
Structural Design of Buildings: Elemental Design

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Structural Design of Buildings: Elemental Design

Feng Fu and David Richardson

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Foreword

Structural engineering is a complex discipline combining science and creativity to develop our built environment and to provide structures that benefit society. As structural engineers, we regularly consider complex problems or challenges and use our skill and training along with an understanding of physics and mathematics to find safe, elegant, buildable solutions.

Structural engineers have a responsibility to protect public safety and, as key players in building and infrastructure design, assist in facilitating the vision of architects, developers, governments, private organisations and individual end users.

In a world with widespread realisation of the Earth's finite resources, combined with the devastating affect that the construction of our built environment is having on the planet's climate and biodiversity, civil and structural engineers practising today have a responsibility to balance the increasing needs of the world's growing population while reducing demand on natural resources. The impact of our actions when creating and maintaining the built environment is rightly at the fore.

As Planet Earth becomes more crowded, increasingly dense populations are subjected to higher risks resulting from any failings within the structures in which they live, work and play. Fire, earthquake, extreme weather, explosion, physical damage and structural neglect are all factors that can, and do, cause buildings and structures to collapse, with devastating consequences. As engineers, it is critical that we fully consider these risks and ensure that our buildings and structures can continue to perform safely under extreme events to protect human life.

It is imperative that structural engineers continue to develop themselves with up-to-date knowledge and best practice throughout the whole of their careers.

Emerald Publishing has drawn together leading experts in the field of structural engineering to write about the fundamentals, materials, processes and generic principles of structural design.

Edited by Professor Feng Fu and Professor David Richardson, each chapter is written by a different expert author and carries its own style and themes. The complete guide covers a wide breadth of structural engineering topics and is split over three books covering: the fundamentals of design, procurement and sustainability, guidance

on structural consideration of the major construction materials, and holistic design approaches. This guide provides a valuable overview and source of information for engineers, in helping to ensure their continued competence and understanding of this wide ranging and very rewarding discipline.

A closing thought ... ‘engineer’ is a word derived from the Latin ‘ingeniare’ meaning to contrive or devise. It is also related to ‘ingenious’ (of a person) clever, original and inventive. In summary, engineers are inventive problem solvers! Let us therefore work together, as a profession, to share knowledge and best practice and make the built environment better, cleaner, safer and more environmentally responsible.

EUR ING Matthew Byatt CEng FStructE
102nd President of The Institution of Structural Engineers

Preface

The *Structural Design of Buildings* series provides an authoritative introduction to the core knowledge for structural engineers to design a building. This series provides a comprehensive reference on structural design for practising engineers, university students of civil and structural engineering, and stakeholders such as developers, architects, surveyors and other non-experts in structural design who require reference information for designing a building.

The *Structural Design of Buildings* series provides timely updates of the advances in structural design principles for modern buildings. The series takes a project-oriented approach, covering the necessary topics that design professionals face at the outset, and throughout the duration, of a project. It presents the key issues needed to grasp a subject quickly and effectively, as well as providing the necessary tools for building design practice. The contributors of each chapter are proven experts from different countries across the world and are leading figures in their subject area, reflecting the best of current practice globally.

The series stems from the *ICE Manual of Structural Design of Buildings*. Rather than update the manual as a whole, it has been split into a series to provide an opportunity for those interested in part of the content to purchase the sections that are relevant for their purposes. The series is comprised of three books

- *Structural Design of Buildings: Fundamentals in Design, Management and Sustainability*
- *Structural Design of Buildings: Elemental Design*
- *Structural Design of Buildings: Holistic Design.*

The range of topics in the series provides comprehensive key knowledge required in structural design, technological advances and best practice for readers.

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In the process of preparing this series, we have been extremely fortunate in being helped and guided by many people. We would like to thank Viktoria Hartl-Vida and Cathy Sellars (the Editors at Emerald Publishing), together with their colleagues for their expert assistance with reviewing material. We acknowledge the contributions of all chapter authors and thank them for their diligence and hard work. Finally, thank you to those parties who granted the copyright of the figures and charts used in this series.

