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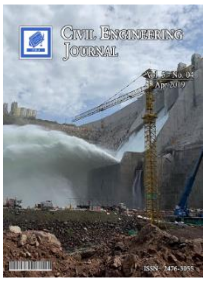

Performance of Concrete MRF at Near-Field Earthquakes Compared to Far-Field Earthquakes

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Abstract

The characteristic of near-field earthquake records has been investigated in the previous studies. However, the effects of the near-field earthquakes on the response of the building structures need to be further investigated. Engineering demand parameters like inter-story drift ratio and floor acceleration can provide a good means for comparing the response of structures to the near-field and the far-field earthquakes. The main objective of this paper was to apply these two parameters to compare the behavior of the concrete Moment Resistant Frame (MRF) subjected to near-field and far-field ground motions. In this study, non-linear numerical simulations were performed on concrete MRF office buildings subjected to two sets of 14 near-field records and 14 far-field records. The analytical models simulated 4-story, 8-story, and 16 story buildings. The obtained results indicated that the near-field effects can increase the inter-story drift ratio and floor acceleration at lower stories of low and mid-rise building subjected to high ground motion intensities.

Keywords: Near-Fault Earthquake; Building Performance; Concrete MRF; Inter-Story Drift Ratio; Floor Acceleration.

1. Introduction

Earthquake events have proven to be destructive to manmade constructions including both buildings and infrastructures [1, 2]. Understating the performance of structures during the seismic events can help to improve the constructions and build more resilient societies.

Previous studies and observations indicated that the building response to near-field and far-field earthquake records have notable differences. Many researchers have tried to apply scientific measures to characterize the effects of near-fault earthquakes on structural response [3-5].

The near-fault earthquake has mainly been investigated from two viewpoints. The first one is the geological aspect of near-fault earthquakes. The studies performed by Cork et al. (2016), Akkar et al. (2018) and Bray and Rodriguez-Marek (2004) concentrated on explaining the physics of near-field earthquakes and can be referred to as examples of the first viewpoint. The emphasis of these studies was to justify the special characteristics of near-fault ground motions including large long period pulse in velocity time history [6-8]. Some other researchers like Somerville (2003) tried to find some rules to predict the properties of near-field earthquake response spectra, considering the geological causes of this phenomenon [9].

The current study is concentrated on the second aspect of the near-field earthquakes which is the special effect of near-field earthquakes on the structural behavior. Most of the previous studies on this subject have compared some

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response parameters such as story shear, story drift or well-known damage indexes (e.g. Park-Ang index), between near-field and far-field ground motion records. Among them is the study performed by Alavi and Krawinkler [10].

While these efforts helped to achieve a more realistic insight into the behavior of structures subjected to the near-field ground motions, still there is a need to better understand the effects of near-field earthquakes on the building performance. In this paper, the inter-story drift ratio and floor acceleration were used to compare the performance of building subjected to near-field and far-field earthquakes.

The applied methodology is summarized in Figure 1. The first step was to develop the nonlinear finite element models for the 4, 8 and 16-story concrete MRF buildings. Then two sets of records including a set of 14 far-field and a set of 14 near-field earthquake records were selected to compare the response of models to far and near field seismic events. In the next step Incremental Dynamic Analysis (IDA) was performed for each record and the demand parameters including Inter-story Drift Ratio (IDR) and Maximum Floor acceleration (MFA) were calculated at different levels of ground motion intensities. Finally, the medians of the results were obtained for each set of records to compare the response of the building models to far-field and near-filed earthquake records.

Prepare the nonlinear finite element model for the 4, 8 and 16-story building models

↓

Select a set of 14 far field earthquake records and a set of 14 near field earthquake records

↓

Perform IDA to calculate the IDR) and MFA at different levels of ground motion intensity

↓

Obtain the median values of IDR and MFA for near filed and far filed records and compare the building performance

Figure 1. Methodology Flowchart

2. Structural Model

In this study, the effect of near-field ground motion on the seismic behavior of concrete moment resisting frames was investigated. For the sake of simplification, 2D frames have been modeled instead of actual 3D models. The experimental data limitation for 3D element calibration was the main reason for the application of this simplifying approach. To assess the effect of building height on the seismic performance in the near-field earthquakes, three models including low-rise (4-story), mid-rise (8-story) and high-rise (16-story) were considered. The frames are designed in accordance with the [11], ACI 318 [12] and ASCE 7 [13]. The bay width was 6 meter and typical story height was 3 meters for all frame models. The frames properties are summarized in Table 1.

