Volume: 10 Issue: VII Month of publication: July 2022
DOI: https://doi.org/10.22214/ijraset.2022.45997

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VII July 2022- Available at www.ijraset.com

Effectiveness of Different Base Isolation on Stepped Buildings

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Abstract: Seismic isolation devices are commonly employed to protect structures from the impacts of severe ground motions. ETABS2016, a modelling and analysis programme, was used in this work to model and analyse the isolated stepped building. Rubber isolator link components were used as a single joint element to represent the rubber isolators between the ground and the superstructure. El-Centro seismic records were used to analyse the isolated building.
The lateral inter-storey drifts, story displacement and peak absolute floor accelerations, of the isolated building were compared to those of the fixed-base structure. The current study aims to evaluate the effectiveness of several types of base isolation systems for seismic protection of 6-story stepped structures using Time history analysis. The isolation systems considered include, i) rubber isolators, ii) rubber isolators with energy dissipation systems, and iii) friction pendulum isolators.
Keywords: Base isolation1; stepped building2; lead rubber bearing3

I. INTRODUCTION

Buildings that are seismically inadequate and were frequently built before current building rules are the prime targets of earthquake destruction. Researchers have concentrated their efforts on creating new and efficient methods for reducing seismic risk. This can be done by adding flexible devices to structures at ground level to protect them from seismic energy transfer.

For strategically significant post-disaster buildings, such as hospitals, schools, and critical facilities, seismic isolation is sometimes employed to protect them from the effects of powerful ground vibrations. Isolation systems comprise isolators and auxiliary devices [1]. The primary structure is isolated from ground vibrations by the isolators, which have low friction or low horizontal stiffness. The isolators also give lateral flexibility at the base. By making the isolated building to be more flexible, the isolators change the structure’s fundamental period beyond the range where ground motions have their greatest effect. In order to significantly reduce inter-storey drifts and floor accelerations, they prevent seismic energy transfer to the superstructure [2].

There are numerous seismic isolation technologies that can be used for structural retrofit. They consist of hybrid devices made up of isolators and external dampers, as well as rubber bearing systems, sliding bearing systems, and combinations of various isolation systems. One of the most popular isolation technologies is the laminated rubber bearing, which comprises of elastomeric steel plates and rubber layers. While the steel plates are responsible for maintaining the isolator's vertical and horizontal stability, the rubber layers give it lateral flexibility [2]. However, LRB systems may not be suitable for powerful earthquakes due to their weak energy dissipation capacity and the limited damping characteristics of the rubber material [3].

Inserting lead cores into the middle of rubber layers to create a lead-rubber bearing (LLRB) system is one method to enhance isolator damping. As the lead plugs undergo significant hysteresis deformation after their yield, the LLRB dissipates a larger quantity of seismic energy [4]. In addition, the lead plug is significantly more lateral stiff than the rubber layers before yielding. As a result, the use of lead plugs can help to reduce base displacements during powerful earthquakes by enhancing lateral resistance to non-seismic stresses. On the other hand, heat caused by the lead core's plastic deformations can reduce its strength, affecting the LLRB system's hysteretic behaviour [5].

The physical stability of bearings has made slide isolation devices very popular in recent years. The sliding bearing, also known as the rubber isolator, integrates into one element the roles of carrying the load of the building and separating the superstructure from the ground. The fictional pendulum bearing is one of the most advanced sliding bearing systems (FPB). A low-friction spherical sliding surface and an articulated slider compose the FPB, a friction-type sliding isolation system [2]. By releasing residual seismic energy from overheating of contact surfaces and the uplifting of the superstructure, this device can generate a high energy dissipation capability [6]. The FPB system has a higher horizontal displacement allowance than the rubber bearing. Due to the restoring force of gravity, it also has the ability to self-center and limit residual displacements [7].

Furthermore, the FPB system can reduce the building's torsional response because its lateral stiffness is proportional to the weight of the main structure and its stiffness centre is located at its centre of mass. Surprisingly, the radius of the sliding surface is the only factor controlling the FPB system's period, regardless of the superstructure's mass [8].

