following shapes of cross-section are commonly used:

- Steel H pile or W sections
- Steel pipe pile
- Concrete pile or steel encased
- Prestressed concrete pipe
- Steel sheet piles

For the selection of the foundation, the expertise of a geotechnical engineer should be utilized.

Prefabricated footings: The soil beneath the precast footing slabs needs to be well compacted and made level to receive the heavy 3–4-ft-thick precast reinforced concrete footing slabs; otherwise, differential settlement can occur. Due to allowance for tolerances in casting the footing slab, the underside of footing slabs is not likely to be level. So far, there has not been sufficient experience reported regarding soil behavior in relation to precast footing slabs.

Any damaged cast-in-place footings can be strengthened by driving micropiles, but this is an expensive operation. On the other hand, conventional cast-in-place concrete will flow into the uneven soil surface without leaving any air pockets, and there will be no lack of contact between the footing and the soil.

Foundations of bridges located on waterways:

- Preliminary or general checks that include checking for scour in bridge bents located in water with possible scour should also include checking the bent piles for buckling failure. In addition, checking the bents is required for transverse to bridge centerline pushover failure (from combined gravity and added flood water loadings).
- Installing spurs or bendway weirs at a bend that is migrating toward a bridge abutment is good practice. Spurs will redirect the flow away from the abutment.
- *Hydraulic countermeasures*: This includes placement of armoring such as riprap around any exposed foundation.
- *Structural countermeasures*: This includes underpinning of footings that were undermined by using grout or grout bags.

Bearing types

Bearings can be classified as substructure components. The following types of modern bearings are commonly used:

- *Type 1: Multirotational*
  - Multirotational (pot-bearing) guided
  - Multirotational (pot-bearing) unguided
  - Multirotational (disc-bearing) guided
  - Multirotational (disc-bearing) unguided
- *Type 2: Elastomeric*
  - Elastomeric with polytetrafluoroethylene (PTFE) (e.g., Teflon)
  - Elastomeric, fabric type with PTFE (e.g., Teflon)
  - Elastomeric, steel laminated
  - Elastomeric, fabric laminated
  - Elastomeric, steel laminated with external load plate
  - Elastomeric, steel laminated with lead core
  - Elastomeric, laminated with PTFE (e.g., Teflon)

9.2.1 Substructure replacement

A survey of structural deficiencies is required to establish the need for replacement (please refer to the textbook by Khan, M.A., 2010. *Bridge and Highway Structure Rehabilitation and Repair*. McGraw-Hill, pages 54 and 363). In the past, there has often been overdesign using gravity and massive wall-type abutments, piers, and foundations. This had a built-in advantage in that when it came to replacement, only the superstructure was replaced.

Steps to avoid foundation soil scour and pile failure after construction include the following:

1. *Pile design*: For bridges located on rivers subject to floods, the ultimate bearing capacity of axially loaded piles must be limited to the compressive and/or tensile loads determined for reduced capacity for any projected scour.
2. *Pile capacity*: This must be limited to the ultimate limit as established by L-pile analysis. Pile group effects must be considered.
3. *Use of a dynamic screening tool for pile bents*: An evaluation procedure developed by the Alabama Department of Transportation and Auburn University may be employed. It is a screening tool described in macro- and microflood charts.

(Refer to Ramey, G.E., Brown, D.A., Hughes, M.L., Hughes, D., Daniels, J., May 2007. Screening tool to assess adequacy of bridge pile bents during extreme flood/scour events, ASCE, Practice Periodical on Structural Design and Construction, vol. 12, No. 2).

Cantilever wingwalls: Precast wall panels of uniform height and splayed panels of varying height are required. A considerable amount of work has been done on precast wall panels. Examples of proprietary wall systems include the following:

Mesa Retaining Wall Systems: Mesa segmental concrete facing units are used in conjunction with Tensar structural geogrids. Mesa units do not require mortar, so the considerable time, labor, and material of cast-in-place construction are eliminated. Heights up to 50 ft are possible. A high level of structural integrity can be achieved with a typical SRW type connection. (See the Design Manual for Mesa Retaining Wall Systems, Tensar Earth Technologies Inc., Atlanta, GA).

Allan Block Segmental Retaining Walls: Heavy-duty professional retaining walls are built. Different types of construction include gravity walls and walls reinforced with soil reinforcement options, such as geogrids and earth anchors.

This type of segmental retaining wall was reviewed by the author for the design of walls by the RBA Group for the New Jersey Oak Tree Road Project, located in Edison, New Jersey. (See the Installation Guide for Allan Block Segmental Retaining Walls, Allan Block Corporation, Edina, MN).

MSE retaining walls: Mechanically stabilized earth or MSE, which is soil constructed with artificial reinforcing, can be used for retaining walls and bridge abutments. Although the basic principles of MSE have been used throughout history, MSE was developed in its current form in the 1960s. The reinforcing elements used can vary but include steel and geosynthetics. MSE is the term usually used in the United States for "reinforced earth." The author has used this type of modular wall on bridge projects. (For more information, see "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes: Design & Construction Guidelines," March 2001).[1]

Cantilever retaining walls with parapets: Precast wall panels can be used at the approaches of a bridge to retain embankments on either side of highway, with the parapets serving as the sidewalks. The design of uniform height walls as secondary elements of a bridge and highway project is similar to the proprietary walls described above.

[1] Available at http://isddc.dot.gov/OLPFiles/FHWA/010567.pdf.

9.3 Design of precast substructure elements

The details for precast substructure elements are based on a design process called **emulative detailing**. This is a process developed by a joint committee of the American Concrete Institute (ACI) and the American Society of Civil Engineers (ASCE). The process is documented in the publication entitled "ACI 550.1 – Emulating Cast-in-Place Detailing in Precast Concrete Structures." This process emulates cast-in-place connections with precast elements.

Conventional cast-in-place (CIP) construction is not monolithic. Construction joints are common. CIP construction joints are typically detailed with dowels and lap splices with the exception of column connections. Emulation design replaces the traditional lap splice with a mechanical coupler. These couplers are allowed by the AASHTO LRFD Design Specifications. AASHTO requires that the couplers develop 125% of the specified yield strength of the connected bar. This is more than adequate in most cases for use in connection emulation for categories such as abutments and walls. The one exception is column connections in high seismic zones. Use grouted splice couplers in connection emulation details for accelerated bridge construction based on the following.

Several companies make similar proprietary precast products. They easily meet the AASHTO requirements for mechanical connectors. They can develop the specified tensile strength of the bars and can easily be cast into precast elements.

Seismic considerations: The design of column connections is especially difficult for high seismic zones. These connections develop plastic hinges to dissipate the seismic forces on the structure. There are no prefabricated bridge connections tested in the United States for plastic hinging to date. Grouted splice couplers have been researched in Japan. A review of the test results shows that the behavior of the grouted splice couplers is almost identical to the behavior of a continuous mild reinforcing column. The coupler showed slightly lower drop-off of moment capacity at the higher ductility ratios.

These connections are currently allowed in high seismic zones in the United States for vertical construction such as buildings. The seismic section of the current ACI 318 code classifies these connections as type 2 mechanical connectors. The ACI code specifies that these connectors are required to develop 100% of the specified tensile strength of the connected bar. Designers are encouraged to review the ACI code provisions.

When working with precast substructure elements, it is important to identify changes, modifications, and enhancements to the AASHTO bridge construction specifications in order to assist states and bridge owners who want to implement ABC. Implement the use of the decision-making matrix to further assist the project. Precast elements and hybrid bridge systems will become standard practice; thus, it will be important to create standard specifications for MSE walls, geosynthetic reinforced soil (GRS), continuous flight augured (CFA) piles, geofoam, and micropiles as we move forward.

9.4 Substructure construction techniques using SPMT units

Advantages of the use of SPMTs were discussed earlier. With the increased use of PBES, some agencies have developed standard drawings and details. Similar to the prefabrication of superstructure, the substructure prefabrication methods are being recommended and promoted by FHWA, NCHRP, and also by some individual states (and addressed in their design manuals and construction specifications).

In addition, FHWA has published several manuals, including the 2009 Connection Details for Prefabricated Bridge Elements and Systems and the 2011 Accelerated Bridge Construction Manual.

Also, the SHRP2 RO4 project has evaluated the different systems in use and published a toolkit of standard drawings, erection schemes, and sample design calculations called *Innovative Bridge Designs for Rapid Renewal: ABC Toolkit.*[2]

The use of SPMTs is required for transporting abutment and pier precast components. SPMTs are high load capacity transport dollies that can be ganged together longitudinally and transversely to fit the bridge length, width, and weight. Some transporters have wheel sets that can rotate 360°, giving the ability to move:

- Laterally
- Longitudinally
- Diagonally
- Pivoting about a central point or moving in an arc

The transporters have their own propulsion system composed of hydraulic drive motors and their own hydraulic lifting system. These attributes allow for transporting, raising/lowering, and setting a complete bridge within tight confines. The entire bridge can be built nearby with SPMTs used to move the bridge to its final location (Figure 9.2).

9.4.1 Limited experience in transporting prefabricated footing and abutment components

The use of prefabricated footing and abutment components is restricted in practice, mainly due to the transportation difficulties of large footings and tall vertical wall components.

The "Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges"[3] by the FHWA (June 2007) only gives examples of the transport and assembly onsite of prefabricated superstructure components.

Precast MSE wall segments can be transported by SPMTs. However, for assembly at the site, several vertical cast-in-place joints will be required for continuity. Besides lateral earth pressure, heavy dead and live load vertical reactions need to be transmitted to the footings and vertical joints located near bearings may have stress concentrations.

The seismic response of such discontinuities (with the resulting lateral seismic forces during an earthquake) needs to be investigated, preferably by laboratory tests on scaled models, before allowing heavy axle loads from truck traffic.

Maryland State Highway Administration (MSHA): The MSHA completed its first SPMT move in 2012 for Nursery Road over the Baltimore–Washington Parkway. The project involved demolition and construction of two single-span bridges with two nighttime parkway closures. During the first nighttime closure, the existing bridges were removed by SPMTs. Each superstructure was constructed several hundred yards from the existing bridge on shoring in a staging area located in the parkway median.

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[2] See http://www.trb.org/Main/Blurbs/168046.aspx for more information.

[3] See https://www.fhwa.dot.gov/bridge/pubs/07022/chap00.cfm.

Recent projects in Maryland serve as good examples of the use of SPMTs. Installation times ranged from 2 to 8 h depending on the travel path complexity, which involve factors such as:

- Length, grade, and curvature
- The bridge geometry (skew, span continuity)
- The specified joint widths, which allows more room to set the bridge

Utah: The Utah Department of Transportation (UDOT) is considered a leader in the use of SPMTs, having installed nearly 40 bridges in the last few years. UDOT has developed their own SPMT manual that includes design, construction, and heavy lift instructions.

- In 2011, UDOT installed the Sam White Lane Bridge over I-15, which was the longest U.S. bridge to date (with two spans of 354 ft long by 77 ft wide). Steel beams and a lightweight concrete deck were utilized to reduce the number of SPMTs and travel path preparation.

Iowa complete ABC projects: The 2012 Iowa U.S. 6 Bridge over Keg Creek required a 16-day road closure and complete off-site prefabrication, excluding the drilled shafts. The heaviest elements were the pier cap beams weighing 168,000 pounds using normal weight concrete and solid sections. Smaller weights would have been possible if roadway transport was required.

The project was intended to demonstrate an ABC concept for a typical multispan stream crossing that could be standardized for use on a large number of projects.
All elements were prefabricated in a staging area near the bridge. The use of 204 ft by 44 ft modular steel beam and deck units on precast piers and abutments was specified.

Massachusetts ABC Projects: The 2011 MassDOT Fast 14 project involved rehabilitation and superstructure replacement of 14 bridges on I-93 in one construction season as compared to conventional construction taking four construction seasons with substantial traffic impact.

Under this design-build project, the contractor utilized modular steel beam and deck units designed as simple spans but made continuous with “link slabs.” Link slabs are heavily reinforced cast-in-place continuity slabs that are purposely not bonded to the beams.
Traffic crossovers were used only during 10 weekends between June and August 2011.

Abutment seats: On the following weekdays, the abutment seats were replaced and other preparatory work was performed. During the second nighttime closures, the new bridges were moved into place.

The move and setting took about an hour, concluding with grouting the anchor bolts and placing steel plates over the deck joints in time for opening to morning traffic.

For cost details and guidance before planning a similar bridge, please contact the state DOT.

Pennsylvania initiatives

Pennsylvania historically has taken advantage of ABC techniques to save time and money and increase efficiency. PennDOT publication (DM 4) has standard design and publication (BD Series) or construction drawings (BC Series) for each of these structure types. Strike-off letters are used for interim changes in the specifications:

- Prefabricated deck beams such as adjacent box beams (to save deck forming and material cost).
- Prefabricated culverts and arches (to minimize stream diversion work).
- Glue-laminated timber slabs (for fast and low-cost construction on low-volume roads).

- The Geosynthetic Reinforced Soil Integrated Bridge System uses geotextile reinforced soil, modular facing elements, and integrated deck beam elements (that are often prefabricated).

1. In 2002, the PennDOT District 6 rail bridge replacement over SR 202 required minimal traffic disruption to SR 202 traffic.
   A 240-ft long truss was assembled off alignment. In one weekend, temporary support towers were placed on SR 202 and the truss was launched over SR 202.
2. In Pennsylvania in 2010, an Amtrak bridge in District 8's Middletown was moved by SPMTs. It was a three-span structure with steel pier bents.
   The bents were included in the off-site assembly and moved with the main span SPMT move. The existing bridge approach spans were demolished in place while the main span was lifted out of place by SPMTs transported to the staging area.
   The new bridge was then lifted, transported, and set into place.
   The modular approach spans were placed independently using cranes.
   This all occurred between early Friday and Monday morning.
3. In 2011, the Huston Township in District 2 was the first in Pennsylvania to construct this bridge type. It took less than 2 weeks to excavate, construct, and backfill the two abutments.
4. A state bridge in District 9 utilized reinforced soil and modular panels for the abutments and wingwalls that were tied together and connected laterally by chain elements.
5. The North Hopewell Township in District 8, the Sandy Township in District 2, and multiple state force projects in District 1 are interested in these new applications.
   Using other rapid delivery technologies in Pennsylvania: PennDOT has approved several standards that may be used to accelerate construction.
6. A 2012 Allegheny County project composed of a single 48-foot span that used steel-rolled beams, grid deck, and lightweight concrete fill was constructed adjacent to the site and lifted in place by a single crane with just a 3-day roadway closure.
7. A recently let District 8 state design-build project on the SR 581 high traffic corridor will require superstructure and deck replacement during one weekend closure for each direction. It is a 122-ft long three-span continuous beam structure that will likely use modular beam and deck units.
8. Central Atlantic Bridge Associates has worked with PennDOT to produce precast substructure standards and guidelines that include precast footings, pier columns, pier caps, integral abutments, cantilever abutments, wingwalls, and approach slabs. In PennDOT Drawing #12-603-BDTD (Approval Date March 18, 2013), design/material/construction specifications for this product are listed.

A geofoam specification is in development that can be used to accelerate embankment construction.

Central Atlantic Bridge Associates (CABA): Precast concrete substructure CABA standards and precast structure elements guidelines by CABA have been approved for use in project development. CABA usage has the following restrictions:

- These precast concrete substructure standards and precast structure elements guidelines meet both AASHTO and Design Manual, Part 4 design criteria.
- Currently being used for Pennsylvania state or local projects.
- The maximum precast pier column height is 50 ft.
- The maximum precast pedestal height for a beam seat is 18 in.

- The included precast concrete substructure standards and precast structure elements guidelines were developed from Utah DOT standards.

Other States Performance: There have also been several total prefabricated bridges.[4] Several well-known examples of such bridges are:

- Puerto Rico's Baldorioty de Castro Avenue overpasses
- New York's Route 9/Metro North Pedestrian Bridge
- New York's I-287 Viaducts in Westchester County
- North Carolina's Linn Cove Viaduct

9.5 Case studies of prefabricated substructures

The purpose of listing the bridges that were successfully completed in many states is to underline the rapid progress made in adopting new technology. Structural details for similar bridges to assist and planning and implementation can be obtained by visiting the websites of the many agencies listed. The objectives are to help in the decision-making process and evaluate quantifiable values, as contributed by each criterion. The vision will help states to adopt and efficiently implement for standard use by their engineers the NHI-training support and technical support for meeting ABC requirements.

Prefabricated substructures commonly in use are MSE-retaining walls at approaches of bridge and noise walls along the highway. Figure 9.2 shows an example of an MSE wall under construction, with precast segments. ABC for highway structures such as culverts has been in use for many years, while ABC application to bridges is more recent.

For the selection of ABC in any upcoming projects at hand, the top favorable criteria should include the following:

- Horizontal/vertical obstructions
- Bridge span configurations
- Construction personnel exposure
- Revenue loss and livability during construction
- Environment
- Marine and wildlife benefits
- Public relations

In addition, the top favorable subcriteria are cost to procure right of way (ROW); inspection, maintenance, and preservation; and design and construction of detours.

When making decisions related to a project, the most effective techniques can be arrived at by selecting the best option from a given set of alternatives, which can be evaluated against several multidimensional criteria and subcriteria, including those listed above.

Similar to the description of ABC for superstructure in the tables in Chapter 8, the following tables (Tables 9.1–9.14) include a description of the project, the ABC methods used, and brief details of the selected bridges. Bold font highlights the bridge name and the application of ABC in relation to substructure components. For cost details and guidance on the alternates considered please contact the state DOT.

[4] See http://www.fhwa.dot.gov/download/total.wmv for a video demonstrating one such project.

Table 9.1 Description of Prefabricated Substructure (with Precast Superstructure) in Alaska

Location	Description	Construction Method	Remarks
Pelican Creek Bridge, Chichagof Island	Precast decked double-tee girders with precast caps and steel piles. It is 178 ft long and 18 ft wide with 3 spans.	All material, including rock for the approach fill, barged to the work site. The contractor floated in barges at high tide and anchored them in the creek. Crews drove **steel piles** from barges, drove a large wheeled crane onto the barges, and then used the crane to install first **caps** and then decked double-tee girders, posttensioning the diaphragms.	All construction completed in approximately 5 weeks in 1992. It facilitated safe construction in a sensitive environment. Total prefabrication improved constructability for Trucano construction crews and reduced labor costs.
Kouwegok Slough Bridge, Unalakleet, Norton Sound	Bridge is 378 ft long and 25 ft wide with 3 spans (25 ft center span and 114 ft end spans).	**Pipe pile extensions support a precast concrete pile cap beam**, superstructure consists of rolled wide flange beams that support prefabricated full-depth concrete deck panels.	Materials had to be delivered by a barge that could not operate until after July because Norton Sound was frozen. It opened to traffic in August 2000, which was 55 days after materials were unloaded from the barge. Good constructability.

9.6 Additional bridges with precast concrete substructures

9.6.1 U.S. and Canadian bridges

Moose Creek Bridge near Timmins, Ontario (Total Precast Concrete Bridge Structure)

The Moose Creek Bridge project is part of a North American initiative looking at ways to speed up bridge construction to minimize costs and inconvenience to the public. The Moose Creek project was commissioned by the Ministry of Transportation of Ontario (MTO) and engineered by Stantec Consulting to try out several new precast construction concepts that could be used to speed up bridge construction in Ontario. This bridge has a single span of 22 m, an overall width of 14.64 m, and a roadway of 13.5 m. The bridge is supported on steel piles and has integral abutments.

Project specification highlights

- Use of high-performance concrete (HPC)
- Casting of concrete trial batches
- Temperature monitoring
- Temperature restrictions
- 7-day wet cure

Concrete trial batch: The final concrete mix developed for each precast unit was cast and tested prior to production of the units. Test results were submitted for 28-day strength, rapid chloride permeability, and hardened air void tests. A comparably thick test unit was cast to monitor the core heat generated by the stem units.

All units were cast with high-performance concrete (HPC). Special curing requirements were carried out in conformance with the specifications. The concrete temperature was monitored and

Table 9.2 Description of Prefabricated Substructure (with Precast Superstructure) in California

Location	Description	Construction Method	Remarks
IH80/Carquinez Strait Bridge, CA	IH80 across the Sacramento River between Crockett and Vallejo and an important link between Sacramento and the Bay Area. Completed in late 2003. The bridge is 3465 ft long with 3 spans.	First suspension bridge in the United States with two batter-leg concrete frame towers, with classic draped cables and vertical suspender ropes (to support the steel box girder deck). Each tower is supported by 12 drilled shafts that terminate in pile caps below sea level.	This project used **prefabricated pier** and cofferdams that functioned as float-in pile-cap shells, expediting construction. It allowed extension of the drilled shaft reinforcing cages, before casting the pile caps. It increased both the constructability and work-zone safety and the service life of the IH80 crossing.
Maritime Off-Ramp at I-80 and I-880, Oakland, CA	Completed in 1997. The ramp is 2356 ft long and has a 250 ft radius horseshoe shape.	Unique seismic detailing includes use of rubber dock fenders as seismic shock absorbers to reduce forces between completed bridge sections. Poly-tetra-fluoro-ethylene (PTFE) spherical bearings allow for rotation and expansion of members and can resist high seismic forces. A central shear key provides additional lateral capacity.	The substructure includes **reinforced concrete "T" bents with a single column with spiral reinforcing ties**. Two special bearings connect the superstructure to each "T" bent.
Richmond–San Rafael Bridge, CA	On I-580 between Richmond and San Rafael. This **precast system with precast cap shells and piles** includes 2 bridges 3624 ft and 2843 ft long and 44 ft wide.	This project uses a 500-ton 100 ft precast superstructure system, precast prestressed cap shells, and piles. Fabricating off-site allowed for controlled quality and increased safety.	Crews install new piles outside the travel lanes of the existing bridge, install new precast prestressed bent cap shells on the piles, and pour concrete and then prestress the caps. Then crews start from the abutment using a barge-mounted crane to sequentially replace the superstructure.

controlled. Thermocouple wires were placed at the center and the surface of the units. Wires were cast at three locations per unit to monitor the temperature. Thermocouple wires were connected to data loggers for recording and downloaded daily. Temperature readings were taken at specified intervals during the 7-day curing period.

Abutment/wingwall installation: The precast units were erected in two mobilizations. First, the stems and wingwalls were installed. Units were shipped flat. The steel pile and HSS knee bracing system was installed by the general contractor. This system also acted as a temporary lateral support for abutment stem units.

Girder/deck shipping: Temporary steel strands were needed for stability during shipping.

Postabutment installation site work: Cast-in-place bearing seats and closure strips between stem units were poured by the general contractor after installation was completed. Lateral bracing was removed when the concrete reached minimum strength.

Table 9.3 Description of Prefabricated Substructure (with Precast Superstructure) in Colorado

Location	Description	Construction Method	Remarks
SH 66 over Mitchell Gulch, CO	SH 66 over Mitchell Gulch between Franktown and Castle Rock. Completed in 2002.	Single span with side-by-side precast slab girders welded **onto precast abutments and wings welded to driven-steel H piles.** Piles were driven in advance outside the existing bridge. Except for steel H-pile supports, the entire bridge substructure was composed of precast concrete elements. Each abutment consisted of a lower and upper backwall unit. Each of the four wingwalls was a separate precast piece.	The bridge superstructure consisted of eight precast deck girder units each 5 ft 4 in wide, 1 ft 6 in deep, and 38 ft 4 in long. The deck girders were placed on the completed abutments and then transversely post-tensioned and grouted together. **The precast substructure units were attached in the field by welding together embedded plates precast into the elements.** This minimized traffic impact and improved work-zone safety by reducing work-zone time from several months to a weekend.

Table 9.4 Description of Prefabricated Substructure (with Precast Superstructure) in Connecticut

Location	Description	Construction Method	Remarks
Church Street Bridge, New Haven, CT	Directly linking downtown New Haven and the Long Wharf and waterfront areas. Truss-span bridge is 1280 ft long with 8 spans including 320 ft truss span, 50 ft high and 60 ft wide.	The crane, which required more than **4 weeks to assemble**, lifted the entire truss span more the 65 ft and moved it more than 100 ft to its final position. The 850-ton bridge was lifted into place by world's largest mobile crane.	Specifying prefabrication saved ConnDOT about a year on its overall contract time and at least $1.1 million. Prefabrication of the center span greatly improved constructability.

Table 9.5 Description of Prefabricated Substructure (with Precast Superstructure) in Florida

Location	Description	Construction Method	Remarks
Reedy Creek Bridge on Osceola Parkway	Main entrance to Walt Disney World's Animal Kingdom theme park in Orlando, FL. The 1000 ft. long bridge consists of five structures, each 200 ft. long with expansion joints at ends and at abutments.	Eastbound and westbound bridges were separated by 14 ft, which carried the utility lines on suspended steel framing. **Precast components included pile caps** and deck panels. All the **pile caps were of the same cross section, made in different lengths as needed**, and simply reinforced and set on a slope to provide the transverse grade.	The shallow precast pile caps supporting the precast deck panels resulted in a total depth just under 5 ft with the deck itself only 2 ft 5 in deep. Except for touch-up painting of the steel piles, all work was completed from the top with no activity on the creek bed below.

Table 9.6 Description of Prefabricated Substructure (with Precast Superstructure) in Missouri

Location	Description	Construction Method	Remarks
IH70/Lake St. Louis Boulevard Bridge	IH70 over Lake St. Louis Bridge in St. Charles County, MO. Completed in 2003.	The new bridge used precast deck and beam sections and **puzzle wall abutments**, which allowed a design with fewer spans. With the prefabrication redesign, MoDOT reduced construction time by several months. By reducing the number of spans, geometrics of the interchange improved, increasing its safety and efficiency.	With prefabrication facilitating faster construction, bridge users were spared several months of inconvenience, and IH70 users were spared a period of reduced vertical clearance. Fewer spans also result in lower maintenance costs.

Table 9.7 Description of Prefabricated Substructure (with Precast Superstructure) in North Carolina

Location	Description	Construction Method	Remarks
Linn Cove Viaduct	Grandfather Mountain on the Blue Ridge Parkway, milepost 304.6, NC. Completed in 1983.	The Linn Cove Viaduct is 1243 ft long and contains 153 superstructure segments, each weighing 50 tons, along with **40 substructure segments weighing up to 45 tons**. The project minimized environmental disruption. Precasting each segment of the bridge allowed construction workers to assemble the bridge with little impact to the most environmentally sensitive section of Grandfather Mountain	To avoid placement of heavy equipment in a sensitive environment, the bridge was built in one direction from the south abutment to the north almost entirely from the top down. The only exceptions to the top-down method were construction of the initial span on falsework and construction of a temporary timber bridge that enabled the **micropile foundation drilling machine to prepare several of the foundation sites** ahead of the superstructure erection.
Beaufort and Morehead Railroad Trestle Bridge	Over Newport River between Morehead City and Radio Island, NC. Completed in 1993.	This project replaced 2298 ft of trestle-span approaches on existing alignment on each side of a single-leaf rolling bascule span. Trestle spans were replaced during weekly track outages of 4-day duration. The bridge was designed and constructed to AREMA standards and to meet NCDOT's highly corrosive coastal environment criteria.	A design-build project consisting of ballasted, precast prestressed T-girders spanning transverse, **precast reinforced concrete caps, supported on composite piles (24 in steel pie piles protected by 36 in concrete cylinder pile sleeves)**.

For stability, the outer abutment stem units were erected first. Wingwall end reinforcing was threaded through the reinforcing of the stem units. Wingwall units were set on steel piles and connections were made between stem and wingwall units. Installation of the stem and wingwall units took place over 2 days.

Table 9.8 Description of Prefabricated Substructure (with Precast Superstructure) in New Hampshire

Location	Description	Construction Method	Remarks
Epping 13940, Mill Street over Lamprey River, NH.	The 115-ft single-span butted box precast elements were placed on an entirely precast substructure. Completed in 2004.	**Nine precast footing pieces** were leveled using leveling screws and then grouted in place. The joints between beams were grouted and transversely post-tensioned. Finally, the deck surface was membraned and paved, and rail was placed. Rapid assembly time precluded the need for a detour or traffic disruption.	Full moment connections were created between wing and abutment stems to precast footings by means of grouted splice sleeves. The connections were cured overnight, the substructure was backfilled, and the butted box beams were placed. It took 8 days from the time the first precast footing was lifted from the trailer to the time when the bridge was opened to traffic.

Table 9.9 Description of Prefabricated Substructure (with Precast Superstructure) in New York

Location	Description	Construction Method	Remarks
Route 9/Metro North Pedestrian Bridge, Croton-on-the Hudson, NY	Ramps are 35 ft long precast concrete units and 20 ft precast stair sections, supported directly on precast columns with cast-in-place seats. Completed in 1998.	The bridges were totally prefabricated with **precast box pier units**, precast ramp sections, precast stair sections, precast crash walls, precast prestressed concrete/steel superstructure units, **precast prestressed cylinder piles, and** precast prestressed deck composite units.	Improved constructability and minimized disruption of traffic by reducing the staging area required and reducing construction time.

Table 9.10 Description of Prefabricated Substructure (with Precast Superstructure) in Puerto Rico

Location	Description	Construction Method	Remarks
Baldorioty de Castro Avenue Overpasses, San Juan, PR	A project built in two states to minimize traffic disruption. Completed in 1992.	**Piles were driven and footings cast with special forms** to facilitate fast connections, then the precast components were erected and post-tensioned. Box piers were positioned and posttensioned to the footings, caps placed, and piers vertically posttensioned. When the first two piers were in place the 100-ft long superstructure box beams, seven per span, were set in place. Using two crews, the overpass then was erected simultaneously from the center span toward each end. Each span then was post-tensioned transversely as it was completed.	The first bridge was erected in 36 h, and the others took as little as 21 h. The project was awarded a Harry H. Edwards Industry Advancement award.

Table 9.11 Description of Partial Prefabricated Substructure (with Precast Superstructure) in Tennessee

Location	Description	Construction Method	Remarks
Route 57 over Wolf River, Fayette County, TN	1408-foot long, 46-ft wide bridge. Completed in 1999.	TDOT and the contractor developed details for **precasting bent caps in two pieces** to suit staged construction of the bridge without putting any equipment in the surrounding wetlands.	"A" plus "B" format was used. The "A" portions of the bids reflected prices for construction items. The "B" portion required the contractor to identify the number of calendar days needed to complete construction, which was then multiplied by a predetermined price per day established by the owner.

Table 9.12 Description of Various Prefabricated Substructure Projects (with Precast Superstructure) in Texas

Location	Description	Construction Method	Remarks
SH 361 over Redfish Bay and Morris–Cummings Cut, Aransas County, TX	Construction of two bridges over Redfish Bay (2020 ft) and the Morris–Cummings Cut (415 ft), posing the challenge of overwater work on the Texas Gulf Coast. Completed in 1994.	The design included **precast pilings** as well as precast double-tee girders with 44 identical precast bent caps. **Bent caps** were fabricated in Corpus Christi and used epoxy-coated reinforcing to protect against corrosion in the marine environment.	Bent caps were transported by barge to the bridge site and then lifted into place over epoxy-coated reinforcing steel hairpin bars embedded in the piling to form the connections. The interface between pile and the bottom of the cap was sealed, and concrete was placed through the slot in the top of the cap to complete the connection.
US 290 Ramp E-3, Austin, TX	Completed in 1996.	Contractor **precast the straddle bent cap** at the work site and lifted it into position. When it was in place, workers post-tensioned bars and grouted the cap-to-column connections.	**Precast bent cap for pier** minimized traffic disruption. The time necessary for closure of the ramp was reduced from an estimated 7 days to 4 h.
Dallas/Fort Worth International Airport (DFW) People Mover, Dallas/Fort Worth Metroplex, TX	Completed in 2004.	DFW Airport People Mover Team decided to design and build a **precast post-tensioned segmental system of columns** that allowed the airport apron to remain clear of guy wires.	Allowed column construction to happen at night with minimal disruption of airport traffic, and improved constructability.
I-45/Pierce Elevated, Houston, TX	Completed in 1997.	To connect the precast caps to the existing columns, the **precast caps were anchored with post-tensioning bars** and hardware.	Minimized traffic disruption: construction time was reduced from an estimated 1.5 years to 190 days, with user delay costs estimated at $100,000/day.

Table 9.12 Description of Various Prefabricated Substructure Projects (with Precast Superstructure) in Texas—cont'd

Location	Description	Construction Method	Remarks
NASA Road 1 over I-45, Houston, TX	Four-span, two-lane, freeway overpass. Completed in 2002.	Careful control of pile leads for plumb during 24-inch pile driving in soft clay allowed placement of piles without templates to within 2 in of plan location. **Trestle piles** could be driven in the soft Houston clay faster than shafts could be drilled and columns poured.	The existing low-clearance bridge was demolished and the new bridge completed in 10 days, which minimized traffic disruption.
SH 249/Louetta Road Overpass, Houston, TX	The bridges are three spans each, nominally 130 ft per span. Completed in 1994.	At the interior bents, each beam is supported by a single **posttensioned pier**.	All beams and piers were designed and fabricated using high-performance high-strength concrete. Precast pretensioned partial-depth deck panels, **precast posttensioned piers,** and pretensioned U-beams were used.
SH 66 over Lake Ray Hubbard, near Dallas, TX	Completed in 2002.	On this project, a total of 43 bent caps were precast. TxDOT designed a **precast bent cap option that included a cap-to-column connection** and a specific construction procedure that allowed early placement of caps and prestressed beams based on achieved cap concrete and cap grout connection strength. The connection design included reinforcing steel dowel bars that protrude from the columns into the precast caps via open plastic ducts that are grouted after cap placement.	*Work zone safety*: Reduced the amount of time required for work near power lines and reduced work time over water (80% of work on caps was done on the ground) *Minimized traffic disruption*: Using precast caps produced a saving of 5–7 days per cap, distributed across activities associated with formwork, curing, steel, inspection, and bearing seats Improved constructability.
SH 36 over Lake Belton, near Waco, TX.	Twin bridges are 3840 ft long. Completed in 2004	Bridges have 62 identical **precast interior bent caps**. The hammerhead bents are some of the highest-moment-demand cap-to-column connections used yet with precast caps in Texas, presenting new design challenges.	TxDOT funded a 2002 research implementation project to adapt and implement guidelines for multicolumn bent cap connections to single-column, high-moment-demand connections.

Table 9.13 Description of Prefabricated Substructure (with Precast Superstructure) in Washington

Location	Description	Construction Method	Remarks
Northeast 8th Street Bridge, Bellevue, WA	This bridge is 328 ft long and 121.5 ft wide. Completed in 2004	WSDOT chose a **total prefabrication** design that allowed it to stage the bridge beside the highway during construction and then move it into place. The contractor moved the 2200 ton structure in about 12 h.	The total prefabrication construction caused relatively few disruptions to area drivers, with most closures limited to nights and select weekends, which resulted in a wider, safer bridge with more lanes of traffic.

Table 9.14 Description of Prefabricated Arch Structure (with Precast Superstructure) in Wisconsin

Location	Description	Construction Method	Remarks
Mississippi River Bridge	US 14/61/WIS 16 over the Mississippi River. This bridge is 2573 ft long and 50 ft. wide. Completed in 2003.	The bridge has a 475 ft **steel arch center span** with a totally prefabricated superstructure system. This allowed the contractor to work on both the river piers and the arch simultaneously, speeding the construction schedule.	The bridge elements were fabricated 90 miles from the site in pieces manageable for shipping and erection. They were then assembled entirely off site on barges. The 475 ft long and 87 ft high center-span steel arch superstructure was finally floated into place. Erecting the tied arch on barges allowed Lunda Construction Company crews to work without interference with river navigation.

Minimum design strength of the cast-in-place substructure portions was required prior to girder/deck erection. Units were erected 3 weeks after the stems and wingwalls. Units were shipped over a 2-day period to reach the site at the required time. They were erected from a temporary bridge adjacent to the site. The middle units were placed first and braced temporarily to the stem units for stability before adding the permanent steel diaphragms. Adjacent units were then installed and connected to the diaphragm steel before releasing the crane.

9.6.2 Total bridge examples

The following states have played an active role in making prefabrication popular for substructure elements.

California bridges

- I-405 Temple Ave, Long Beach, CA
- Rte 710 bridge widening

Colorado bridges

Case study of Mitchell Gulch Bridge

- Owner: Colorado Department of Transportation—Region 1
- SH 86, south of Denver

- 1200 vehicles/day
- 40-ft long single-span bridge
- Redesigned per CDOT value engineering process
- Scheduled in 2002
- Single weekend
- Less than 48 h to complete

Florida Bridges

Reedy Creek Bridge, Disney World, Orlando, Florida

- The environment: Reedy Creek Wetlands
- The need: Provide vehicular access to the new Animal Kingdom theme park.
- The solution: A precast prestressed concrete slab bridge constructed using top-down construction.
- Construction: 5 continuous segments at 200 ft = 1000 ft, each segment = 5 spans at 40 ft.
- Original design: Cast-in-place construction.
- Value engineering proposal: Use precast components in the same configuration.
- Conclusion: The precast alternative saved both cost and time.
- The deck construction used 405 haunched slabs in two sizes.

Iowa bridges

- Sabula, IA: Detailed analysis showed that ABC would save time and money.

One of the keys to this ABC method working smoothly is the design/build relationship between the designer, in this case TranSystems and the contractor SPS New England. Their ability to work together has proven to be as time saving as the method of construction. Problems are solved and avoided when working together.

Precast concrete abutment caps and approach slabs were placed after the demolition of the existing bridge superstructure to facilitate the rapid installation of the new superstructure. Precast barrier rails sections were used to bridge between the cast-in-place (CIP) rails on the approach and on the bridge structure. Precast concrete abutment caps, approach slabs, and barrier rail sections were produced by J. P. Carrarra & Sons, Inc., Middlebury, VT. This project was started in May 2010 and the new bridge was in place on November 1, 2010.

The Phillipston Bridge proves that ABC is a doable system that effectively replaces a deteriorating bridge, without costly and irritating traffic delays.

New Hampshire bridges

I-93 Exit 14 accelerated bridge construction, Bow–Concord, NH

This project studied a range of alternatives for improving safety, enhancing mobility, and adding capacity to I-93 through Bow and Concord, NH. The project included an assessment of widening I-93, reconfiguration/addition of new interchanges, local roadway improvements, multimodal improvements including commuter rail, macroenvironmental analysis, and traffic demand modeling and analysis.

Public participation program: A dynamic and comprehensive public participation program included a Citizen Advisory Committee, project Website (www.i93bowconcord.com), project design center, design charts, and large-scale public meetings. This project was one of the NHDOT’s first to be processed using the context-sensitive solutions approach, in which the public and stakeholders are involved from the outset, and the community, environmental, and transportation context and needs are all considered.

Due to uncertainties regarding the implementation of the corridor improvements, NHDOT identified the need to replace the superstructure of the structurally deficient, single-span I-93 Exit 14 Bridge in Concord. The bridge carries Interstate Route 93 over Loudon Road, one of the main arteries serving the state capital.

After evaluating several conventional rehabilitation options, an innovative ABC solution that allowed each half of the bridge superstructure (one interstate barrel) to be replaced over a single 60-h weekend closure period was developed. Due to the short construction duration, the work could be scheduled during a period of seasonally low traffic volumes using temporary lane closures. Other conventional options that were initially considered required the construction of a long-term detour roadway and temporary bridge on the interstate, at an additional cost of $1.5 million.

This ABC option used full-depth, precast concrete deck panels in combination with high-early strength concrete and longitudinal posttensioning for long-term durability. Other project enhancements included the development of detailed traffic control plans and an extensive public outreach campaign to minimize impacts to the traveling public and local businesses.

New York bridges

Cross Bay Boulevard over the North Channel Jamaica Bay, NY

- Bridge length: 2842 ft, 34 spans, three lanes each way plus bicycle lanes, sidewalks, and fishing access. The following components were used:
  - Cylinder piles
  - Precast pier cap forms
  - Prestressed I-beams
  - Precast diaphragm forms
  - Prestressed subdeck panels
  - Precast traffic barriers

Robert Moses Causeway over Great South Bay, Long Island, NY

- Bridge length: approximately 2 miles, 2 lanes wide, 153 spans
- Original contract:
  - Rehabilitate superstructure girder and truss spans
  - Replace 122 stringer spans with spread P/S box beams
  - Replace deck
- *Value engineering proposal*
  - Substitute full-width quad-tee span segments for spread box-girder spans

Belt Parkway over Ocean Parkway Bridge, NY (2004)

- No lane closures during peak-hour traffic for expansion of two-span, 149 ft long, 78 ft wide bridge to three-span, 221 ft long, 134 ft wide bridge

Oklahoma bridges
The current ODOT 8-year plan has 924 bridge-related projects.[5]

[5] From http://www.tulsaworld.com/homepagelatest/oklahoma-transportation-commission-approves-year-plan/article_e2cdc4f8-2f7d-11e3-bc22-0019bb30f31a.html?mode=jqm

Bird Creek bridge replacement: Another project is the $20 million Bird Creek bridge replacement project near the intersection of U.S. 169 and 56th Street North, according to the plan. The project will replace six total bridges and was moved forward from 2016 to 2015.

Nicknamed the "Six Billion Dollar Plan," the 2014–2021 ODOT plan also has $6 billion in improvements, 1999 total projects, 657 miles of shoulders and other improvements to two-lane roads, and 552 miles of major improvements to high-volume highways and interstates, according to a press release.

ODOT projects will focus on bridges with a goal of having no structurally deficient bridges by 2020 before refocusing on pavement rehabilitation. The 2014–2018 five-year plan includes $900 million in improvements, 680 total projects, 557 county bridge replacement or rehabilitation projects, and nearly 1000 miles of county road improvements, according to the plan. ODOT crews are fighting every day to keep them off the structurally deficient bridge list.

Oregon bridges

US 97 over Union Pacific Railroad Tracks, Chemult, OR

This involved a single-span design of nearly 182 ft on a 60-degree skew that replaced a bridge on major Oregon highway over railroad tracks in less than 7 months. Faced with the twin challenges of a long span and short construction time to design and build a replacement bridge to carry a busy highway over an active railroad in Chemult, Oregon, project engineers turned to precast, prestressed concrete girders to create the best solution.

Other Oregon ABC projects include Elk Creek Bridge and Millport Slough Bridge.

Puerto Rico bridges

Case Study of Baldorioty Bridges, San Juan, Puerto Rico

- Create expressway
- Separate at-grade intersections, two intersections, four bridges
- 100,000 average daily traffic
- *Design and build four urban grade separations*
- *2 bridges: 900 ft long x 30 ft 4 in wide*
- *2 bridges: 700 ft long x 30 ft 4 in wide*
- Maintain continuous traffic
- Complete each bridge in less than 72 h!

Texas bridges

Case study of Copano Bay Bridge

(For details of this case study, refer to a Report on Copano Bay Bridge Replacement by William H. Reitmann, Sinton Area Engineer, Texas Technical Institute)

- Carries SR 35-Gulf Intracoastal Waterway (11,010 ft long, 129 ft wide, and 75 ft tall)
- Main criteria contributions:
  - Schedule constraints: 38.8%
  - Indirect costs: 6.7%
  - Direct costs: 12.3%
  - Site constraints: 37.8%
  - Customer service: 4.4%

Other prefabricated substructures in Texas includeLake Ray Hubbard Bridge (2002) and Lake Belton Bridge (2004).

Utah bridges using CMGC or Design-build Contracts.

(Reference: Carmen Swanwick, UDOT Chief Structural Engineer at FIU, April 2011).

- *800 North over I-15: Precast deck panels, CMGC*
- *Riverdale Road over I-84: Lego bridge, CMGC*
- *4500 South over I-215: SPMT, CMGC*
- *I-80, Lambs Canyon Bridge: SPMT, design-build*
- *I-80, State Street to 1300 East: SPMT, CMGC*
- *I-70, Eagle Canyon Bridge: Precast deck panels, CMGC*
- *SR-66 over Weber River: Slide-in, design-bid-build*
- *I-80, two bridges near Echo Junction: Slide-in, design-build*
- *I-80 over 2300 East*: *Slide-in*, *design-build*
- *South Layton Interchange: Launch, design-build*
- *U.S. 89 over I-15*: *SPMT*, *design-build*
- *I-15 CORE Proctor Lane over I-15: SPMT, design-build*
- *I-15 CORE 200 South over I-15: SPMT, design-build*
- *I-15 CORE Sam White Lane over I-15: SPMT, design-build*

Other slide-in bridges in Utah include the following:

- I-80 over Weber River, Spring 2011
- I-80 at Atkinson, Summer 2011
- I-80 at Summit Park, Summer 2011

Prefabricated bridge elements were used in SR-193 over UPRR and UTA (Spring 2012).

Virginia bridges

In 1995, the George P. Coleman Bridge in Virginia, the largest double-swing bridge in the United States, was dismantled and replaced in only 9 days using barges.

Washington bridges

See http://www.fhwa.dot.gov/publications/focus/04may/04.cfm for a discussion of the Evergreen Point Floating Bridge Project. Other projects include the Grand Mound Project and SR 16 EB Nalley Valley I/C.

9.7 FHWA listed bridges with prefabricated substructures

All bridge and structure information has been made available at the FHWA Website at http://www.fhwa.dot.gov/bridge/. You can review PBES projects by state and by project name at http://www.fhwa.dot.gov/bridge/prefab/projects.cfm. Table 9.15 gives a list of bridge projects using ABC. For bridge details, cost implications and guidance on using alternates planning time can be saved by contacting the state DOT.

Table 9.15 US States with Active ABC and Substructure Projects

Bridge Projects Utilizing ABC	State
Kouwegok Slough Bridge	AK
Pelican Creek Bridge	AK
IH80/Carquinez Strait Bridge	CA
Maritime Off-Ramp at I-80 and I-880	CA
Richmond–San Rafael Bridge	CA
SH 66 Over Mitchell Gulch	CO
Church Street Bridge	CT
Reedy Creek Bridge	FL
Keaiwa Stream Bridge	HI
Illinois Route 29 over Sugar Creek	IL
Wells Street Bridge	IL
US 27 Over Pitman Creek	KY
I-10 Over Lake Pontchartrain	LA
IH70/Lake St. Louis Boulevard Bridge	MO
Linn Cove Viaduct	NC
Epping 13940	NH
Cross Westchester Expressway Viaducts	NY
Governor Malcolm E. Wilson Tappan Zee Bridge (Tappan Zee Bridge)	NY
Main Street Over Metro North Railroad	NY
Route 9/Metro North Pedestrian Bridge	NY
Troy-Menands Bridge	NY
Fairgrounds Road Bridge	OH
Norfolk Southern Railroad Bridge Over I-76	PA
Baldorioty de Castro Avenue Overpasses	PR
Route 57 Over Wolf River	TN
Dallas/Fort Worth International Airport People Mover	TX
I-45/Pierce Elevated	TX
Lavaca Bay Causeway	TX
NASA Road 1 Over I-45	TX
SH 249/Louetta Road Overpass	TX
SH 36 over Lake Belton	TX
SH 361 over Redfish Bay and Morris–Cummings Cut	TX
SH 66 over Lake Ray Hubbard	TX
US 290 Ramp E-3	TX
US 59 under Dunlavy, Hazard, Mandel and Woodhead Streets	TX
Wesley Street Bridge	TX
Dead Run and Turkey Run Bridges	VA
George P. Coleman Bridge	VA
I-95/James River Bridge	VA
Route 7 Over Route 50	VA

Continued

Table 9.15 US States with Active ABC and Substructure Projects—cont'd

Bridge Projects Utilizing ABC	State
Richville Road Bridge	VT
I-5/South 38th Street Interchange	WA
Lewis and Clark Bridge	WA
Northeast 8th Street Bridge	WA
Mississippi River Bridge	WI
Howell's Mill Bridge	WV
Market Street Bridge	WV

9.8 ABC alternative contracting methods

Construction projects of all sizes involve numerous details, demand time, and experience to manage the process. The process of handling the planning, design, and construction phases of the project is referred to as construction management; when it is expanded to include multiple projects, it is called program management.

9.8.1 FHWA's long-term project delivery goals

All contracting agencies should have a project delivery "toolbox," including the following:

- Design-bid-build
- Design-build
- Construction Manager at Risk

The innovative contracting method called Construction Manager at Risk (CMAR) is a delivery method that offers a number of time and cost savings advantages. With CMAR, certain girders might be better suited to construction, with advantages in cost, time of construction, and reduced congestion due to elimination of false work. The success of a recently completed precast girder system has been cited.

With the CMAR process, the CMGC (construction manager and general contractor) is selected early in the design phase. Work is done closely with the designer to examine alternate materials, systems, and equipment for cost, quality, and availability.

The CMAR performs constructability reviews and offers value engineering suggestions. This early coordination fosters collaboration and focuses the entire team on finding the best solutions for the construction project. There is also an effort to coordinate all subcontractor bids and determine a guaranteed maximum price for construction. As with all services, the CMAR process can customize a solution that includes some or all of the responsibilities generally associated with risk:

- Advice and consultation on all aspects of planning
- Management of the design and construction phases
- Establishment of parameters for quality, cost, and time
- Provision of constructability reviews and cost analyses
- Preparation of bid packages

- Preparation of conceptual and detailed estimates
- Development of a phasing and sequencing plan
- Ensuring constructability of the design while minimizing cost and schedule
- Preparation of the overall project schedule and provision of periodic detailed updates
- Establishment and maintenance of all quality control standards
- Guaranteeing the construction cost
- Serving as general contractor

AASHTO Bookstore and latest FHWA publications on ABC: Both FHWA and AASHTO have taken a lead in the specialized development of management for ABC, which has occurred over a number of years. The following useful publications are recommended:

- Website for AASHTO Guide for design-build procurement: https://bookstore.transportation.org/
- Caltrans developed an "Alternative Procurement Guide" in April 2008. It is available at http://www.dot.ca.gov/hq/oppd/contracting/AlternativeProcurementGuide.pdf.

