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Seismic Response of Seismic Isolated Structures Subject to Near Fault &Far Fault Ground Motions

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Abstract-. Seismic isolation systems are one of the most effective technologies for protecting structures from lateral loading, improving the seismic performance of the buildings against dynamic loads and base-isolated buildings have benefits in mitigating damage to the superstructure. Non-linear time history analysis is used to investigate the seismic response of fixed base and base-isolated building frames under far-fault ground motions and near-fault ground motions with fling step and forward directivity characteristics. Peak floor displacement, inter-story drift, absolute acceleration, base shear, and isolator displacement are some of the response characteristics that have been studied and examined as results of the analysis. The results demonstrated that using base isolators improves the seismic behavior of the used building, but it found that the isolator displacement is very large, during near-fault ground motion with the fling step effect particularly. For mitigating large isolator displacement during near-field earthquakes, the influence of a combination of the isolator and friction supplemental damper on the seismic response of a base-isolated 2D building frame is studied, and results demonstrated that using base isolators combined with viscous dampers can reduce the isolator's displacement.

Keywords: Base Isolation, LRB, Friction Damper, Far Field Earthquakes, Near Field Earthquakes, seismic performance, Nonlinear time history analysis.

I. INTRODUCTION

Base isolation is one of the effective structural controlling techniques for the protection of structures during earthquake events. The concept of Base isolation is to insert a flexible layer between the foundation and superstructure thus decoupling the building from damaging action of ground motion. Base isolation is a design that isolates the superstructure from ground shaking to limit the transfer of earthquake excitation to the superstructure. The building's fundamental time period is shifted to a greater value because the superstructure is separated from the base by isolation bearings with very little lateral stiffness. Due to this shift in the time period, the fundamental frequencies of the structure are substantially lower than the dominating frequencies of the earthquake shaking, which significantly minimizes the amount of earthquake energy that is transferred to the building[1-2-3]. Base isolation prevents Seismic damage to both structural and non-structural components, enabling structures to continue to serve even after a significant earthquake event. Due to this, the technique is recommended for designing earthquake-resistant structures, especially in locations with high seismic excitation.

Numerous experimental and analytical studies confirming the applicability of the isolation approaches for the design of structures that are earthquake- resistant were done after a variety of isolation techniques were developed [4-5]. Base isolation is today one of the widely used earthquake-resistant design strategies for significant structures such as schools, hospitals, industrial buildings, nuclear power stations, etc.

The majority of base-isolated structures have been studied and designed for far-field earthquakes with design-level earthquakes in which the superstructure is linear, but the isolator reaches a non-linear state. Recently, the response of the base-isolated buildings due to near-fault earthquakes has become an interesting a topic due to the differences in the seismic response of base-isolated buildings to such earthquakes compared to far-field earthquakes.

Near-field earthquakes, which are often oriented within 20 to 50 kilometers of the epicenter, typically contain a large amount of fault energy in the form of pulses. In time histories of displacement, velocity, and acceleration, pulses are frequently observed. These pulses often have the highest Fourier spectrum in a small range of periods, while far-field ground motions have the highest Fourier spectrum throughout a wide range of periods. [6]

Several researchers [7–8] showed that in base-isolated buildings, the isolator displacement under near-fault ground motions is varying a result of the long pulse characteristics of these earthquakes, and the base-isolated buildings become more flexible because of using bearings. In seismic isolation, the increased isolators' displacement is a risk that must be resolved. Jangid and Kelly [9], showed that increasing the isolation damping causes decreasing the bearing displacement during near-field ground motion. The directivity effect and the fling-step effect are based on the rupture mechanism, the slip direction of the rupture relative to the site, and residual ground displacement. The forward directivity effect occurs when the fault rupture velocity is close to the site's shear wave velocity, and the propagation's direction of the rupture is parallel to or at a small angle from the site. Large-amplitude pulses with long periods (1–1.5 s) and short durations, high ratios of (PGV) to PGA (vPG/aPG), and extremely damaging character are produced as a result of this effect. Somerville et al., (1997) [10]. The geological deformations that cause the fling-step effect also result in permanent ground displacement. It generates a monotone step in the history of displacement and a large-amplitude unidirectional velocity pulse. (Somerville, 2002) [11].

The ratio between the motion's pulse period and the structure's fundamental vibration period determines how near-fault motions affect a structure, mazza et al… (2010) [12]. Davoodi et al.(2012) [13] examined the behavior of near-fault and far-fault earthquakes by taking into account the influence of soil-structure interaction on a single-degree of freedom (SDOF) system's maximum response. Alonso-Rodríguez and Miranda (2015)[14] analyzed floor acceleration and inter-story drift parameters in structures exposed to near-fault ground motions by taking into account simplified building and ground motion models.

Bilal L. Khanna et.al...(2019) [15] .The response of the eight-story structure is investigated under three different bearing pads differentiated on the basis of their effective damping (Low Damping Rubber bearing: LDRB 3% damping, High Damping Rubber bearing: HDRB 13% Damping & Lead Core Rubber Bearing: LCRB 25% damping)and they found that During the dynamic analysis under far-field earthquake excitation, the peak displacement measured for low damping rubber bearing system was more than that of un-isolated system, this shows that dynamic response of the structure is influenced by the source of excitation and can affect the response of structure in a negative way if care is not taken in choosing the right base isolator.

