ASSESSMENT OF HIGHER MODES EFFECTS IN THE STEEL MOMENT RESISTING FRAMES UNDER THE FAR AND NEAR FAULT EARTHQUAKES USING THE DAP METHOD

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ABSTRACT

In this research using the DAP method, the higher modes effects under the far and near-fault earthquakes are investigated. For this purpose 5 intermediate (ductility) steel moment resisting frames with 4, 7, 10, 15, and 20 stories have been investigated. The results show that in all the structures being investigated, the higher modes effects under the far fault earthquakes are greater with respect to the near-fault earthquakes. Also, by increase in the structure's height, the effects of higher modes increase. The base shear resulting from the near-fault earthquakes, considering the higher modes effects, has the negligible difference with the base shear resulting from the first mode of the structures.

1. INTRODUCTION

Nonlinear static methods (NSPs) have priority with respect to the linear analysis methods (LSPs) such as the equivalent static method or the modal combination method, because NSPs could account for the non- linearization of expected yielding components of the structure against the moderate and strong earthquakes. Also, NSPs could calculate unique estimates of the structure response quantities (Lateral displacement, inter-story drift, moments and element forces and rotation of plastic joints) for the purposes of design or seismic assessment.

It is clear that in all pushover methods, the lateral load pattern is essential for pushover

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analysis. In many cases it is assumed that the load distribution pattern is calculated based on the first mode. This issue could in the structures affected by higher modes participation lead into inaccurate results. These methods are classified into two categories. In traditional methods, the load distribution patterns are defined in a manner that during nonlinear behavior of the structure, remain constant in their arrangement and distribution over the height. In the second category, the adaptive load patterns are defined. Various studies have been conducted for the improvement of the pushover methods. Among these the multimodal pushover method has been proposed [1, 2]. As, by entering into the nonlinear zone, the stiffness matrix changes, the load pattern also should correspond to these changes. In this regard the adaptive load patterns are proposed [3-5]. All the adaptive methods, as the method proposed by Aydinoglu, could not account for the interaction between various modes responses which are known as the higher modes effects (HME) [5]. What is important here is that all NSP methods developed in the seismic codes are formulated based on the results of non-elastic analysis of the buildings against normal earthquakes. While in recent years the issue of near-fault earthquakes (NFEs) and their destructive effects upon the buildings have been under consideration of various researchers. Investigating damages related to the near-fault earthquakes shows that significant IDR demands are formed within the structure that could endanger the safety and stability of the structure. Considerable amounts of documents and evidences show that the seismic excitations produced close to a tear fault could be explained by an excitement of long period and short duration, a considerable energy is exerted upon the structure at the beginning of the recorded acceleration . This pulse-like excitation is known as the directivity effect.

In a number of separate studies, while examining the nonlinear behavior of steel moment resting frame (SMRF) against the far and near-fault earthquakes, the effect of two factors namely the Forward directivity and Fling as two important features of the near-fault earthquake in the estimation of the total and the story nonelastic demands are assessed. The studies showed that, on average, the displacement demands of the structure affected by the far fault earthquake are less than those of the near-fault earthquake. In addition, if the ratio of pulse period to the fundamental period of the structure is less than 0.8, the response demands are transmitted from the lower stories to the higher ones. On the other hand, the effect of a record with the Fling feature causes that demands become much greater with respect to the far fault earthquake, but it mainly highlights the structure behavior corresponding to the first mode [4, 6-9].

Examining the comparison made between the displacement-based adaptive pushover (DAP) method and the IDA results showed that this method provides a good estimate of the results concerning the displacement, IDR and capacity curves in comparison to the traditional methods [10]. Maniatakis et al. [11], investigating the higher modes effects on the moment-resisting RC frame structures showed that the effect of higher modes is dependent upon such factors as the earthquake characteristics, extra strength related to both modes and the numerical value of the examined response. Also, the inertia forces of the story and acceleration in all the stories and the shear forces in the upper stories due to ignoring the higher modes effects are considered negligible. Ghahari et al. [12] investigated the higher modes effects in the conventional nonlinear static analysis methods like the MPA method on concrete frames. The results show that due to the effect of higher modes, the conventional

nonlinear static analysis methods have not the capability of accurate estimation of the displacement demands of high-rise structures especially for the upper stories and the MPA method is not accurate against the near-fault mappings.

By studying the most important research work conducted in the recent years, it becomes clear that the focus of these works had been the accuracy of nonlinear static analysis (NSP) results and less is dealt with the higher modes effects under the far fault earthquakes especially the near-fault earthquakes. Also, considering that the present studies which show that the DAP method gives a good estimate of the structures response, in this research this method is used as a method which appropriately incorporates the higher modes effects in the estimation of the responses. In Fig. 1, the flowchart of this research is presented.
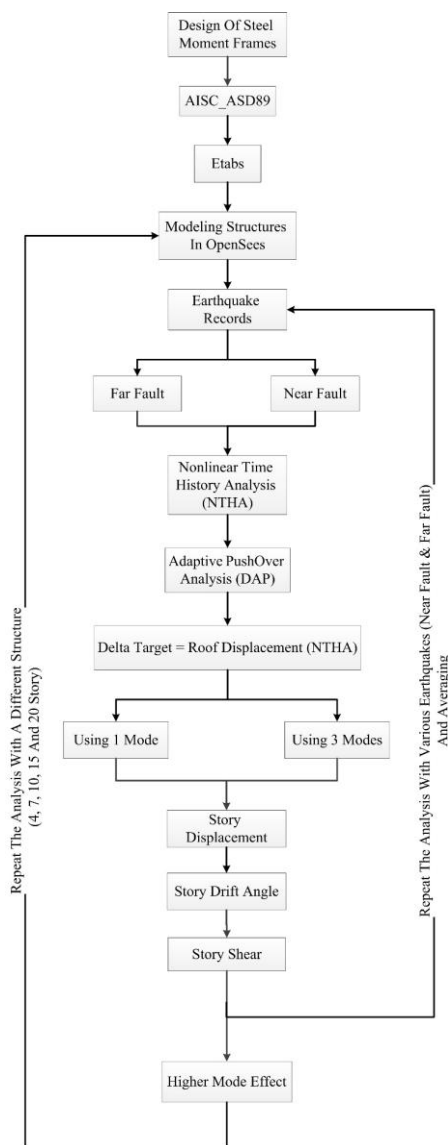

Figure 1. General flowchart of this study

In this article, we would investigate the higher modes effects using the displacement-based adaptive pushover method (DAP) under the far and near-fault earthquakes. In this respect, first the DAP method is applied using the first mode and, then using a number of modes which sum of their effective modal masses equals 90% of the total mass of the structure, is applied under the far and near-fault earthquakes and finally the obtained results are compared with the results of non-linear time history analysis (NTHA) obtained from far and near-fault records. The nonlinear demands required in this research include: the shear base, displacement, drift angle and stories shear which are investigated under the far and near-fault earthquakes. For this purpose a total number of 5 steel moment resisting frames with 4, 7, 10, 15 and 20 stories and 5 spans with intermediate ductility are designed and all nonlinear analyses are performed using the OpenSess [13] software.

