Seismic Design of Concrete Buildings to Eurocode 8

Michael N. Fardis, Eduardo C. Carvalho, Peter Fajfar, and Alain Pecker

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Preface

The main aim of this book, published at the time Eurocode 8 is starting its course as the only seismic design standard in Europe, is to support its application to concrete buildings – the most common type of structure – through education and training. It is addressed to graduate or advanced undergraduate students who want to acquire the skills and knowledge that are necessary for the informed use of Eurocode 8 in their career, to practitioners wishing to expand their professional activity into seismic design with Eurocode 8, to instructors of such students or practitioners in University or professional training programmes, to researchers and academics interested in seismic analysis and design of concrete buildings, to software developers, code writers, to those with some official responsibility for the use and application of Eurocode 8, and so on. Besides its prime aim as support document for education and training in seismic design of concrete buildings with Eurocode 8, the book complements the currently available background documents for the present version of Eurocode 8 as far as RC buildings are concerned; as such, it will be useful for the coming evolution process of Part 1 of Eurocode 8.

The book puts together those elements of earthquake engineering, structural dynamics, concrete design and foundation/geotechnical engineering, which are essential for the seismic design of concrete buildings. It is not a treatise in any of these areas. Instead, it presumes that the reader is conversant with structural analysis, concrete design and soil mechanics/foundation engineering, at least for the non-seismic case. Starting from there, it focuses on the applications and extensions of these subject areas, which are necessary for the specialised, yet common in practice, seismic design of concrete buildings. Apart from these fundamentals, which are only covered to the extent necessary for the scope of the book, the book presents and illustrates the full body of knowledge required for the seismic design of concrete buildings – its aim is to provide to the perspective designer of concrete buildings all the tools he/she may need for such a practice; the reader is not referred to other sources for essential pieces of information and tools, only for complementary knowledge.

A key component of the book is the examples. The examples presented at the end of each chapter follow the sequence of its sections and contents, but often gradate in length and complexity within the chapter and from Chapter 2 to 6. Their aim is not limited to illustrating the application of the concepts, methods and procedures elaborated in the respective chapter; quite a few of them go further, amalgamating in the applications additional pieces of information and knowledge in a thought-provoking way. More importantly, Chapter 7 is devoted to an example of a close-to-real-life multistorey concrete building; it covers in detail all pertinent modelling and analysis aspects, presents the full spectrum of analysis results with two alternative methods and highlights the process and the outcomes of detailed design. Last but not least, each chapter from 2 to 6 includes problems (questions) without giving the answers to the reader. The questions are, in general, more challenging and complex than the examples; on average they increase in difficulty from Chapters 2 to 6 and – like most of the examples – often extend the scope of the chapter. Unlike the complete example in Chapter 7, which relies on calculations by computer for the analysis and the detailed design, the questions – and most of the examples – entail only hand calculations, even for the analysis. They are meant to be solved with help and guidance from an instructor, to whom the complete and detailed answers will be available. Moreover, the questions have been formulated in a way that provides flexibility to the instructor to tune the requirements from students to their background and skills, and possibly to extend them according to his/her judgement.

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Eduardo C. Carvalho graduated at the Technical University of Lisbon in 1974 as a civil engineer and obtained the specialist degree in structures by the National Laboratory for Civil Engineering (LNEC) in Lisbon in 1980. He received the Manuel Rocha Research award in 1982. He is a member of the Portuguese Academy of Engineering. He was a principal researcher at LNEC for 30 years, where he headed the Structural Analysis Division between 1981 and 1995 and the Centre for Earthquake Engineering between 1994 and 2004. Since 2005, he is the chairman of the CEN committee for Eurocode 8: 'Design of Structures for Earthquake Resistance' (CEN/TC250/SC8), after being its Secretary from 1990 to 2005. During this period he participated intensely in the preparation of Eurocode 8. He chairs the Portuguese mirror group for the implementation of Eurocode 8 in Portugal. He was a member of the Administrative Council of CEB-Comité Euro-Internationale du Béton (1995/1998) and is currently member of the Technical Council of federation internationale du béton (***fib***), having received the ***fib*** medal in 2009. He co-authored the book *Designers' Guide to EN1998-1 and EN1998-5: Eurocode 8* (Thomas Telford, 2005) and the book *Sismos e Edifícios* (*Earthquakes and Buildings*) (Edições Orion, 2008). He was one of the reviewers of the book *Seismic Design, Assessment and Retrofitting of Concrete Buildings* (Springer, 2009) by Michael N. Fardis. He is the chairman of Gapres, a structural design office in Lisbon.