FHWA procurement requirements (SEP-14): FHWA has been evaluating various alternative construction techniques through Special Experiment Project No 14 (SEP-14)—Innovative Contracting. A list of active projects under this program is available at http://www.fhwa.dot.gov/programadmin/contracts/sep14list.cfm.

The goal of SEP-14 is as follows:

- Identify alternative contracting practices that have the potential to reduce lifecycle costs while maintaining product quality.
- The contract award should be:
  - Transparent
  - Fair
  - Competitive

ABC requires that projects of every scope and size are undertaken in a collaborative team environment, using innovative techniques to improve productivity, reduce costs, and give clients the best-quality project possible.

According to a seminar by FHWA, during the preconstruction phase, the CMAR uses proprietary databases of construction information compiled from over a dozen projects to create highly accurate cost models that help plan the project and eliminate the risk of making a loss. These models provide a road map for the entire project team that is critical when making decisions about major systems, materials, and equipment.

It is important to determine the constructability of a rapid construction project and develop detailed construction schedules that are realistic and meet the needs of the project in a given construction season. The general contractor's crews can self-perform portions of the work or enlist prequalified subcontractors who meet high standards for quality and cost-consciousness. To reiterate, the key responsibilities of the CMAR are the following:

- Serves as the owner's agent and supplements existing staff
- Evaluates potential sites for early feasibility studies
- Works within the desired delivery system
- Manages planning and design by using an expert consultant to reduce problems during execution

- Assists in selection of the design team
- Establishes cost and time parameters and helps prepare bid packages
- Offers value engineering input and cost analysis.

In addition to prefabrication, ABC requires selection of the proper construction equipment, as well as selection of the proper procedures for excavation and grading, underground utilities and site drainage systems, concrete work, sign structures, and lighting. Using skilled labor, specialized equipment, and hands-on experience to get the job done right from the start are essential to completing a project using ABC.

9.8.2 Design-bid-build

The traditional design-bid-build (D-B-B) process separates design and construction. The oldest and most well-known contracting method for construction projects, D-B-B is still popular with some owners. With D-B-B, the contractor does not enter the process until after the design is complete. The drawings are put out for competitive bid to general contractors and the one with the lowest price is typically awarded the project.

In the mid-1800s, many states adopted “low bid” requirements to protect taxpayers from extravagance, corruption, and other improper practices by public officials. In 1938, the Federal Highway Act required competitive bidding. In 1968, the Federal Highway Act revised Title 23 USC to award construction contracts only on the basis of the lowest responsive bid.

The general contractor coordinates and manages all subcontractors from start to finish, and often self-performs critical portions of work to provide greater value to the owners, usually the transportation agencies. There is at best a partial ABC requirement for an early project completion and delivery using the D-B-B system. It is gradually being replaced by the design-build (D-B) system.

9.8.3 Construction Manager General Contractor

There is no current statutory authority for Construction Manager General Contractor (CMGC). Comparing CMGC projects to traditional projects shows time savings in four primary areas. CMGC is able to begin the project earlier, the design takes less time, the construction takes less time, and overlapping design and construction reduces project time. CMGC gives us a delivery method similar to D-B but provides flexibility in responding to the priorities of cost, schedule, and quality.

The savings are attributed to the improved communication that occurs between the contractor and the designer in the design process. With these benefits, many CMGC projects have been able to save a construction season and reduce inflation costs because they could get started early.

One of the keys of CMGC is the tripartite relationship between the owner, designer, and construction manager. There are separate contracts between the owner and contractor and owner and designer, and the operational structure involves all three of them.

How the team is selected:

- Designer: regular consultant selection process
- General contractor: “best value selection”

CMGC Bid Process:

- Contractor submits bid
- Third-party initial contractor’s estimate
- Engineer’s estimate (EE)

Benefits of CMGC:

- Cost certainty
- Risk reduction
- Schedule optimization
- Collaboration
- Model to implement innovation

There are more than 10 agencies in the United States with CMGC experience, with Utah DOT and the Utah Transit Authority taking the lead. Fourteen state DOTs currently have CMGC authority.

This type of management is also applicable where the project cost is high and multiple subcontractors and subconsultants are on the team. For more information on CMGC, see the Utah DOT Website at http://www.udot.utah.gov/main/.

9.8.4 Design-build management

Design-build construction is another contracting method that is gaining popularity, as it can provide significant cost and time savings for the owners. Design-build provides a single point of responsibility for an entire project; the progress and quality of the project including oversight of the design concept is managed by the contractor.

A historical perspective of design-build is given below in chronological order, where bridge construction was an art rather than a science.

9.8.4.1 Ancient practice

1800 BC—Code of Hammurabi (Design-Build)
450 BC—Classical Greece (Design-Build)
1200 AD—Middle Ages Cathedrals (Design-Build)
1450—Renaissance: Emergence of design-bid-build

9.8.4.2 Modern practice

1960s—Private sector reemergence of design-build and CMAR
1980s—Public sector reemergence of design-build
1993—Establishment of the Design-Build Institute of America
1996—Passage of Federal Acquisition Reform Act of 1996

The design-build team leader is the single source of responsibility for the owner and is normally the member who is financially and legally capable of entering a contract and guaranteeing completion of the work. Most often, this is the general contractor, the firm having the necessary balance sheet and bonding capacity. However, it can be the engineer or an outside party. Design-build delivery is still termed experimental in transportation.

FHWA will allow any fair and transparent selection method to be evaluated and approved under SEP-14. To date, the FHWA has approved the use of design–build in more than 150 projects, representing just over half of the states. Many European countries started using design-build delivery before the United States.

Table 9.16 shows a comparison between CMGC and D-B Methods.

Table 9.16 Comparison of CMGC and Design-Build

Where Owner Spends Effort	
CMGC	**Design-build**
Define goals	Define goals
Project restrictions	Performance spec
RFP development	RFP development
Proposal evaluations	Proposal evaluations
Risk analysis	DB design
Innovation analysis	DB construction
Design decisions	
Cost comparisons	
Contractor construction	

9.8.5 Administrative issues for prefabrication

Contract and bid documents

The following process is applicable to ABC. Variations are possible where instead of pure ABC, only a partial ABC method is selected.

For the selection of fabricators, the CMGC will negotiate on the basis of comprehensive bid documents (such as plans, specifications, and estimates (PSE)).

There are two approaches for the first phase of management:

1. For small-span bridges, ready-made proprietary documents provided by the fabricator may be checked by the designer and reused with minor changes.
2. For medium and long spans, the following typical documents prepared by the designer are required:
   a. Construction plans for the precast members
   b. Specifications for fabricating bridge components
   c. Materials and cost estimates based on material types shown in the drawings, which help in arriving at the cost to be incurred.

The fabricator therefore plays an expert role in the CMGC and D-B management systems.

In the second phase of management, the general contractor still requires specifications from the designer for the following sensitive operations. The first step is preparing the detailed construction schedule showing activities on the critical path. In addition, the following steps are required:

- Soil investigation and foundation construction
- Lifting and placing assembled members on SPMTs
- Erecting substructure bridges and placing cranes at optimum locations
- Coordination with utility companies
- Installing sensors for remote structural health monitoring (SHM)
- Testing the bridge for live load before allowing daily traffic

Postdesign construction tasks for the general contractor's team

- Responses to fabricator's/subcontractor's queries prior to their selection
- Bid approval process
- Construction coordination, field meetings
- Answering requests for information (RFIs) related to drawings
- Design change notices (DCNs) when required
- As-built drawing preparation after completion

9.8.6 Progress in lateral sliding technique for substructure components

The conventional cast-in-place techniques require longer roadway closures unless traffic can temporarily be carried off alignment on the new bridge. A complicated aspect of this method is the construction of the foundations, piers, and abutments. Multiple options are available for substructure construction, including:

- Waiting until the existing bridge is demolished and then using prefabricated substructure elements
- Using the existing substructure when possible with minor repairs
- Constructing the substructure beneath the existing bridge using spread footings
- Driving low headroom pile types (i.e., auger cast piles, micro piles) when a shorter bridge is possible
- Constructing the new bridge with an integral cap beam and back wall that functions as an abutment and setting it on substructure units constructed outside the width of the existing bridge

Many of the construction methods that use lateral slide or launching techniques involve constructing the complete or nearly complete bridge off alignment and moving components into place using heavy lift equipment such as SPMTs, large-capacity cranes, strand jacks, and gantry lifts. It is expected that with the growing advances in details and materials, some of the difficulties currently present in these construction methods (such as limited site access or bridges on rivers) will eventually be resolved.

9.9 Construction specifications and details for accelerated completion

9.9.1 Assembly plans

Most bridge construction projects require contractors to submit erection plans. Prefabricated substructures also require a level of preconstruction planning. Write project specifications to require that the contractor submit an assembly plan for the construction of the entire structure, including the precast substructure.

Include as a minimum the following in the assembly plan:

- Size and weight of all elements
- Picking points of all elements
- Sequence of erection
- Temporary shoring and bracing
- Grouting procedures
- Location and types of cranes
- A detailed timeline for the construction, including time for curing grouts and closure pours.
- The CABA Manual provides guidance with the design and detailing of precast concrete structure elements according to PennDOT DM-4 and AASHTO LRFD bridge design specifications, except as noted otherwise.

(Reference CABA Bridges, Precast Structure Elements Guidelines, Accelerated Bridge Construction, May 2012).

9.9.2 Use of precast substructure details sheet

The sheet will normally contain, but is not limited to, the following listed details:

1. Plan view of each substructure unit
2. Elevation view of each substructure unit
3. Typical transverse sections as needed
4. Individual piece plans, elevations, and sections showing the following:
   a. Dimensions
   b. Internal reinforcing details, including grouted splice couplers
   c. Lifting points
   d. Approximate shipping weight of the piece
5. Connection details, including grouted reinforcing splice couplers
6. Tolerance details for all applicable pieces
7. Bar details
8. Table of estimated quantities

Dimensions on the precast substructure detail sheet include the following:

Structural dimensions: Draw all views and details in feet and inches to the nearest ⅛ in.

Reinforcing steel: Show reinforcement dimensions and locations in all views, including bar details in feet and inches to the nearest ¼ in. All measurements are to the centerline of the reinforcements.

Cover: Show cover for substructure elements with 3 in clear cover for bottom mats of reinforcement for footings and 2 in clear cover for other substructure elements.

Angles: Show in degrees, minutes, seconds to the nearest whole second if such precision is available.

9.9.3 Accelerated bridge guide details for substructures

The PCI Northeast Bridge Technical Committee has a series of guideline drawings that represent the design and detailing of precast concrete substructures. These sheets provide examples of different substructure types for the use of accelerated bridge construction in the Northeast. These guideline drawings may be used unless the state design manual recommends other bridge details.

9.9.4 Need for post-construction repairs

Conventional repairs to the substructure do not normally require ABC or prefabrication of the members. The following types of repairs, where limited use of ABC is applicable, occur more frequently:

- Bearings retrofit
- Pier jacketing
- Column strengthening
- Scour countermeasures retrofit
- Foundation strengthening by micropiles
- Seismic retrofit

9.9.5 Sample specifications for concrete and reinforcement properties

Construction documents need to address all important details. Typical concrete strengths for ABC may be higher than for cast-in-place construction due to higher shear strength required in transportation, lifting, and erection.

- The nominal 28-day concrete strength (f_c') for precast substructure elements typically a much higher strength is 5000 psi.
- Specify this strength at a higher level with prior agency approval where higher strengths are required.
- Specify the final designed concrete strength required on the plans.

Use of mild reinforcement: Coat all mild reinforcement according to agency specifications. Coat all grouted splice couplers with epoxy coating. The coating on the bars within the couplers does not need to be removed to make the connection.

Other precast elements: Allow lap splices in closure pours between elements that are not columns. Use threaded mechanical couples for bars that extend beyond the edges of the precast element, except for columns. Do not weld reinforcement.

9.9.6 Sample specifications for closure pours

Closure pour sizes should conform to the construction drawings. These will be placed where needed and implemented as directed, designed, and detailed by the designer.

Concrete compressive strength in the closure pour will be equal or greater than the precast elements (typically 5000 psi). The designer will design and detail closure pours.

The designer will specify wet curing for at least 7 days to increase the durability of the closure pours. The mix will be air entrained and have shrinkage compensating admixtures to prevent cracking and separation of the closure pour concrete, from the adjacent precast concrete. Typical properties are as follows:

- 6-h strength of 2500 psi
- 7-day strength of 5000 psi

9.9.7 Tolerances in prefabricated members

The tolerance of casting elements is critical to a successful installation. The typical detail drawings include details of recommended tolerances. Include these details in all precast substructure projects.

One of the most important tolerances is the location of the grouted splice couplers. Variation in coupler locations will lead to unacceptable misalignments at the coupler locations. The following steps are required for achieving required tolerances:

- Make the tolerance measurements from a common working point or line in order to specify tolerances of critical elements.
- Dry fitting the elements is not necessary provided quality assurance/quality control (QA/QC) procedures are followed.

- Use mechanical couplers in conjunction with the continuous reinforcement in the connected elements when required. All mechanical couplers should conform to AASHTO 5.11.5.2.2 and ACI 318 12.15.3 and meet all agency requirements.

9.9.8 Use of grouted splice couplers

The grouted reinforcing slice coupler is the only connector allowed between the column and adjacent elements. Couplers will develop the minimum specified tensile strength of the attached reinforcing bars. Reinforcement will not have lap splices within the column.

Coupler locations: The preferred configuration is to have the coupler located above the joint. The benefit of having the couplers located at the top of a footing is that they are located outside the column hinge zone. They still need to develop the tensile strength of the bars.

Maximum spacing: Detailing should be for spacing that is close to the maximum bar spacing requirements in the AASHTO LRFD bridge design specifications.

Minimum spacing: The AASHTO requirements for minimum bar spacing are, in part, based on the ability to place concrete properly between the bars. Check the clear spacing between the couplers using the following approach:

The minimum gap between the couplers should be the greatest of the following:

1. 1 in
2. 1.33 × the maximum aggregate size of the course aggregate
3. The nominal diameter of the connected bars

Clear cover: The clear cover for the element is based on the cover over the coupler and the connected reinforcing. This requires the connected reinforcing to be placed slightly deeper into the element in order to obtain the required minimum cover over the couplers. The dimensional guidelines should be based on a review of the selected manufacturer's manual that is supplying the precast product.

Seismic detailing: Grouted splice couplers can be used in plastic hinging zones. The standard requirements for column confinement still apply around the couplers. The diameter of the spiral and of the ties will need to be increased at the couplers.

9.9.9 Column confinement

Confinement of column reinforcing is possible with precast concrete elements.

The AASHTO design specifications do not mandate the confinement reinforcing bars to be continuous from the column into the adjacent members footing or cap. The confinement reinforcing can be ended in the column and separate confinement reinforcement can be added to the adjacent element.

Closed loop stirrups: Closed loop stirrups are permitted.

The commentary in the AASHTO LRFD specifications offers some guidance on the use of individual hoops or ties when compared to spirals.

9.9.10 Lifting devices

The engineer is responsible for checking the handling stresses in the element for the lifting locations shown on the plans. (The criteria of Chapter 8 of the *PCI Design Handbook—MNL-120* should be used.) Create design plans that show recommended lifting locations based on the design of the element. Other criteria include:

- Use two point picks for columns, pier caps, and wall panels, similar to the prestressed beams.
- Double the number of pick points if element stresses are excessive. Add notes to the plan requiring specialized rigging that includes pulleys.
- Do not show specific lifting hardware on the drawings. The contractor may choose alternate lifting locations with approval from the engineer.
- Use a dynamic load allowance of 15%.
- The contractor will provide the spacing and location of the lifting devices and submit plan and handling stress calculations to the engineer for approval prior to construction of the panel.
- The engineer will consult with fabricators for these situations.

9.9.11 Handling and storage procedures

The contractor is responsible for the handling and storage of all substructure elements in such a manner that does not cause undue stress on the element. The contractor will submit a handling and storage plan to the engineer for review, prior to the construction of any element.

The engineer will inspect all elements and reject any defective elements. The rejected elements will be replaced at the contractor's expense. The contractor is responsible for any schedule delays due to rejected elements.

9.9.12 Use of vertical adjustment devices

The plans may show typical devices and alternate devices that may be used with engineer's approval. Leveling bolts will be preadjusted to approximate required final elevation for the element. The designer will detail the type and locations of the devices. Significant torque may be required to adjust the leveling bolts for substructure elements.

Progress meetings: In keeping with the schedule for construction approved by the Highway Agency, regular meetings must be held to iron out any constraints. Use of RFI and DCN may also be required.

9.10 Precast structure elements guidelines

The design and detailing of precast concrete structure elements may be according to the relevant agency and AASHTO LRFD Bridge Design Specifications (FHWA Every Day Counts, Accelerated Bridge Construction May 2012 Initiatives).

The designer can detail extended reinforcing with a closure pour to connect the two bent caps if there is a need to connect them.

The precast substructure details sheet will normally contain, but is not limited to, the following listed details:

1. *Plan view* of each substructure unit
2. *Elevation view* of each substructure unit
3. *Typical transverse sections* as needed
4. *Individual piece plans, elevations, and sections* showing the following:
   a. Dimensions
   b. Internal reinforcing details including grouted splice couplers
   c. Lifting points
   d. Approximate shipping weight of the piece
5. *Connection details* including grouted reinforcing splice couplers
6. *Tolerance details* for all applicable pieces
7. *Bar details*
8. *Table of estimated quantities*

Show the following dimensions on the precast substructure detail sheet:

Structural dimensions: Draw all views and details in feet and inches to the nearest ⅛ in.
Reinforcing steel: Show reinforcement dimensions and locations in all views including bar details in feet and inches to the nearest ¼ in. All measurements are to the centerline of the reinforcements.
Cover: Show cover for substructure elements with 3 in clear cover for bottom mats of reinforcement for footings and 2 in clear cover for other substructure elements.
Angles: Show in degrees, minutes, and seconds to the nearest whole second if such precision is available.
Width: Keep the narrowest width of the element and any projecting reinforcing below 12 ft. This is to keep the shipping costs reasonable. Widths over 12 ft will require investigation, and 14 ft is the maximum width.
Weight: Keep the maximum weight of each element to less than 100,000 pounds in order to keep the size of site cranes reasonable. In some cases, the element weight should be limited to the maximum beam weight on the project. Weights above 50 tons will require investigation.
Height: Keep the maximum height of any element including any projecting reinforcing to less than 8 ft so the element can be transported below existing bridges. Element heights above 8 ft will require investigation.

The limits can be increased for design-build projects. The designer can work with both the fabricator and contractor to size the elements based on the available equipment and the proposed shipping routes.

Show pier bents as single-, double-, or triple-column bents. The designer can choose to use two independent double-column pier bents if four columns are required in a pier. Detail an open joint between the bents.

9.11 Important sheet checklist

Using a checklist helps in preventing omissions. The list items can be revised as required and refined with experience.

Plan view

Accurate, measurable detail should be used, with exceptions to enhance clarity:

1. Label and locate the control line at each substructure unit. Match the terminology on the layout, such as reference line, centerline, or profile grade line.
2. Show abutment numbers, bent number, or both.
3. Reference control dimensions at all working points. These are usually the intersection of the control line and the centerlines of bents and abutments.
4. Overall dimensions of each substructure unit.
5. Beam lines located and numbered.
6. Skew angles.
7. Label joint locations and type.
8. Design data.
   a. *Elevation view*

Accurate, measurable detail should be used, with exceptions to enhance clarity:

1. Elevations necessary to establish the grade of the substructure.
2. Elevations of all beam seats to the nearest 1/16 in.
3. Joint spacing.
4. Joint types.

Typical transverse sections

Accurate, measurable detail should be used, with exceptions to enhance clarity:

1. Piece width dimensions.
2. Control line or centerline of bearing (if applicable).
3. Typical section reinforcing.
4. Reinforcing cover.
5. The designer can detail extended reinforcing with a closure pour to connect the two bent caps if there is a need to connect them.
   a. *Individual component details*

Accurate, measurable details should be used, with exceptions to enhance clarity:

1. Overall dimensions.
2. Locations and sizes of blockouts and voids.
3. Locations of inserts.
4. Internal reinforcing details, including locations of grouted splice couplers.
5. Lifting points.
6. Approximate shipping weight of each piece.
   a. *Other details*

Accurate, measurable details should be used, with exceptions to enhance clarity:

1. Connection details including grouted splice couplers.
2. Joint details.
3. Installation notes.

4. Tolerance details for all applicable pieces.
5. Bar details.
6. Table of estimated quantities.
7. General notes, including (but not limited to) design criteria, loading, class of concrete, epoxy coating or galvanization, and cross-references to various standard sheets.
8. Title block, information block, and engineer's seal.
   a. *Final checks*
1. Comply with (agency's) detailing standards.
2. Check all details and dimensions against substructure to ensure the details are not in conflict.
3. Double-check bars in various details against the bars shown in the bar table.
4. Check that the name and number of the bridge is same on all detail sheets, including layout.
5. Initial the sheet after back-checking corrected details.

9.12 Toolkit of innovative designs for rapid bridge renewal

The toolkit is intended to provide standards that can be constructed using common equipment.

Publications and workshops on ABC were highlighted in Chapter 8. Additional resources are listed in this chapter and in Appendix 1 (Bibliography). There are notable publications from FHWA, ACTT (Accelerated Construction Technology Transfer), and AASHTO, as well as useful workshops on the subject and studies from the many states where many prefabricated bridges were successfully completed. Some good starting resources include the following:

- Introduction to Prefabricated Bridge Elements and Systems," a video that can be accessed at FHWA website.
- Substructure: Bent Caps," a video showcasing work on Texas SH 66/Lake Ray Hubbard Bridge, available at FHWA website.
- Total Substructure System Piers," a video showcasing work on piers on Texas SH 249/Louetta Road Overpass and the Texas US 183 Elevated in Austin.
- FHWA/AASHTO/TxDOT Precast Concrete Bent Cap Demonstration Workshop.

Other related resources include:

- *Prefabricated Bridge Elements and Systems*, Federal Highway Administration, www.fhwa.dot.gov/bridge/prefab
- *Prefabricated Bridge Elements and Systems Cost Study*: *Accelerated Bridge Construction Success Stories*, www.fhwa.dot.gov/bridge/prefab/successstories/091104/index.cfm
- *Development of a Precast Bent Cap System* (Matsumoto, E.E., Waggoner, M.C., Sumen, G., Kreger, M.E., Wood, S.L., Breen, J.E. Center for Transportation Research, The University of Texas at Austin, Research Report 1748-2; Sponsored by Texas Department of Transportation)
- *Grouted Connection Tests in Development of Precast Bent Cap System* (Matsumoto, E.E., Kreger, M.E., Waggoner, M.C., Sumen, G., 2002. Transportation Research Board, Transportation Research Record, Issue Number: 1814)
- *Innovative Prefabrication in Texas Bridges* (Ronnie Medlock, Michael Hyzak, and Lloyd Wolf, Texas Department of Transportation; www.txdot.state.tx.us/brg/Publications/Innovative_1.pdf)

- *Laying the Groundwork for Fast Bridge Construction* (Mary Lou Ralls and Benjamin M. Tang, FHWA Public Roads Magazine, Nov/Dec 2003)
- *Precast Post-tensioned Abutment System and Precast Superstructure for Rapid On-site Construction (*Scanlon, A., Aswad, A., Stellar, J., 2002. Transportation Research Record, Transportation Research Board)
- *A Precast Substructure Design for Standard Bridge Systems* (Sarah Billington, Robert W. Barnes and John E. Breen, Research report no. 1410-2f, Texas Department of Transportation)
- Prefabricated Bridge Elements and Systems in Japan and Europe Summary Report (FHWA International Technology Exchange Programs, May 2004)
- Precast/Prestressed Concrete Institute (PCI), Chicago, IL, www.pci.org
- Canadian Precast/Prestressed Concrete Institute (CPCI), Ottawa, ON, www.cpci.ca

9.13 Environmental issues with ABC

9.13.1 Environmental concerns for ABC near water

A large number of environmental concerns must be addressed related to water, including the following:

- Avoiding stream encroachment
- Maintaining water quality
- Providing fish passage
- Avoiding wetlands contamination
- Determining construction impact on floodplains

Using ABC over a much shorter duration with prefabrication will reduce the adverse impacts on environment considerably compared to cast-in-place construction.

9.13.2 Issues related to ecology

The benefits of ABC in relation to ecology include the following:

- The landscape will be easier to maintain during the project.
- Issues surrounding the preservation of endangered species can be avoided.
- Impact to natural vegetation can be minimized by controlling construction access points.
- Re-vegetation of disturbed areas may not be applicable due to the limited exposure and construction duration.

9.13.3 Maintaining air and water quality

Air and water quality issues will be less of a problem with ABC:

- Noise from construction vehicles will be less of an issue
- Relocation hazards of underground and bridge-supported utilities remain unchanged.
- Reactions with acid producing soils will be minimized.

9.13.4 Other benefits

- There will be less impact on the historical and cultural aspects and aesthetics.
- Temporary works and scaffolding will be minimized.
- Relocation of labor will be minimized, improving the socioeconomic impact.
- Right-of-way issues during construction will be minimized by avoiding materials storage, the lack of formwork, and avoiding the use of a site office for a long duration.
- Permitting considerations and implementing EPA/DEP procedures are easier as adverse effects on fauna and flora are not as severe.
- Requirements for paint removal and containment and disposal of contaminants are not a factor with factory fabrication.
- The need for sound walls mounted on the bridge or the adjoining roadway can be avoided.

9.13.5 Construction permit approvals

For bridges located on streams, a flood hazard area general permit is required. Engineering data and documentation needs to be submitted for permit approval. As per DEP regulations, the following reports still need to be submitted for DEP consideration irrespective of the method or duration of construction:

Environmental Assessment (EA): An EA needs to be provided when the significance of the environmental impact is not clearly established.

Environmental Impact Statement (EIS): An EIS is required when there are impacts on properties protected by the DOT Act or the Historic Preservation Act. Significant impacts on noise and air quality are significantly avoided by factory manufacture and by minimizing site construction.

EIS documents need to be prepared when a replacement or a new bridge has significant impact on natural, ecological, or cultural resources or on flora and fauna, including endangered species such as bog and wood turtles, wetlands, flood plains, and groundwater.

Categorical Exclusions (CE): An action that does not have a significant effect on the environment falls under CE. There will be limited applications such as for installation of signs, etc. Examples provided by FHWA are reconstruction or modification of two-lane bridges, which are different from erecting prefabricated bridges.

Because the erection of a bridge neither damages (nor is likely to damage) an existing wetland nor adversely affects the historical significance of the bridge itself or its surroundings (except as permitted to a limited extent through the environmental regulations), permit approval is generally not a process that delays the project. A pre-construction meeting with the state department of environment protection is desirable to further simplify the construction permit approval process.

9.14 Conclusions

Superstructure construction is more repetitive and modular in approach than for constructing foundations and abutments in the river environment. Management in production has for a great deal assisted by prefabrication of floors in tall buildings. At times, substructure fabrication cannot keep pace with the modern methods used in say the car manufacturing or the assembling factories in Detroit. But greater experience will show the ways and means to reduce current delays a little earlier completion. Although the structural types of bridges vary, a comprehensive construction methodology and code of practice for typical bridges is required. The innovative techniques being used by many agencies and reported in the tables above and in earlier chapters can be utilized for the future.

The progress for using prefabrication has been slower for substructure compared to that for the superstructure, especially for longer span bridges. It is easier to transport horizontal bridge beams and slab panels on an SPMT than the vertical pier bents due to their sizes. Also, post-tensioning is required for the panels to make them watertight. The general requirements of prefabrication for the superstructure horizontal members also apply to the substructure vertical components. However, for emergency bridge replacements on important routes after floods, earthquakes, or accidents, etc., prefabrication of both pier and abutment members would help.

In the United States, SPMTs and heavy-duty lifting cranes are being assembled and all states have adequate access to these facilities, which are extremely important for ABC. The construction season in some states facing extreme weather is only a few months. During the offseason, the substructure components can be manufactured and transported to the sites and erected at the start of the next construction season. Even within the design-bid-build system, partial ABC is being adopted, at least for precast prestressed beams, composite steel girders, and the use of lightweight concrete. Hence, there is a great potential in the future for entire bridges being manufactured away from sites.

Some of the major operations that need to be considered when using ABC include the following:

- *Soil report*: Because foundation design requires soil investigation, this operation should be started well in advance by the owner, even before the award of the contract.
- *Utility pipes*: Advance coordination with the utility companies for supporting their pipes and transferring from pavement elevation to deck elevation is required.
- *Deck drainage*: The method of disposal of rainwater from the deck into public sewers also needs to be planned.
- *Electrification*: If deck lighting is provided, the power supply needs to be arranged from the electric supply company and negotiations need to be started in advance, as the prefabrication activity is in progress.
- *Precasting concrete and welding*: Although prefabrication in a factory may not take as much time as cast-in-place construction under the site conditions, the time required for the plan layout of rebars, the curing of concrete components, and the welding of steel members, etc. remains unchanged.
- *Planning*: The additional time required for planning a route, obtaining permits for heavy and wide loads, applications for police escort, and the hauling distance for the prefabricated bridge from the factory to the site need to be taken into consideration.
- *Hauling heavy loads*: Loading prefabricated components on the SPMTs and unloading them on-site as well as the required lifting and placing operations by the special cranes on-site need to be taken into account in the overall schedule.
- *Stay-in-place formwork*: Compared to the cast-in-place construction erection time for temporary formwork or using the permanent stay-in-place formwork, the additional time and cost for hauling, lifting, and placing needs to be compared to make prefabrication as economical as possible.
- *Modular construction*: The greatest benefit of prefabrication is for small spans, where the hauling and lifting problems are less and pier construction is avoided. Arch structures combine the superstructure girders with the substructure curved columns and are more aesthetically pleasing.

- *Leading prefabrication companies*: There are a wide variety of bridge manufacturing companies in the United States who are successfully conducting their businesses and have developed specialized bridges for repeated use. Examples are High Steel Structures, Acrow, Jersey Precast, and CON/SPAN.
- *Need for standardization*: AASHTO specifications have recommended minimum vertical and horizontal clearance requirements. Similarly, many states have developed standard details for lane widths, shoulder widths, and bicycle tracks, spaces for plants and flowers, etc. Span length alternatives to conform to the width of the highway can be used to standardize bridge lengths. Such ready-made standard span structures using concrete and steel can be made available off the shelf and ready for delivery to the sites, as required. A choice of colors is also available for aesthetic requirements.

Because the construction contractor normally manages these design-build teams and has cost-saving objectives, incentives and bonuses become paramount in minimizing the man-hours of the personnel spent in the field and design office. The construction contractor is now more heavily involved in the selection of structural steel connections and concrete forming details because these are both relatively higher-cost parts of the structure.

(Reference Concrete International, March 2013, page 50)

9.14.1 Quality control

Construction drawings for precast substructures are more specialized than conventional construction drawings. Typical review comments on reinforced concrete detailing of abutment walls, pier caps, and columns are therefore necessary. Examples are review by expert bridge engineers of the connection details, location of hinges, seismic detailing, lifting points, etc. The following review comments (selected from sets of bridge drawings) should be avoided when submitting construction drawings:

- Design is incomplete and not clear enough.
- Details are too complicated for constructability.
- Follow state standard details.
- Spend time on preliminary investigation of alternative structural systems.
- Identify appropriate structural framing systems for gravity and lateral loads.
- Add a note to structural notes sheet, stating deflection of the precast member should be monitored to avoid overload conditions prior to composite action being achieved.
- Product limitations in specifications and additional items in specifications that is not necessary.
- Not enough information on the drawings for the cross-sections for construction.
- Rebar placing issues and detailing that produces a lot of rebar waste.
- Excessive steel at a joint can lead to poor consolidation of the concrete. To reduce congestion at these member connections, avoid placement of rebar splices within the joint, but rather splice the bars to one side or both sides of the column.
- Varying the beam widths along a continuous line of beams. Congestion at beam/column or beam/beam intersections.
- Check deck slopes for drainage.
- Tolerances and finishes not meeting specifications.

- Check shear reinforcement.
- Drawings should be signed by a registered structural engineer of the state where the bridge is located.

Concrete pour joint details

- Alkali silica reaction (ASR) due to local aggregate properties.
- Deicing salts that spall the concrete surface.
- Insufficient precast concrete cover that leads to corrosion of the rebars, especially at underside of deck slab.
- Allow concrete cover to prevent corrosion of rebars.
- Quality of backfill material behind abutments and wingwall should follow specifications.
- Proper inspection required during construction.

Review of foundation drawings:

- Foundation design is too expensive; footings are too big/deep. Review soil report.
- Monitor compaction before placing footings. Consider soil improvement techniques.
- Always get soil borings and a geotechnical report before foundation design and have geotechnical oversight and testing during construction.
- Use deep piles or drilled piers.
- Use caissons or auger piles.
- Use tied spread footings.
- Check for retaining wall failures from settlement and overturning.

Note: Appendices 1–11 are provided at the end of the book for ready reference.

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CHAPTER

Alternative ABC Methods and Funding Justification

10

10.1 Priority needs and replacement costs

10.1.1 Introduction

Traffic volume on a given highway, the structural performance of existing bridges and structural health monitoring are the basic factors in regular maintenance and asset management. Owners and state highway agencies identify and select the bridges in relation to the funds available.

As a matter of policy, safety considerations, risk management and the need to fix a larger number of bridges take priority.

Value engineering methods are used to optimize the cost allocation, and alternative methods of ABC are compared to meet sensitive issues funding. Use of innovative methods is encouraged.

These are the topics which will be addressed in this chapter.

This chapter advances the concepts of ABC discussed in earlier chapters. Analytical terminology to facilitate structural condition evaluation is emphasized. Federal Highway Administration (FHWA) and American Society of Civil Engineers (ASCE) Report Cards to evaluate the condition of bridges are described in detail. Traffic volume data, traffic counts, and maps are used to determine the need for additional lanes.

The large number of bridges that need to be rehabilitated or replaced must be identified and prioritized so that the funds can be allocated properly. Policy making, the scope of reconstruction, selecting economical alternatives, and the use of modular bridges are also emphasized here.

We should note that besides bridges, there are other highway structures that also need ABC. Most retaining walls located at bridge approaches and along the highway are currently using precast segmental construction and proprietary mechanically stabilized earth (MSE) walls. The trend is to extend this approach to wing walls, due to their secondary importance compared to other bridge components.

Innovative techniques and new applications given in earlier chapters are further expanded. Case studies of successful ABC projects by selected states using self-propelled modular transporters (SPMTs) or lateral slide-in methods are added. Many important publications and Website links are referred to as potential further reading. Essential funding needs, value engineering, and alternate solutions such as public–private partnerships (P3s) are discussed.

A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2, ABC.

10.1.1.1 Impact of modern military engineering on ABC

Some of the concepts in ABC were borrowed from military engineering, in which prefabrication is widely used, since saving time saves valuable lives.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00010-1

10.1.2 Avoiding the many cast-in-place (CIP) construction issues

As stated earlier, bridge construction comprises of men (labor), most modern materials, machinery (such as SPMT and high capacity cranes) and method of construction (CIP or various types of ABC). These aspects are usually inter related and affect the finished product directly or indirectly.

The basic decision in using the type of construction i.e. CIP vs. ABC needs to be made. The selection will be guided by the following considerations:

- Timely labor availability. On sites located at remote parts of the country, availability of labor is generally limited. The labor force will not be willing to relocate for a long duration being away from their families.
- Weather problems. In extremely hot and extremely cold climates CIP construction duration needs to be avoided or kept to a minimum.
- Storage yard area required at site. On congested sites such as close to the downtown areas, space for the storage of construction materials and heavy equipment may not be readily available.
- Quality control not as good as in factory construction, which uses temperature and humidity control.
- Individual construction versus mass production. On a given highway, if there is more than one site to work on, modular construction will ensure quality control.
- ABC acquires products made in other states and throughout the world. Factory products from more than one factory can be utilized to achieve rapid construction.
- Time of construction is longer with CIP, where the contractor is not in control.
- Hazards of collapses, casualties, and injuries are sudden. Greater exposure of labor during long periods would increase the danger of accidents.
- Construction inspection time is reduced with ABC. Modular bridges or precast components are already inspected before leaving the factory.
- A compromise between CIP and ABC methods can nowever be achieved with

  Slide-in construction: Variation of cast-in-place construction can be achieved by casting the superstructure in the field, adjacent to the bridge being demolished, and horizontally sliding the bridge into position.

10.1.2.1 ABC design challenges

The use of an existing bridge is governed by the assignment of the bridge to one of three categories: good; deficient; and near collapse.

ABC is best for replacement projects.

The below mentioned procedure may be adopted.

10.1.2.2 Planning aspects

1. Inspect and prioritize structurally deficient (SD) bridges.
2. Select small-span bridges versus culverts.
3. Location: high land and low land.
4. Planning tools for fabrication, transportation, and erection.
5. Cost considerations for selection of ABC; saving in time of construction.
6. Construction management and planning–fieldwork is required.
7. Design-build system is a boon to ABC; development of design software.

8. Use of fiber-reinforced polymer (FRP) and composites.
9. European practice versus North American practice.
10. Silt, clay, and sand as defined in geotechnical report.
11. Avoid waterlogged soils, wetlands, siltation, and outfalls.
12. Overall cost, maintenance and protection of traffic (MPT).

10.1.2.3 Design aspects

The sequence for selecting the design aspects should relate to the method of construction as follows:

1. Review FHWA publications, including Connection Details for PBES and Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges.
2. Review, as applicable, AASHTO provisions relating to: emergency replacement; recent developments in pedestrian and highway bridges; applications for small and medium spans; applications to long-span segmental construction.
3. Review, as applicable, current applications for steel bridges; temporary bridges in place of detours using quick erection and demolition; availability of patented bridges in steel; and US Bridge, Inverset, Acrow, and Mabey types and case studies.
4. Also review, as needed, the applications for glulam and sawn lumber bridges, precast concrete bridges, and precast joint details; use of lightweight aggregate concrete, aluminum, and high-performance steel to reduce mass and ease transportation and erection; and availability of patented bridges in concrete.
5. For small-span bridges, look at Conspan and case studies; use of precast culverts, single- and twin-cell culverts, and pipe culverts for small-flow rivers and small river widths.
6. Establish design criteria for lifting and transport of modular bridges.
7. Review, as applicable, design methods for accelerated bridge superstructure construction; military and floating bridges.

10.1.2.4 Environmental concerns

Environmental concerns are fewer with ABC. Construction must, however, meet Department of Environmental Protection requirements for construction permits.

10.1.3 Prioritization of bridges for rapid replacement or rapid repairs

In a given fiscal year and construction season, there are more bridges to fix than there is funding available within the transportation agency. With thousands of bridges to fix, big money, in the realm of billions of dollars, is required. The following administrative approach is considered appropriate to minimize the funding gap:

Criteria are required for the selection of bridges for replacement or repair. Besides safety, structural conditions such as deficiency and functional obsolescence need to be evaluated so that selected bridges can be short-listed for rehabilitation and replacement.

Cost-saving measures such as applying value engineering at the planning stage, alternate structural solutions, and the use of innovative technology should be considered.

To meet the shortfall, sources of funding may be extended to P3s.

For reconstruction in the minimum possible time, the ABC technology of prefabrication and use of SPMTs, as well as alternate construction techniques such as slide-in, should be considered.

10.1.4 Basic questions for maintenance prioritization

Questions of structural health and funding that transportation agencies need to investigate are given below. Key words are highlighted in bold font:

1. What are the issues with the **daily traffic flow and average daily traffic (ADT)**, such as traffic jams and slow speed?
2. What is the percentage of average daily truck traffic (ADTT) and **daily overweight vehicles**?
3. What is the level of **structural deficiency**?
4. What bridges pose a danger to public safety, by **possible failure**?
5. What are the **criteria for selection** of deficient and functionally obsolete bridges?
6. What is required: repair, retrofit, or **replacement**?
7. What **type** of ABC methods can be used for rapid delivery?
8. What **alternative options** to the existing road network are available? (Value engineering study will confirm that best returns of the investment are possible.)

An attempt is made to answer these questions and related secondary issues in this chapter. Traffic counts, traffic volume studies, and weigh-in platform analysis can answer **questions 1 and 2**. For light traffic loads, Appendix 8, Rapid Construction for Timber, Aluminum, and Pedestrian Bridges, promotes the use of ABC.

The structural definitions given below and FHWA and ASCE Report Cards are linked to **questions 3–5**.

Question 6, involving the need for repair, retrofit, or replacement, is addressed in the section "Priority Selection of Bridges for Reconstruction."

Question 7, involving the use of ABC methods for rapid delivery, is addressed in the section "Advancing ABC using Lateral Slide-in Methods."

Question 8 is an administrative global option, at the top management level and transportation committee of the state. It is also site specific according to the conditions in the state, requiring engineering judgment.

For structural evaluation and analyzing the condition of bridges, the FHWA and ASCE Report Cards provide guidelines. Also, some states have taken the lead in the application of ABC technology. For example, Benjamin Tang of the Utah Department of Transportation (DOT) has emphasized four basic questions: *what*, *how*, *why*, and *when*. Based on these, the important factors and policy-making issues to be considered when adopting ABC from the owner's perspective are:

- Site selection
- Planning and design considerations
- Cost savings
- Contracting and procurement
- Construction equipment
- Structural analysis and computations using computer software
- Developing drawings and construction details
- Developing construction specifications and special provisions for ABC.

10.2 Study of traffic volume, traffic counts, and traffic maps

Traffic volume is the basic cause requiring rapid solution. The greater the annual average daily traffic (AADT), the greater the number of lanes with major maintenance issues due to wear and tear, leading to structural deficiency and eventual bridge replacement. As discussed in earlier chapters, ABC is helping with the replacement of bridges with high traffic volume. It should be noted that the traffic volume data is the most important parameter in the performance of bridges. If there is no traffic then there will be no need for a bridge. Many states have now obtained daily traffic count records during rush hour and over a 12-month period. Interstate and arterial roads in general carry heavier traffic than the local roads.

Highways and roads that were planned some 50 years ago now are facing issues, as the estimated projected traffic has increased significantly and a greater number of lanes is now required for smooth flow. The traffic seems to be heavier in urban locations and on the exits leading into cities and towns. With more people moving to mega-cities or living within commuting distance of big cities for the available jobs in the industrial areas, there is a trend to use more vehicles per family. Hence bridges located in urban areas are subjected to greater wear and tear compared to those in the rural areas and require the greatest attention for maintenance and fund allocation.

Regular traffic counts and traffic volume studies are required for noting any change in traffic patterns. Traffic maps need to be prepared. Weigh-in platform data analysis can answer questions 1 and 2 from the prior section, i.e., what are the issues with the daily traffic flow (ADT), and what is the percentage of daily overweight trucks (ADTT).

Future projections for traffic volume data can be used to check the adequacy of the existing number of available lanes and to plan new lanes for the projected needs.

For small volumes of traffic on local roads, even a single-lane bridge will be sufficient, while for very large volumes, such as on the interstate, three or four lanes in each direction will be required. The 20- or 25-year projected data (based on an estimated percentage traffic increase per year, based on urban demography) can be used to evaluate the number of lanes for future traffic demands, the width of acceleration and deceleration lanes, and the optimum location of roadway exits. The average annual daily truck traffic can serve as a guide for design of dynamic impact and fatigue loads on bridges.

An example of traffic volume maps prepared by PennDOT (for all counties in Pennsylvania) is shown in Figure 10.1. This is available at http://www.dot.state.pa.us/Internet/bureaus/pdplanres.nsf/infoBPRTrafficInfoTrafficVolumeMap.

The above link provides ADT values for all state highways. In the same way, many states have compiled up-to-date traffic count records. This information is no doubt useful for identifying the roads and bridges with peak traffic and for reducing traffic congestion by widening the roads and bridges or by providing alternate routes.

For planning the width and location of bridges, the highway agency for each U.S. state can be contacted for the latest available data for average daily truck traffic. The black numbers displayed on maps represent annual average daily traffic (AADT). AADT is the typical daily traffic on a road segment for all the days in a week, over a one-year period. Volumes represent total traffic in both directions.

10.2.1 Increase of life cycle costs

With the increase in daily truck traffic and the intensity of axle loads, the number of live load cycles tends to exceed the 20 million per year specified in the AASHTO Load and Resistance Factor Design (LRFD) Specifications. Maintenance of the superstructure every 10 or 15 years further aggravates the peak traffic situation, due to necessary lane closures and detours. Besides the indirect losses from traffic jams and reduced speeds, the life cycle costs for structural repairs are considerably increased.

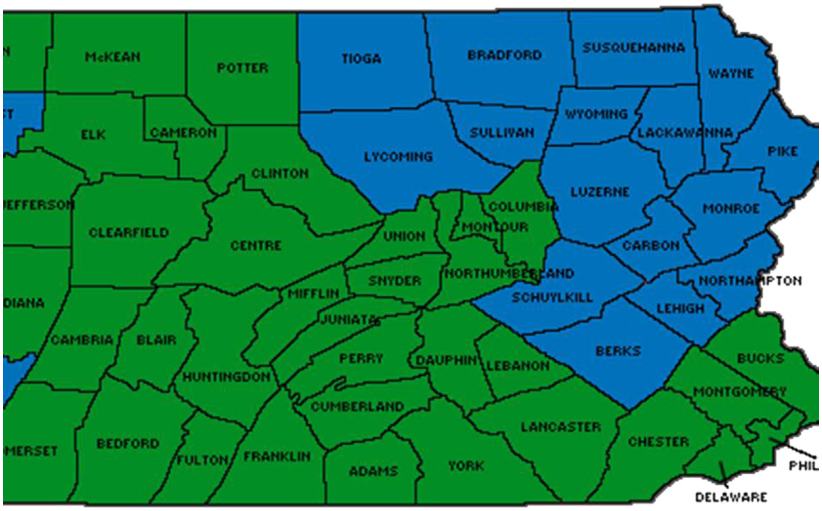

FIGURE 10.1

Selection of each county of Pennsylvania for traffic volume data.

For the owner and the highway authority that is maintaining hundreds of older bridges, for example, major expenses are added to the highway budget each year. Fatigue stresses in steel and concrete girders increase considerably and superstructure replacement becomes due earlier than specified. Further, the wear and tear on the deck topping surface causes cracking, thereby requiring deck replacement.

10.3 Structural performance of existing bridges

Answers to question 3 (the level of structural deficiency), question 4 (what bridges pose a danger to public safety by possible failure), and question 5 (what are the criteria for selection of deficient and functionally obsolete bridges) are addressed in this section.

A diagnostic structural evaluation for traffic issues is possible through detailed inspection and assigning a relative sufficiency rating for each bridge. Such evaluations serve as routine indicators of condition rating (operating and inventory), and for safety classification purposes thereby help in selecting bridges for repair, retrofit, or replacement. The following definitions are used to help analyze the structural health of the bridge and the peak stress in bending and shear. The timely evaluation of these factors can help avoid, the failure of the bridge.

If the main components of the bridge exhibit high levels of deterioration, the bridge is classified as **structurally deficient.** Though not unsafe, these bridges require significant maintenance, rehabilitation, or replacement.

The owner must post limits for both speed and the weight of vehicles permitted to cross such bridges. Within SD bridges, there are three relative deficiency conditions, which can be identified (according to the FHWA criteria) as **poor**, **fair**, and **good**. Very good and excellent also fall in the good category.

Functionally obsolete (FO) bridges are evaluated in terms of outdated design features such as: low traffic capacity; narrow lanes of less than 12 ft width (minimum 10 ft width for temporary conditions); no shoulders or narrow shoulder widths provided for emergency breakdown of vehicles; no bicycle lanes in urban areas to promote use of bicycles; low overhead or underclearances under the bridges; or no deck drainage, no scuppers, or inadequate cross slopes provided. Traffic congestion may result due to the inability to meet the demands of today's traffic or susceptibility to flooding from rain. FO bridges are not automatically rated as SD, nor are they inherently unsafe.

10.3.1 Weight restrictions on structurally deficient bridges

SD bridges often lead to weight restrictions, or "bridge postings," if the bridge is deemed to be incapable of carrying legal truck loads. These weight restrictions contribute to traffic disruptions, such as traffic congestion, slow speed, and detours, and are an inconvenience for commercial vehicles or school buses, which may be forced to take lengthy detours.

As stated above, this directly impacts the economy of the region since transportation of goods will be more expensive due to lengthier routes, loss of time, and increase in use of diesel and gas fuel. In addition to load capacity issues, the high percentage of functionally obsolete bridges in the state indicates that the traffic capacity (bridge width) or underclearance of many bridges in the state is inadequate, as mentioned above. The only practical way to solve this problem is through bridge replacement or by major rehabilitation.

10.3.2 Redundancy, fracture critical members, and other factors used to gauge structural performance

The use of redundancy is an important planning tool as some structural systems are more vulnerable to failure than others. It is a desirable structural quality to have in any bridge or highway structure. Many SD bridges may not have sufficient built-in redundancies. These are a kind of a bonus offered by the configuration of members acting together as an assembly.