Abhishikta Chanda, et al… (2020) [16]: investigated the seismic responses for a six-story reinforced concrete base-isolated building, excited by near-field (NF) and far-field (FF) real ground motions. The base isolator adopted is a lead rubber bearing and the design parameters are in accordance with UBC-97. . Fragility curves are derived using the incremental dynamic analysis method. . Fragility function results illustrated that fixed base buildings have a very high probability of failure in case of both NF and FF earthquakes, which is, however, reduced by the base isolator.

Mohtasham et al (2022) [17].the Direct displacement-based design (DDBD) approach is extended for the isolated structures equipped without supplemental fluid viscous damper (FVD) and with supplemental fluid viscous damper (FVD).they found that using supplemental FVD has a significant effect on the design variables of the superstructure. The seismic performance of isolated frames equipped with FVD shows that these frames have effectively achieved the design performance level under both far-field and near-field earthquakes. -story frames controlled by a hybrid isolation system (LRB + FVD), of earthquakes including both near-field and far-field earthquake records.

The present numerical study is concerned with these objectives. (i) Seismic response of a ten-story building frame is obtained by performing time history analysis for a set of near-field and far-field earthquakes.

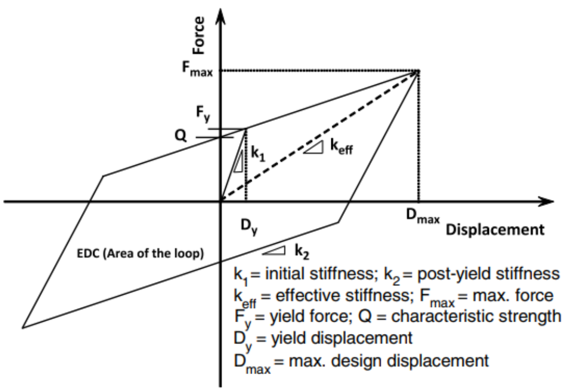


Figure 1. Bilinear force-displacement curves of lead rubber bearing isolator [20].

The seismic response is obtained for both fixed base and base-isolated conditions, (ii) a Comparison of the seismic response is obtained for both fixed base and base-isolated conditions, (iii) Study the difference in responses of structures under far and near field ground motions and (iv) Examination The effectiveness of the combination of the isolation systems and supplemental damping devices with respect to controlling the isolator displacement without adversely and Provide accurate solutions for structures performance during near-fault earthquakes.

II. MODELLING OF ISOLATION SYSTEM AND DAMPERS

A. LRB isolators

Lead Rubber Bearing (NZ System) was selected for the present study. Engineers from New Zealand created a technique that uses a cylinder of lead core in an elastomeric bearing isolation system due to the low damping of Laminated-rubber bearings, which is insufficient to control the displacements of the isolation system (Kelly et al. 2010) [18]. A hysterical bilinear model may be used to represent the behavior of lead-rubber bearings, which is based on the bilinear Bouc-wen hysteretic model (park et al .1986; wen 1976) [19, 20]. Fig (1) depicts an idealized force-displacement relationship of a lead-rubber bearing. The force-displacement model's key parameters are initial stiffness or elastic stiffness, k1, yield displacement, Dy, post-yield stiffness, K2, characteristic strength proportional to lead plug area, and yield strength, FY.

The formulas of these parameters of LRBs were taken from Naeim and Kelly (1990) [21] and expressed as follows Eqs. (1) to (7). The k1 is defined as the ratio of fy/Dy, and K2 is expressed by

$$k2 = GA/H \quad (1)$$

Where G=shear modulus of rubber; and A, and H=cross-sectional area and the total height of rubber layers, respectively. The yield strength, fy, is related to k2, and Dy, and the characteristic strength Q, by

$$Fy = Q + K2 \ x \ Dy \quad (2)$$

$$Q = f\,py \ x \ Ap \quad (3)$$

$$Q = (k1 - K2)\ Dy \quad (4)$$

Where fpy and Ap = yield strength and area of lead core. The effective stiffness is expressed as

$$Keff = K2 + \frac{Q}{Dmax} \quad (5)$$

Where D max =maximum design isolator displacement for a single cycle of loading and unloading, the effective damping ratio ($_{\beta}$eff) is expressed as

$$_{\beta}eff = \frac{4(Dmax - Dy)Q}{2\pi \ Keff \ D^2} \quad (6)$$

The energy dissipation per cycle (EDC) is the area of the hysteresis curve, expressed as:

$$EDC = 4Q\ (D\,max - Dy) \quad (7)$$

Non-linear computer programs can simulate isolator behavior with the help of non-linear link elements. These models often need the specification of three terms Factors, notably the effective horizontal stiffness Keff and pre-yielding stiffness Ke, the yield force FY, and the post-to pre-yielding stiffness ratio α in a table 1.