The effectiveness of rubber bearings (LRBs and LLRBs), friction pendulum bearings, was examined in the current experiment. The 6-story stepped building was subjected to the magnitude 6.9 earthquake of El Centro in 1940 and had foundation isolation mechanisms. In order to evaluate the usability and effectiveness of various types of base isolation systems, this structure was modelled in the ETABS2016 software as a conventional reinforced concrete frame stepped building that benefited from a base isolation system. Building dynamic analyses were performed both with and without the isolation systems. The record used was the EI Centro earthquake excitation. Through a parametric investigation, the effects of isolator characteristics on the seismic behaviour of structures were explored. The analytical building model, the magnitude of ground motion, and various types of isolators with various properties were all taken into consideration. Furthermore, the behaviour of the building was evaluated in the without of any isolation system, and comparisons were made with the performance of structures equipped with various isolation systems. The efficiency of the three isolation systems evaluated under both near-field and far-field earthquakes is observed by comparing the results in terms of lateral drift, peak absolute acceleration, and narrative displacement.

II. MATERIALS AND METHODS

The elasticity modulus and poissons ratio for concrete are 30000 N/mm^2 and 02, respectively. For the modelling of the building's structural elements, concrete of M30 (30 MPa) strength and Fe500 reinforcement steel were used for the construction. The diaphragm of rigid frame is taken into account in the floor systems for seismic analysis, and at the foundation level, support conditions are assumed to be introduced.

It has been investigated how different types of base isolation of stepped building structures on hilly terrain respond to seismic forces. On the seismic performance of the configurations under investigation, the effects of a Laminated lead rubber bearing, friction pendulum system (FPS) and Lead rubber bearing (LRB), base isolation system were examined. The time history approach was used to calculate the building structures' seismic response. The seismic parameters derived from the analysis were used to examine the differences in the values of the lateral inter-storey drifts, story displacements and peak absolute floor accelerations.

III. BUILDING CONFIGURATION

The building is a six-story reinforced concrete frame structure. It has an average inter-storey height of 3.2m, resulting in a total building height of 23.4 m above the ground level. Figure 1. (a) provides a typical plan view of the building. Dimensions of building plan is 30m X 20m. The structural frame system comprises of 450 mm square columns and main beams having 300 mm x 500 mm cross-sectional dimensions. The building also features flexible slabs with 200 mm thickness at each floor and the roof. Seismic isolation layer was placed between the foundation and the superstructure of the building. A total of 30 isolation devices were installed at individual isolated footings. The design properties of the isolators used in the structural system are listed in Table 1. The diameter of the bearings was determined as 350 mm and 450mm depending on vertical load, wind loading, and the required isolator displacement control. The structural plan is Asymmetric in the “y” direction, as showed in Figure 1. (a),