In a simple categorization, the main features and distinguishable aspects of this study with respect to the previous studies could be summarized as follows:
- Investigating the capability of advanced pushover method in providing seismic demands under the near-fault earthquakes.
- Assessment of near-fault earthquakes with Forward directivity effects.
- Investigating the higher modes effects with increase in the structures height.
- Comparison between higher modes effects, under the far and the near-fault earthquakes.
- Investigating the transformation coefficients of the higher modes for the base shear under the far and near-fault earthquakes.

2. DISPLACEMENT-BASED ADAPTIVE PUSHOVER METHOD

In this method presented by Antoniou and Pinho [14], the proposed algorithm includes four stages:
1. Definition of the normal displacement force vector, U_0 and the story inertia mass
2. Computation of the load factor
3. Computation of normalized force vector exerted upon the structure
4. Updating the displacement force vector

At each stage by taking into account the stiffness degradation and consequent changed characteristics of the structure members due to the internal forces, the stiffness matrix and the changed structure characteristics are determined and finally, the displacement pattern is modified with respect to the initial displacement vector and the modal displacement vector based on the expressions presented by the above-mentioned researchers. The complementary explanations concerning this method are given in the reference [14]. The target displacement used in this research is equal to the roof displacement of the structures, obtained from the nonlinear time history analysis (NTHA) under the far and near-fault earthquakes also this method has been utilized in the previous studies by other researchers.

3. STRUCTURAL MODELS AND VALIDATION

Validation of analytical models is one of the most important steps of a study. In numerical

studies and especially when a considerable data base should be prepared for the extraction of the empirical expressions, Lack of certainty concerning the validity of that created model could lead to inaccurate results. To avoid this issue in this article, all models are validated based on the 9-story model shown in Fig. 2. As the 9-story building of the SAC9 project is regular in the plan, in this article only the 2D frame, representative of the north-south peripheral frame, has been modeled. Half of the seismic mass is assigned to this frame. The M1 modeling method presented by Gupta and Krawinkler, is used here for the modeling [15]. The P-Δ effect is considered but effects of the panel zone are neglected. In the M1 model all the beams and columns are modeled according to the centerline method. The main reason for selecting this kind of structural system lies in the fact that in this article the main objective is the assessment of all types of nonlinear seismic demands due to the various pushover methods and examining their adequacy with respect to the results of the nonlinear time history analysis. Therefore, the selected model should present an acceptable explanation of the non-elastic demands distribution so that with the least modeling detail could be reproduced in the numerical models. After Modeling the M1 model in the OpenSees software, the pushover diagram according to the study by Gupta together with the 2D model created by the authors of this article are shown in the Fig. 3. The comparison between two diagrams shows the acceptable accuracy in the modeling phase of this research. The reason for this difference is due to two issues. First, Gupta used the idea of the concentrated plastic hinge in the modeling process while in this research, the spread plasticity property modeled by the fiber element, is implemented. Second, in the software used by Gupta, the P-Δ effect is simulated by a virtual column with gravity load which is connected to the main frame through a truss member with considerable stiffness, while in this study the effects of geometric nonlinearity are defined using translation matrices which are among features of the OpenSees program.
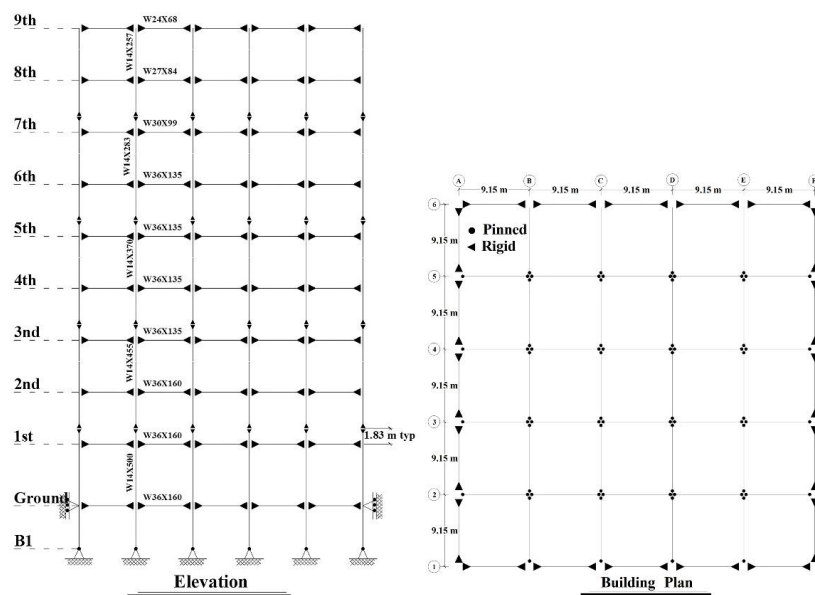

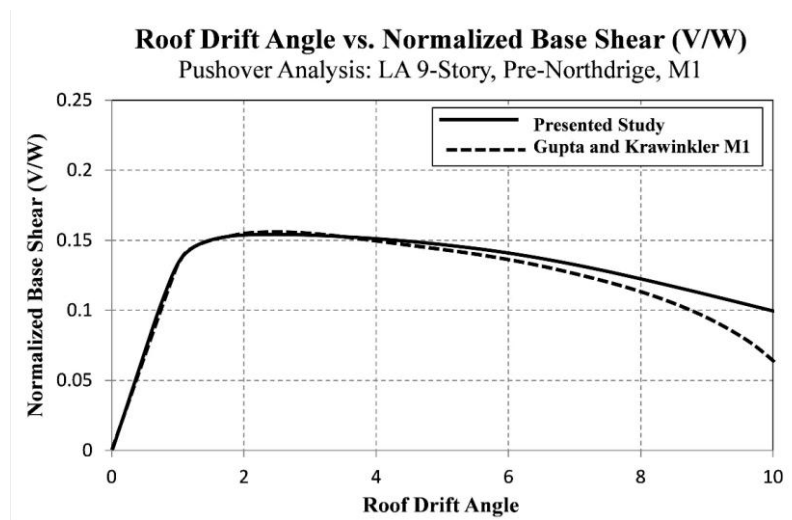Figure 2. Nine-story building (adapted from Reference [15])

Figure 3. Verification of models of presented study with SAC9 steel moment-resisting frame
[15, 16]

In order to investigate the higher modes effects, Use has been made of 4, 7, 10, 15 and 15 story models with the story height of 4 m and 5 spans each having 5 m length. The frames are intermediate (ductility) moment resisting frames. The structures being investigated in this research are designed completely based on the ANSI/AISC 341-05 and ASCE/SEI7-05 codes for gravity and seismic loads. The dead and live loads are $3520\frac{Kgf}{m}$ and $1250\frac{Kgf}{m}$, respectively. Both the equivalent static lateral force and the modal response spectrum analysis were used for the models. ST37-type steel is used in design of the structures with the yield stress of $2400\frac{Kg}{Cm^2}$ and the ultimate stress of $3600\frac{Kg}{Cm^2}$ and the Poisson's ratio is 0.30. The lateral drift values in all the structures are compared with the allowable value in the ASCE/SEI7-05 code. For the 4-story model, the maximum drift is taken 2.5% and for other structures is taken 2%. The sections used in the frames include box sections and plate girder. In Table 1, the sections used in various structures are presented. All elements have been chosen as compact sections (limiting local buckling) assuming enough lateral supports.