Table 1. LRB properties calculated for modelling in finite element program

Effective Stiffness	805	KN/m
Effective Damping ratio	10%	
Distance from End-J	0.01515	m
Stiffness k N/m	4413	KN/m
Yield Strength	60.61	K N

Table 2 Non-linear properties along damper's axis

non-linear stiffness	=	35025.37 KN/m
damping coefficient	=	1395.53
damping exponent	=	0.5

B. Supplemental viscous dampers

Viscous dampers are protection devices that provide a resisting force against seismic excitation which is proportional to the applied velocity [22]. The damper force is described by the equation [22]:

$$FD = C\,V_C{}^{exp} \qquad (8)$$

Where FD is the damper force, c is the damper coefficient VC is the relative velocity between the damper ends, and exp is the damper exponent. Exponential friction dampers' behavior can be simulated in programs by non-linear link elements. These models often need the specification of these terms factors in table 2.

C. Verification

After studying the program and understanding the system of input data and output results, an important stage is to verify the capability of the author to use the program efficiently. This was conducted by comparing the results of a time history of top floor displacement of the fixed base frame under chi –chi 052 earthquake for PGA=.4g as shown in figure (2)and force –deformation curve of isolators under tabas earthquake for PGA=0.2g as shown in figure (3)with those presented earlier by M. Bhandari et al.. (2018). [23]

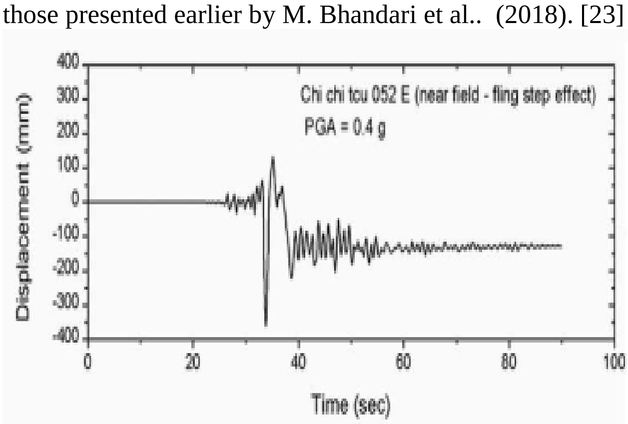


Figure 2. (a) Time history of top floor displacement of fixed base frame under chi –chi 052 earthquake for PGA=.4g. M. Bhandari et al... (2018).

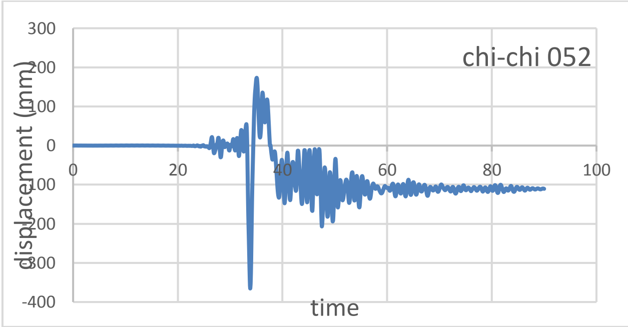


Figure 2(b). Time history of top floor displacement of fixed base frame under chi –chi 052 earthquake for PGA=.4g.

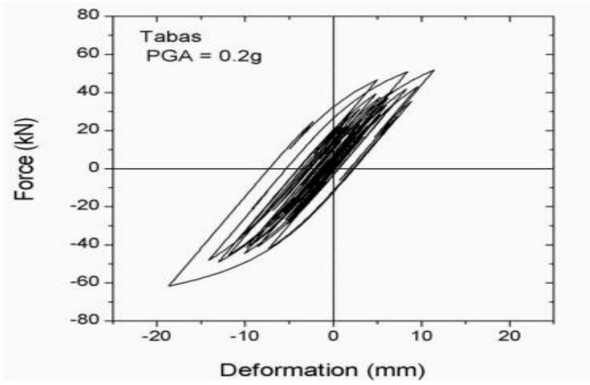


Figure 3. (a) Force –deformation curve of isolators under tabas earthquake for PGA=0.2g .M. Bhandari et al... (2018).

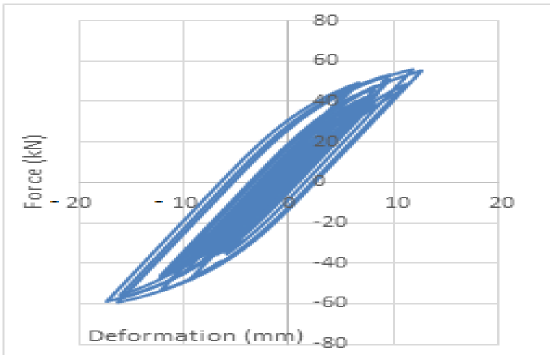


Figure 3(b). Force –deformation curve of isolators under tabas earthquake for PGA=0.2g

III. NUMERICAL STUDY

This study considers a ten-story reinforced concrete frame building with moment-resisting frames. The building represents residential buildings and typical offices, which are widely constructed and expected to be subjected to seismic loading. The building is regular in the plan as shown in figure 4(a).it has three bays in each direction with a 5 m width, and the height of the story is 3.2 m for all stories of the building. The concrete dimensions of the beam section are 400x650 mm, and the column section is 650x650 mm. the dead load and live load remained unchanged for all floors it was 23KN/m and 6.25KN/m respectively. Expected for the top floor, for the top floor the dead load was 22KN/m and the live load was 3.75 KN/m. All columns are installed with base isolators which are fixed in isolated footings. The

Internal frame of the building was selected for the analysis; the elevation view of the selected frame is shown in figure4 (b) .M. Bhandari et al... (2018) [23].