Table 1. Frames properties

Frame	1st mode		2nd mode		3rd mode		Total weight(kg)	Base-shear Coeff.
	Period(s)	Eff. mass ratio	Period(s)	Eff. mass ratio	Period(s)	Eff. mass ratio		
4-story	0.94	77.4	0.3	13.4	0.14	6.3	452571.5	0.144
8-story	1.58	73.7	0.57	12	0.31	5.5	952901.4	0.067
16-story	2.75	71.8	1.02	11.7	0.62	5.4	2103484	0.038

The OpenSEES program was used for numerical modeling and dynamic time history analysis under earthquake excitations. During the earthquake loading, the behavior of reinforced concrete elements becomes inelastic at joints location. The precise method for in capturing the nonlinearity would be to consider the mechanical properties of concrete [14] and steel reinforcement in inelastic range. However, in this study, elastic elements along with plastic hinges were used in the numerical model to account for the nonlinear behavior of the 2-D structural frames, [15]. This simulation approach is known as lumped plasticity modeling and assumes the whole nonlinearity of the elements is concentrated at plastic hinges. Different uniform backbone curves and modes of deterioration can be considered for the plastic hinges in order to simulate the structural behavior beyond the elastic range.

To implement the plastic hinges into the model, the existing JOINT2D element in OpenSEES developed by Altoontash [16] was applied. This element contains rotational springs at each side of a parallelogram. Each of these springs acts as a plastic hinge located at the adjoined end of the elastic beam-column element.

To capture the nonlinear behavior of plastic hinges, Clough material property was assigned to the rotational springs of the JOINT2D element. This peak-oriented material model has a three-linear backbone curve and can simulate four modes for cyclic strength and stiffness degradation including (a) basic strength deterioration, (b) post-capping strength deterioration, (c) unloading stiffness deterioration, and (d) accelerated reloading stiffness deterioration, [17].

Application of these plastic hinges requires to characterize the parameters of the Clough material model. This can be achieved through calibration of the model in accordance with data provided by laboratory tests. In this study for the calibration of the Clough material, the experimental formulations presented by Fardis and Biskinis [18] were used.

3. Ground Motion Selection

As mentioned earlier, one of the objectives of this study was to assess the performance of concrete MRFs in near-field earthquakes. One of the most important characteristics of near-field ground motion records is a single large long period pulse of motion, which can be observed in the time history of the velocity record. This property of the velocity record is caused by the forward directivity effect. Most of the studies that investigated the effect of near-field records have attributed the destructive impact of a near-field earthquake on building to this pulse-like property. In this paper, the effect of the near-field earthquakes on the building was investigated, regardless of the geotechnical causes resulting in the near-field ground motion specifications. To achieve this goal, the building performance was analyzed and compared for several near-field and far-field earthquakes.

For the time history structural analysis, a series of 14 near-field and 14 far-field earthquake ground motion records were selected (Table 2 and 3). All of the selected earthquakes were within a magnitude range of 6-8. The soil category of the site for all of the records was “D”, according to the NEHRP [19] classification. Another condition for near-field record selection was that they could cover the full range of possible pulse periods, as it is shown in the last column of Table 3.

Table 2. Far-field ground motions properties

No.	Earthquake	Year	Station	Magnitude	Distance (km)
1	ChiChi, Taiwan	1999	HWA	7.6	73.34
2	Imperial Valley	1979	Delta	6.53	22.03
3	ChiChi, Taiwan	1999	HWA051	7.6	55.8
4	Imperial Valley	1940	Elcentro Array 9	6.53	21
5	Kocaeli, Turkey	1999	Atakoy	7.51	58.28
6	Loma Prieta	1989	Alameda	6.93	71
7	Loma Prieta	1989	Oakland	6.93	72.2
8	Loma Prieta	1989	SF Airport	6.93	58.65
9	Landers	1992	Indio - Coachella Canal	7.3	55.7
10	Northridge	1994	Santa Fe Spr - E. Joslin	6.7	52.7
11	Northridge	1994	Terminal Island - S Seaside	6.7	60
12	N. Palm Springs	1986	Temecula Fire Station	6	73.2
13	Sanfernando	1971	Gormon - Oso Pump Plant	6.6	48.1
14	whittier Narrows	1987	Downey - Birchdale	6	56.8

