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Assessment of modified consecutive modal pushover analysis for estimating the seismic demands of tall buildings with dual system considering steel concentrically braced frames

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ABSTRACT

According to the previous researches, conventional nonlinear static procedure (NSP), which is limited to single mode response, cannot predict the seismic demands of tall buildings with reliable accuracy. To estimate the seismic demands in upper stories for tall buildings the effects of higher modes should be included. In the recent years, developing traditional pushover analysis to consider the effects of higher modes conducted researchers to propose several methods, such as N2, MPA and MMPA procedures, that have a specific approach to estimate seismic demands of structures but the accuracy of them is doubtable for estimating of hinge plastic rotations. Recently consecutive modal pushover (CMP) procedure was proposed to consider the effects of higher modes with acceptable accuracy especially in prediction of hinge plastic rotations. The CMP procedure was limited to include two or three modes, and use of higher modes might cause some inaccuracy at results of upper stories. In CMP procedure, estimation of modal participating factors is important and choosing inadequate modes may cause large errors. In this paper some changes have been applied to the CMP procedure to improve accuracy of the results and the modified method is proposed and named modified consecutive modal pushover (MCMP) procedure. In this modified method the contribution of mode is used of effective modal participating mass ratio. The comparison of MCMP procedure to exact values derived by nonlinear response history analysis (NL-RHA) demonstrated the reliable predictions and it can overcome the limitations of traditional pushover analysis.

1. Introduction

Nonlinear static analysis, or pushover analysis, has been developed over the past decades and has become the common procedure for building evaluation and design verification; however the procedure involves certain approximations and simplifications. According to literature, the accuracy of pushover analysis in predicting seismic demands has been the controversial discussion, so the proposed approaches are leading researchers to achieve more accurate and reliable method; however nonlinear static procedures suffer a lot of limitations especially for high-rise buildings. The invariant load pattern is one of the most significant limitations of traditional methods, because the actual inertia force distribution changes continuously during seismic events due to higher mode contribution and structural degradation, which modifies the stiffness of individual structural elements and, consequently of the structure as a whole [1]. Therefore the effects of higher modes should be considered for estimating seismic demands of tall buildings.

Generally, using modal properties of the structure in nonlinear static analysis is most accessible approach to take into account the dynamic characteristics of the system. MMP (Multi Mode Pushover procedure) [2] was proposed to involve higher modes effects in pushover analysis. MMP provides better estimation of seismic demands comparing to traditional pushover methods based on load pattern using first mode. Although higher modes have being participated in MMP analysis, responses estimation and distribution of them over height of the structure were inadequate. More recently, PCR (Pushover Results Combination) [3] was proposed to consider the effects of higher modes. In this method several load patterns using mode shapes should be applied and then final responses would be determined as a weighted (using modal participation factors) summation of the results from each pushover analysis. MPA (Modal Pushover Analysis) [4] was developed to consider higher modes effects by analyze each mode as an equivalent single-degree-of-freedom (SDOF) system including nonlinear properties related to that mode. The MPA procedure was able to predict seismic demands with reliable errors at the level of displacements, but in order to calculate hinge plastic rotations MPA procedure had underestimate predictions. Then a modified version of the MPA (MMPA) [5] was proposed. The seismic demands of the structure were obtained by combining the inelastic response of first-mode pushover analysis with the elastic

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