A study on the investigation of the effects of near and far fault on a RC building

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Abstract

The effects of near-fault ground motion (NFGM) and far-fault ground motion (FFGM) on a seven-story reinforced concrete (RC) building are investigated in this study. SAP2000 software is used to model three dimensional finite element model (FEM) and the dynamic characteristics of the building are determined numerically. As NFGM and FFGM, 1992 Erzincan (EW) and 1999 Kocaeli (IZN180) ground motion records are chosen for the analyses. Shear forces and bending moments of the base, and maximum floor displacements are determined with time history analysis. The obtained structural responses are compared with the effects of NFGM and FFGM for emphasizing the importance of the distance of earthquake motions. The results of the study indicate that NFGM is concluded much larger dynamic responses compared with FFGM for the RC buildings.

Keywords: Dynamic behavior, RC building, Near-fault ground motion, Far-fault ground motion

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1. Giriş

Earthquake ground motions are affected by the earthquake magnitude, topographic features, and the geological structure of the ground, as well as the distance from the epicenter to the fault . Because of the enormous disparity between the near and far ground motions from the fault, the dynamic reactions in the building will be quite different depending on whether the seismic source is close to or far away from earthquake motions. The earthquake motions originating at about 20 km from the rupture are mostly termed NFGM (Somerville, 2003; Yang et al., 2010; Zou et al., 2017; Mahmoud et al., 2021).

NFGM such as 1999 Chi-Chi (Taiwan), 1994 Northridge, and 1995 Kobe Earthquakes are short-duration impulsive motions that caused severe structural damage due to high input energy at the start of the record. (Alavi & Krawinkler, 2000). These motions have velocity pulse amplitude, which is not visible in recordings from far-field locations (Alavi & Krawinkler, 2001). The velocity pulse duration and the ratio of the Peak Ground Velocity (PGV) to the Peak Ground Acceleration (PGA) must be respectively larger than 1.0 sec and 0.1 sec (Liao et al..2004). NFGM has two significant features: fling-step and forward-directivity motions, which have different characteristics. Because of the one-sided velocity pulses, a fling-step motion produces a significant permanent static ground displacement, whereas a forward-directivity motion does not produce a permanent ground displacement and has two-sided velocity pulses, large amplitudes, and short durations. In comparison to the FFGM, forward-directivity effects have long-period and high-density and the fling step is mostly qualified by a large-amplitude velocity pulse and a monotonic step in the displacement time history (Yılmaz & Soyluk, 2019).

Recently, much scientific research has focused on buildings in near-fault regions. After the 1971 San Fernando Earthquake, buildings were severely damaged and analytical studies of the non-linear dynamic response of single-degree-of-freedom (SDOF) and multiple-degree-of-freedom (MDOF) systems to several near-fault records were done. It was observed that very large displacement ductility may result from current levels of design forces (Bertero et al., 1978). Evaluation of the nonlinear response of frames is especially susceptible to the pulse acceleration relative to the yield resistance seismic coefficient and to the pulse duration concerning the fundamental period (Anderson & Bertero, 1987). Such motions cause damage to the structure as well as to its contents, decreasing the probability that the structure can remain functional after the earthquake. Reducing the impact of these motions requires exceptional design measures for isolation systems (Hall et al., 1995). For a higher PGV/PGA ratio, pulse-like motions do not contribute too much to higher modes, but a relatively low PGV/PGA ratio fairly contributes. For high-rise buildings, pulses in ground motion records do not always contribute from higher modes (Malhotra, 1999). Seismic response of SDOF systems or MDOF frame structures built near-source region showed that code-prescribed story shear strength patterns lead to a non-uniform distribution of ductility demands over the height. Early yielding takes place in upper stories of long-period structures, whereas high ductility takes place in bottom stories of low-period structures. If moment-resisting frame structures are strengthened with hinged walls against NFGM, it will be a master factor in reducing drift demands at different performance levels (Alavi & Krawinkler, 2004). Forward-directivity motion effects show further instances of higher-mode demand of buildings, but fling-step motion displacement frequently caused fundamental mode. Ratio of motion pulse to natural period ensures design demand (Kalkan & Kunnath, 2006). Retrofitting by using fiber-reinforced polymer (FRP) improved the stiffness, strength, and lateral displacement capacity of structures against to fling-step effect (Mortezaei et al., 2010). To obtain the seismic response of multi-story buildings subjected to NFGM, incremental dynamic analysis was applied. It has been shown that compared to ordinary ground motions the forward-directivity earthquake motions place a greater ductility demand on structure (Sehhati et al., 2011). The near-fault earthquakes containing forward-directivity motions were investigated on the behavior of steel frames having different heights. By comparing nonlinear dynamic analysis and nonlinear static analysis. The results demonstrated that high responses are obtained and NFGM motivates high modes of the structure especially having a 12-story steel frame (Soleimani et al., 2013). Based on incremental dynamic analysis methods, dynamic performances of reinforced concrete (RC) buildings having 15, 10, and 6-story buildings were investigated under NFGM and FFGM. It is obtained that RC buildings are under great deformation requirements in the face of velocity pulses in velocity time history and this is necessary for a great amount of energy to be wasted in more plastic cycles. However, in FFGM, input energy enters the system gradually and deformation demands are less than those in NFGM. Besides, structural systems are exposed to more plastic cycles due to having minor cumulative effects in FFGM. Besides, the cumulative effects are minor in FFGM due to structural systems being subjected to more plastic cycles (Moniri, 2017). The fling-step effects on the SDOF and MDOF systems are examined by removing effects from the