The Editors would like to thank the following authors who contributed to The *Structural Design of Buildings* series

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He has been working as a faculty member for City, University of London and University of Bradford since 2010. He was Changbai Mountain Distinguisher Visiting Professor in Jilin Jianzhu University and Distinguished Visiting Professor in Guilin University of Technology in China. Prior to joining academia, he worked for several world leading engineering consultancy companies and has worked on extensive prestigious construction projects worldwide, including over 20 tall buildings (most of buildings over 200 m), such as the tallest building in western Europe, the Shard in London; Nido Tower in London (the third tallest student dormitory in the world); Nakheel Tower in Dubai (1000 m tall, scheme design, the tallest (proposed) building in the world); 22 Bishopsgate (the second tallest building in London, participated in the first stage design before 2008); Beijing WangZuo Centre; Beijing Yuanyang complex; and Beijing Kerry Centre. He was also the team member of several large-scale complexes, such as the award-winning Bristol Broadmead Shopping Centre, Heathrow Airport T2 and Qin Huang Dao stadium. He has also participated in the design of bridges, long-span structures, hospitals, and almost all types of structures.

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Alexander Gibb and Partners in the UK and overseas. He expanded PBA's portfolio into residential and mixed-use buildings. He worked with the late Peter Brett to develop new forms of structural steelwork and was joint author of a manual for design published by the Steel Construction Institute (SCI). Involvement with the SCI since has included a period as non-executive director as well as contributions to publications and committee work for the British Constructional Steelwork Association (BCSA). At PBA, John most recently worked on a framework commission with Oxford University, mainly involving laboratory buildings. His current focus is on commercial office refurbishment and forensic/expert witness work. He is on the CROSS-UK Structural Safety Expert Panel and has been instructed as an expert witness involving allegations of professional negligence and fatalities. These cases, handled through the Technology and Construction Court, International Chamber of Commerce and Industry, Bucharest, and the Dubai International Arbitration Centre, have involved a range of structural materials and collapses.

Introduction

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The *Structural Design of Buildings* series provides a comprehensive reference on structural design for practising engineers, university students of civil and structural engineering, as well as other stakeholders such as developers, architects, surveyors and other non-experts in structural design who require reference information and it covers the key knowledge required in structural design. The book is written and edited by a wide selection of leading specialists in each area.

Structural Design of Buildings: Elemental Design focuses on the introduction of general design issues in various building elements. This volume of the manual consists of the following chapters:

Chapter 1. Structural design of reinforced concrete elements to Eurocode 2

Owen Brooker and Ashraf Ashour give an overview of the structural design of reinforced concrete framed buildings. They explain the factors to consider in the selection of a particular floor type, including reasons why concrete may be selected ahead of other materials. The chapter also explains how to carry out the detailed design of structural elements for the phenomena covered in Eurocode 2.

Chapter 2. Steelwork

John Rushton outlines an approach to steel design from the viewpoint of a consulting engineer practising in the UK. This chapter presents summaries, design and detailing guidance, project examples and sources of information on aspects of design and construction in steelwork with the aim of achieving a successful design.

Chapter 3. Timber and wood-based products

Bernardino D'Amico introduces and explains the rules for the design of common structural elements such as beams and columns using timber and wood-based products. The chapter looks at design rules for timber connections, and composite systems such as thin webbed sections and thin flanged sections.

Chapter 4. Masonry

Andrew Rolf introduces masonry construction and its components. He provides background information on basic concepts, new-build loadbearing and non-loadbearing construction techniques and briefly discusses existing masonry. This chapter provides details of masonry

units available and widely used in the UK; typical jointing and bonding techniques; and restraint systems employed in masonry construction.

Chapter 5. Aluminium in civil engineering structures

Federico Massimo Mazzolani represents the last important achievement in this field. The chapter gives an overview from the historical beginning to the contemporary development in the design of aluminum alloy structures.

Chapter 6. Glass in facades and other applications

Mauro Overend introduces the salient information about the detailed aspects for designing safe and sustainable glass elements and structures.

Chapter 7. Retrofitting, materials for the thermal upgrade of existing buildings and life cycle impacts

Chiara Piccardo provides an overview of the environmental, economic and social challenges related to energy-efficient renovations. The energy efficiency standards for buildings are briefly reviewed, including Passive House, Nearly-Zero Energy Building and Net Zero Carbon Building. Renovation measures such as thermal insulation, airtightness and energy-efficient windows are described.

The above chapters are part of the *Structural Design of Buildings* series providing guidance on the structural design of buildings. When read in conjunction with the two other books in the series, the range of topics covered will provide the reader with a sound understanding of the design and management processes required when embarking on the structural design of a building. We do hope this book will provide some useful guidance to its readers.

