Structural design – the engineer's role

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The Institution of Structural Engineers

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Foreword

This report has arisen from the Institution's decision to update the following reports:
- *Aims of structural design 2nd edition (1987)*
- *Communication of structural design (1975)*
- *Stability of buildings (1988)*
- *The achievement of structural adequacy (1990)*.

An Institution task group entitled 'The Philosophy of Structural Design' was convened to do this work. After some preliminary discussion it was proposed that these four reports should be replaced by two. This report is the first of those and is intended to bring up to date the contents of *Aims of structural design* and *Communication of structural design*.

The original reports were very much of their time and set out to give advice on what the characteristics of a good structural design might be and also the process for achieving that. What we have tried to do is to describe the roles that structural engineers can play within a construction project and what the nature of the advice they give, and the decisions they take, might be.

In essence of course, the nature of a good structural design hasn't changed. The structure has to:
- perform safely
- be safe to build
- be compatible with the whole of the project needs however prioritised
- be cost effective within the context of all the constraints.

Whilst *Communication of structural design* said that it could be regarded as 'the Structural Engineer's Plan of Work' this new report does not define one uni-disciplinary process but more sets out the principles of a total process in which the structural engineer can make significant contributions.

In the years between the publication of the original reports and now there have been a number of significant changes:
- the codes of practice for structures have been better defined and become more extensive
- information technology has become commonplace
- the concept of sustainability has come to inform all of our work.

The task group feel that these have been reflected in this report.

My thanks are due to all the members of the group who contributed both in the discussions held at the Institution and in the drafting of the various chapters. However particular thanks are due to John Mason who took on the onerous tasks of editing the drafts into a consistent whole and addressing the comments raised in the formal review process.

We commend the report to you.

Martin Manning
Chairman
Philosophy of Structural Design Task Group

Contents

1 Introduction

This guide is about structural engineering design and what structural engineers do.

It is intended to be used not only by those who would like to seek the advice of a structural engineer but also by those who procure the services of, collaborate with, or who are in training to be structural engineers.

The guide gives an introduction to the totality of what the profession is and does, although it focuses on what structural engineers do during design and construction.

A more detailed description of the technical aspects of their work will be found in the companion volume – *Structural Design – Achieving Excellence*.[1]

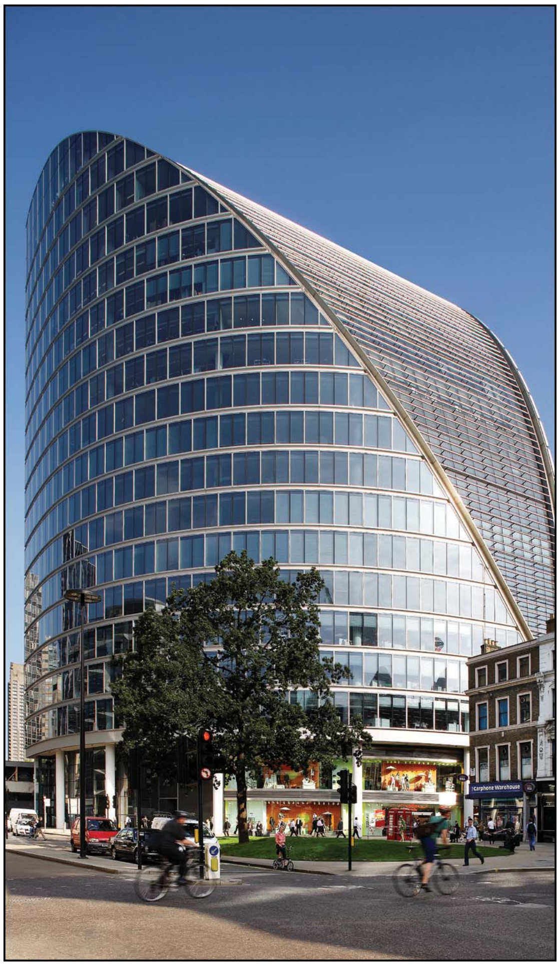
Our concern here is with structures that are normally fixed to the ground such as buildings, bridges, towers or supports for industrial plant.

A structure is a framework which other parts of a construction may be fixed to or on which other activities, systems or plant may be supported. So, for buildings, the structure comprises the primary load bearing elements which include floors, beams, columns, load bearing walls and foundations. For bridges, the structure includes decks, beams, piers, abutments, retaining walls and foundations, whilst towers, masts and industrial structures will usually comprise columns, struts, beams, ties and stays as well as foundations. These are the parts which by acting together can render the whole structure safe, stable and robust. Additional structures (sometimes called secondary structures) may be attached to the main framework to give specific support to, for example, a cladding system.

Other elements of the whole construction, such as the cladding or handrails for example, will be attached to the main or secondary structure. Elements such as these undoubtedly have some structural characteristics and will carry load locally. However, their design is not normally carried out by the designer of the main structure.

Chapters 2 and 3 describe the knowledge and abilities of the structural engineer and the strategic advice the structural engineer is able to provide. Chapters 4 to 7 set out the design process for buildings and bridges, and how the structural engineer contributes to this. The engineer's input relating to procurement and tendering is discussed in Chapter 8. Chapter 9 describes the roles the structural engineer may undertake during the construction stage. Finally, Chapter 10 contains a brief review of the other services and activities a structural engineer can undertake.

(a) Holborn Bars, London



(b) Moorhouse, London

Figure 1 Structural engineers work with structures new and old, large and small. Whatever the age of a building the principles implicit within the structure don't change even if the technology of its construction method does

2 The knowledge and abilities of the structural engineer

A structural engineer's initial training includes learning about loads (actions), structural materials, soils, structural behaviour and how to relate those things mathematically. Later it covers how structures need to be detailed and what drawings and documents are needed for construction; later still it includes producing concepts for a design, developing a concept into a scheme which recognises all of the issues which bear upon it, then preparing a final detailed design and having it constructed.

By the time structural engineers are professionally qualified they are likely to understand a broad range of statutory regulations and their impact, as well as how to work within a multi-disciplinary team of designers and builders. The structural engineer's knowledge is unlikely to be limited to just the interests of the structure but extends to all aspects of the project which are affected by the structure. Structural engineers generally understand how these aspects and others may have implications for the structure.

The majority of qualified structural engineers are designated as Chartered Engineers, whilst some are designated as Incorporated Engineers. In many countries, the authorities may also require qualified engineers or firms to be registered in order to carry out professional duties or for building control purposes.

As a consequence of their training the experienced structural engineer will have gained an understanding of not only the physical aspects of structures and the buildings or other constructions of which they form part but also the processes by which teams work, how the client's aims and users' needs may be realised and how design and construction can take place efficiently and safely.

The roles a structural engineer can play in the development, design and construction of a project are many but an engineer rarely works alone. The construction industry consists of an increasingly wide range of other disciplines and the engineer has to be able to communicate and collaborate with them all. The structural engineer has learnt how all the non-structural aspects of a project influence the design of the structure and how and where compromises may be needed to give a successful overall design.

For more unusual projects, research work on some aspects may be needed to help develop safe and appropriate solutions. The structural engineer can advise on when this is likely to be needed and is able to develop research methodologies and oversee the research on behalf of the client.

Figure 2 Structural engineers devised this new take on the idea of a rotating bridge. This is the Gateshead Millennium Bridge across the River Tyne

3 Before designing starts – strategic advice

The structural engineer can offer clients strategic advice in the planning, design, construction and operational stages of their projects.

The education and training that structural engineers receive can include not only the technical aspects of structural engineering but also the logistical, financial and legal management of the work they undertake. As a consequence of their education and professional training, structural engineers can provide rigorous deductive and creative thinking to establish whether or not a conceptual idea will work in practice. Their specialist knowledge and understanding can be used to advise on not only structural form and the appropriateness of proposed constructional materials but advice can also be given on the implications of future alterations, including extra storeys or extensions or provision for additional mechanical and electrical equipment.

The structural engineer can advise on how the constraints of the site may affect the construction process and how the design of the structure may be adjusted to reduce the impact this may have on the project. The value of obtaining rational, practical guidance from a structural engineer at a very early stage of a project can be very high and help avoid spending considerable resources pursuing technically inappropriate solutions. Limiting the involvement of the structural engineer at the early stages when the full extent of the complexity of the project may not always be apparent may prove to be a false economy.

