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EFFECT OF BIDIRECTIOANAL NEAR FIELD GROUND MOTIONS ON INELASTIC RESPONSE OF 3D MODELED R.C FRAME BUILDINGS

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ABSTRACT

Investigations confirm that near field ground motions differ from far field ground motions. A vast number of studies in the near field area have been conducted on 2-dimensional simiulations of structures, and no comprehensive studies have been conducted on 3-Dimensional nonlinear models of structures subjected to near field ground motion. Since a 2-dimensional analysis might cause some error due to the approximation and presumptions in mass, stiffness and also not taking into account the P-M2-M3 interaction of forces and deformations, the need for a 3-D analysis can be sensed.

The main objective of this study is to investigate the effect of near-fault ground motions with forward directivity on the seismic behavior and inelastic response of 3D concrete frame buildings with various fundamental periods and also determinin whether different faulting mechanisms result in different seismic demands on structures. In addition, investigating whether or not the demands obtained from 2D and 3D analyses conducted on 3D models are in agreement or not, in order to understand the importance of 3D analyses on buildings. The buildings are subjected to far field ground motions as well, and responses of the two cases will be compared to form a better notion of the difference between a structure's behavior under near and far field ground motions

Noticeable difference is observed between strike slip, dip slip and farfield records, both in peak inter story drift patterns, values and the story that experiences the maximum peak inter story drift. As it is expected, the studied buildings show higher inters-story drift demand in comparison with those reported from 2D analyses conducted on 3D models in this study. This would be due to the fact that the P-M2-M3 interaction effects on derived responses are more significant from those of 2D analyses and ofcourse 2D models. The conclusion inferred from current study emphasizes the need to use 3D models instead of 2D, where the influence of near field record is investigated.

INTRODUCTION

It has only been two decades since scientists have paid attention to the subject of near field earthquakes. Since many cities (specially in Iran) have been developed close to seismic sources and in high earthquake zones, building structures near seismic sources and therefore evaluating their behavior while subjected to near field earthquakes is inevitable. Somerville et al. (1996) confirmed that regardless of the faulting mechanism, average amplitude of average horizontal ground motions containing forward directivity are 50% greater than that of records with little directivity for periods longer than 0.5s. yang et al. (2010) and sehatti et al. (2011) also conducted research on near field earthquakes with forward directivity and concluded that these earthquakes enforce more seismic demand on structures. the other hand, it is known that a 3D nonlinear time history analysis is the only most accurate method for determining the seismic demand of structures subjected to an specific earthquake. In fact any static analysis suffer from errors due to neglecting the effects of time and a 2D analysis is not exact since it will give a low estimate of axial forces subjected to the columns. The studies conducted in the near field area are either through a nonlinear 2D analysis or a linear 3D analysis, both of which contain too many simplifications and assumptions in comparison with a nonlinear 3D analysis. Kalkan and kunnath (2006) (Kalkan and Kunnath 2006) conducted nonlinear time history analyse on 2-dimensional steel moment frames, subjecting them to records from far field, near field with forward directivity pulse and near field with fling step pulse. It was demonstrated that seismic demand of buildings in near field area increases noticeably as opposed to the far field demands.

In the vicinity of seismic sources, depending on different rupture mechanisms, fling step and forward directivity pulses are likely to appear in either the fault normal or fault parallel components of the horizontal ground motions. Since conventional data processing procedures eliminate the fling step pulses through filtering and base line correction, and the data set applicated in this study is obtained from PEER ground motion data base, ground motions only contain the forward directivity pulse. Different scenarios can be formed due to different faulting mechanisms. For a strike slip faulting mechanism, the forward directivity pulse appears in the strike-normal direction, and for a dip slip mechanism, the directivity pulse is oriented in the direction normal to the fault dip (Sommervile 2005). İn this paper we take two faulting mechanisms, dip-slip and strike-slip, and subject the buildings to records acquired from earthquakes with these faulting mechanisms. In addition, another scenario taken into account is the far field earthquakes; records from which will be enforced to the buildings as well.

DESCRIPTION OF BUILDINGS USED FOR ANALYSIS

Three concrete moment-resisting buildings categorized intermediate ductility have been designed in accordance with Iranian code of practice for seismic resistant design of buildings (BHRC, 2004) and ACI 318-99 (1999). Further detail on these buildings is given by Hosseini (2009). The floor plan of these buildings is shown in Figure. 1.