Feng Fu and David Richardson

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Chapter 1

Structural design of reinforced concrete elements to Eurocode 2

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1.1. Introduction

Concrete has been widely used in construction from the mid-nineteenth century, but it was not until the turn of the twentieth century that reinforcement was used to enable concrete to be used as flexural elements. Initially, reinforced concrete was a proprietary product with several systems available, but during the twentieth century Codes of Practice were introduced that set out the safe use of reinforced concrete for general use.

The detailed design in this chapter is based on BS EN 1992-1-1 (BSI, 2004a), which is referred to as Eurocode 2 – it is the current concrete design standard for the whole of Europe, and increasingly countries outside of Europe. As part of the Eurocode suite of design standards, it is the most advanced concrete standard in the world. However, preliminary sizing rules and general guidance on the use of concrete should be applicable whichever design standard is used.

The other point to note is that the chapter is written with northern European markets in mind. In this region, the costs of labour and formwork are high when compared with material costs. It is, therefore, recognised that this may not suit some worldwide markets and local conditions should be considered when proposing initial options.

1.2. System selection

The choice of structural system is often determined on the balance of different factors. Each construction project is unique and has a different set of design criteria and parameters. The structural engineers along with the design team and client have to assess different options and the benefits at the initial stage and conceptual design. This section is intended to explain the range of influences so that the engineer can make a rational assessment. As this chapter is focused on concrete, the first consideration is why concrete should be used.

1.2.1 Why use concrete?

Concrete is a versatile material, whose raw materials are found throughout the world and therefore in many situations it is the first-choice building material. However, the reasons for using concrete go deeper than just easy availability and some of the benefits are explained below.

1.2.1.1 Economy

For the vast majority of building projects, economy is the key driver. The material costs of concrete are generally low compared with other construction materials, but other factors also have an influence: labour and in particular formwork costs can be up to half the cost of a concrete frame. However, concrete is still an economical material, having a market share of more than 50% in most countries, the UK being a notable exception.

1.2.1.2 Programme

In the UK, there is a perception that concrete-framed buildings are slow to construct. However, this is not necessarily the case. An in situ concrete-frame construction may take longer than other materials, but overall construction times are comparable. This is because the lead time can be shorter and follow-on trades can follow more closely behind the concrete works. Further details can be found for various building types in a series of studies by [The Concrete Centre \(2007, 2008a, 2008b\)](#).

Prefabrication can also significantly reduce construction programme times and there are many ways in which concrete elements can be prefabricated, including precast columns, twin-wall panels, hollowcore units and lattice girder slabs. Programme times can also be improved by good detailing and consideration of buildability.

1.2.1.3 Sustainability

Sustainability has become an important factor in the design of framed buildings, and concrete can contribute to a sustainable design, especially when the material properties are understood and used to their maximum. Concrete can contribute to a sustainable building in the following ways.

- Concrete is a local material – reducing travel distances for the materials used.
- Concrete is long lasting – a correctly detailed reinforced-concrete building should last comfortably 60 years and would be expected to last considerably longer even with little maintenance.
- Concrete can be exposed – reducing the need for other materials to cover it.
- Concrete is fire resistant – no fire protection materials are required.
- Concrete can be used to minimise operational energy of buildings using its thermal mass – see [De Saulles \(2006\)](#) for more information.
- Concrete can be (and is) recycled at the end of its life.
- Concrete can be used to give flexibility for change of use.
- Materials can be minimised by using prestressing.

However, structural engineers take major responsibility in reducing carbon emission and design for net zero. PAS 2080 ([BSI, 2016](#)) proposed the following hierarchy of carbon-reduction potential, as listed below.

- Build nothing – is new build the only way forward?
- Build less – reuse, repurpose and refurbish – that is, minimise demand for new construction.
- Build clever – provide low-carbon solutions and specify enough materials and not more, including technologies, materials and products.
- Build efficiently – reduce resource consumption in construction.

1.2.1.4 Fire resistance

Concrete offers good fire resistance because

- it is a non-combustible material
- it is a good insulator

- it has low loss of strength at building fire temperatures
- strength loss under sustained periods of elevated temperatures is low.

Guidance on ensuring appropriate fire resistance can be found in the section on ‘cover’ below (Section 1.5.1.4).

