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Accuracy Investigation of CSM-DAP Method in Comparison with FEMA356 Method for Estimating Seismic Demands of Steel Moment Resisting Frames with Geometric Irregularity in Elevation

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ABSTRACT: Estimating seismic demands of structures has acquired renewed importance as a result of recent interests in performance-based seismic design. Consequently, in recent years, different equivalent nonlinear static analysis procedures have been developed to estimate structural seismic demands. However, just a few studies have been conducted to examine the accuracy and adequacy of these developed methods. Thus, it is necessary to conduct thorough investigations of these methods' limitations, possible shortcomings, and their performance. In this paper, the accuracy of the CSM-DAP method in comparison with the FEMA356 method was evaluated for estimating seismic demands of low-rise steel moment resisting frames with geometric irregularity in elevation. The CSM-DAP method is an equivalent displacement-based adaptive nonlinear static analysis method combined with the FEMA440 capacity spectrum method. The CSM-DAP and FEMA356 methods were used to analyze 44 five-story moment-resisting frames subjected to 14 far-field earthquake ground motions and their results were compared with the results of nonlinear dynamic analyses. The selected sample includes a wide range of geometric irregularities in elevation for low-rise structures. The estimated demand responses were namely roof displacement, inter-story drift ratio, and base shear. This study showed that considering the CSM-DAP computational effort, this method did not present significant advantages with respect to the FEMA356 method at least for low-rise structures with geometric irregularity in elevation.

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1. INTRODUCTION

Estimating seismic demands of structures is one of the important steps for the performance-based seismic design of new structures and seismic rehabilitation of as-built Buildings. Although the most accurate seismic analysis for estimating the seismic demands of a structure is the nonlinear time-history analysis, it is not practical for day-to-day design due to the high computational intensity, needs for ground motions, and the difficulty of interpreting its results. The equivalent nonlinear static analysis is one of the tools that can be used for this purpose and it has been considered and developed by researchers over the past two decades. Although different equivalent nonlinear static analysis procedures have been developed in recent years, just a few studies have been conducted to examine the accuracy and adequacy of these developed methods.

In the present paper, the accuracy of displacement-based adaptive equivalent nonlinear static analysis [1] combined with the FEMA440 [2] capacity spectrum method (CSM-DAP[1]) in comparison with the FEMA356 [3] method was evaluated for estimating seismic demands of low-rise steel moment resisting frames with geometric irregularity in elevation. The estimated demand responses were namely base shear, roof displacement, and inter-story drift ratio.

2. METHODOLOGY

The CSM-DAP and FEMA356 methods were used to analyze 44 five-story steel moment resisting frames (SMRFs) subjected to 14 far-field earthquake ground motions and their results were compared with the results of nonlinear dynamic analyses. The selected sample was contained a wide range of geometric irregularities in elevation for low-rise structures. The geometry of these SMRFs was selected from Mazolani et al. [4,5] researches as is shown in Figure 1. Each frame was designed to represent the low and high values of strength ratio (R-factor). More details of these frames are not presented here for the sake of space consideration. For more information, one can refer to [6]. The above-mentioned earthquake

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1 Capacity Spectrum Method-Displacement Adaptive Pushover

