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Araştırma Makalesi

The Seismic Behavior of Buildings with Flat Slab Systems under Near-Fault Ground Motions

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ABSTRACT

It is well known that structural displacement or ductility demands of structures subjected to near-fault ground motions are generally greater than ordinary ground motions. Therefore, the effect of earthquake records in the near region on the seismic behavior of structures has been widely studied in the last decades. Peak ground acceleration (PGA) is an important key parameter, which determines structural behavior. However, structural behavior depends on the distance of the structure to the fault zone, the ratio of peak ground velocity (PGV) to peak ground acceleration, the velocity pulse duration of ground motion, and the natural period of the structure. In this study, the seismic behavior of buildings with flat slab systems was investigated under near-fault ground motions. Linear time history analysis was performed for a 30-storey building designed according to TBEC-2018 using SAP 2000 finite element analysis software. Results were compared with the behavior of the building with a solid slab system. It is concluded that the ratio of PGV/PGA is very effective on the flat slab systems.

Keywords: *Seismic behavior, Near-fault, Slab system*

Düz Döşemeli Binaların Yakın Fay Yer Hareketleri Altındaki Sismik Davranışı

ÖZ

Yakın fay yer hareketlerine maruz yapıların yapısal yer değiştirme veya süneklik taleplerinin genellikle normal yer hareketlerine nazaran daha büyük olduğu iyi bilinmektedir. Bu nedenle, faya yakın bölgelerdeki deprem kayıtlarının yapıların sismik davranışı üzerindeki etkisi son yıllarda yaygın olarak araştırılmaktadır. En büyük yer hareketi ivmesi (PGA), yapısal davranışı belirleyen en önemli parametrelerden bir tanesidir. Bununla birlikte yapısal davranış, yapının fay bölgesine olan mesafesine, en yüksek yer hareketi hızının (PGV) en yüksek yer hareketi ivmesine oranına, yer hareketinin hız darbe süresine ve yapının doğal periyoduna bağlı olmaktadır. Bu çalışmada, düz döşemeli binaların yakın fay yer hareketleri altındaki sismik davranışları incelenmiştir. SAP 2000 sonlu elemanlar analiz paket programı kullanılarak TBDY-2018'e göre tasarlanan 30 katlı bir bina için doğrusal zaman tanım alanında analizler yapılmıştır. Elde edilen sonuçlar, kirişli döşemeli binadan elde edilen sonuçlar ile karşılaştırılmıştır. PGV/PGA oranının düz döşemeli sistemler üzerinde oldukça etkili olduğu sonucuna varılmıştır.

Anahtar Kelimeler: *Sismik davranış, Yakın fay, Döşeme sistemi*

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I. INTRODUCTION

Earthquakes are important natural hazards for buildings since most of the loss of life and property is a result of damage and collapse of structures. Possible losses can be greatly reduced if the knowledge about the effects of earthquakes on structures and constructing earthquake-resistant structures increases. The location of the structures to the fault greatly affects the structural behavior. It has been seen from recent studies that earthquakes close to the faults have significant differences compared to earthquakes occurring far from the fault. Ground motions close to the fault are affected by the direction of the fault and the permanent displacements that occur as a result of the earthquake, except for the fault rupture mechanism [1].

Near-fault ground motions cause much greater structural displacement or ductility demands than far-fault ground motions. Near-fault ground motions differ from ordinary ground motions in that they generally involve strong forward-directivity effects and permanent displacements (fling step effects). The forward-directivity effect has a presence of a long-period impact effect in the direction perpendicular to the fault, which can cause major and significant severe damage. They are generally effective if the shear wave velocity of the soil, which is mostly close to the earthquake source, is close to the rupture velocity of the fault [2]. Static displacements in ground motions close to the fault are caused by the relative motion of the two sides of the fault where the earthquake occurred. Static displacements occur at approximately the same time as large dynamic movements, indicating that static and dynamic displacements should be treated as overlapping loads [3].

After the recent Kobe (1995), Kocaeli (1999), and Düzce (1999) earthquakes, the effect of near-fault ground motions has been better understood. Near-fault ground motions have caused much greater damage to structures than far-fault ground motions due to the pulse and high velocity. For this reason, the determination of the dynamic behavior of structures under the influence of near-fault ground motions has also become an important research topic. Especially, Northridge (1994), Kobe (1995) and Chi-Chi (1999) earthquakes provided new information about the behavior of structures under the influence of near faults [4].

There are many studies in the literature on the static and dynamic behavior of engineering structures using near-fault and far-fault ground motion records. Hall et al. [5] examined the effect of near-fault ground motion in flexible buildings. In addition to the fact that whether base isolation is a good idea or not depends on the site, it has been revealed that the size of the design earthquake, the probability of the structure being in the near-fault zone, the performance level demanded from the structure, the type of isolation system and economic conditions should be evaluated. Malhotra et al. [6] investigated the behavior of tall buildings subjected to ground motions close to the fault. It was seen that ground motions, where the ratio of the peak ground velocity (PGV) value to the peak ground acceleration (PGA) value is high, increase the base shear force, the amount of displacement, and the relative storey drifts. Liao et al. [7] compared the dynamic behavior of five-storey and twelve-storey buildings under the influence of far and near-fault ground motions. As a result of the study, it was seen that the ground motions close to the fault cause much more damage to the structures than the ground motions far from the fault. Ghobarah [8] designed three, six, twelve, and twenty-story buildings that were subjected to a series of near-fault ground motions to examine the response of structures to near-fault effects. As a result of the study, it was observed that the response of the structures to the near-fault ground motions was significantly different from the reaction to the far-fault ground motions. Alavi and Krawinkler [9] evaluated moment-resisting frame systems for ground motion effects close to the fault. Strengthening with hinged shear walls has been found to be very effective in reducing drift demands for structures with a wide range of periods and various performance levels. Providakis [10] evaluated the seismic behavior of various LRB (lead-rubber bearing) base-isolated steel-concrete composite buildings under near-fault ground motion using thrust analysis. The results were compared with the seismic responses of different composite buildings. It has been determined that the use of isolators under the near-fault effect increases the displacements in the first floors, even if it reduces the base shear force. In the study presented by Mazza and Vulcano [11], near-fault ground motions were applied to three buildings with three, six, and twelve-storey symmetrical plans on rock and soft soil. It has been observed that the structural damage potential varies according to the ratio between the pulse period of the motion and the vibration period of the structure. In addition, it was emphasized that special attention should be paid to the design of the columns and beams on the lower floors in buildings on soft soil. Ventura et al. [12] conducted several nonlinear analyses on a 44-storey reinforced concrete building to understand the effect of displacements on the nonlinear response of tall buildings. As a result of the study, it was observed that the near-fault ground motions with fling-step cause more displacement and relative story displacement than ground motions without fling-step. Güneş and Ulucan [13] found that the ratio of the pulse duration to the first mode period (T_p/T_1) has a large effect on the structural behavior of the building in their study on a 40-storey building to determine the effects of small, medium and large pulse period near-fault ground motions on tall buildings. Daei and Poursha [14] studied the applicability of pushover analyses for mid-high-rise buildings under near-fault ground motions. While the maximum interstory demands caused by ground motions with pulse effect are mostly concentrated on the lower and middle floors, it has been understood that the ground motion records without pulse effect cause the maximum response to occur in the upper part of the building. Mahmoud et al. [15] investigated the seismic performance of 12-storey reinforced concrete buildings with different slab systems (solid slab, hollow block slab, and flat slab) under near-fault ground motions. As a result of the study, it was seen that the building designed with a solid slab system caused the least relative floor displacements. In addition, it has been observed that ground movements with fling-step effect cause more displacement than ground motions with forward-directivity effect. In addition, it has been observed that ground motions with fling-step effect cause more displacement than ground motions with forward-directivity effect.

In this study, the effects of near-fault ground motion characteristics on buildings with solid slabs and flat slabs designed according to TBEC-2018 [16] were investigated. For this reason, a 30-storey building with a solid slab and a flat slab system was designed according to TBEC-2018. The dynamic behavior of these buildings with different structural systems has been investigated under near-fault with pulse and non-pulse near-fault earthquake ground motions. The results were compared with the results obtained under the effect of far-fault ground motion. Top floor displacements and interstory drift ratios were examined under pulse and non-pulse near-fault and far-fault motion records. The effects of PGV/PGA, pulse duration, and PGA values of ground motion of the near-fault on buildings with solid and flat slabs were investigated.

II. NEAR-FAULT GROUND MOTIONS

The effects of earthquakes on the structures vary depending on many factors. These factors include the magnitude of the earthquake, the characteristics of the ground motions (amplitude, duration, frequency content etc.), and the distance to the fault etc. Especially, the ground motions recorded in the near region of the fault are very effective on the structural behavior compared to those far away from the fault [17].

Near-fault ground motion records are known as ground motion recorded within 20 kilometers of the fault [4], [15], [18]-[20]. While the velocity pulse duration must be larger than 1.00 seconds, the ratio of the PGV to the PGA must be larger than 0.10 seconds [21]. Ground motions close to the fault cause greater displacement and ductility demands on the structure, which has high-velocity pulse content. Ground motions close to the fault cause greater displacement and ductility demands on the structure and they have large velocity pulse and pulse duration [2].

The motions recorded close to the fault show very different characteristics than those recorded far from the fault. In near-fault ground motions, two main motion characteristics called directivity effect and fling-step effect are observed. Directivity effects, which are principally normal to the fault, are very important for the duration and long-period energy content of ground motions. The fling-step effect causes permanent displacement along a ruptured fault. They include a large, unidirectional velocity pulse to compensate for this displacement in the slip plane [22]. The directivity effect includes large velocity pulses. Although these pulse effects can also be observed in the acceleration-time and displacement-time records, it is important whether there are pulse effects in the velocity-time records regarding the damages on the structures. The pulses, which are a measure of the directivity effect, show themselves with the amplitude of the vibrations in the velocity-time record [17]. The directivity and fling-step effects take place in the direction perpendicular to each other. The fling-step effect appears as permanent displacements in displacement-time records. It can also be seen as a unidirectional velocity wave in velocity-time graphs.

For structures, the main response parameters are the peaks of displacement (PGD), velocity (PGV), and acceleration (PGA). The structural response is significantly impacted by long-period pulses and the ratio of peak ground velocity to peak ground acceleration (PGV/PGA) of ground excitation near rupture [6]. Structural displacements and drift demand increase depending on pulse amplitude and duration. The velocity-sensitive spectral region for ground motion recorded near rupture is substantially narrower, but the acceleration-sensitive and displacement-sensitive sections are much wider. Therefore, greater strength is demanded for the same ductility factor in the design.

The ratio of the pulse duration (T_p) to the first mode vibration period of the structure (T_1) is a crucial number for the structural response [13], [23]-[24]. If the pulse duration (T_p) is smaller than the first mode vibration period of the structure (T_1), large mode effects and maximum reaction at upper stories may be obtained. The short-period structures under the records with a large pulse have a maximum ductility demand in bottom stories.

In the present study, a 30-storey building, which was designed according to TBEC-2018, with a solid slab and a flat slab system was subjected to near-fault ground motions having different pulse durations, PGA, and PGV/PGA. In order to evaluate the results, ordinary near-fault ground motion and far-fault ground motion records were used. The period of the pulse (extracted pulse, T_p) was identified as the time needed to complete a full velocity cycle and was obtained in the velocity time history of the selected ground motions. Besides, every record set given in Table 1 contained two types of near-fault and one type of far-field earthquake motion. Acceleration versus time and velocity versus time graphs were given in Figure 1-Figure 5.