Plastic hinges were put towards the ends of both columns and beams at specific lengths of 0 and 1. Moment (m3) hinges were installed in the beams to account for the influence of the bending moment. In the columns, the p-m3 hinges were inserted, which consider the interaction of bending moment and column axial force. FEMA 356 (2000) [24]. Default properties were used to generate the hinges in the columns and beams in sap 2000 software.

Fig. 5 depicts the idealized moment-rotation curve of plastic hinges according to FEMA 356. In the same figure, different performance levels (as defined by FEMA 356[24].) A time–domain analysis of the building frame is performed for different time histories of far and near-field earthquake records have been taken from PEER Strong Motion Database of Berkeley University in table 3.

Figures (6 and 7) show the comparison between the far-field, near-field (directivity effect), and near-field (fling-step effect) earthquakes by comparing their time histories of acceleration, which are scaled to comply with one–level concept of the earthquake with a PGA of 0.4g.

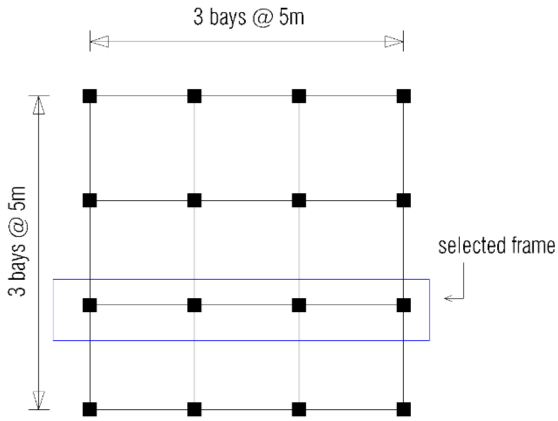


Figure.4 (a) Building plan

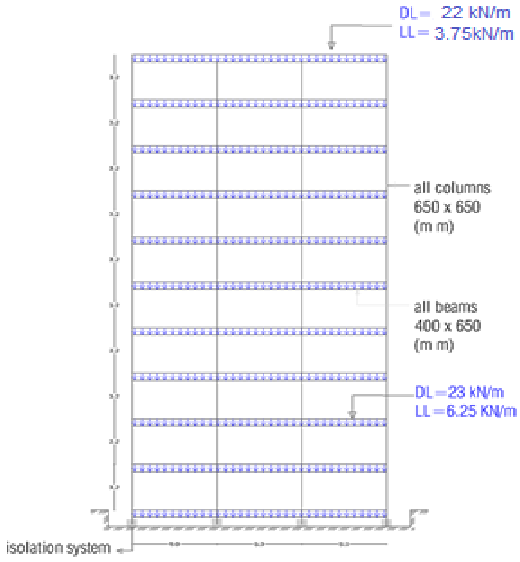


Figure 4 (b). Elevation of building.

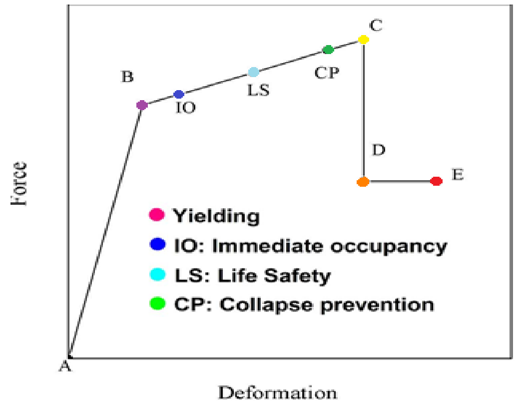
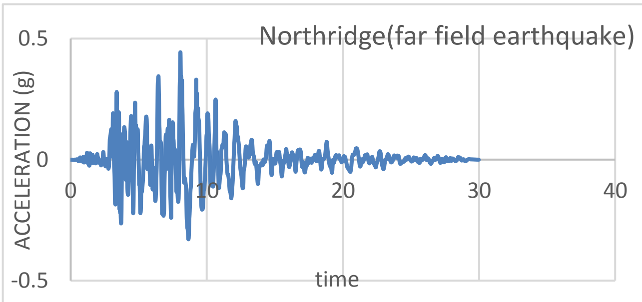


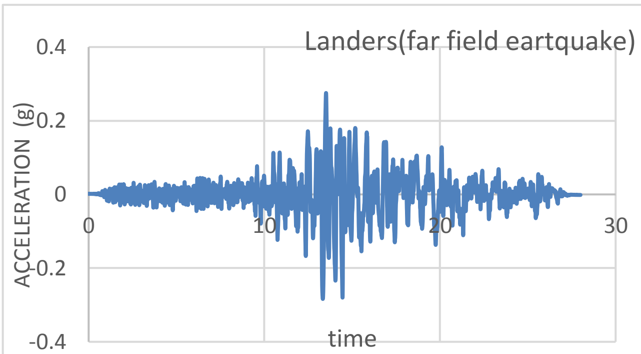
Figure 5. Force deformation relationship of plastic hinge FEMA 356[24].

