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Studying Higher Mode Effects on the Performance of Nonlinear Static Analysis Methods Considering Near-Fault Effects

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Abstract

Daily development in civil engineering arena and the importance of economical aspects in the design of structures have motivated the engineers to shift their approaches from designing upon strength to designing upon performance. This is of more importance regarding the forces induced by earthquakes which have unpredicted and random nature. However, it is not possible to design or assess exactly the structural performance against strong ground motion using analytical methods which are applied for static loads and therefore precise dynamic analysis methods are needed. Despite significant progress in the analytical methods and engineering software, using nonlinear time history analysis is very difficult for engineers and designers due to unpredictable nature of future ground motions as well as complicated behaviour of structures. Consequently, the substituting methods are presented upon nonlinear static analysis. Coefficient method and capacity spectrum method, presented by FEMA356 and ATC40, respectively, are of this kind that have been used in the recent years and modified by newer documents such as FEMA440. Despite acceptable results, neglecting some important items, such as higher mode effects which can be decisive in tall and specific structures, made offering other procedures like Modal Pushover Analysis (MPA). In this study, the performance abilities of nonlinear static methods are studied in order to assess the dynamic response of structures under both far- and near-fault earthquake records. For this purpose, two reinforced concrete frames of 5 and 15 stories are analyzed by a series of nonlinear static and dynamic analyses. Analysis results show that conventional nonlinear static analysis methods cannot estimate accurately the deformation demands of tall building structures, particularly in the higher stories, due to the effects of higher modes. Although MPA method has almost improved the results, yet it has not high accuracy regarding near-fault earthquake records.

Keywords: *nonlinear static analysis, dynamic responses of structures, higher modes, seismic performance, far-fault records, near-fault records*

1. Introduction

The applications of advanced static and dynamic analysis methods have been progressed in accordance with the daily improvement in the structural analysis software. Despite these developments, nonlinear dynamic analysis of structures is not usual due to the human beings' knowledge deficiencies in precise prediction of seismic shocks which affect the structures in the future. Therefore, it is attempted to use the proper substitutions that have simplicities and adequate accuracies.

Nonlinear static analysis is one of the most capable methods in the evaluation of structures which has been used in the codes, documents and papers (ATC 40, 1996; FEMA 356, 2000; FEMA 440, 2005). Although this method has high capability in estimating the seismic demands, it still has some deficiencies and defects which motivated the researchers to study them (Kim and D'Amore, 1999; Fajfar, 2000).

The conventional nonlinear static analysis focuses mainly on the using of first mode as the representative of structure's behaviour; in this regard it is assumed that the response of structure is a function of the first mode so that nonlinearity is distributed uniformly in the height of structure (Krawinkler and Seneviratna, 1998). Meanwhile, this assumption is incorrect in some cases such as tall building structures in which the effects of higher modes are significant. This deficiency causes the presentation of Modal Pushover Analysis (MPA) (Chopra and Goel, 2001 and 2002). In this method, nonlinear static analysis is conducted in every mode separately and then different types of responses of the structure in different modes are combined using proper statistical methods. Further studies showed that the

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seismic demands can be determined by composing the nonlinear results of first mode and linear results of higher modes because of linear responses of structures in higher modes. According to a study conducted on SAC structures, the responses obtained by this method are of higher accuracies in comparison with those of FEMA356 (2000) suggested loading pattern (Goel and Chopra, 2004). It is shown in the following studies that seismic demands, created in the structures, can be determined by combining the nonlinear results of first mode responses and linear responses of higher modes. This fact is ended to the presentation of Modified Modal Pushover Analysis (MMPA) (Chopra *et al.*, 2004).

As mentioned earlier, the effects of higher modes on the responses of structures cause the nonlinear static analysis methods, presented upon the first mode, not to evaluate properly the actual responses of structures. Therefore, the efficiencies of these methods should be evaluated for the structures in which the higher mode effects are considerable. Tall building structures are the ones which have such characteristics. It should be mentioned that the effects of higher modes depend not only on the structure's height but also on the index selected for expressing the structural response and the type of input excitation. That is why many studies have been done on the capabilities of nonlinear static analysis methods, particularly MPA one, in the recent years (Poursha *et al*., 2008). In this research, it is attempted to evaluate the accuracy of MPA method in estimating the seismic demands of tall building structures after assessing the conventional nonlinear static analysis methods used in the FEMA356 (2000) and ATC40 (1996). For this purpose, a 15-story frame (the representative of tall building structures) accompanying with a 5-story frame (the representative of ordinary buildings) is used.

Many studies have shown that accelerograms recorded near active faults have some important characteristics that make them different from those recorded in far-fault regions (Ghahari *et al*., 2010; Ghahari and Khaloo, 2010). Regarding the importance of these types of records, the capabilities of static methods are studied with respect to such seismic excitations as well. In the following, how the considered structures are modeled is expressed first and then the applied records are introduced. Subsequently, the results obtained by nonlinear static analysis are presented based on the documents of FEMA356 (2000) and ATC40 (1996) with focusing on two different kinds of loading. Then, the results obtained by time history analysis and MPA methods are compared and presented.

2. Structural Modeling

In this paper, two reinforced concrete structures, 5- and 15-story, with ordinary moment resisting frames, are used for numerical studies. The 5-story frame is considered as the typical ordinary structure and the 15-story frame as the typical tall building. For meeting the results coincided with the reality, the structures are designed based on 3-dimensional model and then one of the internal frames is put under further analysis as the representative of structure. This approach leads to considering the factors such as bi-axial bending to design columns. These structures are loaded and designed based on Iranian 2800 standard (2005) and ACI code (2002), respectively. Both strength and inter-story displacement (drift) criteria are considered in the design of structures.

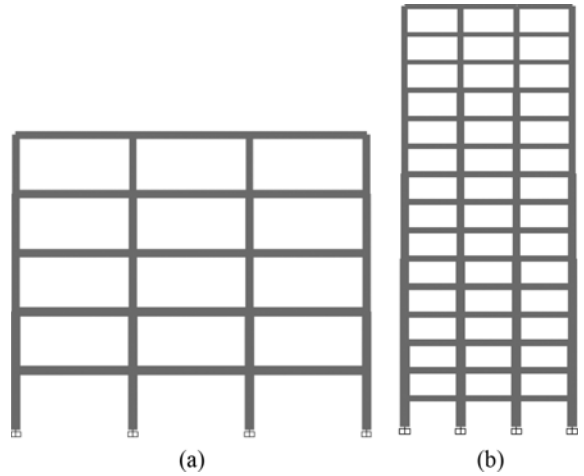


Fig. 1. The Studied Frames: (a) 5-Story Frame, (b) 15-Story Frame

Table 1. Modal Properties of Studied Frames

	5-story frame			15-story frame		
	Period (s)	Modal Participation Factor	Effective Modal Mass (%)	Period (s)	Modal Participation Factor	Effective Modal Mass (%)
Mode 1	1.05	3.93	75	1.76	7.76	65
Mode 2	0.36	1.71	15	0.72	3.58	14
Mode 3	0.19	1.07	5	0.39	2.42	6

After 3-dimensional designing of structures, the frames are used for further analysis and their typical schemes are shown in Fig. 1. The concentrated plastic hinges are used to explain the nonlinear behaviours of elements in nonlinear analysis. Regarding columns, these plastic hinges are defined upon interaction between axial force and bending moment and placed on two ends of each element, while for beams the shear and bending hinges are applied separately, putting at their both ends and middle points. The features of mentioned hinges as well as their acceptable deformation values are determined based on FEMA356 (2000). All modeling nonlinear static and dynamic analyses are performed in SAP2000 ver.12. The modal properties of designed frames are presented in Table 1.