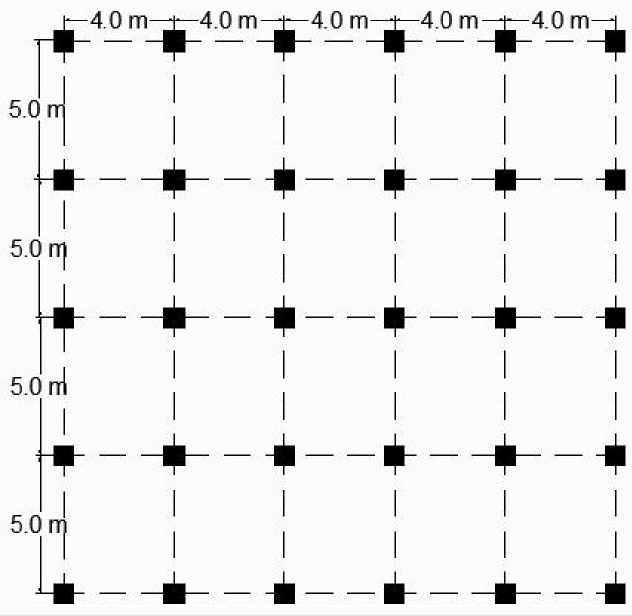

Figure 1. Floor plan of 3, 6 and 9 story buildings

The diaphragm has been assumed to be performing as a rigid deck. The nonlinear evaluations were carried out in OPENSEES through 3D model simulation of buildings. In order to model the nonlinear behaviour of the building, both lumped and distributed nonlinearity have been used. Since a 3D nonlinear model of buildings with numerous number of elements as the buildings used in this research, causes numerical problems in analysis and is time consuming, two different modelling approaches were provided. Since axial forces are very substantial in columns a distributed plasticity model (BeamWithHinges element) that utilizes a layered fiber section has been used to model the columns, so that it can take into account the P-M-M interaction of forces and for beam modelling a lumped nonlinear model has been used.

The concrete assigned to the columns represents two behaviours, an unconfined concrete behaviour for the cover concrete and a confined concrete behaviour for the core concrete, which causes different stress strain curves to be used for modelling the two materials. On the other hand, in order to simulate beams, two springs have been modelled at the ends of the beams. The monotonic and cyclic behaviour models presented by Ibarra et al. (2007) and Haselton et al. (2005) have been used in the simulation process.

The buildings have been chosen so as to cover a reasonable range of periods, so that the analyses can exhibit the effect of near field earthquakes on various periods. Table 1 shows the fundamental periods of each building obtained from OPENSEES.

Table 1. Fundamental periods of modelled structures in X and Y directions

No.	Model	X-direction period	Y-direction period
1	3 Story	1.108	1.037
2	6 Story	1.573	1.44
3	9 Story	2.275	1.83

GROUND MOTION DATA BASE

Selecting records is an important part in the process of nonlinear dynamic analysis, since the results depend extremely on the selected records. According to ASCE 07-10 (2010), if 7 records are provided, the mean of the results can be represented as the final result; however, if 3 records are provided, the maximum results obtained are presented as the final results. The ground motion database considered for this study includes 2 sets of near field records which contain forward directivity pulse, one from dip-slip fault mechanism earthquakes and the other strike-slip, and the third one, a set of far field records, each containing 7 ground motions.

The far field records will be used as a benchmark to compare the near field ground motions against. The first two sets of records, regarding near field earthquakes have been recorded within a 15km distance of the fault, and the far field records have been recorded within 80km of the fault's plane. Information regarding these ground motions is presented in Table 2.

Table 2. Details on ground motion data base, on the left: scenario 1 (strike slip mechanism) in the middle: scenario 2 (dip slip mechanism) on the right: scenario 3 (far field)