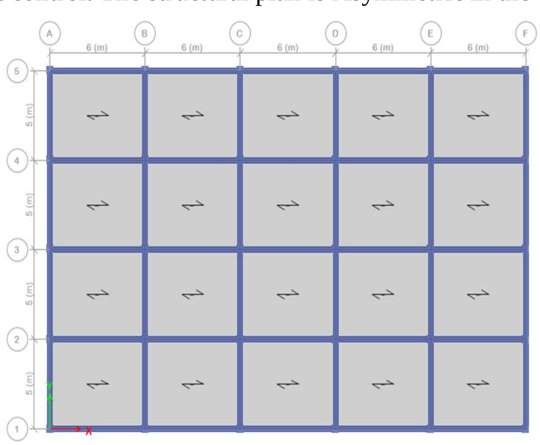


Fig.1.(a) Building Plan

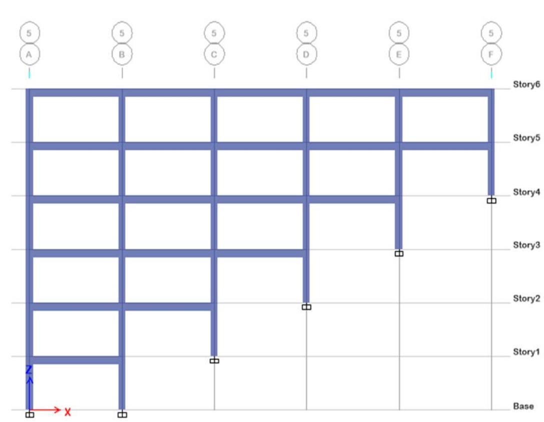


Fig.1(b) Stepped Building with Fixed Base

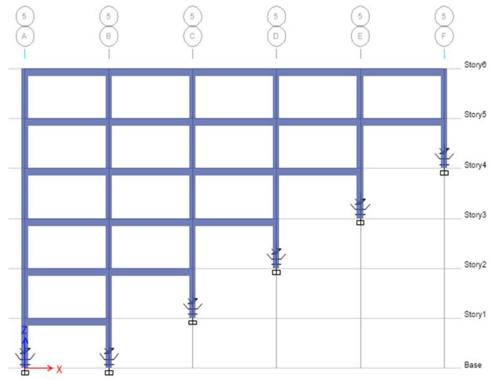


Fig.1(c) Stepped Building with Friction pendulum system

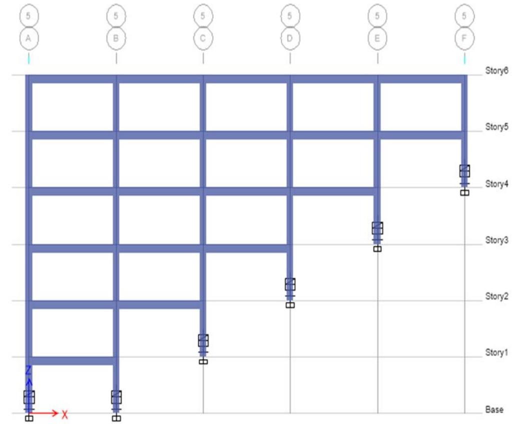


Fig.1(d) Stepped Building with LLRB &LRB

IV. TYPES OF ISOLATOR

A. *High Damping Rubber Bearing (HDRB)*

The only difference between natural rubber bearings and high damping rubber bearings is that the damping ranges from 8% to 20%. High damping elastomeric materials have shear modulus between 0.34 MPa and 1.40 MPa. The material has increased stiffness and damping, which decrease responses to low level seismic load, and is nonlinear at shear strains of less than 20%. Figure 2 illustrates a high-damping rubber bearing.

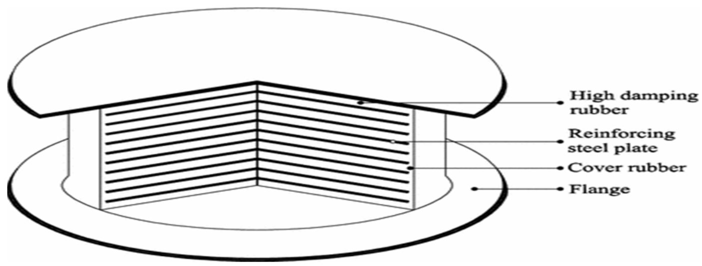


Fig.2. High damping rubber bearing

B. *Lead Rubber Bearing*

The Lead Rubber Bearing, a more modern form of the elastomeric isolator. In addition to the rubber damping, a lead core is used as a dissipative device; steel reinforcements are also required to improve the bearing's vertical stiffness, like in elastomeric isolators. The manufacturer's catalogue contains data about the LRB used for this study [9]. It uses a soft, high-dampening rubber with a damping ratio of 10% and a shear modulus of 0.4 MPa. The LRB's steel and rubber lamina use many of the same mechanical characteristics as the HDRB. The lead core's elasto-plastic behaviour makes a significant contribution to the LRB's overall damping ratio. A lead core has 15 GPa Young modulus and a yield stress 10 MPa, corresponding to a Poisson ratio of 0.42.

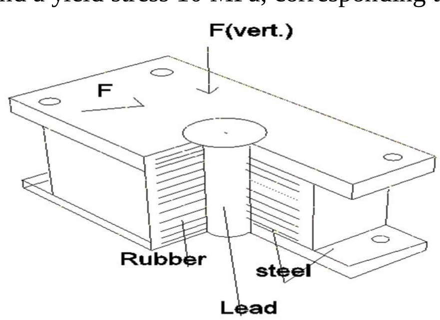


Fig.3. Lead Rubber Bearing

After the lead core has yielded, the stiffness is attributable only to the elastomer's contribution, which is significantly lower than the first one. Eqs. (1)-(4) are used to calculate the LRB isolator's effective stiffness & damping ratio.

$$K_{eff} = \frac{W}{g}\left[\frac{2\pi}{Tb}\right]^2 \quad (1)$$

where W is the maximum vertical load under the certain column for the load case "1.2DL + 1.6LLo" (where LLo reduced live load) and Keff is the effective stiffness of the base isolator, Tb is the isolated time period, "Tb = nT," (where n may be taken as 3 to 4), and T represents the time period for a building having a fixed base.

$$A_r = \frac{W}{p} \quad (2)$$

$$T_r = \frac{GA_r}{K_d} \quad (3)$$

$$A_{pb} = \frac{F}{\sigma_{pb}} \quad (4)$$

where Tr is the thickness of one rubber layer, G is the modulus of rigidity of rubber, G tends to vary between 0.40 and 0.86 MPa for the strain range permitted for rubber bearing, i.e. = 100 - 150%, Ar indicates the area of the rubber layer, F is the characteristic strength obtained while defining the bilinear curve properties of the base isolator, and σpb is the yield shear strength of the lead. The value of σpb is 8–10 MPa.