The design life and maintenance requirements of the finished project can be prime considerations for the client. Again the structural engineer can advise on these aspects of the structure, as well as potential demolition methods and re-use and recycling of the fabric. Often a small and relatively inexpensive enhancement in specification can significantly improve the overall performance of the project and extend its life.

Clients' concerns aren't limited to simple functionality but, for example, can now include global climate change and other environmental and sustainability issues. The structural engineer can help the client decide how best to accommodate these effects. Additionally, clients might have requirements related to extreme loadings such as seismic events (not only in seismically active zones but also in connection with, for example, the nuclear industry), terrorist actions and security requirements.

The structural engineer can also advise (or obtain appropriate specialist advice) on special or unusual behaviour of structures, such as vibrations induced by humans, machines, hydraulic flow and wind.

Structural engineers are not only involved in the creation of new structures but also in the appraisal of the structural adequacy of existing structures. This is of increasing importance as the world's existing structural infrastructure ages and deteriorates. Additionally, existing structures (particularly bridges) are being required to carry more onerous loadings, whilst buildings are being refurbished – often for a change of use. Structural engineers advise on these aspects as well as on the maintenance of existing structures.

Structural engineers may also undertake research (within both firms and universities) and, when appropriately experienced, provide opinions and reports as expert witnesses associated with legal proceedings.

Figure 3 This site in the South Wales valleys was a steelworks. It is being cleared ready for regeneration, to include housing, shops, offices, schools, a hospital and a railway station

4 The design process and how it is undertaken

4.1 Stages of a project

The stages of a construction project may be broadly summarised as follows:
– Project formulation – defining what it is for, why it is being proposed, where it is and what it requires.
– Initial brief – the first definition of what the project comprises.
– Assembling the data and developing the brief – understanding the site and the context.
– Scheme design – studies of various options leading to final scheme definition.
– Detailed design – working out all the various components and elements and how they fit and work together, also obtaining consents and approvals.
– Information for construction – working drawings and performance specifications to enable the constructor to build everything.
– Construction – execution of the project on site and provision of record information.

To these may be appended:
– Maintenance and repair.
– Alteration or change of use.
– Eventual demolition.

On smaller projects, some or all of the stages of a project may coalesce into what appears to be a single stage. However, the tasks described for each stage above still need to be undertaken properly.

Procurement of a constructor (the organisation that will carry out or co-ordinate the construction – usually a contractor or builder) may be undertaken at various points throughout this process, so it is not identified as a separate, specific stage. It is discussed further in Chapter 8.

Different countries have different standard descriptions of the stages and of the detail within each. In the UK, the Plan of Work[2] produced by the RIBA (Royal Institution of British Architects) is a common reference document for buildings. However there are a number of sectors and clients – such as the various transport undertakings – who have developed their own sequences of activities. In other countries there are also different definitions of the sequence of the various stages of design, obtaining statutory approvals, procuring constructors and so on. Whereas all these cover the same total set of items they do so in slightly different ways and care should be taken that a sequence appropriate for one sector or location is not inadvertently imposed on another.

To achieve the process successfully, clients need specialist advice, whether from inside or outside their organisations. The structural engineer is an important source of such advice.

4.2 Project formulation and initial brief

To help formulate the project, and establish the initial brief, the client may take advice from individuals from appropriate professions or may form an initial team. Advisers such as lawyers, planning consultants, surveyors (of various types) and property agents will

Figure 4 Design team members need frequent interactions to generate good ideas

work alongside designers. The structural engineer's experience and knowledge can be of great value at this stage and can make significant contributions to strategic assessments of existing structures and site constraints. This could involve contributing to a review of an existing building to review either its condition or how it performs its function. It could involve a review of a site as to its suitability for development. It could involve a review of the building types that could be provided.

4.3 Design – assembling the data through to production of information for construction

Once an initial brief has been developed, the client then assembles a design team, usually evolved from the initial team to maintain continuity of the process and to avoid losing initial knowledge gained.

As well as a structural engineer a design team might be comprised of:
- architects
- landscape architects
- highways and traffic engineers
- services engineers
- geotechnical engineers
- façade engineers
- acoustic consultants
- fire consultants
- sustainability advisers
- archaeologists
- ecologists
- cost consultants/quantity surveyors
- constructors
- construction advisers
- health and safety advisers
- construction programmers
- project managers.

It is important that the client clearly designates who is the lead designer who will lead the taking of the design decisions and who is the manager of the design team who will organise the process. Depending on the type of project, the structural engineer may play one or both of these roles.

The different scopes of services provided by the different parties in a design team may overlap but, equally, may have gaps between them. The way in which they relate to one another should be defined clearly with the agreement of all. Any gaps in the services to be provided could lead to delay at the least and disaster at the worst. Equally, overlaps may create confusion and also lead to omissions and difficulties.

4.4 Construction

When the construction stage is reached, the role of the project team changes again, as the constructor becomes its focus. The team really should continue to involve those who did the design, as they are most able to deal quickly and easily with any queries or problems that may arise.

To deal properly with the process of constructing any substantial works, the constructor may need the services of a structural engineer to deal with temporary support and stability.

The design engineer has defined the permanent works and in doing so will have envisaged a method of construction but the constructor's engineer has to define the particular way in which it will be built, taking responsibility for the stability, strength, position and protection of the works in their temporary state and for any necessary temporary works.

It is essential that the relationship between the project design engineer and constructor's engineers functions well. This is best achieved by a clear definition of their respective roles and tasks early in the process as part of the placing of the construction contract.

These issues are discussed in more detail in Chapters 8 and 9.

4.5 Maintenance, repair, alteration and eventual demolition

The project team is normally disbanded and its members move on to other projects once the construction stage is over. In the UK, copies of the final versions of the construction drawings are normally deposited with the owner as part of the Owner's Manual/Health and Safety File. Records of modern structures are of great importance, as it is often not possible to obtain full details of the construction by visual inspection and measurement alone. However, many structural engineering firms maintain their own archives of project material and may be able to provide further valuable information or advice when maintenance, repairs, alterations or demolition (in part or in whole) are being considered. Equally, structural engineers have the knowledge and experience to be able to investigate and assess existing constructions and advise on these aspects, even when no records appear to be available.

5 Agreeing the brief and collecting the data

5.1 The brief

The first phase of the design process is to start to establish what needs doing and the constraints limiting what can be done. This is an unfolding process as the client's intentions are examined by the design team, who are also assembling data about the site and other factors that may constrain the choice of design options. The structural engineer has the knowledge and experience to identify constraints within their field, to advise on their likely effect and to make suggestions for alterations to the brief to overcome or avoid them. For a high-quality and appropriate solution to be achieved, the brief should not be regarded initially as a fixed entity; all parts of it should be open to appropriate questioning and challenge.

The initial brief should set out what the client thinks he or she wants to do and achieve. The initial brief may range from a simple oral description (this would only be appropriate for a small straightforward project) through to a large document setting out many detailed and specific requirements. The client may have particular requirements affecting the structure, such as how the project might be built or provisions for future flexibility.

The structural engineer needs to (and needs to be allowed to) develop an understanding of why the client's requirements are as they are, and what constraints are imposed on the proposals by the site, its surroundings and the nature of the project. The structural engineer can then respond to and discuss with the client how their requirements may be met and whether all of them are sensible to try and achieve. The client may decide to modify the brief in the light of this advice.

Clients and their structural engineers should also recognise that the requirements of the brief may also change as the design advances, as well as in response to economic circumstances or to developments in technology and practice (e.g. in sectors such as industrial or healthcare).

5.2 Data collection

So that the various constraints may be identified and understood, data needs to be obtained. This may be provided by the client, if they have it, or obtained by the structural engineer.

Table 1 shows examples of data on potential constraints. This list is not exhaustive. There are many aspects that may need to be considered and what is needed should be assessed on a project-by-project basis.