No.	Earthquake	M	PGA(g)	No.	Earthquake	M	PGA(g)	No.	Earthquake	M	PGA(g)
1	Imperial Valley	6.5	0.22	1	Loma Prieta	7.0	0.37	1	Northridge	6.7	0.26
2	Imperial Valley	6.5	0.35	2	Loma Prieta	7.0	0.37	2	Kern county	7.5	0.18
3	Imperial Valley	6.5	0.22	3	Northridge	6.7	0.83	3	Imperial-Valley	6.5	0.27
4	Kocaeli	7.4	0.31	4	Northridge	6.7	0.84	4	Northridge	6.7	0.14
5	Morgan Hill	6.1	1.16	5	Northridge	6.7	0.45	5	Landers	7.3	0.11
6	Imperial Valley	6.5	0.46	6	Loma Prieta	7.0	0.64	6	Kern county	7.5	0.13
7	Erzincan	6.7	0.50	7	Cape Mendocino	7.1	0.66	7	Loma Prieta	7.0	0.1

TARGET SPECTRUM AND SCALING THE RECORDS

In order to conduct a dynamic nonlinear analysis, the 5% linear spectrum of all the records have been computed and scaled to the MCE spectrum of ASCE07-10 according to scaling regulations of

ASCE07-10. The soil was assumed to be a type C soil for determining the target spectrum. The 7 records in each of the 3 sets were scaled in a manner that the mean of their spectrums matched the target spectrum with minimum error in the period range of o.2T and 1.5T, while the mean spectrum does not exceed a 10% error range at each period point. The mean response spectrum for the 3 sets of records are demonstrated in Fig. 2.

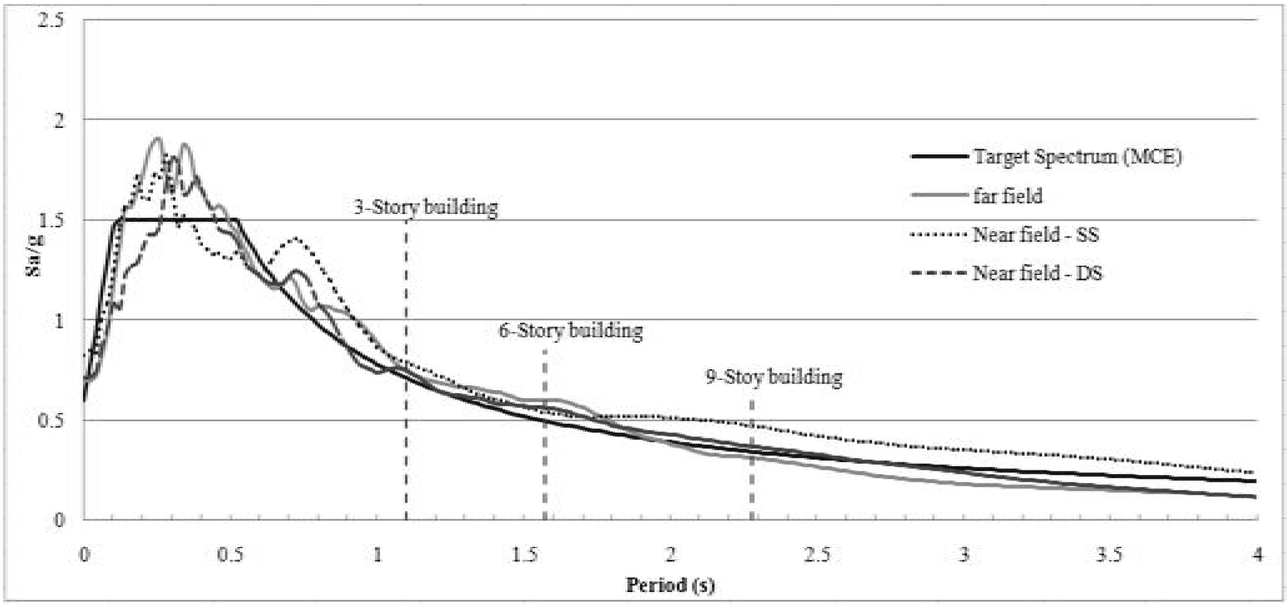

Figure 2. Target spectrum and mean response spectrum of a) Forward directivity from strike slip mechanism b) Forward directivity from dip slip mechanism c) far field records

NONLINEAR TIME HISTORY ANALYSIS

The buildings simulated in OPENSEES have been subjected to two horizontal and a vertical component ofthe records scaled in the previous section; consequently, for each building 21 nonlinear time history analyses has been conducted. For the case of strike slip mechanism, a 2D analyses has been conducted as well by subjecting the buildings to one horizontal component in the fault normal direction, and a vertical component. The maximum inter story drift ratio (IDR) of stories was taken as the measure of seismic demand. In the end the peak inter story drift versus story level curves of the buildings have been obtained from NTH analyses of the buildings subjected to far-fault motions and near-fault motions with forward directivity for strike slip faults and dip slip faults. The peak inter story drift profiles obtained from NTH analyses of buildings subjected to the three sets of ground motions are presented in Fig. 3 as well as their associated dispersion values.