Table 3 Near-field ground motions properties

No.	Earthquake	Year	Station	Magnitude	Distance (km)	Pulse period (s)
1	Cape Mendocino	1992	Petrolia	7.01	8.18	0.72
2	Erzincan	1992	Erzincan	6.9	2	2.02
3	Imperial Valley	1979	Elcentro Array 6	6.53	1.35	3.42
4	Imperial Valley	1979	Elcentro Array 7	6.53	0.56	3.28
5	Imperial Valley	1979	EC Country Center	6.5	7.6	3.44
6	Livermore	1980	Livermore	٦,٤٢	3.6	0.34
7	Northridge	1994	New Hall	6.69	5.92	0.7
8	Northridge	1994	Rinaldi	6.69	6.5	1.1
9	Northridge	1994	Sylmar - Converter Sta	6.7	6.2	1.1
10	ChiChi, Taiwan	1999	TCU052	7.6	0.2	4.48
11	Parkfield	1966	cholame 2	6	7.3	0.19
12	Duzce	1999	Bolu	7.1	17.6	0.57
13	Loma Prieta	1989	Gilroy Array 3	7	14.4	0.48
14	Superstitn Hills	1987	El Centro Imp. Co. Cent	6.6	13.9	1.25

4. Intensity Measure

Intensity Measure (IM) is criteria to determine the severity of ground motion. In this study, the 5% damped spectral acceleration at the fundamental period of the structure, Sa(T1), is considered as the intensity measure. The selected IM has two advantages. First, its probability of exceedance can be calculated by performing a probabilistic seismic hazard analysis, and second, it can be used to evaluate the effect of ground motion intensity on the building performance applying Incremental Dynamic Analysis (IDA) as will be discussed in the next section. However, it should be noted that the selected IM has the weak point of inability to in capture the period elongation of the structures caused by plastic deformations during severe earthquakes.

