Chapter 11
Nonlinear Static Analysis Method

ABSTRACT

This chapter presents the nonlinear static methods of analyses for seismic design of structures considered by Eurocode 8. The first method is the nonlinear pushover procedure, which is based on the N2 method. The second method is the classical nonlinear time history analysis. The first method is studied in more detail, because the second method is a well-established procedure whose only drawback is the time necessary for the analyses. Nonlinear solvers and procedure in program Z_Soil are described. After a simple nonlinear SDOF application, a test-bed application consisting of an existing two-story reinforced concrete building in Bonefro, Italy is used to compare the two nonlinear procedures. The selected building is representative of typical residential building construction in Italy in the 1970s and 1980s. The aim of this chapter section is to compare 2D and 3D procedures implemented in Z_Soil software. The second example is a 14-story reinforced concrete building designed according to the Algerian code using Sap2000 software.

INTRODUCTION

This chapter allows enlightening the reader, on an elegant method by its graphic power and the speed of diagnosing the existing or newly constructed structure called non-linear static method. By detailing all different steps, which allows the correct accomplishment of this method; and compare these results to those of time history analysis on a real structure example.

Modern seismic design codes allow engineers to use either linear or nonlinear analyses to compute design forces and design displacements. In particular, Eurocode 8 contains four methods of analysis: linear simplified static analysis, linear modal analysis, nonlinear pushover analysis and nonlinear time-history analysis, which can be summarized in the following table. These methods refer to the design and analysis of framed structures, mainly buildings and bridges. The two nonlinear methods require advanced models and advanced nonlinear procedures in order to be fully applicable by design engineers. This

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chapter gives an overview of the steps followed to implement state-of-the-art nonlinear models in Z_Soil and presents a test-bed application to a reinforced concrete building.

Displacement-based and force-base elements are used in this study. The first is a classical two-node, displacement-based, Euler-Bernoulli frame element. The second is a two-node, force-based, Euler Bernoulli frame element. The main advantage of the second element is that it is "exact" within the relevant frame element theory. This implies that one element per frame member (beam or column) is used in preparing the frame mesh, thus leading to a reduction of the global number of degrees of freedom. The complete theory for the force-based element can be found in (Aydinoglu. 2004).

The nonlinear response of 2D and 3D models of an existing building are presented as a first full-size application. The building is a residential two-storey reinforced concrete building in Bonefro, Italy(Belgasmia 2006), using Z_Soil software(Zimmermann 2006). It is representative of typical residential building construction in Italy in the 1970's and 1980's. The design spectrum for the building was obtained from Eurocode 8 (2003) using the local soil properties and the peak ground acceleration given by the new Italian seismic map.

Table 1. Summary of four methods analysis

Action **Structure**	*Static*	*Dynamic*
Elastic	*Remplacement Force*	*Response Spectrum*
Nonlinear	*Static nonlinear*	*Nonlinear Time- history*

ON-LINEAR FRAME ANALYSIS METHODS IN EUROCODE 8

In this section, the nonlinear pushover procedures given by Eurocode 8 are presented. The first procedure is the Nonlinear Pushover Method of Analysis; the second is the Nonlinear Time History Method of Analysis.

The nonlinear static analysis (or pushover analysis) consists in applying to the building the gravitational loads (which remain fixed). Then a system of horizontal forces that keeping unchanged the relative relationships between the same forces. This forces are all scaled to make the horizontal movement of a control point of the structure (for example a point at the top of the building) grow monotonic, until reaching the limit state of interest limit (usually the ultimate limit state, in some cases the collapse limit state). There are several pushover methodologies, some already present in today's seismic regulations, others under study and development. These methodologies are similar in the general philosophy of the method, but different in details and verifications. In this chapter, we will refer to the pushover methods of Eurocode 8 (2003).

According to EC8, pushover analysis may be used to verify the structural performance of newly designed buildings and of existing buildings. In particular, pushover analysis may be used for the following purposes:

1. To verify or revise the over-strength ratio values $\alpha u/\alpha 1$. The definition of the over-strength ratio is recalled with the aid of figure 1. If the structure is pushed with a lateral load distribution of con-

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