The redistribution of the peak stress from one member to members with lower stress would prevent the collapse of the structure and is referred to as **redundancy**. For an assembly of members prior to the collapse of an overstressed member, the load carried by that member will be redistributed to adjacent members or elements. The latter have the capacity to temporarily carry additional load. Redundancy therefore reduces the risk of failure and increases the factor of safety. There are three types of redundancy, which may be described as follows:

1. *Structural redundancy*: Structural redundancy is defined as redundancy that exists as a result of the continuity within the load path. Any statically indeterminate structure may be said to be redundant. For example, a single span is statically determinate and cannot distribute load or stress to another span. It is therefore nonredundant. A continuous two-span bridge has structural redundancy. A single-span bridge with span L and distributed load w has a peak bending moment of $wL^2/8$ while a two-span continuous bridge has less bending moment, i.e., $wL^2/10$.

   AASHTO conservatively classifies exterior spans as nonredundant where the development of a fracture would cause two hinges that might be unstable. Also, integral abutment bridges (without any bearing discontinuity) have higher redundancy than bridges with bearing supports.

2. *Load path redundancy*: Load path redundancy refers to the number of supporting elements, usually parallel, such as girders or trusses. For a structure to be nonredundant, it must have two or fewer load paths (i.e., load-carrying members), like the ones that only have two beams or girders. The greater the number of girders, the greater the capacity to share peak load by the adjacent members, which are braced by the composite deck slab in the transverse direction to act as one composite unit. Failure of one girder in a two-girder bridge will usually result in the collapse of the span. Hence these girders are considered to be nonredundant and fracture critical.
3. *Internal redundancy*: With internal redundancy, the failure of one element will not result in the failure of the other elements of the member. The key difference between members that have internal redundancy and those that do not is the potential for peak stress movement between the connected components of the same element. Internal redundancy is not ordinarily considered in determining whether a member is fracture critical but rather affects the degree of criticality.

Plate girders, which are fabricated by riveting or bolting, have internal redundancy because the plates and shapes are independent elements. Cracks that develop in one element do not spread to other elements. Conversely, plate girders fabricated by rolling or welding are not internally redundant and once a crack starts to propagate, it may pass from piece to piece with no distinction, unless steel has sufficient toughness to arrest the crack.

Fracture critical members (FCMs) linked to redundancy: The AASHTO manual "Inspection of Fracture Critical Bridge Members" states that "Members or member components (FCMs) are tension members or tension components of members whose failure would be expected to result in collapse."

To qualify as an FCM, the member or components of the member must be in tension and there must not be any other member or system of members that will serve the functions of the member in question should it fail.

Inspection and maintenance of FCMs is important in avoiding a collapse. Some load-carrying bridge members are more critical to the overall safety of the bridge and, thus, are more important from a maintenance standpoint. Once an FCM is identified in a given structure, the information should become a part of the permanent record on that structure. Its condition should be noted and documented on every subsequent inspection. Although their inspection is more critical than other members, the actual inspection procedures for FCMs are no different.

The criticality of the FCM should also be determined to fully understand the degree of inspection required for the member and should be based upon the following criteria:

- Degree of redundancy
- Live load member stress

The range of live load stress in fracture critical members influences the formation of cracks. Fatigue is more likely when the live load stress range is a large portion of the total stress on the member.

Fracture toughness: Fracture toughness is a measure of the material's resistance to crack extension and can be defined as the ability to carry load and to absorb energy in the presence of a crack.

FCMs designed since 1978 by AASHTO standards are made of steel, meeting the minimum toughness requirements. On older bridges, coupon tests of samples taken from the bridge may be used to provide the strength information. If testing is not feasible, the age of the structure can be used to estimate the steel type, which will indicate a general level of steel toughness.

Special cases of FCMs: Welding, overheating, overstress, or member distortion resulting from collision may adversely affect the toughness of the steel. FCMs that are known or suspected to have been damaged should receive a high priority during the inspection, and more sophisticated testing may be warranted. A bridge that receives proper maintenance normally requires less time to inspect. Those with FCMs in poor condition should be inspected at more frequent intervals than those in good condition.

Fatigue-prone design details: Certain design details are more susceptible to fatigue cracking. The priority of fracture critical member inspection should be based on their susceptibility to fatigue cracks.

The above definitions are important parameters in evaluating structural health. They will help answer question 6 from the beginning of the chapter (involving whether repair, retrofit, or replacement is required). Computations for Sufficiency Rating using the AASHTO formula and Inventory/Operating Rating (using Beam Analysis and Rating or alternative software) are necessary, for which detailed structural analysis of deflections and stress is required. The method of analysis is a subject in itself and is briefly discussed in Chapter 12 and in the author's textbook, *Bridge and Highway Structure, Rehabilitation and Repair* (McGraw-Hill Inc., 2010).

Resilience: This can be defined as the ability to "bounce back" from a catastrophic event or to resist failure of a component in the bridge network. It is a property of the degree of flexibility of the material, leading to a less brittle or fragile property. Steel bridge members are more resilient than prestressed concrete bridges.

10.4 Review of infrastructure health by FHWA and ASCE

Answers to question 3 (level of structural deficiency), question 4 (bridges that pose a danger to public safety due to possible failure), and question 5 (criteria for selection of deficient and functionally obsolete bridges) are addressed by the ASCE Report Card.

Results from a detailed study, in coordination with AASHTO, are now available online in a series of four reports. According to FHWA, "the study's goal was to define a consistent and reliable method to document infrastructure health, focusing on bridges and pavements on the Interstate Highway System." A related goal was to develop tools to provide FHWA and state transportation agencies with key data that will produce better and more complete assessments of infrastructure health nationally.

Study researchers developed an approach for categorizing bridges and pavements in **good**, **fair**, or **poor** condition that could be used consistently across the country. For this study, definitions of good, fair, or poor relate solely to the condition of a bridge or pavement and do not consider other factors such as safety or capacity.

10.4.1 Tiers of performance measures

Three separate tiers of performance measures that can be used to categorize bridges and pavements were then evaluated. These tiers were previously defined by AASHTO.

Tier 1 measures are considered ready for use at the national level. Performance measures for bridges include structural deficiency ratings.

Tier 2 measures require further work before being ready for deployment and include structural adequacy based on National Bridge Inventory (NBI) ratings.

Tier 3 measures are still in the proposal stage. A tier 3 measure was not included for bridges. These measures were evaluated on I-90 in Wisconsin, Minnesota, and South Dakota. The I-90 corridor runs for 1406 km (874 mi), with average annual daily traffic ranging from approximately 5000 vehicles to 90,000 vehicles.

10.4.2 Highway performance monitoring system

Evaluations were done using Highway Performance Monitoring System and NBI data, as well as data collected by the FHWA project team and provided by the participating state highway agencies. State information included documentation of their systems, processes, and corridor inventory and pavement management system data.

The good, fair, and poor analysis for bridges proved to be a viable approach, with NBI data sufficient for the performance management assessment. However, a bridge's structural deficiency status was not as easily incorporated into the analysis. The study report notes that a measure of structural adequacy based on NBI ratings would be a viable supplement to structural deficiency status as a national measure of bridge condition, although "implementation would require developing a general consensus on its definition."

The assessment would enable FHWA to examine corridor health across multiple states in a consistent manner. To download the pilot study report, *Improving FHWA's Ability to Assess Highway Infrastructure Health* (Pub. No. FHWA-HIF-12-049).

FHWA and AASHTO presented the study results to senior-level state transportation agency representatives at a national meeting held on October 13, 2011, in Detroit, Michigan. To view the national meeting report, which summarizes discussion about the recommended condition ratings and health reporting, please visit www.fhwa.dot.gov/asset/health/workshopreport.pdf.

10.4.3 Bridge management and inspection methods

Remote sensors and equipment are used. LIDAR (light detection and ranging) imaging technology is used to detect deck cracking. When pavement repairs are required, leading to lane closures, it will be appropriate to perform bridge repairs at the same time so that the impact on traffic is minimized. If different contractors are used, coordination will be required.

10.4.4 ASCE report card criteria for condition evaluation

The American Society of Civil Engineers is committed to protecting the health, safety, and welfare of the public, and as such, is equally committed to improving the nation's public infrastructure. To achieve that goal, the Report Card depicts the condition and performance of the nation's infrastructure in the familiar form of a school report card—assigning letter grades that are based on physical condition and needed fiscal investments for improvement.

ASCE's July 2011 report found that deteriorating surface transportation infrastructure will cost the American economy more than 876,000 jobs and suppress the growth of our GDP by $897 billion by the year 2020. The ASCE Report Card is based on collecting and analyzing bridge-related data in the following five categories:

1. Capacity & Condition
2. Funding & Future Need
3. Operation & Maintenance
4. Public Safety & Resilience
5. Innovation & Technology

The following is based on "Celebrating Infrastructure Successes in 2013" by **Brittney Kohler**, available at http://blogs.asce.org/celebrating-infrastructure-successes-in-2013/:

Looking back over 2013, we have many successes in making infrastructure a priority to celebrate. Here is a few that really made our year:

The 2013 *Report Card for America's Infrastructure* was launched in March.

Major infrastructure funding legislative initiatives took off in several states including Maryland, Massachusetts, Pennsylvania, Virginia, Vermont, Wyoming, Texas, and Maine.

Several new bills were introduced that would start improving the nation's infrastructure: the Partnership to Build America Act (H.R. 2084), which could reshape the way infrastructure in the United States is financed; the UPDATE Act (H.R. 3636), which would increase investment in transportation infrastructure through an increase in federal gas tax/user fee; and the BRIDGE Act (S. 1716)/National Infrastructure Development Bank Act (H.R. 2553), both of which facilitate infrastructure investment through creation of a national infrastructure bank.

Five states—North Carolina, Oklahoma, Kansas, Missouri, and Washington—put out state-based Infrastructure Report Cards challenging their state's leaders to get to work on the infrastructure issues in their area.

The report released on January 15, 2013 presents an overall picture of the economic opportunity associated with infrastructure investment and the estimated cost of failing to fill the investment gap. The sources used in this discussion are listed in the Bibliography. ASCE's Failure to Act economic report series shows the economic consequences of continued underinvestment in our nation's infrastructure, and the economic gains that could be made by 2020 in terms of GDP, personal disposable income, exports, and jobs if we choose as a country to invest in our communities. To download the full report, Failure to Act: The Impact of Current Infrastructure Investment on America's Economic Future, please visit, </uploadedFiles/Infrastructure/Failure_to_Act/ASCE_FailuretoActReportSummary_Infographics-Package.pdf>.

10.4.5 Safe load capacity rating

Bridge condition issues are governed by the highest number of structurally deficient bridge population. A liberal posting policy is permitted by AASHTO (operating rating). There are a variety of policies regarding at what level to post a bridge, such as:

- Operating rating
- Inventory rating
- Above inventory rating
- Between operating and inventory rating

For example, Connecticut standards allow for posting at 15% above inventory rating. If Pennsylvania were to apply this standard, nearly half of Pennsylvania bridges (11,000) would be posted with weight restrictions. PennDOT has a special permit process (4902 permits) for vehicles desiring to cross a weight-restricted bridge. Emergency vehicles can apply for this permit. The average 9-mile detour length is for SD bridges only and not for the entire bridge population.

For asset management, the dollar amount the state spends on bridges from year to year is required, as well as the dollar amount needed in order to keep all the bridges in a state of good repair, including state and local bridges and those owned by commissions/authorities.

10.5 ABC application in asset management

Question 6 (What is required: repair, retrofit, or replacement?) is addressed in this section. The quality of life for any community is linked to its economy, which requires a highway system that provides a safe, reliable, and efficient driving environment.

Question 7 from the beginning of the chapter (What type of ABC methods can be used for rapid delivery?) is also addressed when discussing the issues of asset management and type of construction management.

10.5.1 Contract management methods

Near the start of the project, the pros and cons of following types of contract management need to be discussed:

- Design-bid-build (partial accelerated bridge construction, partial prefabrication)
- Design-build (full accelerated bridge construction, prefabrication)
- Public–private partnership

10.5.2 Scope of work

The nature and scope of work provides further information on how to best plan and approach a project. For each of these, there are different types of modern applications:

- Widening of bridge deck
- Deck replacement only
- Superstructure replacement on existing footprint
- Complete bridge replacement on existing footprint
- Complete bridge replacement on a new footprint

When determining the scope of the work, further investigation is required to plot the right course:

1. *Identifying the causes of structural deficiency, functional obsolescence*, *and bridge failures*: A review of the issues addressed in previous report cards and what has been implemented so far needs to be discussed. Priorities in selection criteria for rehabilitation or replacement need to be examined.
2. *Life cycle cost analysis*: The value engineering process for reducing the cost of construction should include life cycle cost analysis. Standard software needs to be introduced.

10.5.3 Improvements in design/specification methods

Based on the parameters discussed above, alternatives and new methods should be considered for both the superstructure and substructure. An evaluation matrix based on the following should be prepared:

- Initial construction cost
- Life cycle cost of maintenance
- Environmental and social impact
- Constructibility
- Future maintenance/inspection

Modular construction: High-ADT roads need to be widened. Transportation agencies expect that design and construction costs will be reduced since both design and construction will be standardized and repeated for all SD bridges, on a mass scale. This means fewer traffic interruptions, fewre lane closures, and safer and more reliable connection of people to their homes, workplaces, schools, and communities.

10.5.4 Key planning considerations when using accelerated construction

Good planning includes the following:

- *Bridge width*: Meeting the functional requirements, such as providing an adequate number of lanes to match the width at the approaches.
- *Monitoring heavy trucks*: Preventing overload by installing weigh-in machines.
- *Posting of warning signs and directions*: Locating signs and directions ahead of the bridge exits.
- *Inspection chambers*: Providing facilities for ease of maintenance, such as provision for inspection chambers.
- *Structural health monitoring (SHM)*: Using remote sensors and nondestructive testing.
- *Geometry*: Planning for the required site geometry parameters, skew, and curvature, as well as adequate sight distance.
- *Vertical underclearance*: Providing sufficient vertical clearance under bridge girders (16 ft, 6 in. minimum) over railroads and adequate openings over waterways for peak floods.
- *Horizontal clearance*: Planning for required horizontal edge distance to the abutment walls.
- *High-strength materials*: Using modern high-strength and corrosion-resistant materials to minimize life cycle costs.
- *Girder depth*: Addressing structural design aspects such as keeping deflection and vibration of girders to a minimum.
- *Use of jointless deck*: Integral abutment bridges are an option.
- *Bearings performance*: Allowing unrestricted bearing movements to keep the concrete deck surface uncracked and provide adequate ductility of joints.
- *Modern equipment*: The construction industry has benefited greatly from the use of new machinery, high-capacity cranes, and tractor-trailer vehicles such as SPMTs for freight. Precast concrete technology and transport of prefabricated replacement bridges offer quick and reliable solutions by minimizing delays and reducing construction time (Figure 10.2).

Indirect costs: Experience has shown that if any of these considerations is lacking, indirect costs in terms of structural damage, delays, and accidents (above that provided for in the original budget) will accrue.

A comparison of policies and regulations is required between the state documents (such as DM4 and PUB 408 for Pennsylvania) and the design methods and documents of FHWA, NCHRP, and AASHTO. The author helped in revising the first NJDOT LRFD Bridge Design Manual, which included the following forward-looking policies and standards:

- Construction of pedestrian bridges using structural plastics
- Bridges over rivers using new techniques, as introduced by the FHWA in HEC-18 and HEC-23
- Use of arch bridges/truss bridges (longer spans possible with new steel and new concrete materials)
- Introduction of spliced prestressed concrete I-shaped girder designs (longer spans possible from 225 to 270 ft, competitive with the steel spans)

FIGURE 10.2

Use of prefabricated columns and precast cap.

Photo courtesy of Sung H. Park, Formerly of NJDOT, Trenton, NJ.

- Introduction of long-span segmental construction (for example, Edison Bridge)
- Military bridges (using new military live loads)

Precautions during demolition: Demolition of existing substructure for foundation construction can cause delay in ABC and will have an adverse impact on traffic. Even in phased demolition and phased reconstruction, one or more lanes need to be shut down. To prevent debris from falling below, shielding (such as installing wire nets) below the existing deck must be provided.

Precast deck design: Precasting minimizes traffic impact, improves construction zone safety, creates less environmental disruption, makes bridge designs more constructible, and improves quality and life cycle costs.

A one-course deck slab with a corrosion inhibitor admixture may be preferred. Minimum top reinforcement cover is higher than the cover required by AASHTO LRFD Specifications (e.g., 2¾ in.). Two-course construction with the overlay of LMC or silica fume requires an additional 1–2 weeks construction time. Described as innovative applications in Chapter 4, some of the materials used for precast decks include the following:

- Lightweight concrete (LWC)
- Fiber-reinforced polymer concrete
- High-performance concrete (HPC)/Ultra HPC (UHPC) for superstructure

Planning for minimum dead weight: In seismic zones it is important to minimize inertia forces. Deck slab weight contributes the most to total dead weight. It can be made lighter by:

- Using lightweight aggregate concrete
- Using orthotropic slabs

Promoting aesthetics: There are several options available to make the prefabricated components appear pleasant such as,

- Open appearance
- Avoid abrupt changes

- Pier geometry can have a pleasant look
- Use of MSE walls with patterns

Foundation assessment:

The “Site Data” package includes the substructure boring logs for the bridge. These logs should be evaluated with regard to the following:

- Location with respect to the new bridge and consistency of the soil with respect to each log.
- There should be sufficient information to estimate pile lengths and sheeting depth.

10.5.5 Deck replacement

A cost comparison can be made with selected precast proprietary panels. Deck panels will be designed for main reinforcement, either perpendicular or parallel to direction of traffic flow, as applicable. Shear studs on top of beams will be arranged in groups and will be grouted inside pockets provided in the precast panels.

The cost of stay-in-place forms required for cast-in-place deck construction will be avoided by using prefabricated panels.

1. *Fiber-reinforced polymer bridge deck*: FRP systems can be utilized to replace concrete decks on steel girders, or to serve as a self-supported short-span bridge superstructure. Carbon FRP (CFRP) is also being used.
2. *Precast panels using high-performance concrete*: HPC is a set of specialized concrete mixes that provide added durability for concrete structures. Their benefits include ease of placement and consolidation without affecting strength, long-term mechanical properties, early high strength, and longer life in severe environments. They also conserve material, require less maintenance, deliver extended life cycles, and, if designed well, enhance aesthetics. Use of HPC with galvanized reinforcement steel will enhance durability. HPC has become a conventional bridge construction material partly due to the Strategic Highway Research Program conducted by FHWA. UHPC is also suitable.
3. *Exodermic deck slabs*: For rapid deployment in deck replacement projects, use of adequate span lengths of a lighter Exodermic deck system offers benefits.
4. *Effideck precast panels*: Deck panels such as the Fort Miller Co.’s Effideck may be used. Precast deck can be cast in panels of required sizes, usually 5–6 ft wide or as dictated by existing supporting girder spacing, with the longer side placed transversely.

Multiple-span arrangements: Continuous design using steel rolled beams or built-up plate girders takes into account the continuity over the interior support points. Poor continuous span ratios may result in uplift. For longer spans live load deflection requirements become important.

10.5.6 Selection and design of prefabricated girders

Use of the following types of girders are preferred. A comparative study may be required:

Concrete girders

- Segmental box designs
- Post-tensioned, spliced bulb-tees
- Segmental viaducts with variable depth units

- Prestressed concrete trapezoidal box and tub sections (compare with the alternate bulb-tee sections)
- Use of higher-strength concrete (10 ksi) for prestressed concrete beams
- Corrosion inhibitor aggregate concrete for deck surfaces (compare with alternate latex modified concrete)
- High-performance steel (HPS) 70 W/100 W girders
- Composite/Inverset girders
- Hybrid steel girders

Rolled steel girders versus fabricated plate girders: Rolled sections with welded or bolted cover plates at the bottom flange of the midspan were popular at one time for the small span range. However, due to the limited depth of 36 inches and fatigue at welds of tension connections, they were not economical and had maintenance problems.

Bridge designers frequently use cold-formed plate girders with variable size, shape, and strength. Typically, 80–100 foot lengths of girder are easier to galvanize, transport, hoist in the air, and erect in position. Splice plates are used for longer lengths.

Other girder considerations: Prestressed concrete adjacent beam design is often chosen over spread steel beams or adjacent steel box beams when a structure must be opened to traffic quickly. This type of construction eliminates the need for deck slab forming. It can also accommodate a temporary asphalt wearing surface if the time of the year prohibits placement of the concrete deck.

Where significant space must be provided for utilities, a spread system using steel girders, concrete I-beams, or bulb-tees is the preferred choice. Spread concrete box units can also accommodate some utilities.

Bridge on vertical curves: In addition to skew and horizontally curved bridges, the bridge approaches and the bridge deck can be on a vertical curve. Vertical curves are better handled with prefabricated multi-girder systems, since camber can be fabricated and controlled with greater accuracy. Adjacent prestressed units must accommodate any curve correction by placing a variable depth deck slab. This can result in considerable additional dead load, necessitating a deeper beam. Prefabricated steel girders can be given the shape of a vertical curve more easily than a prestressed concrete girder.

Full composite action between slab and beam is assumed due to adequate use of shear connectors. Composite action helps in equally distributing dead loads from parapets, median barriers, and sidewalks to longitudinal girders.

At locations where either long piles or poor bearing capacity is anticipated, prestressed adjacent box or adjacent slab design has the disadvantage of having a heavier superstructure. Under these conditions a spread box, bulb-tee, or concrete I-beam with deck slab configuration might be considered to reduce the loads.

10.5.7 Bridge types based on span lengths

10.5.7.1 Span lengths less than 40 ft

Prestressed concrete bulb-tees, I-beams, or spread boxes are alternatives worth considering.

The various types of units and materials available for this span range include deep fills, culverts, underpasses, tunnels, aluminum and steel plate pipes, masonry, and concrete arches.

Precast or cast-in-place reinforced concrete structures: Reinforced concrete structures for culverts and short-span bridges consist of four-sided boxes, three-sided frames, and arch shapes. These structures are usually precast in segments and assembled in the field. Four-sided boxes have a maximum practical single-cell clear span of approximately 20 ft. Three-sided structures have a maximum practical clear span of approximately 50 ft.

Deck slabs or deck/girder designs: Prestressed slab units, stress-laminated timber decks, and/or timber decks with steel girders cover this entire span range. Conventional reinforced concrete slabs, however, are inefficient for spans greater than 25 ft due to their excessive depth and heavy reinforcement. Composite deck systems utilizing concrete with built-up steel girders or rolled sections can also be considered for spans in this range.

10.5.7.2 Small spans between 40 and 100 ft

Special prefabricated bridge panels with concrete decks and steel beams can reach spans approaching 100 ft. They have the advantage of reduced field construction time.

Adjacent prestressed concrete slab units can be used to a maximum span of about 60 ft. Prestressed concrete box units, concrete I-beams, bulb-tee sections, etc., are used for the 60–100 foot span range.

Bulb-tees are usually preferred over concrete I-beams. Conventional composite design systems utilizing concrete decks and steel stringers can be used for the entire span range. At the lower end of the span range, rolled beam sections would be used. Fabricated, welded plate girders would more likely be used at the upper end.

10.5.7.3 Medium span lengths between 100 and 200 ft

Special modified prestressed concrete box beam units up to 60 in. deep can span up to 120 ft Prestressed concrete I-beams and bulb-tee beams can span up to approximately 140 ft. The designer should investigate the feasibility of transporting and erecting the beams, especially those with a span longer than 140 ft.

Composite steel plate girder systems can easily and economically span this range. Single spans up to 200 ft have been used. Once the single span exceeds 200 ft, alternate multiple span arrangements should be considered. The cost of additional substructures must be compared to the greater superstructure cost.

10.5.7.4 Long span lengths between 200 and 300 ft

These types of special structures are used to address limited member depths, aesthetics, and compatibility with site conditions. Constructibility concerns and possible alternatives should be discussed in detail due to higher cost considerations.

10.5.8 Inspections required for fixing the bridges

Bridges are inspected a minimum of every other year and are given numeric ratings based on their observed condition. The field inspectors look for various issues on the bridge components (i.e., beams, deck slab, abutments, piers, etc.) and determine the condition of these components.

The federal government requires all new bridges to conform to the AASHTO Bridge Design Specification. In each state, this is supplemented by the state bridge design specifications or those developed by the major highway agencies. These regulations ensure that all bridges are designed to meet a minimum level of safety for the bridge to serve at least 75 years according to AASHTO requirements.

Some states have old highways and bridges that are among the most heavily traveled in the nation. While on average typical highway bridges are designed for a 50-year life span, the average age of highway bridges in now higher than 50 years. The average age of many SD bridges is also higher than 50 years. State, county, local, private, and authority bridges are included in these percentages.

Each year, every transportation agency has hundreds of bridges on its agenda. These need to be fixed or replaced on a priority basis so that traffic flow in the future will not be adversely affected. The following priority levels are currently being used by many states:

1. Emergency repairs due to major damage from earthquakes, accidents, subsidence, and foundation erosion from floods.
2. Less critical situations based on routine inspections and structural ratings for classifying structurally deficient bridges.
3. Bridges identified as functionally deficient that are not meeting traffic demands.
4. Areas of weakness and safety concern that prevent smooth flow of daily traffic identified with the ASCE four-year report cards for highways and bridges (the author was appointed to serve on the ASCE panel and was responsible for evaluating the innovations and new technology category for bridges in Pennsylvania for the 2014 Report Card).

10.5.9 Rapid construction of timber, aluminum, and lightweight bridges

The present progress in ABC applications has its roots in the assembled lightweight bridges, which are designed for lighter loads. Proprietary bridges (such as GatorBridge, Conspan, Backpack, and many others) are being commonly used for small spans as pedestrian bridges and even in gardens. Their aesthetic shapes, light weight, durability and strength, and quick delivery and erection are now extending their applications to longer spans. Timber bridges have been in use for thousands of years and their performance is well known. Aluminum and structural plastics are comparative new applications.

These bridges are known to resist rust. They are also strong, lightweight, easy-to-assemble arches with no steel bars and may solve rapid construction problems.

Figure 10.3 shows an innovative Backpack bridge developed at the University of Maine.

The proprietary bridges are ideal for rapid construction for low live loads and small spans.

The following load combinations are used in accordance with the relevant design codes:

Load Combination I–Dead Load Only
Load Combination II–Dead Load + Pedestrian Live Load

FIGURE 10.3

Backpack arch-shaped bridge over the Little River in Belfast, Maine.

Reference: Murray Carpenter and Fred Field, The Boston Globe Correspondent, November 15, 2010.

Load Combination III–Dead Load + Wind Loads
Load Combination IV–Dead Load + Vehicle loads
Load Combination V–Top Chord/Rail Load

10.6 Evaluating the condition of state bridges and funding

The collapse of the I-35 Bridge in Minneapolis in August 2007 was a focusing event that has changed bridge engineering and management practice in the United States and brought infrastructure into the national dialogue. Technology-based applications such as the following have shown significant cost savings to owners while assuring the efficiency, effectiveness, and reliability of aging infrastructure:

- Structural health monitoring
- Nondestructive evaluation
- Sensing and simulation
- Geometry capture and image processing

Some state agencies like PennDOT have started utilizing a number of advanced testing and monitoring methods to optimize their inspection, evaluation, and rehabilitation of bridges in the Commonwealth. Examples of these are laser sensors (or so-called LIDAR) to monitor movement of walls and bridges, as well as infrared thermographic technologies to detect delamination in bridge decks.

10.6.1 Recommendations

The following generalized recommendations represent a global approach and are applicable to states in general:

1. *Effective maintenance and reducing life cycle costs*
   a. Focus on bridge preservation so that small problems can be corrected before they become significant and costly problems.
   b. Target the most critical structurally deficient bridges by prioritizing their maintenance, repair, and replacement projects.
   c. Improve efforts to enforce state and federal truck weight limits to minimize unnecessary damage to bridges due to unpermitted overweight vehicles.
   d. Continue stricter risk-based weight limitation policies to maintain public safety in light of the aging population of structures.
   e. Continue the rigorous inspection program that is in place. Consider national initiatives to put more inspection effort into aging and vulnerable structures, while putting less effort into simpler structures that are in better condition.
   f. Increase resiliency of the state’s bridge population by gradually replacing or strengthening fracture critical bridges and by replacing aging bridges with structures that are less vulnerable to catastrophic events.
2. *Monitoring and inspection*
   a. Investigate the latest technological advancements in structural health monitoring, nondestructive evaluation, sensing, simulation, and other approved innovations to better evaluate the current condition and capacity of the bridge population.

   b. Supplement conventional bridge design, inspection, and maintenance practice in the case of major, long-span, movable, or complex system bridges. These technologies can also be utilized in identifying of and programming for maintenance needs.
3. *Introducing new technology and innovative structural systems*
   a. Update design manuals and construction specifications as new technologies are introduced to the engineering practice.
   b. Investigate prequalifying contractors based on their ability to handle new technology and by their familiarity with new construction techniques, in addition to the lowest bid amounts. Key technologies include:
      - Integral abutment bridges with prestressed girders that also eliminate deck joints
      - Semi-integral abutment bridges
      - Bridges with integral piers
      - Simplified seismic detailing procedures
      - New erosion protection countermeasures for foundations in rivers
      - Geosynthetic reinforced soil abutments similar to those used by Ohio DOT
      - Limits of splice locations in girders
      - Introduction of NEXT Beam (precast concrete beam system)
      - Introduction of precast substructure (Central Atlantic Bridge Associates standards and guidelines)
4. *Introducing new concepts and major improvements*

Concepts that were successfully used in other states for reducing life cycle costs and improving safety can be learned at Transportation Research Board (TRB) and Structural Engineering Institute international conferences, which are held every year. At these conferences, successful technologies implemented worldwide in the recent years are discussed.

10.7 Need for timely project funding

All funding estimates are linked to value engineering with the objectives of reducing initial costs and life cycle costs.

10.7.1 Rules of thumb for estimating ABC costs

Project cost analysis requires cost evaluation and estimation of the necessary time and materials. In addition, life cycle costs, roadway user costs, maintenance of traffic costs, and safety costs need to be accurately worked out.

For large projects with significant repetition, ABC costs can be less than conventional construction:

- For moderate-sized projects with some repetition, a 10–20% reduction is possible.
- For smaller projects, there could be 20–30% reduction.
- For complex projects with very specialized requirements, the savings could possibly be higher.

However, ABC costs can be higher due to the following:

- Unfamiliarity with the process
- Risk

- First-time use of a design
- Cost of training for staff
- Construction time limits, including fabrication timeline
- Need for specialized equipment such as SPMTs and high-capacity cranes

10.7.2 Project funding and scoping

The decision to continue maintaining a bridge or to demolish and replace it is based on safety considerations and the cost required to overcome deficiencies. Sources of funding for most public works are as follows:

- FHWA provides 80–100% funds on selected bridges.
- The state will provide the remaining necessary funds.
- The local government would not generally provide for new bridges but would for rehabilitation.
- Private funding may sometimes be available but is unspecified.

The results from the following investigations should be included in the scoping document:

Scoping for rehabilitation project: The scoping should address the specific deficiencies of the relevant bridges and structures. The scoping document may also serve as a design approval document. Three major aspects of a scoping document are the following:

- *Physical condition*: This involves considering the overall condition of the bridge and the specific condition of the major structural elements from the inspection reports, and obtaining and examining bridge inventory, load rating data, and the latest inspection report.
- *Age of bridge and loads*: The year of construction and design loading information provides clues to the potential serviceability of a rehabilitated structure.
- *Identifying the geometry and materials used*: It is necessary to evaluate connection details that may limit potential alternatives. Also it is important to obtain and examine record plans, structure width, the type of construction, and the fabrication methods employed.

Verifying documented information: The steps are:

- *Visiting the project site*: This is not meant to be an in-depth bridge inspection, but rather a verification visit to assist in feasibility assessment.
- *Verifying data*: This involves assuring that the information in the bridge inventory and inspection system and on the record plans is accurate.

Evaluating hydraulic adequacy of the structure for river bridges: Some preliminary engineering activities may be done prior to the closure of scoping activities. The steps are:

- Performing a hydraulic assessment
- Identifying susceptibility to flooding: This includes investigating scour and damage from floating ice and debris.

Determining reasonable cost and schedule for the most feasible alternative: The steps are:

- Providing project-specific programming information.
- Comparing the general work requirements to other projects of similar size and type. Based on similar projects, one can estimate a reasonable cost for work and prepare an approximate schedule.

In sum, the information gathered and the conclusions reached through these activities should be presented in the project's scoping document, and any unfeasible alternates should be eliminated.

10.7.3 Maintenance costs and funding sources

Bridges built during 1950s and 1960s are getting old. The average age of the nation's over 600,000 bridges is currently 42 years and increasing each year. Maintenance costs are ever increasing and huge funding is needed: the nation's estimated 67,000 structurally deficient bridges make up one-third of the total bridge decking area in the country, while the bridges that are being repaired are smaller in scale than required.

It is estimated that the United States would need to invest over $20 billion annually to maintain all of these bridges, while only about $13 billion is being spent currently. The federal, state, and local governments need to increase bridge investments by $7 billion annually.

State gas taxes are going up in many states such as Maryland, Vermont, and Wyoming; Virginia is raising added revenue with a switch to sales taxes on the wholesale price of fuel; Arkansas is dedicating a half-cent sales tax increase to transportation. Most of today's state infrastructure advances are based on public–private partnerships. Indiana successfully completed a public–private deal to finance the 157-mile Indiana Toll Road.

The federal credit and credit enhancement program called TIFIA (the Transportation Infrastructure Finance and Innovation Act) provides federal loans or standby lines of credit to finance nationally significant highway or transit projects. The most recent federal transportation-authorization bill increased the total dollars available to TIFIA loans eightfold.

- Local and state governments lack the resources to address the problems more aggressively.
- Funds are needed for fundamental and applied research that encompasses the geosciences, geotechnical engineering, structural and infrastructure engineering, social and economic sciences, and policy decision making. Community resilience to major earthquakes can only be achieved through the implementation of findings from the research and development and through appropriate mitigation and preparedness actions.
- In a 2005 study supported by FEMA and the U.S. Department of Homeland Security (http://www.fema.gov), it was revealed that for every dollar spent by FEMA in mitigation activities during the period from 1993 to 2003, our society was able to save four dollars on average. The mitigation activities, including advanced technology and structural design codes, led to significant potential savings to the federal treasury in terms of future increased tax revenues and reduced hazard-related expenditures.

ASCE's "Failure to Act" economic report series shows the economic consequences of continued underinvestment in our nation's infrastructure, and the economic gains that could be made by 2020 in terms of GDP, personal disposable income, exports, and jobs if we choose as a country to invest in our communities. By 2020, the investment shortfall is likely to exceed one trillion dollars. If not fixed in time, the costs will soar farther. The culminating report released in January 2013 represents an overall picture of the economic opportunity and the cost of failing to fill the investment gap.

10.7.4 Funding needs

Approximately 300 bridges per year in the United States become structurally deficient due to age and deterioration. Without additional funding approved by the state legislature, the number of SD bridges will continue to increase. Many state bridges are in dire need of additional long-term funding.

Public–private partnerships: Commonly referred to as P3s, they are increasingly popular with lawmakers looking for ways to fund infrastructure projects without increasing government spending. The Transportation Infrastructure Finance and Innovation Act program has emerged as a popular resource for states to use federal grants to lure matching funds for transportation project from private companies. A public–private partnership is a government service or private business venture that is funded and operated through a partnership of government and one or more *private sector* companies. These schemes are sometimes referred to as PPP, P3, or P^3.

PPP involves a contract between a *public sector* authority and a private party, in which the private party provides a public service or project and assumes substantial financial, technical, and operational risk in the project.

With the P3 approach, states can replace SD bridges more quickly by bundling hundreds of bridges with similar design into a Rapid Bridge Replacement Project.

According to a FHWA study in 2008, each dollar spent on road, highway, and bridge improvements results in an average benefit of $5.20 in the form of:

- Reduced vehicle maintenance costs
- Reduced delays
- Reduced fuel consumption
- Improved safety
- Reduced road and bridge maintenance costs
- Reduced emissions as a result of improved traffic flow

At current and projected levels of state funding, more than 95% of transportation dollars are exhausted in keeping the existing system functional, leaving very little funding for capacity-adding projects. In addition, funding levels for capacity-adding projects has dropped significantly over the past few years. Capacity-adding projects include wider highways and bridges as well as new highways, bypasses, and bridges.

The lack of funding will do more than create local traffic delays, as the bridge conditions will have an impact on local and regional traffic, emergency response, safety, and the economy of the region. Insufficient load capacity (due to increase in truck weights), structural deficiency (the national average of SD bridges is 11%), and functional obsolescence (the national average is 14%) are all issues that must be addressed.

10.7.5 Public–private partnerships as a funding alternative

For many public owners and other infrastructure project stakeholders, P3s represent tremendous promise as a source of development and financing for much-needed infrastructure projects. With the P3 approach, hundreds of SD bridges can be replaced more quickly by saving money and minimizing the impact on the traveling public.

In some types of P3, the cost of using the service is borne exclusively by the users of the service and not by the taxpayer. In other types (notably the private finance initiative), capital investment is made by the private sector on the basis of a contract with government to provide agreed services and the cost of providing the service is borne wholly or in part by the government. There are usually two fundamental drivers for P3s.

Firstly, P3s enable the public sector to harness the expertise and efficiencies that the private sector can bring to the delivery of certain facilities and services traditionally procured and delivered by the public sector.

Secondly, a P3 is structured so that the public sector body seeking to make a capital investment does not incur any borrowing. Rather, the P3 borrowing is incurred by the private sector vehicle implementing the project and therefore, from the public sector's perspective, a P3 is an "off-balance sheet" method of financing the delivery of new or refurbished public sector assets.

10.7.6 PennDOT promotion of P3 system

According to a report by Jon Schmitz of the Pittsburgh Post-Gazette, PennDOT hopes to team with private industry to reduce the state's inventory of deficient bridges.

At least 500 decaying bridges would be replaced starting in 2015 under a partnership in which a private entity would be selected to design, build, and maintain the bridges, in exchange for payments from PennDOT that would be tied to performance.

The state owns about 4200 bridges that are designated as structurally deficient. While considered safe, the bridges have at least one component that is deteriorating, placing them at risk for weight restrictions or, ultimately, closure. The average age of Pennsylvania's bridges is about 50 years.

With a 2012 public–private partnership law in place, PennDOT initially had hoped to bundle 300 bridges into the program. Enactment of new transportation funding legislation has enabled the department to expand the program.

Modular construction: PennDOT hopes to capitalize on cost savings because most of the new bridges will have similar designs and construction standards. In the past, the department typically would pay for design and construction of bridges one at a time.

The public–private partnership "gives us the ability to accelerate the delivery of 550–650 bridge replacements that otherwise wouldn't happen for 15–20 years if we were to use a traditional contracting model," a PennDOT spokeswoman said. The project has generated a lot of buzz in the construction industry. A presentation on the program in November drew representatives of nearly 150 companies, including contractors, engineers, and financial organizations.

10.7.6.1 Puerto Rico

Baldorioty de Castro Avenue Overpasses.

10.7.6.2 South Carolina

Another example is the reconstruction of Arthur Ravenet Jr. Bridge in Charleston, South Carolina. Over 248,000 tons of concrete was salvaged from demolition of old structures and reused to create 82 acres of reef habitat. California, Texas, Virginia, Michigan, Minnesota, and Utah were identified as being among the highest.

10.7.7 Modification of public–private partnerships for design-build ABC

Initially, most public–private partnerships were negotiated individually, as one-off deals, and much of this activity began in the early 1990s.

Britain: In 1992, the *Conservative* government of *John Major* in the United Kingdom introduced the *private finance initiative* (PFI), the first systematic program aimed at encouraging public–private partnerships. The 1992 program focused on reducing the *Public Sector Borrowing Requirement*, although, as already noted, the effect on public accounts was largely illusory. The Labor government in

1997 expanded the PFI initiative but sought to shift the emphasis to the achievement of “value for money,” mainly through an appropriate allocation of risk.

Australia: A number of *Australian state* governments have adopted systematic programs based on the PFI.

Canada: The federal conservative government under Stephen Harper in Canada solidified its commitment to P3s with the creation of a crown corporation, P3 Canada Inc., in 2009. The Canadian vanguards for P3s have been provincial organizations, supported by the Canadian Council for Public–Private Partnerships established in 1993 (a member-sponsored organization with representatives from both the public and the private sectors). As a proponent of the concept of P3s, the Council conducts research, publishes findings, facilitates forums for discussion, and sponsors an Annual Conference on relevant topics, both domestic and international.

India: The **Government of India** defines a P3 as a partnership between a public sector entity (sponsoring authority) and a private sector entity (a legal entity in which 51% or more of equity is with the private partner/s) for the creation and/or management of infrastructure for public purpose for a specified period of time (concession period) on commercial terms and in which the private partner has been procured through a transparent and open procurement system.

Japan: In Japan since the 1980s, the third sector refers to joint **corporations** invested both by the public sector and private sector.

Russia: The first attempt to introduce PPP in Russia was made in St. Petersburg (Law #627-100 (25.12.2006), “On St. Petersburg participation in public–private partnership”). As of 2013 there were nearly 300 public–private partnership projects in Russia.

European Union: Over the past two decades more than 1400 PPP deals were signed in the European Union, representing a capital value of approximately €260 billion. Since the onset of the financial crisis in 2008, estimates suggest that the number of PPP deals closed has fallen more than 40 percent.

10.7.8 Master funding program MAP-21, for moving ahead for progress (MAP) in twenty-first century

Bridges require a greater emphasis on safety of the public due to greater risk and vulnerability to failures than highway components. In the summer of 2012, the U.S. Congress enacted a surface transportation law known as MAP-21:

- This two-year bill makes some significant changes to transportation policy and funding. It essentially holds spending level at $52.5 billion a year.
- It provides federal funding through September 2014.
- In many ways, MAP-21 feels the same as the previous transportation law, SAFETEA-LU. However, there are significant changes to many subprograms. There are 600+ pages in the law.

Some key features of this new law follow:

- *Funding*: There is more capacity to borrow, but less to introduce innovations.
- *Tolling*: The law allows for the introduction of new tolls for the privilege of using new interstate and high-occupancy vehicle lanes.
- *More local control*: There is less money, but more local control in decision making to help make streets safer for all users.
- *There are multiple* changes now in place for the environmental issues, but it is unclear how these will impact projects at this point.

The core programs: MAP-21 eliminated or consolidated dozens of programs and made significant changes to several others. Six of the core programs in MAP-21 are:

- Surface Transportation Program
- National Highway Performance Program (NHPP) (newly introduced)
- Transportation Alternatives (newly introduced)
- Highway Safety Improvement Program
- Congestion Mitigation and Air Quality
- TIFIA loan program (upgraded with funding increased)

The Surface Transportation Program (STP): States and metropolitan regions may use these funds for highway, bridge, transit (including intercity bus terminals), and pedestrian and bicycle infrastructure projects. Although about $5 billion in new responsibilities were added to the STP, the program could only be increased by $1 billion.

Funding: STP can cover 80 percent of the total cost of a project, with the rest covered by states or localities. The eligible projects for regular maintenance include:

- Congestion pricing and travel demand management
- De-icing of bridges and tunnels
- Development of state asset management plans
- Environmental mitigation
- Federal-aid bridge repair
- Highway and bridge construction and rehabilitation
- Intelligent transportation systems
- Off-system bridge repair
- *Funding requirements*: The current level of funding from all levels of government relative to the estimated need needs to be reviewed. The gap between what is needed and what is spent is high. For future needs, the estimated funding for the category over the next five years is required.

10.7.8.1 Addressing the funding aspects

- Advocate for additional long-term federal and state funding programs for bridges to deliver consistent, reliable funding that is adjusted for inflation.
- Advocate for a user fee that is not based on fuel consumption, but is instead based on vehicle miles traveled.
- Encourage and support innovative and efficient project delivery methods such as public–private partnership (P3) projects or bundling of multiple bridge projects to increase efficiency in design and construction.
- Improve maintenance record transparency for effective allocation of maintenance funds.

10.8 Value engineering goals in ABC

Value engineering (VE), also known as value analysis, is a systematic and function-based approach to improving the value of products, projects, or processes. VE involves a team of people following a structured process. The process helps team members communicate across boundaries, understand different perspectives, innovate, and analyze.

Ohio DOT Value Engineering Change Proposals (VECP): *Ohio State, like many other states, has adopted Value Engineering Change Proposals*. VECP are post-award value engineering proposals made by construction contractors during the course of construction under a value engineering clause in the contract. The Federal-aid Policy Guide, *FAPG G011.9*, defines VECPs as “a construction contract provision which encourages the contractor to propose changes in the contract requirements.”

VECPs are included in each contract, excluding Design–Build projects. 2013 CMS 105.19 & Supplement1113 define the submittal requirements, procedures, and limitations on allowed VECPs.

10.8.1 Internal review procedure for value engineering change proposals

The US Army Corps of Engineers Value Management/Value Engineering Program has been a leader in applying the Value Engineering Methodology to construction projects since 1964, solidly demonstrating Corps cost effectiveness. The program has resulted in construction of over $6.2 billion in additional facilities, without additional funds requests.

The basic thrusts of the program are to increase project value by proactively searching for and resolving issues through very open, short-term workshops, and to stretch precious taxpayer resources by providing the required function(s), most amenities, and the highest quality project(s), at the lowest life cycle cost.

The Corps policy is to perform VE on all design and construction programs, and is based on the Federal Procurement Policy Act (41 U.S.C. 432), the Water Resources Development Act of 1986, the Office of Management and Budget Circular A-131 and Department of Defense strategic plans.

Primary goal: Reaffirm support for the selected scheme.

Secondary goal: Only suggest improvements that are necessary to reaffirm this support or will improve safety or efficiency and save costs.

Shorten duration of construction by using lightweight bridges.

Initial cost and life cycle cost: These may be summarized as,

Preliminary cost estimate
Major items
Square meter base

Life cycle cost (total cost for entire life):

Capital cost
Maintenance cost
Salvage value

10.8.2 Benefit-cost (BC) analysis

Cost of a bridge runs into millions of dollars. It is important to avoid huge expenses or wastages by weighing and analyzing the benefits against the cost incurred. The returns for the investment should be justifiable.

Long term benefits should cover the following:

- Includes user cost of daily delay and detour by not using ABC
- Life cycle cost (Total cost for entire life)

- Discount rate (4%) = Interest rate–Inflation rate
- Economical life = 75 years (LRFD)
- Equivalent uniform annual cost
- Present worth method (use of an Excel spreadsheet or similar is recommended)

10.8.3 Cost optimization

The goal is to review and potentially select alternative methods to minimize total cost and speed up construction. An example of precast pier components is shown in Figure 10.3.

Span length: To determine the best combination of superstructure and substructure cost, the costs of different span lengths of superstructure and substructure are computed and plotted. Different materials and structure types are to be tested to find the optimum solution.

If the substructure cost is less than 30%, a shorter span is cost-effective; if the substructure cost is over 50%, a longer span is economical.

Programs for bridge reconstruction: The big difference relates to addressing structurally deficient bridges: For the first time, the STP is responsible for the 460,000 federal-aid bridges not located on the National Highway System. Previously, any structurally deficient bridge could be fixed with funds from the Highway Bridge program, which was eliminated under MAP-21 with virtually all of the money rolled into the new National Highway Performance Program (NHPP).

The needs of the over 460,000 bridges not on the NHS also should be met. Thus, the NHPP received all the money for repairing bridges while STP received the responsibility for fixing more than 123,000 structurally deficient bridges not on the National Highway System.

- Metropolitan regions over 200,000 in population will continue to receive a portion of these funds to direct toward local priorities.
- Under MAP-21, STP continues to provide flexible funding to states and metro regions to implement local and state priorities.

10.8.4 The infrastructure crisis in the United States

The following is adapted from "On Infrastructure, Funding is the Challenge" by Clark Barrineau, available at http://blogs.asce.org/on-infrastructure-funding-is-the-challenge/.

In the 2013 Report Card for America's Infrastructure, we found that the U.S. faces a $1.6 trillion infrastructure investment need by 2020. Unless our infrastructure investment trajectory changes, the United States will lose 3.5 million jobs and $3.1 trillion in gross domestic product by 2020. Simply, funding our infrastructure and funding for future needs is a colossal challenge, a challenge we are not currently meeting.

Downplaying the impact of funding on our infrastructure is shortsighted. The longer we wait to act and create sustainable funding mechanisms for our infrastructure, the more it will cost.

The following is adapted from "America's Infrastructure Challenge Isn't Overstated" by Janet Kovinsky and Brian Pallasch, available at http://blogs.asce.org/americas-infrastructure-crisis-isnt-overstated/#sthash.

Most of America's infrastructure was built after WWII. These investments of the twentieth century spurred our nation's economic boom and made us a global power. Today, quite simply, that tab is coming due.

Australia currently spends 2.4% of GDP on capital investment, compared to 0.60% by the U.S. Canada's federal government investment in infrastructure is approximately 2.9% of GDP. And though our percentages of GDP spent on infrastructure are indeed comparable to Germany, in 2011, Germany adopted a five-year, $52 billion federal Framework Investment Plan for infrastructure.

ASCE report card findings, in addition to the obvious costs of inaction, our aging infrastructure's effects on our economy continue to grow adversely. In preparation for their Report Card, ASCE conducted a series of economic analyses to see the effects our ailing infrastructure has on businesses and families. ASCE found that if our country continues on our current investment path between now and 2020, the U.S. will lose as follows:

- $3.1 trillion in GDP, almost the equivalent of Germany's entire GDP
- $1.1 trillion in U.S. trade value, equivalent to Mexico's GDP
- 3.5 million jobs, more than the jobs created by the America Recovery and Reinvestment Act
- $2.4 trillion in consumer spending, comparable to Brazil's GDP
- $3100 in annual personal disposable income

Given these impacts, it is easy to see that America is already paying for its D+ infrastructure system. Investment would create long-term jobs, spur growth, and increase America's standing in the global economy.