3. Performed Analyses

In order to evaluate nonlinear static analysis methods, the coefficient modification method, presented in FEMA356, and capacity spectrum method, proposed in ATC40, each of which using two loading patterns, uniform and spectral, are studied along with MPA method. In this regard, nonlinear time history analysis is used to assess the mentioned methods. As the metropolitans and residential regions are mostly located around the active faults, both near- and far-fault records should be considered in the studies related to seismic performance of structures. Therefore, in this research, besides using the records recorded in the regions far from the faults, some similar near-fault records are considered as well. In selecting the far-fault records, it is attempted to consider the following criteria:

- 7 considered records are related to 7 different earthquakes;
- The selected records have Peak Ground Accelerations (PGA) of about 0.35g in order to decrease scaling effects;
- The selected records are related to the important earthquakes with high magnitudes;
- The soil types of recording stations are in accordance with the design assumptions of structure.

For selecting the near-fault records, the following criteria are considered:

- The similarities between the earthquakes causing near- and far-fault records;
- Same soil type conditions as mentioned previously;
- The closeness of PGA to 0.35 g. Meeting this criterion is very difficult for near-fault records having rupture directivity effects, as they usually have long-period pulses with high amplitudes;
- The closeness of dominant pulse period existed in the velocity record to the first mode period of 15-story structure.

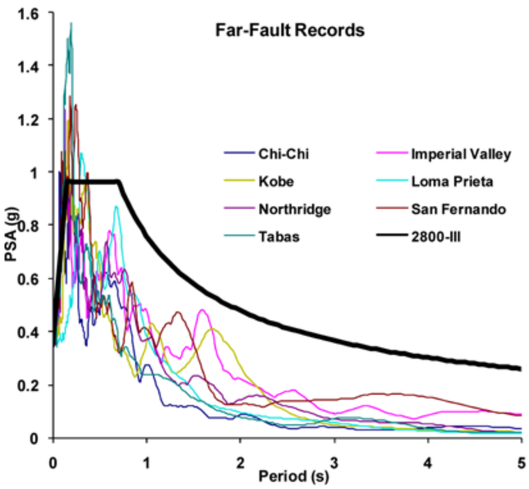
The characteristics of selected records are presented in Table 2. It should be mentioned that all near-fault accelerograms have been rotated in the strikes normal to the fault and permanent displacement, due to the tectonic deformation, eliminated from them. Also, all 14 presented records are scaled to the PGA of 0.35 g for comparing the results obtained by time history analysis with designing assumptions as well as those of other analyses.

There are different methods and diverse indices for scaling earthquake records; the most common one is equalizing maximum acceleration. However, as is well-known, directivity pulses in near-fault records are most affected by the geometry of station against fault; hence, the distance has no significant effects on them. Therefore, the PGA scaling of such records has no strong basis; however, as there is no acceptable method is this regard nowadays, all near-fault records are scaled using PGA criteria as well. The pseudo acceleration response spectra of applied records as well as the designing spectrum of standard 2800 are presented in Fig. 2 in order to show their features. In the following, for easier referring to accelerograms, their causing earthquakes are used with the abbreviations FF and NF for far- and near-fault records whenever needed, respectively.

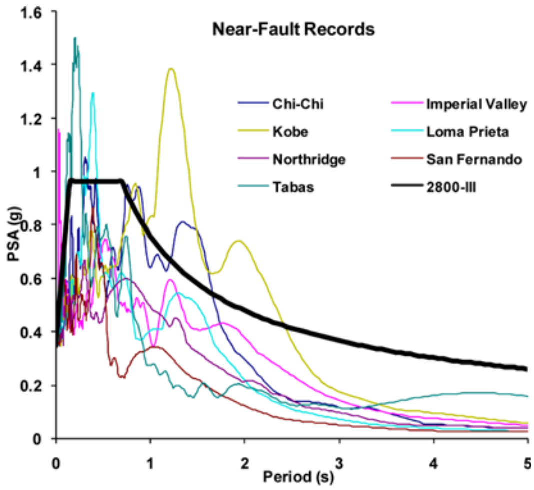
For more compatibility of nonlinear dynamic analysis results with the assumptions used in designing phase, a record, besides 14 ones presented in Table 2, is prepared based on standard 2800 spectrum for the third type soil. There are different approaches for generating such synthetic accelerograms. As using frequency

Table 2. Properties of Selected Ground Motions

Event	Year	M_W	Far-Fault Records					Near-Fault Records				
			Station	Closest Distance (km)	Soil Type	Comp.	PGA (g)	Station	Closest Distance (km)	Soil Type	Comp.	PGA (g)
Northridge	1994	6.7	Centinela	30.9	C-D	245	0.322	LA DAM	5.9	C	Fault Normal	0.576
Chi-Chi	1999	7.6	NST	36.95	C	N	0.388	CHY035	12.7	C	Fault Normal	0.261
Loma Prieta	1989	6.9	SF Intern. Airport	64.4	C-D	090	0.329	Gilroy Array #2	11.1	C-D	Fault Normal	0.406
Imperial Valley	1979	6.5	6605 Delta	43.6	C-D	352	0.351	Agrarias	0.7	B	Fault Normal	0.311
San Fernando	1971	6.6	LA Hollywood Stor	21.2	C-D	090	0.21	Pacoima Dam	1.8	B	Fault Normal	1.435
Kobe	1995	6.9	Takatori	26.4	D	090	0.345	Takatori	1.5	E	Fault Normal	0.682
Tabas	1978	7.4	Dayhook	17.0	B	LN	0.328	Tabas	3	C	Fault Normal	0.852



(a)



(b)

Fig. 2. Response Spectra of Studied Records: (a) Far-Fault Records, (b) Near-Fault Records

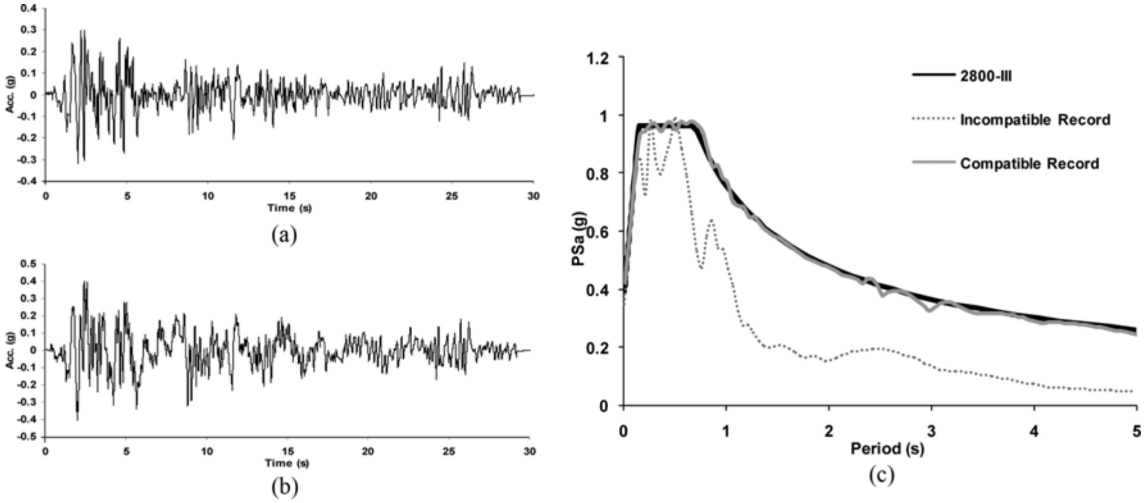


Fig. 3. Generation of Synthetic Accelerogram: (a) Spectrum Incompatible Record, (b) Spectrum Compatible Record, (c) Response Spectra

domain methods, like what is done in Gasparini and Vanmarcke (1976), will change the original properties of earthquake accelerogram, in this study, RSPMatch software (Abrahamson, 1993) is used. Synthetic accelerogram generation in this software is based on time domain calculations. The theoretical basis of this software was primarily presented by Kaul (1978), then developed by Lilhanand and Tseng (1987 and 1988); eventually, its final form was represented by Abrahamson (1993). The initial and modified records with their spectral responses are shown in Fig. 3 along with the target design spectrum.