Consequently, seismic behavior of the structures in near field was evaluated using IDR and compared to that of far filed earthquakes. Since the forward directivity pulse appears in the fault normal component, the focus of this study would mainly be on the results from the fault normal direction of the building.

Firstly, for the fault normal component, as it is demonstrated in figure 3, the first floor of the 3 story building appears to be subjected to the maximum drift in all of the three scenarios; a drift of 2.2% in the far field area, and a 4.8% and a 6.7% while subjected to dip slip and strike slip fault ground motions, respectively. On the other hand, the 2D analyses conducted on the same buildings for the strike slip scenario, gives a lesser inter story demand on the first story with the value of 4.1% as opposed to 6.7% obtained from 3D analyses, which gives an underestimation of the demands up to 60%. In addition, far field motions result in a uniform inter story drift demand, for the near field records, the maximum is produced in the first story.

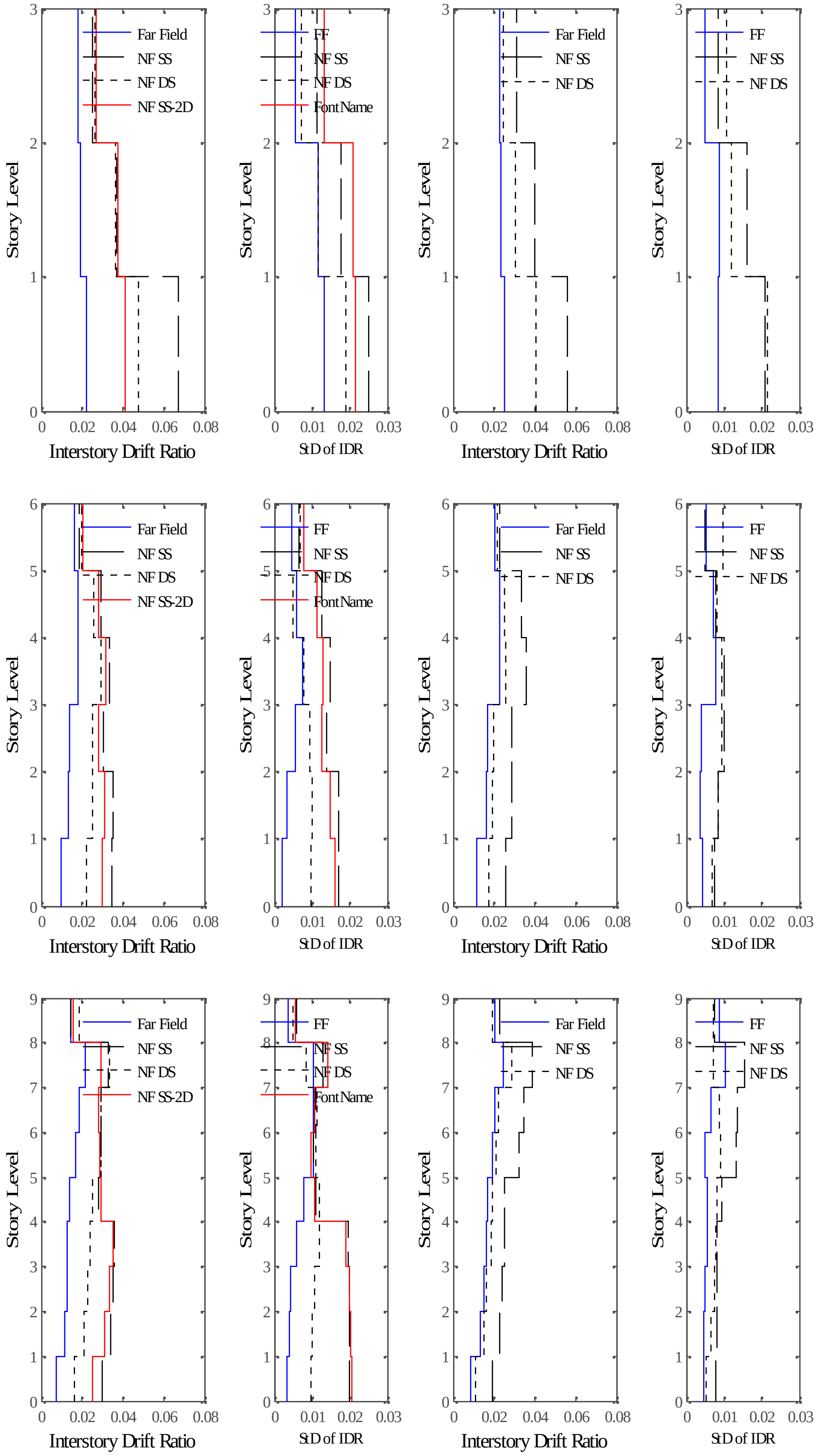

Figure 3. The median and standard deviation of maximum inter story drift for 3-story, 6-story and 9-story buildings for far field, near field strike slip and near field dip slip scenarios and 2D analyses of strike slip records a) median of IDR (fault normal component) b) standard deviation of IDR (fault normal) c) median of IDR (fault parallel component) d) standard deviation of IDR (fault parallel)

For 6 story building, the maximum story drift for far field records and the dip slip records is observed to be at the fourth and fifth story levels with a drift value of 1.8% and 3% respectively. While, for the strike slip records, the maximum occurs at the second story with a drift value of 3.5%, yet, for the 2D analyses of strike slip records, the maximum occurs at the second and fourth floor with a value of 3.1% which gives an underestimation of 13%. Nonetheless, the 2D analyses and the 3D analyses of strike slip records follow the same story drift pattern in elevation. In addition, it is demonstrated that for the 6 story building, the pattern of the inter story drift in the elevation of the building is almost the same for the far field and the dip slip ground motions.

For the 9 story building, the maximum story drift for far field records and the dip slip records is observed at the 8th story level, with a drift value of 2.2% and 3.3% respectively. For the strike slip records, the maximum occurs at the 3d and fourth story level with a drift value of 3.6%. in the case of the 2D analyses, no change is demonstrated in the value of the maximum story drift. However the 2D analyses has resulted in lesser inter story drift values for the first and second and also the 8th story. Though it was obtained that in all three buildings the story that experienced the maximum drift demand and also the drift pattern in elevation are mutual for far field and dip slip fault records, the demands subjected through dip slip motions in all cases are much higher than far field.