5. Structural Analysis and Results

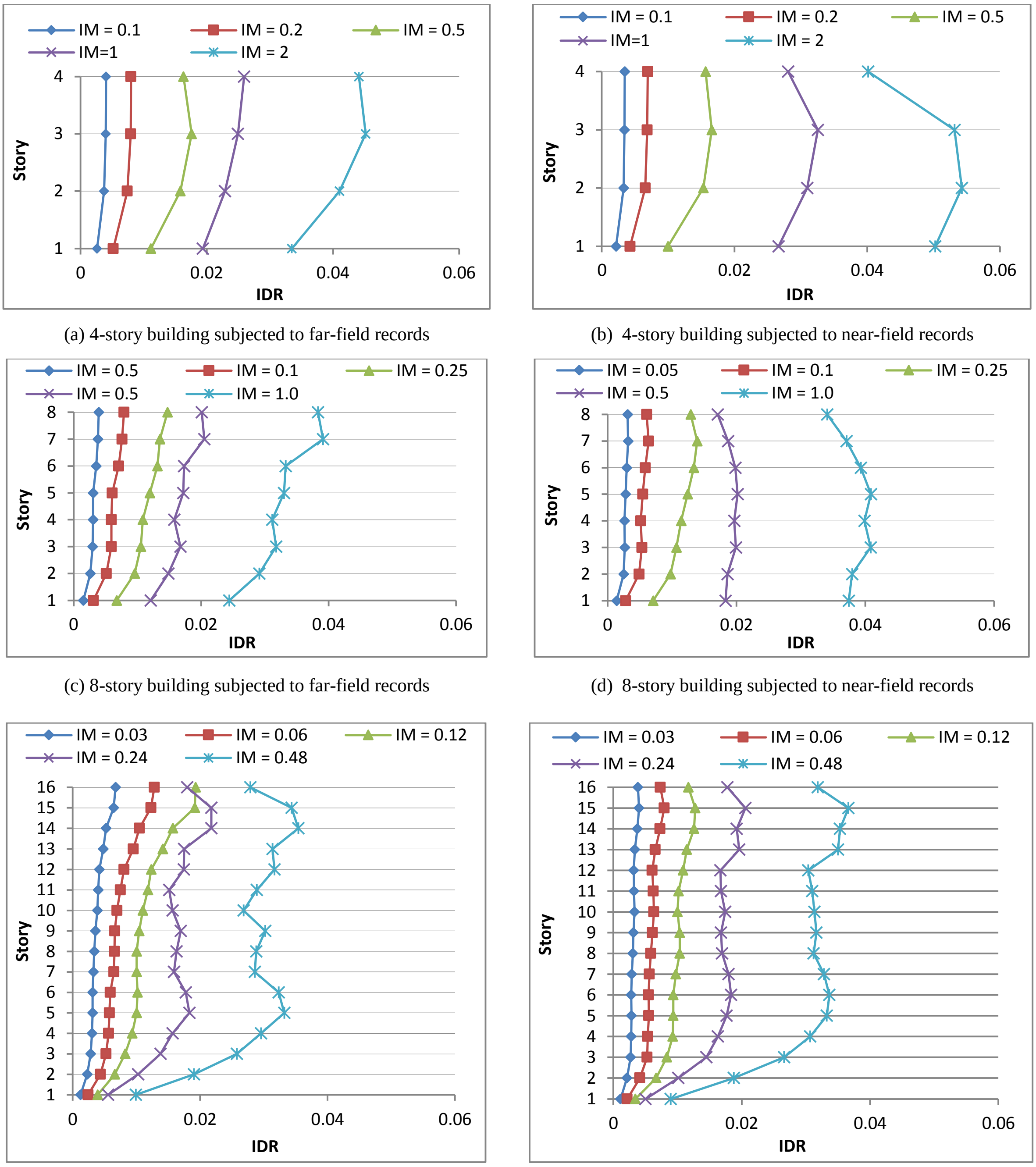
The analytical models were subjected to a set of 28 ground motion records and the selected Engineering Demand Parameters (EDPs) including the inter-story drift ratio and floor acceleration were determine at different intensity levels. For this purpose, the Incremental Dynamic Analysis (IDA) was performed [20]. To perform an IDA analysis, the analytical model gets subjected to the same record at multiple steps. In each step, the intensity of the record is slightly increased.

In this study the intensity measure was the spectral acceleration at fundamental period of the structure, in each step of the IDA analysis, the record was scaled in such a way that the record's acceleration spectrum at fundamental period increased by a predefined increment. The constant increments of 0.1g, 0.05g and 0.03g were chosen for 4, 8 and 16 story frames, respectively. So, using this method the effect of the IM on the building response parameters was evaluated.

The IDA analysis was performed for all the selected records and the resulted maximum drift ratios and the floor absolute accelerations were obtained to compare the response of the models to near-field and far-field ground motions.

5.1. Inter-story Drift Ratio (IDR)

As can be observed from Figure 2, the median IDRs for near-field and far-field records become more similar as the height of the buildings increases. Comparing Figure 2a and 2b, a clear difference can be noted between these two types of records for the 4-story building model, particularly for the higher intensity measures (IM values of 1 and 2 g). Considering the IM value of 2 g, it can be noted that unlike the far-field records, where the maximum drift (4.4%) occurs at the top story of the building model, the maximum drift due to near-fault records happens on the lower stories (5.4% at the second story). This observation can be caused by the impact like pulse of the near fault ground motion records. For the 8-story building model (figure 2, c and d) the same trend is notable and the difference between the far-field and near-field drift ratios becomes more apparent for the larger intensity measures (IM values of 0.5 and 1 g). For example, at the IM value of 1 g, the drift ratios for the far-field records increases by the story height with the maximum values occurring at the two top stories (3.9% at 7th and 3.8% at 8th stories), while for the near-fault records the highest drift ratios occur at stories 3 to 5 (with the average value of 4%) and then decreases with the story height for the stories higher than 5th story. For the 16-story building, the difference between the drift response caused by the near-field and far-field records becomes almost negligible. In the case of 0.48 IM value, for both record types, the drift ratios increase by the story height from base to 5th story (with IDR value of 3.3%), and then stays in an almost steady range of 2.7%-3.5% for the far-field and 3-3.7% for the near-fault records. It can be concluded that the near-field effects on the inter-story drift ratio become less significant at high rise structures. Another important conclusion is that the near-fault effects become more significant for the higher ground motion intensities.