1.2.1.5 Acoustics

Concrete is a good insulator of sound, resisting the passage of both impact and airborne sound, providing sound reduction between spaces and particularly useful for residential, educational and healthcare buildings.

1.2.1.6 Long spans

A common misconception is that concrete is not suitable for long-span situations. However, the use of prestressed concrete can greatly enhance the clear spans. Prestressed double ‘T’, hollowcore units and post-tensioned in situ floors and beams can comfortably span 12 to 16 m – further guidance is given below.

1.2.2 Floor system options

Arguably the most important aspect of a buildable concrete-framed building is the choice of floor system, and there is a vast range of options. However, there is plenty of scope for innovation and designers should not be constrained by the options presented here. [Table 1.1](#) provides guidance on the various options available.

1.3. Preliminary sizing

To enable initial sizes of concrete members, some rules-of-thumb are provided in [Tables 1.2](#) and [1.3](#); the notes to the tables should be read and understood. These rules are only intended to be a quick reference guide and more detailed guidance can be found in *Economic Concrete Framed Elements* ([Goodchild et al., 2009](#)).

1.4. Stability

The stability of buildings is of paramount importance and should be considered at early stages of a project. Assuming the building does not have a basement or part basement, the main considerations for stability are lateral forces that can be caused by

- wind loads
- geometric imperfections
- accidental loads
- earthquakes.

A concrete-framed building should be designed to resist these actions, which can be achieved by using either shear walls or moment resisting frames. Detailed consideration of earthquake loading is not considered here (for more information on earthquake loading, see Chapter 4 of *Structural Design of Buildings: Elemental Design: Loading*).

Where shear walls have been used for lateral stability, they should ideally be arranged so that their shear centre coincides with the resultant of applied forces. In practice, this is often not achievable and, therefore, torsion/twisting moments should be considered. There is also an inherent assumption that the floor acts as a horizontal diaphragm; however, there are occasions when this is not the case: for instance, when precast floor units are used without an in situ concrete topping, or where

Table 1.1 Concrete floor systems (continued on next page)

Slab type	Description	Advantages	Design considerations
Solid flat slab (flat plate)	A solid concrete slab of constant thickness supported directly by columns without the use of beams. Widely used because the formwork is simple and therefore cost effective, suitable for spans up to 9 m only.	<ul style="list-style-type: none"> • Speed of construction • Economy • Easy services distribution • Open plan areas • Minimal storey height • Easy to install partitions • Aesthetically pleasing soffit • Inherent robustness 	<ul style="list-style-type: none"> • Punching shear capacity • Deflection • Requires continuity • Holes should be avoided around columns wherever possible • Limited span range
Flat slab with flared column head	Same as a solid flat slab but provided with a flared column head immediately below the slab to reduce punching shear stresses.	<ul style="list-style-type: none"> • Same as a solid flat slab • Can span further than a flat slab 	<ul style="list-style-type: none"> • Flared heads slow construction (but precast columns could be used) • Vertical services distribution adjacent to the column is difficult
Flat slab with drops	Same as a solid flat slab but provided with a thickened area around the column position, primarily to give increased shear strength.	<ul style="list-style-type: none"> • Same as a solid flat slab • Holes can be formed • Can span further than a flat slab 	<ul style="list-style-type: none"> • Forming the drops slows construction • Drops restrict services distribution
Post-tensioned flat slabs	A prestressed solid concrete slab, supported directly on columns. The prestressing is applied after placing concrete. The prestressing allows thinner slabs, or longer spans than for a reinforced-concrete flat slab.	<ul style="list-style-type: none"> • Speed of construction • Economy • Minimises the use of materials • Easy services distribution • Minimal storey height • Easy to install partitions • Holes can be formed • Aesthetically pleasing soffit • Inherent robustness 	<ul style="list-style-type: none"> • Design is often by specialist • Increased shrinkage due to prestress • Punching shear capacity is limited
Hollowcore units on beams or walls	Precast, prestressed concrete units spanning in one direction and supported by beams or walls. Voids are created within the units through an extrusion process during manufacture.	<ul style="list-style-type: none"> • Speed of construction • Economy • Minimises the use of materials • Easy to install partitions • Low self-weight • Open plan areas • Low deflection • Off-site manufacture 	<ul style="list-style-type: none"> • Suppliers use fixed depths for slabs • Bedding of the units, especially for long spans • Usually supplied with pre-camber, which increases with span