Table 1: Structural member sizes for *ISMRFs* archetypes

storey	4-storey *ISMRFs*		7-storey *ISMRFs*		10-storey *ISMRFs*		15-storey *ISMRFs*		20-storey *ISMRFs*	
	Columns	Beams	Columns	Beams	Columns	Beams	Columns	Beams	Columns	Beams
	Box	PG	Box	PG	Box	PG	Box	PG	Box	PG
1	40X10	40X15	40X15	40X20	40X20	50X20	50X20	50X20	50X25	60X20
2	40X10	40X15	40X15	40X20	40X20	50X20	50X20	50X20	50X25	60X20
3	30X10	40X10	40X15	40X20	40X20	40X20	50X20	50X20	50X25	60X20
4	30X10	40X10	40X10	40X15	40X15	40X20	50X20	50X20	50X25	60X20
5			30X10	40X15	40X15	40X15	50X20	50X20	50X25	60X20
6			30X10	40X10	40X15	40X15	40X20	50X20	50X25	60X20

7	30X15	40X10	40X10	40X15	40X20	50X20	50X20	60X20
8			40X10	40X15	40X20	40X20	50X20	60X20
9			35X10	40X10	40X20	40X20	50X20	60X20
10			35X10	40X10	40X15	40X20	50X20	60X20
11					40X15	40X20	40X20	50X20
12					40X15	40X20	40X20	50X20
13					40X15	40X20	40X20	50X20
14					40X10	40X10	40X20	50X20
15					40X10	40X10	40X15	50X20
16							40X15	50X20
17							40X15	40X20
18							40X10	40X20
19							40X10	40X20
20							40X10	40X20

1- For the columns, the first number is the outside dimension in *cm* and the second one is the thickness in *mm*.

2- For the beams, the first number is the Web depth in *cm* , and the second one is the Flange width in *cm.*. For all beams the Flange and Web thickness is assumed as 10 mm.

4. SEISMIC RECORDS

In order to perform nonlinear dynamic analysis (NTHA), 10 far fault accelerograms and 10 near-fault accelerograms are used according to the Table 2 and Table 3. The near-fault accelerograms have the effects of Forward Directivity, Low Effective Duration and high speed pulse period and are selected from the stations with a distance less than 15 km from the fault [17, 18]. All selected accelerograms have a moment magnitude greater than 6.5 and the soil characteristics are of the D-class soil, based on the classification sited in FEMA 356 guidelines and are taken from the Peer website. SeismoSignal software is used for drawing the elastic response spectrum and all the accelerograms have been normalized to their peak ground acceleration (PGA). All the accelerograms used in this research are scaled according to the method presented in ASCE07-10 [19] and used in the NTHA method. Also in this research, in order to perform adaptive nonlinear static analysis according to the DAP method, use has been made of the displacement elastic response obtained from each of the far and near-fault accelerograms and finally an average is taken over the responses obtained from 10 far fault accelerograms and 10 near-fault accelerograms. In this research, the OpenSees software has been used to perform all nonlinear analyzes.

5. ASSESSMENT OF THE HIGHER MODES EFFECTS USING THE DAP METHOD

In order to assess the higher modes effects upon the displacement parameter, the shear and the drift angle of all stories (As one of the most important measures for assessment of the seismic demand of the structures) under the far and near-fault earthquakes, use has been made of nonlinear static analysis (DAP) method which provides a good estimate of the time history analysis results. The results obtained from the analysis using the first mode and analysis considering the higher modes in the DAP method and comparing the results to the results from the time history analysis under the far and near-fault earthquakes, together with the difference in the results corresponding to the height of each examined structure are shown in Figs. 4-8.

Table 2: Far fault earthqauke records used in this study

Number	Earthquake name	Date (yy-mm-dd)	Station	R (Km)	PGA (g)	PGV/PGA (s)	CAV (m/s)	Tp (s)	Tm (s)
1	Chi-Chi,Taiwan,	99-09-20	CHY065	83.43	0.1	0.14	9.88	0.56	0.79
2	Chi-Chi,Taiwan,	99-09-20	TAP095	109.01	0.15	0.18	56.56	0.98	0.84
3	LomaPrieta,	89-10-18	CDMG58224	72.2	0.24	0.15	27.69	0.32	0.86
4	LomaPrieta,	89-10-18	CDMG58472	74.26	0.26	0.16	28.35	0.64	0.85
5	Kobe,Japan,	95-01-16	HIK	95.72	0.14	0.11	45.02	0.6	0.76
6	LomaPrieta,	89-10-18	CDMG58223	58.65	0.23	0.11	33.26	0.3	0.53
7	Manjil,Iran,	90-06-20	Qazvin	49.97	0.13	0.09	59.48	0.16	0.46
8	Northridge,	94-01-17	CDMG13122	82.32	0.1	0.07	31.22	0.38	0.44
9	Tabas,Iran,	78-09-16	Ferdows	91.14	0.1	0.08	48.38	0.24	0.29
10	Kocaeli,Turkey,	99-08-17	Bursa Tofas	60.43	0.1	0.21	100.9	0.68	0.93