C. Friction Pendulum System isolator (FPS)

Because of its exceptionally low effective horizontal stiffness and excellent damping ratio, the FPS isolator is well recognised as a good base isolation device. The horizontal rigidity of the surface is provided by the sliding material that relies on the curved pads. A sliding solid substance & a double curvature are features of the FPS isolator used in this investigation. The friction coefficient and nominal diameter are each equal to 3% and 4000 mm, respectively. With a 210 GPa Young modulus of and 0.25 Poisson ratio, every component of the FPS model exhibits isotropic-elastic behaviour.

Table 1: -Properties of isolators

	HDRB	LRB	FPS
Diameter	350mm	350mm	450mm
Thickness	7mm	7mm	-
Rubber Shear Modulus	0.4MPa	0.4MPa	-
Rubber damping	10%	10%	-
Maximum displacement	160	210mm	250mm
Nominal Effective stiffness	0.5	0.49kN/mm	0.33kN/mm
Nominal Damping ratio	10%	30%	35%
Maximum Axial Load	1000kN	700kN	1000kN
Lead diameter	-	60mm	-
Nominal curve radius	-	-	4000mm
Nominal friction coefficient	-	-	3%

V. EFFECTS OF NEAR FIELD EARTHQUAKE

The research study is to evaluate the effect of near fault (NF) earthquakes on the seismic response of stepped structures in various (FB and BI) configurations. The acceleration time history of NF earthquakes exhibits a long-period pulse with a higher velocity. They could have destructive impacts on isolated building, particularly in response to isolator displacement. This is because the isolated structure and ground motion have same period values, which could lead to an amplified isolator displacement.