Table 1.1 continued

Slab type	Description	Advantages	Design considerations
Lattice girder slab	A thin precast slab acts as permanent formwork for in situ concrete slab. Reinforcement lattice girders are cast into the precast slab to provide the strength in the temporary situation. Can be one-way spanning onto beams, or two-way spanning onto columns.	<ul style="list-style-type: none"> • Speed of construction • Economy • Easy to install partitions • Holes can be formed • Low self-weight • Aesthetically pleasing soffit • Inherent robustness • Off-site construction 	<ul style="list-style-type: none"> • The joints between the slabs reduce the effective depth at these locations (splice bars are required) • Joints should be placed away from locations of high stress • Interface should be considered between precast and in situ concrete • Effective depth for punching shear is reduced, unless shear links are embedded in precast concrete.
Biaxial voided slab (trade names: Bubbledeck and Cobiax)	Voids are placed within the slab using hollow spheres of recycled plastic to reduce the self-weight of the slab. Usually used in combination with a lattice girder slab (see above). Can be supported by beams or columns.	<ul style="list-style-type: none"> • Speed of construction • Easy services distribution • Voids reduce materials used • Minimal storey height • Easy to install partitions • Low self-weight • Aesthetically pleasing soffit • Inherent robustness • Off-site manufacture 	<ul style="list-style-type: none"> • Currently only available as a proprietary system • For use as a flat slab, voids should be omitted around column heads to increase punching shear resistance • Design is usually by specialist based on test results
Solid slabs on band beams	A solid slab spanning in one direction onto wide shallow beams. Used to reduce self-weight and increase economic spans.	<ul style="list-style-type: none"> • Speed of construction • Economy • Easy services distribution • Minimal storey height for longer spans • Easy to install partitions • Holes can be formed • Inherent robustness 	<ul style="list-style-type: none"> • Band beams can be designed as slab elements (i.e. without shear reinforcement) • The band beams can be post-tensioned to maximise spans

Table 1.1 continued

Slab type	Description	Advantages	Design considerations
Solid slabs on deep beams (or walls)	A solid slab, spanning in one direction only, can be supported on deep beams, but is more often supported by cross-walls. This form of construction is popular in residential buildings.	<ul style="list-style-type: none"> • Easy to install partitions • Holes can be formed • Low self-weight • Aesthetically pleasing soffit • Inherent robustness • Low deflection 	<ul style="list-style-type: none"> • Can be either cast in situ or precast • Not very practical for open plan spaces
Ribbed slab	A thin slab, supported by a number of ribs, or small downstand beams. Used to reduce self-weight, and formed by placing lightweight formers on the formwork. Historically, clay pots were widely used as permanent formers.	<ul style="list-style-type: none"> • Holes can be formed • Low self-weight • Aesthetically pleasing soffit • Low deflection • Inherent robustness • Reduces materials used 	<ul style="list-style-type: none"> • The ribs span in one direction and are supported by beams, which can be the same depth as the ribs to give a constant depth • Slow construction, due to the void formers and placing reinforcement between them
Waffle slab	Voids are introduced into the soffit of the slab, which are known as 'coffers'. These reduce the self-weight of the slab, enabling greater spans than a solid slab. The coffers are usually created using proprietary void formers.	<ul style="list-style-type: none"> • Easy services distribution • Holes can be formed • Low self-weight • Aesthetically pleasing soffit • Inherent robustness • Low deflections • Reduces materials used 	<ul style="list-style-type: none"> • Slow construction, due to the void formers and placing reinforcement between them • Usually supported directly on columns with coffers omitted immediately adjacent to the columns to increase the shear strength
Double 'T' units	A thin slab supported in narrow ribs, or beams. Units are usually 2.4 m wide with two ribs per unit. Structurally very efficient for long spans.	<ul style="list-style-type: none"> • Speed of construction • Economy • Structurally very efficient • Long spans • Holes can be formed • Low self-weight • Aesthetically pleasing soffit • Off-site construction 	<ul style="list-style-type: none"> • Although structurally very efficient, the depth is a significant factor for shorter spans • Beams required to support the units • Usually supplied with pre-camber, which increases with span
Two-way spanning slabs	Solid slabs spanning in two directions and supported on beams.	<ul style="list-style-type: none"> • Good for heavy loads • Long spans • Holes can be formed • Low self-weight • Inherent robustness • Low deflection 	<ul style="list-style-type: none"> • Often only used for long-span or heavily loaded situations because the formwork is complex.

