Chapter 1

Introduction

Seismic design and Eurocode 8

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1.1 THE EUROCODES

The European directive 'Construction Products' issued in 1989 comprises requirements relating to the strength, stability and fire resistance of construction. In this context, the structural Eurocodes are technical rules, unified at the European level, which aim at ensuring the fulfilment of these requirements. They are a set of 58 standards compiled into 10 Eurocodes and provide the basis for the analysis and design of structures and the constitutive materials. Complying with Eurocodes makes it possible to declare the conformity of structures and construction products and to apply the Conformité Européenne (CE) marking to them (a requirement for many products, including most construction products, marketed within the European Union). Thus, Eurocodes constitute a set of standards of structural design, consistent in principle, which facilitates free distribution of products and services in the construction sector within the European Union.

Beyond the political goals pursued by the Union, the development of Eurocodes has also given rise to considerable technical progress, by taking into account the most recent knowledge in structural design, and producing technical standardisation across the European construction sector. The Eurocodes have been finalised in the light of extensive feedback from practitioners, since codes should reflect recognised practices current at the time of issue, without, however, preventing the progress of knowledge.

The methodology used to demonstrate the reliability (in particular safety assessment) of structures is the approach referred to as 'semi-probabilistic', which makes use of partial coefficients applied to actions, materials properties and covering the imperfections of analysis models and construction. The verification consists of analysing the failure modes of the structure, associated with limit states, in design situations with associated combinations of actions, which can reasonably be expected to occur simultaneously.

Inevitably, the Eurocodes took many years to complete, since to reach general consensus, it was necessary to reconcile differing national experiences and requirements coming from both researchers and practising engineers.

1.2 STANDARDISATION OF SEISMIC DESIGN

The first concepts for structural design in seismic areas, the subject of Eurocode 8 (EC8), was developed from experience gained in catastrophes such as those due to the San Francisco earthquake in 1906 and the Messina earthquake in 1908.

At the very beginning, in the absence of experimental data, the method used was to design structures to withstand uniform horizontal accelerations of the order of 0.1 *g*. After the Long Beach earthquake in 1933, the experimental data showed that the ground accelerations could be much higher, for instance 0.5 *g*. Consequently, the resistance of certain structures could be explained only by the energy dissipation that occurred during the movement of the structure caused by the earthquake. The second generation of codes took into account, on the one hand, the amplification due to the dynamic behaviour of the structures, and, on the other hand, the energy dissipation. However, the way to incorporate this dissipation remained very elementary and did not allow correct differentiation between the behaviour of the various materials and types of lateral resisting systems.

The current third generation of codes makes it possible, on the one hand, to specify the way to take the energy dissipation into account, according to the type of lateral resistance and the type of structural material used, and, on the other hand, to widen the scope of the codes, for instance by dealing with geotechnical aspects. Moreover, these new rules take into account the semi-probabilistic approach for verification of safety, as defined in EN 1990.

The appearance of displacement-based analysis methods makes it possible to foresee an evolution towards a fourth generation of seismic design codes, where the various components of the seismic behaviour will be better controlled, in particular those that relate to energy dissipation. From this point of view, EC8 is at the junction between the third generation codes, of which it still forms part of its present configuration, and of fourth generation codes.

1.3 IMPLEMENTATION OF EUROCODE 8 IN MEMBER STATES

The clauses of Eurocodes are divided into two types: (i) Principles, which are mandatory, and (ii) Application Rules, which are acceptable procedures to demonstrate compliance with the Principles. However, unless explicitly specified in the Eurocode, the use of alternative Application Rules to those given does not allow the design to be made in conformity with the code. Also, in a given Member State, the basic Eurocode text is accompanied for each of its parts by a National Annex specifying the values of certain parameters (Nationally determined parameters [NDPs]) to be used in this country, as well as the choice of methods when the Eurocode part allows such a choice. NDPs are ones which relate to the levels of safety to be achieved, and include for example partial factors for material properties. In the absence of a National Annex, the recommended values given in the relevant Eurocode can be adopted for a specific project, unless the project documentation specifies otherwise.

For the structures and in the zones concerned, the application of EC8 involves that of other Eurocodes. EC8 only brings additional rules to those given in other Eurocodes, to which it refers. Guides or handbooks can also supplement EC8 as application documents for certain types of structural elements.