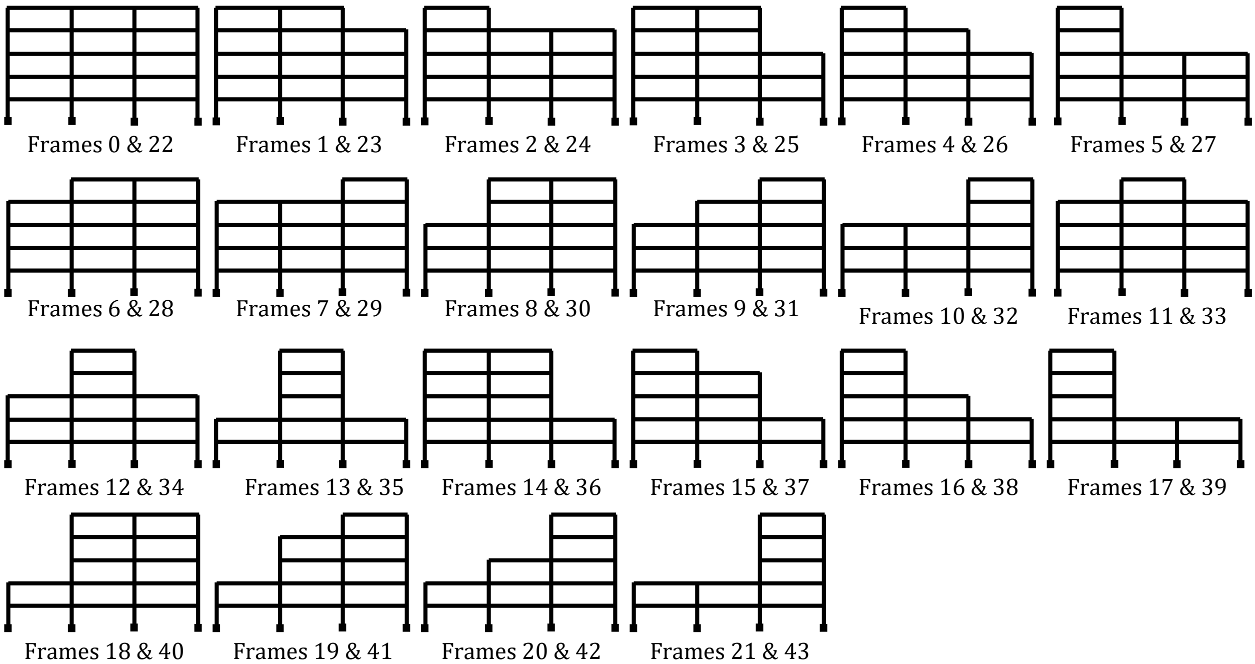

Fig. 1. The geometry of steel moment resisting frames considered in this research

Table 1. Main properties of the considered ground motions

No.	Earthquake name	ID	Station	Magnitude	Distance (km)	PGA (g)
1	Chi-Chi, Taiwan	CHY101W	CHY101	7.6	11.14	0.353
2	Chi-Chi, Taiwan	CHY101N	CHY101	7.6	11.14	0.440
3	Imperial Valley	E11230	5058 El Centro Array #11	6.5	12.60	0.380
4	Imperial Valley	E11140	5058 El Centro Array #11	6.5	12.60	0.364
5	Loma Prieta	G03000	47380 Gilroy Array #3	6.9	14.40	0.555
6	Loma Prieta	G03090	47380 Gilroy Array #3	6.9	14.40	0.367
7	Northridge	CNP106	90053Canoga Park-Topanga Can	6.7	15.80	0.356
8	Northridge	CNP196	90053Canoga Park-Topanga Can	6.7	15.80	0.420
9	Superstition Hills	ICC000	01335 El Centro Imp. Co. Cent	6.5	13.90	0.358
10	Superstition Hills	ICC090	01335 El Centro Imp. Co. Cent	6.5	13.90	0.258
11	Northridge	LOS000	90057Canyon Country-W Lost C.	6.7	13.00	0.410
12	Northridge	LOS270	90057Canyon Country-W Lost C.	6.7	13.00	0.482
13	Loma Prieta	G02000	47380 Gilroy Array #2	6.9	12.70	0.367
14	Loma Prieta	G02090	47380 Gilroy Array #2	6.9	12.70	0.322

ground motions were selected from the strong ground motion database of the Pacific Earthquake Engineering Research Centre (http://ngawest2.berkeley.edu/site). The main properties of the considered earthquake ground motions are summarized in Table 1. These ground motions were scaled using the procedure suggested by FEMA356 [3] while the design spectrum was as recommended in the Iranian code of practice for the seismic-resistant design of buildings (standard No. 2800) [7] for site class III.

To evaluate the accuracy of each equivalent nonlinear static analysis method the following error measure (relative error) is computed:

$$Err_i\,(\%) = \frac{Q_i^{NSA} - Q_i^{NDA}}{Q_i^{NDA}} \times 100 \qquad (1)$$

where Q_i^{NDA} is the nonlinear time history response (such

Table 2. Summary of the results obtained from this investigation

Seismic Response	Investigated Statistical Parameter	FEMA356 Method	CSM-DAP Method
Roof Displacement	Pearson product-moment correlation coefficient (ρ)	0.88	0.81
	Percentage of the cases that the response is conservatively estimated	43%	63%
	Variation of median of relative errors for different MRFs	-17.54% ~ 9.34%	-7.06% ~ 59.95%
	Median of relative errors for all MRFs	-3.00%	10.52%
	Variation of standard deviation of relative errors for different MRFs	13.77% ~ 36.37%	14.07% ~ 58.83%
	The standard deviation of relative errors for all MRFs	22.99%	36.00%
Base Shear	Pearson product-moment correlation coefficient (ρ)	0.98	0.95
	Percentage of the cases that the response is conservatively estimated	67%	16%
	Variation of median of relative errors for different MRFs	-4.14% ~ 24.01%	-26.21% ~ -0.08%
	Median of relative errors for all MRFs	4.89%	-10.61%
	Variation of standard deviation of relative errors for different MRFs	3.11% ~ 19.54%	6.44% ~ 25.56%
	The standard deviation of relative errors for all MRFs	15.46%	16.01%
Inter-Story Drift Ratio	Pearson product-moment correlation coefficient (ρ)	0.68	0.76
	Percentage of the cases that the response is conservatively estimated	48%	28%
	Variation of median of relative errors for different MRFs	-66.70% ~ 150.63%	-46.75% ~ 196.18%
	Median of relative errors for all MRFs	-2.81%	-21.05%
	Variation of standard deviation of relative errors for different MRFs	3.66% ~ 121.08%	12.69% ~ 145.97%
	The standard deviation of relative errors for all MRFs	60.78%	44.27%