Table 3. List of earthquake motions used in this study

NO	Year	Earthquake	Station	PGA (g)
Far-field records				
1	1994	Northridge	Beverly hills	0.44
2	1992	Landers	Cool Water	0.28
3	1978	Tabas	Ferdows	0.09
4	1987	superstition hills	Peo read	0.47
Near-field records (forward directivity effect)				
1	1992	Erzincan	Erzincan	0.5
2	2003	Bam	Bam	0.8
Near-field records (fling step effect)				
3	1999	chi chi	TCU067	0.5
4	1999	chi chi	TCU068	0.37

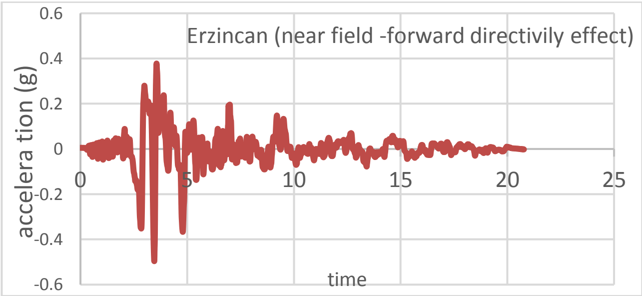


(a) Time history of acceleration of Northridge earthquake.

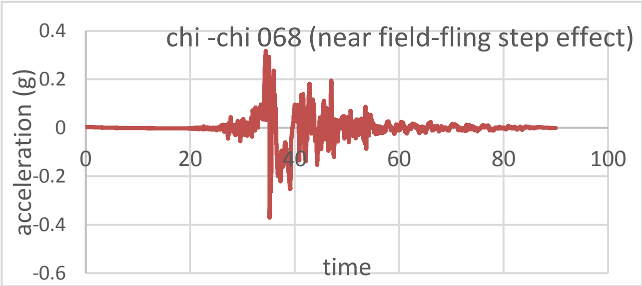


(b) Time history of acceleration of landers earthquake.

Figure (6) time histories of accelerations to Northridge and landers earthquakes (far field earthquakes).



(a) **Time history of acceleration of Erzincan earthquake.**



(b) **Time history of acceleration of chi-chi 068 earthquake.**

Figure 7. Time histories of accelerations to Erzincan and chi-chi 068 earthquakes (near field earthquakes).

IV. RESULTS AND DISCUSSION

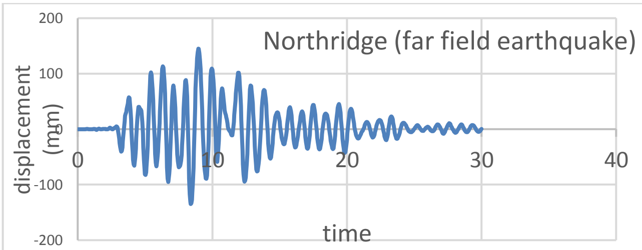
Some typical values of response quantities of interest are shown in the figures for the earthquakes. From such values of responses, the time histories of top story displacement under different far for the fixed base and isolated base conditions, as shown in figures (8 and 9). And near-field earthquakes for the fixed base and isolated base conditions, as shown in figures (10 and 11). It is noticed that the response time history of near field earthquakes for the base-isolated case is distinctly different than far field earthquakes; further, maximum top story displacement is significantly large. This is due to the fact that the near-field earthquakes suddenly induce a large displacement in the isolator, especially for the fling step effect. Percentage reductions in top story maximum joint displacement, maximum story drift and the base shear. Additionally, absolute accelerations, and maximum isolator displacement.

As shown in figure (12), the percentage reduction in maximum story displacement for case far-field and near-field earthquakes compared to fixed base conditions varies between 61.1 to 88% for far-field earthquakes and between 44.1 to 78.7% for near-field earthquakes. Figure (13) shows the percentage reduction in maximum story drift. Depending on the earthquake, there is a wide variation in percentage reduction in the maximum story drift. For far-field earthquakes, the reduction is between 67 to 89.5% and between 62to 81.5% for near–field earthquakes, respectively. As shown in figure (14), the percentage reduction in base shear in the case of far field and near field earthquakes, compared to fixed base condition, varies between 67.9 to 79% for far-field earthquakes, and between 12.7 to 60.1% for far near field earthquakes.

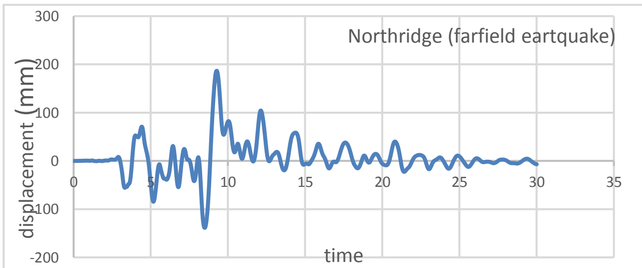
One of the most important advantages of using seismic isolation systems to improve the structure's performance during an earthquake excitation is reducing floors' absolute acceleration. Fig (15) shows the Percentages of reduction of top story absolute acceleration of the base-isolated structure for both far-field and near-field earthquakes compared to fixed base condition**.** The decrease in absolute top-story acceleration varies widely under far-field and near-ground motions in the range of 61.8-72.9%.and 51.6-79.7%, respectively. Also, isolator displacement becomes very large for near-field earthquakes, especially in the case fling step effect compared to far-field earthquakes, as shown in figure (16).