10.9 Policy making and scope of ABC reconstruction

The recurrence of life cycle expenses prevents a rapid remedy to transportation problems, often causing state agencies to resort to frequent repairs rather than one-time replacement. Recent examples in the Northeast United States are the Big Dig Project in the Boston area, the widening of I-95 in the Baltimore area, and the current multibillion-dollar widening of the New Jersey Turnpike in central New Jersey. In the author's experience in planning and designing important replacement bridges, many states still only utilize partial ABC methods, for example the factory prefabrication of precast prestressed and composite girders.

It will be noted that ABC methodology is being introduced gradually in many states due to lack of relevant past experience by bridge engineers and the nonavailability of specialized construction equipment, such as SPMTs and slide-in and slide-out facilities. It is expected that this development trial phase will be temporary and with the establishment of rapid construction and delivery methods, the majority of project managers will adopt ABC technology.

Major projects by the author using partial ABC (in which method of construction rather than the management control by the contractor) include the following:

- *Curved Girder Bridge for Inter County Contract C & Dulles, Ramp C*
- *Ramp TN over I-195 located at Interchange 7A for The New Jersey Turnpike Authority*
- *New Jersey Turnpike Widening*
- *Garden State Parkway Widening Section 3, MP 75.0–80.8*

Such major reconstruction projects are necessitated by the presence of airports, seaports, and major industries and help to maintain the thousands of jobs made possible by commuting on a daily basis.

Reusing unknown foundations: Some of the older bridges do not have drawing details for the foundations. Investigation methods consist of using nondestructive testing techniques. Using modern technology the process of assessing the sizes and depths of foundations can be updated.

Overload prevention and review of live loads: In light of the latest advancements in truck manufacturing industry, it has become important to assess the magnitude of axle loads on highway bridges and also update the military live loads on military routes due to new tanks. ASME design codes need to be reviewed.

Introducing blast loads in design: For the security of important bridges, optional analysis for blast loads needs to be introduced. The City University of New York and the University of Missouri–Columbia have been carrying out research and experimental studies and have developed a type of impact load design (similar to a partial seismic design).

Integral pier bridges: Besides integral abutment bridges, use of semi-integral abutment bridges and integral pier bridges is recommended.

Use of high-friction surfaces: The surface treatment invented in the United Kingdom for asphalt pavements creates a high-friction surface and friction properties between vehicle tires and bridge deck surface and will help in braking and prevent skidding. Binders such as thermo-setting epoxies are used. Maryland has successfully introduced plates on their intersections. A 20-year life span for the treatment is possible. The skid resistance of a deck surface can be measured by a dynamic friction tester. The cost of accidents in terms of fatalities can be considerably reduced. (Refer to FHWA Every Day Counts II Program.)

Seismic design: The latest seismic detailing procedures for bridges and new erosion protection countermeasures for foundations in rivers should be utilized.

Prefabrication of bridge components.

Introduction of precast concrete Wolf girders.

Use of new concrete technology: Introducing LWC, FRP concrete/CFRP concrete, UHPC for superstructure, and HPS 100W.

Structural health monitoring (SHM): This new technology uses lasers and remote sensors for bridge inspections. Bridge inspectors need to be trained in the use of computer software that operates remote sensors, radar technology, and LIDAR for obtaining quick information related to the fatigue-based stress–strain history of a bridge. This approach will make bridges safer and reduce life cycle costs.

- *Use of modern durable deck topping for reducing longitudinal frictional forces*: A new type of resilient minimum friction topping has been developed by FHWA/TRB for highway pavement and for use on the deck slab. It will reduce frequent closures of important highways for deck surface repairs. It can be included in DM-4 as an alternative to the currently used latex-modified concrete (LMC) and corrosion inhibitor aggregate concrete (CIA). Details of specifications can be provided.

10.9.1 Training needs in innovative techniques

Training needs were discussed in Chapter 3. Due to the importance of the subject, additional aspects are presented here.

One-day workshop presented jointly by the ASCE Philadelphia Section and Temple University and organized by the author on November 22, 2013 on rapid construction and delivery. There was participation from FHWA's Benjamin Beerman and PennDOT in addition to leading fabricators such as Acrow, Hi-Steel, and Jersey Precast, along with Temple University. The author gave two presentations on the development of ABC in the United States.

Appendices 6a and 6b provide details of the Temple-ASCE One Day Course on Rapid Bridge Construction. Benjamin Beerman of FHWA gave the links to the latest web resources as follows:

FHWA SEP-14 Active Project List

- FHWA CMGC home page
- FHWA Design-Build home page

- June 2009, "Current Design-Build Practices for Transportation Projects"
- "AASHTO Guide for Design-Build Procurement" (hard copy only https://bookstore.transportation.org/item_details.aspx?ID=1181)
- Caltrans April 2008, "Alternative Procurement Guide" www.dot.ca.gov/hq/oppd/contracting/AlternativeProcurementGuide.pdf

Other useful FHWA references are as follows:

1. *Prefabricated Bridge Elements and Systems in Japan and Europe Summary Report*
2. *SHRP2 Project R04 Part 2–Everyday Solutions: Application of SHRP2-Developed Tools in Case Studies by HNTB Corp* (February 2012)
3. *SHRP2 R04 ABC Demonstration Project #1.* Modular Construction (IADOT). October–November 2011: 14-day ABC period.

Jay Fitzgerald of PennDOT gave an update on the very useful BRADD software (Appendix 6b). Available superstructure types for analysis and design are prestressed adjacent box beams, prestressed spread box beams, prestressed I-beams, steel rolled beams, and steel plate girders. The abutment types, referred to as traditional abutments, can be stub abutments, cantilever abutments, or wall abutments supported by either spread footings or footings on piles.

This new version of BRADD allows for the input and drafting of integral abutments for prestressed concrete spread I-beams, prestressed concrete spread box beams, steel rolled beams and steel plate girders.

Figure 10.4 shows the speakers in the afternoon session of November 2013 Joint ASCE ABC Workshop. The author served as Director, ASCE Philadelphia Section and was Founder Chair of Structural Engineering Institute in Philadelphia.

The speakers at the seminar included:

Bob Cisneros, who is Chief Engineer at High Steel Structures of Pennsylvania (High Steel manufactures a lot of high-quality assembled steel bridges). He has participated in various industry efforts to upgrade fracture critical criteria based upon analytical redundancy, utilize technologies that are available to the industry, and facilitate the understanding of constructibility for steel bridge fabrication and erection.

Scott Patterson, who is the Chief Engineer of the well-known New Jersey company ACROW, located in Parsippany in North Jersey. ACROW has been manufacturing prefabricated bridges in the United States and has supplied them in countries like Ghana and Pakistan. He presented case studies for the Skagit River Bridge, the Alkire Road Bridge, and a bridge for Ghana, East Africa.

AmirUl Islam, who is President of Jersey Precast, a well-known New Jersey bridge manufacturer, was represented by his Chief Engineer. He presented the case studies for ABC of very important bridges such as the Brooklyn Bridge, Tappan Zee Bridge, Tri Borough Bridge, Metro-North 3 Bridges Replacement, and I-93 Rapid 14 Bridge.

Short courses arranged by FHWA, FIU, ASCE, and certain states: Training courses on important developments in ABC technology serve to promote safety and economical design for the repair and replacement of bridges. Examples are introducing full and partial accelerated bridge construction methods for both the substructures and superstructures, prefabricated bridge elements and systems (PBES), prefabrication, use of SPMT, roll-in and roll-out methods, and the design-build method of construction management.

In addition, planning and design of integral and semi-integral abutments and piers (by using precast components) will expedite construction and reduce delays normally involved in conventional construction practices, thereby avoiding discomfort for the bridge users.

FIGURE 10.4

Speakers at the one-day ABC course with Temple University Professor Dr. Philip Udo-Inyang. Benjamin Beerman of FHWA is second from left and author, who organized the course for practicing engineers is on the right. More such courses are needed.

Appendix 6c gives the FHWA-developed specifications on design-build, construction manager at risk, etc. and the *Engineering News Record* list of 100 design-build construction companies that are actively participating in the ABC tasks and challenging projects.

10.9.2 Training in slide-in bridge construction as an alternative to incremental launching

On behalf of the FHWA and Every Day Counts (EDC), the Colorado Department of Transportation (CDOT) has developed training for lateral bridge slides. This training program includes webinars and online training modules. It was designed to help build a foundation for implementing the slide-in bridge construction (SIBC) method. As such, the content will focus on the lateral bridge slide-in method and not SPMTs or other methods of ABC.

The first webinar was held on November 21, 2013 and was titled "Slide-in Bridge Construction (SIBC) from the Owner/Policy Maker Perspective." Subsequent webinars will focus on the engineer/designer and contractor/constructor perspectives. Online training modules are currently under construction in 2014.

10.9.3 Selection of SPMT or slide-in bridge construction from the owner/policy maker perspective

Lateral SIBC is preferred from the owner/policy maker perspective when the economics dictates it. The alternatives for selection of the lateral skidding method are also described in Appendix 3, using the flow diagram from the FHWA.

10.9.4 Advancing ABC using lateral slide-in methods

Questions from the beginning of the chapter, related to using lateral slide-in versus SPMT, is addressed in this section.

As discussed earlier, FHWA has identified the following as important components of ABC:

- Prefabricated bridge elements and systems (PBES)
- Right of way
- Geotechnical solutions and preliminary design
- Utilities
- Environmental impact statement (EIS) programmatic agreements
- Contracting methods

The states that have taken the lead in applying the SIBC method on a number of projects are Utah, Oregon, Colorado, Missouri, Massachusetts, and New York; many other states are taking an active interest. The Colorado DOT has built up specialized experience similar to the Utah DOT in this area, such as acquisition and knowledge of the appropriate mechanical equipment for rollers, screws, etc., for sliding the superstructure into position.

It is not always feasible to use SPMT due to the following reasons:

- Long distance from factory to the construction site
- Transporting components using river and barge
- Nonavailability of SPMT
- Vertical underclearance on bridges on the transportation route not adequate for SPMT with deep precast girders
- Inadequate access at the site to both abutments
- Very heavy bridge components exceeding the capacity of lifting cranes
- No suitable wide roads with exit ramps available for wide loads
- Difficulty in obtaining road permits or police escort
- Long spans that are longer than SPMT lengths
- Value engineering showing relative costs of using SPMTs to be much higher than roll-in, roll-out method for the type of superstructure.

10.9.5 Drawbacks of lateral slide-in

Construction of the superstructure next to the existing bridge requires good weather. Hence construction season is rather limited in the northern states. Prefabrication at the factory site can be done indoors and the prefabricated superstructure can be transported to the site by extending the construction season window. In addition, temporary column bents are required to support the casting beds prior to lateral slide-in. Hence additional costs for erecting and dismantling temporary bents are incurred.

10.9.6 FHWA's long-term project delivery goals

All contracting agencies should have a project delivery "toolbox" including:

- Design-bid-build
- Design-build
- CMGC (construction manager general contractor)

- Alliance contracting
- Best-value performance contracting

Indefinite delivery/indefinite quantity (ID/IQ): IDIQ is a U.S. federal government contracting acronym representing a type of contract that provides for an indefinite quantity of supplies or services during a fixed period of time. The legal origin of IDIQ contracts is the Federal Acquisition Regulation (FAR), section 16.501(a).

An IDIQ contract allows for a certain amount of contract process streamlining, as negotiations can be made only with the selected company (or companies), and such contracts are exempt from protest, per Federal Acquisition Regulations, subpart 33.

IDIQ contracts are frequently awarded by various U.S. government agencies, including the General Services Administration (GSA) and Department of Defense. They can be in the form of multiagency contracts under the Government-Wide Acquisition Contracts (GWAC) system, or they may be government agency-specific contracts.

10.9.7 Owner's and contractor's perspectives

The following aspects are critical in making ABC successful from the perspective of the owner:

- Define goals
- Project restrictions
- Request for proposal (RFP) development
- Proposal evaluations
- Risk analysis
- Innovation analysis
- Design decisions
- Cost comparisons

The contractor must focus on the following in developing a successful ABC project:

- Define goals for rapid delivery
- Performance specifications
- RFP development
- Proposal evaluations

The prime contractor, who is in charge of rapid delivery of the project, must use his or her experience and intuition toward managing risk allocation, cost certainty, and risk reduction.

The focus should be on schedule optimization to meet contractual milestones, and collaboration with such disciplines as design, traffic engineering, prefabrication, and field construction. It is desirable to implement emerging innovations by selecting from alternate rapid-delivery models.

10.9.8 Use of modular bridges as rapid replacements

There are two types of replacements normally required:

1. Replacement in kind for emergency situations where the bridge gets damaged by accidents, floods, or earthquakes–Partial demolition of an existing bridge may be required in stages. This type has the highest priority and the funding comes from emergency funds; without repair, the

entire highway may need to be shut down due to one bridge being out of service. The existing substructure and footprint is used and initial design features such as girder types and sizes are maintained. Modular bridges are constructed in factories and transported by SPMTs. Roll-in, roll-out methods, which involve cast-in-place decks, may not be feasible due to the restricted timetable.

2. Replacement of bridges using a different footprint and a new substructure–Full demolition of the existing bridge would be required. Both modular factory-fabricated bridges and those constructed on the site using roll-in, roll-out (or slide-in, slide-out) methods can be used.

10.9.9 Adding new lanes by widening the highway

It has been a common practice in the United States to widen existing highways and bridges.

This method of bridge construction is more difficult than for a new bridge or a replacement bridge since the addition of new substructure is required.

- Staged construction is a lengthy process with shifting traffic lanes.
- Utilities also need to be relocated.
- It is also not easy to reuse and match the strength of new construction materials with those used in the older technology.
- The performance of the modified bridge with construction joints and different member sizes becomes structurally indeterminate. The newer bridge may behave differently from the existing one. Relative live load deflections and inbuilt fatigue stresses in existing girders make the redesign complex.
- The acquisition of new land for widening adjacent to existing highways may be expensive and litigation may result in the delaying of the proposed road expansion project. It should be noted that land for new bridge approaches may require retaining walls. In some cases the height of the retaining walls may be greater than 20 feet, adding to the cost of the project.

10.9.10 Introducing new highways and bridges near or parallel to existing congested routes

In densely populated areas where widening for long stretches may not be feasible or where land for widening may not be available, other options such as introducing secondary parallel routes may be considered. The total length of the new road may not be one long stretch but may instead be sections with gaps in more congested areas. This approach has the advantage of construction in phases for the bottleneck locations of existing routes where the limited number of lanes is a major problem. New toll plazas may be required and may be built at the start and end of each section of new highway. With the E-Z Pass facility, traffic need not stop at the toll plaza.

Additional secondary highway links between new routes and existing major highways may help in providing access and in the uniform flow of traffic.

10.9.11 Introduction of high-occupancy vehicle lanes

This will increase the speed for vehicles in the HOV lanes and encourage more users to adopt carpooling by meeting the multiple passenger requirements.

10.9.12 Introduction of variable message sign structures

It is now possible to install variable message sign structures on existing highways to help direct traffic flow. Variable electronic messages provide an updated condition of traffic on the roads and bridges ahead. This may be required to warn traffic about an unexpected reduction of speed due to fog or accidents. The drivers of the vehicles have the option to take the next exit and utilize an alternate, less congested route. The author has worked on the design of sign supports subjected to heavy wind on I-76 and the Blue Route in Pennsylvania.

10.9.13 Introduction of subways

At busy intersections, bottlenecks in traffic flow can be removed by introducing subways and tunnels of the required lengths to help maintain higher speeds and prevent slowdowns.

10.9.14 Introduction of new bus routes

With buses utilizing specific routes at frequent intervals, the traffic congestion problem can be substantially reduced. At an average, each bus is likely to replace 20 cars in each direction and also keep traffic accidents to a minimum.

10.9.15 Introduction of railroad and transit bridges

Traffic congestion seems to be creating greater interest in the alternate use of trains in place of thousands of cars for travel and commuting. A train is faster and more convenient than a bus and would take several hundred cars off the road. With less traffic the maintenance efforts and even accidents will decrease.

The bridges over the railroad will require higher clearances at intersections. New bridges carrying railroad will be designed to the AREMA Code. Common locomotives are the Bombardier and Silverliner. Modern railways run on electric traction. Coordination with the track power supply, signaling using catenaries, and other features are required. The author has worked on the planning and design of many railroad bridges for the Northeast Corridor, such as the Greenbush Line for Massachusetts Bay Transportation Authority (Monatiquot River Bridges, MP 0.79 and MP 1.36, located near Boston).

10.9.16 Demolition issues prior to reconstruction

Rapid demolition is completed within a single day by means of two hydraulic breakers mounted on excavators. A crane with a heavy wrecking ball can be used.

When jacking of the beam ends at abutments and piers is required for bearing repairs and replacement, it is customary to apply the load upwards by using hydraulic jacks. Jacks are placed directly under the beams or a jacking beam is installed. Since the direction of load causes tension in the slab, grid beam analysis is required to limit the bending and shear stresses and to control vertical deflection. Jacking load is applied in successive increments of 1/16th inch to 1/8th inch.

10.9.17 Substructure

- Precast piers: Straddle bents and multiple precast columns with precast caps can be used. Grouted splice couplers can be used in low seismic areas only.
- FHWA has developed typical drilled shaft-to-column connections and precast column-to-cap connections. This leads to fast assembly.
- Precast pier assembly with pier caps requires two typical 110-ton cranes to lift objects into position.

10.9.18 Selection of partial or full ABC methods

At the planning stages, it is important to consider the feasibility and economics of using the proposed method. If it is not feasible, then the conventional design-bid-build approach can still be utilized.

One consideration is that there are more experienced contractors ready to bid for conventional methods than for the ABC method. Hence the owner may benefit from a lower competitive cost. The other issue is delivery of prefabricated elements to the site and availability of SPMTs. Where there are long distances between the factory and construction site, narrow roads with sharp exits requiring difficult turning, or weight-restricted bridges, costs may increase.

Other factors are use of a nearby staging area, relocation of any utilities, and the impact of a short bridge closure due to heavy traffic. If the ABC cost is greater than 30% of the conventional cost, the conventional design-bid-build method or partial ABC with modular girders may be used. However, with contractors acquiring experience in ABC, more ABC methods are being used.

Prefabrication in remote factories with use of SPMT: This is feasible for small spans (an example is modular bridges like CONSPAN) and for medium spans by splicing.

Bridge location: In view of the large number of bridges to reconstruct in urban and rural settings, on average there should be at least two prefabrication factories in each of the 50 states, to meet the yearly construction demand.

Travel paths: The availability of SPMTs and transportation of heavy loads on routes to the construction site are not always possible. Barges may be used for some bridges located on fast-flowing rivers, but the use of lifting cranes mounted on boats for loading and unloading may not be feasible if the banks are high.

Size of deck panels: Partial prefabrication can be used in which only the girders are precast and not the deck. Deck panels can be cast in place using steel formwork to avoid the use of too many deck joints. This results in full composite action between slab and beams. Transverse and longitudinal grades are well maintained for deck drainage purposes.

Combination of prefabrication and SPMTs: In many cases, quality control is better for factory manufacture due to readily available labor and equipment. Hence the combination of prefabrication with SPMTs will be most economical.

Prefabrication of substructure: For rapid construction prefabricated abutments and approaches behind the existing abutments may be built in stages.

Space for construction of deck panels adjacent to bridge site: Temporary bents or shoring towers need to be erected for fabrication if construction space is not available. This adds to the cost of the bridge. Also, for bridges on rivers it may not be feasible.

10.9.19 Limitations of nontraditional approach

While cast-in-place construction is time tested, ABC applications are of recent origin. The reality on the ground in achieving rapid construction goals are presented here:

- While there is saving in construction time, design effort is increased due to numerous precast joints and components.
- The time required for borehole tests, pile driving, shop drawing review, and closure pour remains unchanged.
- Span lengths in concrete bridges are restricted to about 100 feet due to the transport restrictions of heavy components.
- Compared to a unified cast-in-place integral abutment bridge, precast bridges with numerous deck joints are weaker during earthquakes.
- Transverse prestress is required.
- Full-scale testing is required to develop confidence, especially for curved bridges.
- MPT, approach slab construction, permits, utility relocation, etc. are unavoidable constraints.
- Contractors, in general, have trained technicians in formwork and cast-in-place construction and new training in ABC is required.
- The manufacturing nature of precast products creates a proprietary system and monopolistic environment, which may lead to unemployment of some number of construction workers.
- Overemphasis of incentives/disincentives pressures the contractor into adopting unrealistic schedules at the expense of quality control.

Alternative design-build construction procedure: This approach has led to faster turnout. For large projects a design/build/finance/operate/maintain approach is a complete solution. The simpler design/build approach is commonly used to streamline procedures by placing the builder and designer on one team.

10.9.20 Other constructibility issues

It will be noted that w*e are engineers and not magicians.* In addition to the parameters for selection described above, in each of the alternatives discussed there are a variety of site-specific constructibility issues. The construction schedule, except for emergencies, should not be a rush job, since more than likely it may affect quality due to human error.

10.9.21 Construction difficulties

- Construction in subzero and freezing temperatures
- Construction in hot weather
- Construction during low and high wind

10.9.22 Maintenance issues

- Construction while traffic lanes are open
- Construction during partial lane closure
- Nighttime construction

10.9.23 Precautions to prevent construction failures

A study on bridge failures carried out by the author concluded that most failures occur during construction or erection. The ABC system must avoid such failures through carefully considering issues such as the following:

- Failure of connections: Overstress from bolt tightening, failure of formwork, local buckling of scaffolding, crane collapse, and overload are some of the causes.
- The stability of girders during stage construction and the deck placement sequence need to be investigated and temporary bracing provided.
- Expansion bearings need to be temporarily restrained during erection.
- Some flexibility in selecting bolt splice locations may be permitted with the approval of the designer.
- Curved and skew bridges require special considerations, such as uplift at supports, achieving cambers, and reducing differential deflections between girders during erection.

10.9.24 Method of analysis and mathematical approach

The proper methods are based on whether the bridge is redundant (statically indeterminate) or nonredundant (statically determinate). The latter can be analyzed by simple laws of equilibrium and boundary conditions, while the former also requires review of the stress–strain and strain-displacement relationships and compatibility equations. It appears that the difference in theoretical approach governs structural behavior and hence inspection and maintenance requirements.

10.9.25 Proposed university course on ABC (Appendix 4)

Proposed 3-credit course for seniors and graduate students:

Accelerated Bridge Construction (ABC) Course Details
Introduction & Objectives of Rapid Bridge Construction
Funding Aspects
Project Management Aspects
Accelerated Construction Techniques
Transportation and Construction Equipment
Modern Durable Construction Materials
Type of Superstructure and Geometry of Bridge
Type of Substructure
Funding Constraints
Typical ABC Construction Specifications
Design Aspects Related to ABC
Application of Codes of Practice, AASHTO LRFD, and State Codes
Post Design Requirements
Case Studies and Examples of ABC Projects
For details, see Appendix 4.

In addition to the courses listed in Chapter 3, see Appendix 5 for details of training courses and workshops in ABC.

10.10 Innovative techniques and new applications

10.10.1 ABC for floating bridges

A floating bridge is a type of bridge design that makes use of barges or pontoons to create a span across a body of water. In many instances, a floating bridge is constructed for temporary use and can be dismantled and transported for reassembly at a different location, making the design ideal for use by military operations. The floating bridge design can also be used to create more permanent solutions when it is not considered feasible to invest the time and money that is involved with constructing other types of bridges. Military construction requires rapid construction and delivery. When crossing streams, it has been possible to assemble lightweight aluminum or timber truss elements. Military engineering concepts have found their way into rapid construction methods being used for ABC. Floating bridge construction over a waterway is one example.

10.10.2 Wolf girders: performance in service

While the design used some standard geometry from Texas tub girders, the difference in depth and width of the Wolf girder precluded use of existing forms. US Concrete Precast Group, who provided the 11,000 linear feet of Stage 1 girders, opted to use a custom-built girder form.

The self-stressing form provided the reaction to the priestess jacking force, eliminating the need for bulkheads. In the case of Stage 1A, the premaster, TPAC, used custom-built conventional metal forms. The Wolf girder used only straight strands, with deboning at the ends to control initial stresses.

The casting and stressing of the girders was largely incident free. In the case of Stage 1 girders, the premaster used a high-workability mix that facilitated placement of concrete. For Stage 1A, the project team allowed the use of self-consolidating concrete that had been recently approved for bridge girders by the Arizona Department of Transportation. In both cases the result was a high-quality surface finish with minimal blemishes.

At this time, the Stage 1 girders have been in service for approximately 3 months, in addition to the period of systems testing, and have performed extremely well. Stage 1A girders were erected late in 2012 and the deck was cast earlier this year, with no notable problems reported in construction or performance.

10.10.3 Additional innovative technologies

A number of innovative techniques were presented in Chapter 4. Additional items such as developments in concrete technology are discussed here. Heavy lifts are now possible for erection purposes. "Bridge-in-a-backpack" is the latest approach, taking advantage of existing technologies such as:

System One: The fabricated girders are precast elements (folded steel plate or NEXT beam with lighter aluminum deck).

System Two: Prefabricated composite elements (inverse).

System Three: Segmental construction with FRP deck.

A cost evaluation that includes the duration of construction needs to be conducted prior to selection of any new technologies or ABC methods. The following steps are needed:

- Develop guidelines for ABC project inclusion
- Develop typical details and manuals
- Develop special provisions for alternate methods
- Include user costs in analysis
- Encourage innovation rather than using conventional design-bid-build method
- Provide training to engineers
- Obtain feedback

10.10.4 Exodermic bridge decks

An exodermic (or "composite, unfilled steel grid") bridge deck is comprised of a reinforced concrete slab on top of, and composite with, an unfilled steel grid. This efficient system maximizes the use of the compressive strength of concrete and the tensile strength of steel to provide a lightweight, strong, and durable bridge deck.

NJDOT Bridge Design Section 20.13 recommends the use of exodermic deck, as follows:

An example of an unfilled grid deck that is composite with the concrete deck slab is the Exodermic bridge deck system.

a. The Exodermic system is comprised of an unfilled steel grid, typically 3 inches to 5.2 inches deep, with a 3.5 inch to 5.2 inch reinforced concrete slab on top of the grid.
b. A portion of the grid extends into the reinforced concrete slab. This creates the composite action.
c. An exodermic deck system can provide a lighter element to a bridge structure without sacrificing stiffness and strength.

10.10.4.1 Exodermic bridge deck systems reduce dead load

By reducing dead load, an Exodermic bridge deck permits a bridge to achieve a higher live load rating. An Exodermic bridge deck typically weighs 35–50% less than the equivalent rebar reinforced concrete slab specified for the same span.

10.10.4.2 Exodermic bridge deck systems facilitate rapid installation

An Exodermic bridge deck can often be erected during a short overnight or weekend work window using precast panels. Cast-in-place panels also offer increased installation rates with nearly all the formwork already in place.

10.10.4.3 Representative exodermic bridge deck projects

One reason Exodermic bridge decks are specified is because they are the cost-effective choice for projects where a reduction in deck dead load has a significant structural benefit–a required load rating without substantial reconstruction or replacement of superstructure or substructure. Many types of bridges have benefited from the light weight of Exodermic bridge decks: arch, deck truss, through truss, pony truss, deck girder, and movable bridges. Exodermic bridge decks are also specified where speed of construction is important. Both precast and cast-in-place Exodermic bridge decks are generally significantly faster to construct than conventional cast-in-place reinforced concrete decks. Taking advantage of this capability has been used to:

- Shorten the time required to reconstruct a superstructure (US 136–Illinois River, Sparkill Viaduct, Boston Central Artery)
- Permit rapid, staged construction (Popolopen Creek, Kingston–Rhinecliff, Milton–Madison)
- Allow for weekend construction (Gowanus Expressway, Mill Creek, OR)
- Allow for nighttime construction (Tappan Zee Bridge, Connecticut Route 185, US 27 Pitman Creek, Troy-Menands)

10.10.5 Progress in the use of new concrete technology

Concrete bridges are more commonly used for smaller spans, since rust in steel members increases corrosion and maintenance costs.

Futuristic construction materials and techniques (FCMT) are now possible due to research into this important construction material for substructure and deck construction. The following types of concrete may be considered:

- High-performance concrete (HPC)
- Ultra-high-performance concrete (UHPC)
- *UHPC longitudinal joints in bridge deck*
  Full moment transfer between adjacent precast members is possible. No post-tensioning is required. Only 6 in. wide. High strength, low permeability; can be reinforced with hairpin bars or straight bars. UHPC joints are reinforced to carry the full LL tension.
  UHPC has been used for transverse joints over pier.

Self-consolidating (or self-compacting) concrete (SCC): As vibration time is saved SCC helps ABC; it is a more workable concrete with lower permeability than conventional concretes.

- Precast abutment construction with single row of H-piles, using self-consolidating concrete (SCC) to fill the pile pockets.
- U-shaped precast wingwall assembly with SCC joints is preferred.
- Polymer modified cement
- Polymer concrete (PC)
- Polymer-impregnated mortar (PIC)
- Fiber-reinforced polymer concrete (FRPC)
- Carbon-fiber-reinforced polymer concrete (CFRPC)
- Polymer composites
- Concrete nanotechnology
- *Ultra-HP FRC*: Compressive strength reaching 30 ksi and flexural strength of 7 ksi is possible.
- *Using HP lightweight aggregates*: Lightweight HPC reduces dead weight, enables longer span lengths, reduces the number of piers in a river, and presents the least obstruction to fish travel.
- *Spliced girder*: Splicing of girders enables lightweight concrete to achieve spans of over 200 ft and helps with the transport issue of precast girders.

10.10.6 Use of nanocrystals for reinforcing concrete strength

Research at Purdue University: Cellulose nanocrystals represent a potential green alternative to carbon nanotubes for reinforcing materials such as polymers and concrete. The same tiny cellulose crystals that give trees and plants their high strength, light weight, and resilience have now been shown to have the stiffness of steel. The nanocrystals might be used to create a new class of biomaterials with wide-ranging applications, such as strengthening construction materials and automotive components.

- Calculations using precise models based on the atomic structure of cellulose show the crystals have a stiffness of 206 GPa, which is comparable to steel, according to Pablo D. Zavattieri, a Purdue University assistant professor of civil engineering. Findings are detailed in a research paper featured on the cover of the December 2013 issue of the journal *Cellulose*.
- According to Zavattieri, for the first time, Purdue have predicted their properties using quantum mechanics. The nanocrystals are about 3 nm wide by 500 nm long–or about 1/1000th the width of a grain of sand–making them too small to study with light microscopes and difficult to measure with laboratory instruments. The findings represent a milestone in understanding the fundamental mechanical behavior of the cellulose nanocrystals.
- Cellulose could come from a variety of biological sources, including trees, plants, algae, ocean-dwelling organisms called tunicates, and bacteria that create a protective web of cellulose. Biomaterials manufacturing could be a natural extension of the paper and biofuels industries, using technology that is already well-established for cellulose-based materials.

Other applications of concrete include the following:

- Use of drilled shaft foundations/concrete cylinder piles of 36″–66″ diameter.
- Precast sheeting has been used for retaining walls and abutment.
- MSE abutments have performed extremely well.
- NJDOT used RFP procedures to fix the damaged fender systems for two bridges along the New Jersey coast (Route 9 over Nacote Creek and Route 9 over Bass River). The repairs performed are environmentally friendly and eliminate marine borers.

One of the first integral abutment bridges in New Jersey, over Peckman's River, was designed by the author. It was an emergency replacement after Hurricane Floyd had hit New Jersey. Innovative approaches such as the use of integral connections between ends of girders and pile cap help prevent settlement.

10.10.7 Use of cast-in-place joints

- Precast details for making durable longitudinal connections between the adjacent beams, modular units, or deck panels are being developed in place of the conventional cast-in-place transverse and longitudinal joints.
- Corrosion-resistant rebar (stainless steel) and glass bars are now available.
- FHWA has performed extensive evaluation of ultra-high-performance concretes. These concretes are composed of an optimized gradation of fine granular constituents, low water:cement ratios (less than 0.25), and a high percentage of steel fibers. Their consistency is more like a grout than concrete. They are self-leveling and self-consolidating, which works well to fill the voids and gaps between adjacent prefabricated elements. Compressive strengths greater than 20 ksi can be achieved.

- The key to the durability of prefabricated element connections is the improved bond to the substrate and their propensity to form multiple micro-cracks, in lieu of a few large cracks. It therefore offers superior resistance to water and deicers. Similarly, their bond to rebar is better than conventional approaches.
- The high-performance concrete should allow for either shorter development lengths and shorter closure pour lengths or simpler rebar connection or lap details. For example, in thin deck elements or deck beam top flanges, use of straight bar noncontact lap splices in lieu of hair pins (and use of shorter shear studs at the deck panel to beam connection) will reduce interference issues that affect constructibility and construction time.

Lab tests of joints

- Assess strength and serviceability of the transverse joint
- Determine ultimate moment capacity
- Tests show good correlation with design strength
- Identified HPC deck cracking and bond issues

Transverse joint serviceability design

- 1-inch HS threaded bar post-tensioned to 70 Kips
- Prevent deck cracking under service loads
- Keep bond between UHPC and HPC deck in compression

Post-construction review

- Best to have two independent surveys as survey errors can lead to major delays during ABC period.
- Could specify longer pile lengths by contract to minimize schedule disruptions.
- Designer should be present on site during the ABC period for quick decision making.
- Conduct a prepour meeting with UHPC supplier and follow procedures. Bond between UHPC and deck is critical.
- UHPC reinforcement should allow joints to be more easily and quickly constructed. Straight bars are preferred.

Construction aspects

1. Develop sample technical specifications for construction.
2. Review construction equipment: availability of mobile lifting cranes, truck mounted cranes, jib cranes, and forklifts, and pallet trucks; other transportation and erection equipment; incremental launching method.
3. Review methods for accelerated bridge substructure construction; MSE abutments; reducing foundation construction time and methods by using pile bents.
4. Use of quality assurance and quality control procedures.
5. Connection details for seismic design; dismantling components and reuse at another site.

10.10.8 Modern construction equipment a boon to ABC

1. The success of ABC is due in part to powerful equipment. Different erection equipment is required for girders, box beams, trusses, arches, cable-stayed bridges, and suspension cable bridges. Timely availability, a leasing facility, and an experienced erection team will be necessary.

2. The erection contractor should utilize robotics, cranes such as a tower crane (for maximum lightweight pick of 20 tons and heights greater than 400 feet), lattice boom crawler cranes, mobile lattice boom cranes, mobile hydraulic cranes, and lattice ringer cranes for varying heavyweight pickups and accessories.

10.10.9 Earthquake early warning system saves lives

California has taken a lead in developing early warning systems. For example, Gov. Jerry Brown of California ordered creation of a statewide earthquake early warning system that could give millions of Californians a few precious seconds of warning before a powerful temblor strikes.

Early warning systems are designed to detect the first, fast-moving shock wave from a large earthquake, calculate the strength, and alert people before the slower but damaging waves spread. The goal is development of a system that can detect a rupturing fault and provide enough time for trains to brake, cars to pull off roads, utilities to shut off gas lines, and people to dive under tables and desks. The system can't predict earthquakes and people at the epicenter won't get any warning, but those farther away could benefit.

During the 2011 earthquake-caused tsunami in Japan, millions of people received 5–40 s of warning depending on how far they were from the epicenter. The notices were sent to cell phones and broadcast over airwaves.

10.10.9.1 USGS development of early warning systems

For several years, the U.S. Geological Survey has been testing a prototype that fires off messages to about two dozen groups in the state, mostly scientists and first responders. Recently it provided up to 30 s of warning of a magnitude-4.7 earthquake in Riverside County. A full-scale system would mean upgrading current earthquake monitoring stations and adding some 440 additional sensors in vulnerable regions, such as the northern tip of the San Andreas near San Francisco and the San Jacinto Fault in Southern California. Further research will provide more reliable advance warnings of earthquakes.

10.11 Conclusions

1. ABC technology is still developing, although significant progress has been made in prefabrication. This chapter highlights the importance of alternate types of construction to the well-established factory prefabrication and SPMT use, such as transportation by barges and lateral slide-in methods. Obtaining traffic count data and the use of value engineering in planning have been useful in implementing ABC methods.
2. In some cases it may be warranted to use lateral slide-in methods due to the limitations of transporting large size bridges by road or on barges in rivers from long distances and fitting them on the SPMTs or barges. Case studies of lateral slide-in methods in some states are shown. The method consists of site casting adjacent to the existing bridge on temporary bents, and using mechanical devices for sliding or cranes to lift the superstructure in position. If the cost increases more than 30% than the cost of using SPMTs, this method will be uneconomical. The indirect benefits to the public, such as the comfort of using a new bridge made available almost immediately, will be there, though at a slightly higher cost. Case studies have shown that many states

have successfully used modern technology with minor modifications like casting beds and mechanical devices. A few states like Utah and Oregon have developed special provisions as part of their construction specifications.

3. In some cases it is possible to construct abutments prior to slide-in of the new bridge, with further savings in time.
4. The use of new types of concrete materials for deck slab will enhance the deck life and reduce life cycle costs. Examples are Exodermic decks, Effidecks, FRP, and HPC deck panels.
5. Several types of lightweight precast girders, such as NEXT beams, Wolf girders, and T-Bulbs, have helped in solving the issues of rapid delivery of bridges and reducing initial and life cycle costs.
6. The ASCE Report Card for infrastructure has put pressure on the federal and state governments to take necessary measures for reconstruction and for creating jobs. FHWA's "Every Day Counts" Program and FIU seminars on ABC have been training bridge engineers in the new technology.
7. Also, courtesy of the FHWA, Website resources are now available. This will help in training contractors in using lateral slide-in methods.

The huge funding issues seem to be partly overcome by public–private partnerships. The important and sensitive issue of generating additional funding by the P3 system is discussed. Public investment has promoted much-needed and timely reconstruction of thousands of structurally deficient bridges.

Wider use of P3 system: With the P3 approach as promoted by PennDOT, we can replace hundreds of these bridges more quickly, save money, and minimize the impact on the traveling public. For many public owners and other infrastructure project stakeholders, P3s represent tremendous promise as a source of development and financing for much-needed infrastructure projects.

Note: Appendices 1 to 11 are provided at the end of the book for ready reference.

CHAPTER

A Review of Chapters, River Bridges, and Conclusions

11

11.1 Introduction to chapter 11

This final chapter is divided into two parts.

Part 1: It deals with the summary and review of the first 10 chapters.

Part 2: It deals with rapid construction on rivers, using alternative float-in method to transport assembled bridge to the bridge site and timber and aluminum bridges.

Part 2 is followed by overall conclusions.

Part 1

11.1.1 Summary of earlier chapters

For early completion or for rapid construction, the main factors and issues discussed in the earlier chapters may be summarized as the five M's, namely:

Management team of design-build engineers,

Modern materials using high-performance steel (HPS), high-performance concrete (HPC), and composites,

Method of assembly of modular construction in factory or on site,

Method of transport using self-propelled modular transporters (SPMT), and

Method of erection by lifting into position, roll-in, roll-out or lateral slide-in.

For bridges on rivers, a float-in method can be used.

Both full and partial accelerated bridge construction (ABC) methods are discussed.

Partial ABC is a compromise between conventional and ABC methods. It is applicable when sophisticated transport and lifting equipment is not available and where the bridge owner wants to keep the in-charge consultant. Some factory fabrication of girders would still be used.

Since the scope of each project is slightly different, full ABC may not always be applicable. The following types of conditions would exist:

1. A new bridge on a new highway. Coordination with highway construction on one or both sides of the bridge will be required. Bridge construction activities may not be on the critical path. Also, no demolition work is needed.
2. Existing bridge requiring superstructure replacement only. Only superstructure demolition may be required. The ABC can be done using staged construction with limited lane closure.
3. Existing bridge requiring both superstructure and substructure replacement. Staged construction may be required since existing footing width may interfere with the new footings. Demolition of entire abutment footing would require shutting down of the entire bridge rather than lane closure.

Accelerated Bridge Construction. http://dx.doi.org/10.1016/B978-0-12-407224-4.00011-3

4. Construction duration for deep foundations such as minipiles or long piles or drilled shafts/ caissons will not change for full or partial ABC.
5. Funding will be unaffected in each case.

Construction season may be geared to local weather and factory manufacture in doors will be an advantage. Also, roll-in, roll-out method may be more expensive than lateral slide-in but has the advantage that the assembled bridge can be lifted and placed over the bearings without relocating the existing utilities.

Training programs in ABC may be necessary. Use can be made of the Federal Highway Administration (FHWA) conferences, and lunchtime seminars organized by FIU and other universities engaged in research in the new technology.

A variety of case studies are presented for superstructure or substructure replacement using prefabrication, self-propelled modular transporters, roll-in and roll-out methods, and lateral slide-in methods. A glossary of ABC terminology applicable to all the chapters is listed for ready reference in Appendix 2 ABC.

Part 1 will provide brief summaries of the chapters and will be the review of Chapters 1–10.

The chapters that follow this introductory chapter on modern ABC will cover the following themes:

Sections 11.2 address coordination with highway construction schedule.
Sections 11.3 to 11.8 address scour issues related to river bridges and design of countermeasures.
The details related to scour are based on author's textbook on Bridge and Highway Structure published by McGraw=Hill 2010.
Section 11.9 provides details of case studies.
Section 11.10 is for the conclusion of the chapter 11.
In addition, Section 11.11 discusses future developments of ABC.
Finally, Section 11.12 discusses acknowledgements and future revisions of codes/
Section 1 Innovative Construction Methods (chapters 1 to 4)
(Chapter 2), Recent developments in ABC concepts
(Chapter 3), Research and training in ABC structural systems
(Chapter 4), Introducing innovative ABC techniques
(Chapter 5), Modular bridge construction issues
Section 2 Recent Developments in ABC Concepts (chapters 5 to 7)
(Chapter 6), Rapid bridge insertions following failures
(Chapter 7), Planning and resolving ABC issues
(Chapter 8), ABC Prefabrication of the superstructure
Section 3 Modular Bridges (chapters 8 to 11)
(Chapter 9), Prefabrication of the substructure and construction issues
(Chapter 10), Alternative ABC methods and funding justification.

Chapter 1 presents an introduction to modern ABC with discussion of the many advantages and deterrents. Deterrents include administrative and planning bottlenecks, construction easements and right-of-ways, permit approvals, and utilities relocation issues. Timely labor availability, weather problems, and the large storage yard areas required at the site are addressed. In addition, the need exists for certification and training, laboratory testing related to the structural behavior of field connections of subassemblies, and mathematical modeling. Design and construction codes, continuous funding, heavy cranes, and erection equipment such as trolleys and SPMTs are required to properly implement ABC.

Major benefits include reducing traffic impacts, and the use of prefabricated bridge components made of HPS, HPC, and other new materials and equipment. Application of the latest techniques in concrete manufacture, including the use of lightweight concrete and other hybrid materials, will contribute to durability and possibly early completion of projects.

It was shown that applying the ABC methodology will result in 50% more completed bridges each year. This will help the economy by reducing wasted man-hours due to traffic jams during construction; commuters will get to work faster, which will benefit commerce by promoting faster delivery of goods.

Primary and secondary consideration for the selection of suitable projects for ABC, in terms of benefit, are addressed. Tables 1.2(a) and 1.2(b) give a format of criteria and allocating points in the point system.

Please see references to FHWA publications in Appendix 1 (Bibliography) for Chapter 1 for details.

In **Chapter 2**, we address recent developments in ABC concepts and their application to infrastructure. We noted that it might be possible to reduce the number of failures with ABC by applying recent advancements in technology and innovative methods. The failed bridges that were built using old technology can be rebuilt on a fast track using ABC.

It appears that there are hiccups that may be holding up a more rapid switch to ABC. A slow but gradual shift from conventional methods to full ABC (with many projects utilizing a partial ABC approach) has been observed. Each management subsystem, such as partial ABC, can be used to accommodate different circumstances and physical conditions. ABC-related design needs to be made part of the American Association of State Highway and Transportation Officials (AASHTO) and state bridge design codes and specifications. Deterrents and bottlenecks such as maintenance and protection of traffic (MPT), construction easements, right-of-way, permit approval, and utilities relocation need to be resolved, and administrative procedures further simplified to facilitate ABC.

There are many feasible applications of the latest techniques in concrete manufacture, composites, HPS, and hybrid materials that need to be promoted. Integrated software that would cover all aspects of ABC, including design calculations and drawing preparation, should be investigated and developed to save engineering man-hours.

A surge has been seen in the manufacturing of bridge components and construction machinery worldwide. FHWA has prepared a comprehensive ABC manual. AASHTO grand challenges by the AASHTO Technical Committee for Construction (T4) present additional goals to strive for. For bridges located on rivers, a survey of scour countermeasures that are being used nationwide was conducted. A form was successfully developed to assist in the field assessment of scour at bridges. Introducing more rapid inspections to identify deficient bridges by using remote sensors is emphasized.

Full-scale testing of joints in precast curved decks for both rectangular and curved decks is required. Modifications to analytical methods applicable to discontinuities of components need to be developed.

Chapter 2 also addresses design-build contracting system and the role of the Design-Build Institute of America (DBIA) in promoting ABC. Construction Manager/General Manager system is described in Chapter 2.

Chapter 3 emphasizes ABC logistics and training and research aspects. For promoting ABC, design-build method of construction management is described in this chapter. The role of the transportation agency in patronizing and promoting ABC is the most critical. The consultant and specialized subconsultant roles come next; they introduce key innovations in design and field connections.

This chapter reviews bridge rating procedures to identify deficient bridges and how to prioritize bridge repair. Structural health monitoring methods using remote sensors will help prioritize bridges for rehabilitation. The key factors dictating a particular type of delivery method include time restraints, level of risk, budget, and level of quality.

Preparing an evaluation matrix for selecting the type of fix or replacement would be helpful. Innovative techniques need to be popularized and adopted as routine bridge construction. Most accidents occur during bridge construction; hence rapid constructability requirements during erection need to be met, and preventive measures in design and construction to prevent failures need to be introduced.

ABC planning, analysis, and implementation methods vary for each of the structural systems and lead to many diverse applications for small, medium, and long spans, each of which has different construction durations and their own specialized construction methods.

Constraints in implementing ABC include MPT, approach slab construction, permits, and utility relocation; these are unavoidable constraints and should be on critical path for early completion.

The nature of manufacturing precast products creates a proprietary system and monopolistic environment, which may lead to unemployment of some number of construction workers. Overemphasis of incentives/disincentives may pressure the contractor into adopting unrealistic schedules at the expense of quality control.

Certain improvements for economical design include the following:

- An upgrade to most modern construction equipment would be required.
- Current plan preparation and presentation should reflect ABC.
- Payment and accounting of pay items need to be accelerated.
- Arching action in deck slabs should be utilized—there is reserve strength that is being neglected.
- Deck overlays for riding surface quality—latex-modified concrete (LMC) or corrosion inhibitor aggregate concrete may be used.
- Bridge deck expansion joints for precast deck units should be investigated.
- Compliance with permitting regulations—environmental permits may hold the start of construction.
- Insurance against risk and liabilities is critical.

Chapter 3 describes training programs in ABC organized by DBIA. It also addresses construction permits issues for air quality and water quality etc. to be award by the Department of Environmental Protection (DEP). Chapters 7 and 9 also describe environmental issues. Chapters 3 and 4 and Appendix 1 (Bibliography) provide a list of relevant references on all aspects of ABC.

Chapter 4 discusses how maintaining the right-of-way philosophy is achievable through innovative ABC techniques. The chapter deals with design-build construction management, addressing modern concrete technology and the philosophy of maintaining the right-of-way at all times for all citizens. There has to be a reward to promote innovation and encourage the undertaking of some risk. The most recent initiatives and innovative techniques are described; they are promoted by federal agencies like FHWA and AASHTO as well as individual states, which are promoting the implementation of ABC for faster bridge delivery. This chapter discusses a comparative study of conventional and innovative methods, along with a review of new design methods and the development of diverse repair technologies.

We look at modern construction equipment, the use of recyclable materials, and examples of recent ABC applications in the United States. The scope of design-build (D-B) contracts and considerations of engineering ethics are also addressed. We also discuss the important issue of ensuring adequate returns of the hundreds of billions of dollars of yearly investments in infrastructure through rapid bridge delivery.

Innovations help in upgrading the quality of construction and in completing the project in a timely manner. A list of advancements in ABC methods include:

- Preventing bridge failures by minimizing the identified deficiencies through maintenance
- Use of advanced methods, including computer-aided analysis and design techniques
- Closer interaction between design documents and construction.

Continued research efforts are required in resolving technical issues. Common examples of innovative concepts that require continued study are ground-penetrating radar (GPR), staged construction, overhead and utility lines, environmental permits, road closures versus detours, precast and composite decks, and the use of stainless steel.

On the administrative side, new procedures for asset management, award of simultaneous multiple contracts, and accelerated highway construction (AHC) to accompany ABC were introduced in this chapter. Using nanotechnology to reveal cracks and corrosion, searching for photographic evidence of defects, and using remote sensing technologies would certainly help in rapid bridge inspection and SHM.

