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EXTENDED ABSTRACT

Evaluation of the Inelastic Deformation Demands in Regular Steel Frames by Comparing the Results of the Pushover Method with the Nonlinear Time Histories Analysis Under the Near-Fault Pulse-type Earthquake

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1. Introduction

In this research, the capability of elastic load patterns, including suggested patterns in prevalent seismic codes, and modified elastic patterns such as the Method of Modal Combinations (MMC) and the Upper-Bound Analysis (UPBA) in estimating the nonlinear demands of steel moment frame are evaluated by pushover method. Afterward the results of pushover analysis compared with the results of Nonlinear Time History Analysis (NTHA) affected by near-fault pulse-type ground motion. This study, not only tried to investigate the ability of load patterns to be used in pushover methods but also obtained different inelastic demands such as absolute displacement story (RD), Inter-story Drift Ratio (IDR), global ductility (μ_g) and story ductility (μ_s). Eventually, the error values of each load pattern were reported. The most important innovation of this research is the analytical study of the ability of various patterns of pushover methods against the values derived from nonlinear time history analysis (affected by near-fault earthquakes) in computing the parameters of the general and interstory deformation (which has been less consideration in previous studies) by applying the effect of higher modes.

2. Methodology

2.1. Experimental study

During the design of 4, 7, 15, 20 story special moment-resisting frames (SMRFs) with 3 spans (Fig.1), with the definition of 5 load patterns, the nonlinear demands are calculated for 4 levels of target interstory ductility (μ_t). In this study, OpenSEES software was used to perform static and nonlinear time history analysis. To determine the inelastic dynamic response of the structures, near-fault earthquakes with forward directivity effect and perpendicular to the fault component were used. All accelerograms are classified as pulse-type earthquakes based on the classification provided by Baker (Baker, 2007). Since the results of the pushover method are highly dependent on the load distribution pattern in height, it is, therefore, necessary to use the different number of load patterns derived from different assumptions. In this paper, five load distribution models are used. The three load patterns LP1, LP2, and LP3 are derived from FEMA356 (FEMA356, 2000). In the first pattern, the uniform mass distribution of the force corresponding to the structural mass is used. For the second pattern, all the models are first analyzed by spectral method (using the elastic mean spectrum obtained from 7 near-fault earthquakes). Then, the distributed force of the

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oscillating modes with the sum of the effective modal mass greater than 90% of the total mass of the structure was combined using SRSS in each story. In the third load pattern, LP3, the load distributed in height according to equation (1) is also used in the Iranian Code-2800 4th edition (Iranian Code of Practice for Seismic Resistant Design of Buildings, 2014).

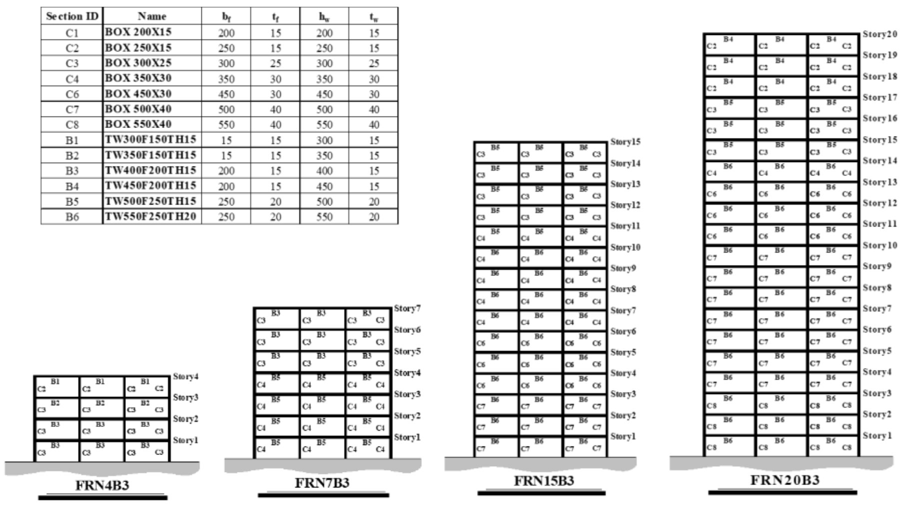
$$F_x = V \frac{w_x h_x^k}{\sum_{i=1}^{N} w_i h_i^k} \quad (1)$$