X-DIRECTION Y DIRECTION

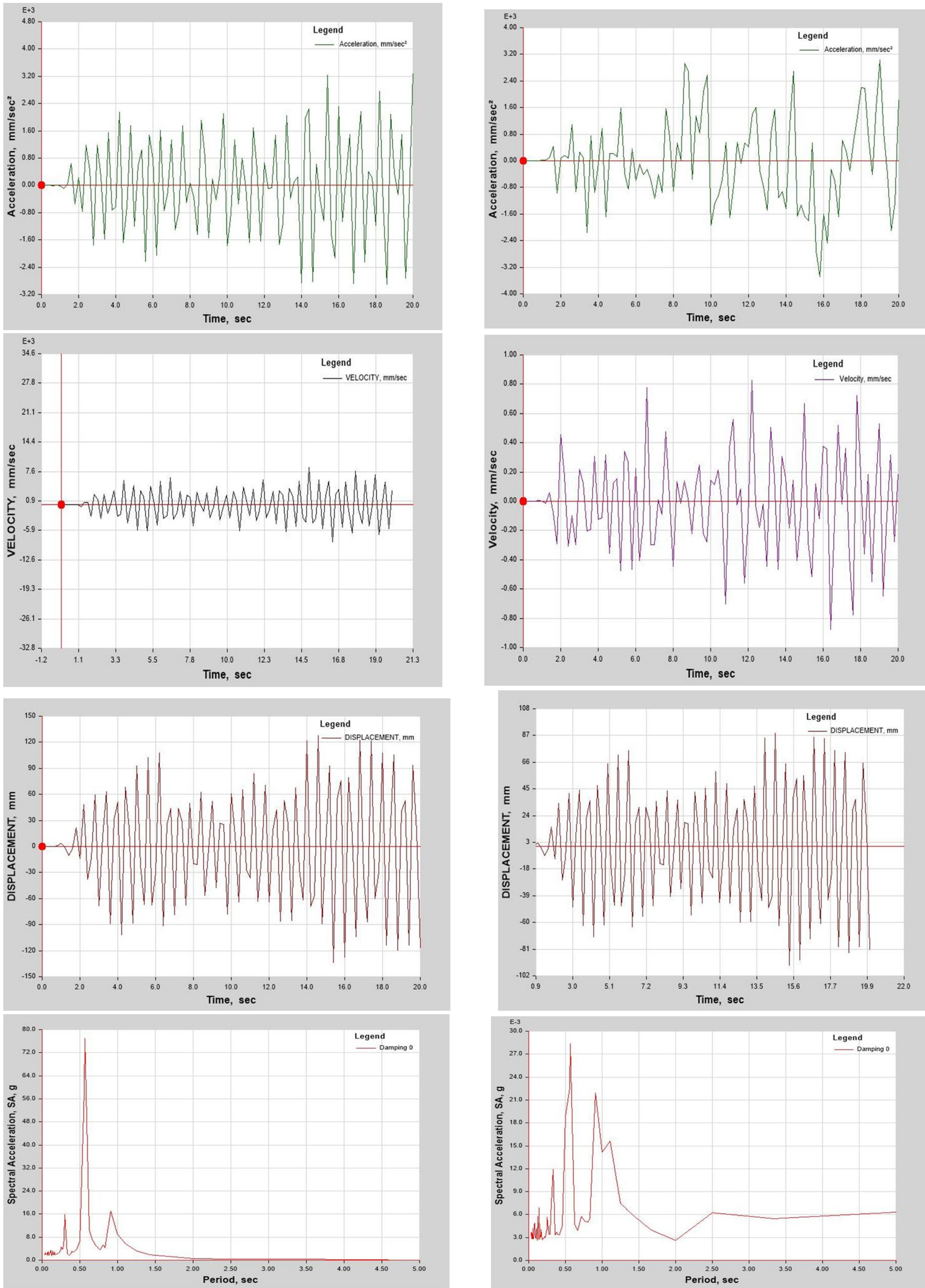


Fig. 4. In the numerical simulations, El Centro ground motion was employed in two directions: east-west in the Y direction and north-south in the X direction

In order to achieve this objective, the ground motion of the El-Centro near-fault earthquake (NF) is assessed and scaled to the same PGA (PGA = 0.25 g) as the far-fault earthquake used in this research. Figure 4 depicts the primary characteristics of the NF El Centro ground motion employed in the numerical calculations. It can be noticed that compared to the FF record, the Near Fault record has displacement and a higher ground velocity. After that, the Near Fault ground motion is applied to the different (FB and BI) configurations model, i.e. stepped building.

