Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(10) (2022) 997-1000
DOI: 10.22060/ceej.2020.18400.6866

Analytical Extension of Higher Modes Participation in The Estimation of Seismic Response of Tall Hybrid Framed Tube Structures comprising Mega Zipper Elements

M. Aboutalebi, A. Meshkat-Dini*, J. Keyvani-Ghamsari

Faculty of Engineering , Kharazmi University , Tehran , Iran

ABSTRACT: This paper presents a computational approach to the analytical performance of the modal pushover method (MPA) in predicting nonlinear response parameters of tall buildings comprising hybrid framed tube with large-scale zipper elements. The accuracy of the results based on MPA is evaluated by comparing the benchmark responses obtained through conducting two sets of nonlinear time history analyses (NLRHA). Also, the effects of higher modes on the structural response parameters are measured by considering three computational vectors of the ordered lateral loading prepared according to the participation of the basic mode, as well as the first 3 and 5 transitional modes, separately. In this study, the determination of the target displacement in MPA was set based on the results of NLRHA under two groups of near and far-field records. The variation range of response parameters of the three high-rise 30-story studied structures was evaluated based on conducting a series of MPA as well as NLRHA analyses. The structural system of the first studied model is a combined framed tube structure. The second and third introduced studied models contain a multi-story arrangement of large-scale zipper elements on the basic skeleton by connecting the aforementioned zipper elements to the columns on the ground floor. The multi-story arrangement of large-scale zipper elements has been aimed at preventing the formation of an intensive expanded plastic mechanism and avoiding the possible buckling mode in the columns of the lower floors. The computational outputs of the MPA are compared with the results of the NLRHA (as exact values) and the standard error percentage is estimated. Evaluation of the results presented in this study demonstrates the relatively desirable computational capability of the MPA method in predicting the behavior characteristics of tall building structures with a symmetric and regular rigid skeleton at plan and height. Moreover, it was observed that the presence of large-scale zipper elements in the resistant system could reduce the seismic response parameters and also relatively increases the overall dynamic stability of the high-rise structural skeleton.

Review History:

Received: May. 10, 2020
Revised: Aug. 10, 2020
Accepted: Aug. 17, 2020
Available Online: Oct. 27,2020

Keywords:

Nonlinear Analysis
Modal Pushover
Higher Modes
Tall Building
Near and Far-field Records

1. INTRODUCTION

Accurate evaluation of seismic demand parameters is one of the key pillars of the evolution of performance-based design methods. Nonlinear response history analysis (NLRHA) is a robust tool for calculating seismic demands, as well as for identifying plastic hinge mechanisms in structure [1]. However, the convergence trend of this analysis is affected by structural modeling parameters and input earthquake characteristics such as frequency content, intensity, and duration of the strong ground motion [2]. Therefore, it is inevitable to select a comprehensive set of earthquake records to fully describe the dynamic behavior of the site. This method will increase the computational efforts [3]. On the other hand, the pushover analysis, unlike nonlinear dynamic analysis, can provide valuable information about structural weaknesses and possible failure mechanisms in the inelastic range without the need for complex modeling and with less computational effort [4]. The pushover analysis method is useful in predicting seismic demands and evaluating the behavior of low-rise structures (the first mode is dominant). This has led to the development of analytical aspects of this method [5, 6].

Recently, extensive studies have been carried out on the assumptions and limitations of the pushover analysis method. An example of these studies is the proposed adaptive lateral force distribution that attempts to follow the time-variant distributions of inertia forces which is also considered more than the fundamental vibration mode to add higher mode effects [7]. These efforts have led to the development of nonlinear static analysis methods and computational techniques. Rooted in structural dynamics theory, the modal pushover analysis (MPA) has been developed to include the contributions of all modes of vibration that contribute significantly to seismic demands by Chopra and Goel [8].

This research investigates the analytical capability and effectiveness of the modal pushover method (MPA) in predicting the important responses of high-rise steel buildings

*Corresponding author's email: meshkat@khu.ac.ir

subjected to both far and near-field earthquake records. This was performed based on the comparison of the predicted values by MPA with the corresponding parameters obtained through comprehensive non-linear dynamic time-history analyses (NLRHA).

