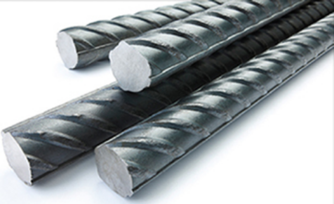
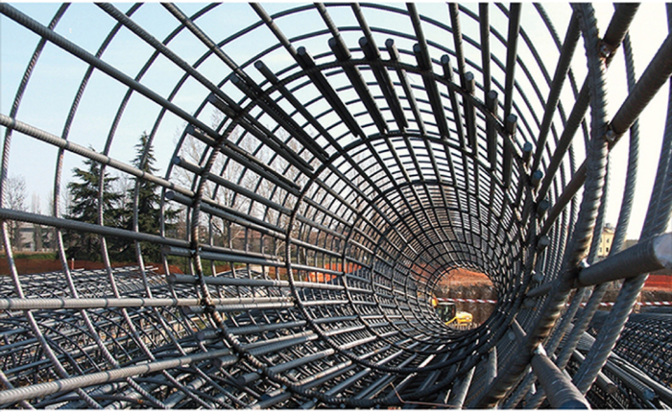


Rebar Cage Construction and Safety

Best Practices



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Michael J. Casey, Ph.D., P.E.
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CI ASCE CONSTRUCTION INSTITUTE

REBAR CAGE CONSTRUCTION AND SAFETY

BEST PRACTICES

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Preface

Background

Although the safety record of heavy civil construction is generally comparable to other construction sectors, the higher public visibility and negative consequences of major accidents has distorted this fact. Catastrophic failures such as collapsed falsework, trench excavation failures, or overturned cranes promulgate the misperception that construction engineering and practice are unsafe. In reality, construction activities are overwhelmingly performed in a safe manner due to rigorous safety programs, construction engineering expertise, and extensive experience from industry stakeholders. While it is important to learn from accidents, it is equally important to learn the best practices of what is being done right in the vast majority of construction projects.

One construction operation that has seen several high-profile accidents in the last decade is the placement of rebar cages for large cast-in-place concrete columns. Iron workers have been severely injured or killed while climbing on column cages that have collapsed while in their temporary condition, i.e., supported by bracing or guy-cable systems. While the causes for these accidents vary from labor-errors, to fabrication problems, to inadequate engineering, it is widely believed that these accidents could be prevented if a standard set of best practices were assembled, shared, and implemented for this particular operation, across the heavy civil construction industry.

Beginning in January 2011, a research team from George Mason University has undertaken an effort to assemble a manual of best practices for the safe handling of large column cages throughout the design, fabrication, and erection process. The research has consisted of extensive interviews, surveys, and discussions with industry, review of literature related to engineering properties of cages, compilation of applicable safety standards, and the development of a standard process for the design and construction of temporary support systems for large rebar column cages. The impact of this work will be for junior construction engineers who may lack experience with handling large columns as well as small contractors without established policies and procedures related to rebar column safety.

Rebar cages used for bridge piers, elevated highway sections, or high-rise buildings are large: as long as 200-ft, up to 12-ft in diameter, and weighing up to 40 tons. They are also inherently unstable, held together usually by tie-wire alone. They are challenging to fabricate, to lift/trip from the horizontal to the vertical position, and to support in the temporary condition until concrete is cast. The latter of these steps is the primary focus of this manual. Engineered temporary support systems consisting of bracing or cable-guy systems that can mitigate the instability of standing rebar cages and resist lateral loads are the best method for assuring the safety of iron workers tasked with climbing the cages for the placement of form work or other activities.

Among our own recommendations, we present numerous best practices used both formally and informally by heavy civil and rebar specialty contractors as well as adopted from research activities investigating the stability of rebar column cages. These are classified according to construction engineering recommendations and construction practice recommendations.

Major Construction Engineering Recommendations

- Any cage with a height/diameter ratio greater than 8, e.g. 24-ft exposed length, 3-ft diameter, should be supported by an internal or external support system.
- Internal rebar bracing, in the form of diagonal or box braces, can significantly improve the rigidity of a column cage. Lift/tripping operations and temporary support systems are made substantially easier through enhanced column rigidity provided by bracing.
- When used, support systems (braces, guy cables, or other systems) should be designed and stamped by a registered Professional Engineer.
- Support system design should account for cage self-weight, applicable lateral loads (environmental and pre-tensioning) and construction loads (including personnel) with appropriate factors of safety.
- Appropriate structural analysis should be performed on the support system taking into account geometry of supports, column base condition (pinned or fixed), rigidity of the cage, and internal bracing.
- Guy wires, if used, should be placed symmetrically, ideally at 45-degrees inclination to the horizontal, but not more than 60-degrees.
- Anchor blocks (deadmen) shall be designed to resist overturning and sliding.
- Once installed, the support system should not be removed or modified in any way without the written approval of the responsible construction engineer.

Major Construction Practice Recommendations

- The overall goal should be to avoid or minimize the need for personnel to climb on a column cage. Alternative access means such as with a mechanical lift are preferred if possible. No one should climb on an unsupported or unbraced column cage.
- Any design elements (dowels, flutes, etc.) or installation of bracing should be pre-fabricated before the cage is lifted/tripped to the vertical position.
- Cages should be protected from damage or deformation on the ground so as to avoid the need for personnel to climb cages to correct damage or fabrication errors.
- For cages over 20' – the suggested method of upending (tripping) would be to rig the cage in multiple locations (top – head, bottom and potentially the mid-point(s) depending on length). This can be accomplished many ways,

not limited to: using a single crane with a rolling block, using a single crane with multiple load lines or with two cranes. Whichever method is utilized, it must be analyzed to not overload the crane or load line with the least capacity. Upending (tripping) of cages over 20' should be reviewed and analyzed by an individual with experience in lifting large rebar cages. Smaller cages can usually be lifted/tripped with one crane.

- Once installed, temporary support systems should be verified by slacking crane rigging and shaking the column. If any movement or deformation of the cage occurs, the crane should not be released and the construction engineer should recommend corrections.
- Support systems, especially guy wires, should be clearly marked with flags or reflective material. All personnel should be instructed to avoid disrupting or removing the support system unless supervised by the designing construction engineer.
- Support systems should be inspected regularly and verified that angles, tension, and placement of deadmen/anchor blocks are within tolerances.
- Support systems should only be altered/removed, e.g., for the placement of formwork, by experienced ironworkers and supervised by the designing construction engineer.

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Chapter 1
Introduction

Heavy civil construction for bridges and related infrastructure increasingly requires tall piers or columns. These cast-in-place concrete structures feature steel reinforcing bar (rebar) cages that are typically fabricated horizontally (either on- or -off-site), lifted to the vertical position using one or more cranes, placed (either above grade or in a drilled shaft), then temporarily supported until poured. A number of engineering and construction challenges are apparent in this process. First, while the permanent design for these columns accounts for all applicable vertical and lateral loads, applied loads in the temporary condition (i.e., the period up until the concrete is cast, sufficiently cured, and formwork removed) are often not determined. Second, the lateral stability of rebar cages in the temporary condition can be inadequate. Third, the design, placement, and eventual removal of the temporary support system are often not engineered. These and other errors have unfortunately contributed to numerous accidents involving the collapse of rebar cages. The accidents have resulted in injuries, fatalities, and project delays. In California alone, fifty-six rebar cages collapsed in the period 1995 – 2010 (Builes-Mejia, Itani, & Sedarat, 2010). Nationally since 2005, there have been at least three fatalities and dozens of serious injuries per year related to rebar cage collapses on construction sites. These accidents may have been avoided if sufficient guidance for the safe handling of rebar cages existed.

Rebar cages are notoriously difficult to work with. Tall bridges or highway fly-overs can require columns up to 200 feet long and 12 feet in diameter. Reinforcing cages for these columns can weigh on the order of 40 tons and are usually required to be continuous (i.e., not lap spliced along the column length). The knowledge and expertise to successfully design, fabricate, lift, and support such cages is distributed across a wide array of stakeholders, not all of whom are aware of each other's role in the process. Still, the successful design and construction of cast cast-in-place columns involving rebar cages is the norm, not the exception. Hundreds of large column cages are placed safely every year in the US alone. What is being done correctly in the majority of cases? What knowledge and expertise is being harnessed to safely erect large column cages?

These questions are the motivation behind the creation of this best practices manual for rebar cage construction and safety. As unfortunate as the numerous accidents and their impacts on life and property have been, there is just as much to learn from what is being done correctly in practice as there is from what is being done incorrectly. Well-designed rebar cages feature sufficient lateral stiffness for lifting and for resisting lateral loads. This is accomplished either through internal bracing, adequate size and number of longitudinal bars, or a combination of both. As shown in Figure 1-1, stiff cages deflect little during a lift (trip) operation. Well-planned, and well-executed lifts include an adequate number and size of cranes as well as proper rigging and lift-support personnel. Once vertical, cages placed on grade or partially in shafts are sufficiently rigid if an engineered, temporary support system such as symmetrically placed guy wires is installed. Formwork and concrete pours are executed in such a way as to avoid or minimize disturbance of the support system. Construction workers are allowed to work on or around a cage only when engineering design of the support system is checked and health and safety plans are enforced. Taken together, these engineering, planning, and execution steps constitute the best practices that this manual is intended to capture.