There have been developments in the use of self-consolidating concrete (SCC), lightweight aggregate concrete (LWAC), recycled concrete aggregate (RCA) concrete, accelerated cure cast-in-place (ACCIP) concrete, blended cement concrete (BCC), fiber mesh concrete (FMC), reactive powder concrete (RPC), and rapid setting concrete (RSC).

Researchers have developed special repair materials. They include nonshrink, multipurpose and high-strength repair mortar. Cementations materials concrete utilizes fly ash, blast furnace slag, and silica fume.

Examples of proprietary bridge systems include the robotic steel beam assembly system by Zeman, which has added a new dimension of structural steel fabrication and erection. The system is designed for fully automated assembling, tack-welding, and full welding of structural steel elements. Other systems include recycled plastic lumber bridges, lightweight titanium pedestrian bridges, Inverset, Effideck bridge decks, Exodermic bridge decks, and full-depth precast concrete deck panels (FDDP).

Chapter 5 addresses construction and rehabilitation using prefabrication, prefabricating bridge elements and systems (PBES) and various other improvements in the manufacture of ready-made bridges. Prefabrication of bridges and their technical issues are discussed in Chapter 5. There are many bridge companies in this area, such as CON/SPAN and Mabey-type temporary bridges. Modular design and prefabrication have a number of benefits, including shorter production cycles and enhanced sustainability. This results in lower production costs, with savings to be passed on to the client. The use of eco-friendly materials and prefabricated design also make these modular structures ideally suited to the changing demands of the transportation industry.

Consider sample projects using the following bridge elements as guidance in the absence of an ABC code of practice:

- Precast foundation elements
- Precast pile and pier caps
- Precast columns
- Precast full-depth deck slabs

- Cored slabs and box beams
- NEXT beams and deck girders
- Full-span bridge replacement units with precast deck
- Bridges installed with SPMTs

Cost evaluations are important and should be accurate. They should include the following categories:

- Time and materials estimates
- Roadway user costs
- Maintenance of traffic costs
- Safety costs
- Agency costs
- Life cycle costs

If the cost of ABC is not greater than 30% of the conventional bridge construction cost, strongly consider ABC. The benefits are in early delivery, improved quality, and longer bridge life. Take advantage of existing technologies, such as Inverset and prefabricated fiber-reinforced polymer (FRP) deck.

ABC methods have evolved ahead of the design codes. Research is required in many aspects, including:

- Developing strengthening methods and corrosion mitigation techniques, including fabricating stronger girders by eliminating the need for shear stiffeners with the use of folded web plate in steel girders
- New methods to monitor and strengthen foundations against scour, earthquake, and impact
- Developing and reviving the concept of full canopy on bridges to facilitate mobility, improve drainage, prevent skidding, and eliminate the use of deicing agents

Chapter 6 deals with rapid bridge insertions following failures. This chapter addresses the reasons for numerous failures of bridges in United States and abroad, which can be prevented by the introduction of new technologies of ABC. Maintenance can avoid failures or at least warn of failures in advance. Use of remote sensors to monitor structural health is desirable. Early failures in conventional construction can be attributed to a variety of reasons, both administrative and technical. Studies shows failures resulting from inadequate oversight of projects, a lack of supervision at the site, design errors, lack of comprehensive codes, contractor's last-minute decisions to meet hasty schedules, and limited resources. Most failures occur during construction due to lack of redundancy in design, inadequate construction, and lack of contracting experience and knowhow. Alternate ABC contracting methods are described in Chapters 6 and 9.

As discussed in this chapter, bridges on rivers failed more than those located on intersections, due to soil erosion. Use of HEC-23 countermeasures is on the rise. Deep foundations are preferred over shallow foundations for bridges that are scour critical. Scour countermeasures need to be designed according to HEC-23 and provided to protect footings. When replacing an existing superstructure, deck elevation may be raised by 1–2 ft. Some progress has been made in making bridges seismic resistant by using lightweight materials and isolation bearings. The large volume of site work in conventional construction is minimized by ABC, which requires as much work offsite as possible.

Use of modern technology: Bridge engineering is changing with time. New technology and innovative ideas developed in the last two years need to be adopted. In planning bridges, cost is still the main criteria. Much of the cost goes into the foundation and substructure concrete construction.

The use of new and stronger construction materials such as HPS, HPC, and Ultra HPC and FRP decks should be encouraged, as these are more durable. Shallow-depth girders will result, which are lighter in weight. Galvanizing will reduce corrosion. Currently, rolled sections in HPS 70W and 100W are not available or are too expensive. Welded girders in HPS are being used.

Prestressed concrete box girders are stronger in torsion and cost-effective, especially with the use of lightweight concrete; they also lower maintenance costs. Also, composite construction, for example using the Inverset system, is more economical and on the rise. Precast integral abutment construction requires greater attention. Peak stress and deformation can be checked prior to lifting. The location of cranes needs to be identified on contract drawings.

Project management, quality control, and MPT are of critical importance. It was observed that the professional relationship between owners, contractors, and consultants needs improvement through increased communication. ABC design-build methods are a step in the right direction.

Widening of highways in urban areas is not always an option. Right-of-way and legal issues are involved to acquire new land. Hence, underpass and/or double-deck highways are often used to overcome the additional lanes problem and traffic congestion once and for all.

Safety checklists: It is critical for personnel to be safe and healthy at construction sites. A checklist of do's and don'ts needs to be prepared and issued.

Erection methods for curved girders are also described in Chapter 6.

Chapter 7 addresses ABC planning and construction issues. Our failing infrastructure and transportation problems are discussed in this chapter. Before launching a multimillion dollar project, it is the professional responsibility of engineers to conduct an effective planning exercise. The continued and ever-increasing infrastructure difficulties faced by the public are highlighted. The economic and public comfort benefits derived from early completion of projects are reviewed. A survey of ABC projects successfully completed in many states illustrates an increased interest in adopting the new technology. Major contractors and fabricators have welcomed the increased responsibility of the design-build system in which their decision making is appreciated. The progress of design-build system and MPT issues are described in Chapter 7.

Various aspects of the contractors' role such as that of Construction Manager/General Manager are described in Chapter 7.

Partial ABC: For rehabilitation of an existing bridge, an engineer's options are restricted as compared to the options available for design of a new or replacement bridge. But partial ABC is still possible. The huge funding issues can be partly overcome by public-private partnerships.

The focus of **Chapter 8** is on bridge superstructure prefabrication, several aspects of prefabrication of the superstructure and includes the stakeholders of ABC. The reasons for its success are as follows:

- The contracting industry is not afraid to take the lead in the management of small- and medium-sized projects and is willing to take the necessary risks and meet challenges that inevitably arise.
- There have been developments in special transportation methods for long and wide loads using SPMT. In addition, heavy capacity cranes for lifting and erection are now available.

- Organizations such as FHWA (with their Every Day Counts Program and ABC Handbook), Transportation Research Board (TRB) and AASHTO have been a motivating factor.
- The design-build contract system helps in the adoption of prefabrication. According to SHRP2 Project R04, ABC is the clear choice. Life cycle costs are significantly reduced.

Promoting modular construction: European practice is to standardize the design of bridges on typical intersections (limiting them preferably to two spans) and wherever possible on river bridges as well. The location of abutments can be adjusted to utilize standard precast girder lengths. The location of field connections are also kept unchanged as determined from analysis.

A list of recent innovations is presented for selection and for further action and implementation, such as:

- PBES
- Connection details for PBES
- NEXT beams, spliced girders, bulb tee, and Wolf girders
- Structural placement methods
- Launching, sliding, and heavy lifting.

On-site construction under open sky is far more difficult than factory manufacture. New bridges have become more complex since the bridge practice of a century ago, when cast-in-place (CIP) construction was the only option. Today a medium-size factory would likely have the necessary facilities for indoor fabrication. Some of the difficulties involved in on-site construction include:

Extreme events and climatic hazards: Most of North America has a subzero cold climate for four months of the year, and southern states have high temperatures in the summer. This may slow down the speed of outdoor work. In large factories, temperature change does not affect the schedule for construction. Also, activities on the critical path are not affected.
Labor availability at remote locations: Most bridge sites are located on distant highways. Hundreds of members of the labor force cannot be relocated. The factory is their regular workplace.
Storage of construction materials: A special building is required on-site for storing construction materials such as aggregates, cement bags, ladders, machinery, and dozens of other appliances. Temporary pathways need to be constructed. This adds to the schedule.
Formwork: This is an expensive item of CIP construction. It needs to be erected for the deck slab and for the CIP girders. This adds to the cost of work and affects the schedule.
Exposure to rain and sunlight: Due to the exposure of steel and cement to the elements, corrosion of steel and wetting of cement, etc., takes place, which lowers the quality of work and is not desirable.
Mobilization: For CIP, a temporary administration building needs to be set up. This adds to the overhead.

Other issues covered in Chapter 8 include the following:

Wider use of the P3 system: With the P3 approach, required funding is made available to replace hundreds of these bridges more quickly.
Introduction of new maintenance and planning techniques: The causes of structural deficiencies, functional obsoleteness, and bridge failures need to be investigated. Methods to prioritize the planning of structural systems and introduce rapid construction need to be researched.
Structural health monitoring (SHM): This is a new technology for bridge inspections that uses lasers and remote sensors. Bridge inspectors need to be trained in the use of computer software

that operates such remote sensors, as well as radar technology and Lidar techniques that can quickly obtain information about the fatigue and stress-strain history of a bridge. This approach will make bridges safer and reduce life cycle costs.

Overload prevention and review of live loads: In light of the latest advancements in the truck industry, it has become important to assess the magnitude of axle loads on highway bridges and also update the military live loads on military routes due to new tanks. American Society of Mechanical Engineers design codes need to be reviewed.

Use of high-friction surface: Introducing the British-invented surface treatment on asphalt pavement to create a high-friction surface and favorable friction properties between vehicle tires and bridge deck surfaces will help in braking and prevent skidding. Binders such as thermosetting epoxies are used. Maryland has successfully introduced plates on their intersections.

Chapter 9 deals with substructure prefabrication techniques and construction management. The progress in using prefabrication has been slower for substructure construction compared to that for superstructure construction, especially for longer span bridges. It is easier to transport horizontal bridge beams and slab panels on an SPMT than vertical pier bents due to their size. Also, post-tensioning may be required for the substructure panels to make them watertight.

For emergency bridge replacements on important routes after floods, earthquakes, or accidents, etc., prefabrication of both pier and abutment members would help. Other key aspects of prefabricated substructure planning and management include:

Soil report: Since foundation design requires soil investigation, this operation should be started well in advance by the owner even before the award of the contract.

Utility pipes: Advance coordination with the utility companies for supporting their pipes and transferring from pavement elevation to deck elevation is required.

Deck drainage: The method of disposal of rainwater from the deck into public sewers also needs to be planned.

Electrification: If deck lighting is provided, the power supply needs to be arranged from the electric supply company and negotiations need to be started in advance, as the prefabrication activity is in progress.

Precasting concrete and welding: Although prefabrication in a factory may not take as much time as cast-in-place construction under the site conditions, the time required for the plan layout of rebars, the curing of concrete components, and the welding of steel members, etc., remains unchanged.

Planning: The additional time required to plan a route, obtain permits for heavy and wide loads, and apply for police escort, as well as the hauling distance for the prefabricated bridge from the factory to the site need to be taken into consideration.

Hauling heavy loads: Loading prefabricated components onto the SPMTs and unloading them at the site as well as the required lifting and placing operations by the special cranes on-site need to be taken into account in the overall schedule.

Stay-in-place formwork: The additional time and cost for hauling, lifting, and placing needs to be analyzed in comparison to the cast-in-place construction erection time for temporary formwork or using permanent stay-in-place formwork to make prefabrication as economical as possible.

Modular construction: The greatest benefit of prefabrication is for small spans, where the hauling and lifting problems are fewer and pier construction is avoided. Arch structures combine superstructure girders with substructure curved columns and are more aesthetically pleasing.

Leading prefabrication companies: There are a wide variety of bridge manufacturing companies in the United States who have developed specialized bridges for repeated use. Examples include High Steel Structures, Acrow, Jersey Precast, and CON/SPAN.
Need for standardization: AASHTO specifications have recommended minimum vertical and horizontal clearance requirements. Similarly, many states have developed standard details for lane widths, shoulder widths, and bicycle tracks, spaces for plants and flowers, etc. Span length alternatives to conform to the width of the highway can be used to standardize bridge lengths. Such ready-made standard span structures using concrete and steel can be made available off the shelf and ready for delivery to sites, as required. A choice of colors is also available for aesthetic requirements.

Quality control: Construction drawings for precast substructures are more specialized than conventional construction drawings. Typical review comments on reinforced concrete detailing of abutment walls, pier caps, and columns are therefore necessary. Examples of necessary quality control measures are review by expert bridge engineers of the connection details, location of hinges, seismic detailing, lifting points, etc. Case studies of a variety of bridges using PBES for the substructure in the United States are summarized in Chapter 9.

Foundation drawing reviews: Expert reviews can raise a number of issues and lead to various recommendations. Some of these include the following:

- Foundation design is too expensive; footings are too big/deep. Review soil report.
- Monitor compaction before placing footings. Consider soil improvement techniques.
- Always get soil borings and a geotechnical report before foundation design and have geotechnical oversight and testing during construction.
- Use deep piles or drilled piers.
- Use caissons or auger piles.
- Use tied spread footings.
- Check for retaining wall failure from settlement and overturning.

Alternate ABC contracting methods are also described in Chapter 9.

Various aspects of engineering management are presented, such as asset management (Chapters 2 and 10), disaster management (Chapter 3), design-build (Chapter 4), bridge failures and risk management (Chapter 6), and construction management (Chapter 9).

Chapter 10 addresses evaluation criteria for deficient infrastructure and alternative ABC methods. ABC technology is still developing, although significant progress has been made in prefabrication. This chapter highlights important alternatives to the well-established use of factory prefabrication and SPMT, such as transportation by barges and lateral slide-in methods. The many impacts of rapid construction and traffic volume and lane closures are also given in Chapter 10.

In some cases it may be warranted to use lateral slide-in methods due to the limitations of transporting large bridges by road or on rivers for long distances and fitting them on SPMTs or barges. The method consists of site casting adjacent to the existing bridge on temporary bents, followed by the use of mechanical devices for sliding or the use of cranes to lift the superstructure in position. Case studies have shown that many states have successfully used this modern technology.

A few states like Utah and Oregon have developed special provisions as part of their construction specifications. In some cases it is possible to construct abutments prior to slide-in of the new bridge, leading to further time savings.

The use of new types of concrete materials for deck slab will enhance deck life and reduce life cycle costs. Examples are Exodermic decks, Effidecks, and FRP and HPC deck panels. Several types of lightweight precast girders such as NEXT beams, Wolf girders, and T-Bulbs have helped in providing rapid delivery of bridges and reducing initial and life cycle costs.

The important and sensitive issue of generating additional funding through the P3 system is also discussed in this chapter. Public investment has promoted much needed and timely reconstruction of thousands of structurally deficient (SD) bridges.

The ASCE Report Card for infrastructure has put pressure on federal and state governments to take the necessary measures to replace, repair, and rehabilitate the growing number of deficient and obsolete bridges nationwide. FHWA's "Every Day Counts" Program and FIU seminars on ABC have been training bridge engineers in new technology. Also, courtesy of FHWA, Website resources are now available. These will help in training of contractors in the use lateral slide-in methods. The conclusions for this chapter are presented at the end of the chapter. A wide range of appendices are presented on the following topics and are referred to in the text in the chapters:

Bibliography
ABC Glossary
Bridge Inspection Terminology
Three-Credit University Course in ABC
Training Courses and Workshops in ABC
Survey Form for Structural Countermeasures
ASCE Report Card—Innovations and New Technology
Rapid Construction of Timber, Aluminum, and Lightweight Bridges
TEMPLE-ASCE One-Day Course on Rapid Bridge Construction

A three-credit course syllabus shows the importance of theoretical and practical aspects and how the AASHTO Load and Resistance Factor Design (LRFD) Specifications and Load and Resistance Factor Rating (LRFR) Provisions need to be supplemented.

The salient features of the topics of the course are as follows:

Introduction and Objectives of Rapid Bridge Construction

Overview of Highway User's Comforts; Examples of Bridge Failures, Deficient and Functionally Obsolete Bridges; ASCE Report Card on Infrastructure.
Problems with Detour and Lane Closures for Considerable Length of Time.
Initiatives for ABC by FHWA, TRB, Selected States and Universities.
Bridge Inspections, Site Surveys, Testing, Alternates and Preliminary Designs.

11.1.2 Funding aspects

Economic Considerations in Planning, Value Engineering, Public-Private Partnership (P3).

11.1.3 Project management aspects

(Lump-sum, Design-bid-build, Design-build, CMAR etc.)

DBIA Recommendations

11.1.4 Accelerated construction techniques

Use of SPMT, Slide-in, Roll-in, roll-out, Float-in, Bridge in a Back Pack, partial ABC.

High-capacity cranes, Rollers, etc.

11.1.5 Modern durable construction materials

Concretes in Deck, Prestressed Girders, Abutments, Piers and Foundations (HPC, UHPC, FRPC, CFRPC, GFRPC, etc.)

Steel Girders (50W, HPS 70W, HPS 100W)

11.1.6 Type of superstructure and geometry of bridge

Slab-beam, Truss, Arch, Segmental, Cable-Stayed etc.

11.1.7 Type of substructure

Shallow Foundations, Piles, Drilled Shafts etc.

11.1.8 Funding constraints

Prioritization, P3 requirements.

11.1.9 Typical ABC construction specifications

- Bidding procedures
- Materials control, Precasting in Factory and Field Conditions
- Quality considerations
- Insurance, Warranty, and Surety Issues

11.1.10 Project management aspects

Technical Proposal to Client, Structural Planning, Feasibility Studies, Preliminary and Final designs, Post design Services.

Part 2

11.2 Coordination with highway maintenance schedule

Maintenance and protection of traffic is a primary requirement during reconstruction. Work on the bridge would affect traffic flow on the highway and vice versa. The volume of tasks for fixing the highway pavement and resurfacing takes much more time than required for the bridge repairs itself.

In practice, highway maintenance requires the following tasks, which can be performed parallel to those on the bridges to avoid frequent lane closures.

- Cracks may happen in the road surface due to frequent rains and snow.
- Due to accidents, the median barrier can get damaged.
- Variable message sign structures may be added.

Bridges are essential parts of the highway. Both the highway and the bridges require maintenance. If a number of bridges need to be fixed on a busy highway, the work will most likely be done in the window available in the same construction season. The schedule needs to be planned by the highway agency.

11.2.1 Construction season restrictions

For deck repairs, longitudinal joints require cast-in-place concrete pours. All outdoor work, which involves minor or major repairs (both for highway and for bridges), must be carried out in reasonable weather conditions. Weather may vary according to the location of each state. Work will not be possible if it rains the day wet concrete is planned for use or in extreme cold or hot weather. The bridge construction schedule and activities on the critical path must be planned while keeping an eye on highway repair work and severe weather conditions.

When bridges on a given highway are due to for repairs or replacement, often some of the highway sections and pavements also require fixing. Generally, bridge deficiencies and highway wear and tear go together. In the interests of minimizing adverse impacts on the traveling public, the owner would like to perform both the highway and bridge work at the same time using the same contractor, who can deploy its resources (equipment and labor) in an efficient manner. This enables all of the work to be done in the shortest possible time.

A review of research challenges by a key AASHTO subcommittee (T-4) on this developing subject presented some areas still in need of further investigation. For more efficient project management and faster implementation, improved coordination and communication skills need to be researched so that ABC methods can be made more economical. A comprehensive construction code that spells out practical steps based on past experience for a refined and rapid type of construction needs to be developed.

11.3 ABC applications for bridges located on rivers

Application of ABC for construction of bridges on rivers is possible, but the scope of work is greater and it may take longer to complete than for bridges located at intersections. This is due partly because banks of flowing rivers are subject to erosion and scour. Deep foundations, including longer piles, are required, which increases the duration of construction. Moreover, the foundations need to be shielded against erosion during floods, which requires special items such as river training, scour countermeasures, and retaining walls along the eroded banks. For the slide-in method, temporary bents adjacent to the existing bridge need to be constructed in the river conditions. The additional work for extra items gets added to the construction schedule and is discussed below.

Environmental Permit requirements: For continuous span bridges, piers are required in the middle of rivers. An application for a construction permit should be made to the state DEP, well ahead of the start of the project. Otherwise, objectives of ABC will be defeated.

Documents need to be prepaid in support of the application forms for review by DEP. Meetings are held to minimize obstructions to the flood flow such as eliminating piers and increasing opening sizes. Cofferdams for foundation construction are required, and in some cases the river needs to be diverted through an auxiliary bridge. Prefabricated members may not require SPMTs for the entire distance, but transportation on barges will shorten the distance of travel from the factory to the site. Deep foundations, scour countermeasures, retaining walls, use of barges, etc., are major items that will increase the overall duration and cost of the project. Nevertheless, the ABC design-build method will still be a great help compared to the conventional method.

11.3.1 Scour and erosion of foundations at river bridges

In the United States, over 36,000 bridges are either scour critical or scour susceptible. Some examples of recent bridge failures are:

- Schoharie Creek Bridge, located on the New York State Thruway, in 1987
- US 51 Bridge over Hatchie River in Tennessee in 1989
- Damage to bridges located on the Mississippi River in 1993
- Interstate 5 NB and SB bridges over Los Gatos Creek in California in 1995
- Route 46 Bridge on Peckman's River Bridge in Passaic County in New Jersey in 1998
- Ovilla Road Bridge located in Ellis County in Texas in 2004

In this chapter the latest technology for scour countermeasures is introduced. Applications for FHWA Circulars HEC-18 and HEC-23 are discussed. Since scour is a major problem for bridges located on waterways, familiarity with the methods presented will benefit the engineer in terms of safety and economical foundation design and also assist in solving constructability issues. According to the AASHTO LRFD Specifications (Section C3.7.5):

Scour is the most common reason for the failure of highway bridges in the United States.

Scour excavates and carries away material from the bed and banks of a stream. Small brooks, streams, rivers, and oceans all possess different degrees of kinetic energy. Scour or soil erosion at a bridge is caused by the dynamic effects of water in motion.

Erosion is a very old subject that is currently analyzed using scientific disciplines such as:

- Hydrology
- Bridge hydraulics
- Soil cohesion
- Scour analysis

Erosion can be minimized by installing "countermeasures." Stone lining or shielding of soil is the oldest form of countermeasure. A countermeasure is defined by HEC-23 as:

A measure incorporated at a stream/bridge crossing system to monitor, control, inhibit, change, delay, or minimize stream and bridge stability problems and scour.

The type of countermeasure is dependent upon:

- The nature of scour contraction or local
- Clear water or live bed
- Aggradation or degradation
- Meander or
- Debris accumulation.

Scour-critical bridges across the United States are currently being retrofitted using different standards for countermeasures. The design procedures depend on individual bridge owners, representing hundreds of city, county, and state government agencies. Design guidelines are being applied differently in different states for old bridges.

The author carried out research on this subject for a joint publication with Anil Agrawal with a goal of developing a "Handbook for Scour Countermeasures." The NJDOT Bureau of Research sponsored the project, and a detailed report is now available on their Website for general use. Some of the countermeasure details provided in this chapter are based on the handbook. See http://www.state.nj.us/transportation/refdata/research/reports/FHWA-NJ-2005-027.pdf.

11.3.2 Factors affecting magnitude and rate of scour

Soil profiles for typical scour-critical bridges: The soil profile for a particular bridge site should be based on boring logs. While detailed geotechnical and borehole testing needs to be carried out to obtain site-specific information, studies will often utilize existing maps and information available with the state and the U.S. Geological Survey (USGS). Different soil and rock materials will exhibit different rates of scour. The kind of geologic material, coupled with the intensity and duration of a flood, will determine scour depth.

Soil classification: Soil types are broadly classified as:

- Noncohesive (e.g., gravels, sands, and silts)
- Cohesive (silts, clays) materials

The magnitude of scour for cohesive and noncohesive soils is different, but scour takes much longer in cohesive soils, resulting in longer bridge life. In cohesive soils such as clay, both the local scour and contraction scour magnitudes may be similar, but scour takes place considerably later than in the noncohesive sand. The threshold of movement of particles of both cohesive and noncohesive materials depends on:

- Particle size
- Density
- Shape
- Packing and orientation of bed material

Noncohesive sediments: Examples are sands, gravels, and silts that have a granular structure. Such soils are considered to be the most susceptible to scour. The unbounded individual particles are susceptible to erosion when the applied fluid forces (drag and lift) are greater than the stabilizing forces (gravity and friction with adjacent bed particles).

Most fine-grained sediments (clay, silty clay, and clay mixtures) possess some cohesion, the clay content being of great importance. Cohesive sediments typically require relatively large forces to detach the particles and initiate movement, but relatively small forces to transport the particles away.

Type of bed material: The bed material is comprised of sediments (alluvial deposits) or other erodible material. If bed materials are stratified, there is a greater risk of scour breaking through the more resistant layer into the less resistant layer. A survey of U.S. bridges indicates that bridges founded in sand have the most scour problems, as summarized in NCHRP 24-7.

The clay content in the soil increases cohesion, and relatively large forces are required to erode the riverbed. Higher pulsating drag and lift forces increase dynamic action on aggregates until the bonds between aggregates are gradually destroyed and aggregates are carried away by the flow. An approach estimating scour in cohesive soil is to couple erosion rate with the cumulative duration of flows that exceed the threshold velocity for particle movement.

Soil types: Jean-Louis Briaud at Texas A&M University has proposed the SRICOS method of scour measurement. Streambeds that either consist of bedrock or contain a high percentage of oversized cobbles and boulders are the most scour-resistant materials. To determine rock quality careful evaluation is needed to assess factors such as:

- Strength
- Fracture frequency
- Weathering
- Slaking

A breakdown of scour problems by soil type is given in Table 11.1. However, since geologic conditions vary widely across the country, the statistics for each state will vary.

11.3.3 River inspections

In the absence of scour analysis, the Recording and Coding Guide of the National Bridge Inspection Standards (NBIS) or AASHTO Guidelines should be used to classify the bridge if it is scour critical. Items 61, 71, and 113 of the Recording and Coding Guide can be of significant concern during underwater inspections (see the Appendix for items 61 and 71). Item 113 is used to determine the Scour Rating. A list of Bridge Inspection Terminology and Sufficiency Ratings used by PennDOT is given in Appendix 3.

11.3.4 Damage from flood scour

Minimal marine life disruption and quick construction are being achieved by gabion baskets, articulated concrete, or cable-tied blocks in lieu of traditional riprap. Sheet piles were used for the new Schuylkill River Bridge and SEPTA's 30th Street Station Bridge (by the author). The author

Table 11.1 Soil Types with Scour Problems (NCHRP 24-7)

Sediment Type	Percent
Sand	48
Cohesive	19
Mixed	13
Gravel	10
Bedrock	5
Uncertain	5
Silt	0
Total	**100**

prepared a “Handbook for Scour Countermeasures” for NJDOT jointly with CUNY, which was approved by FHWA, and helped developed Sections 45 and 46 of the NJDOT Bridge Design Manual.

11.3.5 Structures on water crossings

Study of scour critical bridges in the Northeast USA: In the past twenty years, the author investigated the effects of flash floods and 50-year floods and the many damages caused to the superstructure, substructure and foundations.

Research reports were prepared for the identified scour critical bridges in Massachusetts, New Jersey, Pennsylvania, Delaware and Maryland.

Some of the findings are presented here.

- Unless founded on rock, all structures crossing water shall be supported on piles or have other positive protection to prevent scour of the substructure.
- Cofferdams should be evaluated with regard to need, type, size, constructability, and cost. Alternative types of construction such as causeways, caissons, or drilled shafts should be considered and compared to conventional cofferdam costs.
- The estimated maximum depth of scour should be used to determine overall structure stability. Piles should be socketed into rock if scour can affect their stability. Recommendations for details will be contained in the foundation design report (FDR).
- In addition to areas for repairs identified in the last underwater inspection and evaluation report, a field inspection and a new underwater inspection need to be carried out for field verification of the latest substructure conditions underwater.

Figure 11.1 shows damage to pier concrete due to fast moving flood water making the bridge unsafe for heavy traffic.

11.4 Planning of bridges over rivers

Use of Float-in Method: The modular substructure and superstructure transportation problem to the river site will be solved by the float-in method (as shown in Figure 11.1 to avoid non-composite concrete cracks). It will help immensely in conducting complex construction over rivers. Existing continuous spans may be replaced by a single span, using high-strength construction material such as HPS and HPC that are fabricated in the factory rather than on the site.

The latest methods for repairing deteriorated concrete and repointing mortar joints, the applicable design details from AASHTO, and the applicable state bridge design manual can all be used as necessary. If the current NBIS rating given in the inspection report is higher for the abutments than for the piers, the load rating will be upgraded by performing the recommended repairs.

Perform substructure repairs both above and below the waterline for the following conditions:

- Abutment showing deterioration
- Abutment back wall with wide cracks at the north and south ends

FIGURE 11.1

Damage to pier concrete due to fast moving flood water making the bridge unsafe for heavy traffic.

- Concrete aprons at the piers exhibiting wide cracks
- Deteriorated expansion joint and back wall elements
- Removal of buildup of sand debris at piers
- Removal of any tree trunks or tree roots between piers
- Tooth dam at abutment not functioning and needs to be replaced

An estimate of the cost and repair quantities is required in each case for scour-critical bridges. Unlike the HS-25 live loads, which are defined fairly accurately, flood magnitudes are unexpected and of unpredictable magnitudes and are difficult to compute accurately for the required 50-, 100-, and 500-year intensity floods.

StreamStats hydraulic analysis software: There is a need for preparation of several databases (including demography changes in urban river locations) as required by the latest STREAMSTATS software, which is developed using hydrologic studies on rivers in each state by the USGS. Updates are required for the following reasons:

- The Rational Formula for computing flood discharge (which generally has been used) is approximate and has led to failures of bridges subjected to floods nationwide.
- Also, HEC-18 provisions have recently been revised.
- DM-2 and DM-4 specifications for flood computations and countermeasures design based on the old version of HEC-18 need to be updated so that foundations of bridges located on rivers can be safe in accordance with the new specifications.

Due to increased corrosion of steel bridges on waterways due to daily evaporation, the life of such bridges is adversely affected. During floods, countermeasures should not get displaced. Sediment deposits in some rivers require dredging and clearing of stones under bridges before it is too late. Hence, frequent inspections may be required.

11.5 Issues of scour-critical bridges

Examples of original planning defects are narrow openings and shallow foundation depths. Old bridges are likely to have planning defects as compared to new bridges. The effects of floods include both aggradations and degradation. In earlier days there were no scour analysis criteria. As per AASHTO it is now required to conduct such analysis. There is a considerable increase in velocity due to increase in discharge or reduction in flow area under the bridge.

$$V = Q/A$$

where V = Peak flood velocity

Q = Flood discharge and
A = Cross-sectional area of bridge opening.

Potential issues include the following:

- The original design of the flow area may be inadequate.
- The river has meandered over a long period and direction of flow is skewed.
- Debris may accumulate during floods, reducing the size of the opening.
- Heavy storms, increased snow and subsequent melting, global warming of glaciers, and changes in demography will increase discharge.

When both Q increases and A decreases simultaneously, the magnitude of increase in velocity will make the bridge "scour critical."

Scour is very much a site-specific issue as no two rivers are alike even though bridges may be alike. Physical parameters include:

River configuration types
Straight
Braided or multichannel
Meandering

River bottom types
Aggrading
Stable
Degrading

Scour at bends due to river meander: Special consideration must be given to scour for bridges located on bends. Maynord's equation (Maynord, 1995) is helpful to determine flow depths for these conditions and is equally applicable at abutments and piers. When scour occurs at the confluence of two rivers, flow depths can be estimated using Ashmore and Parker (1983) or Klaassen and Vermeer's (1988) equations; they will be applicable at abutments and piers. It is noted that the magnitudes of scour due to thalweg effects and migration of bed forms are typically small and are usually neglected.

Bridges on waterways have the following additional problems:

- Restrictions from environmental agencies in placing piers in riverbeds, resulting in longer spans
- Difficulties in designing and constructing deep foundations in flowing water
- Difficulties in maintaining bridge substructure underwater and in painting of corroded girders

11.5.1 Scour analysis

Codes and design guidelines: The following FHWA and AASHTO publications serve as major resources for scour analysis and design:

Riverine Flow HEC-18, "Evaluating Scour at Bridges"
HEC-20, "Stream Stability at Highway Structures"
HEC-23, "Countermeasures"
Tidal Flow HEC-25, "Tidal Hydrology, Hydraulics, and Scour at Bridges"
AASHTO LRFD Bridge Design Specifications
Model Drainage Manual (AASHTO)

Also, the Maryland, New Jersey, Pennsylvania, and Florida state codes, among others, can be consulted. NCHRP materials and CIRIA (British code) may also be useful.

11.5.2 Design floods

The aim should be to design bridges for all times and for all occasions. AASHTO (LRFD) load combinations for extreme conditions are applicable. The extreme-event limit states relate to flood events with return periods (usually 100 years) in excess of the design life of the bridge (usually 75 years). Foundations of new bridges, bridges to be widened, or bridges to be replaced should be designed to resist scour based on 100-year-design flood criteria, reviewing conditions that may create the deepest scour at the foundations. The author designed Peckman's River Bridge on Route 46 in North Jersey after Hurricane Floyd had subsided. Figure 11.2 shows damage even to the girders from overtopping.

Check flood for bridge scour: The foundation design should be reviewed using a 500-year check flood, or 1.7 times a 100-year flood, if 500-year flood information is not available.

FIGURE 11.2

Hurricane Floyd High water elevation causing damage from over topping.

(Photo by the author during peak floods.)

11.5.3 Evaluation of the need for countermeasures

1. Post-flood inspection in shallow water
2. Post-flood inspection in deep water

The location of a bridge influences the formation of scour at its foundation. Bridges located on a straight, meandering, or sloping thalweg, at a confluence, or downstream of a dam will all have different degrees of scour.

Bridge footings: Countermeasures are required for scour-critical bridges. Ideally, a recommended scour countermeasure will permanently eliminate a bridge's potential vulnerability to scour damage for the peak floods. A permit from the state is required to install armoring.

Periodic inspections after major floods or coastal storm surge.

Bridge Scour Evaluation: A nationwide survey was conducted by the author's research team for the types of scour countermeasures being used by each state. Appendix 9 shows a questionnaire survey form for scour countermeasures. The feedback received gave useful information on the type of countermeasure used and its performance. Scour-critical bridges located on streams with high flood velocities can cause major foundation settlements. Bridges with narrow waterway openings and soft erodible soils contribute to bridge collapse.

The magnitude and depth of erosion depend upon discharge volume and velocity. Rivers, rivulets, streams, brooks, and channels are all subjected to scour to varying degrees. A channel, for example, may have a small discharge but a high velocity. Hence, scour is present in all types of rivers, narrow or wide. The two main issues are hydraulics and soil science, i.e., the interaction between water and soil. Nonerodible rock will not be subjected to scour.

The following items discuss procedures for the assessment of scour at all bridges that are 20 ft or greater in length that spans water. There are two basic types of assessment:

- Field-viewed bridge site assessments, for which USGS personnel visit the bridge site
- Office-reviewed bridge site assessments, for which USGS personnel compile data and do not visit the bridge site

Both types of assessments are primarily focused at meeting the requirements of the FHWA mandate. Date of bridge construction and the accessibility of the bridge substructure units for inspection determine which type of assessment a bridge receives.

Pennsylvania State Scour Code: A web-based Scour-Critical Bridge Indicator (SCBI) Code as developed by USGS is used. The SCBI Code indicates the vulnerability of the bridge to future scour. It is based on the FHWA code (NBI Item 113) (FHWA 1989) and PennDOT's interpretation of the FHWA Code (Bryan Spangler, PennDOT, written communication, 1999).

The SCBI Code contains a whole number between 9 and 2. Each code number has one or more cases. Scour Assessment Rating (SAR) is computed from select collected and compiled structure components, and hydrologic and hydraulic data. Agency personnel assign the final SCBI Code and an SAR (between 0 and 100) on the basis of their review of all data.

The SCBI Code and SAR calculator use various factors from the field or office scour evaluations to determine the SCBI Code for individual subunits and the bridge. Field view, soil maps, and previous inspection reports are required. The calculator allows inspection personnel in Pennsylvania to determine overall bridge rating when:

- Review of bridge reports identify undetermined historical data or revised field data
- Site conditions change
- New scenarios have developed
- New bridges are constructed

11.5.4 Types of scour

According to HEC-18, general scour is a lowering of the streambed across the stream or waterway at the bridge. This lowering may be uniform across the bed or nonuniform. General scour may result from contraction of the flow or other general scour conditions such as flow around a bend. Total scour is the sum of long-term degradation, general (contraction) scour, and local scour.

Contraction scour is the component of scour resulting from a contraction of the flow area at the bridge. It causes an increase in velocity and shear stress on the bed at the bridge. If the abutments are located outside the width of a channel, no contraction takes place and there will be no contraction scour.

The initial scouring in low flows is known as "clear water" scour. Clear water scour is scour at the pier or abutment (contraction scour) when there is no movement of bed material upstream of the bridge crossing at the flow causing bridge scour. If the flow continues to increase, "live bed" scour can occur, which is general movement of the bed. Live bed scour depth increases with the increase in the size of bed material D_{50} in the riverbed, while clear water scour decreases as mean bed material size D_m increases. The increased velocity affects the stability of the streambed. For HEC 18, scour depth is computed from Laursen's equation for channel contraction within the total bridge opening. In terms of magnitude, it may be higher at the piers or at the abutments.

Local scour is removal of material from around piers, abutments, spurs, and embankments caused by an acceleration of flow and resulting vortices induced by obstructions to the flow. Local features at a bridge such as abutments, piers, weirs, cofferdams, and dikes may obstruct and deflect the flow. The substructures increase the local flow velocities and turbulence levels, giving rise to vortices that may increase the erosion of the riverbed.

At the piers, local scour is computed using the Colorado State University (CSU) equation. It is dependent upon many factors including length of pier, width of pier, and the angle of attack. Abutment scour is computed from Froehlich's and Hire's equations. It is dependent upon many factors including length of embankment.

The flow of water is on both sides of a pier, generating vortices and eddy currents, while the flow is on one side only for abutments. This results in higher scour depths at piers than that seen for local scour at abutments.

Ultimate scour is the maximum depth of scour attained for a given flow condition and may require multiple flow events, in cemented or cohesive soils over a long period.

A flow diagram was developed by the author for the NJDOT Bridge Design Manual Section on scour at bridges. The flow diagram shows that several types of analyses need to be carried out:

Inspection reports
Geotechnical analysis
Hydrologic analysis
Hydraulics analysis

Scour analysis and
Detailed countermeasures design.

The complete original procedures for determining the SCBI Code can be found in Cinotto and White (2000). The SCBI Code algorithm used by the web-based SCBI Code and SAR calculator was modified from Cinotto and White (2000) to eliminate the comparisons of USGS and PennDOT data.

Geotechnical: Both boring information and grain size analysis would be needed for accurate determination of scour. Collection and processing of geomorphic, hydrologic, and hydraulic data for assessment of scour at bridges require borehole information for soil characteristics.

The size of the opening or degree of obstruction from abutments, piers, and foundations will influence the velocity of water. The catchment area of a river, its source of supply, demography, storms, and melting of glaciers will influence the volume of discharge and erosion. The use of a gabion mat and baskets on a New Hampshire project for scour analysis on Monatiquot River is shown in the author's textbook "Bridge and Highway Structure Rehabilitation and Repair" published by McGraw-Hill, 2010.

Figure 11.3 shows use of Gabion Mat between abutment walls.

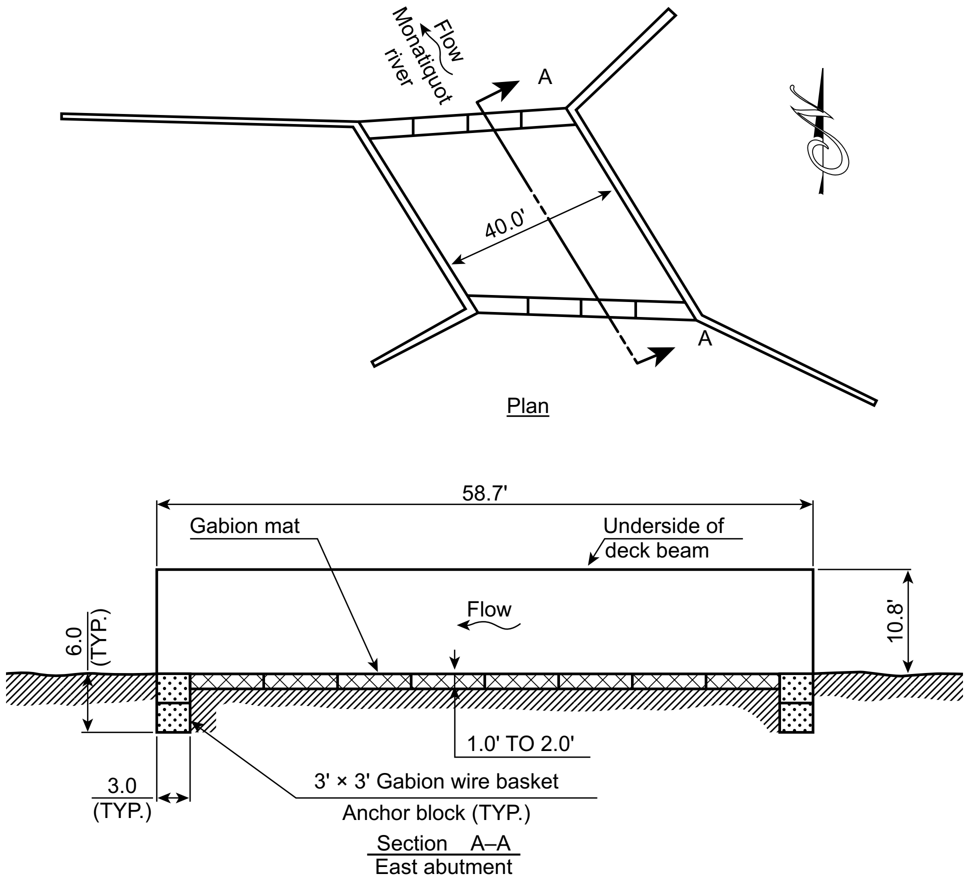

FIGURE 11.3

Use of gabion mat between abutment walls.

11.6 Rapid repairs and replacement of bridges on rivers

11.6.1 NBIS condition rating

The overall condition of substructures of 19 bridges was assigned the following NBIS condition rating:

Very good condition: No problems noted.
Good condition: Some minor problems.
Satisfactory condition: Structural elements show some minor deterioration.
Fair condition: All primary elements are sound, but may have minor section loss, cracking, or spalling.
Poor condition: Advance section loss, deterioration, or spalling of primary structural elements.

Aggradation is a common problem due to the tree environment close to the river banks.

11.6.2 In-depth bridge inspections

The purpose of the inspections is to identify levels and areas of deterioration of all structural and nonstructural substructure elements in order to develop repair recommendations and details. This effort also includes correlating probing measurements taken near the pier edges with the previous substructure inspections. FHWA has adopted three diving inspection intensity levels. The first two levels can be described as follows:

Level I: Visual, tactile inspection (100% "swim-by" at arm's length)
Level II: Detailed inspection with partial cleaning (100% "swim-by" with 10% cleaning)

FHWA Level II requires that portions of the structure be cleaned of marine growth to identify possible damaged and/or deteriorated areas that may be hidden by surface growth. The cleaning must be performed on at least 10% of all underwater elements. The equipment used to inspect the majority of the bridges consists of a small boat, sounding rod, hand tools, and line-tended SCUBA.

FHWA Level III diving inspections: This is a highly detailed inspection with nondestructive testing. Testers are inspecting a critical structural element where extensive repair is contemplated. Based on underwater inspection reports, the defects in Table 11.2 are typical of what may exist for a scour-critical bridge.

11.6.3 Concept study report and plans

Based on the findings of the condition assessment, potential repair/remediation recommendations will be developed. Fluctuating river elevations will be taken into account when developing repair recommendations and reviewing the construction feasibility.

Evaluation shall include but not be limited to:

- Evaluation of constructability and construction staging
- Community impacts during construction: impacts to emergency vehicle response, tourist industry, traffic delays, pedestrians and bicyclists, local businesses, and noise
- Development of construction cost estimates for each feasible alternative along with the anticipated construction schedule

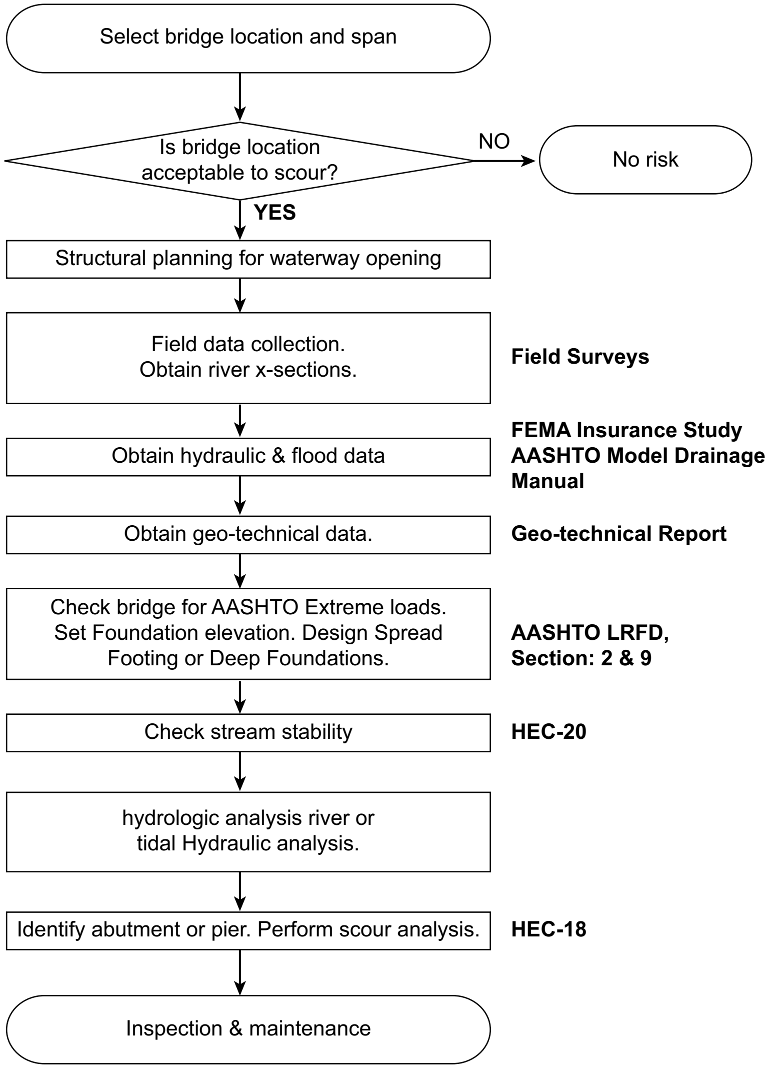

FIGURE 11.4

Flow diagram for scour analysis.

- MPT schemes shall be prepared for each feasible alternative
- Right-of-way requirements
- Environmental impact to the waterway and endangered species

A Draft Concept Study Report, including plans and recommendations, should be created to provide a concise aggregation of the important elements of the condition evaluation and an overall

Table 11.2 Underwater Inspection Results

NBI	Item	Remedy	Alternate
11	Spalls in abutment concrete	Surface repairs with approved patch material	
22	Delaminations and cracks in substructure concrete above water	Pressure grouting	
33	Voids in breast wall	Epoxy grouting	Nonshrink grout
44	Debris accumulation	Clean debris	
55	Mortar loss in masonry joints	Repoint mortar	
66	Undermining	Plug with concrete	Use grout bags
77	Broken stone masonry	Place stone and fill with mortar	
88	Cracks in tremie concrete below water	Pressure inject masonry cracks	
99	Spalling in foundation	Pressure grouting	
110	Missing or broken riprap	Replace by R-8 size stone	
111	Cracks in apron around piers	Repair concrete apron	Place riprap around piers
112	Silting	Dredging	
113	Advance section loss of structural members	Strengthen member	Underpinning

synthesis of conclusions and recommendations. The Draft Concept Study Report shall include but not be limited to:

- Condition assessment
- Scour vulnerability assessment
- Discussion of alternatives, including a discussion of potential impacts for each alternative
- Recommended repairs/remediation including supporting justification
- Requirements for design including required surveys, geotechnical evaluations, and hydraulic analysis
- A list of applicable permits including the permit cost and the anticipated duration to obtain the permit in the light of many requirements, including a discussion of required temporary construction easements, if any
- MPT requirements including sketches and/or conceptual plans for construction staging and detours
- Construction costs
- Anticipated construction schedule
- Plans with details to a level sufficient to clearly demonstrate the repair/remediation type and location along with construction staging and construction access

11.6.3.1 Constructability review

After the Draft Concept Study Report, a one- or two-day workshop may be held with the team members to review the concept study options. The goal of the workshop is to provide review comments in advance of presenting a preferred design concept.