The structure performance levels of the fixed base and base-isolated frame under Northridge earthquake (far-field) and chi-chi068 earthquake (near-field) are shown in Figures (17and 18), it noticed that in the case of the fixed base frame under Northridge earthquake, most of the joints in before the immediate occupancy level, and transformed to the linearity stage in the base-isolated case as a result of using base isolation. And some joints are in the range between immediate occupancy level and life safety which means these joints may have very limited structural damage under chi-chi068 earthquake, and transformed to before the immediate occupancy level, there is no structural damage in the base-isolated case as a result of using base isolation.

The combination of the isolators and dampers increased the damping in the base of the building fig (19) so that it could control isolator displacement that, leads to a decrease in the large isolator displacement for the fling step effect, the percentage reduction of isolator displacement due to using that combination is 75.4 % for chi -chi 068 earthquake.

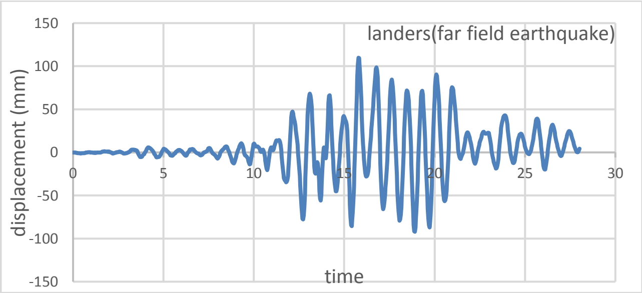


(a)Fixed base frame

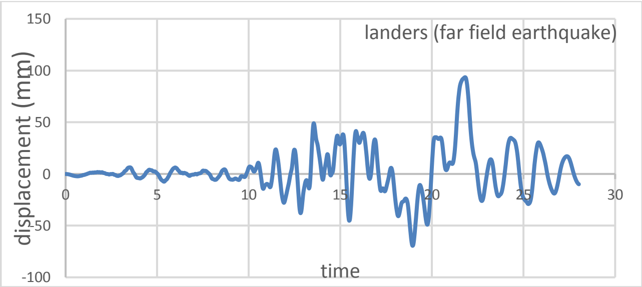


(b)Base isolated frame

Figure 8.Top story displacement time histories for fixed base and base isolated building frames under Northridge earthquake

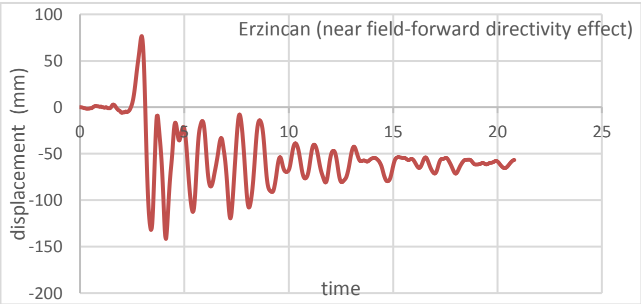


(a) Fixed base frame

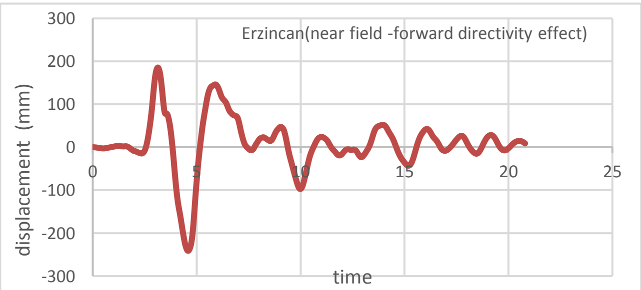


(b) Base isolated frame

Figure 9.Top story displacement time histories for fixed base and base isolated building frames under landers earthquake.

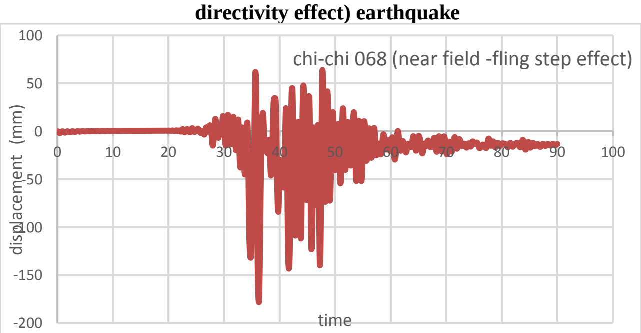


(a) Fixed base frame.