original ground motions. The study has shown that when the fling-step was out of the original ground motions, the displacement ductility demand increase on the SDOF system, and the maximum inter-story drift enhance in the building. It is also obtained that the structural differences hinge on the ratio of the structure fundamental period to the fling pulse period (Hamidi et al., 2020). It is sought out that the use of a tuned mass damper (TMD) examines whether it reduces the dynamic effects under FFGM and NFGM with structure-soil interaction (SSI) responses. In the study, the forward directivity and the fling-step effects in NFGM are included and the dynamic properties of TMD are calculated using a MATLAB code written by researchers. The results of with and without SSI effects have shown that including SSI effects dynamic responses boost as well as changing the role of the TMD. It is also gathered that a TMD greatly increases the dissipated amounts of damping energy and NFGM with fling-step enables the most amount of dissipated damping energy alongside NFGM with the forward directivity and the FFGM (Abd-Elhamed & Mahmoud, 2019). Güneş et al. (2016) examined the direction effect of NFGM and obtained that the maximum velocity direction in two new directions, drift spectrum intensity, and spectral velocity are greatly effective as fault-normal direction. The study, it is aimed to obtain nonlinear responses of a core-wall tall building under the motions of 1 set of FFGM, and 3 sets of NFGM having different ratios of pulse duration (T_p) to the first mode period (T_1). In the NFGM with large pulses, at all stories substantially greater drifts and beam rotations are achieved in the study (Güneş & Ulucan, 2019). Based on NFGM and FFGM effects, it is aimed to determine the dynamic responses of low- or mid-rise masonry residential buildings using nonlinear methods. Nonlinear static analyses and inelastic time history analyses are respectively done to obtain seismic deformation capacities of buildings and to estimate the dynamic displacement demands. It is acquired that there is a considerable dissimilarity in masonry buildings' responses between the NFGM and FFGM (Bilgin & Hysenlliu, 2020). According to an investigation of the behavior of the regular and irregular structures subjected to forward-directivity effects, the high-frequency quantity should not be ignored due to the resonance case takes place at the ratio of $T_p/T_1 = 1$ (Mashhadi et al., 2021). Accordingly, when evaluating the seismic performance of structures under NFGM effects, two options are available: in the first option, the high-and low-frequencies of the NFGM records can be decomposed and can obtain the dominant component with the value of T_p/T_1 close to 1 and in the second option original ground motions can be used.