Table 1. *Dynamic characteristics of selected ground motions [25]*

RSN	***Motion Type***	***Event Name***	***Station***	R_{rup} ***(km)***	PGA ***(cm/s²)***	PGV ***(cm/s)***	$\frac{PGV}{PGA}$	T_p ***(sec)***
184	PLS1	Imp.Valley, U.S.A (1979)	El Centro Differential Array	5.09	345.19	75.56	0.218	3.98
185	PLS2	Imp.Valley, U.S.A (1979)	Holtville Post Office	7.5	253.01	53.13	0.21	3.98
171	PLS3	Imp.Valley, U.S.A (1979)	El Centro-Meloland	0.07	291.25	92.61	0.317	3.08
723	PLS4	Superstition Hills, U.S.A (1987)	Parachute Test Site	0.95	422.66	134.36	0.317	2.40
1084	PLS5	Northridge, U.S.A (1994)	Sylmar-Converter	5.35	610.95	116.22	0.19	2.92
1120	PLS6	Kobe, Japan (1995)	Takatori	1.47	658.02	122.99	0.19	1.26
6	NF1	Imp.Valley, U.S.A (1979)	El Centro #9	6.09	274.58	30.94	0.11	-
162	NF2	Imp.Valley,U.S:A (1979)	Calexico Fire Station	10.45	274.58	22.45	0.08	-
87	FF1	San Fernando, U.S.A (1971)	Santa Anita Dam	30.7	152.00	4.71	0.03	-

3759	FF2	Landers, U.S.A (1992)	Whitewater Trout Farm	27.05	119.64	9.77	0.08	-

PLS* *pulse type motion, NF** *Near-fault ground motions (ordinary), FF* **Far-fault ground motions (ordinary)*

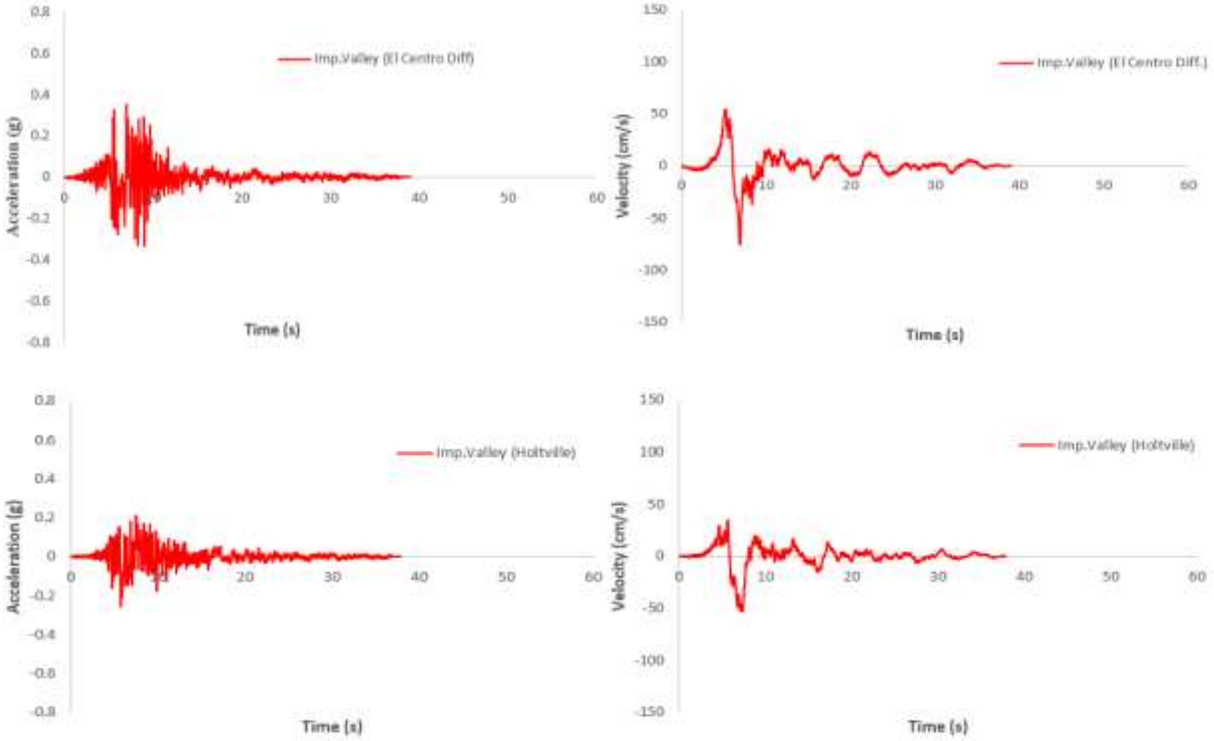

Figure 1. *Acceleration-time and velocity-time histories for near-fault motions with large pulse*

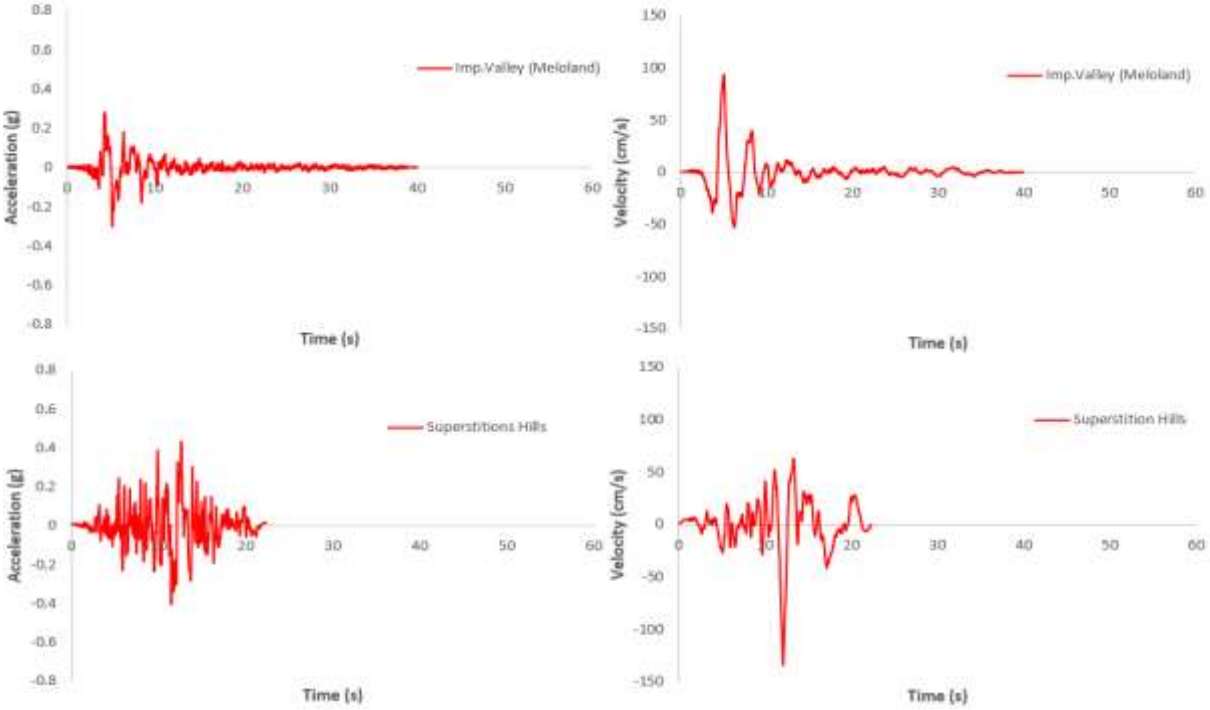

Figure 2. *Acceleration-time and velocity-time histories for near-fault motions with medium pulse and large PGV/PGA*

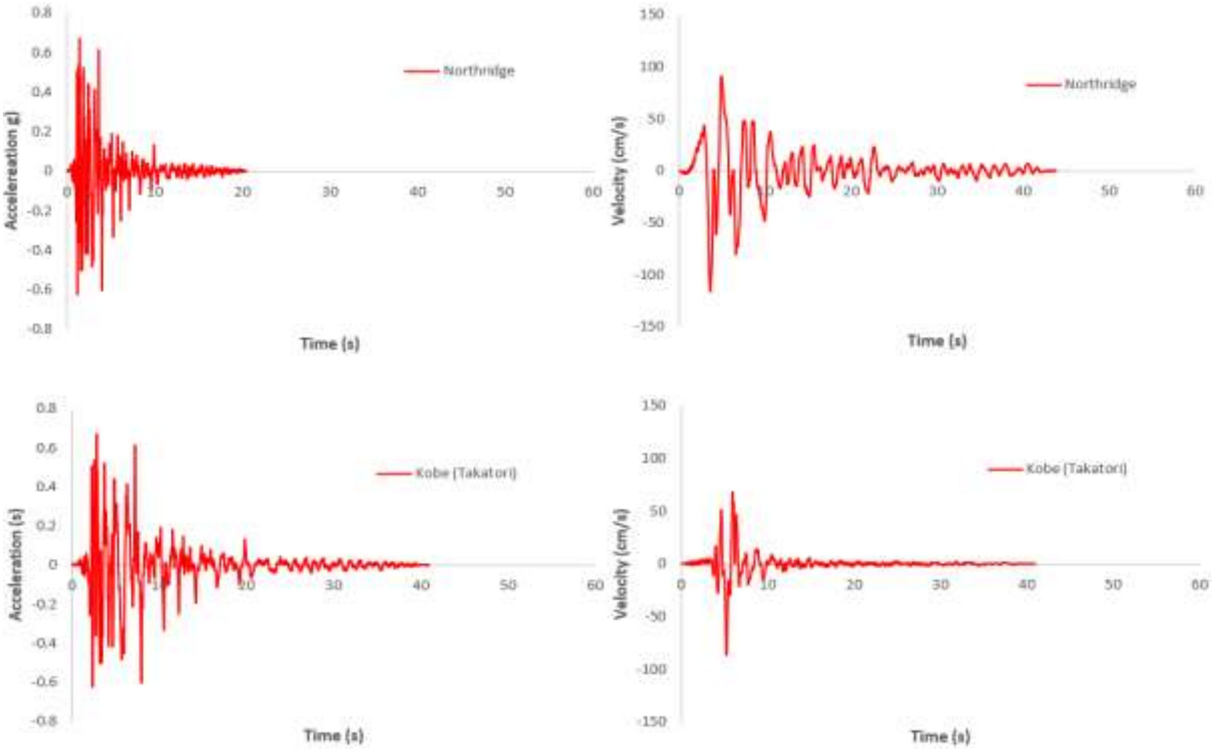

Figure 3. *Acceleration-time and velocity-time histories for near-fault motions with low pulse and large PGA*

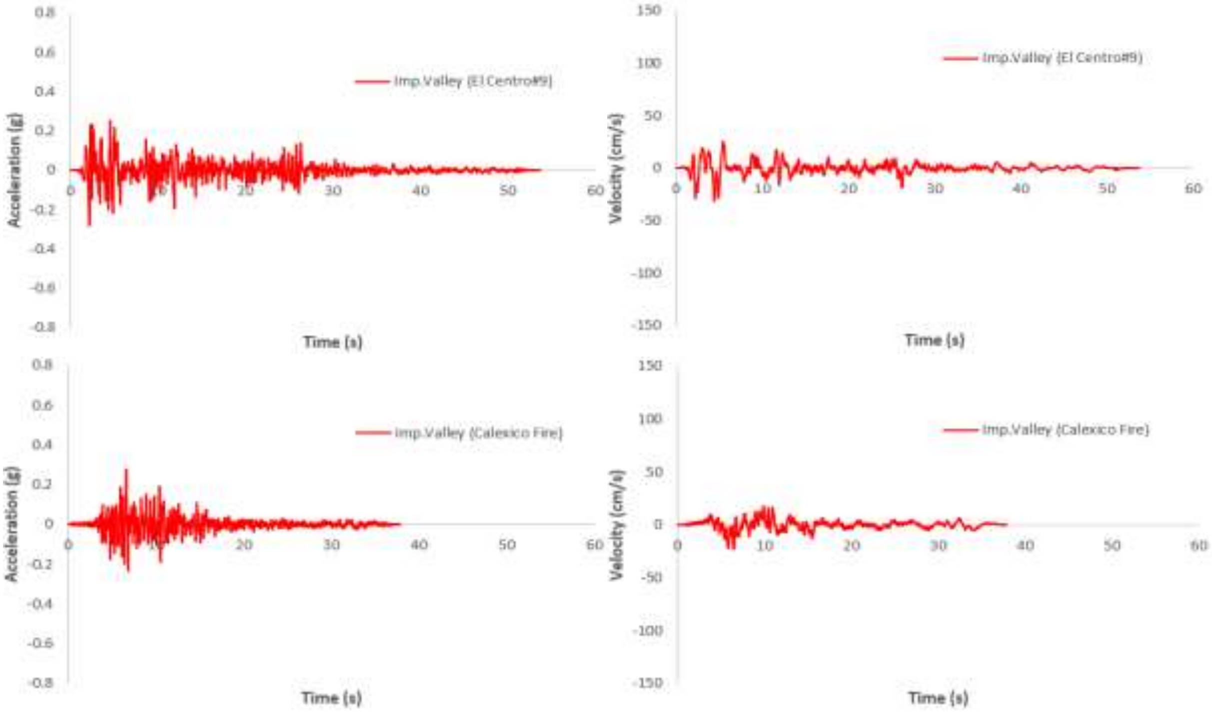

Figure 4. *Acceleration-time and velocity-time histories for ordinary near-fault motions*