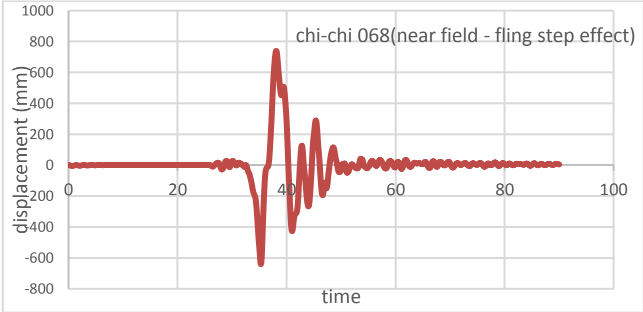


(b) Base isolated frame

Figure 10.Top story displacement time histories for fixed base and base isolated building frames under Erzincan (Near field – forward directivity effect) earthquake



(a) Fixed base frame



(b) Base isolated frame.

Figure 11.Top story displacement time histories for fixed base and base isolated building frames under chi-chi068 (Near field – fling step effect) earthquake.

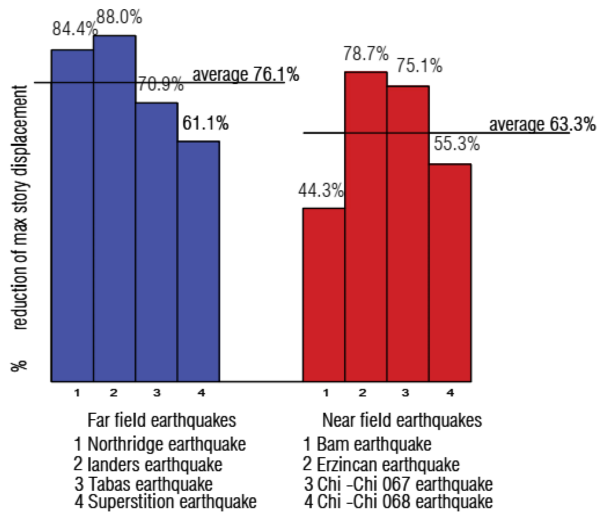


Figure 12. Percentage reduction in top floor displacement under far and near field earthquakes for base isolated frame.

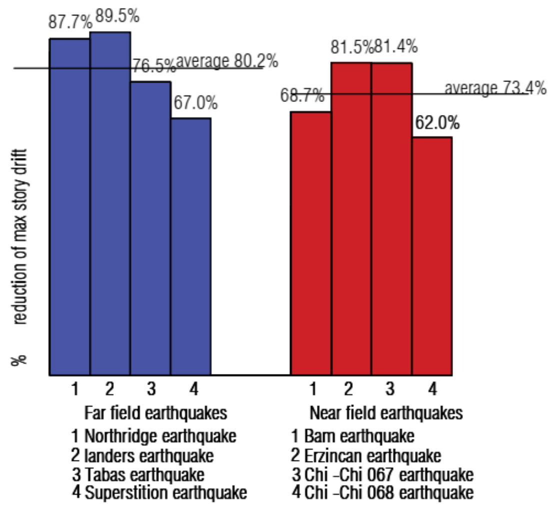


Figure 13. Percentage reduction in maximum story drift under far and near field earthquakes for base isolated frame.

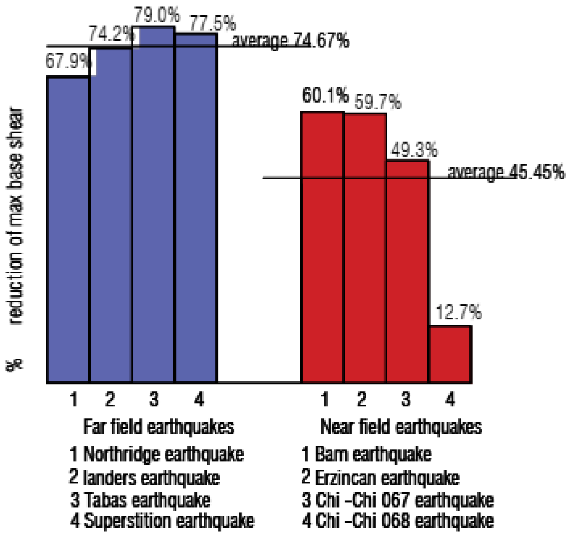


Figure (14). Percentage reduction in base shear under far and near field earthquakes for base isolated frame.

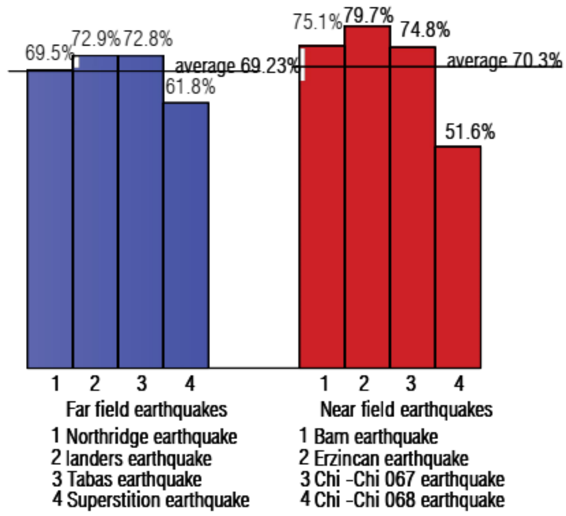


Figure (15). Percentage reduction in top story absolute acceleration under far and near field earthquakes for base isolated frame.