Peter Fajfar is Professor of structural and earthquake engineering at the Faculty of Civil and Geodetic Engineering, University of Ljubljana, Slovenia. He is a member of the Slovenian Academy of Sciences and Arts, of the Slovenian Academy of Engineering and of the European Academy of Sciences (Belgium). He obtained his PhD from University of Ljubljana (1974). He was a visiting professor at McMaster University (1994), Stanford University (1995), University of Bristol (2006) and University of Canterbury (2009). He is the editor of the international journal *Earthquake Engineering and Structural Dynamics* (Wiley) since 2003 and a member of the editorial boards of four international journals. He is a honorary member of the European Association of Earthquake Engineering and was one of the Directors of the International Association of Earthquake Engineering (2004–2012). He was the president of the Yugoslav Association of Earthquake Engineering (1984–1988) and the founding president of the Slovenian Association of Earthquake Engineering (1988–1990). He authored several books in Slovenian and co-authored the first comprehensive book on earthquake engineering in former Yugoslavia. He is the co-editor of three books published by international publishers. In journals and conference proceedings, he has published more than 200 scientific papers. He has been active in the Technical committee TC250/SC8, responsible for the development of Eurocode 8. He was the leader of the implementation process of Eurocode 8 in Slovenia, the first country to implement Eurocode 8. As designer, consultant and reviewer, he has participated in more than 100 design projects, which have mainly dealt with static and dynamic analysis of buildings and civil engineering structures and the determination of seismic design parameters.

Alain Pecker is the president of Géodynamique et Structure, Professor of Civil Engineering at Ecole des Ponts ParisTech in France. He is a member of the French National Academy of Technologies, Honorary President of the French Association for Earthquake Engineering, former President of the French Association for Soil Mechanics and Geotechnical Engineering, one of the former Directors of the International Association of Earthquake Engineering (1996–2004) and is presently member of the Executive Committee of the European Association for Earthquake Engineering. He holds a degree in civil engineering from Ecole des Ponts ParisTech (formerly Ecole Nationale des Ponts et Chaussées) and an MSc from the University of California at Berkeley. He is president of the French committee for the development of seismic design codes and was a member of the drafting panel of EN 1998-5. He is an editorial board member of *Earthquake Engineering & Structural Dynamics*, *Bulletin of Earthquake Engineering*, *Journal of Earthquake Engineering* and *Acta Geotechnica*. He has 130 papers in international journals or conference proceedings. He has been a consultant to major civil engineering projects in seismic areas worldwide, most notably the Vasco de Gama bridge in Lisbon, the Rion Antirion bridge in Greece, the Athens metro, the Second Severn bridge in the United Kingdom, the Chiloe bridge in Chile and several nuclear power plants in France, South Africa and Iran. He has authored two books and co-authored three books, including *Designers' Guide to Eurocode 8: Design of Bridges for Earthquake Resistance* (ICE Publishing, 2012). He received the Adrien Constantin de Magny award from the French National Academy of Sciences (1994).