Table 11.3 Data Collection Items for Scour Study Example

Item	Purpose	Data Collection	Methodology for Obtaining Data	Duration of Each Activity
Field surveys	Waterway opening	Yes	Observations and measurements	Two days
Underwater surveys	Scour holes	Yes	Probing	One day
River cross-sections	HEC-RAS model	Yes	Surveying instruments	Two days
Soil parameters	Roughness coefficients	Inspection and photos	Characteristics of banks and bed	One day
Foundation details	Size and scour damage	Inspection and photos	Probing exposed footings	One day
Test boring	Depth of footing /rock	Boring logs	Drilling/Coring	One day

11.6.4 Condition evaluation and countermeasures design

- Bridge description
- Existing hydraulic study: Generally the Federal Emergency Management Agency's (FEMA) Flood Insurance Study. However, formal hydrologic and hydraulic studies need to be carried out to verify FEMA's results due to changes in channel cross-section.
- Waterway description
- Subsurface feature description
- Streambed description: Grain size analyses are conducted on one sample from the streambed. The grain size distribution curves are given in the laboratory soil test results.
- Field survey results (example): A field survey by an interdisciplinary team of licensed structural, hydraulic, and geotechnical engineers should be carried out. The team should record visual observations (Table 11.3), which may be summarized as:
    - Any scour holes in the bridge area that need to be clogged.
    - Location of thalweg of the main channel; if it has moved toward one of the abutments, increased scour will result.
    - Top of footing elevation if exposed; bottom of footing elevations need to be investigated.
    - If mortar is missing from joints of stone, masonry needs to be fixed.
    - Deposit of stones from earlier floods at both upstream and downstream sides.

  Other steps include:

- Preparation of photographic documentation.
- Evaluation stream and waterway characteristics and roughness coefficients of the channel.
- Due to the diverse nature and extent of data collection, a collection procedure is followed:
    - Compile an inventory of already available data of a reliable nature.
    - A list of remaining data necessary to perform scour analysis and the methods, extent, and duration of obtaining such data. Roughness coefficient values are as described in "Open Channel Hydraulics" by Chow for scour only.

11.6.5 Data collection

Table 11.3 consists basically of:

- Determination of the location and number of required channel cross-sections (based on the channel characteristics) to be surveyed for the HEC-RAS analyses
- Determination of the type and size of the stream
- Determination of the bed material type and the classification of roughness coefficient to be used in hydraulic analysis
- Probing of footings for abutments, pier, and wingwalls
- Obtaining soil samples for soil testing
- Determination of the type of scour and the condition of the banks
- Plotting of size and location of scour holes, and sizes and location of sediment deposits

11.6.6 Evaluation methods for scour of existing foundations

Direct methods: Established methods can be used such as probes, augers, rotary drilling, or digging test pits adjacent to footings. Probes are carried out to locate the top of existing apron footing at the abutment. Digging of test pits is generally not used due to the possibility of increased undermining. To identify areas of scour holes, probing of soil in the riverbed is carried out, adjacent to existing footings.

Nondestructive Methods: Ground-penetrating radar or acoustical emission techniques are considered. However, due to the unknown type of soil and stone masonry supported on stone substrata, it may not be possible to determine accurate depth of footing.

Drilling of test borings: Drilling a test boring to verify existing foundation information is recommended. Drilling through the heel of abutment footing is a reliable method.

The steps used in approach to the analysis are as follows:

Hydrologic analysis: 50-year, 100-year, and 500-year storms will be calculated for the watershed based on the USGS Regional Equations. The regional equation is based on a thorough study of relationships between flood data and meteorological characteristics for dozens of sites located in the state. The parameters for the regional equation are:

Drainage area: Drainage area, channel slope, and surface storage index will be determined from the USGS quadrangle maps for the town where the bridge is located. The drainage area will be delineated based on contour information shown on the map. As a check, the drainage area should be measured using a planimeter on the hard copy of the quadrangle map.

Channel slope: Channel slope will be determined by first selecting the main water channel between the bridge location and the boundary of the delineated watershed basin. Once this path is determined, the channel length will be selected and used to calculate the slope of the main channel.

Surface storage index: Surface storage index will be determined by taking the area of lakes and swamps as a percentage of the overall drainage area plus 1%.

Index of man-made impervious cover: The remaining parameter, index of man-made impervious cover, is a function of population density. The population density information is provided by the state Department of Labor. The data is in the form of people per square mile.

11.6.7 Hydrology programs

HYDRAIN a conglomeration of several programs developed as a pool fund project by several states and FHWA. It includes HYDRO, a hydrology program, and HYDRA, which simulates hydrology and hydraulics on storm drains or sanitary pipe networks.

- TR55
- PENNSTATE Program
- USGS methods for different states (StreamStats): The Stankowski method has been used in New Jersey
- Check flood for bridge scour

Foundation scour shall be based on a 500-year flood. In the present study, the 500-year flood was computed using the USGS method. Scour depths for 50- and 100-year events were investigated.

11.6.7.1 Hydraulic analysis and software

A HEC-RAS analysis is performed using HEC-RAS software. The input data may consist of at least six recently surveyed cross-sections, two upstream, two downstream, and two along the fascia beams. Fifty-year, 100-year, and 500-year storm flows will be calculated from the regional equations, as mentioned previously, and entered as "steady flow data." All elevations obtained from the surveyor will be converted to the National Geodetic Vertical Datum (NGVD). Manning's roughness coefficients for top of banks and bottom of channel are determined (e.g., 0.1 and 0.06, respectively). The channel cross-sections are analyzed for critical depth and normal depth conditions with a slope of 0.0205 ft/ft. Both analysis conditions produce velocities.

As per HEC-18, either UNET software for one-dimensional dynamic analysis or FESWMS software for two-dimensional analysis will be used.

The following programs are available to determine the flood intensity, water elevations, and scour potential; they can also check FEMA compliance and help size the proposed structures over waterways.

HEC-2: This program was developed by the Army Corps of Engineers and has been used by FEMA in the past for most of their studies. It has been replaced by the HEC-RAS computer program, which computes the water surface profiles and velocities using the stream cross-sections, Manning's variable, and the Design and Basic flows.

WSPRO is a computer program developed by FHWA that computes water surface profiles and velocities using stream cross-sections, Manning's variable, and Design (Q50) and Basic (Q100) flows.

HEC-RAS is an Army Corps of Engineers Program. This program can handle variable flows and has a WSPRO subroutine in its water profile routine. In addition, this program computes the possible scour depths at the substructures:

- HY8, which simulates hydraulic analysis or design for culverts, reservoir routing, and energy dissipators
- HYCHL, which analyzes and designs channel and riprap linings
- NFF, which interactively calculates USGS regression equation flows

BRI-STARS is a pseudo two-dimensional hydraulic program that (through the use of stream tubes) provides time- and flow-dependent two-dimensional sediment routing (aggradation and degradation) in a bridge cross-section.

UNET: Unlike the riverine flow, this program deals with tidal flow.
DYNET: Two-dimensional hydraulic program for tidal flow.

11.6.8 Scour analysis

A scour analysis is carried out to evaluate scour depths based on FHWA Publication HEC-18. Scour depths for long-term scour, contraction scour, and local scour are assumed to develop independently. A scour report consists of a detailed field survey, substructure information, scour analysis results, hydraulics-related findings, and countermeasure recommendations. Such a study will be based on scour vulnerability analysis, which was set as a mandatory requirement by the FHWA for bridges on waterways. Scour sufficiency rating also needs to be evaluated (see Figure 11.4).

- In-house Excel spreadsheets based on HEC-18 equations developed by the author (see Appendix for procedure for input data).
- A subroutine in the HEC-RAS program does scour analysis. However, in some cases high values of scour depth are obtained for contraction or local scour.

11.6.9 Rating software

- In-house Excel spreadsheets based on the AASHTO Manual for Condition Evaluation of Bridges.
- A similar approach to the SBCI Calculator developed by USGS.

Channel improvements: Channel lining to prevent degradation and armoring of approach banks by revetment materials are recommended.

Common materials used for shielding of foundations such as standard riprap, stones enclosed in wire nets, gabion mattresses, and artificial riprap such as concrete bags or toskanes are recommended.

Dredging: Increase in waterway width and control of aggradation is recommended.

Filling up of scour holes: Dense material, heavy stones, or concrete blocks are used.

11.6.10 Riprap, the commonly used countermeasure

Riprap grading: Designating 50% of stones in a layer to be equal or greater than a specified size (D50). The specified size can be calculated by hydraulic considerations.

Using FHWA HEC-18 and HEC-23 formulae. The remaining 50% of stones can be of smaller size than (D50) to fill the smaller voids between the stones:

Maximum stone size in a layer <1.5 D50
Minimum thickness of each layer = 300 mm
Minimum number of layers = 3

Place riprap around footings at a maximum slope 1 (horizontal): 1 (vertical), with the slope starting at a distance of 450 mm from vertical face of footing.

The top of riprap shall be below the riverbed to avoid encroachment of the river, since stones protruding above the bed are likely to be dislodged by floating debris, ice, or currents.

11.6.11 Agency coordination and permitting

The engineer will be required to contact and meet with representatives of federal, state, local, municipal, and other agencies to review and determine all necessary project requirements and permits. The engineer is required to obtain all applicable permits for the proposed work. Other agencies may include, but are not limited to:

State DOT
State Department of Environmental Protection
State Department of Conservation and Natural Resources
Local Soil Conservation and Sediment Control
Army Corps of Engineers (ACOE)
National Park Service

11.6.12 Geotechnical considerations

The following steps are required:

Review subsurface information given in geotechnical report.
Evaluate historic scour-related conditions and potential scour holes at the bridge site.
Soil classification: Laboratory tests for grain size samples are required.
Use streambed photographs to estimate the distribution of stones in the riverbed.

Information currently available and recommended methods of obtaining additional required information based on scour codes are shown in Table 11.4.

11.6.13 Qualitative and quantitative levels of analysis

The following types of analyses will be carried out:

Level 1: Qualitative assessment of stream stability, including lateral stability, vertical stability, and determining the profiles of rivers (refer to HEC 20)
Level 2: Detailed quantitative analysis, including hydrologic, hydraulic, and scour analysis to assess scour vulnerability (refer to HEC 18)
Level 3: Bridge scour design of stream instability countermeasures (refer to HEC 23).

Also refer to "Scour of Bridges" and "Bridge Scour in Tidal Waterways" for methods of scour analysis and the semiempirical formulae for scour depths at abutment and pier footings.

11.6.14 Tidal scour

The physical factors affecting tidal scour include the following (refer to HEC-25 for details):

Peak tidal velocities
Variation between flood velocity and ebb velocity
Range of tidal amplitude between neaps and spring tides
Locations and shapes of scour under different flow conditions
Cumulative effect of a series of tides

In tidal locations, scour countermeasure options include:

River training measures
Dredging
Driving sheet piles around the piers and abutments
Filling the gaps with riprap

Alternative measures such as grout bags, cable-tied blocks, and AJAX-type blocks will be considered, based on tidal flow conditions. Other issues include the following:

- The available flow width may be reduced due to construction of cofferdams.
- Tidal conditions will affect working methods and working hours for construction.
- Health and safety of construction personnel may be a concern due to water depth.
- Velocities through the remaining opening will increase, thereby increasing scour in the channel and around the structure.
- Pollution of the river from construction material will need to be monitored. Regular cleaning of the channel may be required.

Table 11.4 Applicable Scour Codes

Scour Code	Abutments	Piers	History
U	Type of foundation not known	Type of foundation not known	No history of scour problems No scour at any pier No movement, scour, or erosion at abutment No channel lowering or lateral movement
9	Bridge foundations (including piles) well above flood water elevations	Bridge foundations (including piles) well above flood water elevations	No history of scour problems No scour at any pier No movement, scour, or erosion at abutment No channel lowering or lateral movement
8	One of the following is true: Pile depth greater than 40 ft Adequate protection (class III riprap or greater; grouted riprap; gabions) in good condition Spread footing on erosion-resistant rock (granite, basalt, gabbro quartzite, or gneiss) When DA < 400 mi^2, stiff clay (shear stress >2000 psi)	One of the following is true: No piers Pile depth greater than 40 ft Spread footing on erosion-resistant rock (granite, basalt, gabbro quartzite, or gneiss) When DA < 400 mi^2, stiff clay (shear stress >2000 psi)	No history of scour problems No scour at any pier No movement, scour, or erosion at abutment No channel lowering or lateral movement
3			No history of uncorrected scour No debris blocking over 10% flow XS

- Approvals for stream encroachment permits would be necessary.
- The effect of driving sheeting or bed armoring on existing utilities needs evaluation.
- Countermeasures may extend into adjacent property limits. Any construction easement needs to be carefully evaluated and permits obtained.
- Modern countermeasure technology requires new construction techniques. The contractor performing such tasks will need properly trained construction crews.
- Providing cofferdams, sheet piling, and bed armoring would require temporary construction work. Alternatives for using quick construction need to be considered.

Additional physical considerations arising from tidal flows include:

- Tidal scour is of more frequent occurrence than fluvial flood flows, which are of much shorter durations. The destructive nature of scour is that it evolves in cumulative smaller steps, rather than occurring in a single flood event.
- Scour is induced due to wave action.
- Scour is induced due to tidal currents.
- Effects of the interaction of simultaneous fluvial and tidal currents may be present. The effects of littoral drift can increase lateral migration and affect long-term erosion.

11.7 Procedures for scour-related accelerated rehabilitation

11.7.1 Selection, and design of countermeasure types

The following tasks are associated with the safety of substructure and the need to provide countermeasures (Table 11.5) based on scour type (Table 11.6):

Riprap placement/providing effective armoring countermeasures
Concrete repairs (patching, spalls, and sealing cracks)
Masonry repairs
Apron repair around piers
Addressing foundation undermining issues
Debris removal
Strengthening of foundations if required

Table 11.5 Typical Examples of Proposed Scour Countermeasures

No.	Deficiencies Commonly Reported in Underwater Inspection Reports	Proposed Repairs
1	Debris accumulation	Clean debris
2	Undermining	Plug with concrete/use grout bags
3	Missing or broken riprap	Replace with R-8 size stone
4	Silting	Dredging
5	Settlement of foundations	Strengthen member/underpinning

Table 11.6 Bridge Scour Countermeasures: Categorized by Scour Type

Scour Type	Counter-Measures Type	Counter Measure Selection
Lateral erosion	Armoring devices (revetment)	Riprap, gabions, cable-tied blocks, tetrapods, precast, concrete blocks, used tire, etc. Vegetation planting
	Retardation	Timber piles, sheet piles Jack or tetrahedron fields Vegetation planting
	Groynes, hardpoints	Groynes, spurs, dykes
Degradation	Check dams	
	Channel lining	Concrete or bituminous concrete pavement
	Bridge modification	Increase of bridge opening width
Aggradation	Channel improvement	Dredging, clearing of channel Formation of a cutoff
	Controlled mining	
	Debris basin	
Local scour	Armoring devices	Riprap, gabions, cable-tied blocks, etc.
	Flow altering devices	Sacrificial piles, deflector vanes, collars
	Underpinning of bridge piers	
	Guide banks	

11.7.2 Resolving constructability issues

Scour depth should be measured from a reference line 1′-0″ above the top of footing.

If eroded elevation is located at a higher elevation than 1′-0″ above the top of footing, the higher elevation should be considered.

The types of countermeasures to be used will depend upon the bed materials under the bridge.

For placing riprap, excavation to the design depth should be carried out.

The depth of riprap should be at least below the contraction scour depth.

If considerable erosion has already taken place and the riverbed elevation is below the top of footing, hydraulic analysis should be based on the new channel profile by considering the new opening size.

Armoring should not be mixed. For economy and ease of construction, the same type of armoring countermeasures should be used for abutments and piers.

If gabions are selected, then they should be used for the whole bridge site. However, armoring can be combined with a structural countermeasure or river training.

Footing settlement is likely to occur due to erosion of soil during a flood. Detailed subsurface information and an understanding of critical ground behavior are essential.

11.7.3 Structural countermeasures (Table 11.7)

Due to high velocities armoring countermeasures such as riprap are not stable enough. (See Figure 11.5). In such cases structural countermeasures may be more durable. For existing

Table 11.7 Selection of Alternative Structural Countermeasures

CM	Scour Type	Description	Remarks
Concrete apron/ curtain wall	Contraction and local scour	Concrete walls precast or cast in place against the sides of footing	Recommended
Local sheet piles	Degradation	Piles driven as shields adjacent to bridge foundations to deflect flow	Recommended for high scour situations with riprap protection
Extended footing	Local scour	Cast wider concrete slab footing to prevent settlement	Recommended for concrete spread footings
Constructing minipiles through spread footings	Degradation	Minipiles driven through footings	Not recommended for high traffic volume bridges
Underpinning	Contraction scour Local scour	Lowering the bottom of footing elevation below scour depth	Not recommended for high traffic volume bridges
Use of open parapet or railings	Contraction scour/ pressure flow	Increases flow area and prevents overtopping of flood water	Recommended only for overtopping flood situation

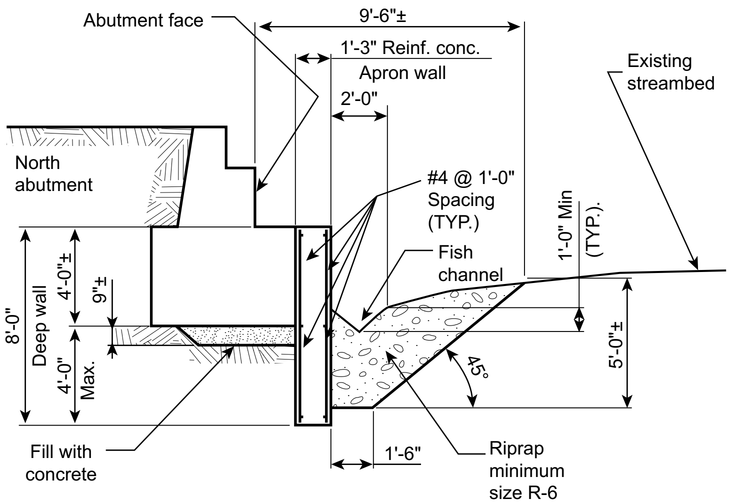

FIGURE 11.5

Using apron wall with riprap.

bridges that are scour critical, the following types of structural countermeasures will be investigated:

- Foundation strengthening by structural repairs and pumping concrete under the footing.
- Driving sheet piling in front of abutment and pier as a shield. Sheet pile can be cut at the streambed level.
- Constructing a reinforced concrete apron wall attached to exposed face of footing.

- Underpinning of foundation.
- Providing a curtain wall in front of pile caps.
- Providing timber fenders around piers for damage against ice and ship collision.
- Sacrificial piles to reduce velocities.
- Pier shape modification if required.

11.7.4 Hydraulic countermeasures

Some of the common types of countermeasures are riprap, gabion baskets, concrete blocks, and sheet piling. If the calculated scour depth lies below the footing, there is a for underpinning and deep foundations prior to installing countermeasure at piers and abutments. Harnessing the river to reduce flood velocities may also be used. Armoring/shield countermeasures such as riprap on geotextile filters, gabion baskets, and articulated or cable-tied blocks on geotextile filters will be considered as alternates.

Monitoring and recording floods: USGS is responsible to erecting and maintaining the gauges at the bridge where flood frequency and magnitude are high. (See Figure 11.6).

Design procedures for geotextiles: A filter is required unless the riprap or armor lining has a thickness of at least three times the D_{50} size of the riprap. Detailed design guidelines for geotextiles are available in the following publication:

FHWA Publication HI-95-038 by Holtz, D.H., Christopher, B.R., Berg, R.R., 1995. Geosynthetic Design and Construction Guidelines. FHWA, Washington, DC.

Identify defects and perform repair: After identification of defects, remedies for certain scour conditions are given in Table 11.8.

The author used some of these remedies (such as for missing or broken riprap) were used by the author on a few projects. A cost comparison may be carried out and the long term remedy should be consistent with the remaining useful life of the bridge.

For river flow restricted to a single span only as a result of meander. In such cases spread footing will be subjected to greater scour and it has been proposed that piles or alternative countermeasures

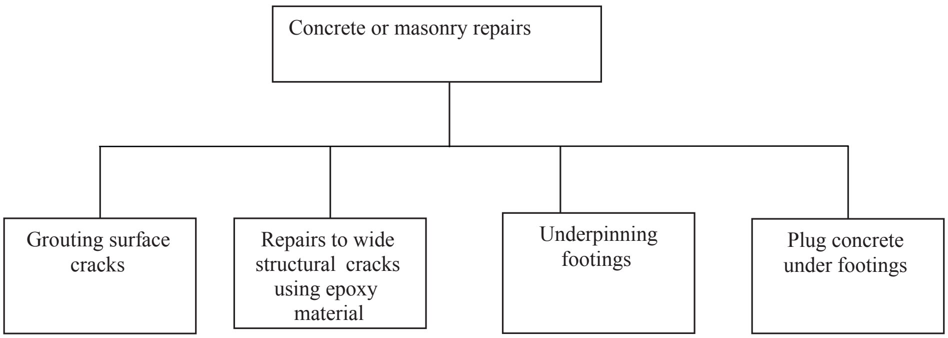

FIGURE 11.6

Substructure repairs and underpinning prior to installing structural countermeasures.

Table 11.8 Recommended Repair Strategy

No.	Item	Quick and Cost Effective Remedy	Alternative Measures
1	Spalls in abutment concrete	Surface repairs with approved patch material	
2	Delaminations and cracks in substructure concrete above water	Pressure grouting	
3	Voids in breast wall	Epoxy grouting	Nonshrink grout
4	Debris accumulation	Clean debris	
5	Mortar loss in masonry joints	Repoint mortar	
6	Undermining	Plug with concrete	Use grout bags
7	Broken stone masonry	Place stone and fill with mortar	
8	Cracks in tremie concrete below water	Pressure inject masonry cracks	
9	Spalling in foundation	Pressure grouting	
10	Missing or broken riprap	Replace with R-8 size stone	
11	Cracks in apron around piers	Repair concrete apron	Place riprap around piers
12	Silting	Dredging	
13	Corrosion of rebars	Clean, paint, and provide adequate cover	Dowel anchor bars in concrete holes
14	Advanced section loss of structural members	Strengthen member	Underpinning

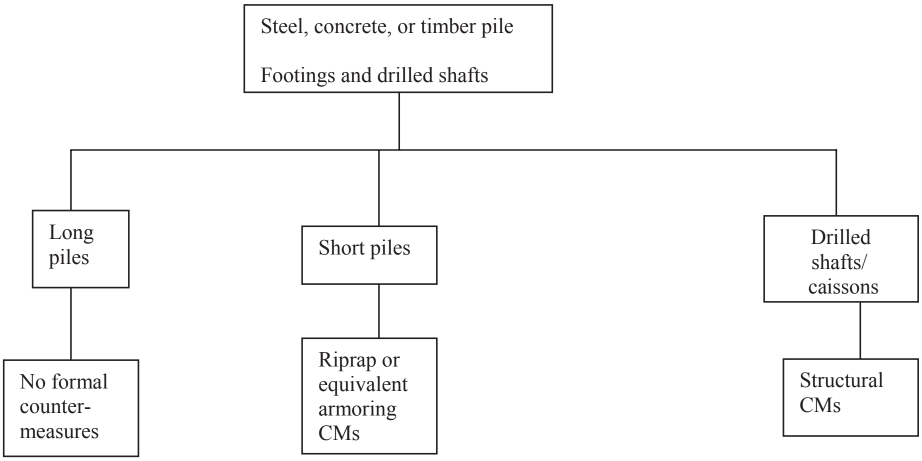

FIGURE 11.7

Relationship between piles and countermeasure requirements.

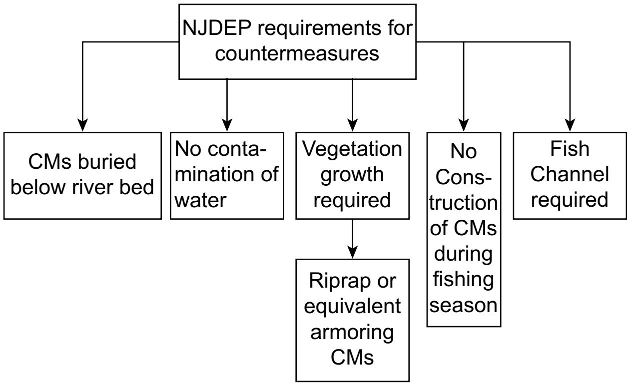

FIGURE 11.8

NJDEP General Requirements for Stream Encroachment Permit.

may be used to prevent settlement. If water elevation is high, overtopping will cause damage of fascia girder from impact. (See Figure 11.8).

11.7.5 Construction of deep foundations

The time taken for construction of deep foundations for both conventional and ABC methods is not likely to change. For example, drilling of piles cannot start unless demolition of the existing foundations has been completed. The alternative is to use staged construction and perform demolition in stages. Provision of shielding by riprap or using structural countermeasures is desirable, even for deep foundations that may become exposed during peak floods (Figure 11.7).

In the case of long piles, countermeasures will not be required unless the bridge is located close to a sea front or on a highly scourable river.

Minimum countermeasure requirements in lieu of deep foundations: If the projected (computed) scour is small or negligible, theoretically design of a formal countermeasure will not be required. Such cases are:

- When a spread footing is located or placed on bedrock or when a spread footing is located or placed below the total scour depth
- When an additional pile length equal to the projected scour depth is provided
- When pile stiffness exceeds the minimum required and the exposed length of pile due to erosion can safely act as a long column

Although minor surface erosion of soil will not cause a danger to footings, a soil cover or protection to the concrete footing or piles is still required. An adequate soil cover needs to be maintained for:

- Frost resistance (minimum frost depth requirement)
- As-built cosmetic appearance
- Unforeseen error in the scour analysis data or computations

There are several countermeasures used for protection of bridge abutments by different state Departments of Transportation and federal agencies. Two typical approaches for protecting bridge abutments from scour are:

- Mechanically stabilizing the abutment slopes with riprap, gabions, cable-tied blocks, or grout-filled bags
- Aligning the upstream flow by using guide banks, dikes, or spurs, or in-channel devices such as vanes and bendway weirs

11.7.6 Countermeasures combined with river training

Experience has shown that providing armoring countermeasures alone may not be adequate and a combination of river training measures and armoring is necessary for high velocity rivers. By providing river-training measures, less pressure will be put on the armoring mechanism. Accordingly, the effectiveness of the system will be increased. However, since large investments are involved, economic considerations become important. Hence, cost reductions should be adopted in the design by optimizing the depth and width of armoring mechanism that are provided as revetment. Using scaling factors discussed later, riprap or gabion blankets may be used.

It is normal practice to protect 100–300 ft of riverbank by revetments upstream and downstream of bridges and culverts. Revetments differ from bed armoring in that they have a smaller thickness and are longer.

The common types of revetment in use are:

- Dumped riprap
- Wire-enclosed riprap mattress
- Articulated concrete block system
- Grout-filled mattresses
- Concrete pavement

It is recommended that some type of river training measure be provided, in addition to armoring countermeasures, when:

- The flood velocity exceeds 10 ft/s
- The average daily traffic (ADT) of the bridge exceeds 500
- Constructing revetment in river to change the direction of flow

Case study of countermeasure construction

- Where gabions are used as countermeasures, they will be overlaid by a soil layer, and vegetation is grown to resist erosion during floods. Use precautionary measures to keep the river water clean, such as a turbidity dam and silt fence and traffic control during construction. This way, local DEP underwater construction permit requirements are fully complied with and there is minimal impact on plant and marine life (Figure 11.8).
- Usually for bridge repairs many alternative solutions are not feasible, and if an appropriate method of construction is adopted there will be fewer constructability issues.
- Changes in structural details during the long construction process may be necessary, due to unforeseen field conditions such as occurrence of different soils. Coordination between design and

construction teams is essential for answering requests for information (RFI) and issuing agreed design change notices (DCN) as revisions to contract drawings to finish work within the construction schedule. For delicate repairs, a more stringent quality control (QC) procedure may be necessary.

11.8 Scour countermeasures for new bridges

The following guidelines are used to minimize different types of scour in the design phase of new bridges.

11.8.1 HEC-18 countermeasure

Scour type to be addressed: Local scour, degradation, lateral erosion.

Description: graded broken rock, placed below riverbed by hand or dumped by boats and overlaid with soil.
Advantages: Familiarity and past experience; relatively low cost and no maintenance is required. Easy to construct, ability to adjust to minor scour; the oldest method in use for shielding footings.
Disadvantages: Not reliable for stability. Except for large-sized stone, it can wash out easily in moderate floods; disturbs channel ecosystem until vegetation is reestablished. Maintenance and monitoring required before and after floods.
Remarks: Not recommended for general bridge substructure use. Recommended for filling scour holes and bank erosion. Meets environmental requirements.

11.8.1.1 Spread footings on soil

Place bottom of footings 3 ft below the total scour line. Although minor surface erosion of soil will not cause a danger to the footings, soil cover or protection to the concrete footing or piles should still be provided for the following reasons:

- Provides frost resistance (minimum frost depth requirement)
- Maintains as-built cosmetic appearance
- Guards against any unforeseen error in the scour analysis data or computations

A minimum 3-ft depth of riprap or an alternative supplementary countermeasure should be provided adjacent to the footings.

11.8.1.2 Spread footings on erodible rock

Place the bottom of footing 6 in. below the scour depth. This provision is conservative compared to that for soil conditions in which scour depth may be reduced by 50%.

11.8.1.3 Spread footings on nonerodible rock

This condition is less common in New Jersey since nonerodible rock is not generally found within 10 ft of river beds.

The following important issues need to be resolved for the successful installation of countermeasures:

- Permit identification
- Right-of-way identification
- Relocation of utilities
- Construction coordination

11.8.1.4 Traffic and utilities issues related to the use of riprap

Site access: Adequate access to the site should be provided for trucks to deliver riprap.

Right-of-way: Construction easements and right-of-way access may be required for the duration of construction.

Detours: Detours, lane closures, or nighttime work may be necessary. Coordination with traffic control may be required. Emergency vehicles and school bus services should not be affected by lane closures.

Delay to ABC due to interference from underground utilities: Coordination with utility company should be made fairly early in the construction process. Installation and maintenance of underground utility pipes close to a bridge foundation can cause significant disturbance to the soil and should be checked. If any interference is likely with the proposed countermeasure and utilities need to be relocated, this may result in an environmental issue. Relocation of any utilities at the sides of an abutment or a pier may be necessary for the duration of construction.

11.8.2 Use of riprap countermeasures

The following documents are good resources on the use of riprap as a countermeasure:

- Publication No. FHWA-RD-91-057, "Stability of rock riprap for protection at the toe of abutments located at the floodplain," 1991
- HEC-11, "Design of Riprap Revetment"
- Design Guidelines 8 and 12 of HEC-23

Spill-through abutments: For spill-through abutments, extend the riprap around the abutment and down to the expected scour depth. The launching apron at the toe of the abutment slope should extend along the entire width of the abutment toe and around the sides of the abutment to a point of tangency with plane of embankment slopes.

The apron should extend from the toe of the abutment into the waterway a distance equal to twice the flow depth in the overbank area near the embankment, not exceeding 25 ft. Figures for typical layouts of abutment riprap for abutments near a channel bank, stub abutment near the top of a high channel bank, and abutment near a flood plain are given by the Maryland State Highway Administration.

Design of riprap at bridge abutments: The author developed a Handbook of Scour Countermeasures for NJDOT with Anil Agrawal of City University, New York. It was approved by FHWA for use by consultants (Publication No. FHWA-NJ-2005-027). In New Jersey, due to high risk of movement of riprap, riprap alone is not recommended as a permanent countermeasure but as emergency shielding only for a period of five years or longer only after regular evaluation from underwater bridge inspection reports. Riprap can be used as secondary local armoring, in conjunction with primary structural countermeasures or with river training measures.

Limitations on the use of riprap monitoring: Riprap shall be used as a countermeasure only if accompanied by field inspection that occurs immediately after floods and by the use of monitoring equipment during floods.

Critical velocities: If a 100-year flood velocity exceeds 11 ft/s, riprap should not be used.
Scour depth: If calculated scour depth is high and excavation to place riprap under the riverbed would endanger the stability of soil adjacent to the footing, riprap should not be used.
Economic considerations: If riprap is not available locally or at a reasonable distance, it may not be economically feasible. In such situations, other alternatives may be considered. Also, if cost of hand placement of riprap is high, other less expensive countermeasures may be considered.
Dumped riprap: Truck-dumped riprap can easily get dislodged during floods and get washed away due to high velocities. It is less stable compared to hand-placed riprap, and its use is therefore not recommended.

11.8.3 Riprap detailing

- Construction drawings have to be prepared. Conceptual sketches for the layout of riprap with details for riprap placement at abutments and piers based on HEC-23 or the applicable state handbook should be used.
- In addition to hydraulic data, construction drawings should show tables summarizing flood elevations, flood velocities, and scour depths.
- Maximum side slope is 1V:2H, although where excavation is difficult, 1V:1H may be used with fractured rock.
- **Cost factors:** The current estimated cost is $350 to $450 per square foot of the plan area of countermeasure. Long-distance freight charges for riprap may increase the unit cost by 10%.

11.8.4 Recommended river training countermeasures

Depending on flood conditions, the following types are recommended:

- Retard (earth, timber, and steel sheet piles)
- Channel improvements (channelization)
- Guide banks/guide walls

The final selection should be made based on project-specific conditions.

11.8.5 Design of common types of countermeasures

Gabions can be sized according to NJDOT Soil Erosion & Sediments Control Standards fusing Table 11.9.

11.8.5.1 Articulated concrete blocks

Design guidelines for articulated concrete blocks (ACB) for abutments are based on Design Guidelines 4 in HEC-23. Design guidelines for ACBs for piers are based on NCHRP 24-07. Other recommended sources of information on design of ACBs are HEC-11 and McCorquodale (1993).

Table 11.9 Soil Erosion & Sediments Control Standards for Sizing Gabions (Estimate of Velocity can be Provided by Experimental Verification from more than one Suppliers of Gabions)

Gabion Thickness (ft)	Maximum Velocity (ft/s)
½	6
¾	11
1	14

11.8.5.2 Concrete armor units/A-jacks

The basic construction element of A-jacks for pier scour applications is a “module” comprised of individual A-jacks which are banded together in a densely interlocked cluster, described as a 5×4×5 module. The design procedure for A-jacks systems for pier-scour protection is stated in Design Guidelines 6 of HEC-23.

11.8.5.3 Design procedures for grout bags

The design size of a bag or depth of a layer depends upon the following:

- A design flood velocity of 5–10 ft/s.
- A computed scour depth for contraction and local scour of 3–6 ft.
- When hydrostatic pressure builds up, the dead weight of bags should exceed the uplift pressure. The mattresses should be provided with filter drains or drain holes for pressure relief.
- Depending upon the application, bags may vary in capacity, from standard cement bag size, to about 5 ft^3, while mattresses are larger in size up to 15 ft^3 in volume.
- Mats must be bound firmly to the pier itself for good performance. Mats should be installed with their top surfaces flush to the bed.
- Grout bags should be sized and placed in a manner similar to riprap, and underlain by a geotextile filter with a partial cover or filter layer. Any means to render the surface of bags rough and angular will aid performance.
- Properly sized bags are more effective when they extend a single layer of protection laterally, rather than if they were stacked. Efforts should be made to avoid stacking of grout bags.
- Flexible bags of sand may be preferable to grout-filled bags.

Replacement or new bridges: Field inspections will show that certain components of a bridge may need repair, retrofit, rehabilitation, or replacement. For safety reasons, railings, parapets, deck slab, bearings, or superstructure may be recommended for replacement. In some cases, the entire bridge may require replacement. Any new design of superstructure and substructure components will require an analysis for bending moments and shear forces. New live loads are based on a family of trucks, namely mandatory HL-93 loads, Permit, Military, and applicable state Legal loads (Type 3, Type 3-3 or Type 3S2 Vehicles).

11.8.5.4 Use of cofferdams

If the water depth is not high, temporary cofferdams may be required for construction in dry conditions. Without dry conditions, the quality of placement of countermeasures will be difficult to monitor or maintain. Figure 11.9 shows a section view of a typical cofferdam.

11.8.5.5 Sheet piling left in position

For underwater construction of the abutments and pier types, temporary sheeting on the streamside is required for installing CMs at the sides of spread footings/pile caps. To prevent long-term scour, temporary sheeting may be left in place after CMs installation is completed.

Debris and silting may reduce river width and increase flood velocity and water pressure on piers. Considerable repairs as shown in Table 11.10 will be required.

11.8.6 Technical specifications and special provisions

Technical specifications deal with description of materials, method of construction, units of measurement, and unit costs. Countermeasures that are proprietary in nature may be obtained directly from vendors, if they are not available in state-standard specifications. They are required for preparing

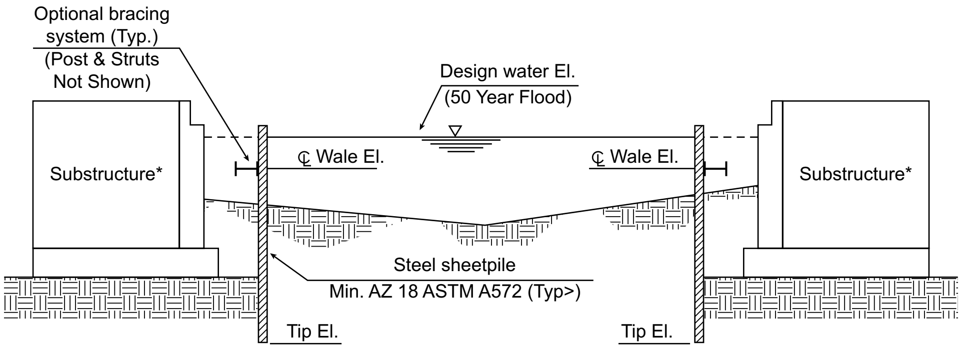

FIGURE 11.9

Cofferdam schematic section using rolled AZ sections. (Heavier sections may be required depending upon the depth of water).

Table 11.10 Typical Examples of Proposed Concrete Repairs (In Addition to Remedies Proposed in Table 11.8).

No.	Deficiencies Reported in Underwater Inspection Reports	Proposed Repairs
1	Spalls in abutment concrete	Surface repairs with approved patch material
2	Delaminations and cracks in substructure concrete above water	Pressure grouting
3	Voids in breast wall	Epoxy grouting/use nonshrink grout
4	Mortar loss in masonry joints	Repointing mortar
5	Broken stone masonry	Replace stone and fill with mortar
6	Cracks in tremie concrete below water	Pressure inject masonry cracks
7	Spalling in foundation	Pressure grouting
8	Cracks in apron around piers	Repair concrete apron or place riprap around piers

contract documents and for award of contracts. The designer should use guidelines provided by the manufacturers only after they have been approved by the engineer in charge for the project. Recommended guidelines should be supplemented by design data provided by the manufacturers for designing such countermeasures. Technical specifications for gabions should be used. Gabions are being frequently used in place of riprap. Any deviations from standard specifications need to be approved as special provisions. Caissons may be preferred over piles.

For long-span bridges on harder ground and dense soils, drilled piers will be more resistant to erosion compared to caissons. Integral abutment piles with a single row of piles would require greater protection by providing shielding in the form of sheeting left in place.

11.9 Case studies and ABC research

Bridges are complicated to replace while keeping traffic flowing, but the Massachusetts Department of Transportation (MassDOT) has found a way to minimize the pain.

Figure 11.10 shows postflood scenario when sediment and debris accumulated mainly at the downstream of bridge. Scour analysis needs to be based on HEC-18 aggradation procedures. ABC is being used on the Phillipston Bridge in Massachusetts, and it is reducing construction time from years to months. This method involves building the bridge or the major bridge elements nearby. When the new bridge is ready, the existing bridge is demolished and the new bridge is eased into place using cranes and self-propelled trailers. Although the bridge is shut down completely, the duration is only 202 h rather than weeks or months.

Design-build Team Relationship: One of the keys to this ABC method working smoothly is the design/build relationship between the designer, in this case TranSystems, and the contractor, SPS New England. Their ability to work together has proven as time saving as the method of construction. Problems are solved and avoided when we work together.

FIGURE 11.10

Post-Hurricane Floyd flood scenario: Aggradation at Peckman's River Bridge on Route 46, New Jersey.

(Photo by author.)

Precast concrete abutment caps and approach slabs were placed after the demolition of the existing bridge superstructure to facilitate the rapid installation of the new superstructure. Precast barrier rails sections were used to bridge between the CIP rails on the approach and on the bridge structure. Precast concrete abutment caps, approach slabs, and barrier rail sections were produced by J.P. Carrara & Sons, Inc., Middlebury, VT.

This project was started in May 2010, and the new bridge was in place on November 1. The Phillipston bridge proves that ABC is a doable system that effectively replaces a deteriorating bridge without the costly and irritating traffic delays. This is now a proven success and MassDOT has several more of these projects on the drawing board.

11.9.1 Hurricane Sandy damage repairs

According to a Reuters report dated December 6, 2012, lawmakers and transportation officials said that billions of dollars are needed to strengthen and repair rail and other transportation networks in the U.S. Northeast in the aftermath of savage Superstorm Sandy. "Estimates of the damage have reached more than $7 billion. Across the region, train tunnels, stations, and rail yards were flooded, rail tracks were damaged and critical equipment was ruined," Senator Frank Lautenberg, a New Jersey Democrat, said at a Senate subcommittee hearing on storm damage.

Hundreds of millions of gallons of salt water flooded the city's subway system, which is more than one hundred years old, the chairman of New York's Metropolitan Transit Authority told the panel. New Jersey's transit agency estimates that Sandy caused nearly $400 million in damage to its networks. That breaks down roughly into a little more than $100 million for rail equipment, including rolling stock, and some $300 million to fix and replace track, wires, signaling, electrical substations and equipment, as well as to cover the costs of emergency supplemental bus and ferry service and lost revenue, Another $800 million is needed "to mitigate and harden the transit system to make it more resilient to future storms." So there is a need to apply ABC for the large volume of work generated by Sandy on an emergency basis.

11.9.2 Substructure construction products by Contech

For bridges on rivers, both erosion and sedimentation controls are required. A range of construction products from CONTECH are shown. Other contractors in this specialized work are also available.

- Geosynthetics for Earthwork
- Erosion and Sedimentation Controls
- Erosion Controls
- Geosynthetic Slope Protection
- Driven Piles
- Composite Piles
- Retaining Walls
- Foundation Drainage
- Subdrainage Piping
- Underslab Drainage

11.9.3 ABC in seismically active states

See "Innovative Technologies and Their Applications to Enhance the Seismic Performance of Highway Bridges: Precast, Segmental Bridges for Accelerated Bridge Construction in Seismic Regions (Project 020)" by George C. Lee, Civil, Structural & Environmental Engineering, University of Buffalo.

> There are no design procedures or guidelines for ABC (such as the types of connection details between vertical and horizontal members) in seismically active states. Typical seismic resistant connections are using bar couplers, using pockets or recess, using socket connections, using grouted ducts and using integral or hybrid systems. The connection details with the required tolerances can be more easily achieved in factory conditions than in the field thereby improving quality control. Thus, MCEER's research work focuses principally on the development of seismic design guidelines for prefabricated reinforced concrete and segmentally constructed highway bridges of short- to medium-span length. Analytical and experimental work is being carried out to formulate design guidelines for practical applications so that all states can benefit from the use of ABC.
>
> These efforts include the evaluation of existing bearings for their long-term performance under various environmental conditions, the deployment of a new generation of bridge bearing developed under a previous FHWA research contract, and exploring the concept of using a structural fuse to protect bridges from extensive damage in the event of an earthquake. The MCEER research project funded by FHWA is a group effort carried out by a number of investigators in the Department of Civil, Structural and Environmental Engineering at the University at Buffalo and coordinated by George Lee.

11.9.4 Rapid bridge erection over rivers

Figures 11.11 show examples of bridge erection over rivers using heavy cranes. Some of the bridges are of proprietary design, which is now becoming popular for the smaller spans.

11.9.4.1 12th Street Pedestrian Bridge, Oakland, California

This beautiful bridge is a dark-colored "Fir Green" and is 15 ft wide by 146 ft long! The bridge was built as one standing structure that was eventually split up and shipped as four pieces. After arrival, it was erected on-site and set into place. The bridge sits adjacent Lake Merritt, a large tidal lagoon that lies just east of downtown Oakland, California.

11.9.4.2 Jackson Hill Street Bridge, Houston, Texas

Located near Jackson Hill Street in Houston, Texas, this pedestrian bridge is 10 ft wide by 345 ft long and spans Buffalo Bayou Park as part of the Buffalo Bayou Partnership.

11.9.4.3 Cheyenne Ave Bridge, Las Vegas, Nevada

This prefabricated pedestrian bridge is located in Las Vegas, Nevada, crossing Cheyenne Avenue. This steel truss bridge is fully enclosed and painted for durability and beauty.

FIGURE 11.11

High-capacity crane lifting the assembled truss.

11.9.4.4 Ojai Valley Trail Bridge

The recent installation of this Greenwood, South Carolina, bridge showcases the original "tied arch" bridge design as beautiful and strong. The arch's geometric shape provides the strength that allows the bridge to reach its incredible span of 244 ft with a 10-ft deck width. The bridge is fabricated from weathering steel with a pressure-treated wood deck providing its natural and timeless look. The installation took place in Greenwood adjacent to the beautiful hunting club "The Territories."

11.9.5 Partial ABC for the world's tallest lift at Staten Island, New York

Raising the road bed of the Bayonne Bridge 64 ft while traffic continuously flows across the span is unprecedented in the annals of engineering; a unique set of circumstances, starting with the bridge's design more than 80 years ago, has made this project possible. Upon completion, the bridge will include four 12-ft wide lanes—two in each direction—a 12-ft wide pedestrian/biking path, nearly 5-ft wide shoulders on each side, and the possibility of a future light rail.

The span currently has the lowest navigational clearance of any bridge in the area and one of the lowest in the country at 151 ft. Raising it to 215 ft above the Kill Van Kull will put it more in line with the average of about 290 ft nationally or closer to its immediate neighbor the Verrazano-Narrows Bridge, which sits about 217 ft above the water depending on the tide.

The span crosses the busiest shipping channel on the East Coast of the United States, which sees 30% of shipping traffic from Maine to Florida navigate under it and supports 280,000 related jobs.

Portable sound barriers have been put in place around work areas to mitigate some of the construction noise, and the contractor measures noise levels with meters.

11.9.6 Examples of research projects at the New Hampshire DOT

The NHDOT Project Information Center is a source for information about ongoing and planned Department of Transportation projects. Other states are also investing in new projects to promote ABC technology with the view that research results will pay back the funds' investment in terms of confidence from laboratory model tests, economy through developing design procedures, and resulting safety during construction and under live loads, especially for the untested newer ABC technology.

11.9.6.1 Substructure and scour projects

Examples are:

- Estimation of Flood Discharges at Selected Recurrence Intervals for Streams in New Hampshire
- Field Performance Evaluation of Pile Points
- Ground-Penetrating Radar to Detect Pre- and Postflood Scour in NH
- Pier-Scour Measurement Methods and Predictions at New Hampshire Bridge Sites
- Ground Vibrations Emanating from Construction Equipment
- Effectiveness of a Pile Driving Analyzer for Determining Pile Capacity in NH Soils
- Enhancing Geotechnical Information with Ground Penetrating Radar
- GIS and the New Hampshire Rock Cut Management System
- Effect of Freeze-Thaw and Frost Heaving on Flowable Fill

11.9.6.2 Superstructure and traffic projects

Examples are:

- New Hampshire Road Weather Information System (RWIS)
- Fiber Reinforced Polymer Demonstration Project and Bridge Deck Test Facility
- Bridge Deck Evaluations Using High Speed Ground Penetrating Radar
- Concrete Cover Determination Using Ground Penetrating Radar
- Ground Penetrating Radar for Delineating Bridge Deck Repair Areas
- Mitigation of Alkali-Silica Reactivity in New Concrete in New Hampshire
- New Hampshire's Concrete Aggregate and Alkali-Silica Reactivity—Statewide Assessment of Fine and Coarse Concrete Aggregate
- Shrinkage Characteristics of Concretes with Type K Cement, Mineral and Chemical Additives
- Frost Susceptibility of Recycled Crushed Glass Aggregate Mixtures

Construction methods for bridges have been undergoing many changes over the centuries. From laying timber logs and tying ropes at each end to sophisticated beam, arch, truss, cable tied and suspension bridges and from partial ABC to full ABC. The objectives are safety, economy and public comfort of the millions of users.

Construction materials used are timber, aluminum, steel, reinforced and prestressed concrete. Composite and hybrid bridges are of more recent origin.

Types of construction involve minor repairs to rehabilitation, retrofit and replacements or new bridges on new highways. Bridges on waterways are more difficult to construct due to floods and soil erosion than those on two way intersections.

Environmental permits are required for construction and need to be obtained from DEP before construction commences. Changes in design may be required. Substructure and foundation usually take longer to build than the superstructure.

It is always a matter of team work. In selecting a team, experience in ABC methods and minimum bid cost are important. Access to site, location of factories and availability of skilled labor are important considerations. Factory production of modular bridges minimizes construction duration.

Construction management plays the most important role in rapid construction and delivery. The methods of ABC construction with design-build management are incremental launching, roll-in roll-out, slide-in and float-in methods. Facilities such as transporters /SPMTs, heavy lift cranes and equipment come next.

New sources of funding such as public-private partnership have made possible the funding of a variety of bridges. The design of ABC bridges would require a separate code and specifications. Both AASHTO and State design manuals need to be developed to be in conformity with the method and sequence of construction. Training of engineers in ABC methods is required.

Emphasis should be on using innovative approach as each site is different.

11.10 Conclusions

The subject of modular bridges is still in its infancy, but it is developing gradually for highway bridges. ABC was first used successfully in railway bridges, which has a narrow construction window. Due to its success, it is now being extended to highway bridges.