4. Analysis Results

4.1 Conventional Nonlinear Static Analysis

Figure 4 shows the story displacements of 5- and 15-story structures in the target displacements in both ordinary static nonlinear analysis methods, i.e. coefficient modification and capacity spectrum methods, using spectral and uniform loading patterns. As it is seen, the spectral loading pattern causes higher displacement, due to the loading at critical points of structure, in comparison with uniform method. Also, the story displacements are higher in the coefficient modification method in comparison with those of capacity spectrum one. This much meets its highest value in the roof.

Similar to Fig. 4, the drift distributions of 5- and 15-story structures are compared in Fig. 5 for target displacement regarding both coefficient modification and capacity spectrum methods. As it is seen in the graphs, the inter-story displacement demands of middle stories are dramatically higher than others; therein, the first story and roof have the least drift values.

4.2 Nonlinear Time History Analysis

The results obtained by time history analysis are presented after surveying the ones gained by conventional nonlinear static analysis. The maximum displacements of stories under near- and far-fault records are shown in Fig. 6. Despite different response values of 5- and 15-story structures, they have almost equal variation patterns in their heights under far-fault accelerograms. But, under near-fault records, 5- story structure shows relatively shear behavior, while the 15-story structure has bending behavior

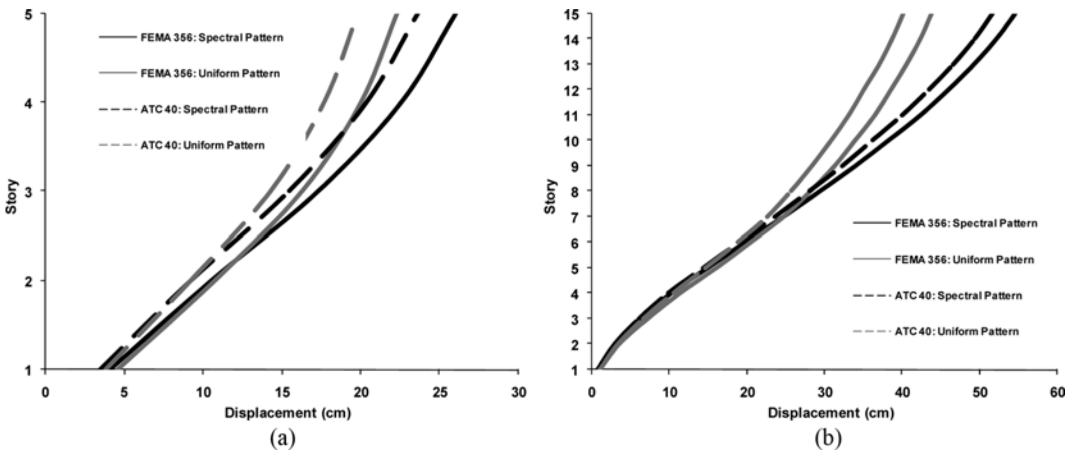


Fig. 4. Displacement of Stories in the Target Displacement: (a) 5-Story Structure, (b) 15-Story Structure

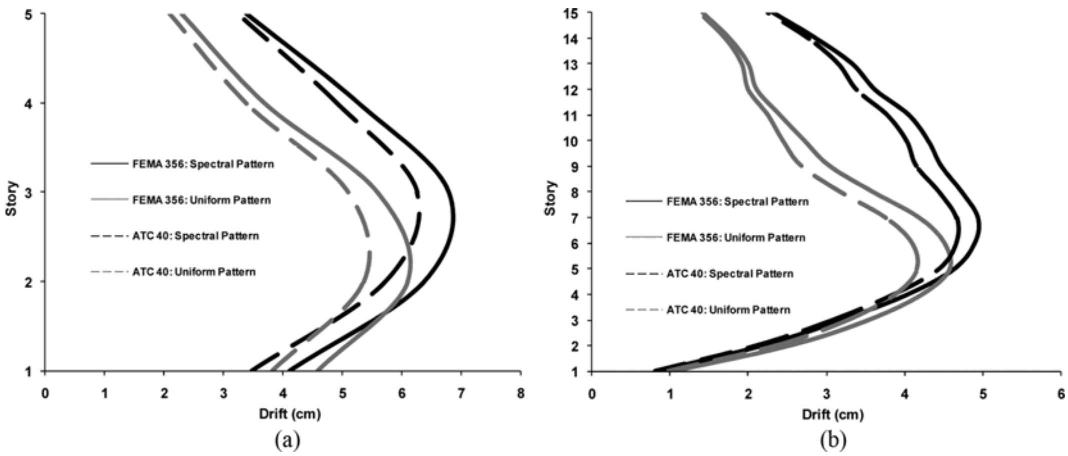


Fig. 5. Story Drifts in Target Displacement: (a) 5-Story Structure, (b) 15-Story Structure

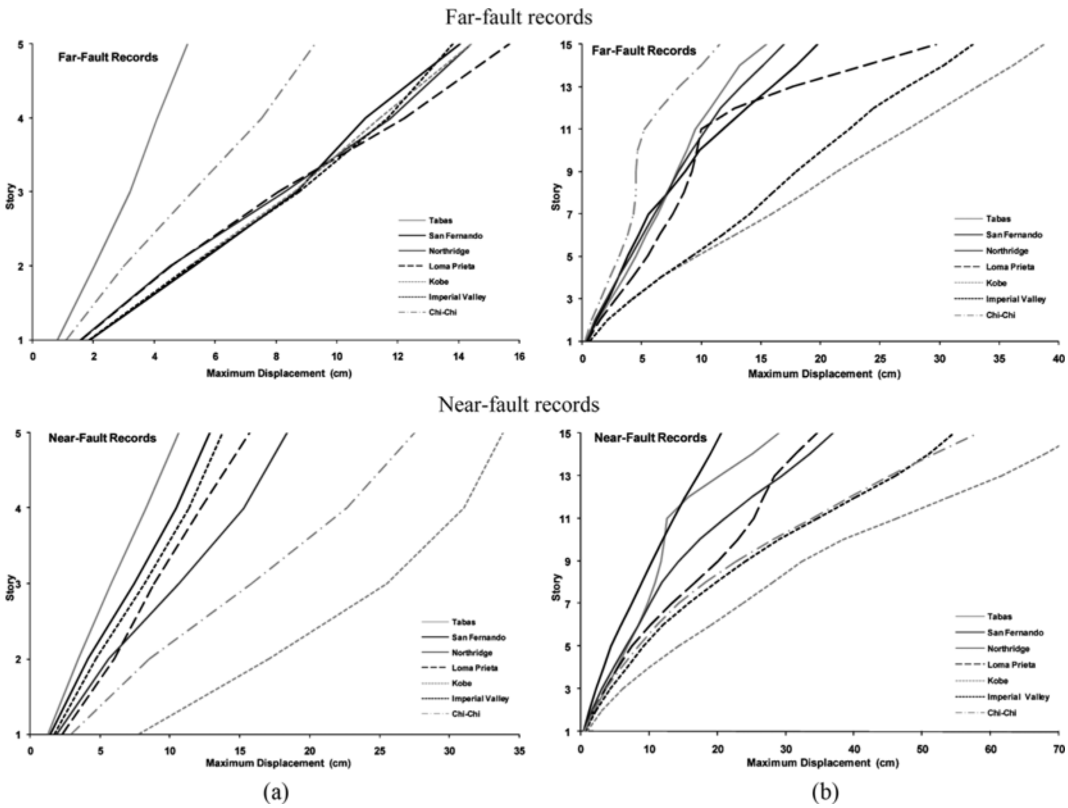


Fig. 6. Maximum Displacements of Stories in Nonlinear Time History Analysis: (a) 5-Story Structure, (b) 15-Story Structure

and its roof displacement value increases suddenly.

