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Evaluation of ASCE-41, ATC-40 and N2 static pushover methods based on optimally designed buildings

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ABSTRACT

Alternative static pushover methods for the seismic design of new structures are assessed with the aid of advanced computational tools. The current state-of-practice static pushover methods as suggested in the provisions of European and American regulations are implemented in this comparative study. In particular the static pushover methods are: the displacement coefficient method of ASCE-41, the ATC-40 capacity spectrum method and the N2 method of Eurocode 8. Such analysis methods are typically recommended for the performance assessment of existing structures, and therefore most of the existing comparative studies are focused on the performance of one or more structures. Therefore, contrary to previous research studies, we use static pushover methods to perform design and we then compare the capacity of the outcome designs with reference to the results of nonlinear response history analysis. This alternative approach pinpoints the pros and cons of each method since the discrepancies between static and dynamic analysis are propagated to the properties of the final structure. All methods are implemented in an optimum performance-based design framework to obtain the lower-bound designs for two regular and two irregular reinforced concrete building configurations. The outcome designs are compared with respect to the maximum interstorey drift and maximum roof drift demand obtained with the Incremental Dynamic Analysis method. To allow the comparison, also the life-cycle cost of each design is calculated; i.e. a parameter that is used to measure the damage cost due to future earthquakes that will occur during the design life of the structure. The problem of finding the lower bound designs is handled with an Evolutionary type optimization algorithm.

1. Introduction

Performance-based earthquake engineering has put forward the need for high level analysis procedures. Recent design codes and guidelines introduce comprehensive frameworks for dynamic and nonlinear analysis procedures [1–3]. The choice of the analysis procedure to be adopted depends on several parameters, such as the importance of the structure, the performance level, the structural characteristics (e.g. regularity, complexity, frequency properties), the amount of data available for developing a structural model, etc.

Static pushover analysis (SPO) requires a mathematical model that directly incorporates the nonlinear load-deformation characteristics of the individual components and the elements of a building. The structure is subjected to monotonically increasing lateral forces that represent the seismic inertia forces. Compared to nonlinear response history analysis (NRHA), Static Pushover (SPO) methods offer simplicity and reduced computational effort. Despite their ease-of-use, such methods can provide important information regarding the capacity of a structural system, while their limitation is mainly related to the level of violation of their underlying assumptions in real-life applications. The assumption that the response of a multi-degree-of-freedom system is directly related to the response of an equivalent single-degree-of-freedom (SDOF) system, in several cases, is not accurate enough, since apart from the fundamental mode, higher modes may contribute to the response. Furthermore, the lateral load pattern is usually applied without taking into consideration the member yielding and its influence on the modification of the building properties as the lateral forces are incremented.

A number of comparative studies assessing the performance of the methods have been published in the past. After the capacity spectrum method was adopted by ATC-40 [1], Fajfar [4] and Chopra and Goel [5] pointed out that the ATC-40 procedure significantly underestimated the deformation demands of systems for a wide range of periods when used for the Type A idealized hysteretic damping model. Furthermore, Lin et al. [6] compared the FEMA 273 [7] displacement coefficient method

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