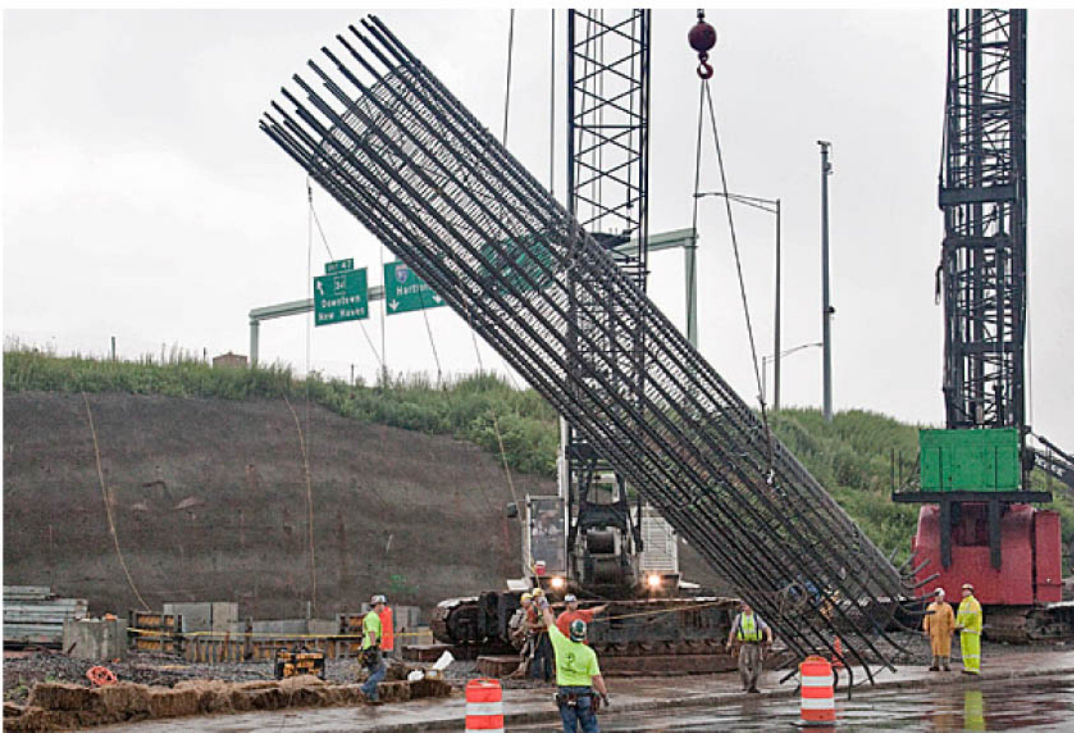

Figure 1-1: A bridge pier rebar cage being lifted into place for a Connecticut highway project. (Photo courtesy of Dimension Fabricators, Inc. Reproduced with permission)

1.1 Anatomy of a Rebar Cage

Rebar cages are usually craft-fabricated (i.e., by iron workers or craft labor) from steel reinforcing bars (#4 to as large as #18). The reinforcement will typically include concentric hoops (or spirals) along the length of the cage, which are tied to longitudinal bars perpendicular to the hoops. Tying is done according to design requirements, usually using Concrete Reinforcing Steel Institute (CRSI) standard methods (CRSI, 2005). Additionally, larger longitudinal bars ("pick-up") bars may be included to make the cage more rigid during a lift from the horizontal to the vertical position. Internal braces may be included to maintain the proper spacing and orientation of longitudinal bars, prevent racking or deformation during a lift, and to improve the cage's lateral stability in the vertical position. Internal braces may be of the "Z" type and placed in a "X" pattern when viewing the cross section of the cage.

Figure 1-2 shows the basic anatomy of a rebar cage for a vertical cast in place concrete column being temporarily supported by guy wires. Beginning at the base and rising to the top, formwork is erected and concrete is poured in segments. Temporary supports are moved as necessary to accommodate formwork.

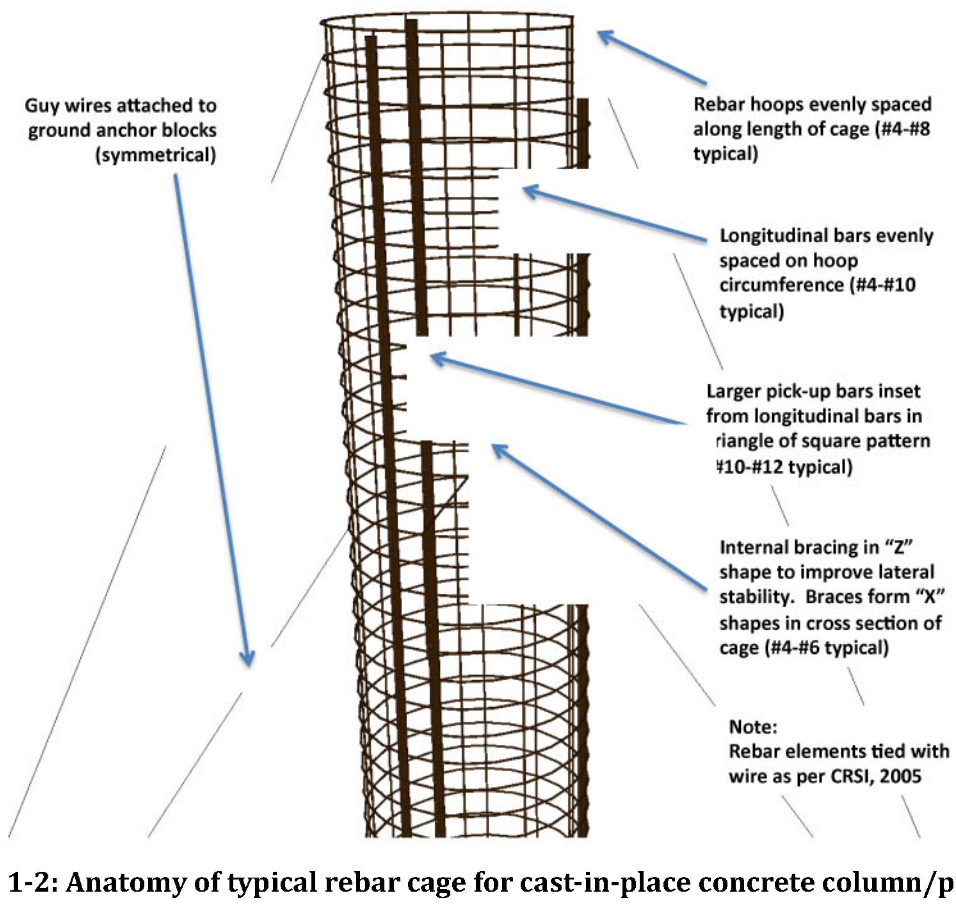

Figure 1-2: Anatomy of typical rebar cage for cast-in-place concrete column/pier.

Large rebar cages are also used in the construction of segmental slurry walls or in top- down construction. For these cages, the geometry is usually rectangular with similar arrangement of longitudinal bars and perpendicular rectangular hoops. These cages, if placed entirely or mostly in a trench or drilled shaft, do not have a temporary support system.

1.2 Best Practices

A best practice is a generally accepted, informally standardized method or process that has proven over time to accomplish a given task. Best practices tend to emerge from a community of organizations or individuals based on experiential learning and sharing of knowledge. They rarely come from a single authority or viewpoint. A manual of best practices is a compendium of available and accepted resources, guidelines, or procedures that is representative of the domain and built from consensus.

This manual of best practices fits well with the above definition. It is based on research in the design and construction of rebar cages as practiced by a wide cross-section of designers, fabricators, contractors, and iron workers. It is not a standard, nor is it intended to be prescriptive. Rather, this manual is a starting point for those individuals and organizations working with cages to develop their own policies and procedures for appropriate temporary engineering and safety methods during the construction process.

1.3 Scope, Mission, and Intended Audience

Construction safety is a broad topic and one that involves many constituents and interests. While this manual deals with many safety standards and best practices, its scope is limited only to those related to rebar cages used for bridge piers or other heavy civil applications. These columns are placed either on grade (on a footing pad, attached to dowels) or partially in a shaft such as a cast in drilled shaft (CIDH) pile with the majority of the column length above grade.

According to several industry experts, the lifting and temporary support of large rebar cages is amongst the most hazardous operations in heavy civil construction. This is due to their size, weight and their inherent instability. The negative consequences associated with the collapse of a rebar cage are sufficiently large to warrant specific guidance in the form of this document. When rebar column cages fail, they fail catastrophically usually with injury, loss of life, and significant project disruption.

The mission of this manual is to provide a reference document, drawn from a wide swath of the heavy civil construction industry, that summarizes general best practices and engineering guidance for the handling of rebar cages.

Who should use this manual?

The primary audience for the manual includes construction engineers working in one of the following two roles:

1. Supervisory construction personnel responsible for construction operations for the builder or general contractor either directly or in a consulting engineering capacity, or;

2. Resident Engineers or EICs (Engineers in Charge) representing the owner in a construction administration and/or inspection capacity.

For Number 1, the Engineer is assumed to have the responsibility and authority for the engineering design of the temporary support system and may also have oversight of the lifting/trip operation. For Number 2, the Engineer is assumed to have overall review and inspection authority in the context of life-safety and owner interests.

The secondary audience for this manual is all of the stakeholder roles in the design and construction of rebar cages. This includes structural engineers, and fabricators, rebar subcontractors, rigging and lifting personnel, iron workers, as well as owners. Some Engineering knowledge is assumed (e.g., statics, forces, understanding of structure loadings), but all of these constituents should benefit to some degree from reading this manual.

If you are a construction engineer representing the contractor or the owner…
This manual is essential because it bridges the gap between the requirements of the design and specifications and any applicable safety and health procedures.

> Chapter 2 describes our standardized process for cage design and construction, and guidance for distributing responsibility in the cage construction process;
> Chapter 3 outlines the construction engineering guidance for supporting cages;
> Chapter 4 provides best practices for field operations.

If you are a fabricator…
This manual will present a reference design and construction process to help envision the downstream operations involved with the lifting and placement of rebar cages.

> Chapter 2 describes our standardized process for cage design and construction;
> Chapter 3 describes the requirements for temporary support system selection, design, and installation;
> Chapter 4 provides best practices for field operations.