Table 1.2 Preliminary span-to-depth ratios for various floor elements

Floor type	Span range (m)	Practical minimum thickness (mm)	Span-to-depth ratio			
			Single span	End bay	Multi-span	Cantilever
Flat slab	6–9	200			23–28	
Post-tensioned flat slab	7–12	200			26–40	
Flat slab with drops	6–12	200			23–30	
Flat slab with flared column heads	6–12	200			21–31	
Waffle slab	6–12	250			14–23	
Biaxial voided slab	7–12	150			20–35	
One-way slab	4–11	150	23–27	27–32		7–10
Beams	–	–	15–20		17–26	6–10
Slab supported by band beams	4–11	150		27–40	33–40	
Band beams	6–12	250	13–24		14–24	
Ribbed slab	6–12	250	17–24		17–27	
Lattice girder slab	4–9	150	20–30	23–35		
Hollowcore slab	4–16	150	24–45			
Precast double 'T' units	8–16	300	17–26			
Two-way slab	4–12	150	25–34	29–39		–

Notes:

1. The span-to-depth values given encompass a range of loads from 2.5 kN/m² to 10 kN/m²; a lower value should be used for the higher loads.
2. The span-to-depth values given cover a range of spans; as the span increases, a lower value should be used. The combination of high load and long span may be outside the range of span-to-depth values given and a more detailed check should be carried out.
3. For flat slabs, punching shear must also be checked; for small columns in particular, the slab depth may need to be increased to be economic.
4. Hollowcore units are often supplied to fixed depths, which can vary depending on supplier.
5. The use of composite toppings on hollowcore and double units could reduce the depth of the units required.

there are large openings on a particular floor. The designer should sketch out the load path for all lateral loads from their source down to their reaction in the ground. This will enable potential gaps in the structural resistance to be identified.

A moment frame relies on the stiffness of connections between vertical and horizontal members, so a frame with deep beams would have less deflection than one using flat slabs. It is generally considered that three storeys are a sensible maximum height for a moment frame, although clearly this will vary depending on the structural system, the floor-to-floor height and the depth of the floor plan (for more discussion on stability, see Chapter 3 of *Structural Design of Buildings: Holistic Design: Stability*).

Table 1.3 Preliminary column sizes (mm)

Percentage of reinforcement	Ultimate axial load (kN)								
	1000	1500	2000	3000	4000	5000	6000	8000	10 000
1.0%	250	300	350	400	475	525	575	650	725
2.0%	225	275	325	375	425	475	525	600	675
3.0%	225	250	300	350	400	450	500	550	625
4.0%	225	250	275	325	375	425	450	525	600

Notes:

1. Suitable for concrete class C30/37; higher strength will reduce the section sizes.
2. Suitable for internal columns, the following factors can be used to increase the vertical loads
 - Edge column – 1.5
 - Corner column – 2.0
3. Columns are not slender and are braced (i.e. not suitable for moment frames).

1.5. Detailed design

Before beginning the final design, the structural engineer should ensure that all the design data are assumed and available, including

- fixed geometry for structural elements
- finalised actions on the structure, especially finishes
- position of any openings
- fire-resistance periods
- any particular requirements for serviceability – for example, vibration limits
- material classes.

The guidance below follows the Eurocode 2 approach, which can then be applied as appropriate to various elements. [Figure 1.1](#) gives the overall design process for a phenomenon, rather than individual elements.

1.5.1 Cover

The reinforcement cover is an important aspect of concrete durability, bond and fire resistance, especially when exposed to an aggressive environment or for long fire periods. Accordingly, Eurocode 2 gives guidance on determining cover for

- bond
- durability
- fire resistance.

1.5.1.1 Bond

The cover requirements for bond are given in [Table 1.4](#).

1.5.1.2 Durability

The minimum cover for durability is denoted $c_{\min, \text{dur}}$ and can be determined from [Tables 4.1, 4.3, 4.4 and 4.5](#) of BS EN 1992-1-1 ([BSI, 2004a](#)). However, in the UK, [Tables 4.3 to 4.5](#) should not be used and BS 8500-1 ([BSI, 2006](#)) should be used instead.