Chapter 1
Introduction

Andreas J. Kappos

Modern codes for seismic design of buildings, bridges, and other civil engineering structures offer to the designer the choice between elastic and inelastic analysis methods, i.e.

- 'Traditional' methods wherein design is based on the results of a series of *elastic* analyses that provide linear action effects (moments, shears, axial loads) which are reduced by a global force reduction factor (q-factor in Europe, R-factor in the US) that depends on the overall ductility and overstrength capacity of the structure.
- Displacement and/or deformation based methods, wherein inelastic deformation demands in the structure are estimated for a given level of the earthquake action (typically expressed in terms of the displacement of a control point of the structure) with the aid of a series of *inelastic* (i.e. material nonlinear) analyses of either the static or dynamic type. These demands are then checked against the corresponding deformation capacities of the critical structural elements.

Over the last two decades, researchers and engineers have gradually shifted towards the *performance-based assessment and design* concept, wherein inelastic deformation demands are (preferably) directly obtained from the aforementioned nonlinear response analysis of the structure. The safety verification then involves comparing these demands against the deformation capacities (acceptance criteria) to verify the performance of the structure with respect to a given performance objective (e.g. allowable member rotation for ensuring life safety under a ground motion having an appropriately selected probability of occurrence). It is worth noting that since inelastic analysis presupposes knowledge of the strength of members (which is not required in elastic analysis, unless member stiffness is

A.J. Kappos (✉)
Department of Civil Engineering, Aristotle University of Thessaloniki,
54124 Thessaloniki, Greece
e-mail: ajkap@civil.auth.gr

A.J. Kappos et al. (eds.), *Seismic Design and Assessment of Bridges: Inelastic Methods of Analysis and Case Studies*, Geotechnical, Geological and Earthquake Engineering 21,
DOI 10.1007/978-94-007-3943-7_1,

formally determined as the secant value at yield), applying such an analysis to a reinforced concrete structure requires an initial design to be carried out, from which member reinforcement will be selected. Hence, this type of analysis is more suitable for the assessment of existing structures than for the design of new ones.

This book focuses on the use of inelastic analysis methods for the seismic assessment and design of bridges, for which the work carried out so far, albeit interesting and useful, is nevertheless clearly less than that for buildings. It should be pointed out that although some valuable literature, including books like those by Priestley et al. (1996) and Chen and Duan (2003), is currently available, the most advanced inelastic analysis methods that emerged during the last decade are currently found only in the specialised research-oriented literature, such as technical journals and conference proceedings. Hence the key *objective* of this book is two-fold, first to present all important methods belonging to the aforementioned category in a uniform way and to a sufficient for their understanding and implementation length, and to provide also a critical perspective on them by including selected case-studies wherein more than one methods are applied to a specific bridge, as well as by offering some critical comments on the limitations of the individual methods and on their relative efficiency. The last point is a crucial one since, as will be made clear later in this book, 'simplified' inelastic methods, notably those based on static (as opposed to dynamic, response-history) analysis, were recently made quite sophisticated and able to handle problems hitherto tackled solely by dynamic analysis, but (perhaps inevitably) they also became quite complex, while the computational effort involved has increased to an extent that makes questionable the benefits (if any) gained by using these static methods in lieu of the dynamic one. Hence the material included in the book constitutes an aid for seismic design and assessment of bridges, presenting both the methods (Chap. 3) and the analytical tools (Chap. 2) available for their implementation, and providing guidance (Chap. 5) for selecting the method that best suits the specific bridge project at hand.

The main part of this book consists of Chaps. 2, 3 and 4. In ***Chap. 2*** the analytical tools necessary for the implementation of inelastic methods for bridges are presented. The chapter starts with available models for the bridge deck and their role in seismic assessment, addressing not only elastic modelling of the deck (which is the most commonly adopted approach) but also far less explored issues like the verification of deck deformation demands in cases that inelastic behaviour of the deck is unavoidable. Then the topic of modelling bearings and shear keys is presented, which is of paramount importance in the case of bridges, logically followed by the related issue of seismic isolation and energy dissipation devices; modelling of all commonly used isolation and dissipation devices is discussed and practical guidance is provided. The longest section in this chapter is devoted to inelastic modelling of different types of bridge piers, which is not surprising if one notes that piers (especially single-column or multi-column ones) are the bridge components wherein seismic energy dissipation takes place in non-isolated structures. All types of inelastic models for members, with emphasis on reinforced concrete columns, are presented in a rather detailed way, including both lumped plasticity and distributed plasticity models (distributed flexibility elements and fibre models of different types). Several examples of application of the previously mentioned models to bridges of varying complexity are provided and critically discussed. The last two sections of the chapter (Sects. 2.6 and 2.7) deal with modelling of the foundation of bridges and its interaction with the ground. Simple and more sophisticated models for abutments and (surface and deep) foundation members are provided, followed by models for the surrounding ground, with emphasis on the embankments that often play a crucial role in the seismic response of bridges, in particular short ones. Soil-structure interaction modelling of bridges is presented in both its commonly used forms, i.e. linear, as well as nonlinear soil-foundation-bridge interaction analysis in the time domain. These last sections of the chapter also include a brief overview of a major topic, i.e. the characteristics of seismic ground motion which is used as input for the analysis, the detailed presentation of which is beyond the scope of the book.