If you are a permanent designer (structural) engineer…
This manual will provide some insight into the hazards associated with lifting and placement of rebar cages, particularly large ones, and provide suggestions for improving constructability and stability during the temporary condition.

If you are a rigging engineer, crane operator, or lifting crew…
This manual will be important for identifying the distribution of responsibility and authority throughout the design and construction process.

Chapter 2 describes our standardized process for cage design and construction and guidance for distributing responsibility in the cage construction process;
Chapter 4 provides best practices for field operations.

If you are an owner…
This manual is useful in understanding the unique issues involved with rebar cages including their size, weight, and inherent instability.

Chapter 1 introduces the problem, the manual structure, and approach;
Chapter 2 describes our standardized process for cage design and construction;
Chapter 5 summarizes the major recommendations, conclusions, and recommendations for future work.

For all users, this manual will provide guidance for the handling of rebar cages when neither owner specifications, nor engineering (designer) requirements, nor safety regulations do so.

1.4 Objectives of the Manual

The objectives of this manual are to

1. Provide an objective, industry driven resource for all stakeholders to use;
2. Put forth a standard process for the handling of rebar cages for benefit of all stakeholders involved with rebar cages;
3. Summarize the available engineering aspects of rebar cages and how they pertain to stability;
4. Provide a task-based approach for best practices organized by each phase in the rebar design and construction process;
5. Foster a community via a companion website, www.rebarsafety.org, whereby additional best practices can be shared, additional resources can be assembled, and knowledge can be distributed to the widest possible audience.

1.5 What This Manual Does Not Provide

While it would be desirable to address all aspects of the engineering and construction of column cages, certain aspects are not covered in this manual so as to keep the scope focused:

- The engineering performance of column cages subject to lateral loads is not directly addressed. Recent research supported by CalTrans has investigated this issue and provided recommendations for tying and internal bracing that promote improved stability (Builes-Mejia, Itani, & Sedarat, 2010). Numerical and experimental studies have produced equations for predicting the lateral stiffness for different cage geometries. These may be beneficial in performing the structural analysis needed for a temporary support system design.

- This manual does not give detailed guidance on how to perform structural analysis of rebar cages supported by internal or external support systems. In surveying construction engineering practice, our research has found wide variation in the preferred methods used. These range from indeterminate structural analysis, to moment frame analysis, to full finite element modeling using commercial software. The construction engineering best practices provided in this manual are intended to define the parameters and requirements for the structural analysis, but the analysis techniques to be used are at the discretion of the Engineer.
- Construction lifting and tripping operations are not covered in detail in this manual, nor are rigging requirements for rebar cages. Our research in surveying fabricators and rebar contractors has revealed considerable expertise in this area that is already widely deployed in practice. Moreover, the accident record of collapsed rebar cages shows few if any instances when a cage failed during a lift or when a crane is still attached. Some specific recommendations are included in Chapter 2.
- Finally, recommendations for column cages placed entirely in shafts are not covered. Our research has found that there is great interest in best practices for handling rebar cages for deep foundations (piles or slurry walls). These applications usually have no need for a temporary support system, and so are not addressed here.

Chapter 2
Organizational Management for Rebar Cages

Like many construction operations, the design and construction of a concrete cast in place column, including its rebar cage, is a distributed process. Different entities perform different roles; have different responsibilities, yet they must all function collaboratively, safely and efficiently. The purpose of this Chapter is to highlight the "soft side" of the rebar cage design and construction process, particularly an explanation of the lifecycle that follows column cages from design all the way through construction. The distribution of responsibility and authority is discussed, as is a general framework for handling risks associated with rebar cages.

2.1 The Rebar Cage Design and Construction Process

In the course of our research for this manual, we discovered wide variation in the construction engineering and construction practice for rebar cages. Some variation was geographic in nature. In the Western US, rebar subcontractors for heavy civil construction projects use a turnkey approach and are responsible for fabrication, erection, and placement of concrete formwork. In the East, a fabricator may deliver a pre-assembled cage to a job site, which is in turn rigged/lifted by one contractor, and turned over to another for formwork. In California, especially for CalTrans jobs, an engineered temporary support system consisting of braces or guy wires must be design and sealed by a registered Professional Engineer. In the Southeastern US, no such requirement exists.

Variations exist based on the size and capability of the contractor. We have found that large (greater than $500 million annual revenue) contractors sometimes have corporate policies and procedure manuals for handing temporary works, particularly rebar cages. Smaller contractors, by contrast, work based on the experience of their superintendents and foremen and have no such materials.

Other variations are contractual in nature. In locales where Design-Build project delivery is popular, the permanent designer of the concrete column can also serve as design support for construction engineering needs. In locales where conventional Deign-Bid-Build is used, the permanent designer is barred from interfering in contractor means and methods and is silent on construction engineering concerns.

In an effort to develop a single set of Best Practices that can be adopted across the industry, these and other practice variations present a daunting challenge. How can best practices be implemented when the engineering and construction roles and responsibilities vary so greatly? Our solution is to consider only the life cycle of the cage itself, and not the individuals or entities responsible for the work. As such, we have broken the lifecycle down into a standardized rebar cage design and construction process. The process was formulated based on surveys, interviews, and correspondence with industry practitioners. It represents a generalized linear flow from initial design of a cage all the way through the point at which all formwork and temporary support is removed, that is, the cage's permanent condition.

The standard process is meant as a guide. The aforementioned regional, contractual, or other variations may still apply. Our process, however, as depicted in Figure 2-1, is generally applicable and designed to map to defined lines of responsibility mentioned later in this Chapter.

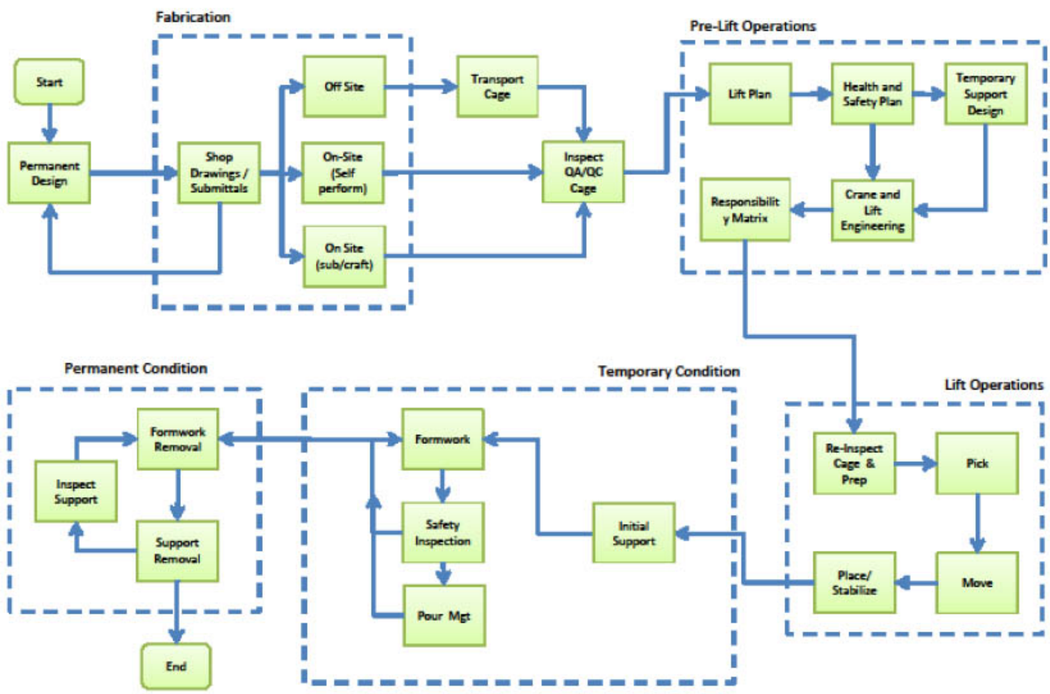

Figure 2-1: Flowchart for the standardized Rebar Design and Construction Process.

The flow chart is divided into five process areas each of which is described in the following sections. The process is applicable to a single cage for a single column, or can be scaled for multiple cages across a construction site or multiple sites.

2.1.1 Structural (permanent) Design

The start of the process is for the column geometry and reinforcing steel to be designed by a structural engineer as part of the overall bridge or infrastructure design.

It is uncommon for structural engineers to design bracing, reinforcement for lifting, or reinforcement for improved lateral stiffness in the temporary condition. This will instead be done by a fabrication shop or rebar subcontractor. Shop drawings with bracing, tying details, and additional pick-up reinforcement are submitted to the permanent designer and, once approved, become part of the permanent design.

At this point, the permanent designer is no longer involved in the process apart from review of inspection reports during the construction process. This designer should, however, be involved in a construability and coordination review to insure that the column/cage design is reasonable considering the constraints of the site and that no unnecessary safety hazards are imparted on construction personnel due to the required lifting or placement of the cage. We have also identified some specific factors for the permanent designer to consider:

1. We recommend that permanent designers allow for some internal bracing even if considered detrimental to the seismic performance of the column.
2. We recommend that the permanent designer make clear the desired base condition for the column in the plans and specs so that all "downstream" parties (fabricator, contractor, construction engineer) can plan accordingly.

2.1.2 Fabrication

Fabrication occurs next where the rebar cage is assembled either off-site at a fabrication shop or on-site by iron workers employed by a rebar, bridge, or heavy civil subcontractor. Smaller cages assembled in fabrication shops are easily transported to the site by tractor-trailers and have the advantages of factory quality control and just-in-time delivery for placement (i.e., no site staging required). A possible disadvantage is that, if these off-site suppliers of pre-assembled cages play no role in lift (trip) operations, they may not detail cages for this purpose. Turnkey rebar subcontractors that provide both fabrication and lift services are more likely to engineer cage details and lift requirements concurrently.

For larger, more complicated cages or when mandated by local construction practice, on-site fabrication is necessary. Assembly and lifting may be done by a single entity or by two entitles coordinated by the general contractor.