Contents

Chapter 1

Introduction

1.1 SEISMIC DESIGN OF CONCRETE BUILDINGS IN THE CONTEXT OF EUROCODES

As early as 1975, the European Commission launched an action programme for structural Eurocodes. The objective was to eliminate technical obstacles to trade and harmonise technical specifications in the European Economic Community. In 1989, the role of Eurocodes was defined as European standards (European Norms (EN)) to be recognised by authorities of the Member States for the following purposes:

- As a means for enabling buildings and civil engineering works to comply with the Basic Requirements 1, 2 and 4 of the Construction Products Directive 89/106/EEC of 1989, on mechanical resistance and stability, on safety in case of fire and on safety in use (replaced in 2011 by the Construction Products EU Regulation/305/2011 (EU 2011), which also introduced Basic Requirement 7 on the sustainable use of natural resources)
- As a basis for specifying public construction and related engineering service contracts; this relates to Works Directive (EU 2004) on contracts for public works, public supply and public service (covering procurement by public authorities of civil engineering and building works) and the Services Directive (EU 2006) on services in the Internal Market – which covers public procurement of services
- As a framework for drawing up harmonised technical specifications for construction products

It is worth quoting from EU Regulation/305/2011 of the European Parliament and the European Union (EU) Council (EU 2011), given its legal importance in the EU, which deals with the basic requirement for buildings and civil engineering works (called 'Construction works' in the following text) which the Eurocodes address:

> Construction works as a whole and in their separate parts must be fit for their intended use, taking into account in particular the health and safety of persons involved throughout the life cycle of the works. Subject to normal maintenance, construction works must satisfy these basic requirements for construction works for an economically reasonable working life.
>
> 1. Mechanical resistance and stability
>   Construction works must be designed and built in such a way that the loadings that are liable to act on them during their construction and use will not lead to any of the following:
>   (a) collapse of the whole or part thereof;
>   (b) major deformations to an inadmissible degree;

- (c) damage to other parts of the construction work or to fittings or installed equipment as a result of major deformation of the load-bearing construction;
- (d) damage by an event to an extent disproportionate to the original cause.

2. Safety in case of fire
   Construction works must be designed and built in such a way that in the event of an outbreak of fire:
   - (a) the load-bearing capacity of the construction work can be assumed for a specific period of time;
   - (b) the generation and spread of fire and smoke within the construction work are limited;
   - (c) the spread of fire to neighbouring construction works is limited;
   - (d) occupants can leave the construction work or be rescued by other means;
   - (e) the safety of rescue teams is taken into consideration.

[...]

4. Safety and accessibility in use
   Construction works must be designed and built in such a way that they do not present unacceptable risks of accidents or damage in service or in operation such as slipping, falling, collision, burns, electrocution, injury from explosion and burglaries. In particular, buildings must be designed and built taking into consideration accessibility and use for disabled persons.

[...]

7. Sustainable use of natural resources
   Construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:
   - (a) reuse or recyclability of the construction works, their materials and parts after demolition;
   - (b) durability of the construction works;
   - (c) use of environmentally compatible raw and secondary materials in the construction works.

Totally, 58 EN Eurocode Parts were published between 2002 and 2006, to be adopted by the CEN members and to be fully implemented as the sole structural design standard by 2010. They are the recommended European codes for the structural design of civil engineering works and of their parts to facilitate integration of the construction market (construction works and related engineering services) in the European Union and enhance the competitiveness of European designers, contractors, consultants and material and product manufacturers in civil engineering projects worldwide. To this end, all parts of the EN Eurocodes are fully consistent and have been integrated in a user-friendly seamless whole, covering in a harmonised way practically all types of civil engineering works.

In 2003, the European Commission issued a 'Recommendation on the implementation and use of Eurocodes for construction works and structural construction products' (EC 2003). According to it, EU member states should adopt the Eurocodes as a suitable tool for the design of construction works and refer to them in their national provisions for structural construction products. The Eurocodes should be used as the basis for the technical specifications in the contracts for public works and the related engineering services, as well as in the water, energy, transport and telecommunications sector. Further, according to the 'Recommendation', it is up to a Member State to select the level of safety and protection (which may include serviceability and durability) offered by civil engineering works on its national territory. To allow Member States to exercise this authority and to accommodate geographical, climatic and geological (including seismotectonic) differences, without