Figure 5 As this former steelworks site is cleared, formerly hidden features become exposed and any contamination in the soil can be identified

Table 1 Potential constraints

Physical	– what is on the site (above ground)	– existing structures – existing plant/infrastructure – people – rights of access – vegetation – its topography – water
	– what is in the site (below ground)	– contamination – gases – geology/geotechnics – sewers, tunnels, pipes, cables, etc. – previous basements, tanks, foundations and excavations – unexploded ordnance – water – archaeology[a]
	– what was previously on the site	– buildings – plant – infrastructure – vegetation
	– what is next to the site	– buildings – topographical features – water – roads, railways, infrastructure – access
	– what is further afield	– sources of flooding – sources of contamination – airports and aircraft – climate change
	– what is proposed in the future	– permitted future plans – safeguarded schemes
Economic		– costs – viability – availability of resources
Societal		– environmental impact assessments – carbon emissions, embodied energy – energy sourcing, use of renewables – sustainable sourcing of materials – re-use rather than reconstruction – recycling of materials, elements – whole life costing – safety and constructability during construction, operation and dismantling – access for inspection and maintenance – facilities for replacement of shorter-life components.

Note

a Graves with human remains are a particular problem, as procedures for reburial can be time consuming, delaying progress on a project.

Some of these constraints may be determined by surveys and measurements. Others need research and study. Study of precedents or similar constructions may prove necessary where it is not possible to access or interfere with an existing building. Study of past methods of construction may also help determine how an existing building has been constructed. There needs to be early discussion with the client as to which party will undertake relevant surveys and research.

Most conditions of engagement for structural engineers put the onus on the client to provide all relevant information. However, the structural engineer needs to advise the client what information is relevant. It can often be more effective for the structural engineer to agree to obtain the information themselves, because they understand better what is needed and may be able to obtain it more easily.

The key to a successful data collection stage is for those involved to be alert to the potential significance of the leads or factors they may encounter. Effective lateral thinking at this stage may save large amounts of abortive effort later in the project. Any of the constraints may have a significant impact on the client's expectations and the brief may then need to be revised. Part of the structural engineer's role can be to help identify such situations and to advise on how the brief may be modified to overcome them. It is important that the data and constraints obtained via the various members of the design team are assembled and their implications reviewed together. This should normally be coordinated by the lead consultant.

Figure 6 Archaeological remains need to be identified and allowed for in the design

5.3 Societal constraints

Structural engineers should generally be aware of the many demands society places on construction projects and processes. Main requirements are expressed in laws and regulations, supported by standards and guidance documents produced by learned bodies such as the Institution of Structural Engineers. Other expectations that society has may be less clearly defined, less tangible and may be open to interpretation.

Certain aspects of structural design may be prescribed by laws or regulations in some circumstances but in other cases may be for the designer and client to agree between themselves. Some topics that are of concern at the time of writing are given in Table 1 and include aspects of sustainability, in one way or another.

5.4 Process

It is not normally possible for a client to define a complete brief at the outset. There needs to be an interactive, iterative process between the client and their design team of the following form:

(1) Client defines an initial brief.
(2) Designers (including the structural engineer) examine it, comment on it and agree an information gathering process.
(3) Information gathered is collated and its significance is assessed.
(4) After discussion with the client, the brief is modified, if appropriate.
(5) Further rounds of examination, information gathering and brief modification take place until an agreed developed brief has been established.

The structural engineer's participation in this iterative process can be of great importance and value. It will help to establish an appropriate scope for the project and to set the design work off on a sound footing. Without the structural engineer's participation, significant changes may need to be made later on in the design process, with consequent additional costs, fees and delay. The appointment of the structural engineer needs to recognise this and to make sure the agreed payment process covers it adequately, as it may not be provided for properly in commonly-used conditions of engagement.

There also needs to be effective communication between the client and the structural engineer to allow development of the brief. This may be impaired or obstructed if the structural engineer is not appointed directly by the client, or if all communications are channelled through another party. In such cases, it is important that intermediaries, such as project managers, architects or contractors, understand and appreciate the benefits to be gained from the structural engineer's understanding and commenting on the initial brief and allow that process to take place effectively. If they do not enable this, they must appreciate that they are increasing the risk of later alterations being needed with their associated additional costs, fees and delays.

5.5 Reporting

Once the collection of data and constraints has been completed, it is appropriate for a report to the client to be prepared, summarising what has been found and what its consequences may be for the project. Such a report would usually form part of a report produced by the design team at the end of the feasibility stage of the project.

6 Preparing the scheme design

6.1 Introduction

With the brief and the relevant data and constraints identified, and an understanding of the aspirations of the client, architect and other members of the design team, the structural engineer is ready to start designing, and to work towards a scheme design.

In practice the structural engineer will reflect on the design as the data become available and may already have a good idea of the likely outcome. Before pushing ahead to prepare the scheme drawings and report the design would benefit from the engineer being given time to consciously step back and think. This can be a key stage in the design process. Options can be thoroughly explored, as this will be the last stage at which any significant decisions which affect the overall configuration should be made.

6.2 Options

The process of selecting an initial list of options involves a mix of sketches and jotted thoughts. A page or two of jottings may record specific characteristics of the project and start to identify their importance:
– What makes this project different from others?
– Which requirements are going to be difficult to satisfy?
– Why?
– Can the difficulties be circumvented?
– What other projects does it have similarities with?
– What worked well before?
– Why?
– What should be avoided?
– Are the standard solutions still relevant?
– Are there any emerging technologies or new ideas which might work well here?
– Do more or different data need to be obtained?
– Should the brief be modified to allow more appropriate, economical or less risky solutions?

From this process, the structural engineer can identify the key issues which will drive the design, together with a list of generic solutions and some thoughts on specific details that might be appropriate. It can be helpful to record the logic chain which supports a particular proposal. What aspect of the project drives a particular decision? If circumstances change, the design logic may be affected.

In parallel with the identification of options, the structural engineer will be thinking about how to assess and rank them. They will be assessed against criteria from the brief. Sometimes changing the brief may be a better answer than finding solutions that fit it as it stands.

At this stage in a project the processes may seem haphazard and unstructured. Pursuing every thought as it arises seems inefficient, but there is no way of ensuring that the same thought will ever arise again.

The structural engineer should take (and be allowed to take) sufficient time because every thought produces insights. The process of collection of fact, conception, appraisal and return may be repeated several times with occasionally a leap; it may be only after much hard and detailed thought and sketching that the most appropriate answer is revealed. The mind needs a different focus from that needed later on in the design and construction process when the procedures are more linear and clear cut.

Usually, options and ideas will be exchanged frequently between the structural engineer and the other design team members and modified or discarded as a result.

Different strategies may be adopted in appraising the options and selecting the final scheme:
– Options may be discarded when other, superior ones are produced.
– A shortlist of options may be assembled.
– A complete review of all conceivable options may be undertaken.

Which of these strategies may be adopted will depend on the nature of the project and of the client. A straightforward project may allow a final option to emerge very easily, whereas for a complex brief, a publicly-answerable client may want to be able to show that every option has been explored.

For each option, the structure will be drawn and elements described either with indicative sizes or with generic quantities. The amount of structural analysis at this stage depends on the experience of the structural engineer and their familiarity with the structural form (or their access to results from something similar). If the design relies on a particular and unusual structural detail then it may be appropriate that a comprehensive analysis of that detail and its context should be performed. Sketches of critical details may also assist the rest of the team.

The list of criteria that may be invoked when comparing options can be long and may include the following:
– estimated cost
– buildability
– speed of construction
– safety of construction
– availability of resources
– co-ordination between design disciplines
– operational efficiency
– appearance
– maintainability
– replaceability
– sustainability.