In equation (1) the w_x and h_x is the seismic weight of story x and the height of x-story from the base level. K is the value in which depends on the period of structure (between 1 to 2). To apply the effects of higher modes and to improve the elastic load distribution pattern in the pushover method, the fourth model of lateral loading based on the mode combination (MMC) proposed by Kalkan was used (Kalkan and Kunnath, 2004). In this method, the lateral force distribution at height is defined as follows:

$$F_j = \sum \alpha_n \Gamma_n m \phi_n S_a(\xi_n, T_n) \quad (2)$$

The fifth loading pattern, LP5, is used by the UPBA pushover analysis method (Jan et al., 2004). In this method, by using equation (4) the combined loading pattern of the first and second vibrational modes is calculated as a single load pattern:

$$F_j = \omega_1 m \phi_1 + \omega_2 m \phi_2 (q_2/q_1) \quad (3)$$



Section ID	Name	b_f	t_f	h_w	t_w
C1	BOX 200X15	200	15	200	15
C2	BOX 250X15	250	15	250	15
C3	BOX 300X25	300	25	300	25
C4	BOX 350X30	350	30	350	30
C6	BOX 450X30	450	30	450	30
C7	BOX 500X40	500	40	500	40
C8	BOX 550X40	550	40	550	40
B1	TW300F150TH15	15	15	300	15
B2	TW350F150TH15	15	15	350	15
B3	TW400F200TH15	200	15	400	15
B4	TW450F200TH15	200	15	450	15
B5	TW500F250TH15	250	20	500	20
B6	TW550F250TH20	250	20	550	20

Fig. 1. Details of the structural models used in the pushover & NTHA methods

3. Results and discussion

As previously mentioned a set of general interstory and local needs (including deformation and rotation) have been calculated and compared. Some of the results of this research are shown in Fig. 2 to 4.

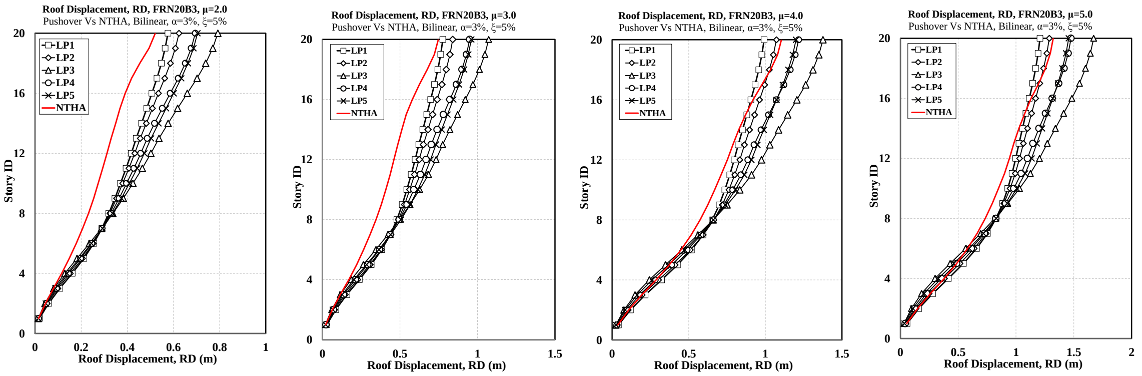


Fig. 2. Floor displacement height-wise distribution for different load patterns vs the mean NTHA in a 20-story frame-ductility demand of 2, 3, 4, and 5

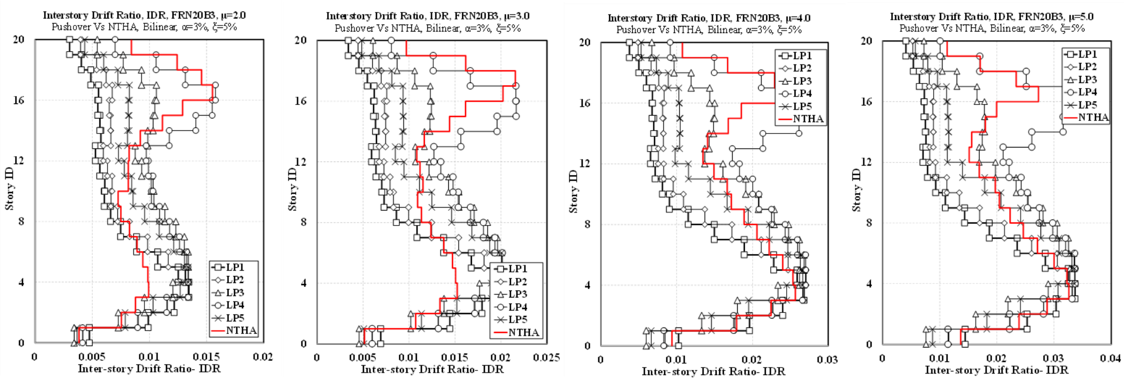


Fig. 3. Interstory drift height-wise distribution for different load patterns vs the mean NTHA in a 20-story frame- ductility demand of 2, 3, 4, and 5