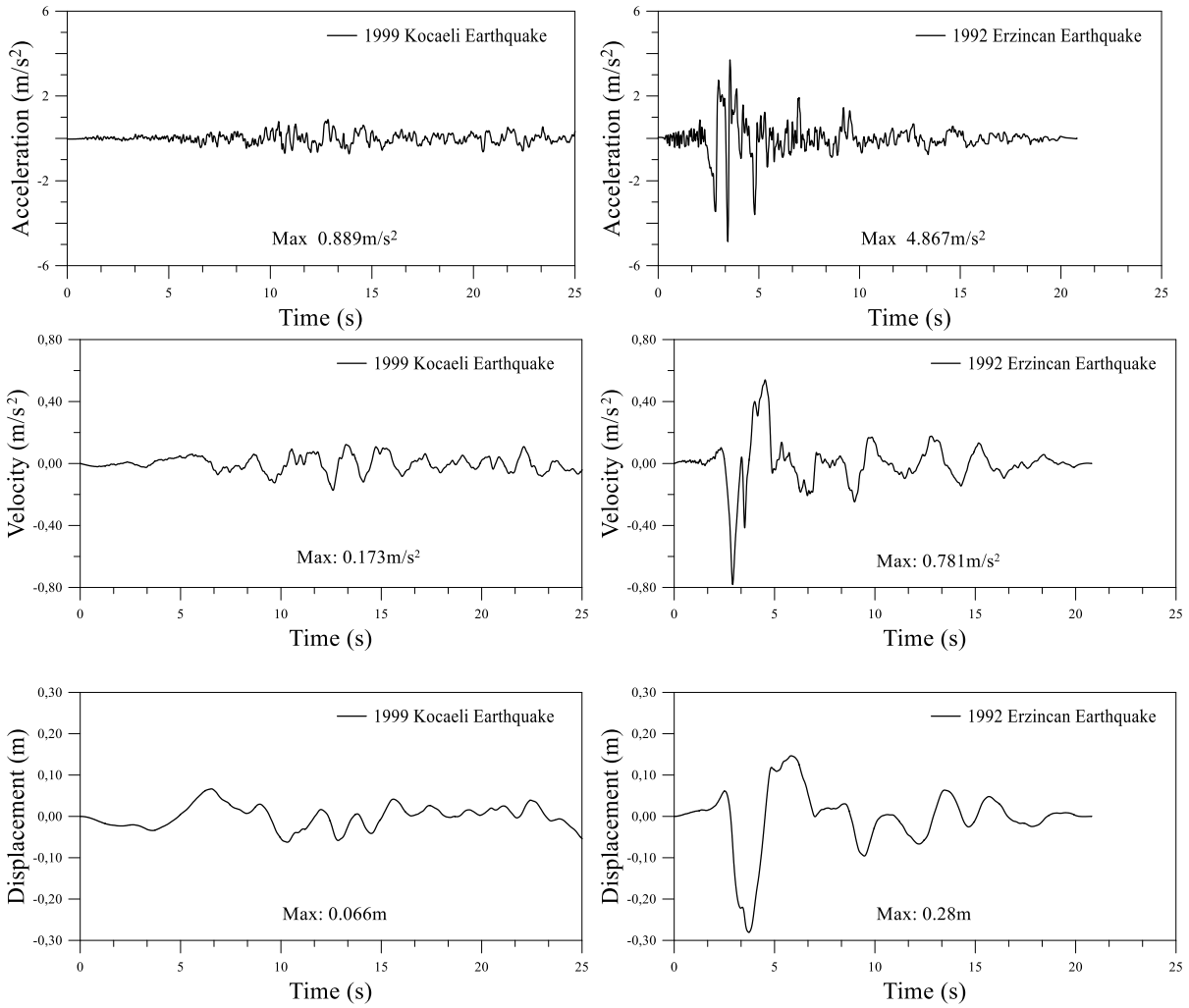
The goal of this research is to see how an RC building responds to pulse-like NF movements and regular FF motions without soil-structure interaction. The buildings are designed as special structures for life safety. Acknowledgments about possible seismic effects on buildings will contribute to minimizing the damage level from vibration in the life duration. For this reason, the seismic response of a 7-story building is investigated under NFGM and ordinary FFGM motions, taking into consideration the above-mentioned literature survey and information.