Table 3: Near fault earthqauke records used in this study

| Number	Earthquake name	Date (yy-mm-dd)	Station	R (Km)	PGA (g)	PGV/PGA (s)	CAV (m/s)	Tp (s)	Tm (s)
1	Denali, Alaska	02-11-03	Pump st. 10	2. 74	0. 32	0. 43	47. 83	0. 94	1. 52
2	Bam, Iran	03-12-26	Bam	R<15	0. 59	0. 43	118. 26	0. 78	0. 91
3	Chi-Chi,Taiwan	99-09-20	CHY101	9. 96	0. 44	0. 27	48. 15	0. 9	0. 98
4	Chi-Chi,Taiwan	99-09-20	TCU068	0. 32	0. 56	0. 32	30. 52	0. 42	1. 51
5	ImperialValley	79-10-15	CDMG	1. 35	0. 43	0. 26	23. 33	0. 24	1. 31
6	Northridge	94-01-17	DWP 75	5. 19	0. 49	0. 15	25. 50	0. 22	0. 72
7	Silakhor,Iran	06-03-31	Chalan Cho.	R<15	0. 45	0. 33	93. 81	1. 52	1. 82
8	Kocaeli,Turkey	99-08-17	Yarimca	4. 83	0. 26	0. 25	39. 12	0. 52	1. 29
9	Zanjiran,Iran	94-06-20	Meymand	R<15	0. 42	0. 28	123. 41	1. 36	1. 73
10	Kobe,Japan	95-01-16	Takatori	1. 47	0. 61	0. 21	42. 52	1. 22	1. 10
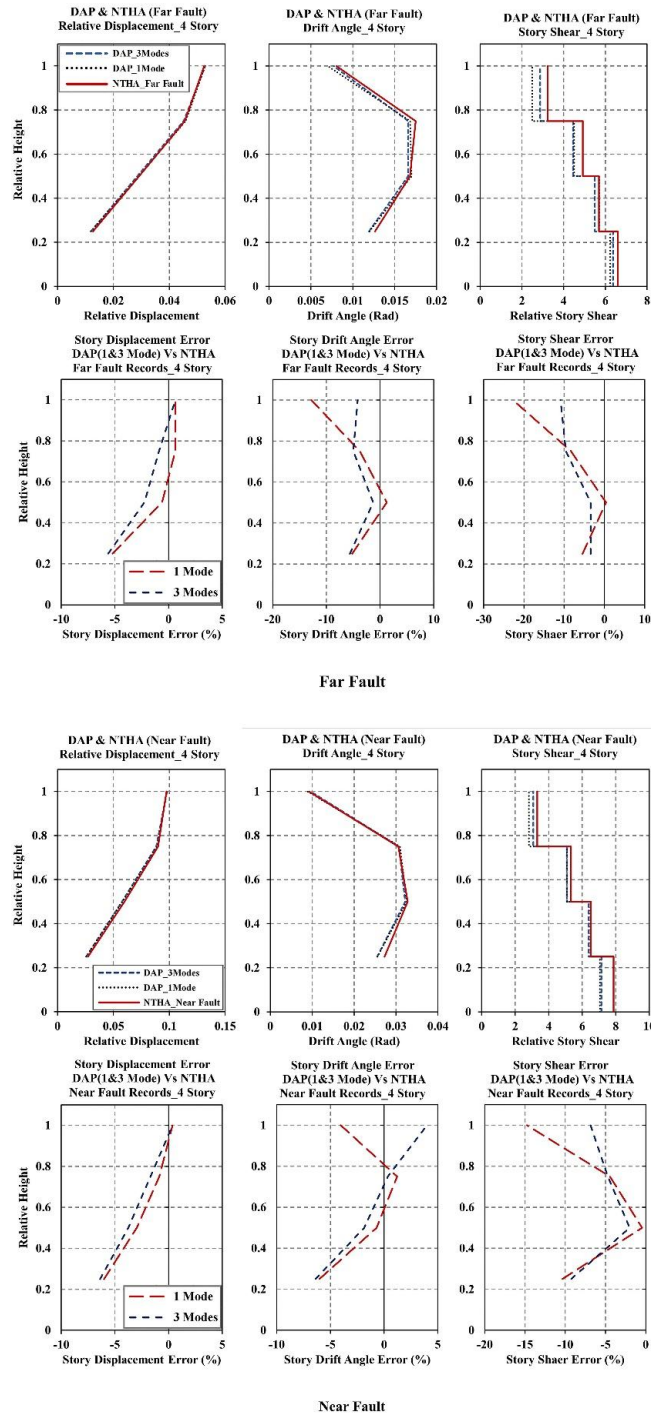
Figure 4. Comparison of the displacement, drift angle and stories shear results obtained from the DAP method using the first mode (DAP_1Mode) and the higher modes (DAP_3Modes), with the time history analysis results under the far fault earthquakes (NTHA_Far Fault) and the near-fault earthquakes (NTHA_Near Faut) for the 4-story structure