In the European Union, it is noted that buildability, safety of construction, maintainability and replaceability can require specific consideration because the designer has a legal duty (such as in the UK, the CDM regulations[3]) to consider them. They should not only be considered, but demonstrated that they have been considered. This is usually met in part by the structural engineer producing drawings

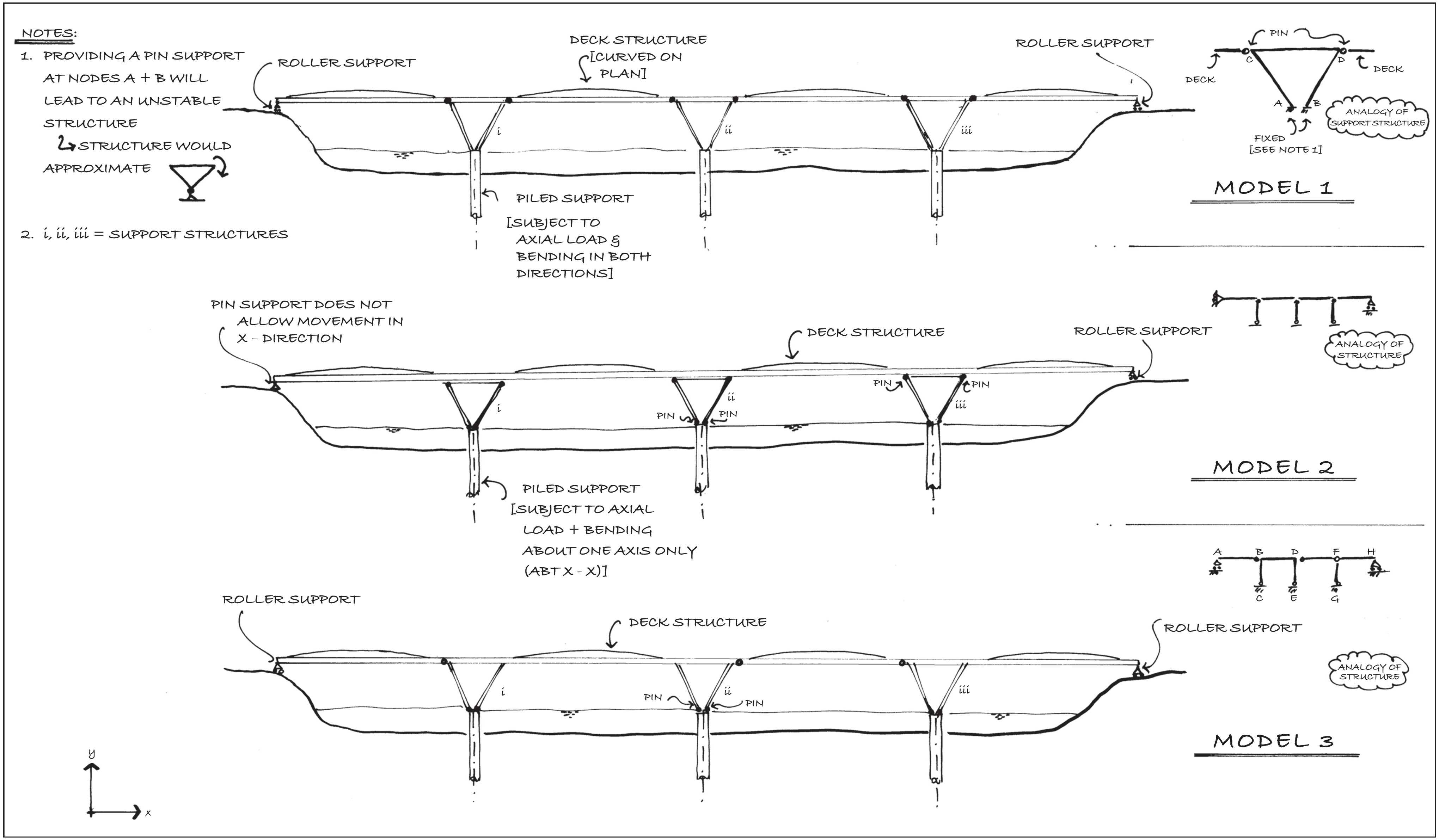


Figure 7 This drawing shows some early sketches exploring different forms of articulation for this new bridge across the River Aire at Castleford

Figure 8 The art of the structural engineer lies in being able to use simple sketches as in the previous illustration to understand and develop complex designs, as the finished Castleford Bridge shows

which indicate one way in which the structure can safely be built and, for unusual structures, maintained and/or demolished.

Various methods of selecting the option to be developed range from informal discussions with the other members of the design team through to formal scoring systems and SWOT (Strengths, Weaknesses, Opportunities, Threats) analyses. The making of notes can help the mind to find its way around the sea of data, and assist in making appropriate judgements. It may be beneficial that these notes are kept as a record of the thought that has gone into the selection process, as sometimes designers are required to provide evidence of a decision making process.

6.3 Reporting

Once the preferred scheme has been identified, a scheme design report is often prepared for the client, to formally record the options considered and the final decision.

Most of the information in the report is in the form of drawings (or a computer model) which include sufficient details to describe the overall scheme. Usually there will also be a description in words of the structure indicating the functions of the different components. The report must give sufficient information so that the other team members can check that it is compatible with their needs. For example, it may be easier to use words on the drawing or in the text to indicate the provision of openings for complicated service runs, rather than sketching the details of all the openings.

For bridges in the UK, the chosen scheme is documented in an Approval in Principle design statement, the formal acceptance of which is signed off by the client. This document describes the structure, its form, foundations and loading, as well as the means of analysis to be adopted in the final design.

Ideally, any report at this stage should record some key elements of the logic which resulted in the chosen configuration and also any outstanding unresolved risks.

7 Detailed design and information for construction

7.1 Introduction

This chapter covers two stages in the production of a structural engineering design. The stages usually overlap so they are considered together. Detailed design involves the final working out of every detail of the design, and justifying it. The design also needs to be coordinated or checked with the work of other design disciplines. Information for construction is then produced to instruct a constructor to build the structure.

7.2 Pre-requisites for detailed design

Several conditions need to be met before work can start on the detailed design stage. Firstly, each design discipline's parts of the design need to have been completed to scheme design stage. There needs to be a single settled scheme where all the key issues are resolved. This scheme design then needs to have been presented to and signed off by the client. If these conditions are met the detailed design and production of information for construction should be a straightforward process involving working up agreed principles. This means that each designer should be able to work up their design in isolation without input from the other disciplines (but see 'Co-ordination', Section 7.5 below).

In reality these conditions are rarely fully met, perhaps due to pressure of time, or information awaited from a third party. In such cases design can proceed if the gaps in the scheme design are acknowledged and managed appropriately. For the structural engineer working on buildings with several other design disciplines, a key issue is to have agreed, dimensionally 'frozen' layouts which incorporate a workable services strategy early in this stage of the process. Matters such as the precise arrangement of floor and ceiling finishes may not be needed during the early stages of detailed design, but are needed before construction information is produced because they affect the levels to which the structure is set out. External works for the buildings may be much less important and can often be fed in later in the process.

Alternatively, for a rail underbridge, the arrangement of track, ballast, waterproofing, drainage, signalling, power supply and telecommunications, as well as the structure and earthworks, need to be sufficiently worked out and defined before detail design may properly progress.

Sometimes there will be a small part of a scheme whose design is lagging behind that of the main works, and this too can be managed, as long as it is possible to isolate the effects to that one area of the project. However any approach that seeks to push forward the design with some parts missing increases the total amount of work required from the designers and increases the risk of errors occurring.

7.3 Deliverables from each stage

At the completion of the information for construction stage (see Section 7.6), fully dimensioned and set-out drawings of all elements of the structure are produced. These usually consist of plans which show the general arrangement of the structure, supported by overall sections and elevations. Details are also produced which explain how parts of the structure fit together including making appropriate allowances for movements and tolerances. This information is produced in draft format during the detailed design stage, and is reviewed by the rest of the design team. Following detailed co-ordination the draft information is updated and becomes information for construction.

Formal calculations (mathematical analysis of the structure) are produced during detailed design to verify the sizes of elements.

The drawn information for construction sets out how the structure is laid out and fits together geometrically. It is supplemented by a set of final specifications, which need to be consistent with the final scheme. These set out the requirements for materials and workmanship, and some other matters that are not easily covered by drawings, such as testing.

At all stages the structural engineer will be considering the health and safety implications of the design. Generally the design will be developed to reduce risks where it is reasonably practicable to do so, but some hazards may remain that the constructor and/or the end user will have to manage. The structural engineer therefore produces an assessment of the significant residual hazards for inclusion in the tender information that records the health and safety issues with the structural design.