For studying more precisely the differences between near- and far-fault records, the displacement responses values are considered under several records of both kinds, i.e. near- and far-fault records, for 5- and 15-story structures and presented in Figs. 7 and 8, respectively. According to the results, the differences between the structural behavior against near- and far-fault accelrograms strongly depend on the ratio of the first mode period of structure (Table 1) to the velocity pulse period existed in the near-fault records (Table 3). If this value is lower than 0.5, then the structure shows similar behavior under both near- and far-fault records. According to Fig. 8, in the 15-story structure, all near-fault records show different behavior in comparison with those of far ones, as first mode period of this structure is larger than half of pulse period of all near-fault records. While, in the 5-story structure, near-fault accelerogram recorded during Imperial Valley earthquake, has no difference with its correspondent far-fault one because the ratio of structure's first mode period to the pulse period is lower than 0.5, shown in Fig. 7.

The comparison conducted for displacement index can similarly

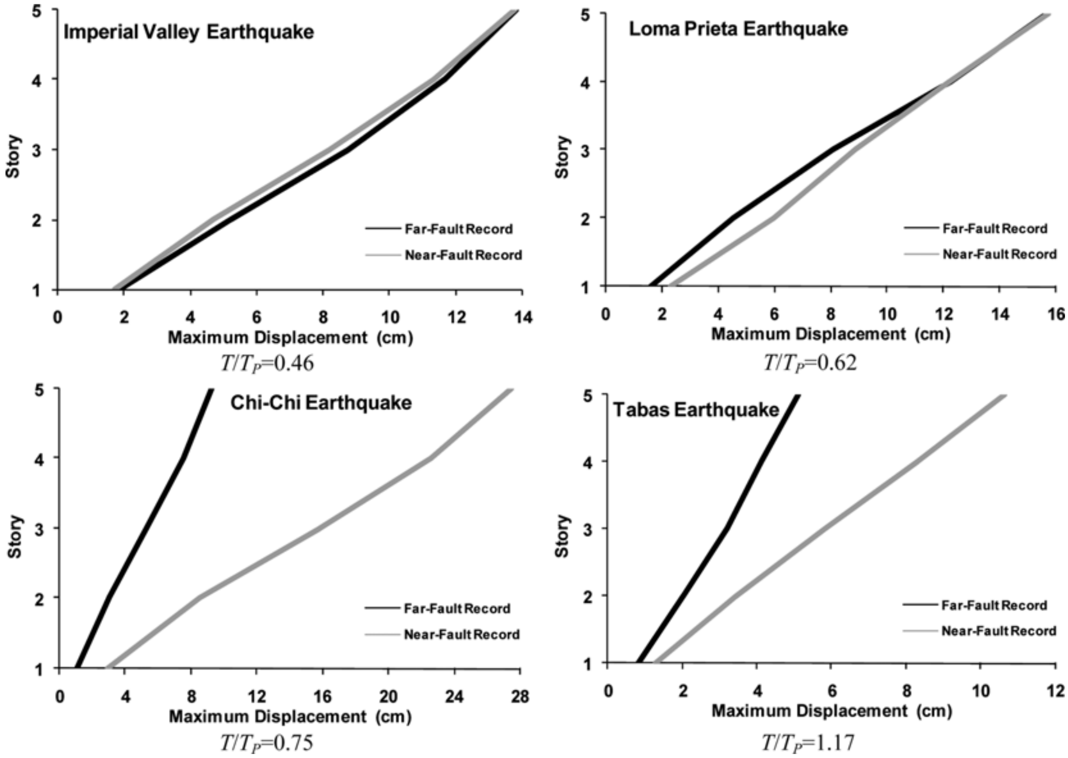


Fig. 7. Comparing Maximum Displacements of 5-Story Structure under Far- and Near-Fault Records

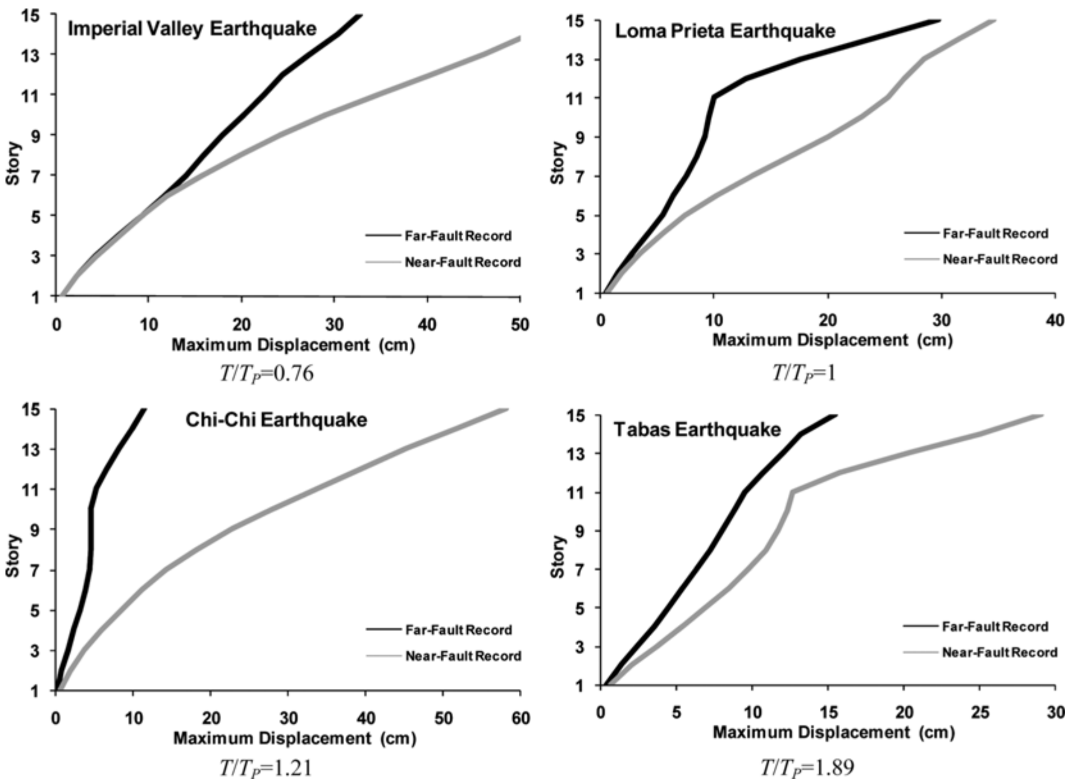


Fig. 8. Comparing Maximum Displacements of 15-Story Structure under Far- and Near-Fault Records

be done for inter-story displacement index, i.e. drift. Fig. 9 shows maximum drifts, imposed on the 5- and 15-story structures under near- and far-fault records. As it is observed, the behaviours of 5- and 15-story structures are obviously differed with changing in the indexes even under far-fault records. Inter-story displacement distribution is properly in accordance with what observed in Fig.

Table 3. Dominant Velocity Pulse Period Existed in the Near-Fault Records

Record Name	Kobe	Tabas	Loma Prieta	Imperial Valley	Northridge	San Fernando	Chi-Chi
Pulse Period (s)	1.6	0.9	1.7	2.3	1.7	1.6	1.4

5 in the 5-story structure. However, the pattern seen in the 15-story structure is strongly contradicted with the results of conventional nonlinear static analysis. In the other words, in opposing to what is seen in Fig. 5, the inter-story displacement values are in their highest levels in the upper stories. This fact is more significant under near-fault earthquake records. The reason for this difference, observed between nonlinear static analysis and time history analysis, is related to higher modes effects. While the more local indexes of structure's behaviour are studied, the effects of higher modes are emerged more; the behaviour changes in the inter-story displacements are more obvious in comparison with those of story displacements. Larger discrepancy between static and dynamic nonlinear analysis for 15-story structure under near-fault records can be justified by the wave propagation along the height of the structure. The near- and far-fault records are compared as those presented in Fig. 7 and 8, not mentioned here for shortening the results.