Chapter 3 is the core of the book, in the sense that it presents in a uniform way the available inelastic analysis methods for the seismic assessment and design of bridges. Since inelastic response-history analysis has long been used for bridges without substantial changes or developments during the last decade, it is presented in a rather brief and concise manner, leaving aside details of the numerical integration of the equations of motion that can be easily found in structural dynamics textbooks (e.g. Chopra 2006). On the contrary, inelastic static (pushover) methods, which have been the focus of extensive research in the recent years, particularly in the direction of extending them to structures with significant higher mode effects (a typical example being the transverse direction of many bridge types), occupy the largest part of the chapter. It should be noted that the methods described do not encompass all variations of pushover analysis techniques that deal with approximate ways for treating higher mode effects; instead, only those methods that have been specifically applied (after proper tailoring) to bridges have been selected. Having said this, the authors believe that the methods presented in Chap. 3 practically include all different approaches to the problem, and very few techniques are left outside on the grounds that they were used solely for buildings. To allow for a more rational presentation, the different methods are presented not in a strict chronological order, but by classifying them into ‘single-mode’ and ‘multi-mode’ pushover analysis procedures. In the first category the now well-known N2 method is described in sufficient length as a typical representative. Within the ‘multi-mode’ pushover category a distinction is made between

- procedures involving a series of *individual-independent* modal pushover analyses (among which the modal pushover analysis technique adapted to the needs of bridges is presented in detail)
- multi-mode procedures based on adaptive incremental implementation of response spectrum analysis for simultaneous modal pushover analyses (the IRSA method is described in detail), and
- multi-mode procedures based on single-run pushover analysis with modal-combined adaptive seismic load or displacement patterns (the ‘Adaptive Capacity Spectrum Method’ is presented as the most recent version of this approach)

Finally, a brief overview of an approach presented some time ago but not elaborated further ever since, the ‘Modal Adaptive Nonlinear Static Procedure (MANSP)’ is provided. For all major approaches to pushover analysis, which, as noted earlier, are only available in the specialised literature, an effort is made to describe them in such detail that would permit their implementation by the reader, provided, of course, that he/she has the appropriate analytical tools (cf. Chap. 2) and the expertise to use them. Practical application is also facilitated considerably by the information provided in the next chapter.

In ***Chap. 4***, the methods presented in the previous chapter are applied to specific case-studies, involving bridges with different length and configuration. The chapter starts with a critical discussion of the basic parameters that influence the applicability of pushover methods. Then, a number of case-studies are presented in a rather uniform and detailed way; they were selected among those available with a view to including at least one application of each category of methods described in the previous chapter and (wherever feasible) to applying two or more 'simplified' methods to the same bridge structure. In addition to a number of pushover analyses, all case-studies include also response-history analysis of the inelastic response of the bridge, which serves as a reference for evaluating the results of the various approximate (static) procedures. It is worth pointing out that in the case studies, in addition to the four pushover methods described in detail in Chap. 3, some other variants of the key approaches are also used and comparatively evaluated, so that at the end a more global picture of practically all analysis and assessment techniques available for bridges is provided. To allow for an even broader view on the issues involved and put the purely analytical methods into the proper perspective, the final section of Chap. 4 presents an experimental evaluation of analytical methods, i.e. results from analytical methods (response-history, as well as pushover) are compared with those from the shaking table testing (using three shaking tables) of a 1:4 scale bridge model.

The key conclusions regarding the range of applicability and the relative performance of the analytical assessment methods presented in the book are summarised in ***Chap. 5***, and some specific recommendations are made regarding the selection of analytical model and analysis method in a practical context. It must be emphasised that it is *not* the aim of this book to suggest the 'best' method of seismic assessment of bridges, since none of the existing methods would qualify as such; selection of analysis method is heavily problem-dependent and to a large extent available software-driven, while, in practical applications, code requirements also affect the selection of analytical tools.

References

Chen WF, Duan L (eds) (2003) *Bridge Engineering: Seismic Design (Principles and Applications in Engineering)*, CRC Press, Boca Raton

Chopra AK (2006) The dynamics of structures: theory and applications to earthquake engineering, 3rd edn. Prentice-Hall, Upper Saddle River

Priestley MJN, Seible F, Calvi GM (1996) Seismic design and retrofit of bridges. John Wiley and Sons, Inc (Editor), New York

http://www.springer.com/978-94-007-3942-0

Seismic Design and Assessment of Bridges
Inelastic Methods of Analysis and Case Studies
Kappos, A.J.; Saiidi, M.S.; Aydınoğlu, M.N.; Isaković, T.
(Eds.)
2012, XII, 224 p., Hardcover
ISBN: 978-94-007-3942-0