2. METHODOLOGY

In this research, three 30 story structural models with rigid castled tube resistant skeleton were selected and designed. The first studied model is classified as the basic structure with a castled tube structural system and is identified by the CT symbol. The second and third studied models are introduced by setting two different multi-level configurations of large-scale zipper elements in the structure of the basic model. The large-scale zipper elements are connected to one or two perimeter columns at the first story level and introduced with the symbols MZCT-1C and MZCT-2C, respectively.

The reason for setting a multi-story arrangement of large-scale zipper elements is preventing the formation of expanded plastic mechanism and block the occurrence of possible lateral-torsional buckling in the columns of lower stories. The connection of the large-scale zipper elements to the columns is considered flexurally rigid. The plan and configuration of the studied structures are shown in Figure 1. The studied structures were loaded and designed based on the Iranian national building codes (issues six and ten) as well as the standard 2800 (fourth edition) [9-11]. The assigned performance profiles of plastic hinges for the description of the non-linear behavior of structural elements have been adapted from the report FEMA 356 [12]. All of the nonlinear

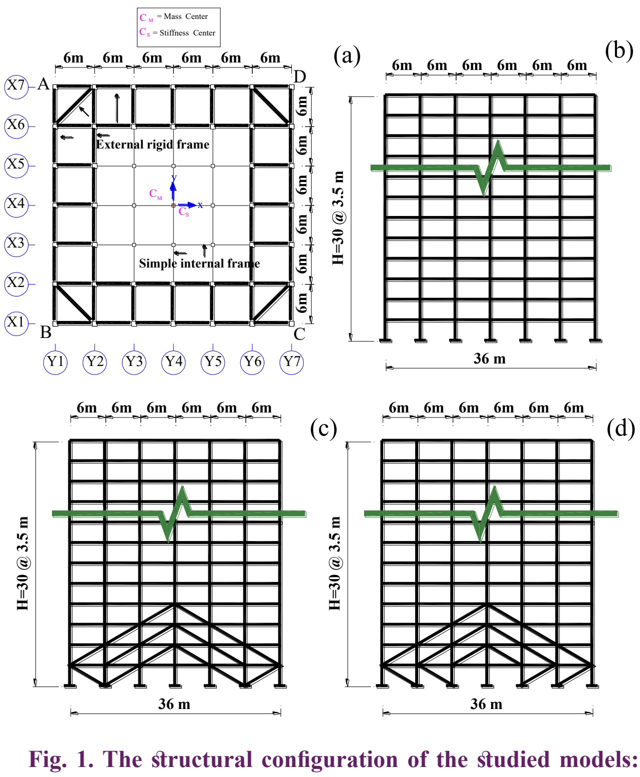

Fig. 1. The structural configuration of the studied models: (a) The plan of the castled tube skeleton; (b) The CT model; (c) The MZCT-1C model; (d) The MZCT-2C model

analyses were conducted through SAP2000 software [13]. The seismic tremors were selected in an ensemble of twelve earthquake records, including six far-field and six near-field ground motions which contain forward directivity effects. The main criterion in choosing these records is the existence of coherent pulses and high-amplitude spikes in the velocity time history caused by the powerful rupture directivity process [14, 15].

In this research, the response parameters of the studied structures CT and MZCT-1C and 2C (Figure 1) were obtained and assessed analytically through conducting NLRHA analyses. The other phase of this study was accomplished via performing modal pushover analyses subjected to assigned lateral load patterns corresponding to three separate participations of the essential mode (load case 1), the first three lateral modes (load case 2) and the first five lateral modes (load case 3). To investigate the accuracy of the MPA method in estimating seismic demands of the studied structures, the nonlinear dynamic responses were calculated under two sets of near and far-field records. These results were considered as the exact values. Then, MPA analyses were conducted for the studied structures under assigned lateral load patterns explained above. The target displacement value was set equal to the maximum lateral movement of the mass center CM at the top level (i.e., z=H) subjected to each record which is calculated through NLRHA analysis. Then, the mean value of the response parameters obtained via MPA was compared with the corresponding ones calculated through NLRHA analyses. The evaluation of the higher modes effects was investigated by assessing the calculated values related to the maximum lateral displacement of CM, the inter-story drift ratio and the maximum rotation of the plastic hinges formed in beam-columns, which all have been obtained via performing MPA and NLRHA analyses.