For summing up the comparing of 5- and 15-story structures as well as observing the effects of higher modes in time history analysis, the average values of inter-story displacement, obtained by time history analysis of these structures are presented side by side in Fig. 10. Although averaging makes the curves flat and removes the effects of single record, still the effects of higher modes are clearly observed on intensifying the seismic responses of upper stories in the 15-story structure in all four curves of the above figure. These effects are more observable under the near-fault records in comparison with those in far-fault ones as well as the records adapted to design spectrum. In brief, we can say that in tall building structures, nonlinear static analysis in which only first mode is used, is improper for estimating local seismic indices such as inter-story displacement; this fact is observed even in the far-fault records.

4.3 Modal Pushover Analysis (MPA)

As it was observed, ignoring the effects of higher modes in the structures where such effects are considerable can result to incorrect estimation of local seismic indices, particularly in upper stories. To overcome this deficiency, Modal Pushover Analysis method was presented by Chopra and Guel (2001). The details of this method and how to determine the responses of structure are found in the mentioned reference and here only the results are concerned. Note that for MPA method, first three modes have been used. In 5-story frame, these three modes contain almost 100% of effective mass ratio. Although cumulative modal participating mass ratio is about 85% for 15-story structure, our calculations showed that 4th and other higher modes do not have significant contribution on the response of the structure calculated by SRSS technique in MPA method.

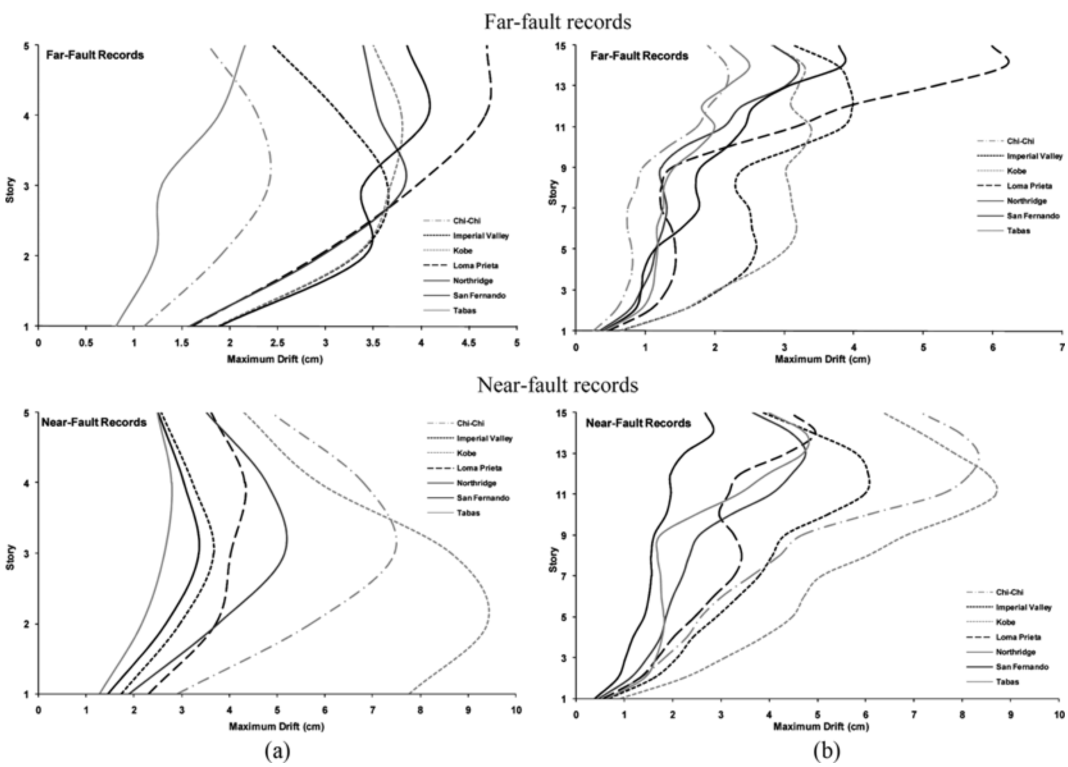


Fig. 9. Maximum Drifts of Stories in Nonlinear Time History Analyses: (a) 5-Story Structure, (b) 15-Story Structure

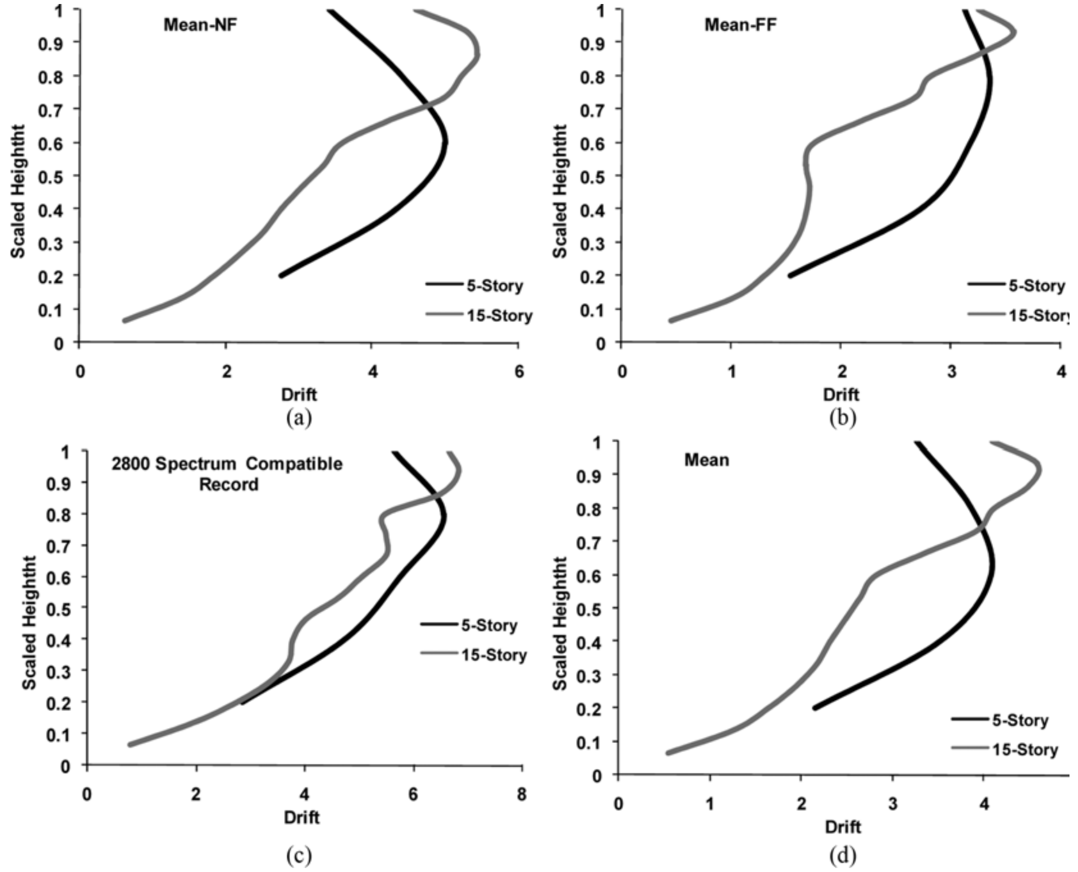


Fig. 10. Maximum Values of Average Drifts in 5- and 15-Story Structures: (a) Near-Fault Records, (b) Far-Fault Records, (c) 2800 Spectrum Compatible Record, (d) All Applied Records