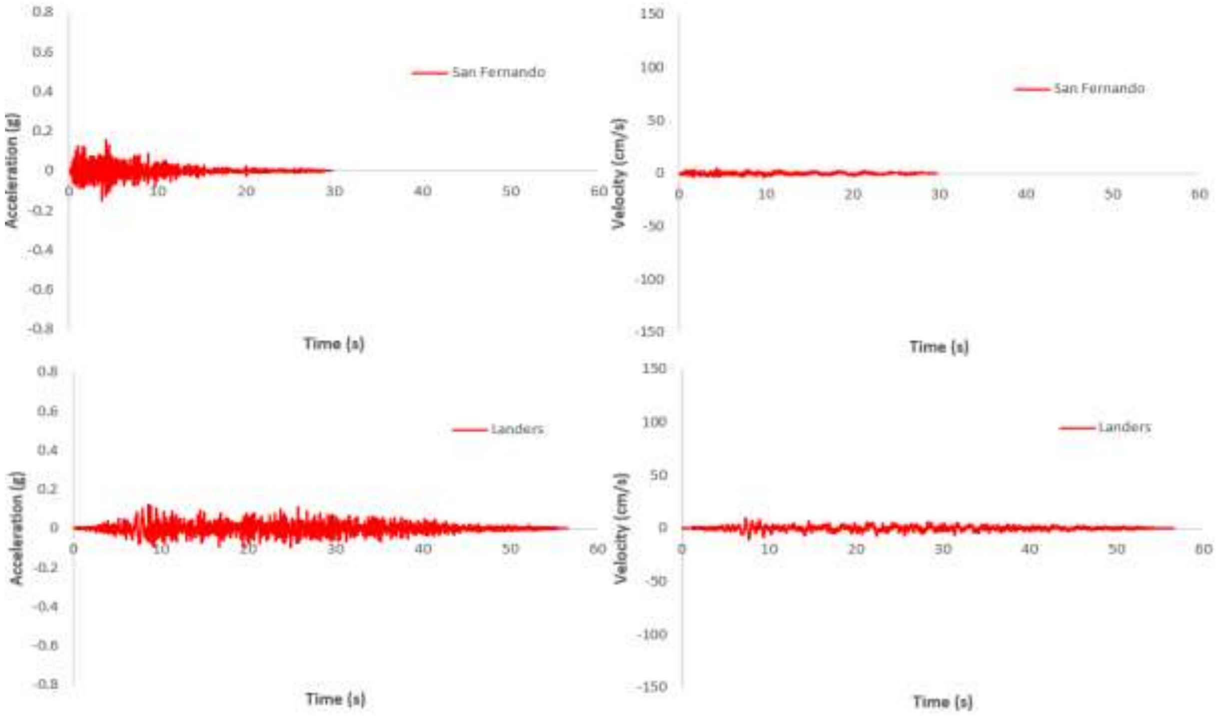

__Figure 5.__ Acceleration-time and velocity-time histories for ordinary far-fault motions

III. STRUCTURAL SYSTEMS AND MODELING

In the presented study, it was aimed that the dynamic behaviors of the buildings with solid slabs and flat slabs were investigated under the near-fault ground motion. For this reason, a 30-storey building with a solid slab and a flat slab system was designed according to TBEC-2018. The buildings were designed with a 1-6 axis in the x-direction and an A-F axis the in the y-direction. The axis distances are 6 meters in both directions of the buildings. Plan views of the buildings are given in Figure 6. The 3-D finite element models of the buildings are given in Figure 7. Shear wall-frame systems were chosen as the lateral force-resisting systems for the buildings. Since the study considered the effects of slabs on structural behavior, solid slab and flat slab systems were used in the structural systems. The placing of the columns and shear walls is given in Figure 8. Both buildings have the same plan for the placing of columns and shear walls. In both buildings, the columns are sized starting from 1000 mm x1000 mm and decreased by 50 mm for every five-floor level. The dimensions of the shear walls used in the buildings are 400 mm x 2400 mm, 400 mm x 3000 mm, 400 mm x 4000 mm, 400 mm x 4500 mm, and 400 mm x 7500 mm. In the building with a solid slab, the beams have a dimension of 400 mm x 70mm mm and the floor thickness is 160 mm. In the building with a flat slab, the slab thickness was chosen as 300 mm. Story height of both structures was chosen as 3000 mm. The compressive strength, unit weight, and elasticity modulus of concrete were chosen as 50 MPa, 25 kN/m^3, and 37000 MPa, respectively. According to TS 498 [26], the live loads were chosen as 3.20 kN/m^2 and 2 kN/m^2 for the roof and typical floor, respectively. The load of mortar of 20 mm and covering of 20 mm were considered as 2 kN/m^2 in the structural design. The load of infill walls in the frames was determined as 6.50 kN/m^2. Dynamic analyses were performed with SAP 2000 finite element analysis software [27].

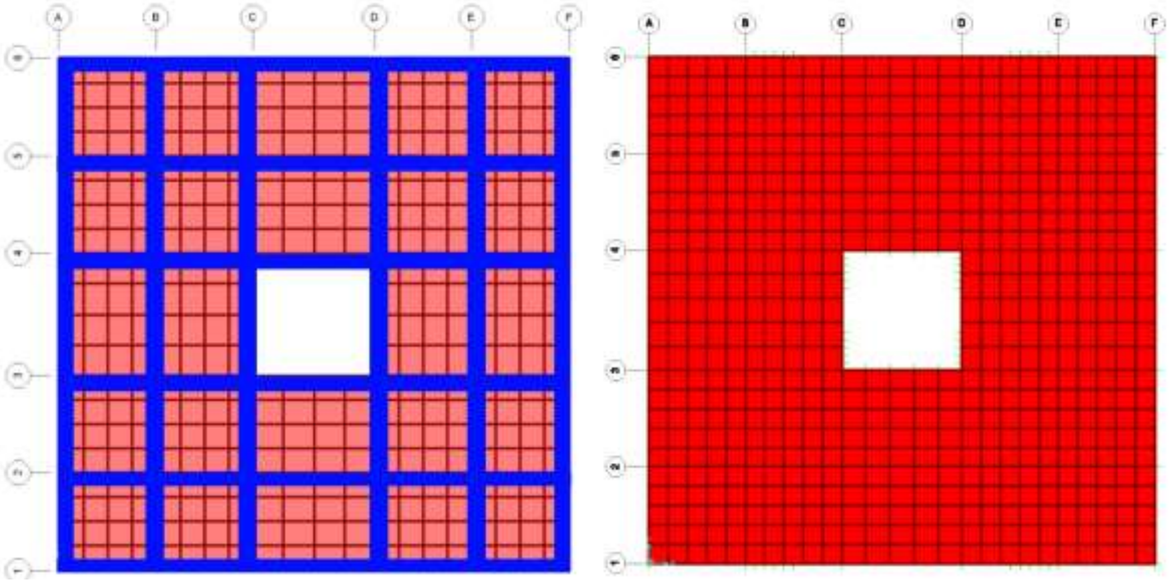

Figure 6. *Plan views of solid slab and flat slab*

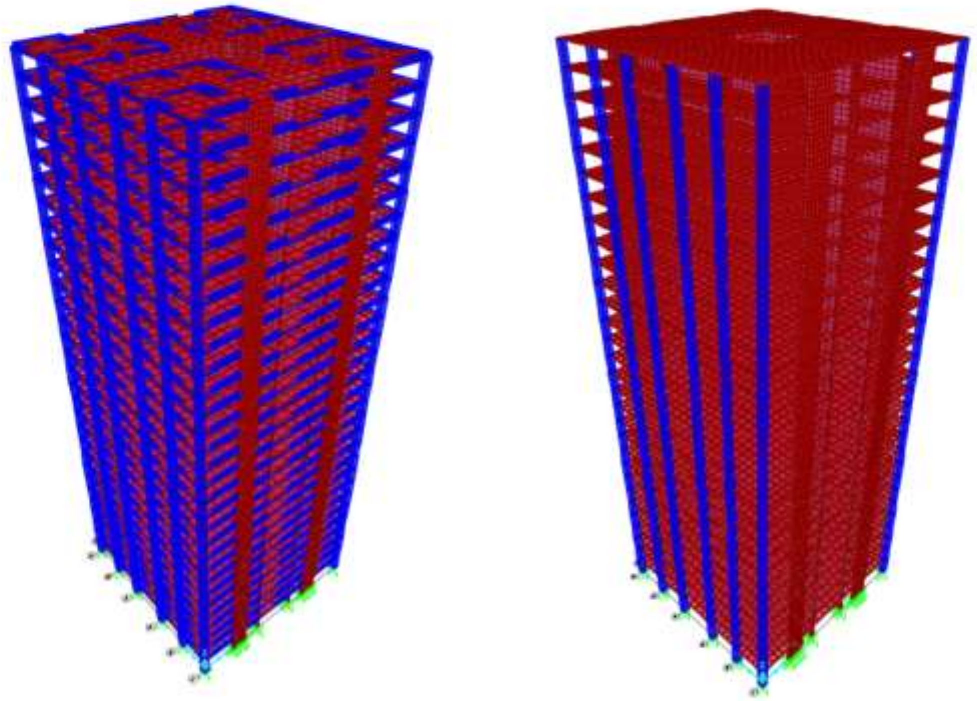

Figure 7. *The 3-D finite element models of the buildings*

Firstly, modal analyses were performed for building models. The first three mode shapes of the building are given in Figure 9 and Figure 10. The first two modes are translational modes in the plan directions of the building, but the third mode is the torsional mode for the building.

The modal analyses were performed for 90 modes to ensure the efficiency of modal masses. For the determination of the dynamic behavior of buildings, the first three modes and the corresponding fundamental periods were used. The natural periods were presented for building models versus the mode numbers in Figure 11. The periods of the first three vibration modes were given in Table 2.

