Preliminary Validation of a Multimodal Adaptive Procedure

Francesca BARBAGALLO
Ph.D. Student
University of Catania
Catania, Italy
fbarbaga@dica.unict.it

Melina BOSCO
Assistant Researcher
University of Catania
Catania, Italy
mbosco@dica.unict.it

Aurelio GHERSI
Professor
University of Catania
Catania, Italy
aghersi@dica.unict.it

Edoardo M. MARINO
Assistant Professor
University of Catania
Catania, Italy
emarino@dica.unict.it

Summary

The nonlinear static method of analysis is allowed by modern seismic codes for seismic assessment of existing buildings and Eurocode 8 suggests the N2 method developed by Fajfar *et al*. This method evaluates the performance curve of the structure by a pushover analysis and relates each point of this curve to a value of peak ground acceleration (a_g) through the equivalent SDOF system. One of the proposed variants of the original N2 method has been recently developed by Ghersi *et al*. It is a multimodal and adaptive procedure, which does not require the definition of the equivalent SDOF system and relates directly each point of the performance curve to the corresponding value of a_g. In this paper the procedure is applied to four steel moment resisting frames. Its effectiveness is investigated by comparing the obtained performance curve to that provided by the original N2 method and to the actual seismic response determined by incremental dynamic analysis. The performance curve is represented in terms of base shear (or peak ground acceleration) versus top displacement.

Keywords: nonlinear static method; adaptive procedure; existing structures, performance curve.

1. Introduction

Nonlinear static methods of analysis have become very popular tools for the assessment of existing buildings. The N2 method proposed by Fajfar *et al*. requires the evaluation of the base shear versus top displacement relationship (performance curve) and relates each point of this curve to the value of peak ground acceleration a_g. The base shear versus top displacement relationship is determined by pushover analysis. Then, as an intermediate step, a Single-Degree-Of-Freedom (SDOF) system equivalent to the examined structure is used to relate each point of the performance curve, and thus the displacement demand, to the value of a_g. The nonlinear static method of analysis proposed by Ghersi *et al*., here named "Displacement Adaptive Procedure" (DAP), permits to take into account the effect of higher modes of vibration and to update the modes of vibration at each step of the analysis so to consider the variation of the dynamic properties of the structure. Furthermore, DAP offers an important advantage because it relates directly the required top displacement to the corresponding peak ground acceleration. Thus, it allows a thorough vision of the structural behaviour with reference to several performance objectives, as now required by the most recent seismic codes. In order to validate the DAP, it is applied on a set of steel framed structures. The displacement demand is determined for different levels of seismic excitation by DAP, N2 method and incremental dynamic analysis (IDA). Then, the response prediction obtained by DAP is compared to that provided by the N2 method and to the "actual" seismic response obtained by IDA.

2. The Displacement Adaptive Procedure

DAP is described here with reference to a plane frame. The proposed approach involves the use of a multimodal response spectrum analysis with incremental seismic input. The procedure adopts a numerical model based on an ensemble of beam-column members with plastic hinges at their ends. The nonlinear analysis is carried out on the frame which already sustains gravity loads in seismic combination. A modal response spectrum analysis of the structure is performed at each (i-th) step of the analysis. The structural model is updated at the end of each step by replacing the yielded cross-section with a hinge. The elastic response spectrum corresponding to the considered soil type and scaled at a reference value of a_g, here assumed equal to unity, is used. The modal contributions to the response are determined and the maximum storey displacements are evaluated using a combination rule for modal responses. These displacements provide the load vector corresponding to a unitary a_g. This displacement profile is applied to the frame. The corresponding internal forces, for instance the bending moment $M_i^{a_g=1}$, are scaled by the Δa_g, cumulated to those attained at the end of the previous step ($M_{i-1}^{a_{g,i-1}}$) and equated to the yielding value (M_{pl})

$$M_i^{a_g} = M_{i-1}^{a_{g,i-1}} + \Delta a_g \, M_i^{a_g=1} = M_{pl} \tag{1}$$

This equation is solved for each end cross-section of all the members and the minimum value of Δa_g represents the increase of the peak ground acceleration ($\Delta a_{g,i}$) that causes the next plastic hinge. Finally, the a_g corresponding to the end of the current step $a_{g,i}$ is calculated as follows

$$a_{g,i} = a_{g,i-1} + \Delta\, a_{g,i} \tag{2}$$

Equation (1) is used for all the response parameters, assuming $\Delta a_g = \Delta a_{g,i}$ to evaluate the seismic response at the end of the i-th step. DAP analysis continues until a prefixed limit state is reached.

3. Validation of DAP and conclusions

A set of four steel moment resisting frames has been considered to assess the effectiveness of DAP. The frame 3ADH is 3-storey high and the frame 8CFL is 9-storey high. For both the frames columns are designed so that the two frames achieve a global collapse mechanism. Afterwards, the columns of the frames 3ADH and 8CFL are redesigned to sustain gravity loads only. This second design leads to frames (named 3ADHsm and 8CFLsm) that attain a soft storey collapse mechanism. The fundamental periods of the four considered frames range from 0,50 s (3ADH) to 2,90 s (8CFLsm). The validation involves two stages. First, the performance curve of the considered frames determined by the DAP is compared to that obtained by the N2 method, here applied considering two load patterns (horizontal forces proportional to the first mode of vibration and proportional to the storey masses) as specified in EC8. Second, the performance curve obtained by the DAP and N2 method is compared to the actual performance curve of the frames determined by IDA. The performance curves are considered in terms of base shear V_b and top displacement D_t, or peak ground acceleration a_g and D_t.

It was found that the performance curves, in terms of V_b and D_t, of the 3-storey frames obtained by DAP are virtually coincident with those provided by the N2 method with first mode load pattern. In fact, because the fundamental periods of these frames are not large the first mode of vibration basically captures the response. Furthermore, both the DAP and the N2 method lead to a base shear demand corresponding to a given top displacement close to that of the IDA. The base shear demand of the 9-storey frames obtained by DAP is significantly larger than that given by the N2 method applied with the first mode load pattern. This may be explained by the important contribution given by the higher modes of vibration to the total response of these long period structures, which is taken into account by DAP while it is neglected by the N2 method with the first mode load pattern.

For both the frames which exhibit a soft storey mechanism, the DAP and N2 method lead to the same top displacement demand for each value of a_g. The relation between a_g and D_t is basically linear and almost identical to that obtained by IDA. The DAP and N2 method provide the same top displacement demand also in the case of the 8CFL frame. In fact, its fundamental period falls in the displacement sensitivity region and thus, even in the inelastic range of behaviour, the top displacement increases with the peak ground acceleration according to the same linear relation. Finally, the relation between a_g and D_t is nonlinear for the 3ADH frame. This result is expected for low period frames that gradually experience inelastic deformation. In these cases because of the period elongation, the slope of the performance curve becomes lower. The period elongation is moderate in the case of N2 method and is more significant for DAP. As a consequence, DAP provides larger top displacement demand especially when the frame is well excited in the inelastic range of behaviour. Both the DAP and N2 method lead to a conservative estimation of the top displacement demand given by IDA for the frames designed to achieve a global mechanism.