(a) 4-story building subjected to far-field records

(b) 4-story building subjected to near-field records

(c) 8-story building subjected to far-field records

(d) 8-story building subjected to near-field records

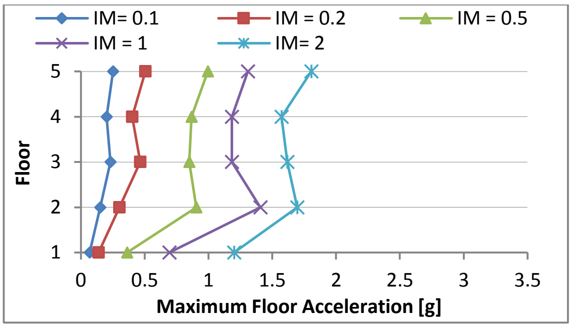
(e) 16-story building subjected to far-field records

(f) 16-story building subjected to near-field records

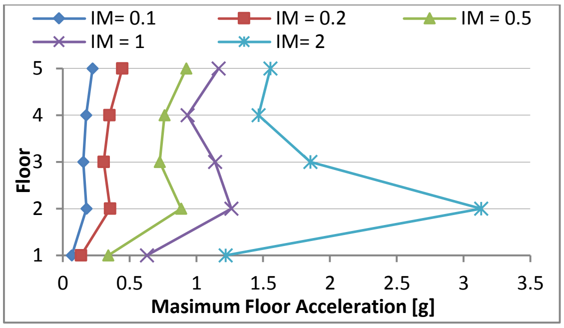
Figure 2. Median of maximum inter-story drift ratios for 4, 8 and 16-story buildings under far-field and near-field earthquakes records

5.2. Maximum Floor Absolute Acceleration

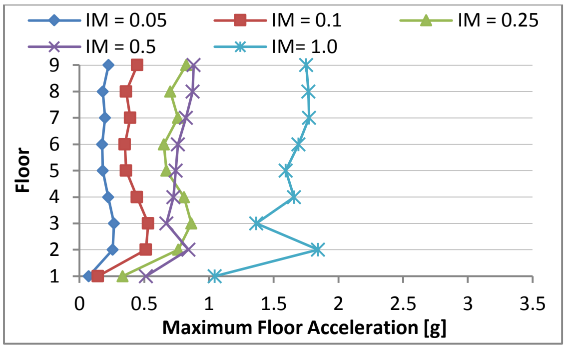
Figure 3 displays the median of maximum floor absolute acceleration along the building height for 4, 8 and 16-story models at near-field and far-field records. Generally, it can be observed that the absolute acceleration at the second floor is relatively larger compared to the rest of the floors for higher ground motion intensities, and this difference is more dramatic for the near-field records. For the far field records the large second-floor acceleration becomes notable as the height of the building increases. Considering the far-field curves for the largest shown ground motion intensities (2g, 1g and 0.48 g for 4, 8 and 16-story models, respectively) it can be noted that the second-floor acceleration is 102%, 114% and 164% of the average floor acceleration for 4, 8 and 16 story models, respectively. For the largest shown ground motion intensities of the near-fault earthquake records (2g, 1g and 0.48 g for 4, 8 and 16-story models, respectively), the second-floor acceleration is 170%, 169% and 237% of the average floor acceleration for 4, 8 and 16-story building, respectively. So, for the near-fault records the large second-floor acceleration is more notable at the 16-story model like what was observed in the case of far-field records, however the increased acceleration at the second floor is more significant for near-fault records (237% at near-fault compared to 164% at far-field records). This can be attributed to the pulse-like effect of the near-field earthquake records that results in transferring a large amount of energy to the building in a short time. This mechanism is partially accountable for the high acceleration at the near base floors and makes the second-floor absorb the energy of the pulse. It can be concluded that the pulse-like effect of near-fault earthquake records on the near base floor acceleration is more important for the high rise buildings subjected to large ground motion intensities.