ABC is a series of principles put into practice in a special way. It is equally applicable to all types of bridges. More than full ABC due to certain limitations, partial ABC applications, especially for superstructure replacement, is becoming more popular. The reasons are as follows:

1. **Multiple configurations and shapes:** This is a specialized subject and each of the large variety of bridges is based on a structural configuration of beam, arch, truss, and cable (or the variations thereof) requiring a different theoretical and practical solution. Thus far, steel and concrete beam bridges have received greater attention than other types. Timber bridges, which can be used for smaller spans, can be more easily adapted to ABC. For smaller spans, CON/SPAN has come up with prefabricated concrete arches.
2. **Investments in machinery:** The transportation of prefabricated bridges requires specialized trucks like SPMTs, which are not readily available. For lifting and erection of modular bridges, large-capacity cranes are required, which may not be available with small contractors.
   Luckily, the essential heavy equipment is being made available from the construction industry for refineries and for modular tall buildings. Its use in industries other than bridge construction helps to keep down the huge costs of manufacture and maintenance of the construction equipment. Renting or leasing is possible for the duration of the project.
3. **Major shift in project management:** The transformation from conventional project management of design-bid-build to design-build (or the CMGC system) has not been easy. Most owners are used to the conventional system and are reluctant to switch over to the design-build system, due to fear of any mysteries involved or due to lack of experience with ABC. There are only about 10 agencies with CMGC experience, including those in Utah, Florida, and Michigan.
   For smaller projects costing less, say about $25 million, there may be friction between the contractor and consultant's teams. The consultant usually considers himself the advisor and right-hand man of the owner. He uses alternate structural solutions, but with ABC, the prime contractor has the upper hand in decision making. There is far less time for research into alternate solutions, which the consultant prefers.

On smaller jobs, these differences in perspectives may be resolved with the intervention of the owner. The contractor tries to reduce the cost through value engineering, which helps the owner greatly. It appears that the greater interaction between the contractor and consultant during an ABC project, with the primary aim of completing the project as fast as possible, helps the project's objectives by arriving at optimum solutions. Better communication can also increase quality and increase the contractor's understanding of the goals of the project.

4. **Lack of ABC codes and specifications:** For these innovative practices, there are only a few design codes and specifications available. New structural geometry resulting from hinge locations and erection loads need to be addressed. A few states have developed interim provisions for selected types of bridges. More work is required by other states and in particular by AASHTO. The LRFD method of design remains unchanged. Structural software for analysis such as SAP 2000 is still applicable. For example, when using the lateral slide-in method, methods for calculating jacking forces and the sizes of diaphragms are needed.
5. **Need for training:** For safety reasons, there should be formal on-the-job training offered to engineers working on ABC projects so that the ABC projects are completed on time and without errors. This training may be specific to the type of bridge to be built, whether on an entirely new route or a bridge replacement over an existing footprint. Web-based training modules for owner policy issues and continuing education through seminars and workshops by FHWA, active states, and universities are important steps in the right direction.
6. **Greater use of prefabricated deck slab:** When deck slab segments are prefabricated and transported to the site for assembly, their assembly requires longitudinal joints. The joints cause discontinuity and are subjected to impact loads and cracks from differential shrinkage. Cast-in-place concrete decks do not have these problems. However, these joints can be filled up with cast-in-place UHPC, with compressive strengths exceeding 20 ksi.
   Prefabrication in a controlled environment would allow accurate longitudinal and transverse grades for drainage that are better than cast-in-place construction.
   Also, a topping layer made of latex-modified concrete or concrete with corrosion inhibitor aggregate may not be required, reducing the dead weights. The top layers of rebar can be made of stainless steel rebar of high tensile strength, requiring a thinner concrete cover than ordinary rebas. This also helps in reducing deck slab thickness and dead weight.
   Precast approach slabs can be constructed simultaneously with the deck. Staging may be required to allow traffic flow at least in one direction. With overnight work there should not be much holdup of traffic flow.
7. **Construction while utilities remain intact:** Progress in roll-in, roll-out and lateral slide-in methods has made it possible for existing utility pipes to remain in position undisturbed. This leads to time savings and avoidance of the unnecessary costs of temporary relocation of utilities.
   During erection, the bottom of girders can be kept slightly higher than the top of pipes. Temporary supports may be required for water pipes if necessary.
   Roll-in, roll-out is in one direction only using two temporary bents on either side of the bridge. The slide-in method is not accompanied by slide-out if the previous bridge is demolished. Jacking may be required for lateral slide-in. For environmental reasons, debris needs to be collected and prevented from falling below.

8. **Need to make wider use of prefabricated abutments:** The use of ABC has been rather limited for the substructure as compared to superstructure ABC use. This is either due to less wear and tear of substructure compared to the superstructure or the difficulty in constructing the abutment while traffic is on the deck. Substructure construction will be a lot easier for new bridges compared to replacement bridges.
   However, after demolition of the existing abutment, new prefabricated segments can be erected overnight or in one weekend. In many cases, the existing substructure can be reused. In other cases, staging may be required for maintaining limited traffic flow. Prefabricated wall components that are commonly being used include MSE walls, T-walls, and georeinforced earth walls.
9. **Wider use of prefabricated piers:** For ABC construction, the use of precast pier caps and precast concrete columns constructed in segments is becoming popular. The columns can be prestressed in the axial direction. On a busy highway in New Jersey, the author used an innovative precast column construction approach by extending the precast round pile length by approximately 15 ft and elevating pile cap as precast pier cap. The piles are designed to act as columns. The system is stronger with fewer connections.
10. **Prefabricated footing slabs:** Foundation costs may be higher than that of the superstructure or substructure components. The problem with prefabricated footing slabs lies in transport with its tremendous weight, even when SPMTs are used. Footing slabs may be over 5 ft deep, while precast deck slab is only about 9 in. Hence, transportation on routes that have bridges with weight restriction will not be possible. In such cases, footing slabs need to be cast next to the site and lifted into position with heavy cranes.
    For sign structures, prefabricated cantilever slabs are currently being used with ABC. In some cases existing footing slabs can be reused and, if required, strengthened by driving minipiles. However, if existing cantilever footing slab needs to be replaced, it is demolished, along with the abutment wall. This would be necessary when the projections of the footing slab on either side of the abutment are large and are likely to interfere with the new footing slab.
    For existing deep foundations such as piles or drilled shafts, use of the existing grid layout may not be feasible, due to interference with old piles. New piles need to be located a few feet away from the existing ones, to act as frictional piles only when sufficient soil media is available. Sometimes bored and drilled piles may be necessary.
11. **Bridge in a Backpack:** A revolutionary approach to construction by doing away with formwork for the deck is being promoted by laboratory testing at the University of Maine. Carbon fiber–reinforced polymer (CFRP) is used for long spans, and steel tubes are erected at close spacing. Composite deck is placed on top of the arches. The initial cost and life cycle costs are lower than for the conventional slab-beam bridges.
12. **Infrastructure Report Card:** The ASCE Report Card's constructive criticism can form the basis of a blueprint for modernizing infrastructure with sustainable technology. Much needed reconstruction and applying sustainable technology will provide more reliable and long-term solutions. Modernized roads, bridges, and traffic systems can have a ripple effect on efficiency. The shortage of funds can partly be overcome by the P3 method. Banks may also cooperate in lending.

13. **Segmental Concrete Construction:** For long-span construction, prestressed box sections are added on both sides of the pier using cantilever post-tensioning of box sections. There are specialist contractors like Figg Construction who specialize in launching using high-capacity cranes. With the advancements in high-strength, lightweight concrete and high-capacity cranes, segmental construction has become very useful. One of the latest examples is the Bahrain Ministry of Works Project, which is one of the largest projects of its kind.
14. **Construction schedules for ABC:** Reduction in the duration of the construction schedule is the most important benefit of using ABC. A comparison between conventional Design-bid-build and Design-build methods will show that both the methods use CPM but definitions of critical path activities may not be exactly the same. The duration assigned in the construction schedule is shorter for Design-build and the majority of activities are listed as critical path activities. On a given *superstructure replacement project*, a comparative study between conventional construction of the superstructure with the following ABC methods is required to appreciate the differences in construction time:
    - Identify the construction season and months in a given year for the allowable fieldwork window (for bridge sites that are subjected to extreme weather).
    - Identify activities on the critical path when using prefabrication and SPMT methods and with design-build management. Compare the overall duration of construction with the design-bid-build method.
    - Identify activities on the critical path when using the lateral slide-in method with temporary bents and design-build management. Compare the overall duration of construction with the design-bid-build method.

    On a given *substructure and superstructure replacement* project, a comparative study between conventional construction of the substructure and superstructure with the following ABC methods is required to appreciate the differences in construction time:
    - Identify activities on the critical path when using prefabricated abutment wall components and precast pier columns and caps. Can the new abutments be constructed prior to the demolition of old abutments?
    - Does the existing foundation need to be removed before constructing new foundations, if pile driving is required?
15. **Study of contract clauses for ABC:** A sample set of contract clauses between the owner and contractor involving successful implementation of prefabrication and SPMT, roll-in, roll-out, and lateral slide-in methods is required. What incentives are given to the prime contractor and his team for completion in minimum time? What penalties exist for any delay? There is an old saying that "it is easier said than done." An investigation is required before a major commitment is made. There are instances where contractors become bankrupt when trying to meet a deadline or there are other unfeasible construction challenges.
16. **Need for new contract documents and special provisions in construction specifications:** ABC requires changes in conventional construction documents such as bid tabs; estimates of quantities, costs, construction schedule; activities on the critical path; specifications; and special provisions. A sample set of special provisions as approved by the owner for the prefabrication and SPMT method and lateral slide-in method is required to appreciate the responsibility and liabilities.

17. For bridges located on rivers, a survey of scour countermeasures that are being used nationwide was carried out. A form was successfully developed to assist in the field assessment of scour at bridges. Introducing more rapid inspections to identify deficient bridges by using remote sensors is emphasized.

11.11 Future deployment of ABC

ABC is a boon for restoring travel in the case of natural disasters. Rapid construction helps in disaster management.

USA has a very large network of highways and bridges are occasionally subjected to extreme events.

Floods, breach of levees, tornados and earthquakes seem to hit some locations in the vast country. Dozens of bridges get damaged and need to be replaced asap and communications need to be restored. Each day that is lost adversely affects public comfort, commerce and industry. The progress in switching over to ABC and PBES needs to be expedited and the work force trained and SPMTs and high capacity cranes made available.

ABC is comprised of many bridge movements during construction. Examples are as follows:

- Transport on SPMT
- Lifting
- Launching
- Floating
- Pivoting
- Skidding
- Rolling
- Sliding

It is always helpful to the users of highways if there is greater flexibility in the construction of highway structures to allow the designers to avoid construction joints and multiple bearings if possible. One example is the use of integral abutment bridges.

The history of the design-build method for rapid delivery goes back to 1998 for TEA-21. The Federal Highway Act was initiated back in 1938, and a list of design-build projects completed is available with National Project Exchange Users Guide published in July 2013. Some projects are already addressed in the chapters of this book. There are considerations of indirect costs, risk, safety, and minimizing environmental concerns compared to conventional construction.

Due to the many advantages of using ABC methods, such as avoiding detours during construction, agencies like FHWA and NCHRP have taken initiatives to provide technical information through Website resources. Case studies of successfully completed projects have been provided by a number of states. FHWA has held international conferences such as the one in Baltimore in March 2008. The proceedings discuss the state of the art and are helpful in the development of the subject. A few universities are also holding regular seminars.

It is expected that the use of ABC methods will become more popular as more projects switch from conventional management to design-build. Bridge owners have a major role to play in adopting

ABC, as they can provide incentives and encouragement to contractors to invest in the necessary equipment and training to minimize the delays in the delivery of bridges. While superstructure replacement costs may be comparable to conventional construction (which requires much more time), complete bridge replacement costs with ABC may be higher than $500 per square foot of bridge deck area. Of course, with the implementation of new technology with higher strength, the life cycle costs are lower.

Note: Appendices 1 to 11 are provided at the end of the book for ready reference.

Appendix 8 gives a Survey Form for Structural Countermeasures adopted by transportation agencies in the United States. It was used to summarize the valuable experience gained by the U.S. states in the use and application of countermeasures on river bridges during peak floods.

11.12 Literature review/acknowledgements

The chapters in the assigned sections 1 to 3 cover innovative construction methods, recent developments in ABC concepts and the use of modular bridges.

It will be noted that PBES, as an important requirement of ABC is a relatively new subject. There is research in progress by many federal and state organizations and universities as outlined in the chapters. Hence it is likely that some of the procedures and methodology for rapid bridge construction and delivery will change for the better.

The author's own practical applications in bridge construction in the northeast of USA are reported here.

USA has a unique network of highways, which has promoted the use of SPMTs and helped in the development of the subject. A great deal of publications on the development of the subject is reported by FHWA, AASHTO, NCHRP, TRB and many states and the universities such as FIU. Even prefabricating companies such as Hi-Steel, Acrow and Jersey Precast etc. have implemented the innovative ideas in an effective manner. Their contributions cannot be ignored.

The bibliography lists a volume of references. For each chapter, a vast number of references are given, with the sources of information mentioned. Website links to important publications are presented.

However, those references which were inadvertently missed out in the literature review can be seen in the bibliography list. Care will be taken to update any references if missed, in the next revision of the textbook. The author is grateful to Mr. Benjamin Beerman of FHWA and Professor Atorod Azizinamini of FIU for their tireless and ongoing work on promoting the use of ABC and for providing access to their publications.

The objectives of the book are to help teach the subject to the students and promote the use of ABC in the multi-billion dollar construction industry.

AASHTO and state regulations and those by FHWA etc. are being updated after every few years, with further research in the developing subject of ABC.

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APPENDIX

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1

References to Literature

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Glossary of Terms

2

The following terms may be used in this document. The description of each term is written in the context of this document.
(**Reference PENNDOT Bridge Safety Inspection Manual #238** available resources for the inspection, maintenance, rehabilitation, and replacement of bridges)

Bridge Owner: An organization or agency responsible for the inspection, load rating, and maintenance of highway bridges.
BQAD: Bridge Quality Assurance Division within the Department's Bureau of Design.
Condition Rating: An evaluation of the physical condition of a bridge component in comparison to its original as-built condition.
Culvert: A soil interaction structure in an embankment that functions as a bridge. This structure may carry a highway railway or pathway over a waterway, railway, highway, or pathway. Culvert structures types include pipes, pipe arches, boxes, and rigid frames and may be constructed of various materials.
FHWA: The Federal Highway Administration, United States Department of Transportation.
Load Rating: The determination of the live load carrying capacity of an existing bridge using existing bridge plans supplemented by information gathered from a field inspection.
National Bridge Inspection Standards (NBIS): Federal regulations establishing requirements for inspection procedures, frequency of inspections, qualifications of personnel, inspection reports, and preparation and maintenance of bridge inventory records. The NBIS apply to all structures defined as bridges located on or over all public roads.
National Bridge Inventory: Inventory containing Structure Inventory and Appraisal Sheet (SI&A) information for the nation's NBIS bridges.
Quality Control (QC): Quality control is the enforcement, by a supervisor, of procedures that are intended to maintain the quality of a product or service at, or above, a specified level.
Quality Assurance (QA): Quality assurance is the independent verification or measurement of the level of quality of a sample product or service.
Representative Load: A live load configuration used to represent/envelop a group of live loads with similar axle spacing and weights.
Structure Inventory and Appraisal Sheet (SI&A): A summary sheet of bridge data required by NBIS.

Accelerated bridge construction: Construction methods that result in an overall decrease in construction time when compared to the historic construction methods used to build bridges.
Additives: Substances (typically chemical) that are added to a grout mixture to counteract the natural tendency of grouts to shrink.
Air release grouts: A type of grout that does not rely on a chemical reaction to achieve expansion. The additive reacts with water to release air and cause expansion of the grout.
Anchor rods: Steel rods that are used to transfer loads from the superstructure to the substructure. Often referred to as "anchor bolts," anchor rods differ in that they do not have a hexagonal head. Anchor rods are normally specified according to ASTM F1554.

Approach slabs: Structural slabs that span between the bridge abutments and the approach fill. They are used to span across the potential settlement of the approach roadway fills directly behind the abutments.

Backwall: A structural wall element that retains the backfill soils directly behind the beam ends on a bridge abutment.

Barrier: A structural wall element that is used to contain aberrant vehicles. They can be used on the bridge (parapet), or on the approach roadway.

Batching: The process of combining and mixing the materials to form concrete.

Bearing: A structural element that connects the bridge superstructure to the substructure, while allowing for movements such as thermal expansion and contraction.

Bleed water (grout): Water that seeps out of the surface of a grout due to expansion of a grout in a confined or semiconfined area

Blockouts: Voids that are cast in prefabricated concrete elements that are used to connecting the elements in the field

Bottom-up estimating: A process of construction estimating that breaks the individual tasks into discrete segments where the cost for time, equipment, and materials can be determined for each segment. The total of all segments are then combined for the total construction estimate.

Breastwall: A wall that is typically nonstructural that covers the beam ends at the corners of the bridge abutments. Sometimes referred to as "cheekwalls" by some states.

Bridge deck: A structural slab that spans between support elements (typically beams and girders) on a bridge. Bridge decks can be made of many materials, including reinforced concrete, steel, timber, fiber reinforced polymers, etc.

Cable restrainers: Structural elements that are used to restrain a bridge superstructure from excessive lateral movement during seismic events. The goal being to prevent the superstructure from falling off the substructure, which is a very common form of failure during seismic events.

Camber: A geometric adjustment of a bridge beam that is designed to compensate for the vertical deflection of the beam when subjected to dead loads. Camber is typically built into steel beams during fabrication. Camber is an inherent side effect of prestressed girder construction.

Carbon fiber: A material that is used in fiber reinforced polymer (FRP) elements to provide the structure performance. These fibers are oriented parallel to the direction of stress.

Cast-in-place concrete: Concrete that is cast on site (as opposed to cast in a fabrication plant)

Cheekwall: A wall that is typically nonstructural that covers the beam ends at the corners of the bridge abutments. Sometimes referred to as "breastwalls" by some states.

Cofferdam: An enclosure used to retain water and support excavation in order to create a dry work environment. Typically used for bridge substructure construction in rivers and along riverbanks.

Composite beam action: The process of connecting the bridge deck to the beams or girders to form a combined structural element.

Composites: The combining of multiple structural materials to form a structural element.

Compressive strength: The value of uniaxial compressive stress reached when a material fails.

Concrete: A construction material that consists of cement (commonly Portland cement), coarse aggregates (such as gravel limestone or granite), fine aggregates (such as sand), and water. Often other materials are added to improve the structural properties such as chemical admixtures and other cementitious materials (such as fly ash and slag cement).

Concrete/steel hybrid decks: A structural bridge deck system that combines structural steel elements with composite concrete to create a prefabricated deck system.

Confinement steel: Reinforcing steel used to contain the concrete core of a column when subjected to plastic deformations brought on by seismic loading.

Consistency: The state of a mixture of materials where the formulation is of uniform quality.

Constructability: The extent to which a design of a structure provides for ease of construction yet meets the overall strength and quality requirements.

Construction joints: Joints in structures that are used to facilitate the construction of a portion of the structure. Construction joints typically have reinforcing steel passing from one side of the joint to the other providing continuity of the joined elements.

Construction stages: A process of building a bridge in segments in order to maintain traffic during construction.

Continuity connection: A connection used to connect two longitudinal bridge element (beams) to form a continuous bridge system. Typically these connections are only designed to resist live load.

Continuous spans: A structural system where the beams span across more than two supports without joints.

Contraction joints: Joints in structures that are used to allow the concrete elements to shrink without causing excessive cracking. Contraction joints typically do not have reinforcing steel passing from one side of the joint to the other.

Controlled density fill: See “flowable fill”.

Conventional bridge construction: Construction methods that do not include prefabrication. Methods that employ nonadjacent butted girders that have cast-in-place (CIP) concrete deck and CIP concrete substructures.

Cover concrete: The specified minimum distance between the surface of the reinforcing bars, strands, posttensioning ducts, anchorages, or other embedded items, and the surface of the concrete.

Critical path: The portion of the sequence of construction activities, which represents the longest overall duration. This in turn determines the shortest time possible to complete a project.

Cross frame: A transverse structural element connecting adjacent longitudinal flexural element used to transfer and distribute vertical and lateral loads and to provide stability during construction. Sometimes synonymous with the term “diaphragm.”

Crown: The apex of the roadway cross slope.

Curing compounds: Chemical compounds that are used to prevent the rapid evaporation of water from concrete during curing.

Curb: A structural element that is constructed at the edge of the bridge deck that is used to contain rainwater runoff. Curbs are often combined with structural railings to retain vehicles.

Debonding: The process of disconnecting prestressing strand from the surrounding concrete in a prestressed concrete element. This is done to control stresses in prestressed elements (typically at the ends of the element).

Deck: The structural portion of a bridge that is directly beneath the wheels of passing vehicles.

Dewatering: The process of removing water from an excavation that is below the water table or surface of adjacent water.

Diaphragm: A transverse structural element connecting adjacent longitudinal flexural element used to transfer and distribute vertical and lateral loads and to provide stability during construction. Sometimes synonymous with the term “cross frame.”

Differential camber: A variation on the camber of two adjacent beams. See “camber”.

Dimensional growth: The phenomenon that results in the change in overall structure width or length when multiple elements are butted together. This is brought on by a build up of element-side variations or tolerances that are a result of the fabrication process.

Distribution direction: A direction that is normally parallel to the supporting members and is perpendicular to the direction of beam action in reinforced concrete slabs that are designed for one-way slab action.

Drilled shafts: A deep foundation unit, wholly or partly embedded in the ground, constructed by placing fresh concrete in a drilled hole with or without steel reinforcement. Drilled shafts derive their capacity from the surrounding soil and/or from the soil or rock strata below its tip. Drilled shafts are also commonly referred to as caissons, drilled caissons, bored piles, or drilled piers.

Dry pack grout: A form of grout that has very stiff consistency that is placed by packing the material into voids by hand and hand tools.

Effective prestress: The stress or force remaining in the prestressing steel after all losses have occurred.

Elastomeric bearing pads: A type of structural bearing that is comprised of virgin neoprene or natural rubber. Sometimes combined with internal steel plates, fiberglass sheets, or cotton duck sheets.

Emulation design: A design method where a prefabricated connection is designed and detailed to act as (or emulate) a conventional concrete construction joint.

Epoxy adhesive anchoring systems: A method of embedding reinforcing rods into hardened concrete to form a structural connection. The process involves a drilled hole and a chemical adhesive. Note: Epoxy adhesive anchoring systems should not be used in sustained tension applications.

Epoxy grouts: Grout materials with chemical adhesives used in place of cementitious materials.

Ettringite expansive grout: Ettringite is crystal that forms as a result of the by-product of reactive chemicals that can be interground into the cement in expansive grouts to produce nonshrink grout.

Exodermic bridge deck: A bridge deck system that is composed of a steel grid deck combined with a top layer of concrete to form a composite system. This system differs from filled grid decks in that the concrete is placed above the top of the grid to maximize the composite action between the steel and the concrete.

Expansion joints: Joints in structures that are used to allow the concrete elements to expand and contract with temperature variation without causing excessive cracking. Expansion joints are similar to contraction joints except they are normally wider and often include a compressible material to allow for thermal expansion. They also do not have reinforcing steel passing from one side of the joint to the other.

Fiber reinforced polymers (FRP): A structural matrix of materials used to produce a structural element. FRP are commonly made reinforcing fibers that are combined with polyester, epoxy, or nylon, which bind and protect the fibers from damage, and transfers the stresses between fibers. FRP are typically organized in a laminate structure, such that each lamina (or flat layer) contains an arrangement of unidirectional fibers or woven fiber fabrics embedded within a thin layer of light polymer matrix material. The fibers, typically composed of carbon or glass, provide the strength and stiffness.

Filled steel grids: A bridge deck system that is composed of a steel grid deck combined that is either fully or partially filled with concrete.

Flowable fill: A material used to rapidly fill a void in embankment backfills or under structures without compaction. It normally has high flow characteristics and is commonly made up of sand, water, and a minor amount of cement. It is also referred to as "controlled density fill."

Flying wingwalls: Walls used to retain embankment soils at the corners of abutments that are cantilevered from the end or rear of the abutment as opposed to being supported on a footing.

Foam block fill: A material made with expanded polystyrene used to rapidly fill embankments where low-unit weight materials are desired. This is often used over highly compressible soils such as clays. This material is also referred to as geofoam.

Full-depth precast concrete deck slabs: A bridge deck system that is composed of reinforced concrete elements that when placed, make up the full structural deck system.

Gantry crane: A crane type that is characterized by two or more legs supporting an overhead beam with a traveling trolley hoist.

Gas generating grout: A type of nonshrink grout that expands due to the production of gas during the curing process. The gas is generated by adding reactive materials to the mix (often aluminum).

Geosynthetic reinforced soil–integrated bridge system (GRS-IBS): GRS technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. GRS-IBS includes a reinforced soil foundation, a GRS abutment, and a GRS integrated approach. When integrated with a bridge superstructure, the system blends the embankment with the superstructure to act as a single unit with respect to settlement.

Girder-floor beam bridges: A bridge framing system that is composed of main girders that run parallel to the centerline of the roadway combined with transverse floor beams that support the deck. Often the system includes stringer beams that run between floor beams (parallel to the roadway).

Glue laminated wood: A structural framing material that consists of multiple layers of dimensional lumber glued together to form a large timber element.

Greenfield: A construction area where a bridge or highway is being built on land that previously did not support a roadway or bridge.

Grout: A material (often cementitious or epoxy) that is used to fill voids between elements.

Grouted reinforcing splice couplers: A proprietary product used to join precast concrete elements by connecting reinforcing steel bars at the ends of the elements. They consist of a steel casting sleeve that is filled with grout. The reinforcing bars are inserted into the ends of the casting and developed by the interaction of the grout with the sleeve.

Haunch: The material between the top of a beam element and the bottom of the bridge deck that gaps the space between the two elements (also referred to as the "web gap" in some states).

High early strength concrete: A concrete mixture that gains strength rapidly in order to accelerate construction.

Integral abutment: A bridge abutment type that is made integral with the bridge superstructure through a combined shear and moment connection. They are often constructed with a single row of piles that allow for thermal movement and girder rotation. Soil forces behind the abutments are resisted through the strut action of the superstructure.

Integral abutment connection: The connection between the superstructure and the integral abutment substructure that can resist both shear and moment.

Integral pier connection: The connection between the superstructure and the pier substructure elements that can resist both shear and moment.

Keeper assemblies: Devices that are placed on top of substructures to prevent lateral movement of the bridge superstructure. They are often used to resist lateral seismic forces. They can be constructed with structural steel or reinforced concrete.

Leveling bolts: Bolt assemblies embedded in various prefabricated elements that are used to make grade adjustments in the field during construction.

Life cycle cost analysis: A process for evaluating the total economic worth of a usable project segment by analyzing initial costs and discounted future costs, such as maintenance, user costs, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment.

Match casting: A process of joining two precast concrete elements with high precision. This is done by casting one element against the adjoining element in the fabrication yard, separating them, and then re-joining them in the field. The field connection is normally made with thin epoxy adhesives combined with posttensioning.

Mechanical splices: Devices used to connect reinforcing through mechanical means. Examples of these systems include grouted sleeves, wedge assemblies, and threaded bar ends.

Mechanically stabilized earth (MSE) retaining walls: A soil-retaining system, employing either strip or grid-type, metallic, or polymeric tensile reinforcements in the soil mass, and a facing element that is either vertical or nearly vertical. In this system, the soil mass is engaged by the strips to become a gravity-type retaining wall.

Mild reinforcement: Steel bars or grids within concrete elements that are used to resist tension stresses. Mild reinforcement normally consists of deformed steel bars or welded wire fabric.

Modular block retaining walls: A soil-retaining system employing interlocking soil-filled timber, reinforced concrete, or steel modules or bins to resist earth pressures by acting as gravity retaining walls.

Near-site fabrication: A process of constructing prefabricated elements near the bridge construction site in order to minimize problems with shipping of large elements.

Network arch bridge: A type of tied arch that includes suspender cables that are run diagonally forming a crisscrossing pattern

Nonshrink cementitious grout: A structural grout used for filling voids between elements that is formulated with cement, fine aggregates, and admixtures. The admixtures are used to provide expansive properties of the material during curing. This expansion counteracts the natural tendency of cement grouts to shrink during curing.

One-way slab: A reinforced concrete slab system that primarily spans between two parallel support members. In this system, the majority of the reinforcing runs perpendicular to the support members.

Open grid decks: A bridge deck system that is composed of an open steel grid spanning between supporting members.

Orthotropic bridge deck: A steel bridge deck system comprised of a top deck plate supported by open or closed ribs that are welded to the top plate.

Parapet: A structural element that is constructed at the edge of bridge deck that is used to contain aberrant vehicles.

Partial-depth precast concrete deck panels: A bridge deck system that consists of relatively thin precast concrete panels that span between supporting members that are made composite with a thin layer of site cast reinforced concrete. The precast panel makes up the bottom portion of the structural slab. The site cast concrete makes up the remainder of the structural slab.

Pier box: A prefabricated system that includes a precast concrete box that is placed over driven piles or drilled shafts. The box becomes the form to contain site cast reinforced concrete. Often pier boxes are used in water applications to form a cofferdam for the footing concrete.

Pier cap: A structural beam spanning between pier columns.

Pier column: The vertical structural element in a bridge pier

Pile bent pier: A bridge pier without a footing that is comprised of driven piles or drilled shafts supporting a pier cap.

Pile cap footing: A footing that is supported by driven piles or drilled shafts.

Plastic hinge: A method of dissipating lateral seismic forces by allowing portions of reinforced concrete pier columns to bend beyond the yield point. Stability of the structure is maintained by providing adequate confinement reinforcement.

Posttensioning ducts: A form device used to provide a path for posttensioning tendons or bars in hardened concrete

posttensioning (PT): A method of prestressing in which the strands or bars are tensioned after the concrete has reached a specified strength.

Precast concrete: Concrete elements that are cast in a location other than their final position on the bridge.

Prefabrication: The process of building bridge elements prior to on-site construction in order to accelerate the construction of the bridge.

Prefabricated bridge elements: Portions of a bridge structure that are constructed away from the final bridge site.

Prefabricated bridge systems: Portions of a bridge structure that are made up of several elements that are combined to form a larger portion of the bridge such as the superstructure, substructure.

Prestressed concrete: Concrete elements in which force is introduced into the element during fabrication to produce internal stresses that are normally opposite of the anticipated stresses in the completed structure. Prestressing can be accomplished with pretensioning or posttensioning.

pretensioning: A method of prestressing in which strands are tensioned before the concrete is placed, and released after the concrete has hardened to a specified strength.

Quality assurance and quality control (QA/QC): The process of inspection and control during fabrication to ensure that the specified quality is achieved.

Reflective cracking: A crack that can form in site cast concrete that is placed over a joint between two elements below the pour.

Reinforced closure pours: A method of connecting two prefabricated elements by casting a segment of reinforced concrete between two elements. The connection is often made using lap splices or mechanical reinforcing connectors.

Reinforced concrete: Concrete elements with reinforcing steel cast into the concrete to form a structural element. The steel is normally used to resist tension stresses in the element.

Reinforcing steel: Steel placed in concrete elements (either be mild reinforcement or prestressing steel).

Return on investment (ROI): Measurement of the efficiency of spending from the viewpoint of net benefit to society. ROI analysis is essentially identical to benefit/cost analysis, incorporating benefit concepts that do not directly result in a revenue stream.

Right of way: The land used for the route of a railroad or public road

Road user costs: Costs that incurred by users of a highway network when they are delayed due to construction activities.

Saturated surface dry (SSD) condition: A condition that is normally specified for concrete surfaces that are to be grouted. SSD describes the condition of the concrete surface in which the pores are filled with water; however no excess water is on the surface. This condition minimizes the absorption of water from the grout into the surrounding concrete.

Segregation: A condition where the distribution of course or fine aggregates in the concrete or grout mix become nonuniform.

Self-propelled modular transporter (SPMT): A high capacity transport trailer that can lift and move prefabricated elements with a high degree of precision and maneuverability.

Shear key: A shaped joint between two prefabricated elements that can resist shear through the geometric configuration of the joint.

Shear studs: Headed steel rods that are welded to elements to provide composite action between two bridge elements. Typically used between beams and the deck slab.

Sheeting: A structural system used to retain earth and water and allow for excavation during the construction of a bridge substructure.

Shims pack: Flat plates placed between two prefabricated elements used to provide a specified separation. Shims are also used to make vertical grade adjustments. Shims are typically made of steel or polymer sheets.

Shrinkage (grout): A property of cementitious concretes and grouts that occurs during curing where the material reduces in size.

Skew angle: In most state agencies, this is defined as the angle measured between the centerline of the bridge elements (abutments, piers, joints, etc.) and a line perpendicular to the roadway alignment. (i.e., a bridge with zero skew is square bridge). This definition is used in this manual. Several states define the skew angle as the complimentary angle (i.e., a bridge with 90° skew is square).

Spandrel wall: A wall that is constructed on the sides of earth filled arch structures that are used to retain the fill soils.

Spiral reinforcement: Transverse reinforcement used in reinforced concrete columns to resist shear. Spirals are also used for confinement of the concrete core as a plastic hinge forms.

Steel stay-in-place forms: Corrugated steel sheeting that is used to support the wet concrete in a bridge deck during construction, and left in place in the permanent structure.

Strength direction: A direction that is normally perpendicular to the supporting members and is parallel to the direction of beam action in reinforced concrete slabs that are designed for one-way slab action.

Stress laminated timber deck bridges: A timber bridge deck that is comprised of multiple layers of dimension lumber placed on edge and connected with transverse prestressing. Shear transfer between the laminations is accomplished through friction.

Stringers: There are two common uses for this term. 1. Longitudinal steel beams on short span multibeam bridges. 2. Secondary framing members on floor beam type bridges that span from floor beam to floor beam.

Stub abutments: A short cantilever type abutment that is constructed near the top of the approach embankment.

Substructure: The portion of the bridge that is below the beam and/or deck elements. It typically includes piers, abutments, and walls.

Superstructure: The portion of the bridge that is above substructure. It typically includes bearings, beams, girders, trusses, and the bridge deck.

Surface preparation (grout): The process of preparing a concrete surface for grouting by cleaning or intentionally roughening the surface. This is done to improve the adhesion of the grout to the concrete. It typically includes sand blasting, water blasting, or hand tool cleaning.

Sweep: The lateral curvature of a prefabricated element caused by fabrication form irregularities and/or internal stresses.

Test pours and test mock-ups: A method of quality control where a contractor will build a model of a portion of the bridge structure that includes a void that requires grout placement. These are used to demonstrate proper grout placement in complex voids.

Tied arch: An arch structure where the thrust forces at the supports are resisted by a continuous bottom chord that runs from end to end.

Timber deck panels: Prefabricated timber panels that are made with glue laminated lumber.

Tolerance: Specified allowable dimensional variations in prefabricated elements. The variations are a result of irregularities in formwork and minor deviations in measurements during fabrication.

Transverse ties: Reinforcement used in reinforced concrete columns to resist shear. Ties, if properly detailed, can also used for confinement of the concrete core as a plastic hinge forms.

Tremie concrete pour: Concrete that is placed underwater and within a cofferdam to resist the vertical pore pressure of the water below a footing during construction.

Variable web gap: See “Haunch”

Water content: The specified amount of water in a concrete or grout mix.

Wearing surface: The top portion of the bridge deck that is directly below the vehicle tires. Often wearing surfaces are designed to be sacrificial and replaceable.

Wet curing: Curing is the process of retaining sufficient moisture (water) in freshly placed grout/concrete to complete the hydration reaction, which occurs when water is introduced to Portland cement. Wet curing leaves the freshly placed grout/concrete in an environment of 100 percent humidity

Working time: The amount of time that a concrete or grout mix remains in a liquid or plastic state so it can be placed and consolidated.

Yield strength: The stress at which an elastic material begins to deform in a plastic manner. Prior to yield, the material will deform elastically and will return to its original shape when the applied stress is removed. If loaded beyond yield and then unloaded, the material will not return to its original shape.

APPENDIX

3

PennDOT Bridge Inspection Terminology and Sufficiency Ratings

Column Identification and Name	Definition			
a. County	Name of county where bridge is located.			
b. Bridge identification	Unique identification number assigned to bridge.			
c. Location/structure name	Geographic location of bridge, or the official, or commonly used, name for bridge.			
d. Feature carried	Roadway that continues (or is carried) over bridge. Roadway is identified by either the assigned street name or number, and possibly the direction of traffic using the bridge (for example, EB means eastbound). Abbreviation indicates whether the roadway is a federal highway (I for interstate), state-owned roadway (SR for state route), or local roadway owned by township/municipality.			
e. Feature intersected	Roadway, waterway, or railroad (or combination of these) that exists underneath the bridge.			
f. Owner code	Two-digit code identifying governmental agency or railroad that owns bridge and is responsible for inspecting and maintaining the physical structure.			
Codes:	01	PennDOT	31	State toll authority
	02	County highway agency	32	Local toll authority
	03	Town or township highway agency	60	Other federal agencies (not listed below)
	04	City, mmunicipal highway agency, Borough	62	Bureau of Indian Affairs
			64	U.S. Forest Service
	11	State park, forest, or reservation agency	66	National Park Service
			68	Bureau of Land management
	12	Local park, forest, or reservation agency	69	Bureau of Reclamation
			70	Military Reservation Corps of Engineers
	21	Other state agencies		
	25	Other local agencies	80	Unknown
	26	Private (other than railroad)		
	27	Railroad		
g. Length (feet)	Length of the bridge measured in feet.			
h. Number of spans	Total number of sections (or spans) to the bridge from edge of roadway to support (pier), and from support to support.			
i. Structure type	Material and construction type of bridge's superstructure.			
j. Year built	Year the bridge was built.			

Continued

—cont'd

Column Identification and Name	Definition
k. Post status	Operational status of bridge: *Open*—bridge is open to traveling public *Closed*—bridge is closed to vehicular traffic (barriers and signs put in place). Pedestrian traffic may/may not be allowed. *Posted*—bridge is open but signs have been placed stating a weight limit that can travel across the bridge. *Temp*—bridge has temporary supports and/or restrictions in place. *U/CON*—bridge is closed because of construction
l. Weight limit—single (tons)	If bridge is posted, signs are placed to indicate the maximum weight (in tons) of a single vehicle (for example, a concrete mixer truck) that can travel on the bridge. "1 TRK" means that the bridge is limited to one truck traveling on it a time without a weight limit.
m. Weight limit—comb (tons) (combination)	If bridge is posted, signs are placed to indicate the maximum weight (in tons) of a combination vehicle (for example, tractor trailer) that can travel on the bridge. "1 TRK" means that the bridge is limited to one truck traveling on it a time without a weight limit.
n. Condition rating—deck	Single-digit number that describes the physical condition of the **deck** (top surface of bridge that carries traffic) compared with its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every 2 years. Number range is 9 to 0. See the description for condition rating—super for a general definition of each number.
o. Condition rating—super *Superstructure* is the underlying or supporting part of a bridge, for example steel members under the deck.	Single-digit number that describes the physical condition of the **superstructure** compared to its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every 2 years. Number range is 9 to 0. A rating of 4 or below indicates poor conditions that result in a structural deficient classification. N = not applicable 9 = excellent 8 = very good 7 = good, some minor problems noted 6 = satisfactory, structural elements showing minor deterioration 5 = fair, primary structural elements are sound but showing minor cracks and signs of deterioration 4 = poor, deterioration of primary structural elements has advanced 3 = serious, deterioration has seriously affected the primary structural components 2 = critical, deterioration of primary structural components has advanced and bridge will be closely monitored, or closed, until corrective action can be taken 1 = imminent failure, major deterioration in critical structural components. Bridge is closed but corrective action may put the bridge back into light service 0 = failed, bridge is out of service and beyond corrective action

—cont'd

Column Identification and Name	Definition
p. Condition rating—sub *Substructure* is the part of the bridge that supports the superstructure such as piers and abutments.	Single-digit number that describes the physical condition of the **substructure** compared with its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every 2 years. See the description for condition rating—supers for an explanation of each number.
q. Condition rating—culv *Culvert* is a curved or rectangular structure below the roadway surface used primarily for water flow.	Single-digit number that describes the physical condition of the **culvert** compared to its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every 2 years. See the description for condition rating—supers for an explanation of each number.
r. Struct def (structurally deficient)	Indication of bridge's overall status in terms of structural soundness and ability to service traveling public. "SD" indicates that the bridge has deterioration to one or more of its major components.
s. Func obsol (functionally obsolete)	Indication of bridge's overall status in terms of structural soundness and ability to service traveling public. "FO" indicates that the bridge has older features (for example, road widths and weight limits) compared with more recently built bridges.
t. Suff rate (sufficiency rating)	A calculated rating indicating the bridge's sufficiency (or capability). Factors included in the calculation are: • the structure's adequacy and safety (accounting for 55% and based on inspection data), • the structure's serviceability and functional obsolescence (accounting for 30% and based on ability of bridge to meet current traffic conditions), and • how essential the bridge is for public use (accounting for 15%) Ratings range from 100 (entirely sufficient) to 0 (entirely insufficient or deficient). The sufficiency rating is considered by the federal government when a state requests federal bridge dollars to improve the condition of the bridge. Bridges with low sufficiency ratings are eligible for more funds. Sufficiency Rating — Funding Eligibility 80–100 — Not available 50–79 — Eligible for costs to rehabilitate or refurbish bridge 0–49 — Eligible for costs to replace bridge

References are made to PennDOT procedures as an example. Other states would have a similar NBIS approach. Latest publication shall be referred to as revisions are likely to occur after every few years.

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PART

Training in ABC

2

Proposed 3 Credits Course for Seniors and Graduate Students 4

Developed by Author.
Equivalent to about 14 hours of class room or webinar attendance to comply with the professional development hours for P.E. License renewal.
Sample topics related to ABC are presented but topics may be magnified if required.

Accelerated Bridge Construction (ABC) Course Details

Introduction and Objectives of Rapid Bridge Construction
Overview of highway user's comforts; Examples of Bridge Failures; Deficient and Functionally Obsolete Bridges; ASCE Report Card on Infrastructure;
Problems with Detour and Lane Closures for Considerable Length of Time;
Initiatives for ABC by FHWA, TRB, Selected States, and Universities;
Bridge Inspections, Site Surveys, Testing, Alternates, and Preliminary Designs.
Economic Considerations in Planning, Value Engineering.

Funding Aspects
Economic Considerations in Planning, Value Engineering, Public–Private Partnership (P3).

Project Management Aspects
(Lump-sum, Design-bid-build, Design-build, CMAR, etc.)
DBIA Recommendations.

Accelerated Construction Techniques
Use of SPMT, Slide-in, Roll-in roll-out, Float-in, Bridge in a Back Pack, partial ABC.

Transportation and Construction Equipment
SPMTs, High capacity cranes, Rollers, etc.

Modern Durable Construction Materials
Concretes in Deck, Prestressed Girders, Abutments, Piers and Foundations (HPC, UHPC, FRPC, CFRPC, GFRPC etc.
Steel Girders (50W, HPS 70W, HPS 100W).

Type of Superstructure and Geometry of Bridge
Slab-beam, Truss, Arch, Segmental, Cable-Stayed, etc.

Type of Substructure
Shallow Foundations, Piles, Drilled Shafts, etc.

Funding Constraints
Prioritization, P3 Requirements
Typical ABC Construction Specifications
- Bidding procedures,
- Materials Control, Precasting in Factory and Field Conditions,
- Quality considerations, and
- Insurance, Warranty, and Surety Issues.

Project Management Aspects
Technical Proposal to Client, Structural Planning, Feasibility Studies, Preliminary and Final designs, Post design Services.
Coordination with Highway, Geotechnical, Environmental and Manufacturers for Design Data and Approvals.

Design Aspects Related to ABC
New Bridges, Replacements, Widening, Rehabilitation, Retrofit, Concrete, Steel, Timber Bridge.
Application of Codes of Practice, AASHTO LRFD, and State Codes.
Superstructure Components Design-Modeling and Analysis Method, Rating, Computer Software, Detailing.
Substructure Components Design-Modeling, Analysis Method, Hydraulics, Computer Software, Detailing.
Deflection Control of Modular Bridges during Lifting and Transportation.

Post Design Requirements
Preparing Contract Documents, Specifications, Quantities, and Cost Estimates.
Bridge Maintenance and Management Systems.

Case Studies and Examples of ABC Projects
Use of State Codes, Handbooks, Technical Journals, and Computer Software.
Attending Webinars, Home Assignments, Mid-term and Final Examinations and Submission of Construction related Project.

APPENDIX

Training Courses and Workshops in Accelerated Bridge Construction

5

1. For archives please click the Web site links.
2. For future training courses please contact FHWA (http://www.fhwa.dot.gov/bridge/abc/events.cfm) and FIU Web site (Accelerated Bridge Construction abc@fiu.edu)

ACTT Workshops. Used to initiate projects around the country, Accelerated Construction Technology Transfer (ACTT) workshops offer a point of convergence for state transportation agencies interested in developments or best practices in accelerated construction techniques.

http://www.fhwa.dot.gov/construction/accelerated/ir04_2.htm,
http://www.fhwa.dot.gov/construction/accelerated/agenda.htm, and
http://www.fhwa.dot.gov/construction/accelerated/question.htm.

A July 2003 *Focus* article describes workshops in Pennsylvania and Indiana, as well as accelerated construction on a Connecticut bridge: http://www.tfhrc.gov/focus/july03/03.htm.

August 2002 issue includes several relevant articles—http://www.tfhrc.gov/focus/aug02/index.htm/

"Accelerated Highway Construction: Workshop Series Summary," *Transportation Research Circular E-C059*, **December 2003.** This recently posted circular provides a thorough review of ACTT workshops held in 2000 and 2002. http://trb.org/publications/circulars/ec059.pdf

AASHTO Technology Implementation Group: American Association of State Highway and Transportation Officials (AASHTO) offers useful introductory materials, including presentations, fact sheets, and more.

2003 TRB Annual Meeting PowerPoint presentation:

Contractors, in general have trained technicians in conventional formwork.

For resources related to steel bridges, visit: http://www.steelbridges.org

Thursday, July 14, 2011 **Featured Presentation Lightweight Concrete for Accelerated Bridge Construction,** Reid W. Castrodale, Ph.D., P.E., Director of Engineering, Carolina Stalite Company, Salisbury, North Carolina (www.abc.fiu.edu)

Full-Depth Precast Bridge Decks.

September 29 State-of-the-Art Full-Depth Precast Concrete Bridge Decks by Sameh Badie representing PCI & Ben Graybeal, **FHWA**.

October 11 Field-Cast UHPC Connections in Full-Depth Precast Bridge Decks by Ben Graybeal, FHWA.

November 17 Full-Depth Prefabricated Bridge Deck Options for Durability and Cost by Bruce Johnson, **Oregon Department of Transportation (DOT)**.

Iowa DOT

2012 FHWA Accelerated Bridge Construction Conference

Minneapolis, MN Latter part of 2012

The last FHWA ABC Conferences were held in Orlando, Florida; more than 700 attended (www.fhwa.dot.gov/bridge/prefab/events.cfm)

NHI Innovations Webinar: Meeting the Implementation Challenges of Accelerated Bridge Construction on Interstate 93.

October 20, 2011

Idaho DOT/FHWA Deck Panel Workshop November 16, 2011.

Design-Build Conference and Expo, Orlando October 19–21, 2011 Sponsored by the Design-Build Institute of America:

http://www.dbia.org/conferences/expo/

PCI National Bridge Conference, Salt Lake City October 22–26, 2011 (Committee meetings earlier in week)

ABC Sessions, Parts 1 & 2—Monday, October 24, 2011

Evaluation of Connections Session—Tuesday, October 25, 2011

2012 Structures Congress, Chicago March 29–31, 2012 Sponsored by Structural Engineers Institute (SEI) of ASCE: http://content.asce.org/conferences/structures2012/

ABCs of Rapid Construction Session—Thursday, March 29.

Featured Presentation: A Planning Phase Decision Tool for Accelerated Bridge Construction Sponsored by *Center for Accelerated Bridge Construction (ABC) Center at* Florida International University.

Web site: abc.fiu.edu, Email: abc@fiu.edu **August 25, 2011**.

A Planning Phase Decision Tool for ABC

Benjamin Tang, P.E., Preservation Managing Engineer, Bridge Engineering Section, Technical Services, **Oregon DOT;** (Co-author: Toni Doolen, Ph.D., Oregon State University).

MassDOT Fast 14 Showcase July 16–17, 2011

- 14 bridges on I-93 replaced in summer 2011
- Innovative technologies include ABC, PBES, D/B, and I/D

2-day event: field trip to construction site and 1-day workshop with presenters from **MassDOT**, FHWA & project contractors.

Innovative Technologies

Upcoming Events (http://www.fhwa.dot.gov/bridge/abc/events.cfm)

Illinois/Missouri ABC/PBES Workshop July 20–21, 2011

SHRP2 Iowa ABC/PBES Showcase October 6, 2011 (Tentative)

FHWA ABC National Conference Minneapolis, MN.

Later part of 2012 (http://www.fhwa.dot.gov/bridge/abc/events.cfm)

FHWA ABC/PBES 2-Day Webinar Training.