No matter the fabrication method, safety hazards from workers placing bars for the cage assembly exist. Cage accidents have occurred during the fabrication process while still horizontal, and even in fabrication shops with experienced personnel.

Upon completion of the fabrication process, inspection for verification of the reinforcing design is crucial. This may include:

- Verification of all number, location and size of bars as designed by the structural engineer and approved through applicable submittals by the fabricator.
- Verification of type and location of wire ties. Are ties of acceptable quality as per the permanent design/submittals?
- Quality assurance for the pre-lift cage condition. Was it assembled on level ground? Is it racked, twisted, or out of alignment?
- Have lift points been specified or clips installed and inspected for the lift?

The completion of the inspection process constitutes acceptance of the fabricated cage.

2.1.3 Pre-lift operations

Planning for lift operations for rebar cages can be done concurrently with the fabrication process.

An appropriate lift plan prepared by qualified rigging and crane operating personnel is required. Lifts for rebar cages must first and foremost account for the loads and geometry of the cage to be lifted, but also for anticipated deflections and site interferences. In general, the ideal method for upending (tripping) any large cage is to use two cranes, one attached to the head end and the other attached to the tail end. In situations where only one crane is available or when site conditions limit access for two cranes, crane model-specific guidance has been developed (Billodeau, 2010). In general, cages being lifted by one crane shall use two lines, whereby the total weight being lifted by the two lines must be less than the lesser capacity of either of the two lines. A single cage being lifted by two hooks is considered one load.

In addition to a detailed and appropriate lift plan, pre-lift operations require review of contractor or other health and safety plan information. Ideally these plans describe how personnel are allowed to work on or around a cage during the lifting and erection process. The temporary support system design, to be discussed in detail in Chapter 3, must be complete. It will include engineering calculations and checks based on the cage to be placed, the support system required (e.g., symmetrical guy wires), and the constraints of the site. Coordination between the lift plan, health and safety plan, and temporary support system shall be done iteratively. This expands upon the normal levels of approval that are part of a standard lift plan to include roles and responsibilities throughout the entire rebar design and construction process.

2.1.4 Lift-Operations

Detailed guidance on crane operations is beyond the scope of this manual. The reader is referred to ASCE Policy 424 (Crane Safety on Construction Sites) and other applicable references.

2.1.5 Temporary Condition

The temporary condition is arguably the most important part of the overall rebar cage process. This is because even highly engineered cages, lifts, and support systems can still result in collapse, injury, or death if the temporary supports are changed, prematurely removed, or damaged.

The General Contractor is almost always responsible for the project under construction. He or she has ultimate supervisory control, unless the owner has specific requirements for temporary support (falsework) that require their own independent verification and inspection.

2.1.6 Permanent Construction

The culmination of the rebar design and construction process is a permanent column capable of supporting its own weight, service loads, as well as lateral loads as per its design. For tall cages, the casting process for concrete is segmental. It is possible for the lower portions of a column to be considered permanent while any exposed length not cast in concrete is considered temporary. Numerous accidents have occurred for partially complete columns where the base of the column was cast. Vigilance and care is needed until the entire column is cast, formwork removed, and temporary support system (if used) removed.

2.2 Roles and Responsibilities

The principles of responsibility and authority are described partly by standard construction practice and partly by the specific requirements of the construction contract. Lines of authority stem from the need to make decisions and give approvals on a project. Individual and organization responsibilities define who must perform what specific actions. In terms of safety, the interplay of authority and responsibility are tightest as they dictate the trade-off between resources to complete the work and protection of life, health, and property

Fisk and Reynolds (Fisk & Reynolds, 2010) provide a summary of the Responsibility and Authority as described by ASCE's 1975 survey (Goldbloom, 1975).

An agency relationship is established in the contract documents between two parties, typically the inspector/EIC and the owner (Fisk & Reynolds, 2010). The EIC is charged with verifying the work for compliance with the contract documents and also for overall site safety. This is made possible through the delegation of authority.

Roles of the inspector:

- Recognize when work is not being performed according to the plans and specifications;

- Required to provide timely notification to the contractor when work does not conform to project requirements;
- Fulfill the duties of the inspector while still being a member of the construction team and not acting in a manner to delay or interfere with work progress;
- Avoid inspection, testing, or activity that could be construed as the contractor's responsibility. Don't interfere with contractor quality control and don't dictate means and methods;
- Observe work while it is being performed so that there is continuity of inspection
- Documentation as a requirement,
- Expeditious testing and feedback to the contractor for materials and workmanship that do not conform with the contract requirements
- Whenever possible, problems should be anticipated in advance. Given knowledge of the existence of specific guidance, it is incumbent on the resident engineer or EIC to anticipate problems.

Authority of the inspector:

- Inspector should have the authority to approve support systems for cages and to promptly give approvals where necessary;
- Stop work
- Inspector should not have authority to approve deviations from the contract
- Inspector does not have the authority to require more from the contractor than is written in the contract
- Under no circumstances should the inspector attempt to direct the contractor's work.
- Instructions or decisions should be channeled through the contractors approved communication channels (i.e. superintendent and foreman, not workers or subcontractors)

Inspection can occur on the part of the contractor for quality control purposes or on the part of the owner for quality assurance. The above provides and general activity listing that might be used to define the specific roles and responsibilities needed for rebar cage operations.

2.3 The Rebar Cage Responsibility Matrix

A responsibility matrix is a common tool used to map the required activities for a work operation to specific roles or individuals. We propose a template for a responsibility matrix to be used for each cage or cage group for the design and construction overall process. A sample is shown in Figure 2-2. The five processes defined for the standard flowchart (Figure 2-1) comprise the activities. The columns describe the eight defined roles. In the intersecting cells, three levels of responsibility may be assigned: no responsibility (blank), direct responsibility (R), or consulting responsibility (C). The concept here is for a single individual to "own" responsibility for an activity in the process, regardless of how it is distributed amongst fabricators, sub-contractors, or construction engineers. Figure 2-2 is populated with suggest responsible/consulting relationships, but this is meant only as a guide. Individual teams should tailor their own matrix to capture the unique requirements of their project.

ASCE CI Rebar Cage Roles and Responsibilities Matrix

R = Responsible
C = Consulting

Process Name	Permanent Designer	Temporary Designer	Vendor/Fabricator	Engineer-in-Charge/Owner Rep	Construction Engineer (Contractor)	Project Manager	Superintendent	Crew Foreman	Responsible Individual Name
Fabrication									
Column Design and Constructability	R	C			C				
Design of longtitudnal pick-up bars			R		C				
Design of internal bracing	C		R						
Tying requirements									
Quality Control, Inspection, Verification				R	C				
Design/Spec of lift points		R			C		C		
Pre-Lift Operations									
Site Management				C	R				
Health and Safety Plan						R	C	C	
Crane Access/Staging				R	C	C			
Lift Plan					R	C	C		
Design of Temporary Support		R			C	C			
Lift Operations									
Preparation/Equipment Verificatinon						C	R	C	
Pick/Lift					C			R	
Move					C			R	
Stabilize/Place		C			C			R	
Temporary Condition									
Initial Support		C			C			R	
Formwork Installation							C	R	
Safety Engineering				C	R				
Pour Management							C	R	
Formwok Removal							C	R	
Support Removal		C			C			R	
Permanent Condition									
Inspection				R			C		
Acceptance				R	C				

Figure2-2: Proposed Responsibility Matrix for Handling Rebar Cages

The responsibility matrix is a useful planning tool at the outset of the cage design and construction process. It provides a baseline plan for how lines of responsibility and authority should flow. However, it should also be treated as living document. As changes occur during the life cycle of a cage, the responsibility matrix should trigger reviews, inspections, and design checks to verify that all duties have been performed.

2.4 The Need for Communication

A climate of open communication needs to be fostered in the handling of rebar cages. The most obvious means to do this is through the use of simple "toolbox" or “tailgate” meetings with all construction personnel who might be involved with the placing of a rebar cage on a particular day.

2.5 Managing Change

The fact that intricate plans for fabricating and erecting rebar cages can be changed at the last minute needs to be considered. A responsibility matrix is an important baseline, but it must also serve as active work control such that if changes to the cage, the lift, or to the temporary support system are made, that those changes are communicated throughout the members on the matrix.

Chapter 3
Construction Engineering of Rebar Cages

The previous chapter has discussed the overall process, roles, and responsibilities involved in the design and construction of rebar cages for columns. This Chapter focuses on the construction engineering aspects and best practices for: 1) temporary support system selection, design, and installation, and; 2) the engineered installation, modification, and removal of the support system.

3.1 Scope

The guidance herein is provided for pre-fabricated column rebar cages. Rebar cages for concrete columns generally have two applications, either entirely or partially installed in a drilled shaft such as a CIDH (cast in drilled hole) pile, or placed on-grade atop a footing or slab. Because of rebar cages' inherent instability, the latter requires a temporary support system until concrete is cast and cured, but the former does not.

Column cages with a height/diameter ratio of 8 or greater should be supported. Any cage that requires an iron worker to climb it for the placement of form work or other elements should be supported.

3.2 Temporary Support Systems

The engineering of a temporary support system for above grade column cages is difficult due to the structural analysis of the semi-rigid cage. Lateral loading conditions and site-constrained placement of bracing or guying are also a challenge. The process begins with load determination, followed by structural analysis, and then; design (including installation and modification plans if required).

3.2.1 Determination of Loads

Service loads for the permanent conditions are determined as part of the permanent design and are separate from the loads that impact a rebar cage during construction. The load considerations for the design of a rebar cage support system should include the following and are based on ASCE Standard 37-02 Design Loads on Structures During Construction:

- ***Dead loads***- this includes the self-weight of the rebar cage. This can be determined from the fabricator's bill of lading for the cage, shop drawings, or field estimates. If at anytime the support system will be attached to forms, the weight of those forms should be added to the self-weight of the cage.