as base shear, roof displacement, and inter-story drift ratio) of the frame subjected to the *i*th ground motion and Q_i^{NSA} is the analogous response, resulted from the equivalent nonlinear static procedure for the frame subjected to the *i*th ground motion. If the relative error is negative ($Err_i < 0$), the equivalent nonlinear static procedure underestimates the response, while $Err_i > 0$ means that the method overestimates the response.

The precision of each equivalent nonlinear static analysis method was measured by the standard deviation of the relative errors which is computed as follows:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(Err_i - \overline{Err}\right)^2}{n-1}} \tag{2}$$

where Err_i is the relative error of demand response of the frame subjected to the *i*th ground motion and $\overline{Err}$ is the average of Err_i for all ground motions. *n* is the number of ground motions used for each frame.

In this research, the Pearson product-moment correlation coefficient, ρ, was also used which is computed as follows:

$$\rho = \frac{\sum_{i=1}^{m}\left(Q_i^{NDA} - \bar{Q}^{NDA}\right)\left(Q_i^{NSA} - \bar{Q}^{NSA}\right)}{\sqrt{\sum_{i=1}^{m}\left(Q_i^{NDA} - \bar{Q}^{NDA}\right)^2} \times \sqrt{\sum_{i=1}^{m}\left(Q_i^{NSA} - \bar{Q}^{NSA}\right)^2}} \tag{3}$$

where *m* is the total number of data, $\bar{Q}^{NDA}$ is the average of *m* nonlinear dynamic analysis response, and $\bar{Q}^{NSA}$ is the average of *m* nonlinear static analysis response. This coefficient is the measurement of correlation and ranges between +1 and -1. $\rho = 0$ indicated no relationship between the two measures, $\rho = +1$ indicated the strongest positive correlation possible and $\rho = -1$ indicated the strongest negative correlation possible.

3. RESULTS AND DISCUSSION

Summary of the results is presented in Table 2. Based on the median and the standard deviation of the roof displacement errors, it can be concluded that the accuracy and precision of FEMA356 were better than the CSM-DAP method for the estimation of roof displacements. Using the FEMA356 method for estimate base shear resulted in an overestimate value in most cases, while the CSM-DAP method was underestimated base shear in most cases. The estimated base shear using both CSM-DAP and FEMA356 methods had a very good correlation with the base shear obtained from the nonlinear dynamic analysis. Using the CSM-DAP method for estimating the inter-story drift ratio resulted in more un-conservative predictions compared to the FEMA356 method. The correlation between the estimated inter-story drift ratios using any of the nonlinear static analysis methods and those obtained from the nonlinear dynamic analysis was not suitable.

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4. CONCLUSIONS

This study showed that considering the CSM-DAP computational effort, this method did not present significant advantages with respect to the FEMA356 method at least for low-rise structures with geometric irregularity in elevation.

REFERENCES

[1] Antoniou S., Pinho R., 2004. “Development and verification of a displacement-based adaptive pushover procedure”. *Journal of Earthquake Engineering*, 8, pp. 643-661.

[2] Applied Technology Council (ATC), 2005. *FEMA 440: Improvement of Nonlinear Static Seismic Analysis Procedures*, Federal Emergency Management Agency (FEMA), Washington, D.C.

[3] American Society of Civil Engineers (ASCE), 2000. *FEMA 356: Prestandard and Commentary for the Seismic Rehabilitation of Building*, Federal Emergency Management Agency (FEMA), Washington, D.C.

[4] Guerra C.A., Mazzolani F.M., Piluso V., 1990. “On the seismic behaviour of irregular steel frames”. In 9th European Conference on Earthquake Engineering, Moscow.

[5] Mazzolani F.M., Piluso V., 1996. *Theory and Design of Seismic Resistant Steel Frames*. First ed., E & FN Spon, London.

[6] Karimi M., 2010. “Evaluation of Equivalent Nonlinear Static Analysis for Irregular Steel Moment Resisting Frames using Capacity Spectrum Method with Displacement-Based Adaptive Pushover Analysis”. MS Thesis, Shiraz University, Shiraz, Iran.

[7] Permanent Committee for Revising Standard No. 2800, 2015. *Iranian Code of Practice for Seismic Resistant Design of Buildings*. 4 ed., Road, Housing and Urban Development Research Center, Tehran, Iran.

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