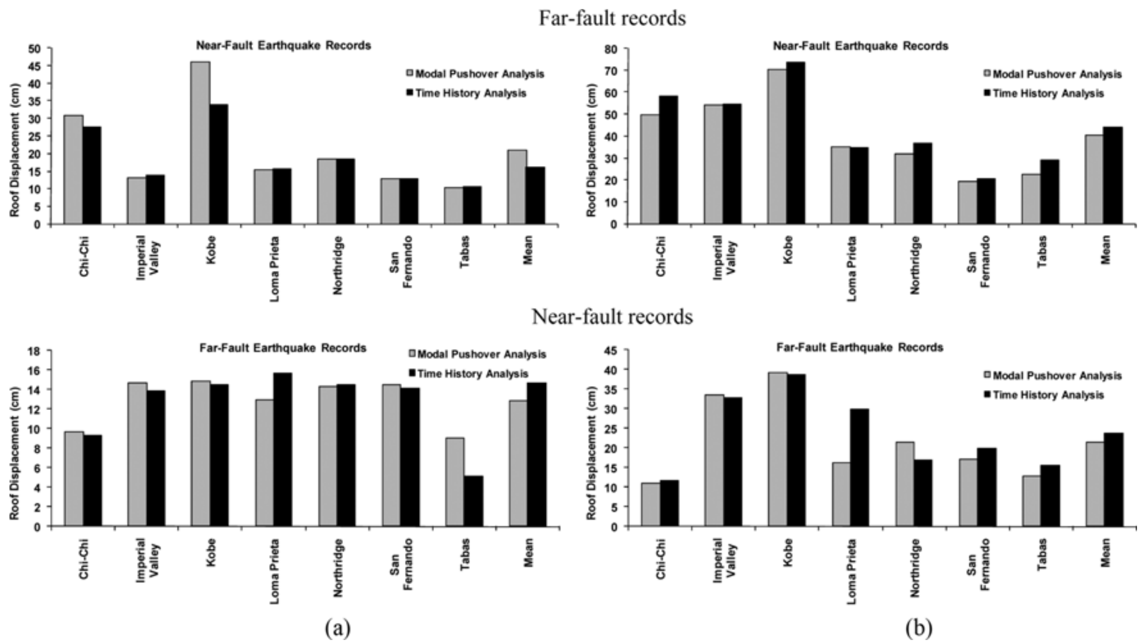


Fig. 11. Maximum Roof Displacements Obtained by MPA and Time History Analysis: (a) 5-Story Structure, (b) 15-Story Structure

As the most general seismic indices, maximum roof displacement values for both MPA and time history analysis methods regarding 5- and 15-story structures are presented in Fig. 11. It should be mentioned that the accelerograms applied in time history analysis and MPA are the same. As observed, MPA is successful in estimating maximum roof displacement for both 5-

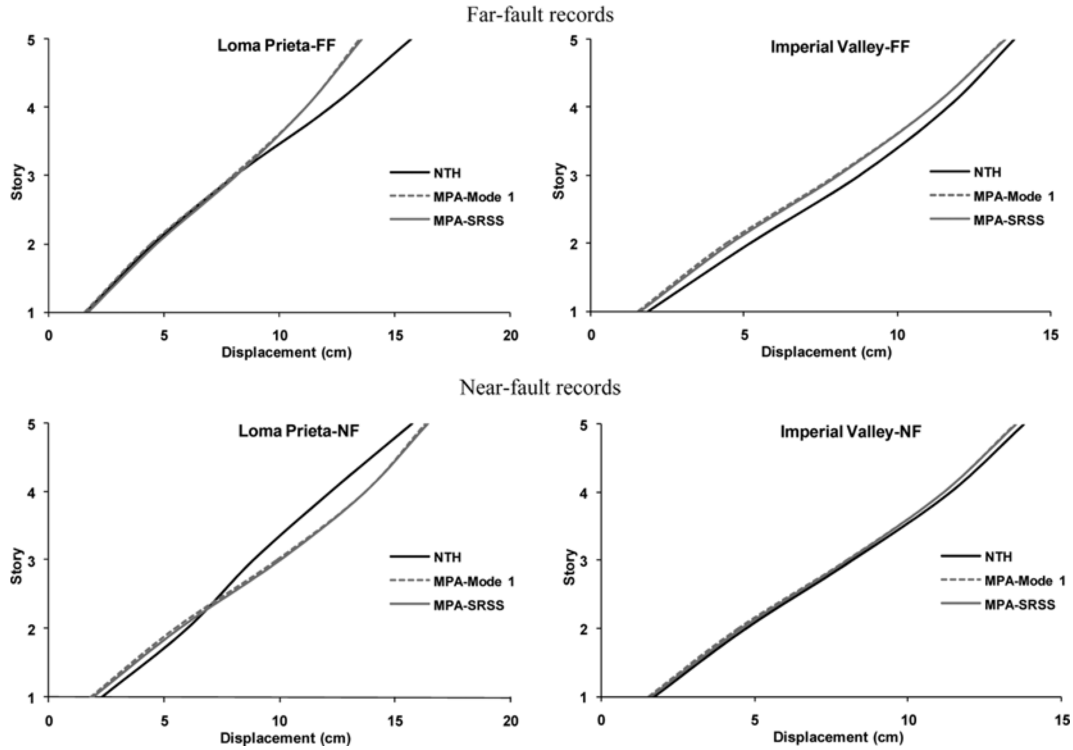


Fig. 12. Displacement Distribution of 5-Story Structure Obtained by MPA and Time History Analyses

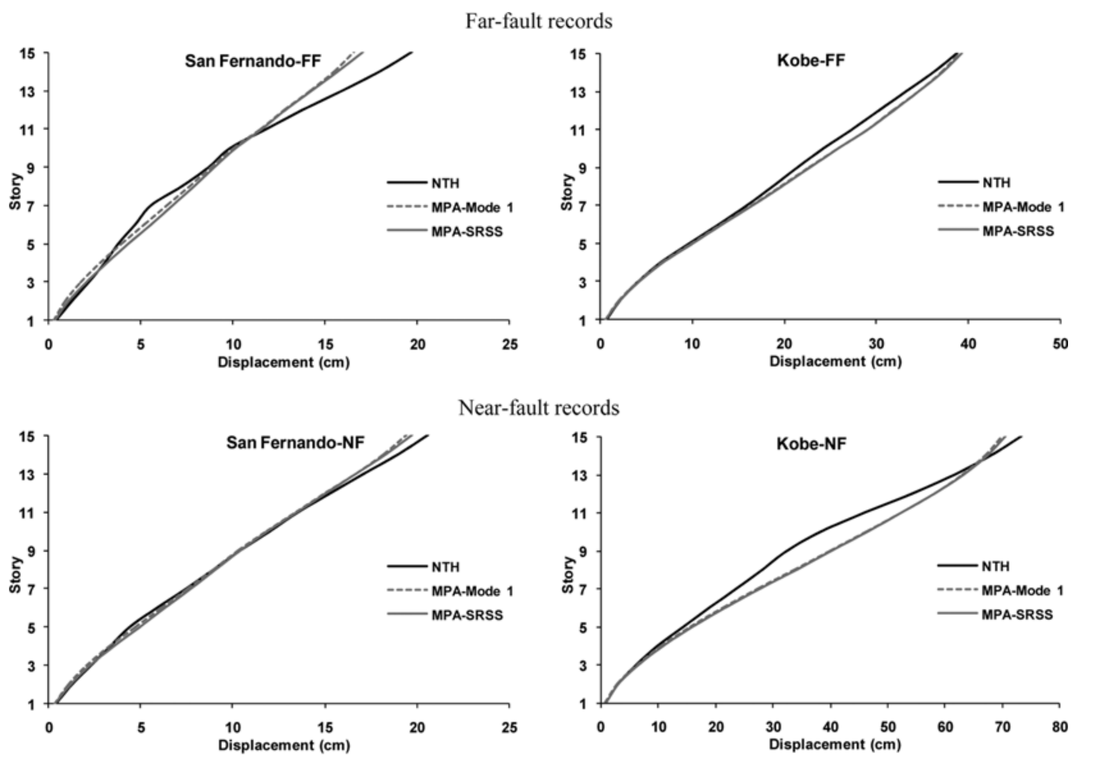


Fig. 13. Displacement Distribution of 15-Story Structure Obtained by MPA and Time History Analyses

and 15-story structures under all near- and far-fault records. Moreover, this method is successful in estimating the story displacement under both near- and far-fault records in addition to the roof displacement, observed clearly in Figs. 12 and 13 for both 5- and 15-story structures, respectively. According to these figures, the story displacement is affected just by the first mode; hence, using a conventional nonlinear static analysis in which the loading pattern is based on the distribution of the first mode can

