# Chapter 15
# Numerical Modeling of RC Bridges for Seismic Risk Analysis

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## ABSTRACT

*The main purpose of this chapter is to present numerical methodologies with different complexities in order to simulate the seismic response of bridges and then use the results for the safety assessment with one probabilistic approach. The numerical simulations are carried out using three different methodologies: (i) plastic hinge model, (ii) fiber model and (iii) damage model. Seismic response of bridges is based on a simplified plane model, with easy practical application and involving reduced calculation efforts while maintaining adequate accuracy. The evaluation of seismic vulnerability is carried out through the failure probability quantification involving a non-linear transformation of the seismic action in its structural effects. The applicability of the proposed methodologies is then illustrated in the seismic analysis of two reinforced concrete bridges, involving a series of experimental tests and numerical analysis, providing an excellent set of results for comparison and global calibration.*

## INTRODUCTION

It is during the occurrence of earthquakes that deficiencies, which cause a bad behavior of structures, has been highlighted and that can be drawn lessons with regard to design aspects that allow to provide

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it with a good seismic behavior.

Reports of seismic effects on reinforced concrete bridges, especially those built according to the codes of practice of the seventies, show that a lot of them behave poorly and have an inadequate safety assessment. Some efforts, therefore, must be made to accurately define bridge assessment and hence evaluate the need for reliable solutions to improve safety levels and behavior during seismic activity in the future.

In recent earthquakes it has been demonstrated that bridges and viaducts are structures that suffer extensive damage. Even in "moderate magnitude" earthquakes, the consequences in these structures have been very important, on many occasions causing their partial destruction or even total collapse, with correspondingly heavy costs. When compared, these consequences have been greater than those observed in current structures. Some examples of these earthquakes in the United States are the Loma Prieta (Soberón *et al.*, 1999; Priestley *et al.*, 1996) and the Northridge (Oliveira *et al.*, 1995), in Japan the Kobe earthquake (Legeron, 2000) and in China the Sichuan earthquake (ISSN, 2008), with a magnitude of 7.9 on the Richter scale and more than seventy thousand deaths.

The evaluation of seismic vulnerability of bridges, considering their nonlinear behavior (a necessary consideration when a realistic analysis of the seismic response is intended), involves enormous computing resources and corresponding calculation efforts. On the other hand, the development of research studies in this field has enabled a better understanding of their behavior, and the availability of numerical and experimental results allows the possibility of the calibration of simplified procedures.

However very high refined models could be adopted, involving a 3D space modeling and the spread of the plasticity along the member length as well as across the section area, in this work a substantially more simplified model (without losing accuracy) is also explored. This simplicity is evidenced by a much lower number of parameters involved and an enormous lesser computing time – about 50 times less when compared with a more refined model. Therefore, the adoption of such simplified model shows the great advantage, from the practical usage point of view, when a large number of analysis is needed, as is the case of vulnerability analysis.

In this chapter some methods for numerical analysis of bridges are suggested, from the simplest, with a reduced calculation time, to the more complex and detailed, obviously with longer time of analysis and computational demands. Thus, three different type of numerical models to analyze the seismic behavior of bridges are proposed: (i) models with nonlinearity concentrated in plastic hinges, (ii) fiber models with distributed nonlinearity and (iii) models based on continuous damage with distributed nonlinearity. One procedure for the seismic risk evaluation is also proposed, involving the calculation of the failure probability through a nonlinear transformation of the seismic action in its structural effects. The applicability of the proposed methodologies is then illustrated in two practical applications. In the first application, a static analysis of the piers is carried out, imposing cyclic displacements, in order to calibrate the hysteretic parameters that characterize the energy dissipation of the bridge piers. These parameters are used in the seismic analysis, defining the characteristics of the piers for the structural modeling of the bridge. In the second application, the structural modeling of the bridge is performed using two numerical models, both with plane bar elements, but with different consideration of the nonlinear behavior: concentrated in plastic hinges and plasticity distributed along the element. The cyclic behavior of the piers and the seismic response of the bridge are compared with experimental results, in order to evaluate the capacity of the models to assess the seismic behavior of reinforced concrete bridges. Finally, the structural seismic safety of the bridge is evaluated, with a probabilistic procedure (Duarte *et al.*, 1990), that compute the collapse probability through the convolution of the probability distribution of demand with the probability distribution of capacity.