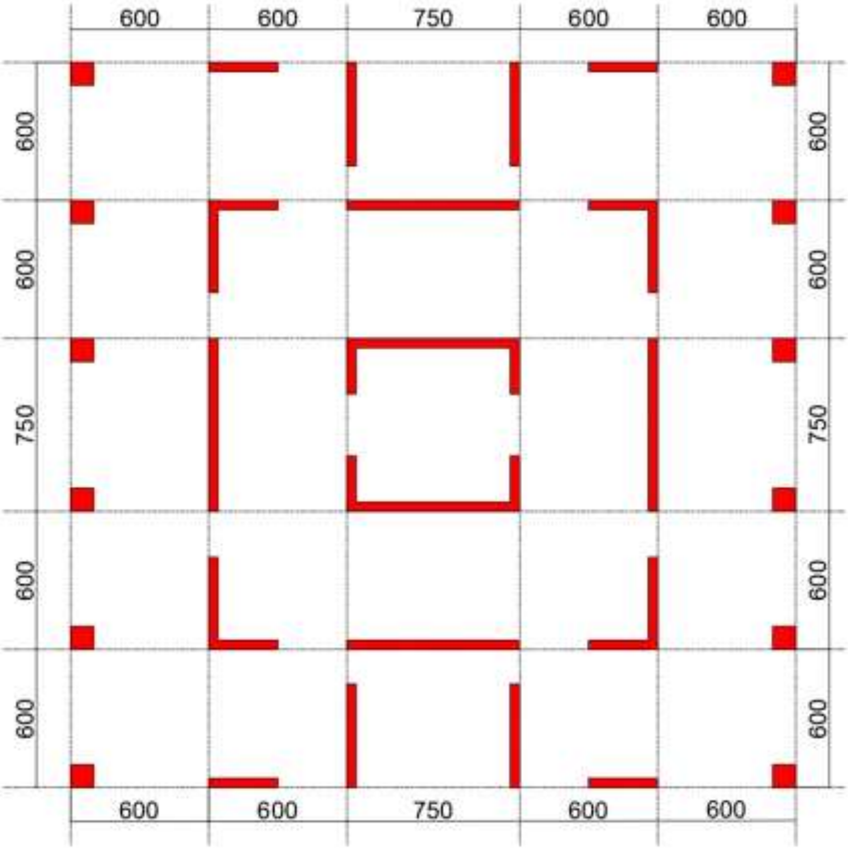

Figure 8. *The placing of the columns and shear walls in the plan*

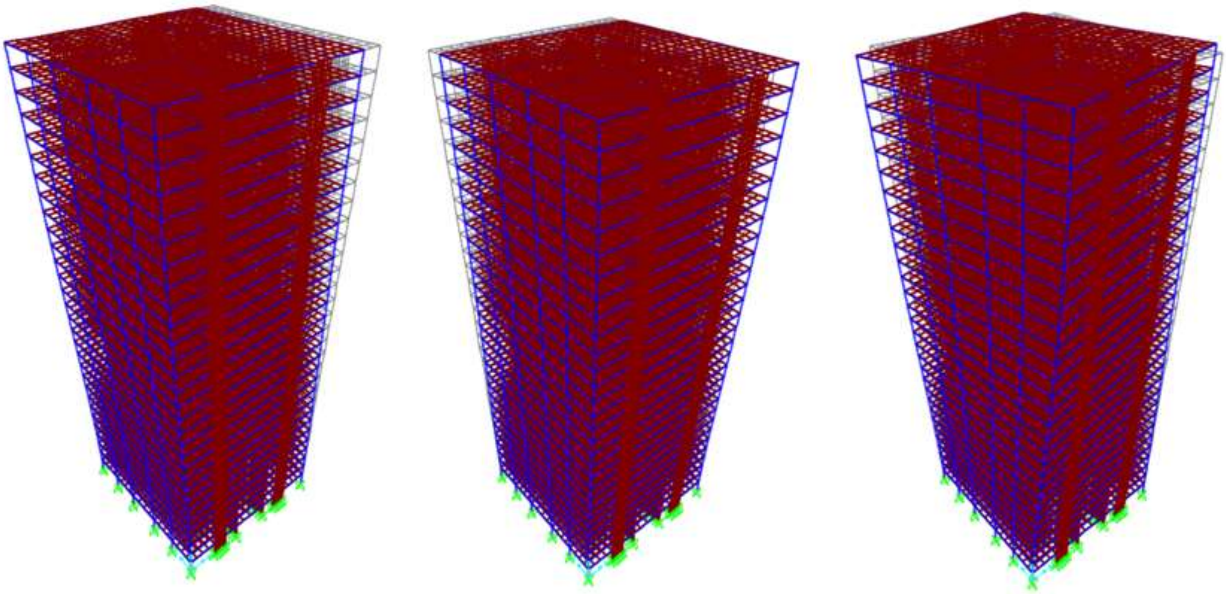

Figure 9. *Mode shapes of the building with solid slab*

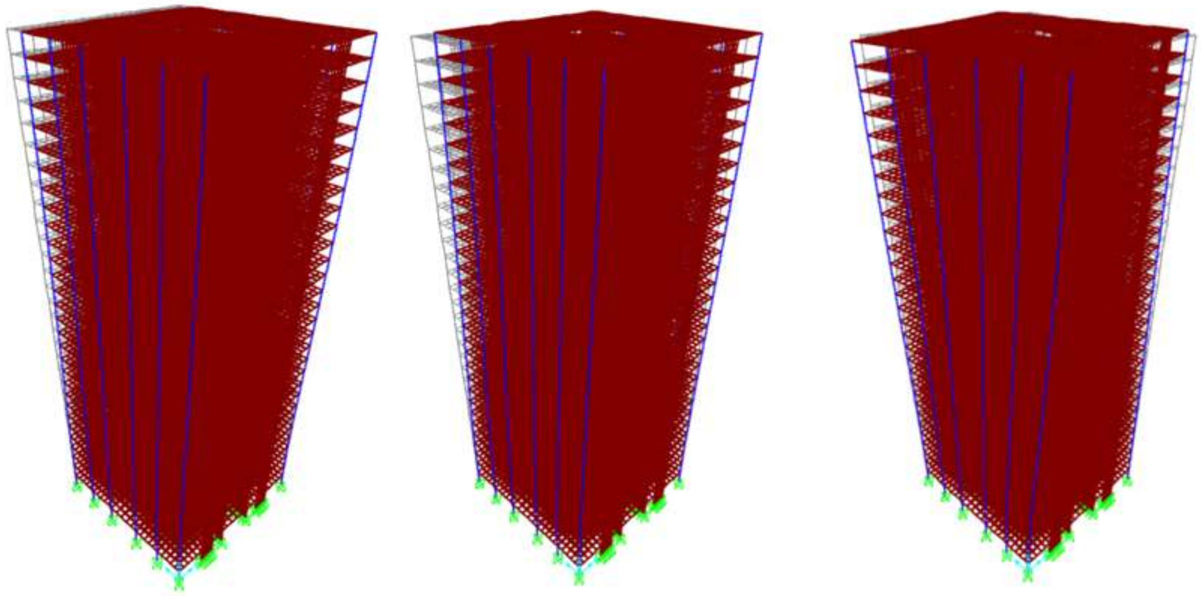

Figure 10. Mode shapes of the building with flat slab

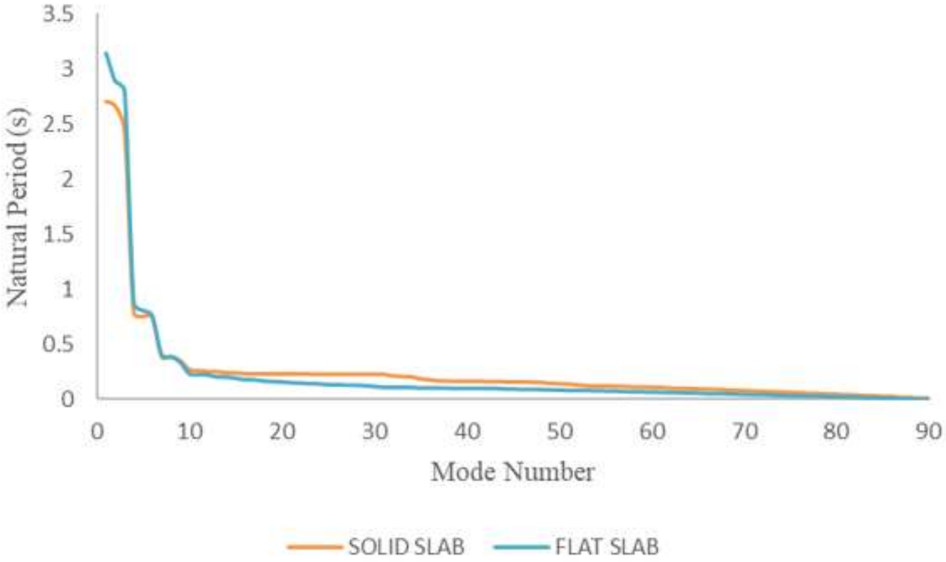

Figure 11. *The natural periods versus the mode numbers*

Table 2. *The periods versus mode shapes of the models*

Models	*Natural Period (s)*		
	1st Mode	*2nd Mode*	*3rd Mode*
Solid slab	2.70	2.66	2.43
Flat slab	3.13	2.88	2.79

III. RESULTS AND DISCUSSION

Many of the buildings are designed with different floor systems depending on the requirements at the architectural design stage. In practice, especially solid and flat slabs are frequently used as a floor system. It is known that the choice of floor system has a direct effect on the stiffness and natural period of the structure. It is known that near-fault motion records of an earthquake, which have high-velocity pulse intensity, have influenced the seismic behavior of structures. In this study, the effects of near-fault ground motion characteristics, which are pulse duration, PGA value, and PGV/PGA ratio, on buildings with solid slabs and flat slabs were investigated. For this reason, two 30-storey buildings with a solid slab and a flat slab system were designed according to TBEC-2018. The dynamic behavior of these buildings with different structural systems has been investigated under near-fault with pulse and non-pulse near-fault earthquake ground motions. The results were compared with the results obtained under the effect of far-fault ground motion. For this manner, 5 different sets of near-fault earthquake motion were used in the analysis. Analysis results were summarized in Table 3 and Table 4.

Table 3. *Minimum and maximum displacement results of the models for all ground motions*

Motion	***Displacement (mm)***			
	Solid Slab System		***Flat Slab System***	
	Minimum	***Maximum***	***Minimum***	***Maximum***
Imp. Valley (El Centro)	-621.70	565.86	-673.35	598.55
Imp. Valley (Holtville)	-514.97	416.30	-556.35	486.70
Imp. Valley (Meloland)	-1187.31	1255.45	-1261.06	1340.13
Superstition (Parachute)	-1223.74	989.06	-1235.19	970.86
Northridge (Syl.-Conv.)	-1787.16	1734.54	-1855.52	1762.61
Kobe (Takatori)	-1134.90	1173.68	-1165.06	1119.82
Imp.Valley (El Centro #9)	-339.60	301.47	-369.52	331.51
Imp.Valley (Fire)	-151.04	158.12	-163.88	165.19
San Fernando (Santa)	-28.47	28.29	-31.96	31.25
Landers (Whitewater)	-79.72	81.88	-78.25	89.13

The first one of the earthquake motion sets was motions with a large pulse duration. In this set, El-Centro and Holtville-Post station records of the 1979 Imperial Valley Earthquake were used. Although the pulse durations of both earthquakes were the same, PGA values were approximately 345.19 cm/s^2 and 253.01 cm/s^2 for El-Centro and Holtville-Post station records, respectively.

In Figure 12 and Figure 13, floor displacements and interstory drift ratios obtained under El-Centro and Holtville-Post station records of building with solid slabs were given depending on the floor level. The largest displacement value on the top floor was 621.70 mm for the El-Centro station record. The largest displacement was obtained as 514.97 mm for the Holtville-Post station record. Under the El-Centro station record motion, the maximum interstory drift ratio was obtained as approximately 2.33% at 11th floor level. The maximum interstory drift ratio was 1.76% for the Holtville-Post station record at 16th level.

Table 4. *Minimum and maximum interstory drift ratios of the models for all ground motions*

Motion	***Interstory Drift Ratio (%)***			
	Solid Slab System		***Flat Slab System***	
	Minimum	***Maximum***	***Minimum***	***Maximum***
Imp. Valley (El Centro)	-2.33	2.03	-2.26	2.20
Imp. Valley (Holtville)	-1.76	1.52	-1.91	1.70
Imp. Valley (Meloland)	-4.02	4.23	-4.20	4.56
Superstition (Parachute)	-4.05	3.29	-4.11	3.20
Northridge (Syl.-Conv.)	-6.34	5.63	-6.28	5.84
Kobe (Takatori)	-3.82	3.88	-3.94	3.77
Imp.Valley (El Centro #9)	-1.15	1.03	-1.25	1.14
Imp.Valley (Fire)	-0.46	0.53	-0.58	0.58
San Fernando (Santa)	-0.10	0.09	-0.10	0.10
Landers (Whitewater)	-0.28	0.30	-0.24	0.31

Floor displacements and interstory drift ratio, which were obtained under El-Centro and Holtville-Post station records for building with flat slabs, were given in Figure 14 and Figure 15. The top floor displacements were 673.35 mm and 556.35 mm for the El-Centro station record and Holtville-Post station record. While the interstory drift ratio was obtained as approximately 2.26% at 12th floor level for the El-Centro station record motion, it was obtained as 1.9%1 at 18th for the Holtville-Post station record. Although the difference between the PGA values of El-Centro station and Holtville-Post station records was 36%, the difference between floor displacements was approximately as 21% and 21% for both slab systems, respectively. On the other hand, differences between interstory drift ratios were obtained as approximately 33% and 18% for two slab systems.