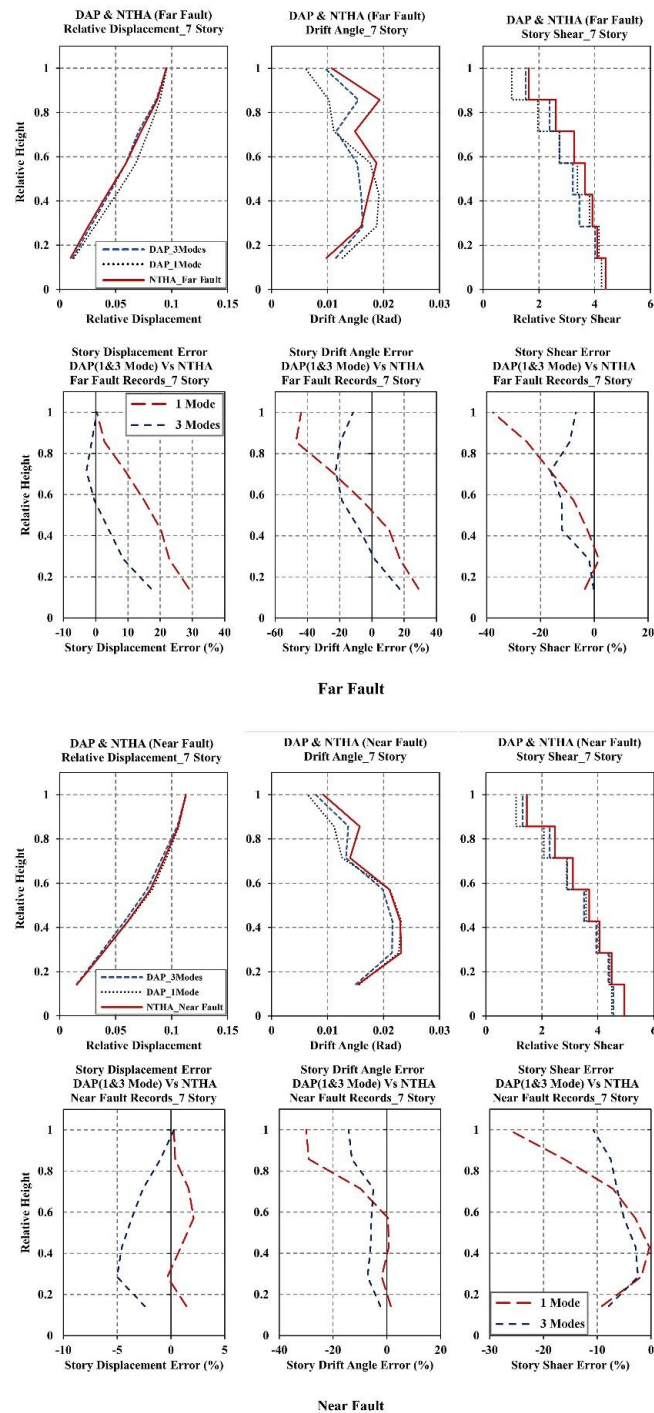
Figure 5. Comparison of the displacement, drift angle and stories shear results obtained from the DAP method using the first mode (DAP_1Mode) and the higher modes (DAP_3Modes), with the time history analysis results under the far fault earthquakes (NTHA_Far Fault) and the near-fault earthquakes (NTHA_Near Faut) for the 7-story structure
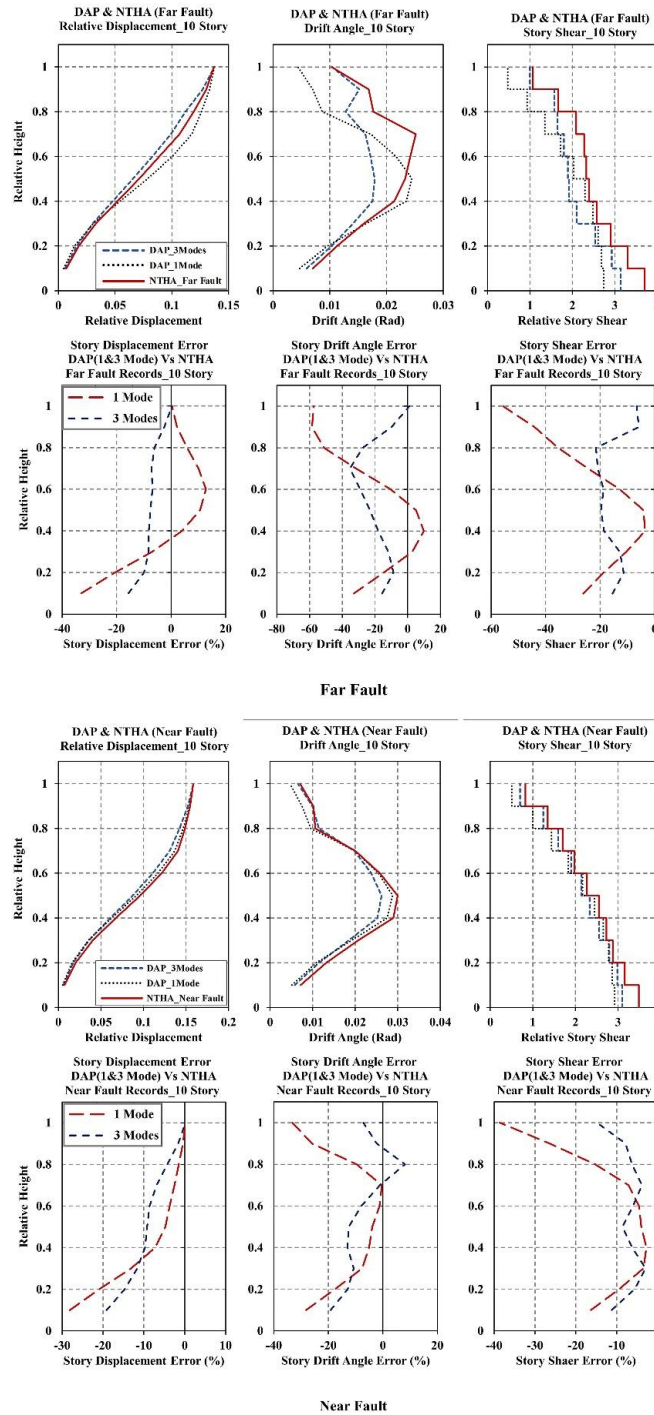
Figure 6. Comparison of the displacement, drift angle and stories shear results obtained from the DAP method using the first mode (DAP_1Mode) and the higher modes (DAP_3Modes), with the time history analysis results under the far fault earthquakes (NTHA_Far Fault) and the near-fault earthquakes (NTHA_Near Faut) for the 10-story structure
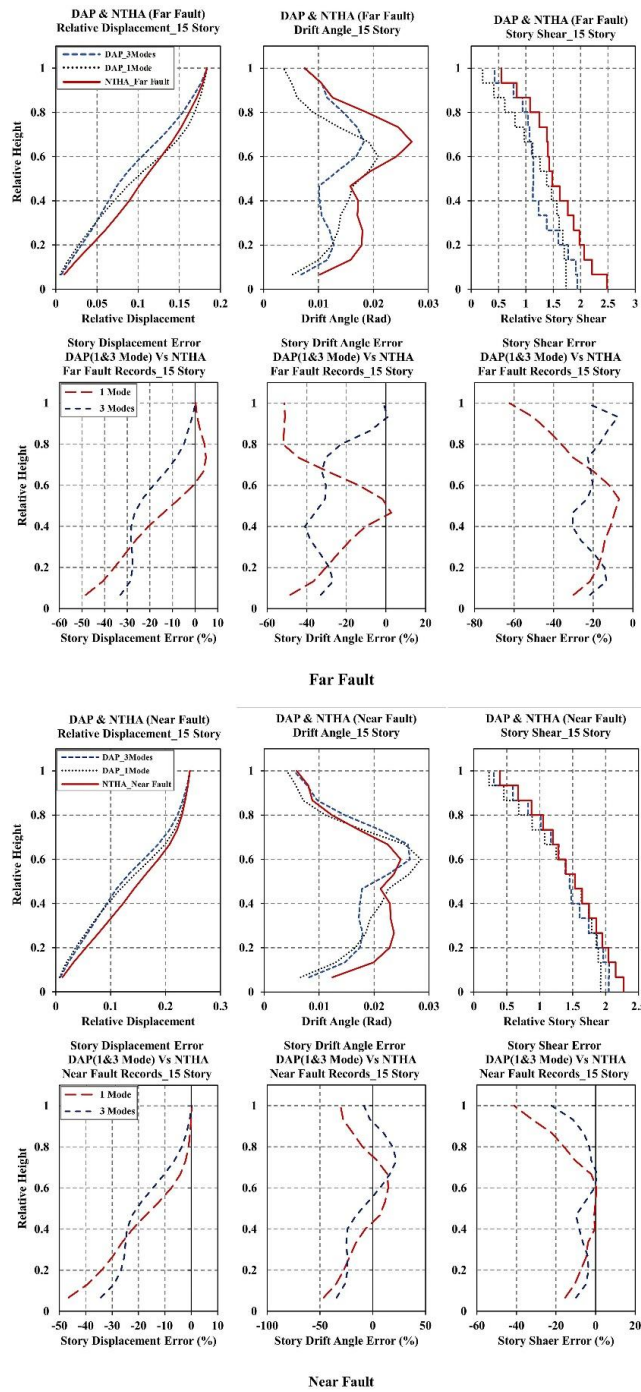
Figure 7. Comparison of the displacement, drift angle and stories shear results obtained from the
DAP method using the first mode (DAP_1Mode) and the higher modes (DAP_3Modes), with
the time history analysis results under the far fault earthquakes (NTHA_Far Fault) and the near-
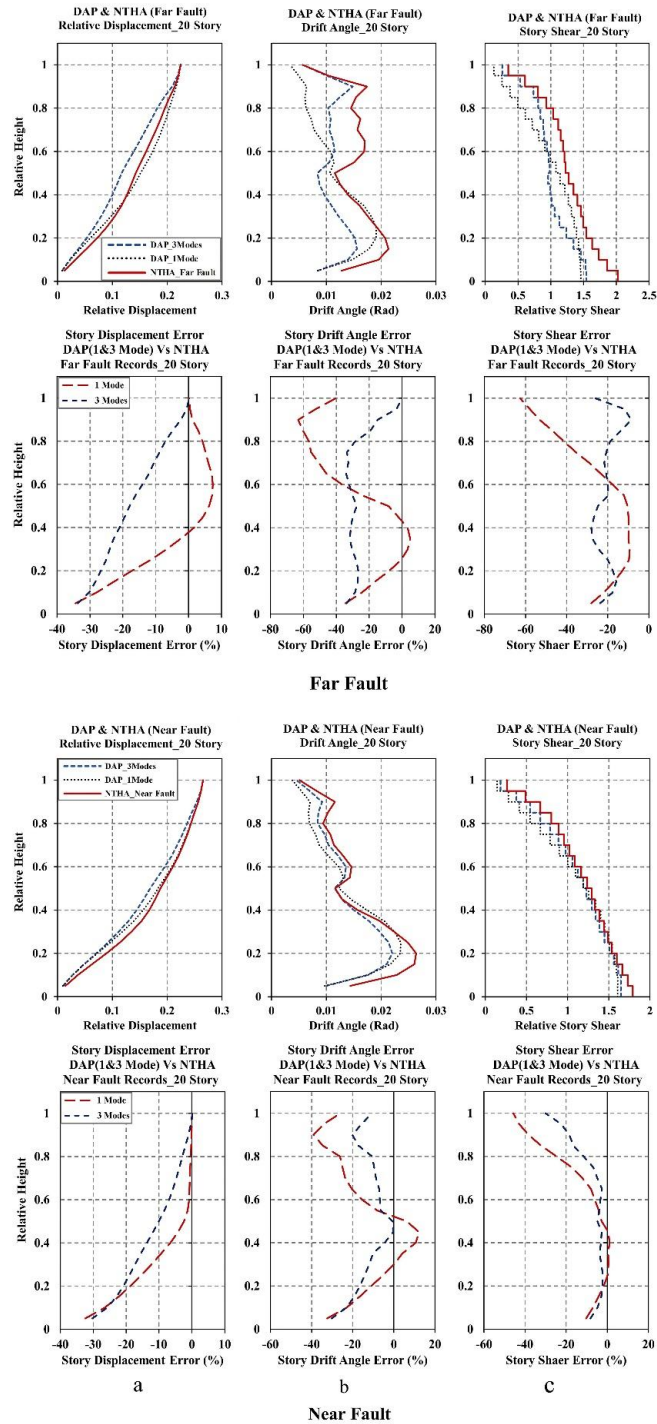fault earthquakes (NTHA_Near Faut) for the 15-story structure