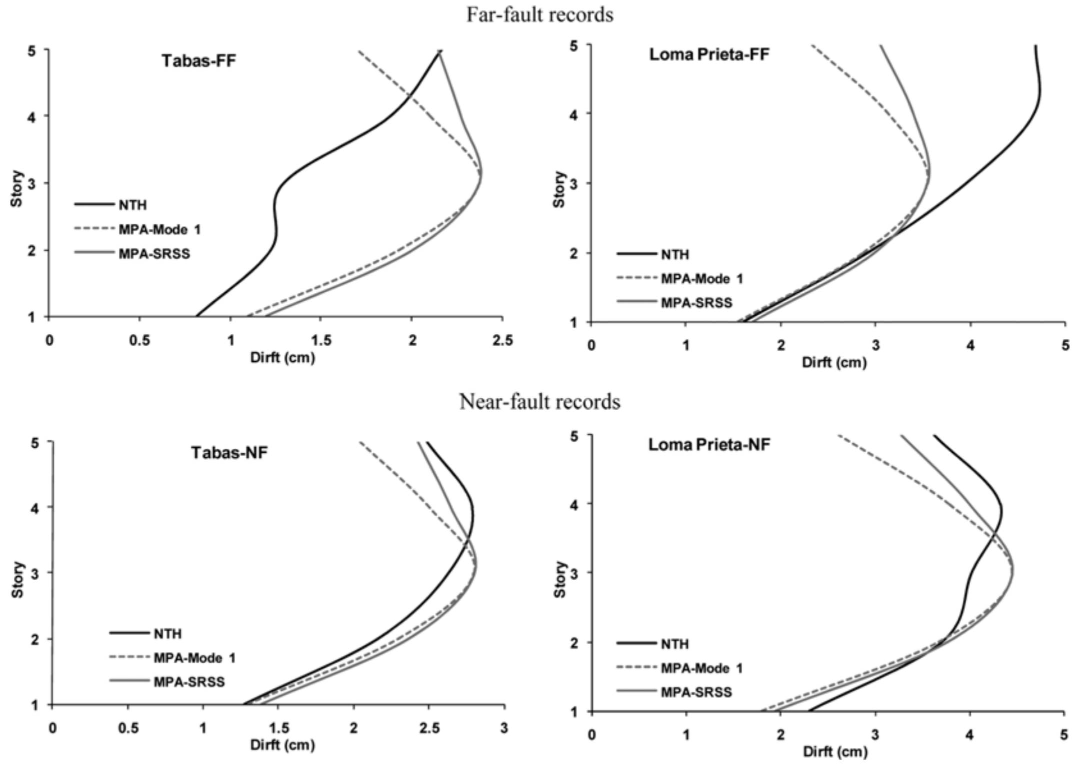


Fig. 14. Drift Distribution of 5-Story Structure Obtained by MPA and Time History Analysis

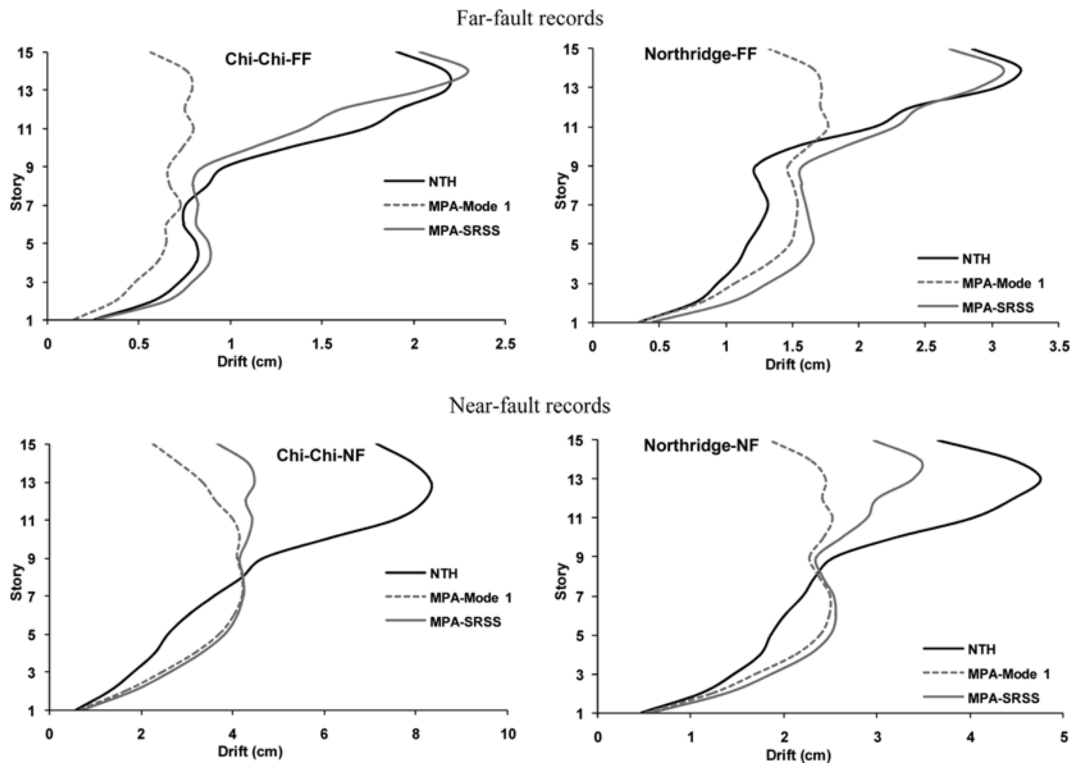


Fig. 15. Drift Distribution of 15-Story Structure Obtained by MPA and Time History Analysis

properly determine the maximum displacement of stories.

As mentioned earlier, the effects of higher modes on the inter-story displacement of tall building structures are more significant and the curves, obtained by MPA method based on the first mode, are expected to be different from the ones related to the sum of all modes especially in the upper stories. This fact is seen

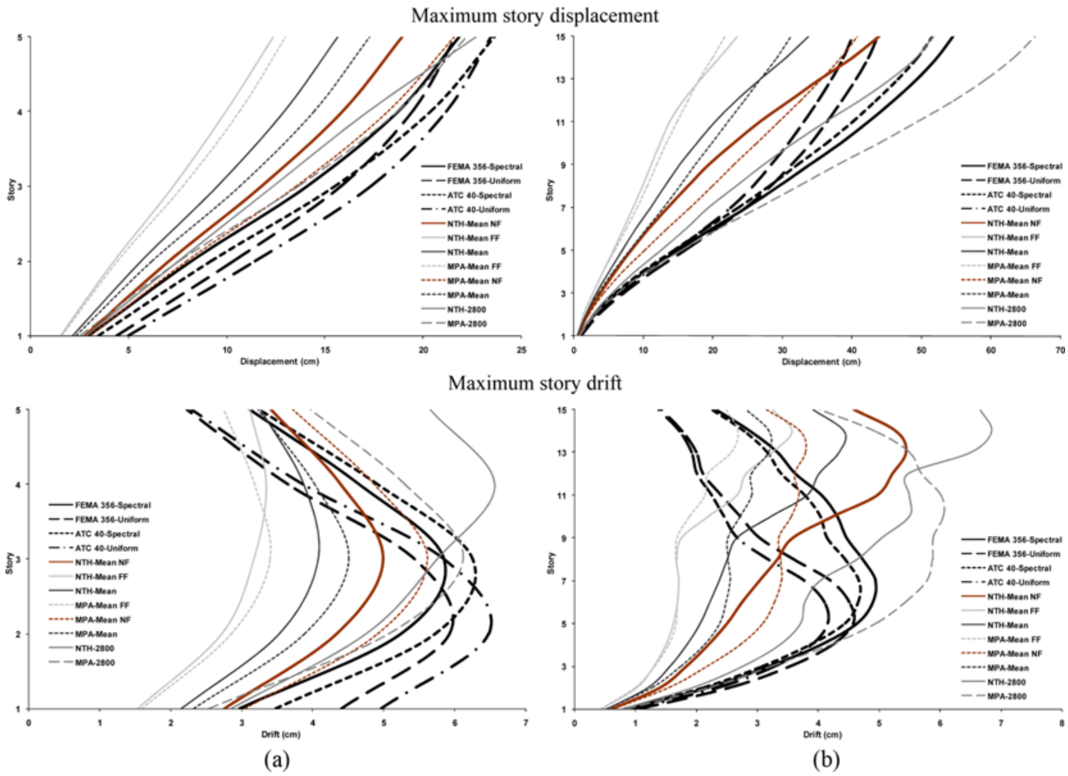


Fig. 16. Comparing the Values of Drifts and Displacements in Different Applied Methods: (a) 5-Story Structure, (b) 15-Story Structure