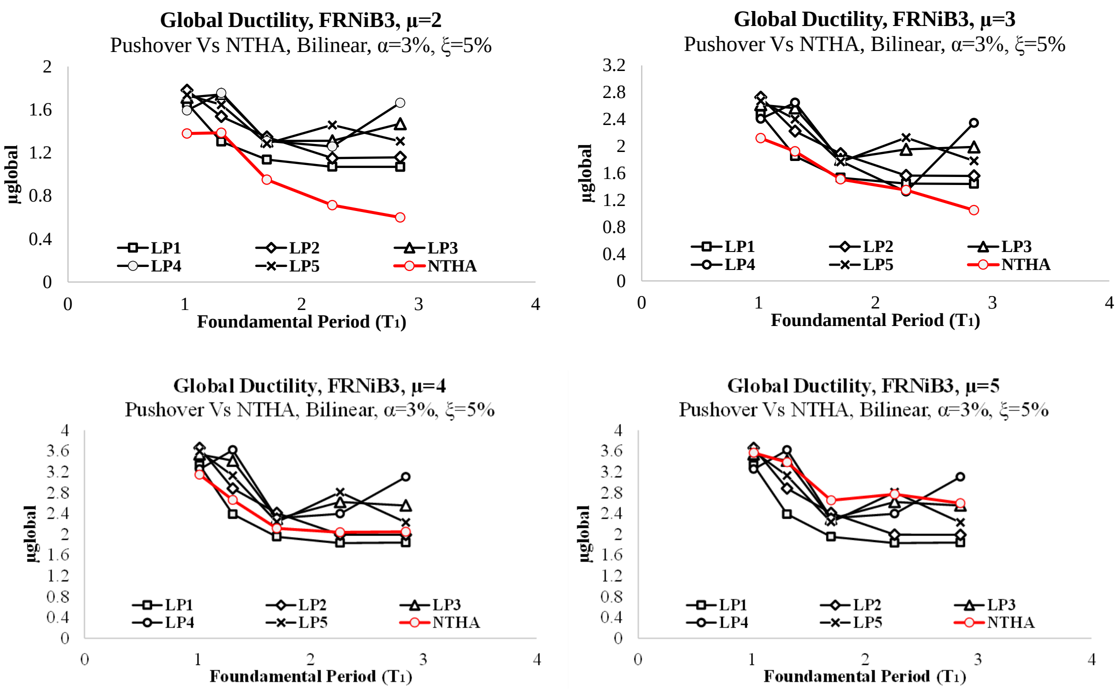


Fig. 4. Global ductility variations for different load patterns compared to the mean NTHA in terms of ductility

To capture the MMC capability in estimating IDR against the value resulting from NTHA, the error distribution over the height of models has been calculated via equation (5) for different ductility values. The results have been depicted in Fig. 5.

$$Error(\%) = \left|\frac{IDR_{NTHA} - IDR_{MMC}}{IDR_{NTHA}}\right| \times 100 \tag{4}$$

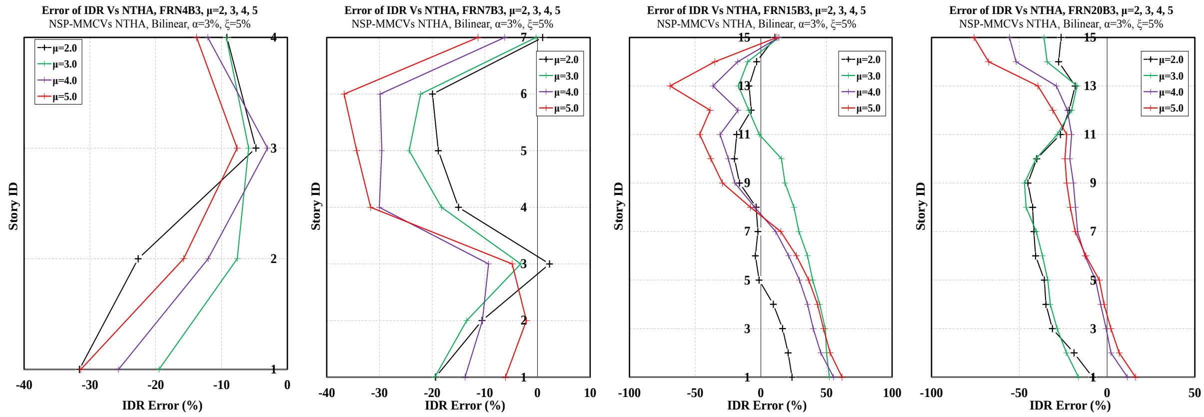


Fig. 5. The error of MMC load pattern to calculate IDR for different interstory ductility against NTHA

4. Conclusions

The results of the models of this study show that with increasing μ_t, the tendency of the structure to oscillate in the first mode has increased and all the load patterns can be calculated the story deformation in the bottom 25% of the structure independently of the number of stories. However, the drift interstory derived from the MMC method has the best accuracy. Moreover, with increasing μ_t, the accuracy of this method decreases. As with the increasing elevation of the structure, the IDR is lower in some stories, and in some cases, it is higher than the NTHA values. Also, with increasing μ_t, the accuracy of all load patterns was increased determining the position of the critical story corresponding to the interstory ductility, so that the MMC method has the best conformity with the distribution of interstory ductility in elevation.

5. References

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