Figure 8. Comparison of the displacement, drift angle and stories shear results obtained from the DAP method using the first mode (DAP_1Mode) and the higher modes (DAP_3Modes), with the time history analysis results under the far fault earthquakes (NTHA_Far Fault) and the near-fault earthquakes (NTHA_Near Faut) for the 20-story structure

In order to perform displacement–based adaptive pushover analysis(DAP), the displacement linear response spectrum obtained from the 10 far fault earthquakes accelerogrms and 10 near-fault earthquakes accelerograms have been used and finally an average is taken over the responses obtained from the displacement, drift angle and stories shear, then the results would be presented separately.

Investigation of the results shows that the higher modes effects are greater at the upper stories of the examined structures while the above discussed seismic demands at the lower stories are affected by the first mode of structure vibration. The difference in the results for analysis using the first mode and higher modes over the height of the structures under the near-fault earthquakes is less with respect to the far fault earthquakes, which shows greater higher modes effects under the far fault earthquakes. The DAP analysis error values (first mode and higher modes) compared to those of the time history analysis under the far and near-fault earthquakes are shown in Fig. 9. Investigation of the results of this difference shows that the higher modes effects under the far fault earthquakes for the drift angle and the stories shear demands is greater in comparison with the stories displacement. The error values for various structures are calculated using the Equation (1).

$$Error(\%) = \frac{100}{n}\sqrt{\sum_{i=1}^{n}\left(\frac{\Delta_{i_{NTHA}} - \Delta_{i_{Pus\,hover}}}{\Delta_{i_{NTHA}}}\right)^2} \tag{1}$$
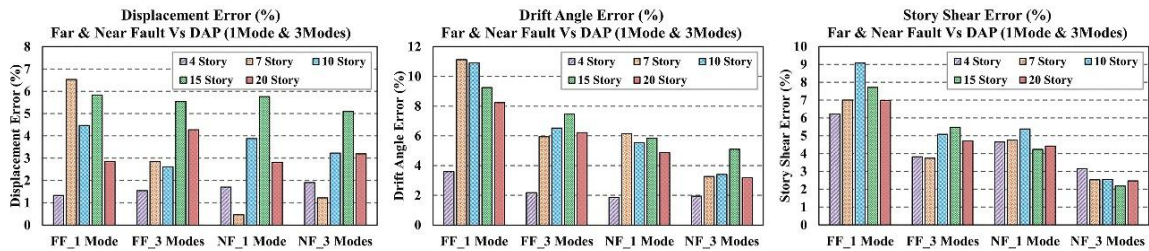

Figure 9. Difference in displacement , drift angle and stories shear values obtained from the DAP method for the first mode (1Mode) and the higher modes (3Modes) in comparison with those of the nonlinear time history analysis under the far fault (FF) earthquakes and the near-fault (NF) earthquakes for various stories