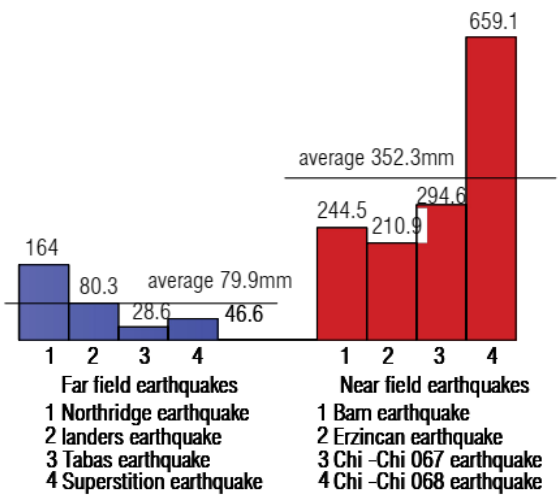
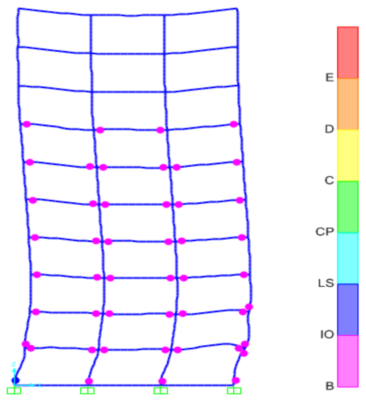


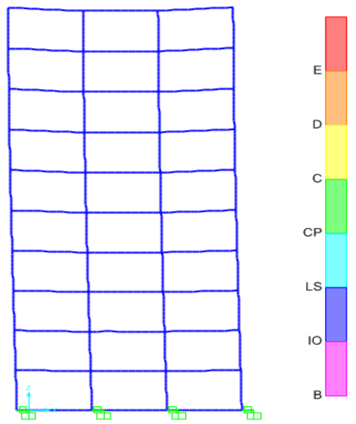
Figure. (16)Isolator displacement under near field earthquakes

V. SUMMARY AND CONCLUSIONS

The behavior of the base-isolated building frame is investigated for near-field and far-field earthquakes to show the difference between the system's response characteristics for the two types of earthquakes. Two types of near-field earthquakes, namely with directivity effect and the fling-step effect, are considered. Seismic isolation has proven to be successful under far-field earthquakes more than near-field earthquakes.

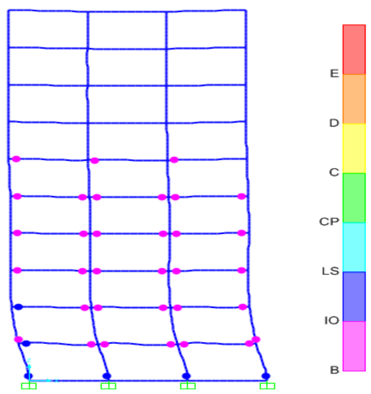


(a) Fixed –base frame

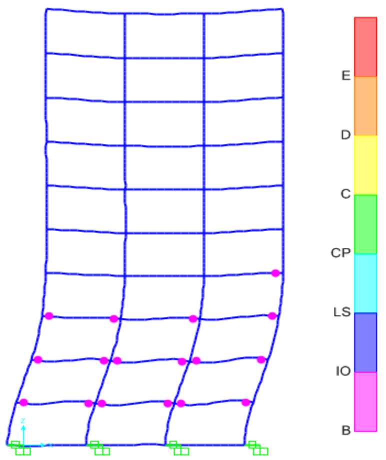


(b) Base –isolated frame

Figure .17 performance hinge pattern under Northridge earthquake



(a) Fixed-base frame



(b) Base –isolated frame

Figure 18. Performance hinge pattern under Chi-Chi 068 earthquake

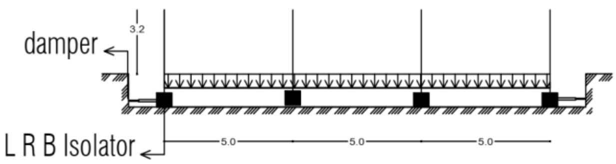


Figure 19. Combination of LRB and damper.

Base isolators can reduce maximum top displacement with average percentages of 76.1% and 63.3%, can reduce maximum inter-story drift with an average percentage of 76.5% and 73.4%, can reduce base shear with an average percentage of 74.67 and 45.45%, and can reduce absolute acceleration with an average percentage 69.23 and 70.3% compared with a fixed base condition for a set of far and near-field earthquake respectively earthquakes. But it produces great displacement in isolators as a result of near-fault earthquakes especially the fling step effect as a result of the long pulse characteristics of these earthquakes, which makes it ineffective in this case, so it needs to improve or develop its performance to control in isolator displacement so isolators provided with dampers to overcome this problem.

LRBs base-isolation devices with supplemental viscous dampers are examined for their seismic performance in terms of isolators' displacement under chi –chi 068(fling step effect for near-fault motions.), the percentage reduction of isolator displacement due to using that combination is 75.4 % for chi -chi 068 earthquake. And it became an effective strategy in reducing isolators' displacement.

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