2. Material and method

NFGM has quite impact properties in the first records of ground motion having high energy as well as the pulse duration is usually larger than 2-3 sec and contains permanent ground displacements at times. The ratio of PGV/PGA (the peak ground velocity/ the peak ground acceleration) of the NFGM is greater than 0.1 sec (Zhang & Wang, 2013). In our study, we choose the ERZ-EW component of the 1990 Erzincan and the IZN180 component of the 1999 Kocaeli earthquakes as the NFGM and FFGM, respectively. These motions were obtained from PEER Ground Motion Database and the main characteristics of the earthquakes are given in Table 1. In addition, acceleration, velocity, and displacement time history graphs of the earthquakes are given in Figure 1. To achieve the dynamic structural response of the selected RC building are conducted time history analyses.

Table 1. Characteristics of the selected NFFM and FFGM (PEER, 2021)

Earthquake	Station	PGA *(cm/s²)*	M	R_{Rup} *(km)*	Ground motion type
1992 Erzincan	Erzincan	486.76	6.69	4.38	Near-Fault
1999 Kocaeli	İznik	88.99	7.51	30.73	Far-Fault



a) Far Fault Earthquake *b) Near Fault Earthquake Motion*

Figure 1. Kocaeli and Erzincan earthquake ground motion records

2.1. Numerical Study

A seven-story building is selected for dynamic analysis. The building to be analysed is designed with a 1–5 axis in the x-direction and a 1–6 axis in the y-direction as shown in Figure 2a. The axis distances in both directions of the building are 7 meters. A 3D finite element model of the building is given in Figure 2b. A reinforced concrete frame system is used as the structural system. The slab plate is chosen as the slab type. Column, beam dimensions, and floor slab thickness are (80*x*80)cm^2, (40*x*70)cm^2, and 15*cm*, respectively. The live and dead loads are chosen as 5kN/m^2 and 1kN/m^2, respectively (TS498, 1997). The unit volume weight of reinforced concrete and wall weight are 25kN/m^3 and 4*kN/m*, respectively.

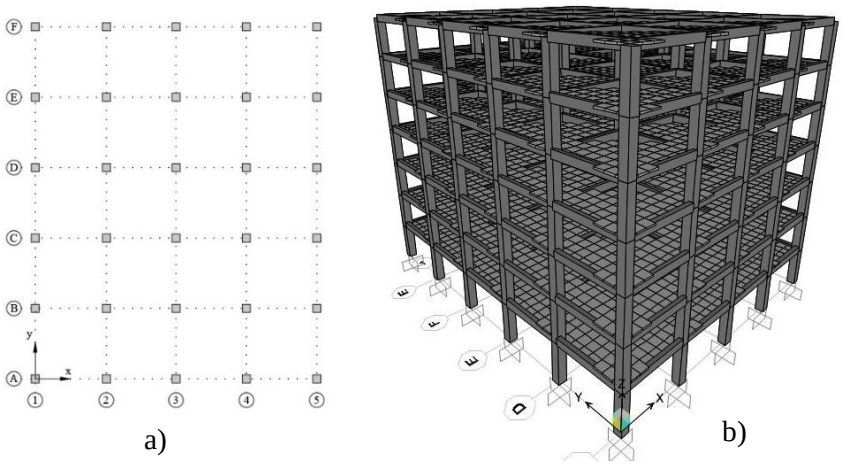


Figure 2. a) The plan, and b) 3D FEM of the building

The first three mode shapes and frequency ranges obtained from numerical modal analysis of the building are presented in Figure 3. As shown in the Figure, the first and second modes are translational modes in the X and the Y directions respectively, while the third mode is a torsional mode for building.