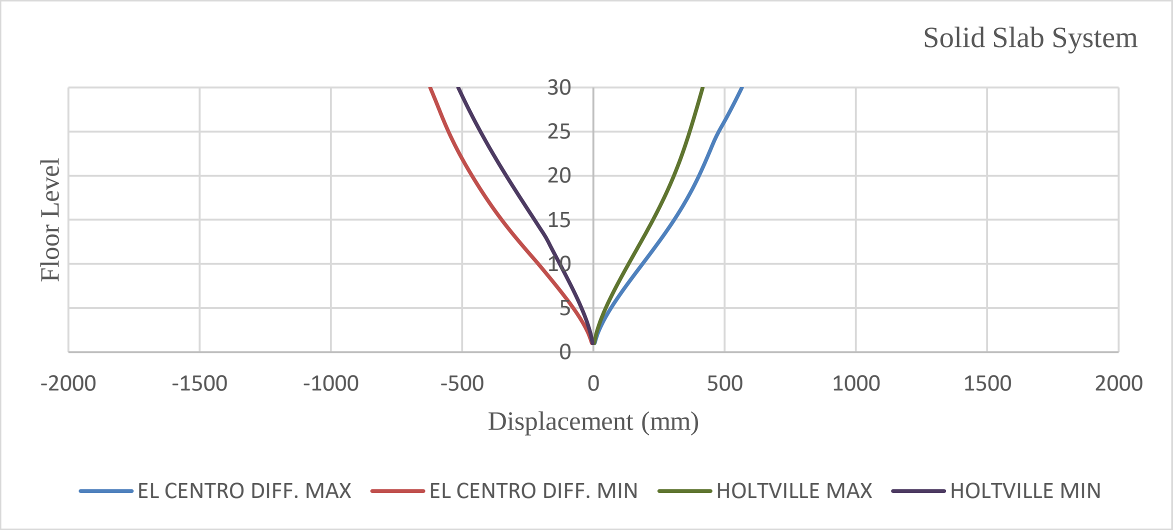

Figure 12. *The floor displacements versus floor level for solid slab under large pulse effect*

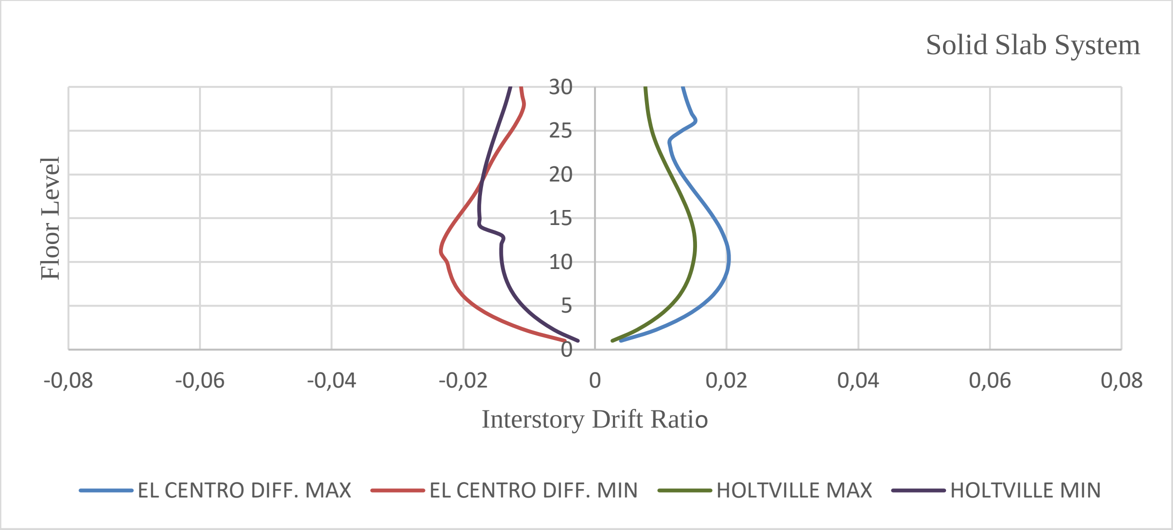

Figure 13. *The interstory drift ratio versus floor level for solid slab under large pulse effect*

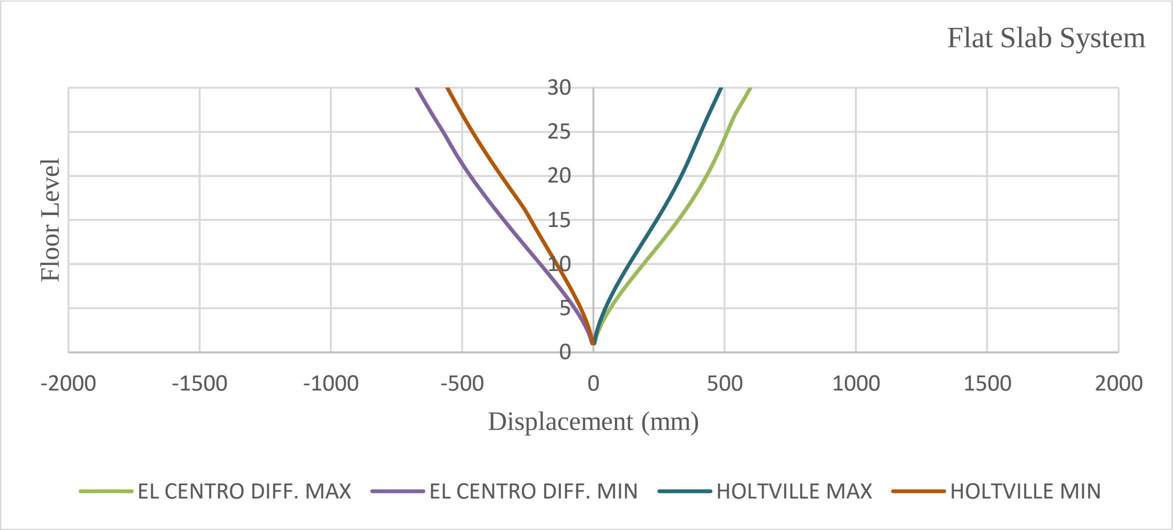

Figure 14. *The floor displacements versus floor level for flat slab under large pulse effect*

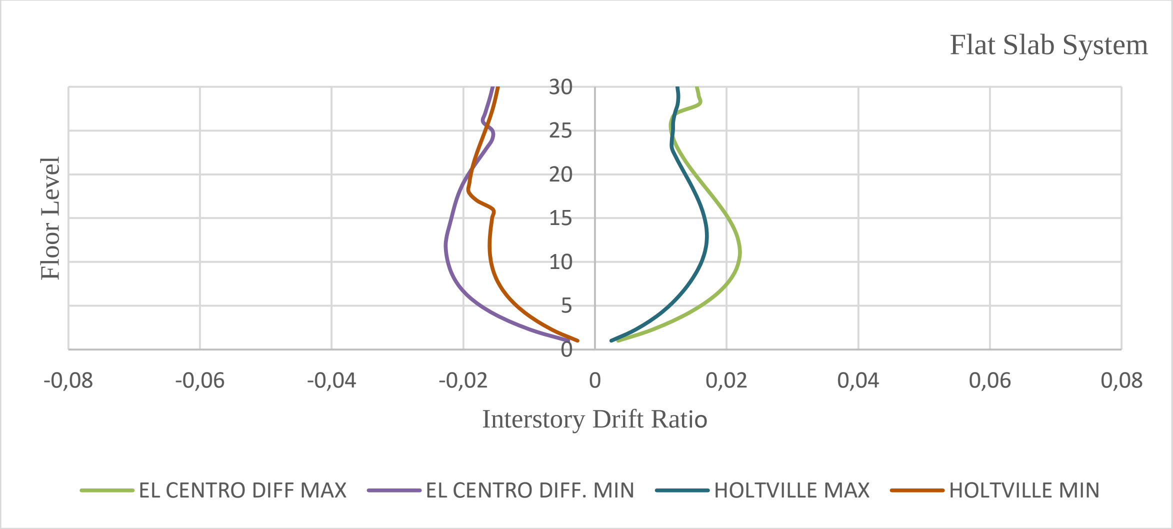

Figure 15. *The interstory drift ratio versus floor level for flat slab under large pulse effect*

El-Centro-Meloland station record of the 1979 Imperial Valley Earthquake and Parachute Test Site station record of the 1987 Superstition Hills Earthquake were chosen as the second motion set. These motions were recorded as motion with large PGV/PGA. The pulse durations of both earthquakes were 3.08 and 2.40 seconds for the Meloland and Parachute Test Site station records, respectively. Although the Meloland station record had 291.25 cm/s^2 of PGA, the PGA of the Parachute Test Site station record was 422.66 cm/s^2.

For the building with solid slab, floor displacements, and interstory drift ratios were given in Figure 16 and Figure 17. Under the El-Centro-Meloland station record motion, the maximum displacement of the top floor was evaluated as 1255.45 mm. It was obtained as 1223.74 mm for Parachute Test Site station record motion. The maximum interstory drift ratio was obtained as approximately 4.23% at 14th floor level for the El-Centro-Meloland station record motion, but it was obtained as 4.05% at 15th floor level for the Parachute station record.

In Figure 18 and Figure 19, floor displacements and interstory drift ratios were given for the building with flat slab system. The maximum floor displacements were obtained as 1340.13 mm and 1235.19 mm for the El-Centro-Meloland station and Parachute Test Site station record motions, respectively. The interstory drift ratio was obtained as 4.56% at 14th floor level for the El-Centro-Meloland station record motion, but it was obtained as 4.11% at 16th floor for the Parachute station record.

Although PGA value of the El-Centro-Meloland station record was less about 45% than Holtville-Post station records, the El-Centro-Meloland station record had a 28% greater pulse duration. The differences between floor displacements of solid and flat slab systems were 2.59% and 8.50%, respectively. Differences between interstory drift ratios were obtained as 4.44% and 10.95% for solid and flat slab systems.

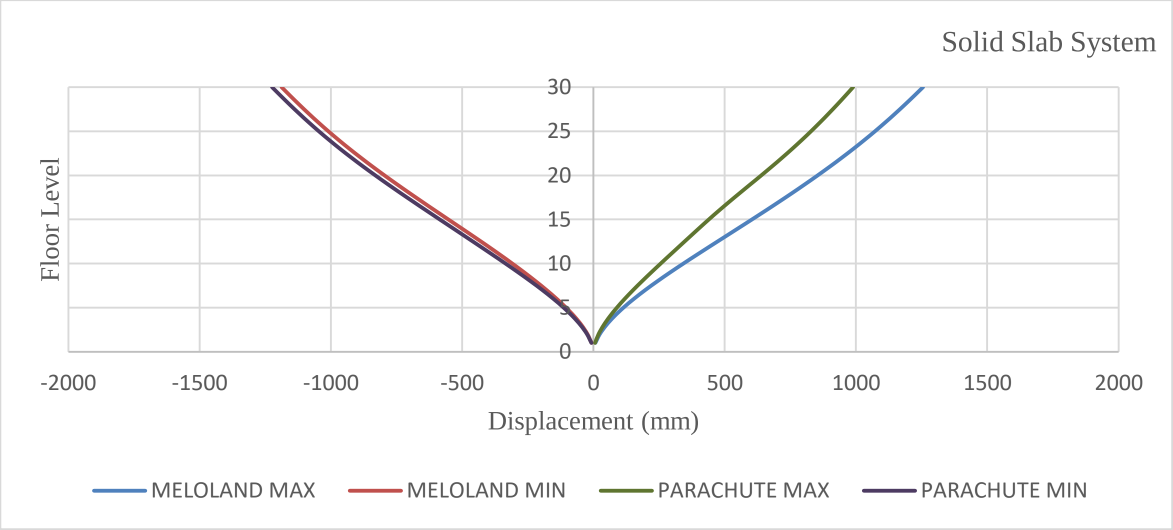

Figure 16. *The floor displacements versus floor level for solid slab under large PGV/PGA*

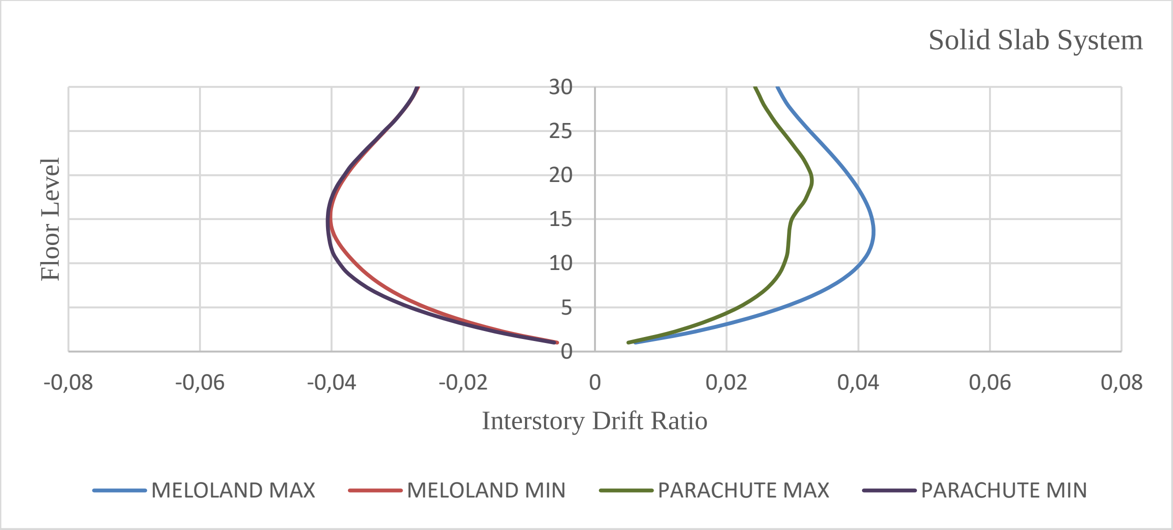

Figure 17. *The interstory drift ratios versus floor level for solid slab under large PGV/PGA*