3. RESULTS AND DISCUSSION

One of the most important response parameters which control and evaluate the seismic behavior of tall buildings is the lateral drift. Figure 2 shows the drift ratios obtained from MPA using the different number of modes in addition to the NLRHA results for all three models subjected to selected near and far-field ground motion records. The computational results are for CT, MZCT-1C and MZCT-2C models, respectively. With the presence of zipper elements in the lower four floors of the structures, the relative lateral displacement ratio (lateral drift) in this section has decreased significantly by an average of 47%. There was also an average drop of 6% in the overall height of the resistant skeleton. The maximum value of the drift also decreased from 0.033 to 0.03, indicating an 8% drop. It is observed that in most cases, the estimated values obtained based on the assigned lateral load patterns are very close to the exact values and also close to each other. Comparison of the results of the three case studies shows that the presence of large-scale zipper configuration may reduce the need to consider the effect of modes above 3 without losing so much accuracy.

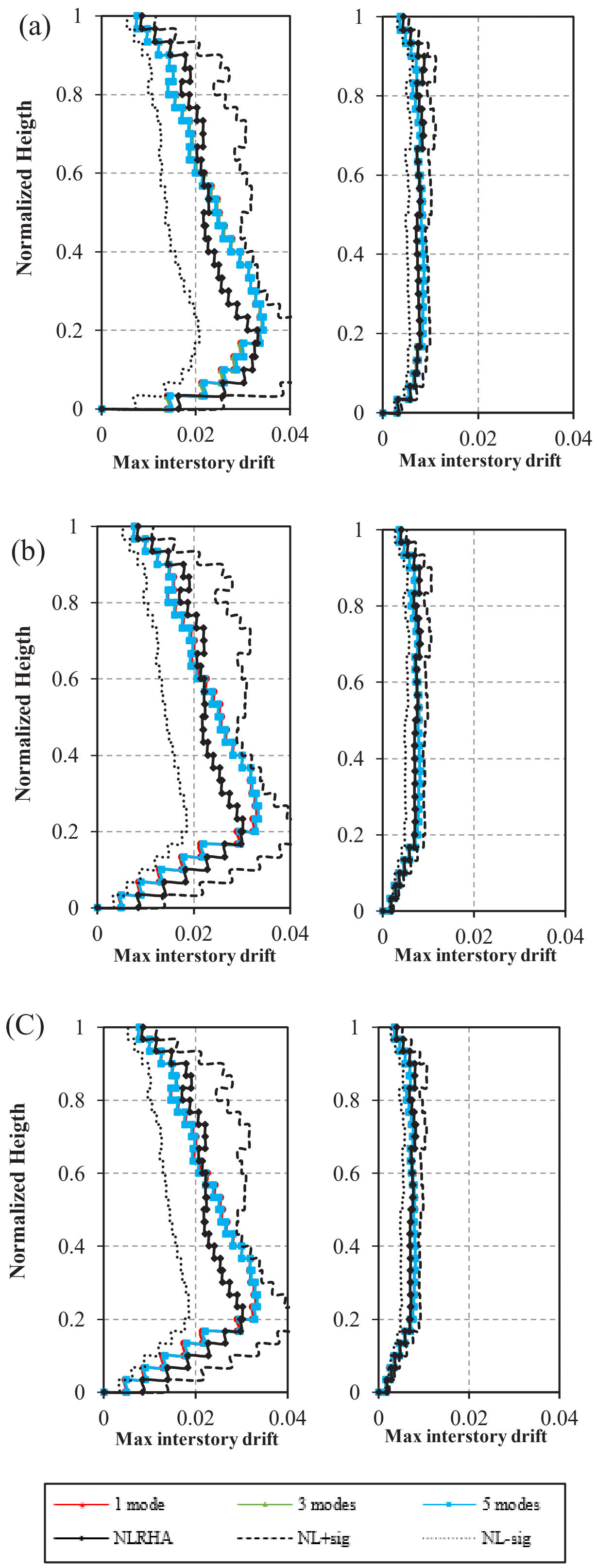

Fig. 2. The mean values of the maximum inter-story drift ratio related to the floor mass center (C_M) in the y-direction of the plan under near and far-field records respectively; (a) The CT model; (b) The MZCT-1C model; (c) The MZCT-2C model, (all of the above left and right diagrams are corresponding to the near and far-field records respectively)

4. CONCLUSIONS

This paper presents a computational approach to the analytical performance of the modal pushover method (MPA) in predicting nonlinear response parameters of tall buildings comprising hybrid framed tube with large-scale zipper elements. The accuracy of the results based on MPA is evaluated by comparing the benchmark responses obtained through conducting two sets of nonlinear time history analyses (NLRHA).