To allow the application of EC8 in a given territory, it is necessary to have a seismic zoning map and associated data-defining peak ground accelerations and spectral shapes. This set of data, which constitutes an essential basis for analysis, can be directly introduced into the National Annex. However, in certain countries, seismic design codes are regulated by statute, and where this applies, zoning maps and associated data are defined separately by the national authorities.

1.4 CONTENTS OF EUROCODE 8

EC8 comprises six parts relating to different types of structures (Table 1.1). Parts 1 and 5 form the basis for the seismic design of new buildings and its foundations; their rules are aimed both at protecting human life and also limiting economic loss. It is interesting to note that EC8 Part 1 also provides design rules for base isolated structures.

Particularly because of its overlap with other Eurocodes and the cross-referencing that this implies, EC8 presents some difficulties at first reading. Although these can be easily overcome by a good comprehension of the underlying principles, they point to the need for application manuals to assist the engineer in design of the most common types of structure.

1.5 FUTURE DEVELOPMENTS

Although all the Eurocodes have undergone a rigorous process of development, drafting and revision before publication, it is only through their application by practicing engineers on real projects that areas for improvement become apparent, whether it is the need for clarification or omissions that should be addressed. Against this background, there is a need to collate comments from code users and compile these into a coherent list of improvements and developments to be implemented in future updates of the codes.

The current revision cycle for the Structural Eurocodes, including EC8, has already started in 2015/2016, but is likely to take at least five years before it is approved and made available to practicing engineers. Two revision mechanisms are involved, namely a ‘systematic review’ and an ‘evolution process’. The ‘systematic review’ takes the form of a line by line review of the code, focusing on clauses that require editorial or technical correction or improvement in clarity, on identifying aspects that need to be extended or shortened, or on clauses whose application may lead to excessive design effort or uneconomic construction. The ‘systematic review’ informs the ‘evolution process’ that incorporates the drafting of revisions including, where necessary, additional codified rules. The evolution process is nonetheless constrained by the need to maintain the ‘stability’ of the code, by avoiding radical changes, and by the desire to maintain ‘ease of use’ and to reduce the number of NDPs that are set separately by Member States.

Although the main emphasis in this book is on the existing provisions in EC8, the scope of several chapters extends beyond this in order to address specific aspects that are currently being addressed within the ‘evolution process’ of EC8. These aspects are clearly highlighted, where relevant, within the individual chapters.

Table 1.1 Parts of Eurocode 8

Title	*Reference*
Part 1: General Rules, Seismic Actions and Rules for Buildings	EN 1998-1:2004
Part 2: Bridges	EN 1998-2:2005
Part 3: Assessment and Retrofitting of Buildings	EN 1998-3:2005
Part 4: Silos, Tanks and Pipelines	EN 1998-4:2006
Part 5: Foundations, Retaining Structures and Geotechnical Aspects	EN 1998-5:2004
Part 6: Towers, Masts and Chimneys	EN 1998-6:2005

1.6 OVERVIEW OF THIS BOOK

Seismic design of structures aims at ensuring, in the event of occurrence of a reference earthquake, the protection of human lives, the limitation of damage to the structures and operational continuity of constructions important for civil safety. These goals are linked to seismic actions. Chapter 2 provides a detailed review of methods used in determining seismic hazards and earthquake actions. It covers seismicity and ground motion models, with specific reference to the stipulations of EC8.

To design economically a structure subjected to severe seismic actions, post-elastic behaviour is allowed. The default method of analysis uses linear procedures, and post-elastic behaviour is accounted for by simplified methods. More detailed analysis methods are normally only utilised in important or irregular structures. These aspects are addressed in Chapter 3, which presents a review of basic dynamics, including the response of single- and multi-degree of freedom systems and the use of earthquake response spectra, leading to the seismic analysis methods used in EC8. This chapter also introduces an example building, which is used throughout most of this book to illustrate the use of EC8 in practical building design. The structure was specifically selected to enable the presentation and examination of various provisions in EC8.