As well as documents that define what is to be constructed, submissions are produced for approval by regulatory bodies. For the structural engineer the key information is a full set of final calculations, which are, in any case, required to produce the construction information.

Where elements of the structure are to be designed by the constructor, the structural engineer will need to produce documentation to define the parameters for this work.

7.4 Justification – analysis

Final mathematical analysis is required to support the structural engineering design. It is used to inform the engineer in defining the design of the structure, and is usually required as part of a submission to outside bodies for approval. The analysis defines the actions on the structure, calculates the effects of the loads arising from these actions, and demonstrates that its resistance is adequate for the applied loads. This may

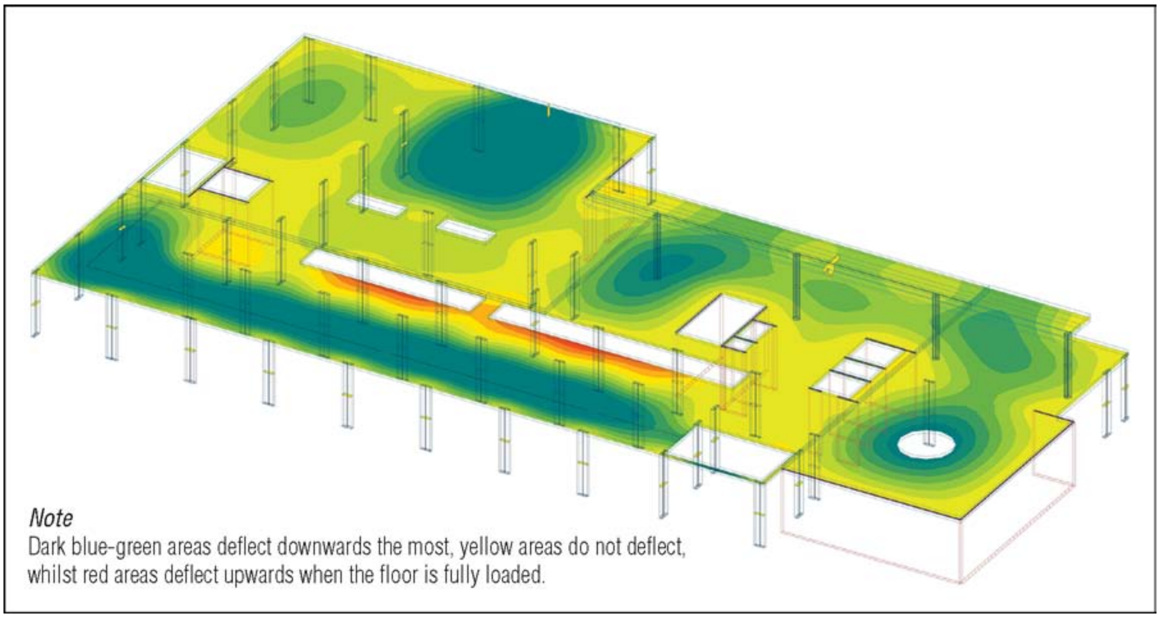


Figure 9 Computer modelling of structures produces results in a visually comprehensible form. This diagram shows how much a reinforced concrete floor slab will deflect

be achieved by appropriate computer programs, hand calculations or graphical methods. In some simple cases, an experienced structural engineer may be able to verify the design without further calculation by direct comparison with similar structural elements previously verified and built. This process is sometimes referred to as 'by inspection'.

Whatever the format any analysis will be set down clearly and checked in detail by an appropriately experienced engineer.

Generally analysis proceeds in parallel with final design, and informs the design as it is being produced. Often these calculations build on preliminary calculations produced at earlier stages of the design process. Detailed designs and their associated analyses are checked to see that the final construction details are consistent with the assumptions made in the analyses.

7.5 Co-ordination

Co-ordination between the designs produced by the various disciplines working on a project is required to ensure that all elements of the construction fit together. This process is usually led by the lead designer. In addition to the co-ordination between disciplines, each designer also needs to check that every element of their own design fits together. The principles of how co-ordination is to be achieved need to be established at scheme design stage.

The intensity of co-ordination required for building projects can vary, depending on the degree of integration of the structural and services zones. Some designs separate the structure and services into separate zones, and in such cases there can be a relatively loose fit between the structure and the services. Co-ordination in these cases can focus on integrating the architectural and structural designs. Sometimes the structure and services occupy the same zones, and the co-ordination process needs much greater care and effort to avoid potential clashes between structure and services.

During the co-ordination process it is normal to overlay drawings from different disciplines to see if there are clashes. Electronic exchange of information allows drawings to be quickly and accurately overlaid. This process increasingly involves the exchange and integration of three dimensional models, or the entire team working on a single, central model. However it is unwise to rely solely on electronic checks; manual checks should also be made on key dimensions.

7.6 Production of final information for construction

When the design is fully developed and coordinated, final construction documentation is produced. For buildings, it's worth noting that the nature of construction drawings produced by the structural engineer is not the same as those produced by the architect, or the services or façade engineers. The structural engineer produces drawings which show a detailed picture of what has to be made; the others generally prepare diagrams of how components detailed by suppliers or specialists are to be assembled.

Information provided by other members of the team is incorporated into the structural engineer's documents. Usually, production of information progresses from the general to the particular, starting with general arrangement drawings and following on with details and final specifications. Thus, the first information the structural engineer needs is the finalised general layout. Final details of major service openings or fixings for other elements are also needed at an early stage even though these have usually been identified at the scheme design stage. Later on, the engineer will

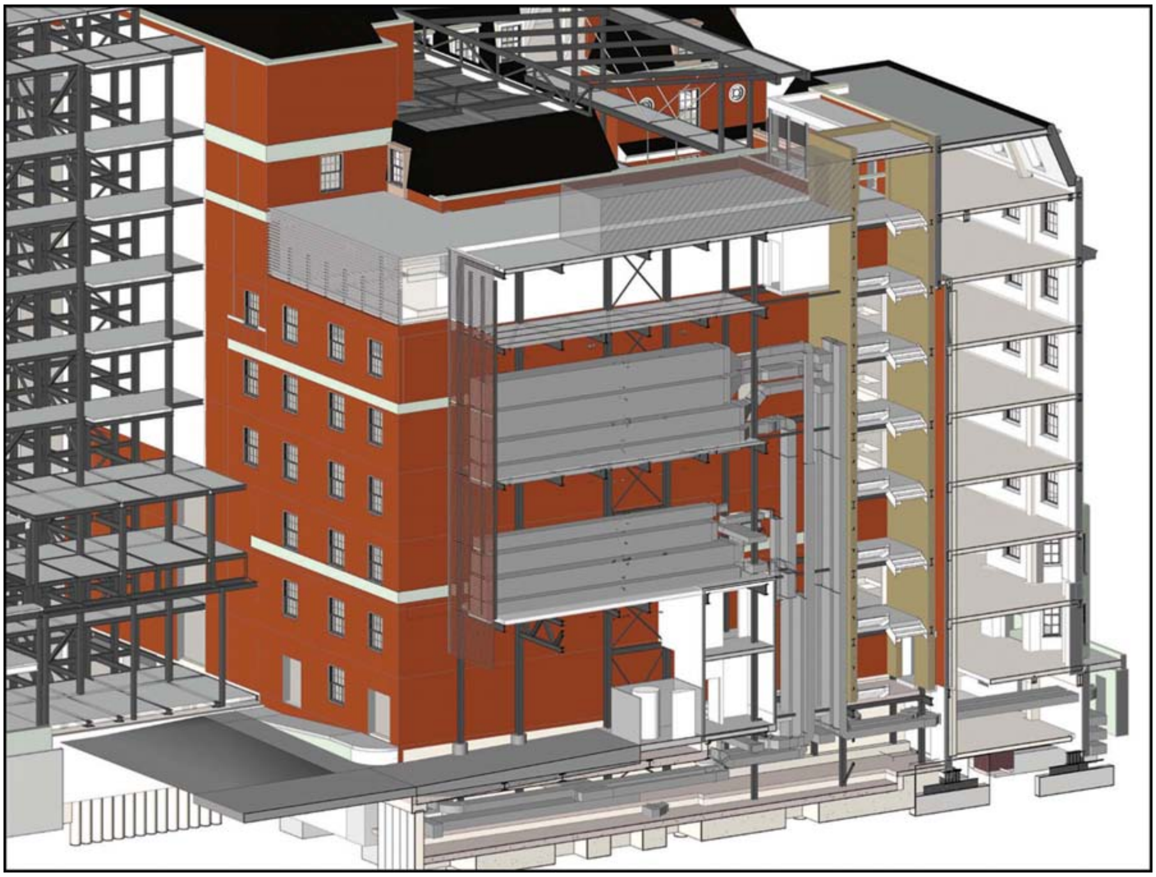


Figure 10 Design teams are increasingly using Building Information Management computer models which can combine designs for structure, services and building fabric and allow clashes to be identified readily and resolved

need to know more detailed information such as the location of smaller service openings or fixings and details of any cladding that the structure will have to interface with.