- ***Construction (live) loads***- this includes loads imposed during the construction processes such as personnel, material, and equipment loads (ASCE, 2002).
- ***Erection and fitting forces***- this includes forces caused during the erection process such as during aligning, fitting, bolting, or guying (ASCE, 2002).
- ***Environmental loads***- this typically includes wind loads. Rebar cages should be stabilized during construction to resist wind loads. The minimum horizontal wind load to be applied to the reinforcing steel assemblage (or to a combined assemblage of reinforcing steel and forms) should be the sum of the products of the wind impact area and the applicable wind pressure. Wind pressures are obtained based on height zone as required by CalTrans (Caltrans, 2006), but may be applicable elsewhere. The wind pressure resistances by zone are tabulated in Table 3-1.

Table 3-1: Applicable wind loads by structure height (data from CalTrans 2006).

Height Zone (height above grade)	Wind Pressure (psf)
0 – 30	20
30 – 50	25
50 – 100	30
Over 100	35

These values are provided as a sample only: follow applicable local design requirements.

Surfaces subject to wind loading are assumed to be continuous and, in the case of rebar cages, are not reduced to account for the space in between bars. Non-orthogonal wind loading should also be considered. Lastly, a minimum lateral load design check is recommended. The greater of the applied wind load at the top of the cage or two-percent of the cage self-weight should be taken as the lateral force used (KDOT, 2009).

Given these load requirements, effective load combinations should be developed based on ASCE 37-02.

3.2.2 Selection

The temporary support system chosen should depend on the constraints of the site, cage size and configuration, and expertise of the installing contractor. Many Departments of Transportation use standard specifications that require that temporary guying or bracing be provided, as necessary, to withstand all imposed loads during erection, construction and removal of any falsework (CalTrans, 2010). As stated above, we recommend that all column cages with a height/diameter ratio greater than or equal to 8 be supported. All engineered support systems, regardless of the type used should be sealed and stamped by a Professional Engineer. Support systems may be external, internal, or if the cage is sufficiently rigid, they may be omitted.

External supports include struts in the form of pipes or timber (recommended only for very short cages), or telescoping poles such the pole braces shown in Figure 3-1 (left). Struts in this case should resist both tension and compression and are a good choice for rebar cages less than 20 feet tall. A minimum of two strut braces should be used, placed at 90-degree angles to one another. They should be rigidly attached (i.e., lagged or bolted) to the cage and to anchor blocks on the ground to resist lateral movement as shown in Figure 3-1 (right).

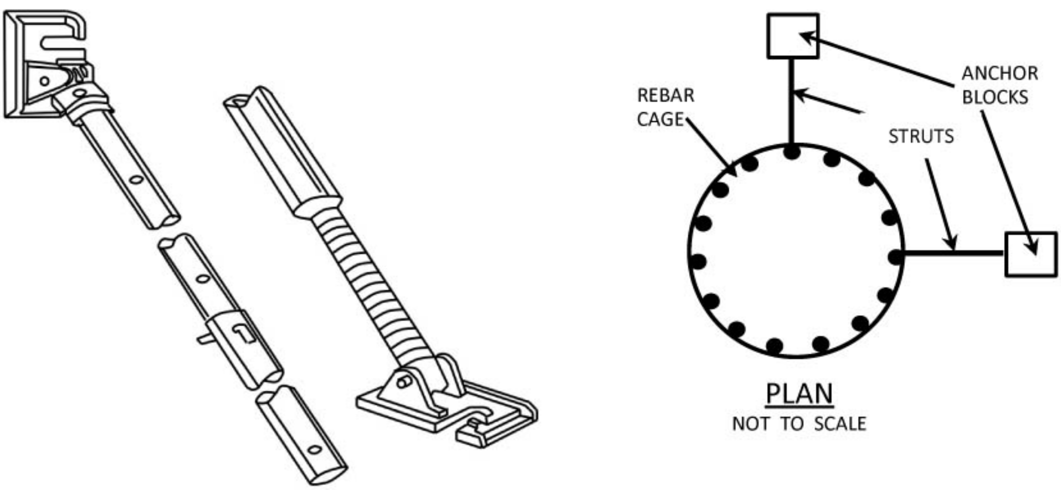

Figure 3-1: (left) Adjustable pole brace. (right)Typical external bracing of rebar column cage using struts and anchor blocks.

Guy wires are another external support system. Inclined wires act in tension between the rebar cage and anchor blocks on the ground to resist opposing lateral loads. Guys are placed symmetrically around the cage to resist lateral forces and are the recommended option for cages taller than 20 feet. The use of four guy wires placed 90-degrees apart is common. Before selecting a guy wire system, verify that site conditions are compatible (wire angles will not be too steep, anchor blocks, anchor points are accessible and adequate). Guy wire inclination to the horizontal is ideally 45-degrees but should be no more than 60-degrees. Guy wire angles in excess of 60-degrees create excess downward force for which the longitudinal bars in the column cage may not be designed to resist in the temporary condition. Multiple-level guy systems should be used for columns taller than 40 feet or when guy wire angles are too steep.

Horizontal supports (either cables or solid members) that hold the cage by “clotheslining” is another external system. This technique allows the cage to hang from the horizontal supports as if being attached to a clothesline. This is applicable only for relatively light cages and should not be the sole bracing used.

Internal support systems that are capable of supporting the rebar cage entirely from within exist as well. These systems may be the only option for marine construction or where no external system can be anchored to the ground. An internal guying system consists of a rigid pipe or structural frame that supports the self-weight of the cage and resists lateral loads. Figure 3-2 shows an example internal guying system for a bridge pier.

Finally, the Engineer may select no support system if the cage based on its reinforcement design is sufficiently rigid and if the H/D ratio is low (e.g., less than 2). Rigidity can be enhanced in the cage through the inclusion of fabricator-installed internal bracing or field techniques that add strapping or spot welds. Such measures are subject to review and approval by the permanent design engineer as they may affect the engineering performance of the finished column.

It is common for multiple support system configurations to be selected/designed for a given column and only the best alternative be implemented. It is also common for hybrid systems that use a combination of external and internal systems. Finally, the type and configuration of the support system may change during construction as concrete is cast and form work erected along the length of the cage.

3.2.3 Structural Analysis

Temporarily supported rebar cages subject to lateral loads are statically indeterminate structures. Determination of the resistance forces to lateral loads can be achieved for braced or guy systems using established structural analysis procedures. The standing rebar cage can be idealized as a beam-column system, but the lack or rigidity in the cage complicates the analysis. For best results, analysis using a finite element method software package is recommended. A 2D (assuming symmetrically placed braces/guys) or 3D analysis can be used to solve for the needed resistance forces in the selected internal or external support system. If the cage is assumed to be rigid, frame analysis may also be used.

The goal of the structural analysis is to determine the reaction forces at the temporary supports and at the connections. Understanding of the base condition of the column is important in selection and design of the support system. Lap-spliced base connections (footing dowels tied to longitudinal bars) are idealized as pinned connections. Mechanically spliced base connections (with an approved mechanical rebar coupler) may be idealized as fixed. Pinned connections should be assumed if unspecified or unknown.

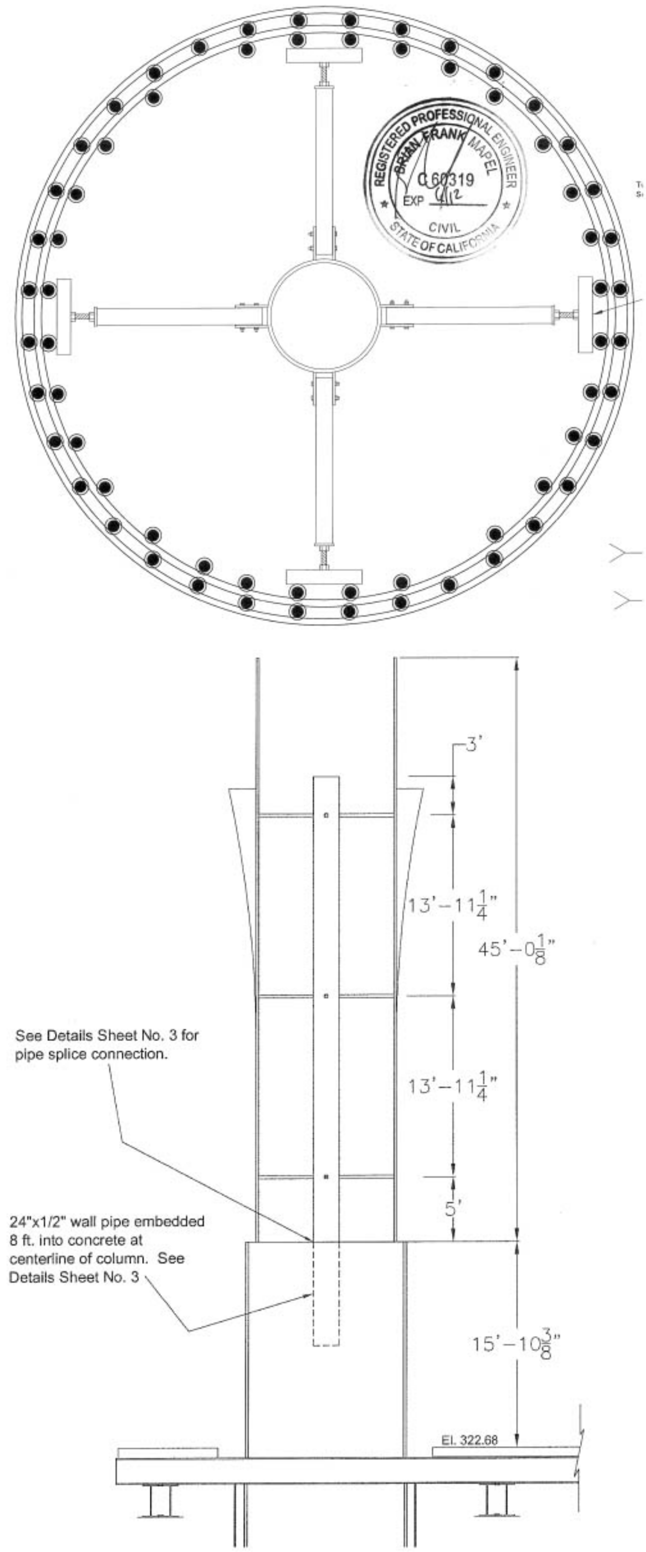

Figure 3-2: Internal Guying System for Bridge Pier Column Cage (Image courtesy of BMA Construction Engineers, Inc. Reproduced with permission.)