The design of buildings benefits from respecting certain general principles conducive to good seismic performance, and in particular to principles regarding structural regularity. The provisions relating to general considerations for the design of buildings are dealt with in Chapter 4. These relate to the shape and regularity of structures, the proper arrangement of the lateral resisting elements and a suitable foundation system. Chapter 4 also introduces the commonly adopted approach of design and dimensioning referred to as 'capacity design', which is used to control the yielding mechanisms of the structure and to organise the hierarchy of failure modes. The selected building introduced in Chapter 3 is then used to provide examples for the use of EC8 for siting as well as for assessing structural regularity.

Chapter 5 focuses on the design of reinforced concrete structures to EC8. It starts by describing the design concepts related to structural types, behaviour factors, ductility provisions and other conceptual considerations. The procedures associated with the design for various ductility classes are discussed, with particular emphasis on the design of frames and walls for the intermediate (medium) ductility class. In order to illustrate the design of both frames and walls to EC8, the design of a dual frame/wall lateral resisting system is presented and discussed.

The design of steel structures is discussed in Chapter 6. This chapter starts by outlining the provisions related to structural types, behaviour factors, ductility classes and cross-sections. This is followed by a discussion of the design procedures for moment and braced frames. Requirements related to material properties, as well as the control of design and construction, are also summarised. The example building is then utilised in order to demonstrate the application of EC8 procedures for the design of moment and braced lateral resisting steel systems.

Due to the similarity of various design approaches and procedures used for steel and composite steel/concrete structures in EC8, Chapter 7 focuses primarily on discussing additional requirements, which are imposed when composite dissipative elements are adopted. Important design aspects are also highlighted by considering the design of the example building used in previous chapters.

There has been a renewed interest in recent years for the use of timber as a main structural material largely due to a combination of the rising environmental concerns and the wider availability of newly developed high-performance timber-materials. Chapter 8 of this book starts by reviewing fundamental concepts of the cyclic behaviour of timber structures with particular emphasis on current building practices, followed by a summary of current EC8 provisions, which are still rather limited in scope. Finally the same example building used in previous chapters is used for illustrating the design of a laminated-timber shear-wall system.

Chapter 9 deals primarily with the seismic design of unreinforced masonry structures, although reinforced and confined masonry, for which limited guidance is provided in EC8, are also discussed. General structural behaviour and design concepts for the specific building typologies of reinforced, confined and unreinforced masonry are presented. The primary analysis methods available to design masonry structures are then discussed, followed by a design example that highlights the benefits and limitations of these analysis options. The eight-storey building considered in previous chapters could not be realistically used and, instead, an alternative three-storey unreinforced masonry building is considered in this chapter.

Seismic isolation involves the introduction of low lateral stiffness bearings to detune the building from the predominant frequencies of an earthquake. On the other hand, supplemental damping involves the addition of damping elements to the structure. EC8 covers seismically isolated structures in general, as well as specific rules for base isolation of buildings. In Chapter 10, background concepts on seismic isolation, types of devices available, numerical results and design criteria from EC8 are discussed and an illustrative example using the same case study building used in most chapters of this book is adopted. Moreover, although EC8 does not cover passive energy dissipation systems (supplemental damping) that are distributed over several storeys or levels, Chapter 10 includes a discussion of this topic together with a summary of available devices, as well as an outline of recommended design criteria for viscous and viscoelastic damping systems.

It is clearly necessary to ensure the stability of soils and adequate performance of foundations under earthquake loading. This is addressed in Chapters 11 and 12 for shallow and deep foundations, respectively. Chapter 11 provides background information on the behaviour of soils and on seismic loading conditions, and covers issues related to liquefaction and settlement. Focus is given to the behaviour and design of shallow foundations. The design of a raft foundation for the example building according to the provisions of EC8 is also illustrated. On the other hand, Chapter 12 focuses on the design of deep foundations. It covers the assessment of capacity of piled foundations and pile buckling in liquefied soils as well as comparison of static and dynamic performance requirements. These aspects of design are illustrated through numerical applications for the example building.

In the illustrative design examples presented in Chapters 3 through 12, reference is made to the relevant rules and clauses in EC8, such that the discussions and calculations can be considered in conjunction with the code procedures. To this end, it is important to note that this publication is not intended as a complete description of the code requirements or as a replacement for any of its provisions. The purpose of this book is mainly to provide background information on seismic design in general, and to offer discussions and comments on the use of EC8 in the design of buildings and their foundations.