Ideally, all information should be complete before any construction starts, but this is not often possible. The structure gets built first so the structural construction information is needed early. Other design team members therefore need to provide key information in a timely manner to allow the structural engineer to complete work before it is needed on site for construction. The structural engineer needs to communicate information requirements to the rest of the team, and it is often useful to provide a schedule of information required identifying dates when key information is needed from other team members.

7.7 'Constructor design' of some structural elements

It is not uncommon for structural engineers working for the constructor to complete the detailed design of some elements of the structure. This is usually done where the method of construction and the constructor's equipment have significant influence on the final details. In principle it could be applied to any element, but the structural components where the detailed design is most commonly completed by constructors are:
– steelwork connection details
– secondary structure (eg cladding, plant supports)
– precast concrete floors
– piles
– timber trussed rafters
– reinforcement details for concrete.

For 'constructor-designed' elements, the structural engineer responsible for overall design produces documents setting out the engineering requirements. These requirements then form part of the construction contract and the responsibility for developing the details of the design of these elements lies with the constructor's engineers. For steelwork connections, the BCSA publication *Allocation of Design Responsibilities in Constructional Steelwork*[4] gives useful guidance on normal UK practice.

For bridges, constructors do not normally develop or complete the steelwork connections, but they do so for components such as bearings or vehicle restraint systems.

Sometimes there are non-structural elements of the construction designed by specialist suppliers which may have an impact on the structure. An example might be a proprietary cladding system. Generally the structural engineer will design the structure to accept the expected system, and make clear the assumptions regarding load capacity and structural movement (deflection and tolerances) that have been made in the design of the structure. The specialist will then be responsible for designing and fitting the system within these constraints. However some specialists do define constraints themselves. The engineer needs to be made aware of these at the earliest possible time.

Figure 11 Steelwork structure – completion of the design of connections may be undertaken by the constructor

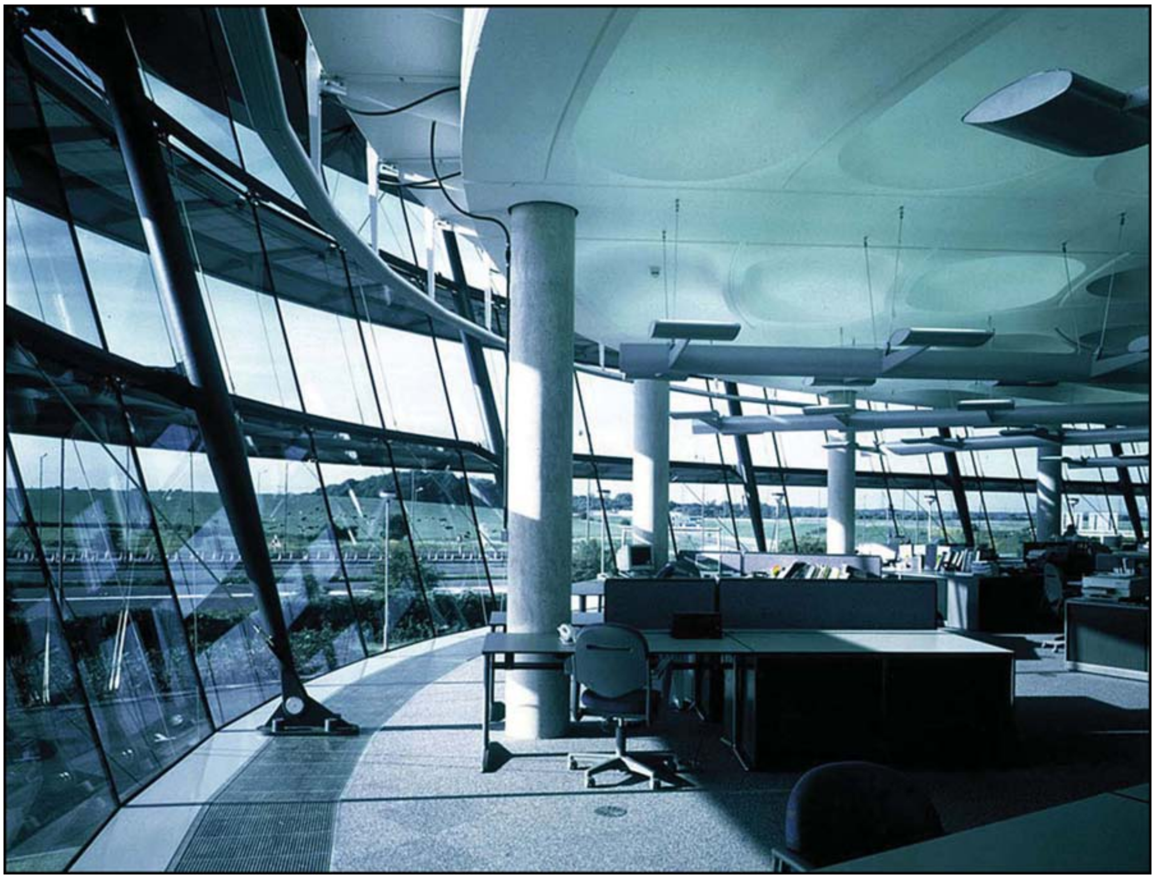


Figure 12 Glass cladding fixed to a steel sub-frame in a reinforced concrete structure. Arrangements such as these need careful co-ordination of design and construction disciplines to develop appropriate connection details to deal with tolerances and fit

7.8 Checking

During the design development and construction documentation stage it is recommended that the design should be checked to see that the structural issues have been addressed and the structure will be appropriately safe and durable; such checking helps to avoid errors of principle being overlooked. The check can be done in parallel with the final design, and this can be useful in helping the designers hone the scheme. Whenever it is done, it is vital that the check is completed before the design is constructed on site. The principles are checked first with the final design being checked as it is produced.

The checking described here is appropriate whether or not any checking for compliance with laws, regulations or other external requirements is needed. For very important or complex designs, independent checking by another firm ('Category 3 checking') may be required. This is a particular feature of the design of UK highway or railway structures and needs provision making for it in fee and time budgets for the project. Other systems may apply in other countries.

7.9 Alterations

Alterations to the brief at these stages need careful handling and should, if possible, be avoided. They bring with them a high risk of delay, cost increase and technical error. The importance of getting the initial brief correct and the client properly considering and signing off each stage of the design should be recognised. If changes are instructed they need to go through the same process as the rest of the design and be fully checked. For minor changes this may be possible in a matter of hours, but more significant changes can take some time. Significant additional design costs, and therefore fees, may be incurred. Corners should not be cut in this process – the same care needs to be taken with the design of the changes as was taken with the original design.

8 Procurement – its effects on the design process

8.1 Introduction

This section considers how the various methods of procurement and tendering can affect the work of the structural engineer and the other members of the design team. Methods of procurement range from the ideal 'traditional' process of preparing full working details prior to obtaining tenders or negotiating with a constructor, through approaches using individually tendered work packages (e.g. construction management), to design and construction all being provided by the constructor. Procurement occurs at a different stage (or stages) of the design process in each case and the design team, including the structural engineer, have to prepare different types and amounts of information, and to different timescales. This in turn affects the resourcing needed, the costs involved and the fees charged.