In Fig. 10 the higher modes effects (the difference between values obtained from the DAP analysis using the first mode and analysis considering the higher modes) in estimating the displacement, drift angle and stories shear values over different structure heights under the far and near-fault earthquakes have been shown. Also, values of this difference corresponding to the various structures are presented in Fig. 11.
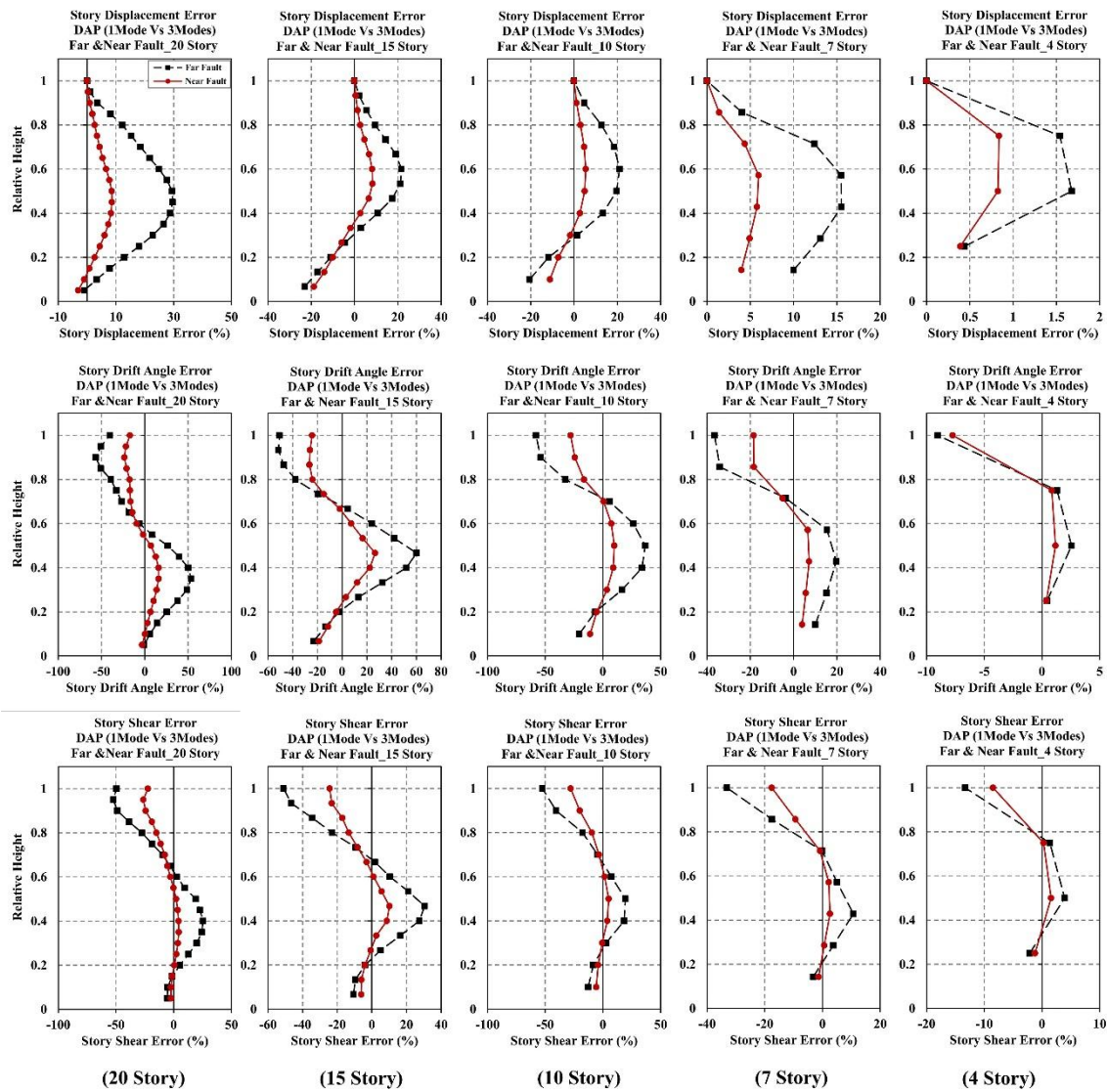
Figure 10. Difference in displacement, drift angle and stories shear values obtained from the DAP analysis using the first mode and analysis considering the higher modes (DAP_1Mode Vs DAP_3Modes) over the height of the structures being studied under the far and near fault earthquakes

5.1 Stories drift angle

The results show that considering higher modes effects in the DAP method cause the results come closer to the results of time history analysis and this issue is common in both far and near-fault earthquakes, but this difference is greater for the far fault earthquakes. In other words, the higher modes effects under the far fault earthquakes in estimating the stories drift angle are greater with respect to the near-fault earthquakes. The drift angle at the lower stories of the structures under the far and near-fault earthquakes are affected mainly by the

first mode and by the increase in the structure height, the difference in the analysis using the higher modes and the NTHA method decreases. Generally, The DAP method through considering the higher modes effects provides the appropriate estimate of the stories drift angle values under the far and near-fault earthquakes so that the greatest difference with the far fault earthquakes is 7.5% and with the near-fault ones is 5.1%.
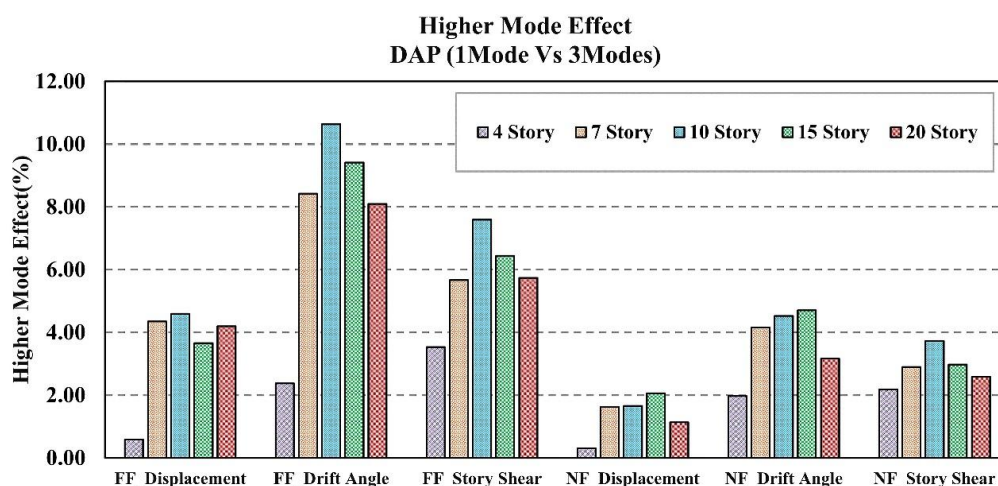

Figure 11. Difference in displacement, drift angle and stories shear values obtained from considering higher modes effects in the DAP method (DAP_1Mode Vs DAP_3Modes) for various structures

5.2 Stories shear

In all structures being investigated and under far and near-fault earthquakes, the shear at the lower stories of the structures is mainly affected by the first mode, that is while the difference in the results from the first mode and the higher modes (3Modes), under the near-fault earthquakes is less than the far fault earthquakes. In fact, the higher modes effects in the shear of the lower stories of the structures under the near-fault earthquakes are less than those of the far fault earthquakes. That is while at the upper stories of the structures, the results of the stories shear obtained from the analysis using the first mode have the great difference with the results of the nonlinear time history analysis (NTHA) and this issue is common in both far and near-fault earthquakes. In fact, the upper stories shear for all the structures is affected by the higher modes.

5.3 Higher modes effects based on FEMA 356

Higher modes effects are important factors causing difference in the responses obtained from the multi-degree of freedom (MDOF) structures and single degree of freedom (SDOF) structures. The research done show that by the increase in the height and the period of the MDOF structures, higher modes effects increase [20]. The building codes have presented regulations for considering higher modes effects and the number of the modes to be used in the analysis. According to the Iranian seismic code, that number of the modes should be considered which sum of their effective modal masses is at least 90% of the total mass of the

structure. Based on the FEMA 356, when the story shear obtained from the linear dynamic analysis, considering that number of the modes which sum of their effective modal masses is at least 90% of the total mass of the structure, is 30% more than the story shear from the single mode, then both the nonlinear static analysis and the linear dynamic analyzes should be considered. In other words, when the stories shear obtained from the higher modes is 30% more than the stories shear obtained from the fundamental mode of the structure then the higher modes gain importance. The DAP method as a method capable of considering effects of different modes during the analysis process is utilized in this research for assessment of the higher modes effects. This method has the capability of receiving the displacement spectrum obtained from various accelerograms. The following stages have been implemented to investigate the higher modes effects:

a) Performing analysis using the DAP method, considering the first mode of the structure for all discussed structures under the far and near-fault records, according to the Table 2 and Table 3.

b) Performing analyzes of the first step with all vibrating modes which sum of their effective modal masses is at least 90% of the total mass of the structure.

c) Calculation of the stories shear (corresponding to the second step), to stories shear (corresponding to the first step) ratio for all the accelerograms.

d) Averaging over the accelerograms results obtained in the third step.