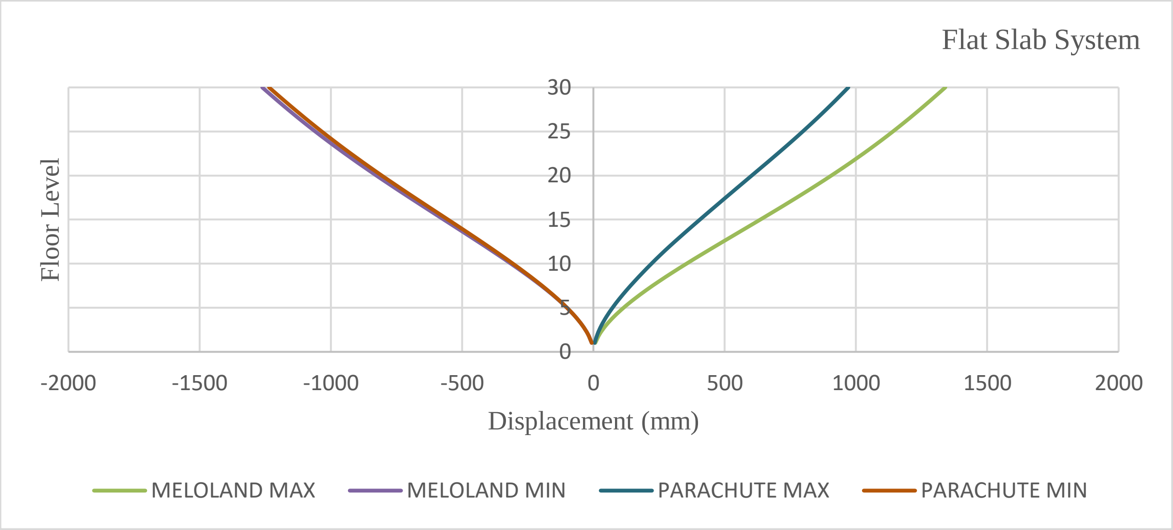

Figure 18. *The floor displacements versus floor level for flat slab under large PGV/PGA*

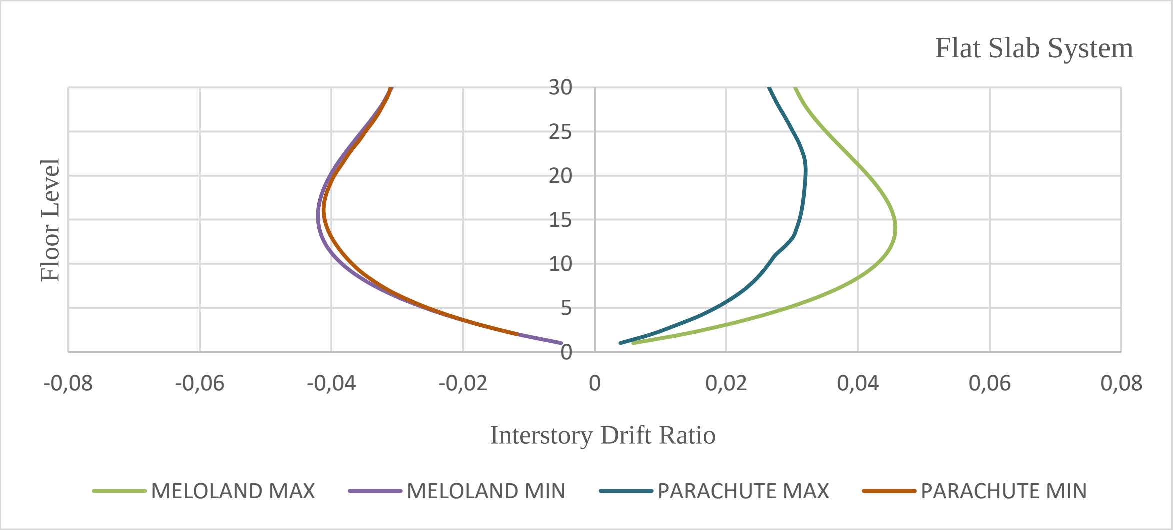

Figure 19. *The interstory drift ratios versus floor level for flat slab under large PGV/PGA*

The third set of the record motions was composed of the Sylmar-Converter record of the 1994 Northridge Earthquake and Takatori station record of the Kobe-Japan Earthquake. Although PGV/PGA ratios of these earthquakes were low, PGA values were large. Under nearly the same PGV/PGA ratio and PGA values, the effect of pulse duration was investigated with these motions. PGA values of the Sylmar-Converter record of the 1994 Northridge Earthquake and Takatori station record of the Kobe-Japan Earthquake had 610.95 cm/s^2 were 658.02 cm/s^2.

Floor displacements and interstory drift ratios were given in Figure 20 and Figure 21 for the building with the solid slab. The maximum top floor displacements were founded as 1787.16 mm and 1173.68 mm for the Sylmar-Converter record of the 1994 Northridge Earthquake and Takatori station record of the Kobe-Japan Earthquake, respectively. The maximum interstory drift ratio was obtained as 6.34% at 11th floor level for the Sylmar-Converter record of the 1994 Northridge Earthquake, but it was 3.88% at 16th floor level for the Takatori station record of the Kobe-Japan Earthquake.

Floor displacements and interstory drift ratios were given in Figure 22 and Figure 23 for the building with the flat slab system. For the Sylmar-Converter record of the 1994 Northridge Earthquake and Takatori station record of the Kobe-Japan Earthquake, the top floor displacements were 1855.52 mm and 1165.06 mm, respectively. Moreover, interstory drift ratios were approximately 6.28% and 3.94% for these record motions, respectively. The maximum interstory drift ratios were obtained at 14th and 18th floor level for Sylmar-Converter record and Takatori station record, respectively.

The pulse duration of the Sylmar-Converter record of the 1994 Northridge Earthquake was greater about 132% than Takatori station record of the Kobe-Japan Earthquake. The differences between top floor displacements of solid and flat slab systems were 52.27% and 59.26%, respectively. Differences between interstory drift ratios were obtained as approximately 63.40% and 59.39% for solid and flat slab systems. It was seen that the pulse durations of such ground motions are very effective on flat slab systems.

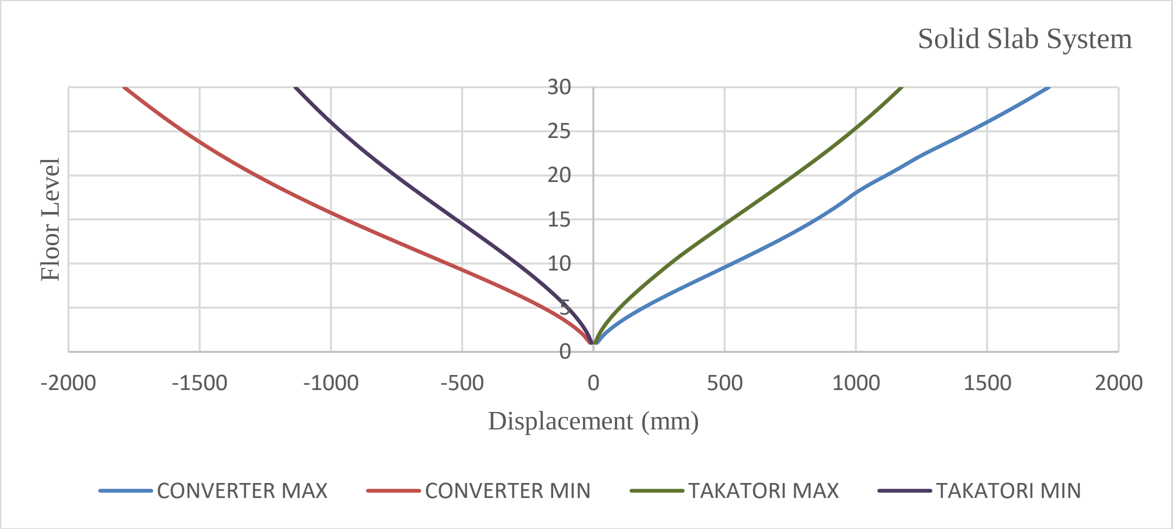

Figure 20. *The floor displacements versus floor level for solid slab under the nearly same PGV/PGA and PGA*

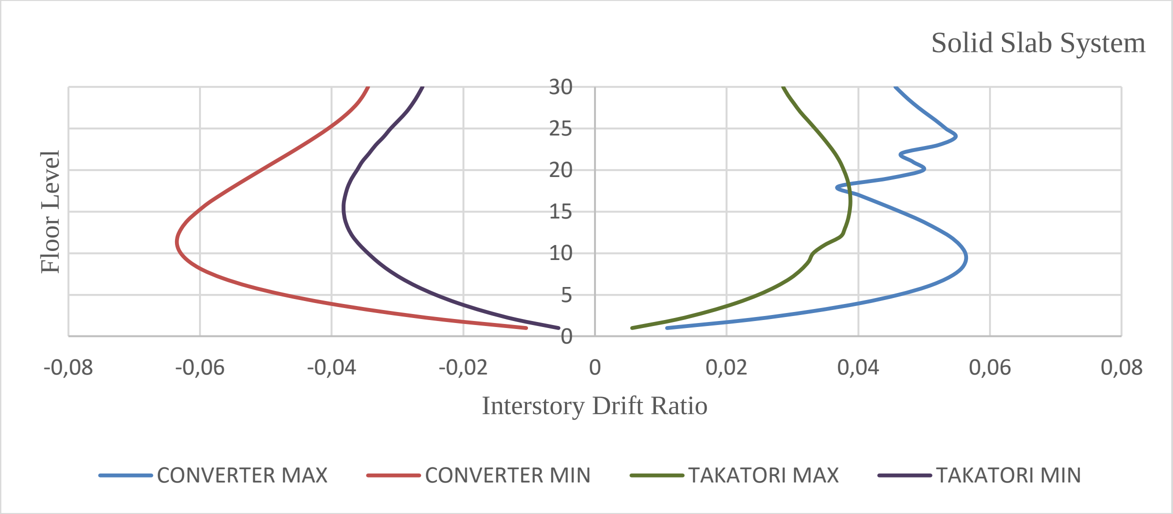

Figure 21. *The interstory drift ratios versus floor level for solid slab under the nearly same PGV/PGA and PGA*

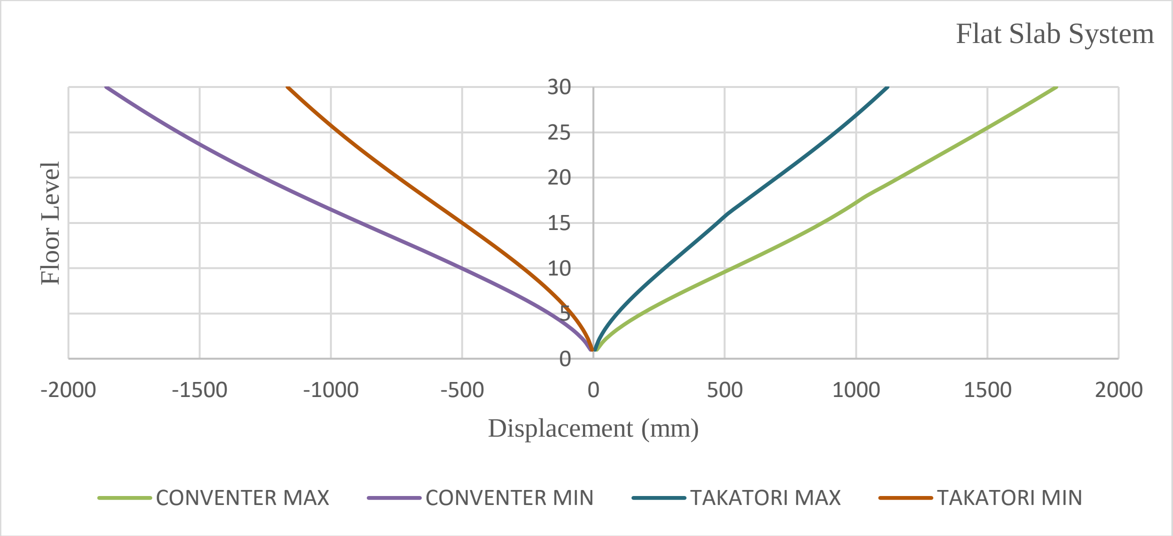

Figure 22. *The floor displacements versus floor level for flat slab under the nearly same PGV/PGA and PGA*