8.2 Traditional contract – 'ideal' approach

For an 'ideal' traditional construction contract, all elements of the project should be fully designed and described before any contract documents are prepared. This ideal is rarely, if ever, achieved in practice. The intention is that this should allow the constructor to fully price all items of work, so that any

Figure 13 A reinforced concrete framed apartment block under construction in East London. A building such as this could be procured by one of a number of different approaches

claims for delays in provision of information or for later amendments or additions are avoided. However, the client must be prepared to allow sufficient time for the preparation of design information, followed by the contract documentation (including measurement and bills of quantities), followed in turn by pricing by constructors prior to commencement of construction. In addition, any changes brought about by the constructor's suggestions on buildability and methods of construction may result in reworking of the already finalised details by the design team, giving rise to additional costs and delay. So, to many clients, this approach seems far from ideal.

For work on existing structures, final information on the nature of the existing construction may not become available until after the constructor has started work and opened up what is there. With an 'ideal' traditional approach, this may then result in late changes in the design, delays and additional costs.

8.3 Traditional contract – pragmatic approach

To try to avoid some of the difficulties of the 'ideal' case, many applications of the traditional contract do not wait until all final details are complete before the preparation of contract documents. Instead, the design team, including the structural engineer, produces a set of tender drawings and specifications, which aim to show the designers' understanding of what the completed design is likely to be. These documents are then used to prepare contract documentation and to obtain tenders or to negotiate prices. Because the design is incomplete, there will always be some uncertainty over what the final output will be. The designers use their skill and experience to make appropriate estimates, but these may prove inaccurate, leading to later negotiations with the constructor over contract variations. Designers usually then try to complete the design within the constraints of the tender information, but this may lead to compromises in the final design, compared to that achieved through an ideal tendering process.

Clearly, producing a set of tender drawings and documents as well as the final design information involves additional work for the designers (and therefore additional cost) compared to the 'ideal' case and this may be reflected in the fees charged. On the other hand, earlier input by the selected constructor may allow some minor adjustments to the design to be made to suit the methods of construction proposed without incurring delay or further cost. However, this constructor input would still come too late to allow any significant design changes to take place without a cost or time penalty.

For work on existing structures, the comments given in Section 8.2 above still apply.

8.4 Two-stage tendering

In this case, tendering constructors are asked at a first stage to provide rates for the various items of construction, based on preliminary design information provided by the design team. These rates, together with prices for overheads and profits and other information (e.g. capability, capacity), are used to select a preferred constructor. The design is then advanced, but not finalised, and contract prices negotiated with the preferred constructor on a set of tender drawings and specifications in a manner similar to that for a pragmatic traditional procurement, except that the already agreed rates are used. Here, the design team, including the structural engineer, needs to undertake a greater amount of additional work, producing the preliminary design information for the first stage of the process and then tender information for the second stage. Again this will be reflected in the design costs and, therefore, fees.

The significant benefit of this approach is that the constructor can be involved earlier in the design process and contribute advice on buildability and methods of construction which may be incorporated into the design without significant cost or time penalties.

For existing structures, where opening-up work is needed before aspects of the design can be finalised, it may be possible to arrange for some or all of this to be undertaken prior to commencement of the main site works and thus reduce the risks of cost or time overruns.

8.5 Approaches using work packages

Some procurement arrangements, such as construction management, divide the proposed work into separate packages, which are usually trade related. Each package is then priced and contracted for separately at a time to suit the overall construction programme. However, the design needs to be sufficiently well advanced to make sure that each package of work will fit together and work together with the preceding and ensuing ones. Full co-ordination of packages is essential, but is difficult to achieve solely through the means of specifications and contract documents. Matters such as achieving satisfactory fit of all elements and quality of finished work require careful supervision on and off site as well as good specification by designers.

The design team, including the structural engineer, usually needs to produce sets of tender information for each package as well as producing the final design information. On top of this, further work and documentation are often needed from the designers to help coordinate the packages. Under a traditional contract, this co-ordination of trades and suppliers would be undertaken by the constructor without normally involving the design team. The additional work the design team has to undertake for packaged contracts is thus usually greater still than any of the preceding approaches. However risks still remain of additional costs and for delays arising as designs are finalised and as later packages are adapted to fit earlier ones.

The division of work into trade packages seldom suits the complexity of co-ordination of trades needed for work on altering existing structures. It is usually more sensible for such work to be undertaken as a complete contract in itself.

8.6 Design and construct

There are many different arrangements of combined design and construct contracts and there is insufficient space to discuss them all here. However there are some common features as they affect the structural engineer working as a member of a design team.

In the first instance, a structural engineer may be a member of a client's project team and/or design team. Initial designs may be produced to various stages:
– To an early stage, involving the preparation of an initial brief, collection of data and identification of constraints.
– To scheme design stage, selection of a final option.
– To near the end of detailed design and preparation of construction information.

The stage to which the client will ask the team to take the design will depend on the degree of certainty the client seeks over what is finally built.

From the initial designs, contract documents are prepared, prices obtained and a contract placed with a constructor to take over the design, complete it and construct it. Specifications prepared for such contracts differ from other forms as they need to define only the range of standards of design development, materials and workmanship that will be acceptable to the client, not stipulate specific items.

The tendering constructors may need input from a structural engineer when preparing their prices and proposals. The structural engineer on the client's team would not be in a position to provide such input, due to a conflict of interest.

Once the contract has been placed, the constructor then has to complete the design, either that proposed initially by the client or an accepted alternative. This will be undertaken by the constructor's design team, including the constructor's structural engineering designer (to be distinguished from the constructor's temporary works designers and engineers managing and supervising work on site).

'Design and construct' arrangements often involve a certain amount of duplication of design work, more so when the final design differs significantly from the initial design. The costs of this additional design work will form part of the overall costs of the project, but they may not be immediately apparent as they will be incurred by different parties at different stages of the process.

8.7 Advice on constructors

During the procurement process, the structural engineer may be able to advise the client on the suitability of proposed constructors and appropriateness of their skills and experience to constructing the proposed structure satisfactorily. The structural engineer is also likely to be able to assess and comment on any alternative proposals put forward by prospective constructors.

9 The construction stage

9.1 The process of construction

The construction of a building or structure is the end product of the complex and sequential process of design, specification of materials and management of the works. Responsibilities for these different aspects fall on different people and are dealt with at different points in time. A safe and serviceable structure will be obtained only if all parts of the process are compatible in practice. This requires a proper system for inspection, supervision and acceptance by appropriate parties at each stage, and the importance of that should be recognised by all the parties involved.

Experience has highlighted certain factors that require closer attention if the client's reasonable expectations of a well built structure are to be satisfied. These include:
- A need by all parties to take realistic account of the rigours and practicalities of work on site, which often has to be undertaken in adverse weather conditions.
- The need to make provision in the design for handling and assembly of prefabricated construction, with the capability to adjust the setting of elements to cope with tolerances and permit the construction of satisfactory joints.
- The need in 'fast-track' projects to select types of structure and materials that facilitate speedy construction, while retaining the necessary standards of quality and performance.
- The importance of the knowledge of tolerances of differing materials and how that affects their interface connections.
- The particular importance of supervision for work involving innovation in materials and techniques of construction, and the need to commission test work where this is required to establish suitability for the application concerned.
- The need to provide a contractual framework that encourages positive attitudes and speedy action in the resolution of technical difficulties.
- When dealing with alterations and modifications to existing buildings and structures, the making of appropriate follow up site inspections, surveys and tests and any subsequent design works.
- The need to achieve appropriate understanding of the stability of both existing and new structures throughout the construction process.

When dealing with alterations and modifications to existing buildings and structures, allowance needs to be made in the construction stage of the project for opening up works and follow up site inspections and any subsequent design works.

9.2 Roles of the structural engineer

During the construction stage the structural engineer can be the designer of the finished structure or part of the constructor's team. In some countries or systems, the designing structural engineer does not have an involvement at site stage. The designer is primarily concerned with the permanent works and the constructor with realising the finished structure and the design of any temporary works. This division of responsibilities between designer and constructor needs to be clearly defined, understood and accepted by all parties involved in the construction

(a)

(b)

Figure 14 Timber, used for many years, is now thought of as a low carbon structural material stage of projects. In the UK, those parties include the client, the design team, the constructors and the health & safety co-ordinators. The constructor needs to take responsibility for the process of constructing the structure within the constraints set by the designer and without damaging the performance of the finished structure.