The results from the investigation of higher modes effects under the far and near-fault earthquakes for various structures are shown in Fig. 12. Examining these results one could see that with the increase in the height, the higher modes effects under the far fault earthquakes increase with respect to those of the near-fault earthquakes so that these effects are greater at the upper stories than the lower stories. The higher modes effects under the far fault earthquakes are greater with respect to the near-fault earthquakes so that these effects are greater in the high-rise structures.

Fig. 13-a shows the base shear transform coefficients of higher modes (3Modes) obtained from the nonlinear static analysis (DAP) under the far and near-fault earthquakes. It is observed that in these diagrams the values of this coefficient for the far and near-fault earthquakes is greater than unity. In fact, the base shear from the higher modes is always greater than the base shear from the first mode. That is while in the near-fault earthquakes the value of this coefficient is closer to the unity. This issue shows that in the near-fault earthquakes, the first mode base shear has a negligible difference with the higher modes base shear. In Fig. 13-b the base shear transform coefficient from the higher modes under the near-fault earthquakes to that of the far fault earthquakes is presented which helps in the more rapid analysis and the preliminary estimate of the base shear under the near-fault earthquakes considering the higher modes effects. Also, the relationships resulted from the linear regression of the transform coefficients are presented. These relationships could be implemented for the preliminary estimation of higher modes effects in the base shear of the structures and the difference in the base shear under the near-fault earthquakes in comparison with that of the far fault earthquakes.
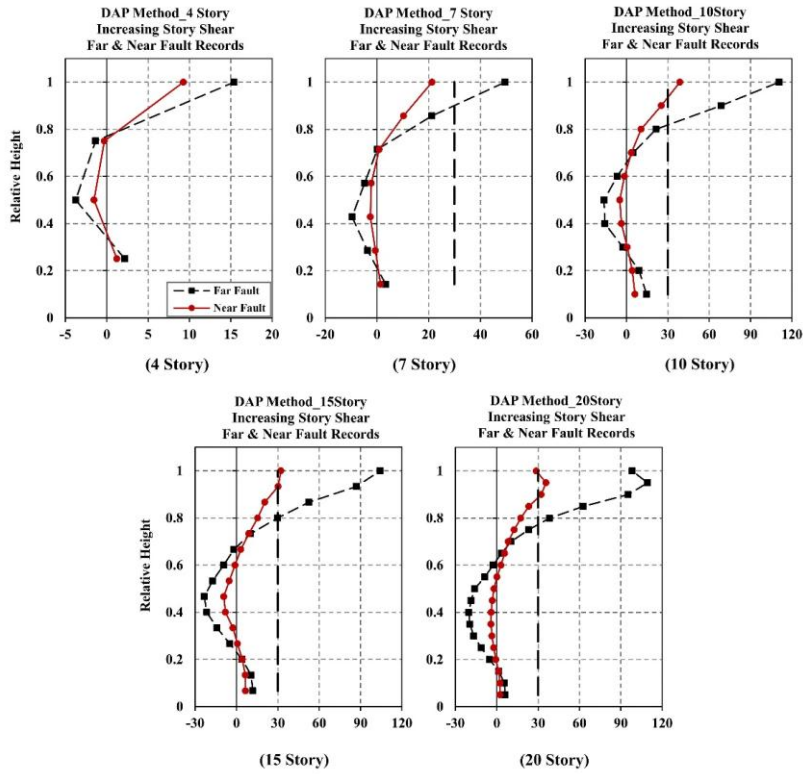
Figure 12. Higher modes effects under the far and near fault earthquakes, in the studied structures
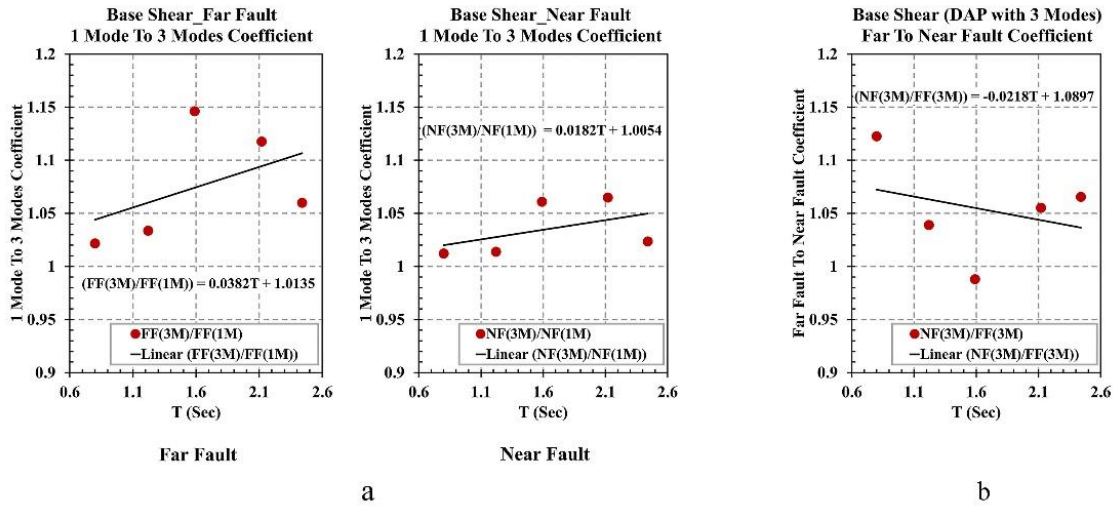

Figure 13. **a)** Base shear transform coefficients from the first mode to base shear from the higher modes under the far and near fault earthquakes. **b)** Base shear transform coefficients of the far fault to those of the near fault earthquakes from the DAP method considering the higher modes effects

6. CONCLUSION

In order to assess the higher modes effects under the far and near-fault earthquakes in the steel structures, 5 intermediate moment resisting frames with 4, 7, 10, 15, 20 stories have been designed. The nonlinear static analysis DAP which well incorporates the higher modes effects in the analysis is used in this study. The following results were obtained in the scope of these models:

- The higher modes effects are greater for the far fault earthquakes with respect to the near-fault earthquakes.
- The higher modes effects increase, by increase in the height of stories (period).
- At the upper stories of the various structures, the higher modes effects are greater with respect to the lower stories.
- The base shear from the nonlinear static analysis DAP, under the far and near-fault earthquakes using the higher modes, is larger than the base shear obtained from the first mode.
- The base shear obtained from the higher modes under the near-fault earthquakes has a negligible difference with the shear base obtained from the first mode.

The higher modes effects under the far fault earthquakes for the seismic demands of the drift angle and the stories shear are greater with respect to the stories displacement.

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