It is common practice to perform the structural analysis based only on the gross geometry of the cage and constituent number and size of bars. Internal bracing added by a fabricator or rebar sub contractor is usually not accounted for and may improve the rigidity of the column. Consequently, a conservative estimate of resistance forces needed in the support system may result.

3.2.4 Design

The design of the temporary support system involves sizing of the bracing/guying components and determining the configuration of anchor blocks. Only design considerations for bracing/guying systems are presented here. Internal guying using pipes or internal frames is relatively rare and uses more specific structural design steps.

Bracing or guying systems are designed to resist combined axial and bending action of the rebar cage subject to lateral loads. Appropriate design guidance should be sought from the most recent AISC Steel Construction Manual or other appropriate reference for steel beam-columns. Rebar for column cages are slender with slenderness ratio $KL/r > 200$. The effective length for design is the longitudinal distance between support points or the length of the cage if only a single tier of bracing is used. All of the longitudinal bars can be used to resist the bending moment, but only 25% of the vertical bars should be used for transfer of axial loads from a brace or guy cable (assuming four braces or guys).

Design of Bracing Support Systems
As mentioned earlier, bracing (tension and compression) support systems are appropriate for columns less than 20 feet tall with H/D > 8. A minimum of two strut braces placed 90-degrees apart is recommended. Struts must be mechanically attached to rebar cage and anchor blocks, and locked from expansion of contraction if telescoping poles are used. They should be lagged or bolted to the rebar cage at two-thirds the height or higher. At the height of the brace, a horizontal "wagon wheel" element is recommended for transferring lateral loads through the column section.

Braces should be mechanically attached to the longitudinal bars, or if used, to the larger pick-up bars. Fixed strut braces should be installed at an angle to the horizontal not greater than 45-degrees. Appropriate factors of safety should be used in designing the brace system. A compressive/tensile force factor of safety of 1.5 is recommended.

Design of Guy Wire Support Systems
Numerous design considerations are required for guy wire systems. Based on the structural analysis and factors of safety, appropriate number and size of guy wires should be specified.

Note that not more than 25% of total longitudinal bars should be used to transfer axial loads from one guy cable. The pre-tension and/or cable drape should be specified as well which may require catenary analysis depending on the gauge of guy cable specified.

Guy wires should be placed symmetrically (i.e., opposite one another, in even numbers). Four cables separated 90-degrees from one another is a common configuration. Asymmetrical configurations are possible, but may result in twisting of the cage due to torsional stress when cables are moved for the placement of formwork.

When rebar cages exceed 30 feet tall, multiple levels of guy wires are recommended. Spacing for multiple levels of guy wires is recommended at 20 feet with no more than 20 feet of unsupported length. Guy wires should be placed at the top of the cage if possible, but no lower than 2/3 of the cage height measured from the bottom. The multiple levels should all be in the same vertical plane for each guy wire group and can be attached to the same or multiple anchor blocks. Multiple levels of guy wires provide greater lateral support, but also provide redundancy in the event that a higher or lower guy cable is removed or damaged.

As already stated, guy wires, when tensioned, introduce downward compressive force on the cage, guy wire angles need to be controlled. Guy wires are ideally 45 degrees inclined to the horizontal, but not more than 60 degrees. Multiple levels of guy wires promote higher, more desirable wire angles.

Cable pre-tension requirements should also be satisfied and this is determined by an allowable drape. The weight, length of cable, and pretension force are used to determine the drape of the cable. Pre-tensioning will stretch out slack in the guy wires. The amount of pre-tensioning depends on the type of guy wires and the effective height of the guy wire location compared to the rebar cage. Applying a large pre-tension load will reduce the ability of the guy wire to absorb additional load before it reaches the breaking strength (Gantes, Khoury, Connor, & Pouangare, 1993). A pre-tension load of ten to fifteen percent of the ultimate breaking strength of guy wires is recommended. The guy wire should not be designed up to its breaking strength and an appropriate factor of safety should be included to obtain an allowable strength value.

For long cables, or for cables requiring larger than normal pre-tension, design checks should be performed for thermal effects on guy wire stress. Periodic wind or other forces can also cause “galloping” guy cables, a situation that should be avoided.

Guy wires should be a minimum of 3/8” IWRC braided steel wire or EHC guy wire cable. A factor of safety of 3.0 recommended.

Design of Anchor Blocks

The design of anchor blocks is needed for both guy wire systems and braces. Based on the structural analysis, the size, number, and layout are determined. Anchor blocks can be standard construction elements such as jersey barriers or k-rails, or they can be reinforced concrete blocks with embedded steel anchor points for attachment to poles or guy cables. When possible, anchor blocks should be placed on level grade, although not all blocks for all cables need to be at the same grade. Surface water diversion plans for anchor blocks should be created to prevent erosion and undermining.

Anchor blocks should be designed to resist sliding and overturning. A minimum overturning factor of safety of 1.5 is suggested.

Design of Internal Bracing
The placement of internal braces is dependent upon the height of the cage, the diameter of the rebar cage and the experience of the fabricator. The use of internal braces varies in detail and location from one fabricator to another.

Two types of internal braces are commonly used in construction, X-braces and square braces. X-braces are normally made of 4 bars bent in a Z shape and welded to two inner rings at the ends of the bars. The braces are tied to the longitudinal bars and spaced at specified intervals along the length of the rebar cage. The X-braces have a single point in common in the center of the brace where they are welded to each other. Unlike the X-braces, square braces are normally made of 8 bars and they have three points in common with adjacent bars, two of which are close to the ends and on in the center of the brace where they are welded to each other (Builes-Mejia, Itani, & Sedarat, 2010).

The design of internal braces involves standard structural frame analysis techniques. Proper understanding of load path and reactions acting on the frame supports are needed if stability is relied on internal braces. Temporary support system designs should include proper placement of internal bracing at support and lift points of the rebar cage. Most rebar cages with a height to diameter ratio of greater than 8 and reinforcement ratios of 1 to 2 percent are susceptible to instability and collapse. Tables 3-2 and 3-3 provide lateral stiffness estimates for cages with internal bracings and with longitudinal reinforcement ratios of 1% and 2% respectively.

3.2.5 Installation

Beyond the design of the temporary support system, it is also incumbent on the construction engineer to specify how to install it. This includes the staging, movement and installation sequence.

For rebar cages supported by guy wires, the following general procedure is presented (adopted from BMA Construction Engineers, Inc.):

1. Set the rebar cage with crane
2. Attach guy cables to anchor blocks and rebar cage
    a. Guy cables should be attached to both longitudinal bars and hoops.

Table 3-2: Estimated lateral stiffness (lb/in) of rebar cages with internal braces (1% reinforcement ratio)

<table>
<tr><th rowspan="4">Cage height (ft)</th><th rowspan="4">Design wind pressure (psf)</th><th rowspan="4">No. of internal bracings along cage height</th><th colspan="8">Cage height to diameter ratio</th></tr>
<tr><th colspan="4">8</th><th colspan="4">10</th></tr>
<tr><th colspan="4">Size of internal braces</th><th colspan="4">Size of internal braces</th></tr>
<tr><th>#8</th><th>#9</th><th>#10</th><th>#11</th><th>#8</th><th>#9</th><th>#10</th><th>#11</th></tr>
<tr><td>20</td><td>20</td><td>2</td><td rowspan="9">99</td><td rowspan="9">101</td><td rowspan="9">104</td><td rowspan="9">106</td><td rowspan="9">67</td><td rowspan="9">68</td><td rowspan="9">69</td><td rowspan="9">71</td></tr>
<tr><td>30</td><td>25</td><td>2</td></tr>
<tr><td>40</td><td>25</td><td>2</td></tr>
<tr><td>50</td><td>30</td><td>3</td></tr>
<tr><td>60</td><td>30</td><td>3</td></tr>
<tr><td>70</td><td>30</td><td>4</td></tr>
<tr><td>80</td><td>30</td><td>4</td></tr>
<tr><td>90</td><td>30</td><td>4</td></tr>
<tr><td>100</td><td>35</td><td>4</td></tr>
</table>

Table 3-3: Estimated lateral stiffness (lb/in) of rebar cages with internal braces (2% reinforcement ratio)

<table>
<tr><th rowspan="4">Cage height (ft)</th><th rowspan="4">Design wind pressure (psf)</th><th rowspan="4">No. of internal bracings along cage height</th><th colspan="8">Cage height to diameter ratio</th></tr>
<tr><th colspan="4">8</th><th colspan="4">10</th></tr>
<tr><th colspan="4">Size of internal braces</th><th colspan="4">Size of internal braces</th></tr>
<tr><th>#8</th><th>#9</th><th>#10</th><th>#11</th><th>#8</th><th>#9</th><th>#10</th><th>#11</th></tr>
<tr><td>20</td><td>20</td><td>2</td><td rowspan="9">128</td><td rowspan="9">134</td><td rowspan="9">143</td><td rowspan="9">152</td><td rowspan="9">90</td><td rowspan="9">93</td><td rowspan="9">97</td><td rowspan="9">102</td></tr>
<tr><td>30</td><td>25</td><td>2</td></tr>
<tr><td>40</td><td>25</td><td>2</td></tr>
<tr><td>50</td><td>30</td><td>3</td></tr>
<tr><td>60</td><td>30</td><td>3</td></tr>
<tr><td>70</td><td>30</td><td>4</td></tr>
<tr><td>80</td><td>30</td><td>4</td></tr>
<tr><td>90</td><td>30</td><td>4</td></tr>
<tr><td>100</td><td>35</td><td>4</td></tr>
</table>

3. Remove slack from the cables using 500-1000 lb of tension (recommend 10% of the published ultimate strength of the cage)
    a. Verify the tension using a cable tension meter
4. Slack the crane and rigging (but not the guy wires) and verify cage is stable by shaking/bumping/pushing
5. If cage shows no indications of instability, remove the crane. If unstable, leave the crane attached until more bracing/reinforcement can be installed as per engineer.
6. Install reflective tape, ribbon, or flags on guy wire system to improve visibility for crane operators and other crews.