12 Training Modules on ABC/PBES August 16–17, 2011

Highways for LIFE Innovations Series

PC Bent Systems for Use in High Seismic Regions August 18, 2011 2:30–4:00 PM Eastern http://www.fhwa.dot.gov/hfl/innovations/pbs_webinar.cfm

New Publications

PCI State of the Art Report on Full Depth Precast Deck Systems, Contact PCI.

Michael P. Culmo, P.E., Vice President of Transportation and Structures CME Associates, Inc., East Hartford, CT.

Public perception of ABC: The public is our "customer." They prefer shorter construction time. Our customers fund our work through taxes, legislators listen.

Washington State Department of Transportation

Accelerated Bridge Construction Resources

Reports

- **WSDOT ABC** Strategic Plan (draft)
- FHWA Seismic ABC Workshop Report
- ABC Seismic Connections—TRB Research Proposal (Oct 15, 2008)
- Design of Precast Concrete Piers for Rapid Bridge Construction in Seismic Regions
- A Precast Concrete Bridge Bent Designed to Re-center after an Earthquake
- Rapidly Constructible Large-Bar Precast Bridge-Bent Seismic Connection (Final Report)
- Anchorage of Large-Diameter Reinforcing Bars Grouted into Ducts
- Design of Precast Concrete Piers for Rapid Bridge Construction in Seismic Regions
- Fully Precast Bridge Bents for Use in Seismic Regions

Presentations

- Presentations from WSDOT ABC Workshop (September 30, 2008) (500 MB)
- Presentations from WSDOT-CalTrans TRB 2009 Seismic ABC Collaboration (612 MB)
- Lewis and Clark Bridge Deck Replacement
- Rapid Replacement of the Hood Canal Bridge Approach Spans
- ABC Pooled Fund Meeting, March 2010
- HFL Testing Briefing, August 2010
- A precast Concrete Bridge Bent for Seismic Regions: Achieving both Performance and Constructability
- Unbonded prestressed connections
- Concrete Filled Steel Tubes for Bridge Foundations and Substructures

Links Highways for Life.

Official Web sites for FHWA Initiatives and Development of ABC Provisions

- **Illinois/Missouri** ABC/PBES Workshop July 20–21, 2011
- **SHRP2 Iowa** ABC/PBES Showcase September 25–30, 2011
- **FHWA's** Accelerated Construction Technology Transfer Web site offers publications, case studies, and reports: http://www.fhwa.dot.gov/construction/accelerated/
- **Past events:** FHWA Activities shown on FHWA ABC Web site, "one place to shop" http://www.fhwa.dot.gov/bridge/abc/
- **Future events:** (http://www.fhwa.dot.gov/bridge/abc/events.cfm)
- **Web conferences***:* http://www.nhi.fhwa.dot.gov/resources/webconference/
- **Projects constructed to date:** http://www.fhwa.dot.gov/bridge/prefab/projects.htm
- **Research:** http://www.fhwa.dot.gov/bridge/prefab/research.htm
- **Calendar of upcoming events:** http://www.fhwa.dot.gov/bridge/prefab/calendar.htm
- **Highway for Life:** www.fhwa.dot.gov/hfl

FHWA ACTT Workshops

Used to initiate projects around the country, ACTT workshops offer a point of convergence for state transportation agencies interested in developments or for best practices in accelerated construction techniques.

Spring 2004 ACTT Interim Report. This site offers historic background, notes upcoming workshops around the country, and describes projects and steps taken in several states, including New Jersey, Montana, and California:

http://www.fhwa.dot.gov/construction/accelerated/ir04index.htm.
http://www.fhwa.dot.gov/construction/accelerated/ir04_2.htm,
http://www.fhwa.dot.gov/construction/accelerated/agenda.htm, and
http://www.fhwa.dot.gov/construction/accelerated/question.htm.

A July 2003 *Focus* article describes workshops in Pennsylvania and Indiana, as well as accelerated construction on a Connecticut bridge: http://www.tfhrc.gov/focus/july03/03.htm

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This recently posted circular provides a thorough review of ACTT workshops held in 2000 and 2002; http://trb.org/publications/circulars/ec059.pdf

AASHTO Technology Implementation Group: AASHTO offers useful introductory materials, including presentations, fact sheets, and more.

2003 TRB Annual Meeting Power Point presentation:

Contractors, in general have trained technicians in conventional formwork and cast in place construction and new training in ABC is necessary. Following workshops have been a step in the right direction:

Workshop 109: Technologies and Connection Details for Accelerated Bridge Construction

The new U.S. Federal Highway Administration manual *Connection Details for Prefabricated Bridge Elements and Systems* will be used as the basis for the discussion, which will include an example of an accelerated bridge project?

Connection details will be selected, a full schematic bridge design will be developed, and case studies of past accelerated bridge projects will be presented.

Workshop 150: Issues in Highway Quality Assurance

Issues to be addressed include percent within limits necessity, effectiveness, alternatives, and effectiveness and cost of contractor acceptance testing.

The construction phase of a public–private partnership presents unique challenges for contracting agency construction representatives, agency consultant advisers, and firms on the developer's team. The session explores contract compliance, performance criteria, operational and warranty criteria, and contractual commitments.

Free webinars

High Performance Precast Structures and Frames

Presenter: Marty McIntyre Executive Director, PCI Illinois-Wiscons in June 28, 2012.

This presentation will provide attendees with an introduction to precast concrete structures and frames. Many applications will be covered including parking structures, residential, offices, manufacturing and institutional settings. The session will discuss typical structural components, precast concrete manufacturing, design considerations, and construction and erection considerations. Several of the concepts discussed will be illustrated with project examples and case studies.

Accelerated Bridge Construction using Precast Concrete

Accelerated Bridge Guide Details for Substructures has just been released

The PCI Northeast Bridge Technical Committee has just completed a series of guideline drawings, which represent the design and detailing of precast concrete substructures. These sheets provide an example of different substructure types for use on bridge projects in the Northeast. The presentation will discuss the developed material in more detail and how they can be used for accelerated bridge construction.

Overview of Precast/Prestressed Concrete Topics:

- Precast Substructures
- Full Depth Precast Panels for Deck Replacements
- Case Study of Projects including details

Publications

PCI Offers Designer's Notebook on "Tolerances"

PCI has recently published a Designer's Notebook on envelope tolerances for architectural precast concrete. The Designer's Notebook explains the three groups of tolerances established for architectural precast concrete: product tolerances, erection tolerances, and interfacing tolerances. The Designerâ€™s Notebook is registered for 1 LU/PDH of CE credit. Take a look.

Third Edition of PCI Bridge Design Manual

The third edition of the popular **PCI Bridge Design Manual is now available to order from the PCI Bookstore**. The manual has been updated to conform to the fifth edition of the AASHTO LRFD Bridge Design Specifications, including the 2011 Interim Revisions.

For resources related to steel bridges: http://www.steelbridges.org.

In Chapter 3, presentation at FIU BY UDOT Structures Division, Carmen Swanwick was discussed. (E-mail to Structures cswanwick@utah.gov for details).

Educate and communicate with industry

The following steps will be helpful in developing ABC:

- Relentlessly pursue reducing traffic congestion during construction,
- Add value by furthering Department themes and meeting project goals,
- Improve worker safety and safety to the traveling public
- Improve quality.
- Implement Standardization
- Develop guidelines for ABC project inclusion,
- Develop typical details and manuals,
- Include user costs in analysis,
- Encourage innovation,
- Provide training and obtain feedback.

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Appendix 6a: ASCE–Temple University College of Engineering

ASCE -TEMPLE UNIVERSITY COLLEGE OF ENGINEERING

Joint One Day Bridge Engineering Course On

Rapid Bridge Construction and Delivery

LOCATION: Temple University Student Center, Room 220, 1755 North 13th Street, Philadelphia

DATE: Friday, November 22, 2013

PROGRAM DETAILS

9:15 A.M. to 9.30 A.M. – Registration

1. **Recent Developments in ABC Technology**

9:30 A.M. to 9.45 A.M. *Introduction to Modern Construction Technology* – Dr. Philip Udo-Inyang Ph.D, P.E.
Chairman, Civil and Environmental Engineering Department

9.45 A.M. to 10.15 A.M. *Overview of Accelerated Bridge Construction* - Dr. M. Ali Khan Ph.D, P.E.

10.15 A.M. to 10.25 A.M. – **Tea Break**

10.25 A.m. to 11.15 A.M. *FHWA Policy on Promoting ABC* - MR. Benjamin Beerman, P.E. FHWA

11.15 A.m. to 12.00 P.M. *Use of BRADD Software* - Mr. Jay Fitzgerald, P.E., SECB, **PennDOT** BRADD Manager,

12.00 Noon to 12.40 P.M. – **Lunch Break**

2. Fabrication, Assembly, Transportation and Erection Aspects

12.40 P.M. to 1.25 P.M. *Projects Case Studies* - Mr. Bob Cisneros P.E., Chief Engineer, High Steel Structures Inc., PA

1.25 P.M. to 2.10 P.M. *Projects Case Studies* Mr. Scott Patterson, PE. Chief Engineer, Acrow Bridges, NJ

2.10 P.M. to 2.55 P.M. *Project Case Studies* Chief Engineer, Jersey Precast, Hamilton, NJ

2.55 P.M. to 3.05 P.M – **Tea Break**

3. Design-Build Contract Aspects and Future of ABC

3.05 P.M. to 3.50 P.M. *Future of Design-Build Contracts* FHWA - Mr. Benjamin Beerman P.E.

3.50 P.M. to 4.20 P.M. *Success of Design-Build Contracts and its Implementation* - Dr. M. Ali Khan Ph.D, P.E.

4.20 P.M. - **Award of Joint ASCE-Temple University Certificates of Attendance**

Note: The one day course will qualify for obtaining six professional development hours (PDH).

Registration: Before November, 18, 2013 please e-mail Dr. Ali Khan Mohidin@temple.edu or Tel: 856 273 1855 or RSVP using our online; payment system. $80 per person. For students and Government employees $40.

Appendix 6b: Use of BRADD Software

After 25 years, Still Moving Forward

Overview

The Pennsylvania Department of Transportation (PennDOT) Bridge Automated Design and Drafting (BRADD) Software for the design and drafting of simple span bridges has been a production tool for the department since November 1988.

PennDOT's BRADD software is a computer software program that was developed for PennDOT to automate the bridge design process from problem definition through contract drawing development. BRADD combines and automates the design, analysis, and drafting process for specific types of simple span bridges. The software provides user-friendly Windows-based graphical user interface menu-driven input, numerous application design programs, and a drawing generation built around Bentley's MicroStation CADD technology to enable an engineer to design and produce scaled contract drawings automatically for simple span bridges.

Appendix 6c: FHWA-Recommended Alternate Construction Specifications

Background: ABC consists of a variety of applications. Construction specifications will vary for each. One type of specification will not fit all. In some cases, the agency needs to obtain Federal Highway Administration (FHWA) approval. Examples include the following:

- Project management (e.g., design-build, CMAR, etc.)
- Construction techniques (e.g., use of SPMT, slide-in, roll-in roll-out, float-in, bridge in a back pack, partial ABC)
- Construction equipment (e.g., SPMTs, high-capacity cranes)
- Construction materials (e.g., HPC, UHPC, FRPC, CFRPC, GFRPC, HPS 70 W, HPS 100 W)
- Type of superstructure and geometry of bridge (e.g., slab-beam, truss, arch, segmental, cable-stayed)
- Type of substructure (e.g., shallow foundations, piles, drilled shafts)
- Funding constraints, such as from P3 requirements

  In addition, typical ABC specifications will be based on:
- Bidding procedures
- Materials control
- Quality considerations
- Insurance and surety issues

SEP-14 Objectives

The genesis for the FHWA's Special Experiment Projects-14 (SEP-14) began in 1988, with the establishment of a Transportation Research Board (TRB) task force to evaluate innovative contracting practices. The objective is to evaluate project-specific innovative contracting practices undertaken by state highway agencies that have the potential to reduce the lifecycle cost of projects, while at the same time maintain product quality. Federal statutes and regulations set forth specific federal-aid program requirements; however, some degree of administrative flexibility does exist. The intent of SEP-14 is to operate within this administrative flexibility to evaluate promising nontraditional contracting practices on selected federal-aid projects.

Design-build

(See the FHWA's Design-Build Web Page for more information on FHWA design-build policy and other related information.)

The design-build concept allows the contractor maximum flexibility for innovation in the selection of design, materials, and construction methods. With design-build procurement, the contracting agency identifies the end-result parameters and establishes the design criteria. The prospective bidders then develop design proposals that optimize their construction abilities. The submitted proposals may be rated by the contracting agency on factors such as design quality, timeliness, management capability, and cost. These factors may be used to adjust the bids for the purpose of awarding the contract.

By allowing the contractor to optimize its work force, equipment, and scheduling, the design-build concept opens up a new degree of flexibility for innovation. However, along with the increased flexibility, the contractor must also assume greater responsibility. Extended liability insurance or warranty clauses may be used to ensure that the finished product will perform as required.

From the contracting agency's perspective, the potential time savings is a significant benefit. Because the design and construction are performed through one procurement, construction can begin before all design details are finalized. For example, pile driving could begin while bridge lighting is still being designed. Because both design and construction are performed under the same contract, claims for design errors or construction delays due to design errors are not allowed and the potential for other types of claims is greatly reduced.

Warranty

Warranties have been successfully used in other countries and by some states on nonfederal projects to protect investments from early failure. Prior to 1991, the FHWA had a longstanding policy that restricts the use of warranties on federal-aid projects to electrical and mechanical equipment. The rationale for the restriction was that such contract requirements may indirectly result in federal-aid funds participating in maintenance costs, and the use of federal-aid funds for routine maintenance is prohibited by law.

The 1991 Highway Act, The Intermodal Surface Transportation Efficiency Act (ISTEA), permitted a state to exempt itself from FHWA oversight for federal-aid projects located off the National Highway System. For projects under these conditions, warranty clauses may be used in accordance with state procedures.

Prior to the rule makings noted above, eight states participated in the evaluation of warranties under SEP-14. Since the implementation of the warranty regulation in 1995, FHWA no longer requires the evaluation of warranties. See the warranty briefing for additional information.

Cost-Plus-Time Bidding

Cost-plus-time bidding, more commonly referred to as the A + B method, involves time, with an associated cost, in the low-bid determination. Under the A + B method, each bid submitted consists of two components:

- The "A" component is the traditional bid for the contract items—the dollar amount for all work to be performed under the contract
- The "B" component is a "bid" of the total number of calendar days required to complete the project, as estimated by the bidder. (Calendar days are used to avoid any potential for controversy that may arise if workdays were used.)

Construction Manager at Risk

A few contracting agencies have begun to evaluate a project delivery system that is relatively common in the vertical building industry: Construction Manager at Risk (CMAR). The contracting agency selects a construction manager (on the basis of past performance or qualifications) to provide construction expertise and contract management and to be contractually responsible for price, schedule, and quality during construction. The CMAR Firm provides preconstruction advice to the owner concerning constructability, pricing, scheduling, staging, value engineering, and other areas related to the construction of the project. At some point in the design, the contracting agency and the CMAR firm agree on a guaranteed maximum price for construction. At this point, the CMAR firm begins to function like a general contractor and is responsible for completing the work on schedule at the guaranteed price.

The FHWA is continuing to develop guidelines and regulations for design-build contracting as mandated by section 1307(c) of the Transportation Equity Act for the Twenty-First Century (TEA-21), enacted on June 9, 1998. The TEA-21 required the Secretary of Transportation to issue regulations to allow design-build contracting for selected projects. The regulations list the criteria and procedures that will be used by the FHWA in approving the use of design-build contracting by state transportation departments. The regulation does not require the use of design-build contracting, but allows state departments of transportation (DOTs) to use it as an optional technique in addition to traditional contracting methods. Use of design-build was formalized by the FHWA in 2002 with the issuance of the Final Rule (Federal Register, 2002).

Now that innovative contracting methods have been practiced for several years in many states and the federal government has recognized and defined many standard practices for innovative contracting, the need has arisen to examine and compare the effectiveness of different innovative contracting methods to each other, instead of independently comparing them to the traditional method of delivery.

Several states have researched innovative contracting methods with the objective of developing a protocol to assist agency personnel in selecting the most effective contract type based on certain project parameters. There have also been reports by various nongovernmental organizations and institutions that have researched one or more innovative contracting techniques. The main reports and most comprehensive studies are outlined in the following paragraphs to develop an integrated summary and synthesis of current thinking on the comparative effectiveness of innovative contracting methods.

Although extensive literature and agency reporting is available for review, for brevity we have highlighted a few of the most important, comprehensive, and/or innovative reports in the following literature review. The discussion below reflects a mix of comprehensive studies examining a variety of contracting methods as well as some studies that focused on a single contracting method, looked at performance criteria, or used project criteria as a basis for selection. This represents a reliable cross-section of the types of reports extant in the literature.

The Utah Technology Transfer Center also generated a best practices guide for innovative contracts (Bolling and Holland, 2003). The contract types that were examined in their report include design-build, A + B, lane rental, warranty, and job order contracting. This report is similar in style and content to the Ohio DOT manual, but it offers perhaps more definitive discussions of the performance implications of different contracting types. The Utah center examined the impact of different contracting methods on five performance parameters: administration, risk, time, cost, and complexity. In addition, the Bolling and Holland report listed project parameters that would lend themselves to the different contracting methods.

A University of Minnesota report by Cadenhead and Hippchen (2004) examined the design-build contracting method as it is used in the highway construction industry. This report gave examples of past and current design-build projects, and attempted to describe project parameters where the value of design- build delivery could best be captured. The report also described the performance benefits that can result from using design-build contracts for highway construction projects.

The primary intent of the lane rental contracting method is to bring the cost of inconvenience to the public into the contract award equation. Under the lane rental contracting method, contractors are forced to consider and include both construction costs and the costs to the public in their bid. The effect of lane rental is similar to liquidated damages in nontransportation construction. Lane rental is particularly valuable when alternative routing and detours are unavailable and when the time savings can be readily calculated in dollar terms (Herbsman and Glagola, 1998).

References

Bolling, D.Y. and J. Holland. 2003. Factors to consider in innovative contracting. Utah Technology Transfer Center.

Cadenhead, C. and J. Hippchen. 2004. The use of design-build contracting methods for highway construction projects. (University of Minnesota Transportation Capstone Project Report).

Federal Register. 2002. Rules and regulations. Federal Register 67.237.Federal Highway Administration. 2002. FHWA briefing special experimental projects No. 14. innovative contracting.

Herbsman, Z.J. and C.R. Glagola. 1998. Lane rental: Innovative way to reduce road construction time.J Constr Eng Manage 124.5, pp. 411–417.

Ohio Department of Transportation. 2003. Innovative Contracting Manual.

Shr, J.-F., B.P. Thompson, J.S. Russell, B. Ran, and H.P. Tseng. 2000. Determining minimum contract time for highway projects. Transport Res Rec 1712, pp. 196–201.

Shr, J.-F., B. Ran, and C.W. Sung. 2004. Method to determine minimum contract bid for A + B + I/D highway projects. J Constr Eng Manage 130.4, pp. 509–516.

South Dakota Department of Transportation. 1996. Criteria and guidelines for innovative contracting. Office of Research Report SD95-07-X.

Appendix 6e: *Engineering News-Record* List of 100 Design-Build Companies Working on ABC Projects

The top 100 design-build firms list, published annually in June by the *Engineering News-Record*, ranks the 100 largest U.S. design-build firms, both publicly and privately held, based on revenue derived from projects delivered using the design-build project delivery system.

The complete list is below, including revenue and market data.

Rank 2012	Rank 2011	Firm Name and Location	Total Revenue (million $)
1	1	Fluor Corp., Irving, TX	16,502.1
2	2	Bechtel, San Francisco, CA	12,798.0
3	3	Jacobs, Pasadena, CA	7830.5
4	4	Kiewit Corp., Omaha, NE	4904.0
5	8	KBR, Houston, TX	3653.0
6	6	CB&I, the Woodlands, TX	3634.7
7	7	McDermott International Inc., Houston, TX	3445.4
8	5	The Shaw Group Inc., Baton Rouge, LA	2755.8
9	9	Chapter 2M HILL, Englewood, CO	1645.3
10	10	Clark Group, Bethesda, MD	1479.1
11	**	First Solar Inc., Tempe, AZ	1242.5
12	12	Balfour Beatty US, Dallas, TX	1182.0
13	11	Hensel Phelps Construction Co., Greeley, CO	1177.2
14	14	The Turner Corp., New York, NY	1121.8
15	**	The Babcock & Wilcox Co., Charlotte, NC	1099.8
16	17	Mortenson construction, Minneapolis, MN	1081.3
17	13	URS Corp., San Francisco, CA	1025.4
18	18	Black & Veatch, Overland Park, KS	916.0
19	70	PCL Construction Enterprises, Denver, CO	793.7
20	16	Clayco Inc., St. Louis, MO	779.0
21	22	Zachry Holdings Inc., San Antonio, TX	772.8
22	21	Burns & McDonnell, Kansas City, MO	732.7
23	33	Swinerton Inc., San Francisco, CA	647.5
24	23	Contrack International Inc., McLean, VA	600.7
25	32	Haskell, Jacksonville, FL	575.5
26	55	DPR Construction, Redwood City, CA	572.0
27	30	The Whiting–Turner Con. Co., Baltimore, MD	571.9
28	31	Parsons, Pasadena, CA	526.9
29	25	Flatiron construction Corp., Firestone, CO	522.0
30	20	Lend Lease, New York, NY	481.8
31	19	The Walsh Group Ltd., Chicago, IL	478.8

Rank 2012	2011	Firm Name and Location	Total Revenue (million $)
32	39	Barton Malow Co., Southfield, MI	459.5
33	34	Stellar, Jacksonville, FL	453.3
34	53	Tutor Perini Corp., Sylmar, CA	435.3
35	54	Primoris Services Corp., Lake Forest, CA	430.0
36	38	Lakeshore TolTest Corp., Detroit, MI	424.3
37	57	Gray Construction, Lexington, KY	411.4
38	47	S&B Engineers & Constructors, Houston, TX	399.0
39	56	ECC, Burlingame, CA	375.1
40	**	Ferrovial Agroman U.S. Corp., Austin, TX	374.0
41	42	McCarthy Holdings Inc., St. Louis, MO	372.0
42	**	Manson Construction Co., Seattle, WA	367.1
43	37	Ryan Cos. US Inc., Minneapolis, MN	358.0
44	61	Science Applications Int’l Corp., McLean, VA	357.6
45	51	Duke Construction, Indianapolis, IN	355.9
46	44	CDM Smith, Cambridge, MA	338.9
47	58	Fagen Inc., Granite Falls, MN	337.5
48	**	The McShane Cos., Rosemont, IL	337.5
49	28	Caddell Construction Co. Inc., Montgomery, AL	323.8
50	**	HOK, St. Louis, MO	318.3
51	46	Jingoli - DCO, Lawrenceville, NJ	311.0
52	36	Granite Construction Inc., Watsonville, CA	300.0
53	41	HBE Corp., St. Louis, MO	279.2
54	66	H&M Co. Inc., Jackson, TN	266.0
55	50	Arcadis U.S./RTKL/RISE, Highlands Ranch, CO	262.0
56	92	Big-d Construction Corp., Salt Lake City, UT	259.0
57	29	Skanska USA, New York, NY	256.1
58	49	Zachry Construction Corp., San Antonio, TX	251.9
59	83	Walbridge, Detroit, MI	248.6
60	26	Hunt Building Co. Ltd., El Paso, TX	243.6
61	**	C. Overaa & Co., Richmond, CA	241.4
62	**	Fugro (USA) Inc., Houston, TX	241.3
63	52	The Korte Co., Highland, IL	241.2
64	**	Hunt Construction Group, Scottsdale, AZ	238.0
65	**	ARCO/Murray Construction cos., St. Louis, MO	230.7
66	35	The Yates Cos. Inc., Philadelphia, MS	224.1
67	71	The Dennis Engineering Group, Springfield, MA	219.0
68	27	Sundt Construction Inc., Tempe, AZ	208.0

Rank			Total Revenue
2012	2011	Firm Name and Location	(million $)
69	77	HITT Contracting Inc., Falls Church, VA	201.4
70	**	Sauer Inc., Jacksonville, FL	199.1
71	69	Ames Construction Inc., Burnsville, MN	199.0
72	**	Panattoni Construction Inc., Sacramento, CA	190.0
73	40	Harper Construction Co. Inc., San Diego, CA	185.8
74	**	Klinger Cos. Inc., Sioux City, IA	180.0
75	73	Consigli Construction Co. Inc., Milford, MA	174.1
76	87	JE Dunn Construction Group, Kansas City, MO	174.1
77	64	Webcor Builders, San Francisco, CA	171.0
78	59	Gilbane Building Co., Providence, RI	164.8
79	**	CORE Construction Group, Phoenix, AZ	159.3
80	**	Posillico Inc., Farmingdale, NY	157.0
81	**	Weston Solutions Inc., West Chester, PA	153.8
82	**	The Rudolph/Libbe Cos. Inc., Walbridge, OH	153.0
83	67	BBL Construction Services LLC, Albany, NY	151.7
84	78	McGough Construction, St. Paul, MN	144.4
85	**	Choate Construction Co., Atlanta, GA	141.0
86	89	Structure Tone, New York, NY	140.0
87	72	The Neenan Co., Fort Collins, CO	136.0
88	65	Gemma Power Systems, Glastonbury, CT	131.0
89	**	Uhde Corp. of America, Bridgeville, PA	130.5
90	60	Woodward Design + Build LLC, New Orleans, LA	125.4
91	**	CD Smith Construction, Fond du Lac, WI	125.0
92	**	Sterling Construction Co. Inc., Houston, TX	122.8
93	**	BIS TEPSCO Inc., Deer Park, TX	120.0
94	**	Bernards, San Fernando, CA	119.8
95	88	Osborne Construction Co., Kirkland, WA	118.7
96	91	Erdman, Madison, WI	118.6
97	90	TB Penick & Sons Inc., San Diego, CA	117.0
98	**	Denham-Blythe Co. Inc., Lexington, KY	116.4
99	**	MEB General Contractors Inc., Chesapeake, VA	115.7
100	**	Conti Group, Edison, NJ	111.7

PART

3

ASCE Report Card and Survey Form

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ASCE Infrastructure Report Card 2014

7

Sample Summary Topics to Address Innovation and New Technology

The technical and available funding method reviews carried out will depend upon each state's performance and level of work.

It is meant as an unbiased observation.

The team of consultants and contractors which guides the state agency are also responsible for the results. They may need to provide training to their engineers in innovative methods in analysis, design and construction.

A. MANAGEMENT RELATED ISSUES

1. **Identifying the causes for structural deficiency, functional obsolescence and failures of bridges in PA:** A review of the issues addressed in previous report cards and any implementations so far need to be discussed. Priorities in selection criteria for rehab or replacement to be examined.
2. **Life-cycle cost analysis (LCCA):** Value engineering method for reducing cost of construction should include LCCA. Standard software needs to be introduced.
3. **Bridge management and inspection methods:** Remote sensors and equipment to be used; LIDAR imaging technology for detecting deck cracking.
4. **Contract management methods**: Pros and cons of following types to be discussed:
   - Design-Bid-Build (Partial Accelerated Bridge Construction, Partial prefabrication)
   - Design-Build (Full Accelerated Bridge Construction, prefabrication)
   - Public–Private Partnership (P3).

B. DESIGN RELATED ISSUES

1. **Different types of bridges:** For each of these, there are different types of modern applications namely:
   - Deck replacement only on existing foot print
   - Superstructure replacement on existing foot print
   - Complete bridge replacement on existing foot print
   - Complete bridge replacement on a new foot print
   - Widening of bridges.
2. **Improvements in design/specification methods:** The following categories of bridges to be considered: A comparison of policies and regulations is required between state documents with the design methods and documents of FHWA, NCHRP, AASHTO and also from

selected states such as NJDOT, CALTRANS, NYSDOT, ILDOT, ODOT, FDOT, etc. (I was involved in revising the first NJDOT LRFD Bridge Design Manual):

- Pedestrian bridges using structural plastics
- Bridges over rivers and new HEC-18 and HEC-23
- Arch bridges/Truss bridges (longer spans possible with new steel and concrete materials)
- Introduction of spliced P/S concrete I-shaped girder designs (longer spans possible from 225 to 270 feet, competitive with steel spans)
- Introduction of long span segmental construction (example Edison Bridge, NJ).
- Suspension cable bridges/Cable-stayed bridges (longer spans possible with new steel and concrete materials)
- Military bridges (new military live loads).

3. **New construction materials:** Following new materials can be considered:
   - Prestressed concrete trapezoidal box and tub sections/comparison with bulb T sections
   - Composite timber and concrete decks
   - LWC
   - FRP concrete/FRPC concrete
   - UHPC for superstructure
   - Use of higher strength concrete (10 ksi) for P/S concrete beams
   - Corrosion inhibitor aggregate concrete for deck surfaces (compare with LMC)
   - HPS 70W/100W girders.
   - Composite/inverset girders
   - Hybrid steel girders
4. **Introducing new technology** and innovative structural systems:
   - Integral abutment bridges with prestressed girders, eliminating deck joints
   - Semi-integral abutment bridges
   - Bridges with Integral Piers
   - Simplified seismic detailing procedures
   - New erosion protection countermeasures for foundations in rivers
   - Geosynthetic Reinforced Soil (GRS) Abutments similar to those used by Ohio DOT
   - Limits of splice locations in girders
   - Introduction of NEXT Beam (precast concrete beam system)
   - Introduction of precast substructure (Central Atlantic Bridge Associates standards & guidelines)

Transportation

Bridges

- **The number of** bridges in the state considered as **structurally deficient.**
- **The number of** bridges in the state considered as **functionally obsolete.**

State 2014 ASCE Report Card Grade Awarded

APPENDIX

Survey Form for Scour Countermeasures

8

The following format was used as a request for information sent to highway agencies of U.S. states. Their feedback in providing detailed answers is appreciated. It has shown the current state of art of the developing subject.

Research Survey Form

Date:
Attention: Name of District with Address

Subject: Research Survey on the Type/Selection and Design of Scour Countermeasures for River Bridges

Sir/Madam:

Our department is conducting a survey pertaining to type/selection and design of scour countermeasures for old and new bridges located on rivers. The survey is part of a research study and is aimed at improving scour countermeasures type/selection and design. All districts in your state are participating in this important survey.

We are interested in the performance of scour countermeasures installed on scour-critical bridges in you district, either against peak or recurring smaller floods. Your participation in this survey is respectfully requested. The survey involves answering eight questions.

We greatly appreciate your cooperation and time in providing useful information for this project. It is important that you include the name and contact information of the person completing this survey for follow-up purposes. *Please provide your response no later than one month from the above date*.

Sincerely,
Researcher Team

Survey of Scour Countermeasures

Q1: Have you had any bridges that have failed due to scour? Please consider outright failures as well as bridges that you may have replaced "preemptively" on account of erosion concerns.

____ Yes
____ No

** If yes, please forward any available reports describing the cause of failure(s) as well as the physical and hydrologic data surrounding the failure(s) via a web link, e-file, or hard copy.*

Q2: In your experience, or from scour analysis calculations, what are the most prevalent types of erosion that have caused failure and/or created potential danger of failure to existing bridges (*may check more than one*)?

____ Contraction
____ Local
____ Degradation (long term)
____ Other (please specify)
_____ Meandering
_____ Overtopping
_____ Debris (not aggradation)

____

Q3: For each type of erosion, specify the type of countermeasure used.

Erosion Type	**Countermeasure(s) Used**
Contraction	______________________________
Local	______________________________
Degradation	______________________________
Meandering	______________________________
Overtopping	______________________________
Debris	______________________________
Other:	

Q4: Have you made any field measurements of erosion rates of soil or rock materials for the purposes of scour evaluation?

____ Yes
____ No
* *If yes, please forward any available reports describing erosion rate measurements via a web link, e-file, or hard copy.*

Q5: Have you installed fixed instrumentation to measure scour at abutments or piers (*either automated or semiautomated*)?

____ Yes
____ No
* *If yes, please forward any available reports describing the type and effectiveness of instrumentation via a web link, e-file, or hard copy.*

Q6: All bridge agencies are required to monitor scour at existing structures. Have you generated any summaries that compare field measurements with predicted scour (*either published or unpublished*)?

____ Yes
____ No
* *If yes, please forward the comparative summary(s) via a web link, e-file, or hard copy.*

Q7: Has FEMA installed any gauges to measure flood discharge?

____ Yes
____ No

** If yes, please forward any available reports including the rivers and/or bridges that have been gauged via a web link, e-file, or hard copy.*

Q8: Does your agency have a preference for particular kinds of scour countermeasures? (May check more than one; please specify which countermeasures are used on newly constructed bridges and which are used on existing bridges.)

____ Concrete pavement
____ Riprap
____ Gabion/gabion mattress
_____ Articulated concrete blocks (*interlocking or tied*)
_____ Foundation strengthening
_____ Debris deflection/removal
____ Other (please specify) ____

**Please indicate the guidelines used for selecting such countermeasures, the long-term performance of countermeasures used, and the type of soil conditions, cost, and any case studies.*

Contact Information for Person Completing This Survey (*very important*):

Name:
Title:
Agency:
Email:
Phone:
Mailing address:

Please mail completed survey to the undersigned. We will provide you with our assessment on the condition of your bridges by identifying deficient bridges at no cost.

For bridges not located on rivers, please provide copies of the latest inspection reports. The standard inspections procedures are summarized below for your information.

Again, our Research Team thanks you for your time!

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PART

Lightweight Bridges

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APPENDIX

Rapid Construction of Timber, Aluminum, and Lightweight Bridges

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A9.1 Ideal low live loads and small spans for rapid construction

It has been observed that light weight materials bridges with low live load intensity such as pedestrian bridges and those located on local roads that have small spans are easier to fabricate, transport, and erect. They do, however, need to be weight posted. The maximum span normally does not exceed 100 ft. They are cost-effective and save construction time. The substructure is also lightweight because of an overall reduction in dead and live loads.

Proprietary bridges: There are proprietary manufacturing companies such as the GatorBridge and its parent company, Crane Materials International, who have decades of experience in plastic, composites, and aluminum.

1. **Timber bridges:** Timber bridges have a long history because of the availability of good-quality timber such as southern pine and that they are low maintenance. Sawn lumber and glue-laminated bridges are popular because of advancements in timber technology reflected in the American Association of State Highway and Transportation Officials (AASHTO) Design Specifications. The allowable stress design method has been replaced by load resistance factor design method.

Pressure-treated pine: For a rustic look and feel of pine or for vehicular loading, pressure-treated heavy pine decking is a good economic option.

Composite wood decking: The premium aesthetic of a composite decking plank provides color and texture options as well as low-maintenance benefits.

At every step during planning, drawing, approval, fabrication, and delivery, an entire team of people is working to ensure project completion in time and under budget.

Pressure-treated pine: Decking shall be Southern Pine No. 1 Structural (1200# extreme fiber bending) Stress Grade. All wood shall comply with American Softwood Lumber Standard PS 20-70. Each piece of lumber shall be identified by the grade and treatment mark of recognized organization or independent agency certified by the American Lumber Standards Committee, Washington, DC, to grade the species. All lumber specified for treatment shall be treated to the requirements of American Wood Preservers Bureau AWPB LP-22.

Tropical hardwood: Hardwood decking shall be Ipe hardwood decking meeting or exceeding mechanical properties as defined by US Forest Products Laboratories testing methods. All decking material is to be produced from an IBAMA (Brazilian Institute for the Environment and the Renewal of Natural Resources) registered mill and produced from legally harvested logs as defined under

Brazilian Forest Code Law 4771 as regulated by IBAMA and the International Timber Trade Organization.

Composite wood: Composite decking shall be TimberTech Earthwood composite decking meeting or exceeding mechanical properties per ASTM D6109 with a minimum ultimate modulus of rupture of 3150 psi.

2. Prefabricated aluminum bridge trusses

The light aluminum frames result in less fuel used during transportation and quicker installation in the field, reducing the carbon footprint of your installation. The aluminum used has been approved for use in areas with strict environmental regulations.

Low maintenance: No need to spend lots of time or money maintaining it. There is no routine painting, sealing, or staining required when using timber or natural aluminum.

A Gator aluminum bridge being transported for erection

A9.1.1 Aluminum materials

All primary structural members are to be 6061-T6 aluminum for its high strength and corrosion resistance. Secondary members are to be 6000 series aluminum for corrosion resistance.

Deck: Decking shall meet one of the following criteria in accordance with Section 3.6 of this specification.

Aluminum: Aluminum decking shall be aluminum alloy 6061-T6 extruded in accordance with the requirements of applicable sections of Federal Specifications QQ-A-200. Extruded aluminum slats shall have a raised ribbed surface integral to the extrusion. The legs of each decking slat shall be welded to the side members and to any longitudinal with a minimum of 1–1/4 in of weld per leg.

Bearing pads: All bearing pads shall be 1″ thick ultra-high-molecular-weight polyethylene adequately dimensioned to provide support to the structure over the full travel resulting from expansion and contraction.

Fasteners

All fasteners required for assembly shall be stainless steel type 304. Insulating washers shall be provided where stainless steel and aluminum contact is anticipated to minimize the potential for galvanic action.

A9.2 General Guidelines

Documentation shall be in compliance with the specifications and shall include the following minimum criteria to be considered:
The standard practice shall be followed but not restricted to:

- Representative design calculations
- Representative drawings
- Splicing and erection procedures
- Warranty information
- Inspection and maintenance procedures
- Welder qualifications

A9.2.1 Applicable codes and standards

Governing codes and standards

- Bridge(s) shall be designed in accordance with the AASHTO, Guide Specification for Design of Pedestrian Bridges, latest edition, where applicable and unless otherwise stated in Section 3 and 4 of this document.

Reference codes and standards

Latest provisions of applicable codes will be adopted. Commonly used specifications are as follows but there may be other project requirements:

- AASHTO, Guide Specification for Design of Pedestrian Bridges
- The Aluminum Association, Specifications and Guidelines for Aluminum Structures, latest edition
- Aluminum Structures, A Guide to Their Specification and Design, latest edition
- American Welding Society, Structural Welding Code, D1.2, latest edition
- National Design Specification for Wood Construction, ANSI NDS, latest edition
- American Wood Preservers Association Standards, latest edition.

A9.2.1.1 Engineering design aspects

Dead load

The bridge shall be designed considering its own dead load including structure and originally designed decking only. No additional loads shall be considered.

Pedestrian live load

Main supporting members, including trusses, primary beams, and arches shall be designed for a uniformly distributed load of 90 pounds per square foot.

Secondary members, including deck and supporting floor system, shall be designed for a live load of 90 pounds per square foot, with no reduction allowed.

Vehicle load

The bridge shall be designed for an occasional 2500-lb vehicle loading, where 60% of the load is considered to act on the rear axle and 40% on the front. All floor beams and main supporting members shall be designed to support the vehicle load, uniformly distributed across their width at a maximum wheel base of 6 ft.

All deck members and stringers shall be designed for a concentrated load of 30% of the vehicle load, positioned to produce the maximum load effect.

The loading outlined in this section shall supersede AASHTO suggested loading requirements. No vehicle impact or dynamic loading requirements are required.

Horizontal wind load

The bridge shall be designed for a horizontal wind load of 35 lb per square foot, applied to the full vertical projected area of the bridge as if enclosed, at right angles to the longitudinal axis of the structure. Wind loads shall be proportionally distributed across all exposed primary member surfaces including chords, vertical posts, and truss diagonals on the windward side.

Fatigue effects shall be considered for all load combinations incorporating wind loads, where n = 100,000 cycles.

Overturning wind load

The effect of forces tending to overturn the structure shall be calculated assuming that the wind direction is at right angles to the longitudinal axis of the structure. In addition, an upward force shall be applied at the windward quarter point of the transverse superstructure width. This force shall be 20 pounds per square foot of deck influence area.

Top chord/rail load

The top chord, top rail, and vertical posts shall be designed for a simultaneous vertical **and** horizontal load of 50 pounds per linear foot or a 200 pound point load, whichever is greater, positioned to produce the maximum load effect.

A9.2.1.1.1 Design limitations

Deflection

The vertical deflection of the main truss from any load combination shall not exceed L/360, where L is the length of the unsupported span.

The horizontal deflection of the structure from any load combination shall not exceed L/500, where L is the length of the unsupported span.

Allowable stresses

All allowable stresses for aluminum shall be determined in accordance with the Aluminum Association, Specifications and Guidelines for Aluminum Structures, supplemented by Aluminum Structures, Allowable Stresses for Load Combinations, which include wind loads, may be increased by 25%.

All allowable stresses for pressure treated pine shall be determined in accordance with NDS, Design Values for Wood Construction.

Analysis shall be completed to determine that all bridge members, critical connections, and bridge configurations are sufficient to adequately resist the following load combinations and in accordance with Section 4.2 of this specification:

- Load combination I: Dead load only
- Load combination II: Dead load + pedestrian live load
- Load combination III: Dead load + wind loads
- Load combination IV: Dead load + vehicle loads
- Load combination V: Top chord/rail load

Note: Seismic loads have been neglected due to:

Single spans, small spans and lightweight materials used.

A9.2.1.2 Aluminum materials

Structural members

All primary structural members are to be 6061-T6 aluminum for its high strength and corrosion resistance. Secondary members are to be 6000 series aluminum for corrosion resistance.

Deck

Decking shall meet one of the following criteria in accordance with Section 3.6 of this specification.

Aluminum: Aluminum decking shall be aluminum alloy 6061-T6 extruded in accordance with the requirements of applicable sections of Federal Specifications QQ-A-200. Extruded aluminum slats shall have a raised ribbed surface integral to the extrusion. Ribs shall be mechanically knurled transversely to the ribbing to provide a nonskid surface. The legs of each decking slat shall be welded to the side members and to any longitudinal with a minimum of 1–1/4 in of weld per leg. The decking slats shall be placed transversely.

Fasteners

All fasteners required for assembly shall be stainless steel type 304. Insulating washers shall be provided where stainless steel and aluminum contact is anticipated to minimize the potential for galvanic action.

Vibration

The fundamental frequency of the unloaded pedestrian bridge shall be no less than 3.0 Hz to avoid the first harmonic.

Frame stability

Buckling analysis shall be completed to determine that the bridge frame is adequately stable and sufficient to resist forces causing it to buckle for the following load combinations and in accordance with Section 4.2 of this specification. The buckling load factor for the bridge structure shall be no less than four for any combination of applied loads, to ensure adequate overall stability and stiffness.

As for the timber single span bridges, seismic forces in aluminum bridges are negligible compared to wind loads.

Load combination II: Dead load + pedestrian live load
Load combination III: Dead load + wind loads
Load combination IV: Dead load + vehicle loads

Frequency

Frequency analysis shall be completed to determine that the bridge frame is sufficient to avoid resonance due to frequencies likely encountered under normal use for the following load combinations and in accordance with Section 4.2 of this specification.

- Load combination I: Dead load only

A9.2.1.3 Fabrication and assembly

Welding

All aluminum members shall be welded using 5356 aluminum filler wire in accordance with AWS D1.2.

Expansion slots

Slots shall be cut into bridge bearing area to allow for proper expansion and contraction of the bridge.

A9.2.1.4 Submittals requirements similar to steel bridges

Fabrication drawings

Fabrication drawings and calculations shall be prepared and submitted for review after receipt of the order. Submittal drawings shall be unique drawings to this project, prepared to illustrate the specific portion of the bridge(s) being fabricated. All relative design information such as member size, material specification, dimensions, and required critical welds shall be clearly shown on the drawings. Drawings shall have cross-referenced details and sheet numbers. All drawings shall be stamped, and signed by a Professional Engineer registered in the state of location of bridge.

At minimum the following criteria must be included for approval:

- All relevant bridge dimensions
- Bridge cross-sections
- Sufficient detailing
- Member cross-sections
- General notes indicating material specifications
- Weld details
- Detail of bolted splices (if applicable)
- Signature and seal of Professional Engineer licensed in accordance with this specification
- Camber details

Calculations and results

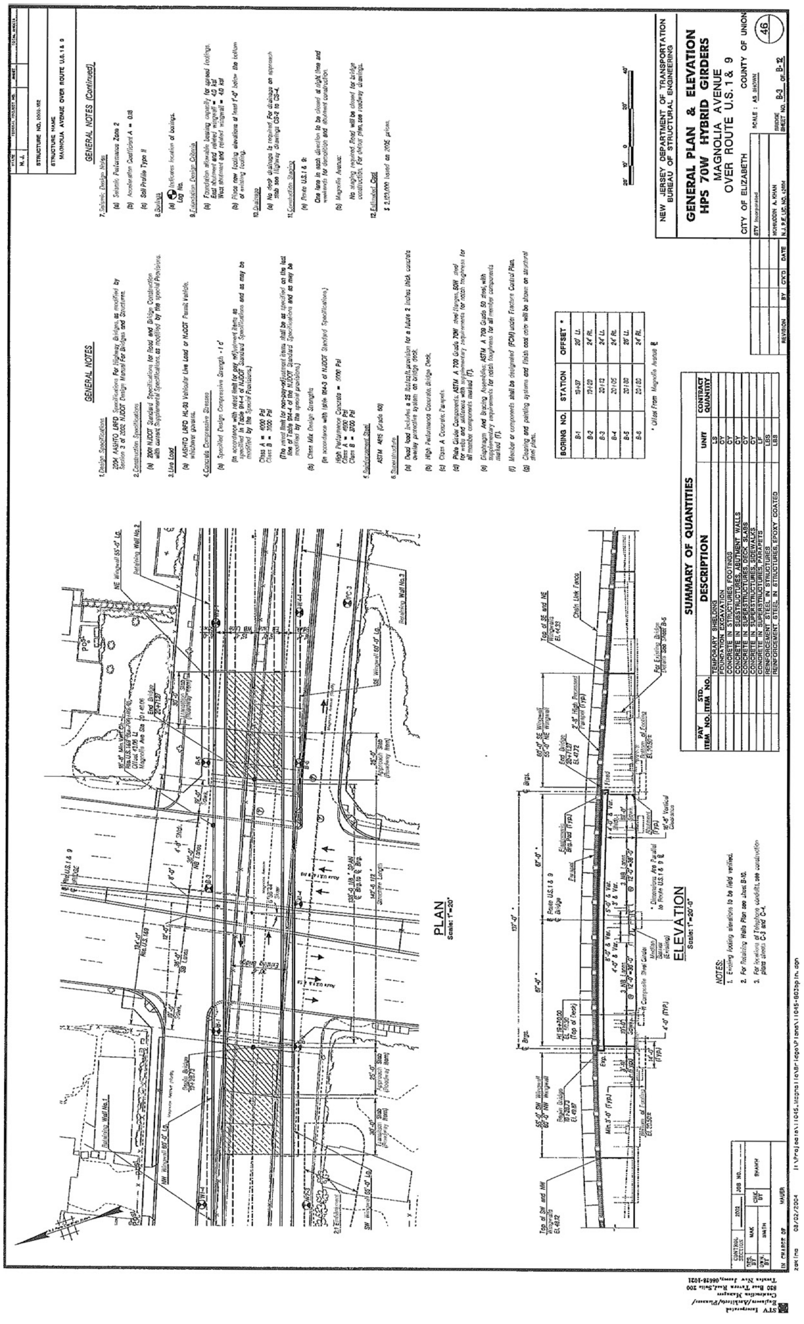
Structural analysis results and calculations shall be prepared and submitted for review after receipt of the order. All analysis and results necessary to determine the structural adequacy of the bridge shall be shown.

At minimum the following criteria must be included for approval:

- Use of a sophisticated software using finite elements or line elements is preferred
- Bridge reactions for all load combinations (I–V) as outlined in Section 4
- Expansion and contraction requirements and/or induced loads
- Critical weld analysis results
- Bolted splice calculations (if applicable)
- Detailed description of applied loads and conditions for all load combinations
- Member maximum allowables for all load and design conditions
- Finite element analysis (FEA) boundary conditions
- FEA data input or line elements analysis with pinned end
- FEA results and supplementary calculations for all stress and deflection analyses
- FEA results for frame stability analysis
- FEA results for frequency analysis

Reference: AASHTO LRFD Specifications and State Bridge Design Manual; Timber and Aluminum Institute Design Codes.

Replacement of Route 1&9 NJ Bridge by the author:
Example of a 70W hybrid steel bridge designed by the author near Newark Airport in North Jersey rapid construction. Partial ABC was introduced to reduce the construction duration.



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11 Manufacturers of Prefabricated Bridges Using Accelerated Bridge Construction (ABC)

Kraemer has a long history of successfully implementing Accelerated Bridge Construction (ABC) for transportation and rail projects across the nation. We are experts in providing innovative planning, design, and construction methods that reduce on-site construction time, impacts to the traveling public, and construction cost for new and existing bridges. Kraemer's ABC experience includes:

- Innovative construction methods
  - Incremental launching
  - Superstructure roll-in
  - Superstructure slide-in
  - Superstructure float-in
- Prefabricated bridges and components
  - Precast bent caps
  - Precast columns
  - Precast abutments
  - Full-depth precast deck panels

Edward Kraemer & Sons, Inc.
One Plainview Road, Plain, WI 53577-0220

Note: Other manufacturers of prefabricated bridges located in the northeast of USA (who participated in the Temple University-ASCE Workshop in November 2013 are High Steel of Pennsylvania, Acrow of North Jersey and Jersey Precast located in NJ and PA. CONSPAN have ready made concrete bridges in small spans for quick construction.

A list of similar manufacturers in other US states (and international companies) can be obtained from FHWA website and/or archives of monthly FIU webinars.