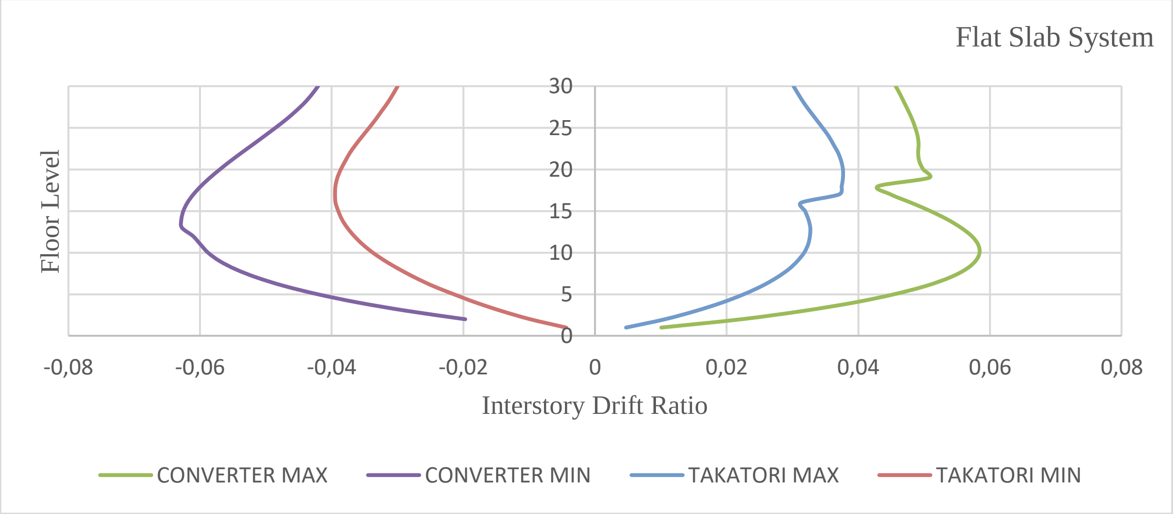

Figure 23. *The interstory drift ratios versus floor level for flat slab under the nearly same PGV/PGA and PGA*

One of the motion sets was ordinary near-fault motions, which were the El-Centro#9 and the Calexico Fire Station record motion of the 1979 Imperial Valley Earthquake. Both earthquake ground motion records have the same PGA value.

For the building with the solid slab system, floor displacements, and interstory drift ratios, which were obtained from ordinary near-fault ground motions, were given in Figure 24 and Figure 25. The maximum top floor displacements were obtained as 339.60 mm and 158.12 mm under the El-Centro#9 and the Calexico Fire Station record motion of the 1979 Imperial Valley Earthquake, respectively. The interstory drift ratio was obtained as 1.15% for the El-Centro#9 station, but it was 0.53% for the Calexico Fire Station. The maximum interstory drift ratios were obtained at 12th and 19th floor level for El-Centro#9 station and the Calexico Fire Station, respectively.

Floor displacements and interstory drift ratios were given in Figure 26 and Figure 27 for the building with the flat slab system. For the El-Centro#9 station of the 1979 Imperial Valley Earthquake and the Calexico Fire Station record motion of the 1979 Imperial Valley Earthquake, the top floor displacements were 369.52 mm and 165.19 mm, respectively. Interstory drift ratios were approximately 1.25% and 0.58% for these record motions, respectively. The maximum interstory drift ratios were obtained at 15th and 21st floor level.

PGV/PGA ratio of the El-Centro#9 station of the 1979 Imperial Valley Earthquake was approximately greater 22% than the Calexico Fire Station record motion of the 1979 Imperial Valley Earthquake. The differences between top floor displacements of solid and flat slab systems were 115% and 124% according to two record motions, respectively. Differences between interstory drift ratios were obtained as approximately 117% and 115% according to two record motions for solid and flat slab systems.

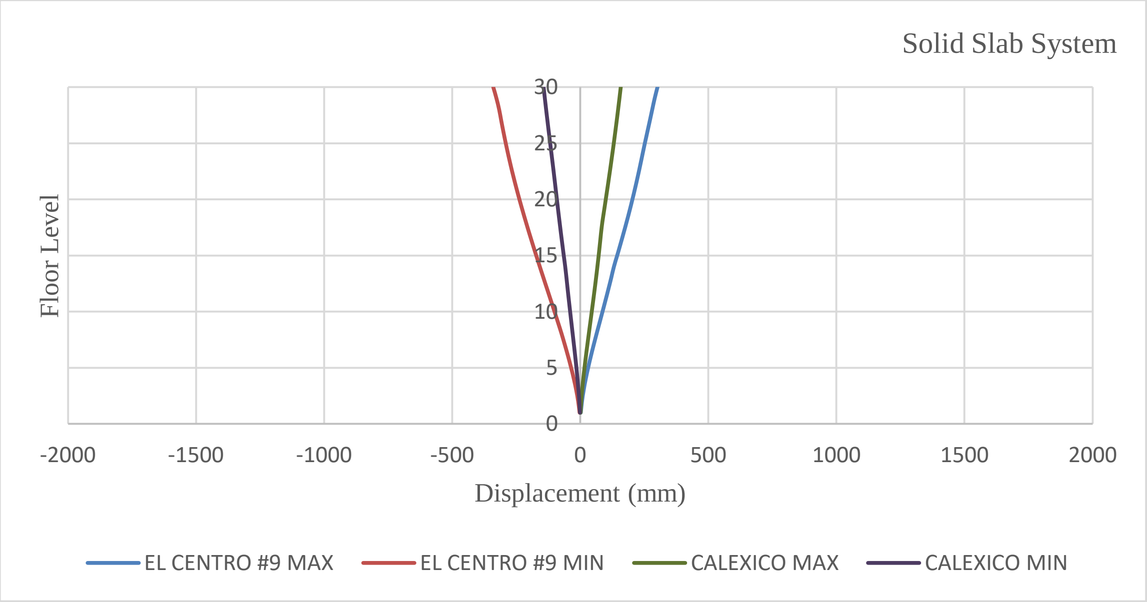

Figure 24. *The floor displacements versus floor level for solid slab under the ordinary near-fault ground motion*

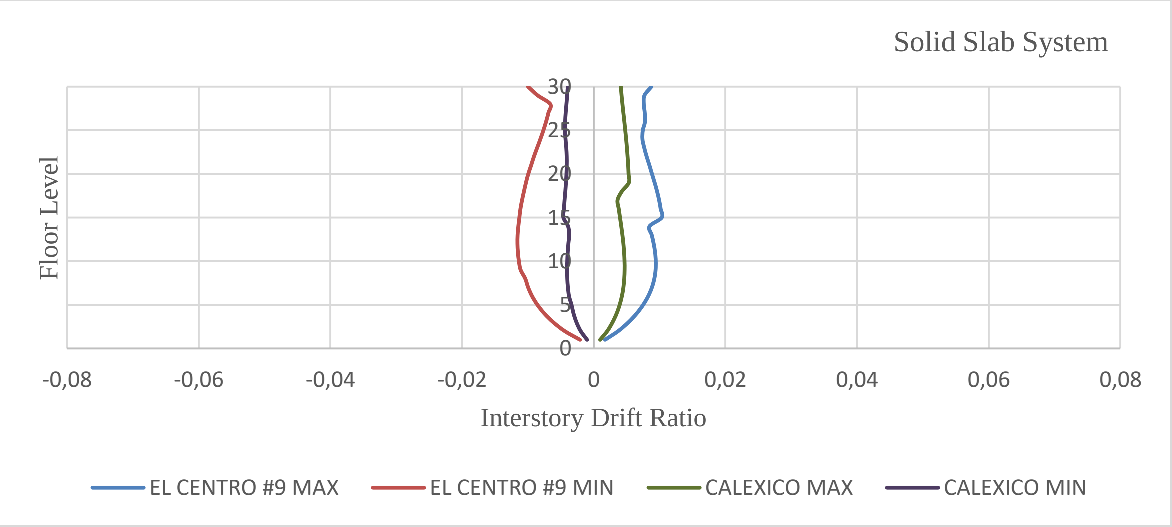

Figure 25. *The interstory drift ratios versus floor level for solid slab under the ordinary near-fault ground motion*

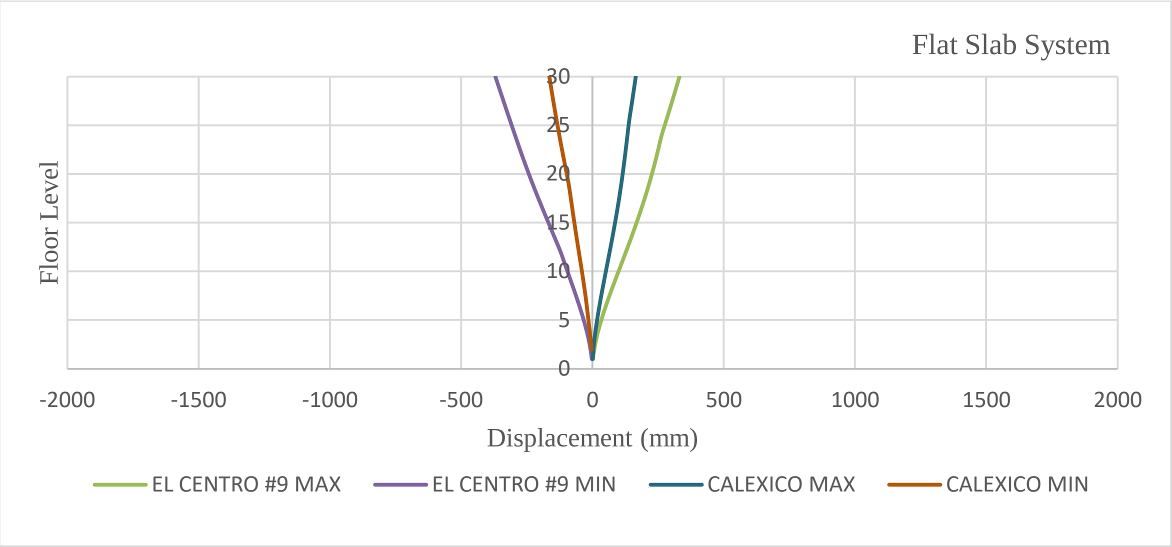

Figure 26. *The floor displacements versus floor level for flat slab under the ordinary near-fault ground motion*

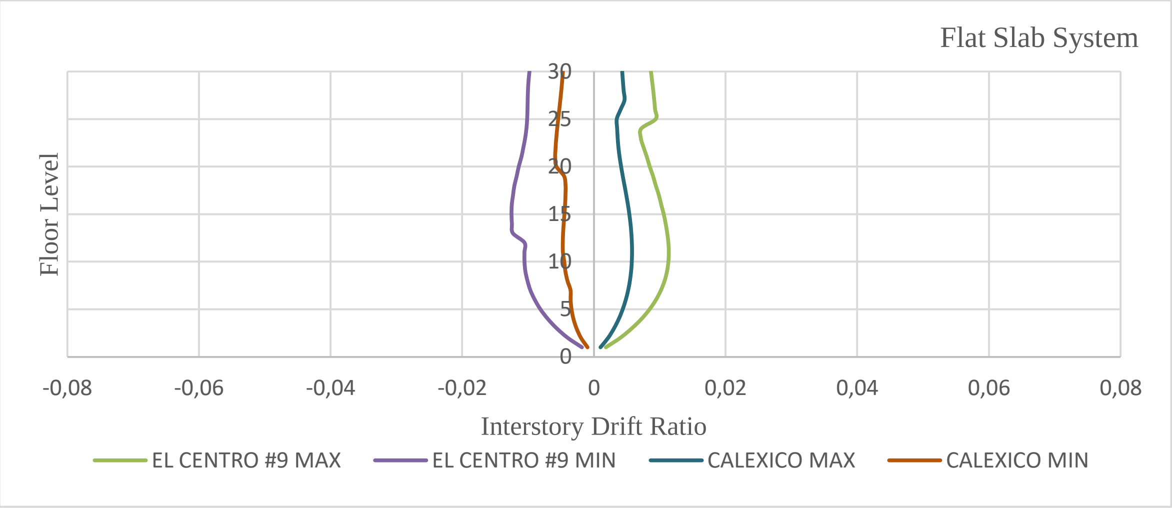

Figure 27. *The interstory drift ratios versus floor level for flat slab under the ordinary near-fault ground motion*

Far-fault motion set was used for comparison of the results obtained from near-fault motions. Therefore, the Santa Anita Dam Station record of the 1971 San Fernando Earthquake and the Whitewater Trout Farm station record of the Landers Earthquake was chosen as far-field earthquake motion.