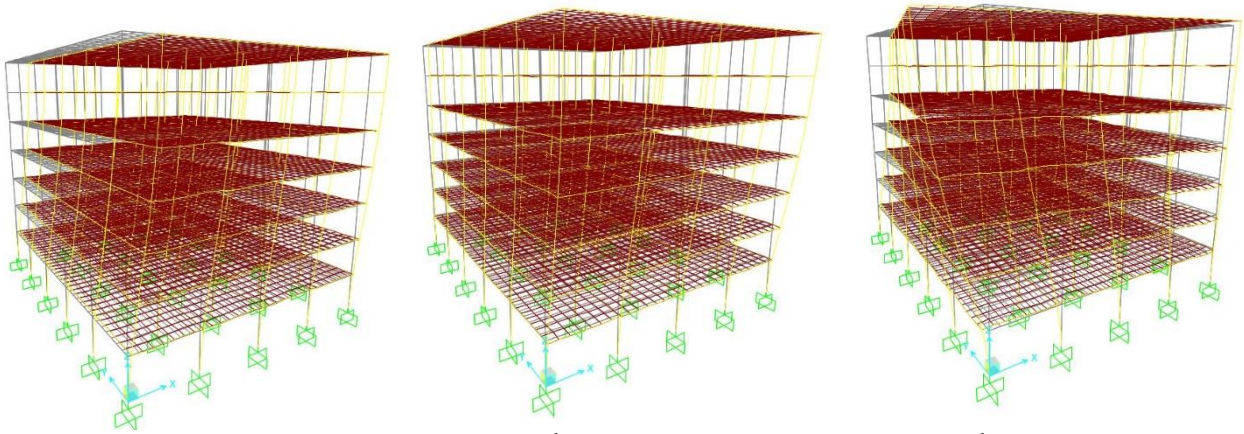


Figure 3. The first three numerical mode shapes and periods of the building

The modal analyses were carried out considering the first 15 modes to check the effect of modal masses. In Table 2, the modal effective masses, the cumulative modal mass fractions, and, numerical frequencies for all directions of the first 15 modes of the building are given. The modal participating masses of the first three mode shapes are about 80% for building in Table 2. The first 8 modes give a cumulative mass of 95% in *x* and *y* directions.

Table 2. The numerical natural frequencies, modal effective, and cumulative mass fractions of the building

Mode	Frequencies (Hz)	X Direction(%)		Y Direction(%)		Z Direction(%)	
		M_{eff}	$\sum M_{eff}$	M_{eff}	$\sum M_{eff}$	M_{eff}	$\sum M_{eff}$
1	1.010	0.80	0.80	0.00	0.00	0.00	0.00
2	1.026	0.00	0.80	0.80	0.80	0.00	0.00
3	1.155	0.00	0.80	0.00	0.80	0.00	0.00
4	3.243	0.11	0.91	0.00	0.80	0.00	0.00
5	3.285	0.00	0.91	0.10	0.91	0.00	0.00
6	3.696	0.00	0.91	0.00	0.91	0.00	0.00
7	6.035	0.04	0.95	0.00	0.91	0.00	0.00
8	6.092	0.00	0.95	0.04	0.95	0.00	0.00
9	6.841	0.00	0.95	0.00	0.95	0.00	0.00
10	8.943	0.00	0.95	0.00	0.95	0.59	0.59
11	9.234	0.00	0.95	0.00	0.95	0.00	0.59
12	9.371	0.00	0.95	0.00	0.95	0.00	0.59
13	9.498	0.02	0.97	0.00	0.95	0.00	0.59
14	9.558	0.00	0.97	0.02	0.97	0.00	0.59
15	9.633	0.00	0.97	0.00	0.97	0.00	0.59

The earthquake analysis of the building was carried out to evaluate the NF and FF effects on a building. The relationship between the lateral displacements of the floor and the height in the X-direction under earthquake motions is given in Figure 4. The displacements increase with the increasing height of the building, as can be seen from Figure 4. The captured peak displacement values at the top floor of the building under near-and FF ground motions are 19.96*cm* and 5.81*cm*, respectively.