obviously in the Fig. 14 and, more particularly, in Fig. 15 which is related to 15-story structure. According to these figures, the results obtained by static analysis become closer to those gained by time history analysis as the higher modes effects are considered in MPA method. However, the curves related to the near-fault records in Fig. 15 show that despite more appropriate performance of MPA method in comparison with conventional nonlinear static methods, it still has noticeable defects in the estimation of inter-story displacement of upper stories in tall building structures under near-fault records.

4.4 Summary

Finally, the results obtained by all methods applied in this research are plotted side by side and compared in Fig. 16. The results obtained in this study can be summarized as follows:

1. The displacement values obtained by conventional nonlinear static analysis methods with both uniform and spectral patterns are higher than those of other analysis methods;
2. The average displacement values obtained by MPA method are slightly higher (for both near- and far-fault records) in comparison with those of conventional nonlinear static analysis methods;
3. The displacement values obtained by MPA method corresponding to the design spectrum compatible record are in proper accordance with those of nonlinear time history analysis;
4. The curvatures of displacement curves in static analyses (coefficient method, capacity spectrum and MPA) are different from those of nonlinear time history of 15-story structure. More parametric studies are needed for assessing this phenomenon;
5. The processes presented by conventional nonlinear analysis methods are severely weak and have very high errors in estimating inter-story displacement of upper stories of tall building structures;
6. The agreement between MPA and nonlinear time history methods is lower in estimating the inter-story displacement of 15-story structure. Indeed, contrary to time history analysis, MPA method offers higher values for the lower stories and lower values for the upper stories. This condition is intensified with changing the type of input record from far-fault to near-fault.

5. Conclusions

In the recent years, the developed nonlinear pushover analysis methods have been applied as the capable procedures in assessing and evaluating the seismic responses of structures due to the complexity and high uncertainty of dynamic analysis. Along with many studies conducted on the developing of these methods, their accuracies and capacities have also been controlled as other important subjects in the earthquake engineering investigation.

In this research, the seismic performance of 2 moment resisting reinforced concrete frames of 5- and 15-story are studied in order to verify the accuracy of the results obtained by conventional nonlinear static methods, including coefficient modification (suggested by FEMA356) capacity spectrum (suggested by ATC40), and Modal Pushover Analysis (MPA) methods. For this purpose, the results of nonlinear dynamic analyses are applied under 7 far-fault records and 7 near-fault records, all scaled by designing peak ground acceleration. According to the results, conventional methods (FEMA356 and ATC40) overestimate the displacement values, while underestimate inter-story displacement of upper stories of tall building structures. So, to properly estimate inter-story displacement through static methods, higher modes must be considered. It was shown that inter-story displacement estimated by MPA would become closer to those gained by time history analysis as the higher modes are considered in MPA method. However, despite more appropriate performance of MPA method in comparison with conventional nonlinear static methods, it still has noticeable defects in the estimation of inter-story displacement of upper stories in tall building structures under near-fault records. Parametric investigation of this phenomenon can be subject of future studies.

References

Abrahamson, N. (1993). *Non-stationary spectral matching program*, RSPMatch.

American Concrete Institute (2002). *Building code requirements for structural concrete*, ACI 318-02.

Applied Technology Council (1996). *Seismic evaluation and retrofit of concrete buildings*, ATC 40, Redwood City, CA.

Building and Housing Research Center (2005). *Iranian code of practice for seismic resistant design of buildings*, Standard 2800-05, Tehran, Iran.

Chopra, A. K. and Goel, R. K. (2001). *A modal pushover analysis procedure to estimate seismic demands for buildings*, PEER Report 2001/03, Pacific Earthquake Engineering Center, University of California, Berkeley, CA.

Chopra, A. K. and Goel, R. K. (2002). “A modal pushover analysis procedure for estimating seismic demands for buildings.” *Earthquake Engineering and Structural Dynamics,* Vol. 31, No. 3, pp. 561-582.

Chopra, A. K., Goel, R.K., and Chintanapakdee, C. (2004). “Evaluation of a modified MPA procedure assuming higher modes as elastic to estimate seismic demands.” *Earthquake Spectra*, Vol. 20, No. 3, pp. 757-778.

CSI, SAP 2000 (2009). *V-12. Integrated finite element analysis and design of structures*, Computers and Structures Inc., Berkeley, CA, USA.

Fajfar, P. (2000). “A nonlinear analysis method for performance based seismic design.” *Earthquake Spectra*, Vol. 16, No. 3, pp. 573-592.

Federal Emergency Management Agency (2000). *Pre-standard and commentary for the seismic rehabilitation of buildings*, FEMA 356, American Society of Civil Engineers, Washington, D.C.

Federal Emergency Management Agency (2005). *Improvement of nonlinear static seismic analysis procedures*, FEMA 440, Applied Technology Council, Washington, D.C.

Gasparini, D. A. and Vanmarcke, E. H. (1976). *Evaluation analysis of safety of buildings - simulated earthquake motions compatible with prescribed response spectra*, Massachusetts Institute of Technology, Report No. 2.

Ghahari, S. F., Jahankhah, H., and Ghannad, M. A. (2010). “Study on elastic response of structures to near-fault ground motions through record decomposition.” *Soil Dynamics and Earthquake Engineering*, Vol. 30, No. 7, pp. 536-546.

Ghahari, S. F. and Khaloo, A. R. (2010). *Considering rupture directivity effects, which structures should be named “Long-period buildings”?* The Structural Design of Tall and Special Buildings (accepted).

Goel, R. K. and Chopra, A. K. (2004). “Evaluation of modal and FEMA pushover analysis: SAC Buildings.” *Earthquake Spectra*, Vol. 20, No. 1, pp. 225-224.

Kaul, M. K. (1978). “Spectrum consistent time history generation.” *ASCE Journal of Engineering Mechanics*, Vo. 4, No. 104, pp. 781-788.

Kim, S. and D’Amore, E. (1999). “Pushover analysis procedure in earthquake engineering.” *Earthquake Spectra*, Vol. 15, No. 3, pp. 417-434.

Krawinkler, H. and Seneviratna, G. D. P. K. (1998). “Pros and cons of a pushover analysis of seismic performance evaluation.” *Engineering Structures*, Vol. 20, Nos. 4-6, pp. 452-462.

Lilhanand, K. and Tseng, W. S. (1987). *Generation of synthetic time histories compatible with multiple-damping response spectra*, SMIRT-9, Lausanne, k2/10.

Lillhanand, K. and Tseng, W. S. (1988). “Development and application of realistic earthquake time histories compatible with multiple damping response spectra.” *Proceedings of the Word Conference on Earthquake Engineering,* Tokyo, Japan, Vol. 2, pp. 819-824.

Poursha, M., Khoshnoudian, F., and Moghadam A. (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*, Vol. 19, No. 3, pp. 291-308.