All too often, the structural engineer whether working as the designer or as part of the constructor's team can be assumed to be providing input in areas which rightly should be dealt with by another party.

9.3 Consideration of buildability in the design

Frequently, buildability appears to be one person's or the team's mostly subjective opinion about the ease or otherwise with which a particular design can be translated into reality. It depends so much on the designers' and constructors' past experiences and successes. The question of what can be built and what cannot needs to be addressed early in the design process, and continually revisited. Often the constructor has structural engineers who understand the constructor's preferred methods of construction which can influence the choice of the structural form or sequence. Early involvement of such staff is beneficial. If it is known that specialist sub-contractors will be required for elements of the work then their input should also be sought at the earliest opportunity.

Just as it is important for the construction team to be prevailed upon to comment on the design, so should the designer be given access to the preferred construction methods, have them explained and understand the implicit constraints. It is often a variation of these methods that leads to some of the last minute design changes, so it is recommended that the designer keeps in touch with the construction process. Once fundamental construction sequences have been chosen, they should be left alone unless there is a very good reason to change them.

9.4 Health and safety

Health and safety issues should be considered by designers as an aspect of buildability. In the UK, this is a legal obligation for most projects. Many safety incidents on site result from unplanned activities. All changes should be carefully assessed against the contract programme and rescheduled to ensure all site operatives follow agreed planned sequences.

Figure 15 This example of reinforced concrete construction is for a lecture theatre in Edinburgh. The combination of many decisions made by different design disciplines are integrated into the construction of the finished product

9.5 Communication

Good communication links between all the parties are essential. At a project's inception those responsible for setting up the construction works should ensure that robust, well recorded communications are established between the design and construction teams. Where one or both of the parties fails to appreciate the tasks of the other, designers and constructors may find it difficult to work together. A good interface manager can play a crucial role with the progress of a project by avoiding such lack of awareness.

The constructor has to plan the works and so needs to know in advance the sequence and timing of the drawings and specifications. Many constructors operate an 'information required schedule' which, with discussion, can mirror the flow of required information from the designers. The key is discussion and having a schedule that suits both the sequence of construction of the project and the sequence in which the designers are able to produce the information.

Formal technical queries, and their register, provide a simple method to control, and subsequently audit, information flow. These can go in both directions as designers and constructors develop their designs/ methods of construction.

Normally it is the constructor who retains responsibility for deciding their own detailed method of construction, as well as for maintaining stability of partially completed structures and existing buildings and structures while it is under their control. However, where there are critical points of erection, or aspects of the design that require detailed instructions on the method of working, these need to be made clear in the contract documents. At the commencement of construction the designing structural engineer will usually have a much better understanding of the nature and condition of the site and any existing structures involved in the project. It is very important that this knowledge is communicated effectively to the constructor and the brief of the designing structural engineer should include provision for doing this.

9.6 Monitoring of site works by the design team

It will be beneficial to the project for the design team to maintain close communication with the constructor to advise on a day-to-day basis, to provide detailed interpretation of the designer's intentions. However, some forms of procurement do not retain the services of the design team during the construction phase and, in such circumstances, complete reliance is placed on the constructor's ability to interpret requirements from the construction documents alone.

9.7 The roles of the constructor's structural engineer

Where the constructor employs a structural engineer, the roles undertaken may include the following:

Figure 16 Structural engineers also work for constructors, designing complex temporary supports. This example is for the refurbishment of a historic railway viaduct near Kilmarnock in Scotland

– management of site works
– preparation of construction method statement(s)
– temporary works coordinator (TWC)
– temporary works design
– supervision of work on site (temporary and permanent work)
– setting out
– completion of design of certain elements.

Construction method statements include:
– sequence of works
– erection procedures
– use, weight and location of plant and construction materials
– temporary works design, including temporary bracing
– information regarding the temporary works co-ordinator and temporary works supervisors
– monitoring of ground, structures and other features on or adjacent to the site.

9.8 Temporary works design & management

For construction projects, no matter how small or large, simple or complex, the constructor would benefit from the appointment of a temporary works coordinator (TWC) to be responsible for the stability of the permanent, partially completed and temporary works during the whole of the construction period. On large construction projects where temporary works operations are carried out by various subcontractors, each of the subcontractors should appoint an individual as their temporary works supervisor.

Where special provisions are required in the temporary works, the design team should clearly indicate these to the constructor. Where the loads on such temporary works arise from features in the conceptual design, then the design team needs to give the constructor sufficient information to determine the loads and to enable the design of the temporary works.

Where possible, the TWC and the principal structural engineer in charge of the design should consult in advance of construction works to share and exchange project knowledge.

The appointed TWC should see that:
– There are always clearly defined paths through which the construction loads are transmitted to temporary or permanent foundations.
– Structural members and connections are securely restrained.
– The permanent works in their incomplete form can accommodate the temporary loads applied to them.

10 Other roles a structural engineer can undertake

The preceding sections have described the two principal roles for a structural engineer:
- To produce technical briefs and structural designs described to whatever level of detail the constructor needs.
- To develop safe sequences and methods of working which will allow the project to be built to specification, programme and budget.

There are also more general roles that structural engineers contribute to. They play a pivotal role in the development of new knowledge and understanding in the field of structural engineering and its application in the service of society. Much of the innovative work and research by structural engineers is recorded in learned journal publications such as the Institution's own journal *The Structural Engineer* and finds its way into legislation and codes of practice. Structural engineers also seek to influence society internationally through a learned dialogue not only with other professionals and clients but also with governments and their legislatures. Changes to standards and legislation achieved by structural engineers help reflect society's attitudes, for example the changing attitudes towards the use of recycled materials even when they may be more expensive than virgin materials. Additionally, structural engineers disseminate their work through the Institution's technical meetings, continuing professional development events and conferences.

Finally, a structural engineer can also undertake a number of other roles in the construction process, for example:
- in or with the client's own organisation to provide early advice on the development of a credibly feasible functional brief and a suitable team
- as the project manager
- as the design team manager
- as the design team leader for certain more technical projects
- as the supervising officer for the construction contract,

and in more detail:
- as an adviser on the issues associated with building on a site, maintaining or altering a building or other structure, dealing with neighbouring buildings or structures, or just establishing what is actually there
- as an approver to check whether the design as described will meet the client's requirements or whether the construction has proceeded to the standards specified. In some countries this can be part of a statutory approvals process
- as an assessor of the structure to monitor the completed structure in-service and advise on the need for maintenance, remedial work or alterations. The structural engineer's ability to carry out sophisticated technical appraisals of structures can sometimes reduce the need for costly alterations or repairs
- as an expert to comment on the adequacy of designs or construction carried out by others.

Lastly, with their special skills combination of technical knowledge, practical application and rigorous thinking, structural engineers may also be found contributing to other departments or organisations more removed from the direct process of construction.

Figure 17 As well as working on designs, structural engineers often work on appraising the nature and condition of the structures of existing buildings

References

1 Institution of Structural Engineers. *Structural Design – Achieving Excellence* (in preparation)

2 RIBA. *Plan of work: multi-disciplinary services*. London: RIBA Publishing, 2008

3 *The Construction (Design and Management) Regulations*. Norwich: The Stationery Office, 2007 (SI 2007/320)

4 BCSA. *Allocation of design responsibilities in constructional steelwork – for buildings*. London: BCSA, 2007

Bibliography

Institution of Structural Engineers. *Appraisal of existing structures 3rd ed* London: Institution of Structural Engineers, 2010

References

1 Institution of Structural Engineers. *Structural Design – Achieving Excellence* (in preparation)

2 RIBA. *Plan of work: multi-disciplinary services*. London: RIBA Publishing, 2008

3 *The Construction (Design and Management) Regulations*. Norwich: The Stationery Office, 2007 (SI 2007/320)

4 BCSA. *Allocation of design responsibilities in constructional steelwork – for buildings*. London: BCSA, 2007

Bibliography

Institution of Structural Engineers. *Appraisal of existing structures 3rd ed* London: Institution of Structural Engineers, 2010