Evaluation of the results demonstrates the relatively desirable computational capability of the MPA method in predicting the behavior characteristics of tall building structures with symmetric and regular rigid skeleton at plan and height. Moreover, it was observed that the presence of large-scale zipper elements in the resistant system could reduce the seismic response parameters and it also relatively increases the overall dynamic stability of the high-rise structural skeleton.

Comparison of the results related to the three studied models shows that the presence of large-scale zipper elements relatively reduces the effects of higher modes in the analytical process of modal pushover procedure. Furthermore, the difference in the geometric arrangement of the mentioned elements would have little effect on the structural response parameters.

REFERENCES

[1] Kerawinkler, H., 2006. "Importance of good nonlinear analysis", *The Structural Design of Tall and Special Buildings*, 15(5), pp. 515-531.

[2] Tenchini, A., D'Aniello, M., Rebelo, C., Landolfo, R., Dasilva, L.S., Lima, L., 2014. "Seismic performance of dual-steel moment resisting frames", *Journal of Constructional Steel Research*, 101, pp. 437-454.

[3] Vafaee, M.H., Saffari, H., 2017. "A modal shear-based pushover procedure for estimating the seismic demands of tall building structures", *Soil Dynamics and Earthquake Engineering*, 92, pp. 95-108.

[4] Poursha, M., Khoshnoudian, F., Moghadam, A.S., 2008. "Assessment of modal pushover analysis and conventional nonlinear static procedure with load distributions of federal emergency management agency for high-rise buildings", *The Structural Design of Tall and Special Buildings*, 19, pp. 291-308.

[5] Vafaee, M.H., Saffari, H., 2016. "Evaluation of the higher modes contribution in the seismic demands of buildings subjected to far-field and near-field ground motions", *Asian Journal of Civil Engineering (BHRC)* 18(5), pp. 719-746.

[6] Kalkan, E., Kunnath, S.K., 2007. "Assessment of current nonlinear static procedures for seismic evaluation of buildings", *Engineering Structures*, 29(3), pp. 305-316.

[7] Ferraioli, M., 2017. "Multi-mode pushover procedure for deformation demand estimates of steel moment-resisting frames", *International Journal of Steel Structures*, 17(2), pp. 653-676.

[8] Chopra, A.K., Goel, R.K., 2004. "A modal pushover analysis procedure to estimate seismic demands for

unsymmetric-plan buildings", *Earthquake Engineering and Structural Dynamics*, 33(8), pp. 903-927.

[9] Building and Housing Research Center (BHRC), Iranian National Building Code, Issue 6, Design Loads for Buildings, 2015. (in Persian)

[10] Building and Housing Research Center (BHRC), Iranian National Building Code, Issue 10, Steel Structures, 2015. (in Persian)

[11] Standard No. 2800, Iranian code of practice for seismic resistant design of buildings (4th Edition), Tehran, Iran, 2014. (in Persian)

[12] Federal Energy Management Agency (FEMA), (1998), Prestandard and Commentary for the Seismic Rehabilitation of Buildings: Fema 356: Createspace Independent Publication.

[13] SAP 2000, Integrated Software for Structural Analysis and Design. Computers and Structures Institue (CSI), Berkeley, California

[14] Mukhopadhyay, S., Gupta, V.K., 2013. "Directivity pulses in near-fault ground motions - II: Estimation of pulse parameters", *Soil Dynamics and Earthquake Engineering*, 50, pp. 38-52.

[15] Mukhopadhyay, S., Gupta, V.K., 2013. "Directivity pulses in near-fault ground motions - I: Identification, extraction and modeling", *Soil Dynamics and Earthquake Engineering*, 50, pp. 1-15.

HOW TO CITE THIS ARTICLE

M. Aboutalebi, A. Meshkat-Dini, J. Keyvani-Ghamsari, Analytical Extension of Higher Modes Participation in The Estimation of Seismic Response of Tall Hybrid Framed Tube Structures comprising Mega Zipper Elements , Amirkabir J. Civil Eng., 53(10) (2022) 997-1000.

DOI: 10.22060/ceej.2020.18400.6866