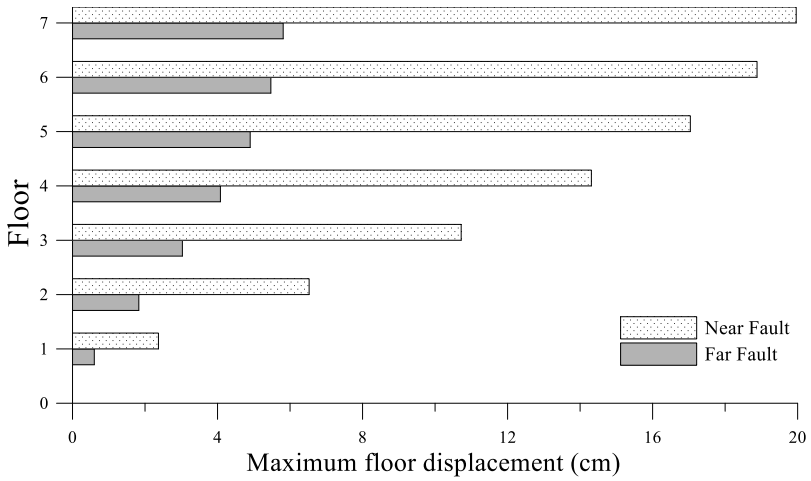


Figure 4. Variation of lateral displacements along with story height under the effect of NF and FF

Figure 5 shows the time histories of lateral displacements at the building's 1st, 4th, and 7th floors, obtained from the analyses for NF and FF ground motions. In Figure 5, these results indicate that NF records significantly increase the induced displacement story responses compared with FF records. The bending moments and shear forces occurring at the building base under the near-and FF ground motions are given in Figures 6-7. As is seen from Figures 7-8, dynamic responses occurring at the base of the building for NF ground motion are greater than those for FF ground motion. The maximum base bending moments of the building are 824735*kNm* and 239353*kNm* for near-and FF ground motion, respectively. The maximum base shear forces of the building are 46435*kN* and 12823*kN* for near-and FF ground motion, respectively.