Figure 28 and Figure 29 gave floor displacements and interstory drift ratios of the building with the solid slab system. The maximum top floor displacements were obtained as 28.47 mm and 81.88 mm under the Anita Dam Station record of the 1971 San Fernando Earthquake, and the Whitewater Trout Farm station record of the Landers Earthquake, respectively. The interstory drift ratios were obtained as 0.1% and 0.3% for the Santa Anita Dam Station record of the 1971 San Fernando Earthquake and the Whitewater Trout Farm station record of the Landers Earthquake. The maximum interstory drift ratios were obtained at 13th and 11th floor levels.

Floor displacements and interstory drift ratios were given in Figure 30 and Figure 31 for the building with the flat slab system. The top floor displacements were 31.96 mm and 89.13 mm for the Anita Dam Station record of the 1971 San Fernando Earthquake, and the Whitewater Trout Farm station record of the Landers Earthquake respectively. Interstory drift ratios were approximately 0.1% and 0.31% for these record motions, respectively. The maximum interstory drift ratios were obtained at 16th and 29th floor levels.

The differences between top floor displacements of solid and flat slab systems were 188% and 179% according to two record motions, respectively. Differences between interstory drift ratios were observed to be almost the same, around 200% for solid and flat slab systems. There were no differences between interstory drift ratios according to two record motions for solid and flat slab systems.

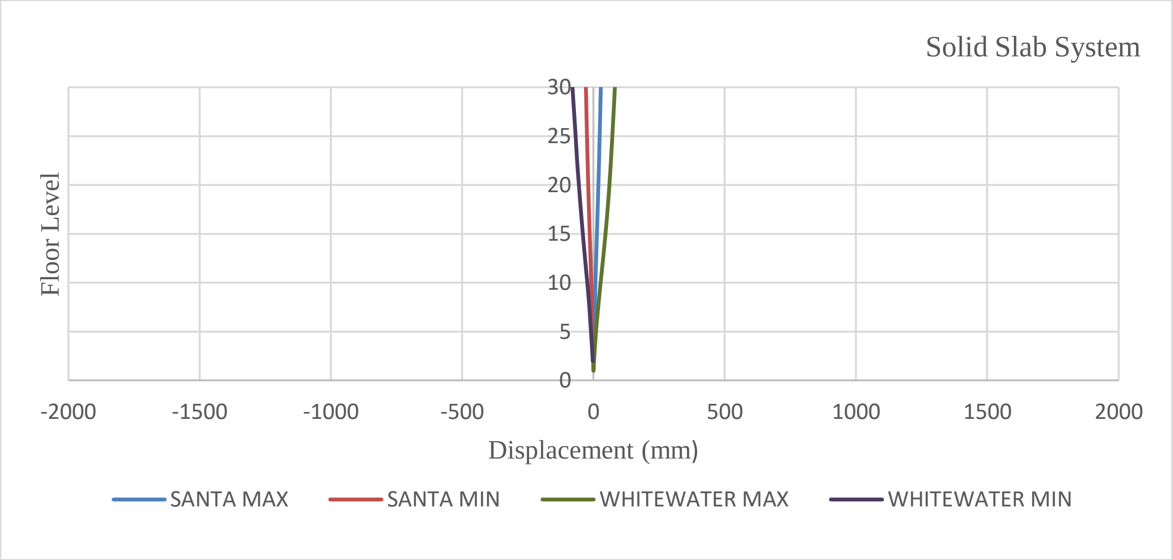

Figure 28. *The floor displacements versus floor level for solid slab under the ordinary far-fault ground motion*

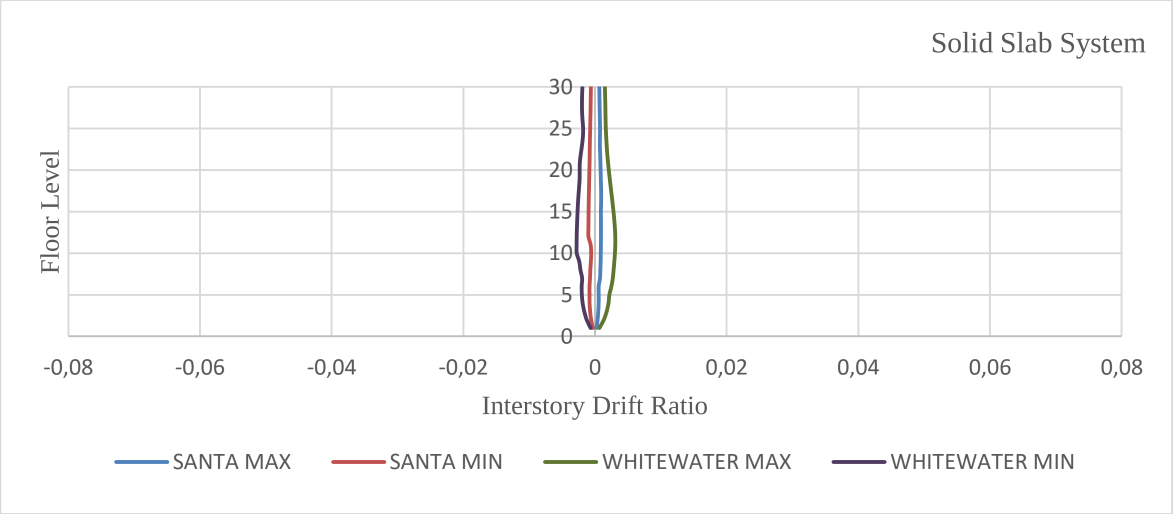

Figure 29. *The interstory drift ratios versus floor level for solid slab under the ordinary far-fault ground motion*

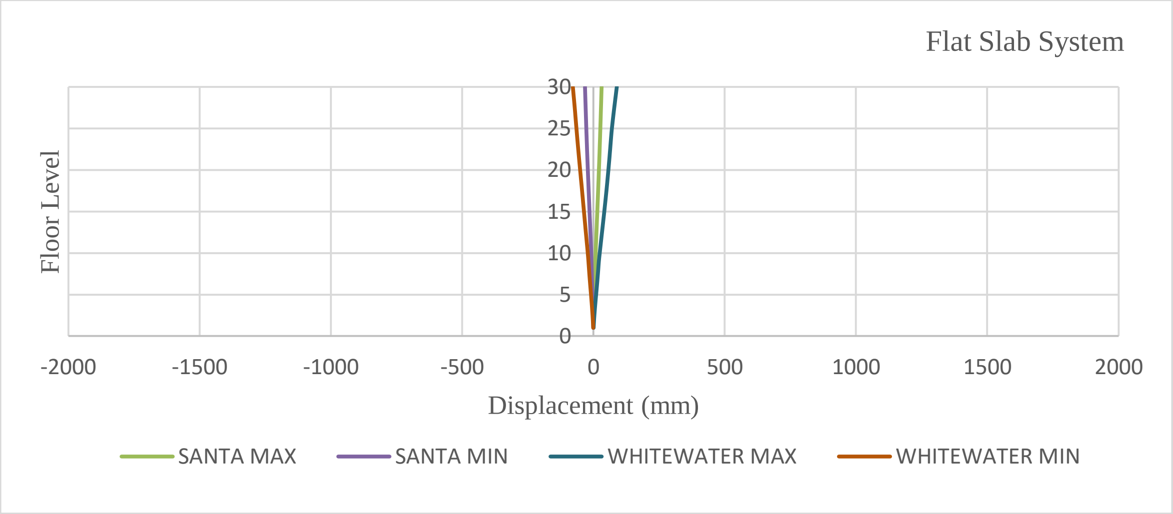

Figure 30. *The floor displacements versus floor level for flat slab under the ordinary far-fault ground motion*

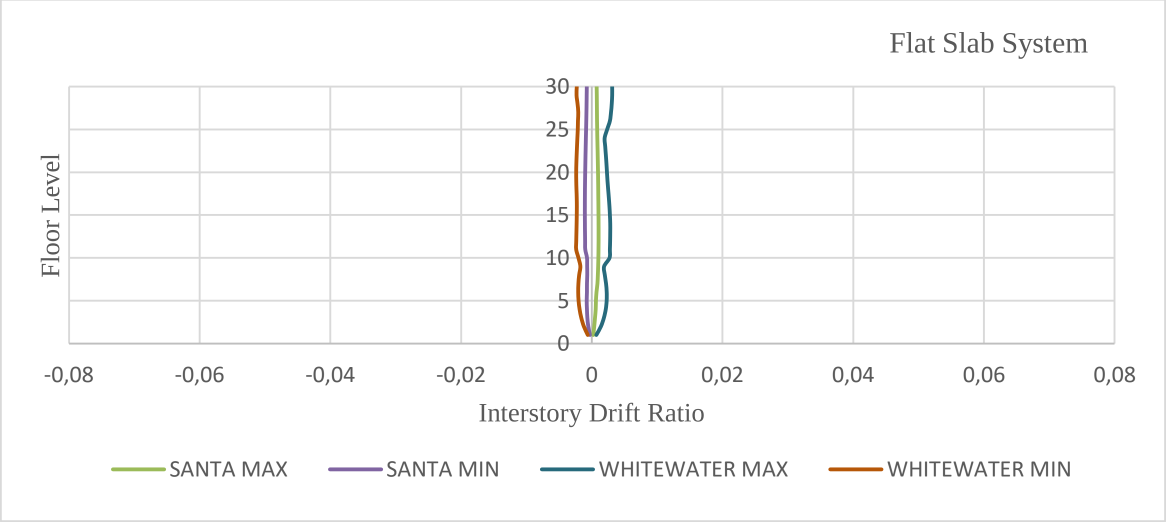

Figure 31. *The interstory drift ratios versus floor level for flat slab under the ordinary far-fault ground motion*

IV. CONCLUSION

The following results were obtained from the dynamic analyses of a 30-storey building designed with solid and flat slab system under near-fault ground motions:

- The solid slab system provides the lowest displacement compared to the other flat slab systems. The larger stiffness of the building designed with a solid slab may generally cause this behavior.
- If the ratio of pulse period to first mode vibration period (T_p/T_1) is greater than 1.0, interstory drift ratios of flat slab systems are less affected by the PGA value.
- Although top floor displacements of buildings with flat slab systems are greater, the variation of displacements for both slab systems are nearly the same according to the variation of PGA under large pulse.
- Flat slab systems are very sensitive to PGV/PGA. If the pulse period and PGV/PGA increase, top floor displacements of flat slab systems will be very high. In addition, the variation in displacements and interstory drift ratios of flat slab systems are very high even if PGA is very low. It can be said that the pulse durations of such ground motions are very effective on flat slab systems.
- Interstory drift ratios of solid slab systems are obtained higher than flat slab systems under low PGV/PGA and high PGA for motions with high velocity-pulse.
- PGV/PGA is very effective for both slab systems for ordinary near-fault ground motions. Ordinary near-fault ground motions do not have a significant effect on flat slab systems.
- Although far-fault ground motions have very low PGV/PGA, PGV/PGA values of far-fault ground motions are very effective parameters for solid and flat slab systems.

This study did not investigate the shear and moment response of the slab systems. In addition, linear time history analysis was performed but future studies should examine the nonlinear analysis of structures for near-fault motion characteristics.

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