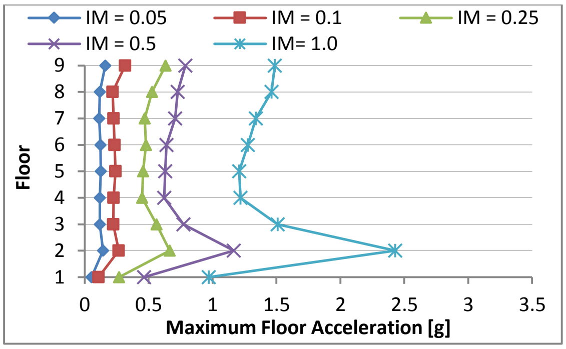
(a) 4-story building subjected to far-field records



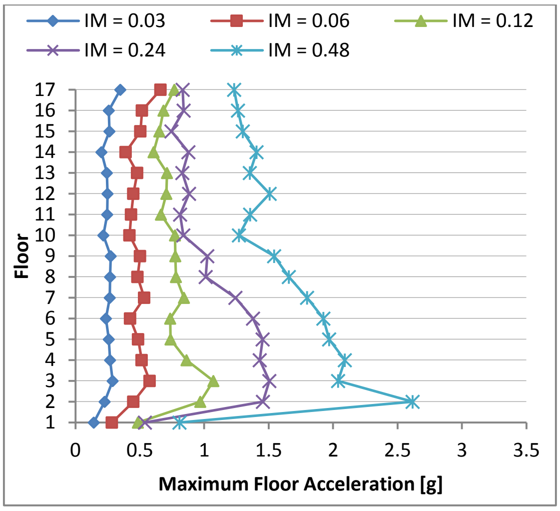
(b) 4-story building subjected to near-field records



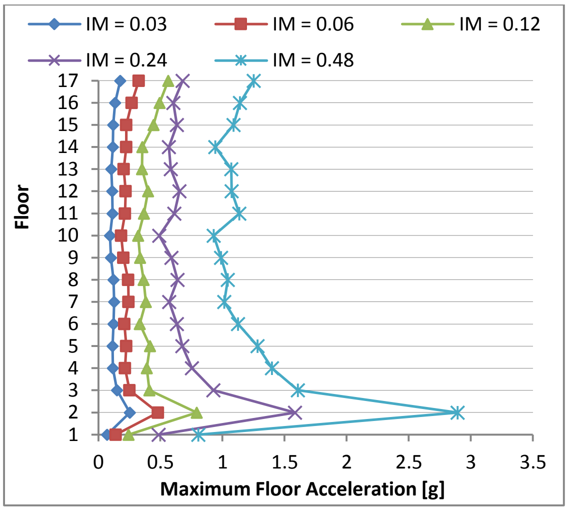
(c) 8-story building subjected to far-field records



(d) 8-story building subjected to near-field records



(e) 16-story building subjected to far-field records



(f) 16-story building subjected to near-field records

Figure 3. Median of maximum floor absolute acceleration for the 4, 8 and 16-story building under far-field and near-field records

6. Conclusion

In this study, the inter-story drift ratio and floor acceleration were used to compare the performance of the concrete MRF buildings subjected to the near-field and far-field earthquake records. The buildings were modeled at three heights including 4-story, 8-story, and 16-story. The nonlinear time history analysis was performed for two sets of 14 near-field and 14 far-field ground motion records. The conclusion can be summarized as follows:

- The near-field effects on the response of the building were more notable at higher intensities. For lower IM values, there was not a significant difference between the response of the buildings to the near-field and far-field ground motions.
- The near-field ground motion affected the inter-story drift ratios of low and mid-rise models (i.e. 4-story and 8-story models) more notably compared to the high-rise model (i.e. 16-story model)
- For the low and mid-rise models (i.e. 4-story and 8-story models), the near-fault ground motions resulted in larger inter-story drift ratio at lower stories of the models.
- For all building height models, the near-field ground motions resulted in higher floor acceleration at the second story compared to far-field ground motions.

7. Conflicts of Interest

The authors declare no conflict of interest.

8. References

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