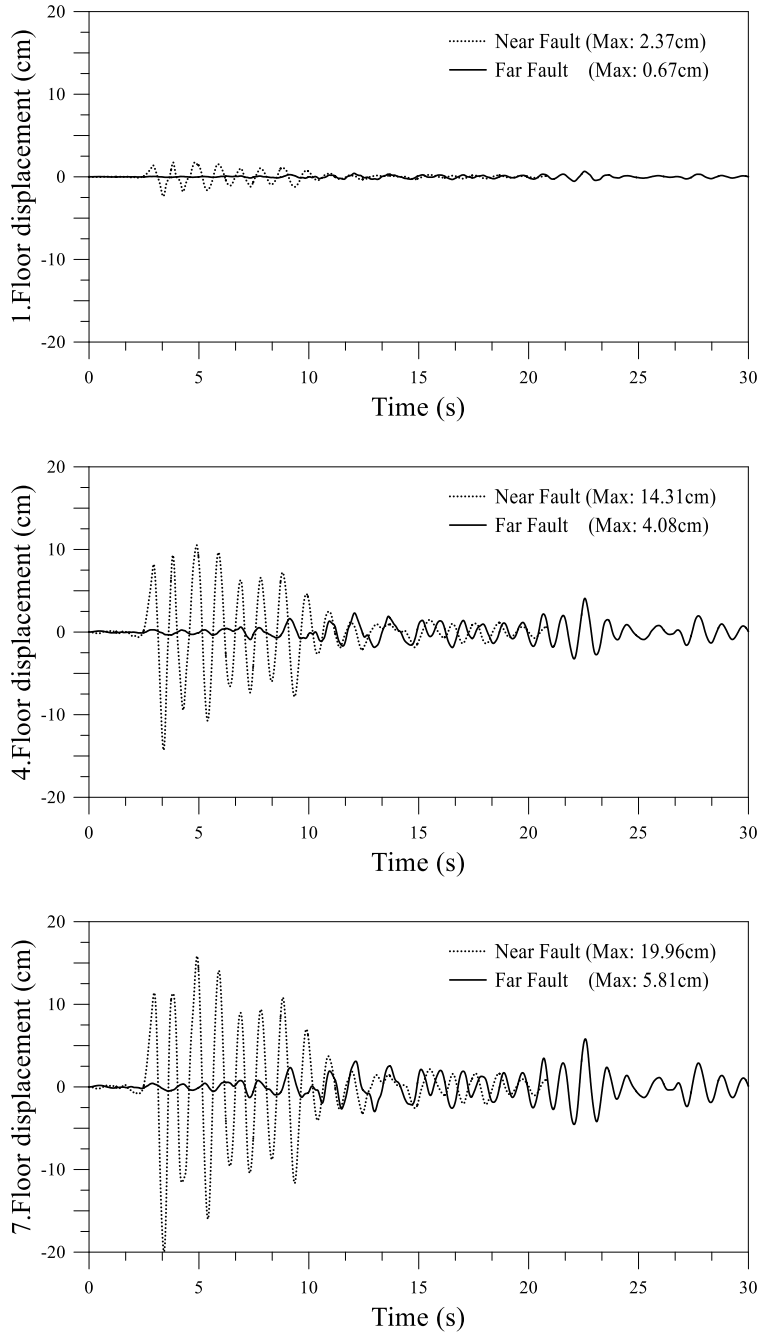


Figure 5. The time histories of lateral displacements on the 1st, 4th, and 7th floors of the building

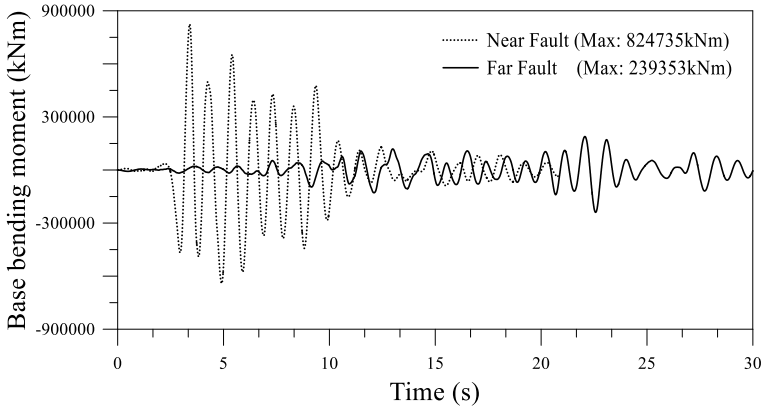


Figure 6. The time histories of the bending moments at the building base

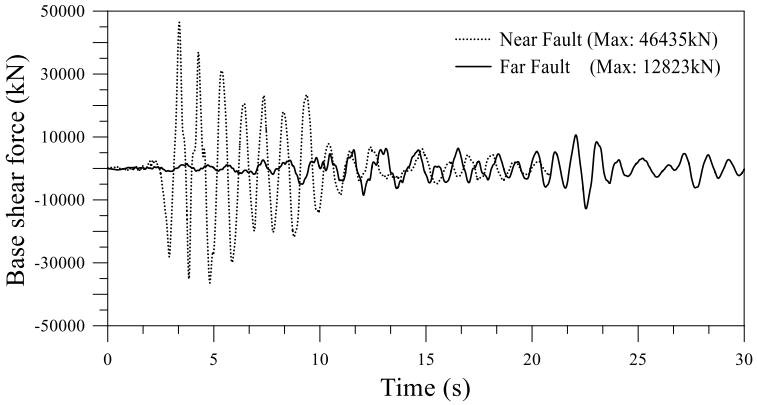


Figure 7. The time histories of the shear forces at the building base

3. Conclusions

The responses of near-and FF ground motion to a RC building are being investigated. 1992 Erzincan (EW) and 1999 Kocaeli (IZN180) earthquake ground motion records are used as near- and FF ground motions. For this purpose, time-history analyses were performed on the building, and the results obtained from the study are summarized below.

- The maximum lateral floor displacement at the top floor of the building under the NF ground motion is about 244% greater than the FF ground motion. From the first to the seventh floors, the distance between the near- and FFs narrows.
- The maximum base shear force and maximum base bending moment under the NF ground motion are 262% and 245% greater than the FF ground motion, respectively.

When the response values obtained are compared, it has been seen that the response values obtained for NF ground motions are larger than the response values obtained for FF ground motions.

Conflict of interest
Çıkar çatışması beyanı

No conflict of interest was declared by the authors.

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