In the case of the fault parallel component, for the 3 story building, the first story experiences the maximum demand for all scenarios, the values of drift demands are 2.5%, 4.1% and 5.6% for far field, dip slip and strike slip records respectively. For the 6 story building, the fourth story is subjected to the maximum drift in all three scenarios as well. However, it can be noted that the maximum values of drift for far field and dip slip records are 2.3% and 2.5% which are almost the same. And the maximum value of drift for the strike slip records is 3.6% which is much greater than the other two. For the 9 story building the maximum drift demand is produced in the 8th story with the values of 2.5%, 2.8% and 3.8% for the far field, dip slip and strike slip records, respectively. It is also distinctly clear that for the 9 story building in addition to the 6 story building, the pattern of drift, as well as the maximum values of drift, is almost the same for the far field and the dip slip records.

CONCLUSIONS

As explained before, due to the fact that the fault normal component contains of the forward directivity pulse, as expected, buildings subjected to the fault normal components have experienced larger drifts. To conclude, the median of the maximum demands as well as the standard deviation of the peak values for the three buildings were higher for near field records than the far field motions. Also the strike slip motions put higher drift demands on all of the three buildings in comparison with the dip slip motions, in both fault normal and fault parallel components. Also, it is illustrated that in the fault parallel component that does not contain a forward directivity pulse, the story drift pattern in the elevation is the same for all three scenarios, and the demand that dip slip and the far field records put on the buildings are almost the same.

In addition, it can be concluded that the values of drift demands for the near field motions obtained from 3D analyses of buildings are noticeably higher (as high as 60%) than those obtained from 2-dimensional analyses. This underestimation can better be seen in the case of the 3story building. The difference in the maximum demand values can be justified by taking into consideration the existence of great axial forces exerted on the end frames of the buildings in the 3-dimensional models having been subjected to 3-dimensional ground motion components in comparison with 2-dimensional analyses.

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