The Engineer should further state inspection requirements for checking the support system and verifying its integrity after installation and for the entire duration of the temporary condition. It is assumed that the entire temporary support system design and installation, inspection, and modification procedure will be specified prior to any rigging or lifting operations and prior to any work on or around the cage can begin.

3.3 Rigging and Lifting

Detailed rigging and lifting requirements are not provided in this manual, but it is obvious that a proper lifting plan should be developed for all rebar cage-lifting operations. It is important to properly support rebar cages during lifting to avoid excessive bending of the rebar cage and distorting it permanently. All lifts must be designed such that the crane will not exceed its configured chart capacity at any point during the lift operation. Once positioned in an upright position, the top of the cage is to be within a specified tolerance of elevations shown in the drawing plans. Lifting plan should also comprise the implementation of a risk assessment procedure, the selection of safe and proper equipment as well as the assignment of competent personnel (Gransberg, Popescu, & Ryan, 2006).

Typical cage lifting processes include preparing the cage so it can be rigged and lifted, rigging the cage (gripping), hoisting the cage for placement, walking the cage for placement and placing the load where a boom tip is swung to a vertical point above the placement point to lower the rebar cage. Regardless of the size of cage being lifted, an analysis should be performed by someone with relevant experience preferably an engineer.

Under no circumstances should the crane be released until the temporary support system is installed and verified stable according to the installation procedure above.

3.4 Change to the Support System

It is a common practice to use multiple levels of guy wires, which are typically greater than 40 feet in height. However, multiple levels of guy wires may be in conflict with column forms and a few wires may have to be temporarily removed to accommodate the forms. Most accidents are attributable to this stage of construction (Builes-Mejia, Itani, & Sedarat, 2010). If such a construction sequence is to be implemented, the stability of rebar cages during the partial removal of some of the guy wires should be considered and the remaining guy wires should be able to withstand the temporary loads for which the cage was designed.

The stability of the rebar cage should also be checked before all temporary support system are released from cranes or lifting device. This will ensure that the temporary systems are secured and the rebar cage will not be inadvertently displaced after release. It is recommended that cage deflection limits be set to ensure stability of the cages before releasing cranes or lifting devices.

Formwork Procedure

1. Install the first level of formwork up to the first level of guy wire
2. With Crane attached to the cage and rigging taught, move the guy wires, one-at-a-time from the rebar cage to the form
3. Re-tension guy wires
4. Install formwork above guy wires

Chapter 4
Best Practices for Rebar Column Cage Construction

The purpose of this Chapter is to outline our recommendations and guidelines applicable to field personnel based on the process and engineering background presented in the last two Chapters. The style is terse and direct based on the assumption that the reader is now familiar with information or is using this Chapter as a reference.

4.1 Checklists

The following sections present high-level check lists that should be useful for verifying each stage of the rebar cage design and construction process.

4.1.1 Permanent Design Checklist

- Have design alternatives been considered that allow for smaller column cages or allowances for segmental construction?
- Was additional longitudinal reinforcement or stronger ties considered to promote greater stiffness for the cage's temporary condition?
- Has the fabricator or rebar sub-contractor detailed internal braces and will they provide sufficient stiffness?
- Was a constructability review done in consultation with the general contractor to identify potential conflicts with staging, lifting, or supporting of the cage on site?

4.1.2 Fabrication Checklist

These checks are adopted from Builes-Mejia et al. (2010).

For bridge column cages with diameters of 4 ft and larger:

- Tie wire connections shall use not smaller than 15 gauge tie wire made of soft annealed black steel with a minimum ultimate strength of 40 ksi.
- At least four vertical bars forming a square shall be tied at every intersection with at least a double tie wire connection. The strength of these connections shall be adequate for cage pick-up.
- At a maximum of 8 ft increments, template hoops shall be tied at every intersection with at least a wrap and saddle tie wire connection.
- At least 20% of the remaining reinforcement intersections shall be tied with single tie wire connections. The connections shall be staggered from adjacent connections.

The fabricator has the biggest role to play in increasing the lateral stiffness of the cage by following the above recommendations. The goal is to prevent catastrophic bucking of the cage, and with sufficient internal bracing, proper ties, and sufficient pick-up and longitudinal bars, if a collapse occurs it will be gradual and will minimize risk to workers.

4.1.3 Pre-lift and Lift Checklist

The construction engineer working for the general contractor and the superintendent and foreman of the erection crew will perform the pre-lift and lift-checklist. The following checklist is recommended two weeks prior to a cage lift (adopted from Harris Salinas Rebar, Inc.):

1. Review access to the job site and column rigging area. Verify the bracing pattern for pipes (tremies) for pouring.
2. Discuss hoisting information (weights, heights and other dimensions) including allowable lengths for charging, if required.
3. Discuss crane (capacity, reach, and radius) with lifting crew, foreman, and superintendent.
4. Review and discuss hazards, (underground, overhead electrical lines, reach concerns.)
5. Have a copy of and review pre-planning column plan.
6. Have there been any changes to the drawings on site since the initial detailing plan was completed?
7. What is being used to do the lifting? Crane? Forklift?
8. What size of crane or forklift will be required?
9. What access is available for crane or forklift? Is it adequate?
10. Check weights of lifts; is it the same as your pre-plan procedure?
11. What are your factors of safety to crane, rigging?
12. What is the dowel pattern? Are the dowels the correct height? Are they in the correct location?
13. What rigging are you going to use? What rigging do you have?
14. Check size of rigging. Do you require a strong back or spreader?
15. What rigging blocks and/or special rigging are required? (Snatch blocks, shackles)
16. Do you need a rigging plan or is it a standard or typical lift for this project?
17. Have you inspected the rigging?
18. If guying or bracing is required, do you have a written plan? Who is going to supply?
19. Who will be on the crew doing this work, what is their experience, have they done this type of work before?
20. Ask for different opinions on pick points.
21. Do you have all the information needed or are you missing anything?
22. Review your plan with another foreman or supervisor.
23. Are there any flares to be built on the column, will they be done in the yard or field?

24. Obtain guying procedure from General Contractor or Construction Engineer, whichever applies.
25. Is the guying procedure appropriate for this column? Who is going to supply and install?
26. Is it engineered and stamped?
27. Carefully review guying procedure.
28. Is there proper truck access?
29. Is there room to off-load column from truck to ground?
30. Are you lifting off the trailer?
31. Do you need a crane with a main line and a whip line or 2 cranes?
32. Is boom, main line, whip line & column going to line up when tripping column?
33. Have someone your level or higher to talk over the hoisting plan with.
34. Compare each others plans.
35. Get together to review each others plans.
36. Look for the following: things that are the same, things that are different, discuss the differences. Make drawings with the necessary changes. Agree on the best hoisting plan.
37. Start drawing the hoisting plan you agree on.
38. On the drawing, provide the following information: length of column, diameter of column, weight, unit weight of column per foot, layout of the pick points.
39. Start planning rigging; discuss the safety factors you want to use.
40. Start with the strong back or spreader beam, shackles, skoocums' (snatch blocks, shackles.)
41. Running line, wire rope length sizes? Double check jewell out. (i.e., rigging fits as it runs through skoocums or snatch block as column is tripped. Check angle for right size)
42. Chokers nylons or wire rope (length and sizes.)
43. Back up bars. What back up bars do you need?
44. Check bracing within the column, is it sufficient?
45. Is a Rat slab going to be needed for soil conditions?
46. Does contractor need crane packs or metal plate for ground stabilization?
47. Make sure picking bars are tied solid.
48. Top few hoops above pick point should be tied solid.
49. Will spreader bar fit onto hook of crane?
50. Will running line rigging fit on hook?
51. On single barrel columns added brace bars wrapped around the outside of the column approximately 15 feet up to keep column from cork screwing down (depending on size of verticals.)

The following checklist is recommended before the column erection work:

1. Have you completed a Job Hazard Analysis?
2. Establish who will direct the crane operator; determine if hand signals or radio will be used to communicate.

3. Have all guy lines & braces (if required) been installed on column prior to erection? Ensure guy lines & braces are easily accessible without the need to climb the column. Check cable clamps.
4. Notify contractor and other subs that all guying & bracing only to be removed by Harris personnel. Have guying and or bracing check off sheet on site.
5. Foreman to inspect bracing and guy lines to ensue materials are good.
6. Is fall protection required? If so, is there a procedure in place? Are there other methods available (i.e. man baskets, genie lifts, scaffolding, etc?)
7. Are there other trades working in the vicinity of the erection & if so, ensure that adequate warning is given of the impending hazard. (When picking column all personnel need to stay at least the length of the column away, except for the signal person & persons on the tag lines.) Foreman to check each cable clamp.
8. Rig column as per Harris safe work procedure for your area (state/province) to ensure all hoisting rigging can be removed without the need to climb the column. (Alternately, climb only after a foreman confirms that all guying & bracing is complete and column is safe to disconnect rigging.)
9. Establish if tag lines need to be used and if so, that the person holding them has been properly trained. (Where to go in case of emergency.)
10. If column is going to be secured to formwork, ensure that the formwork has been designed to support the additional weight of the cage. In addition, review formwork details to ensure that there are means of tying off the column.
11. Inspect the cage to be flown to ensure no loose verts or untied pieces; Ensure column is adequately tied to carry weight of other ties or verts.
12. Ensure no one stands below column as its being flown throughout the job site.
13. Make good all dowels in preparation of accepting column.
14. Have a tail-gate meeting with the crew responsible for rigging, including crane operator and contractor's rigger (if applicable) to review all actions and hazards just prior to erection operation commences, include a written sign off sheet.
15. Does everyone on the erection crew agree with the plan? If yes – proceed, If NO – resolve the differences before beginning work.
16. Install all chairs or spacers on the column prior to erection to prevent the need to climb the column or formwork after the column is erected. (Alternately, climb only after a foreman confirms that all guying & bracing is complete and column is safe to disconnect rigging.)
17. All guying & bracing to be adequately identified with reflective tape or flags at appropriate heights to make highly visible to crane operators, mobile equipment operators and personnel.
18. Tie all the right angles on the bottom of footing solid.

Finally, the on the day of the erection work, the following summary checklist is recommended:

- Know the set up of the cranes
- Know the effect the hoist has on the crane
- Know where to look when hoisting, watch for the unknown – all eyes should be watching.
- Watch for side loading
- Watch for non-plumb vertical lines.
- Watch for line and sheave problems.
- Watch and understand boom deflections
- Watch for column trip problems.
- Special rigging training by a wire rope manufacturer, 3 classes on jobsite training required.
- On heavy picks a person should be watching the back side of the crane to make sure its not raising up.
- If we are using the contractor's spreader bar, make sure it is certified before using.

4.1.4 Temporary Condition Checklist

The cage should be released from its guy wires: 1) only when necessary for the placement/movement of formwork, 2) in symmetrical pairs only to keep the cage in static equilibrium, 3) for a minimum amount of time only and with extra care for knocking or bumping an unsupported cage.

Additional recommendations are adopted from Harris-Salinas Rebar, Inc.:

1. Tie off bottom of cage to dowel rebar as determined during pre-planning. Alternately, are bottom of column right angles secured to bottom mat or support frame as determined during pre-planning?
2. Ensure column is not released from crane until all bracing and /or guy lines (if applicable) are installed. Foreman to inspect columns and/or bracing or guying and complete a check list for all columns set in a day and record on sign off sheet. Turn in copy of check off to general contractor if required.
3. Instruct General Contractor and other trades not to touch bracing and/or guy lines.
4. Foreman to check cable clamps or braces.

4.1.5 Permanent Condition Checklist

The permanent condition is achieved when all concrete is poured and sufficiently cured and all formwork is removed from the column. The following recommendations are made about the permanent condition:

- Have the guys or temporary supports been moved or removed in a manner inconsistent with the temporary support plan? If so, document.
- Has all rigging and support hardware been removed and inspected for damage?
- Have the support systems of adjacent or nearby cages been affected by the removal of this columns supports?

4.2 Summary

These checklists are intended to provide informed guidance at each stage of the proposed standard rebar design and construction process.

Chapter 5
Summary, Conclusions, and Recommendations for Future Work

5.1 Summary

The placement of rebar cages for large, cast in place concrete columns has become a common operation in heavy civil construction. Tall bridge piers or highway fly-overs are some examples that require these large concrete columns. This manual has assembled best practices related to construction engineering and to construction practice for handling cages. The best practices are intended as guide for those organizations who lack standard procedures for handling rebar cages to adopt their own.

The major recommendations are summarized in the Preface of this manual, but the following are the most crucial ones that, if nothing else, should be adopted:

- Any cage with a H/D ratio greater than 8 needs to be supported, as does any cage that requires an iron worker to climb on it.
- A registered Professional Engineer should select, design, and inspect a temporary support system used for rebar column cages. Any changes or deviations from the support plan should be reviewed and approved by the construction engineer.
- Internal bracing supplied by the fabricator or rebar contractor should be included. Square-type braces can be used to allow for placement of tremie tubes or conduits and negative impacts to seismic response can be accounted for in the design process.
- During lifting/tripping, cages should not be released from a crane until the support system is completely in place and verified stable.
- For cages over 20' – the suggested method of upending (tripping) would be to rig the cage in multiple locations (top – head, bottom and potentially the mid-point(s) depending on length). This can be accomplished many ways, not limited to: using a single crane with a rolling block, using a single crane with multiple load lines or with two cranes. Whichever method is utilized, it must be analyzed to not overload the crane or load line with the least capacity.
- Upending (tripping) of cages over 20' should be reviewed and analyzed by an individual with experience in lifting large rebar cages.

5.2 Conclusions

The following conclusions can be made:

- Some of the most experienced contractors with the best safety records have no formal policies for handing temporary works at all. Their engineering and construction practice is based on experience, "the way they have always done it", and it works. One main goal of this manual is to aid organizations or individuals, e.g., junior construction engineers, who may lack this experience.
- The largest cages are not usually the cause of accidents because they tend to receive a lot of engineering scrutiny and oversight. Cages as small as 20ft tall have collapsed and have led to fatalities. Any cage requiring an iron worker to climb on it must be supported.
- Change to the engineered support system (i.e., the removal or movement of guy wires) is the number one cause of accidents involving guy wires. Construction engineers must specify not just the system itself, but its removal sequence.
- A responsibility matrix is a useful tool for defining the roles and responsibilities necessary for the safe handing of rebar cages. However, the matrix is not static. It must be binding and updated throughout the process. Contractors have to use it as an instrument that is capable of stopping work completely when it is dangerous or unknown conditions warrant it.

5.3 Recommendations for Future Work

The problem of safety with the handing of rebar cages is a broad one and encompasses the interest of a wide array of stakeholders including large owners, general contractors, fabricators, rebar sub-contractors, and iron workers. Unfortunately, this Manual could not address all issues for all constituencies, but is focused primarily on the temporary support of rebar column cages standing above grade.

We recommend that additional research be performed that broadens the scope of this Manual, perhaps with the co-sponsorship of other professional organizations such as CRSI or DFI (Deep Foundations Institute). Collaboration with a larger group or stakeholders has the potential to broaden the impact of this research and to promote wider adoption of the best practices presented in this Manual.

More research-specific recommendations are related to an investigation of wind pressure reductions and adequacy of drilled shaft reinforcement. For the former, amongst construction engineers working in this area, it is believed that temporary support systems such as guy-wire/anchor systems are generally over-designed because of conservative estimates of lateral wind loads incident on vertical cages. The spaces between rebar permit wind-pass through such that wind reduction factors might be applied in determining lateral loads. It is estimated that such reduction factors could reduce the anchor block size requirements and guy-wire size/tension by up to 25%. Further research is needed, perhaps experimental programs involving wind-tunnel type studies, to test these claims and affect construction engineering practice in this area.

In considering rebar cages for deep foundations, it is similarly believed amongst practitioners that these cages are possibly over-designed. Rebar hoops, which normally provide confinement for concrete to resist blow-out during bending action, should be less important for cages used for CIDH piles as the piles are confined by the shafts themselves. Smaller, lighter cages to be placed in deep shafts would be easier to handle and arguably safer during the tripping and lifting process. Further research, perhaps in partnership with DFI and geotechnical experts is warranted.

The most challenging aspect in designing temporary support systems for rebar cages is the lack of rigidity of the cage itself. Large cages are analogous to "wet pasta noodles" and present problems during tripping/lifting and the temporary condition. While shop or field tying with tie wire has been the industry standard practice for decades, research is alternative fabrication techniques that can greatly improve cage stability without impacting seismic, i.e. plastic-hinge, behavior are needed. Limited spot-welding and semi-automated fabrication may address this issue in the future.

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Appendix A
Glossary

Bent	A cap or horizontal member for multiple bridge piers on top of which a bridge super structure rests.
Block	An anchor point for attaching guy wire cables
Clip	A lift point attached to a rebar cage for hosting.
Dead Guy	A guy, because of its placement, that does not carry any load.
Deadman (men)	A bracing member used to support tall structures such as walls or columns. Capable of resisting compression or tension.
Equalizer beam	Distributes a load equally between two sling legs or two hoist lines when making a lift in tandem.
Guy	A tension member, usually a braided or solid metal wire, used to support tall structures. Typically applied symmetrically to resist wind or other lateral loads. May be temporary or permanent.
Hoop	Circular-formed rebars that make up the concentric rings of rebar cages.
Longitudinal bar	Reinforcing bars placed along the length of the rebar cage and tied to the hoops.
Pick-up bar	Longitudinal bars inside a rebar cage designed to provide stiffness for lifting from the horizontal to the vertical position.
Shackle (Clevise)	A piece rigging hardware for affixing a lifting line. Typical types include a screw pin, round pin, or plate shackle.
Spiral	Reinforcing steel for concrete confinement used in stead of or in addition to hoops.
Spreader bar (beam)	A member attached to a crane lift line for converting a single lift point into two for long objects. Helps prevent, tipping, sliding, and bending during lifts.

Template hoop	Sparsely spaced rebar rings used to rough-in the diameter of a rebar cage during fabrication.
Tie	A wire attachment between two or more intersecting rebars.
Tremie pipe	Pipes used to transfer (pump) concrete to the bottom of a pile or peir.
X-Brace	Arrangement of Z-braces (see above) to form an "X" in the cross section of a rebar cage.
Z-brace	An internal brace inside a rebar cage consisting of a leading leg tied to the longitudinal bars, a diagonal brace across the diameter of the cage, and another leg again, tied to the longitudinal bars on the opposite side.

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