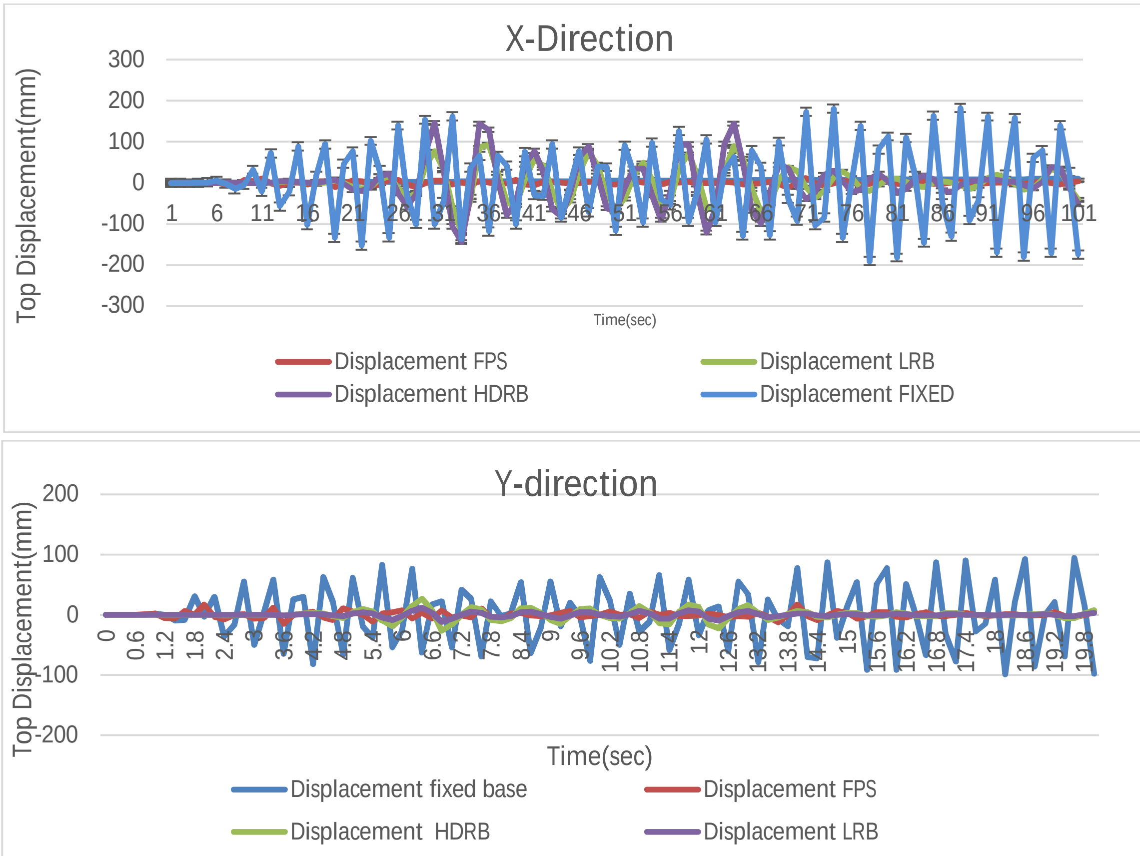


Fig. 5. Top displacement time history obtained for the base isolated (BI) model and fixed-base (FB) model under the NF earthquake from non-linear dynamic analysis.

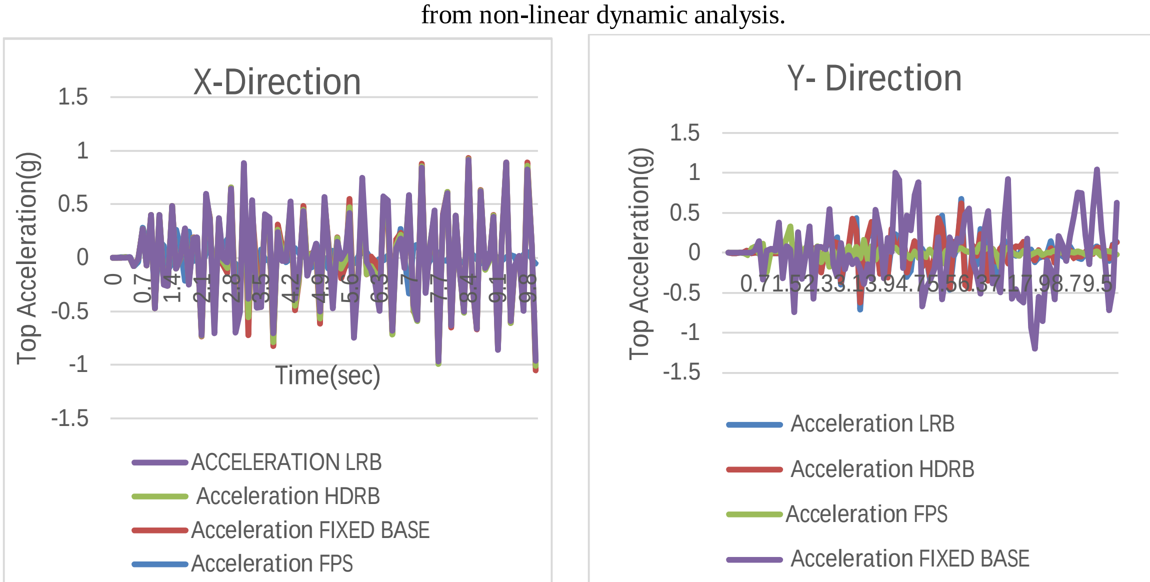


Fig. 6. Nonlinear dynamic analysis was used to get top acceleration time histories in the X and Y directions for the fixed-base (FB) and base isolated (BI) models during the NF earthquake.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VII July 2022- Available at www.ijraset.com

Figure 5 displays the top displacement time history for the fixed-base (FB) and base isolated (BI) models during the NF earthquake in the X and Y directions. When compared to alternative isolation systems, the top displacement is reduced the most when FPS isolators are used. In addition, the FPS isolation system significantly decreases the residual displacements after the seismic excitation. The peak top displacement of the BI-HDRB model is greater than that of the Fixed Base model, clearly demonstrating numerically that the application of HDRBs amplifies the building reaction.

The top acceleration time history for the base isolated and fixed-base models under the Near Fault earthquake is depicted in Fig. 6. in X and Y directions. The acceleration response is amplified by the FB model up to 1.0 g, whilst all isolation techniques can significantly reduce the acceleration response.

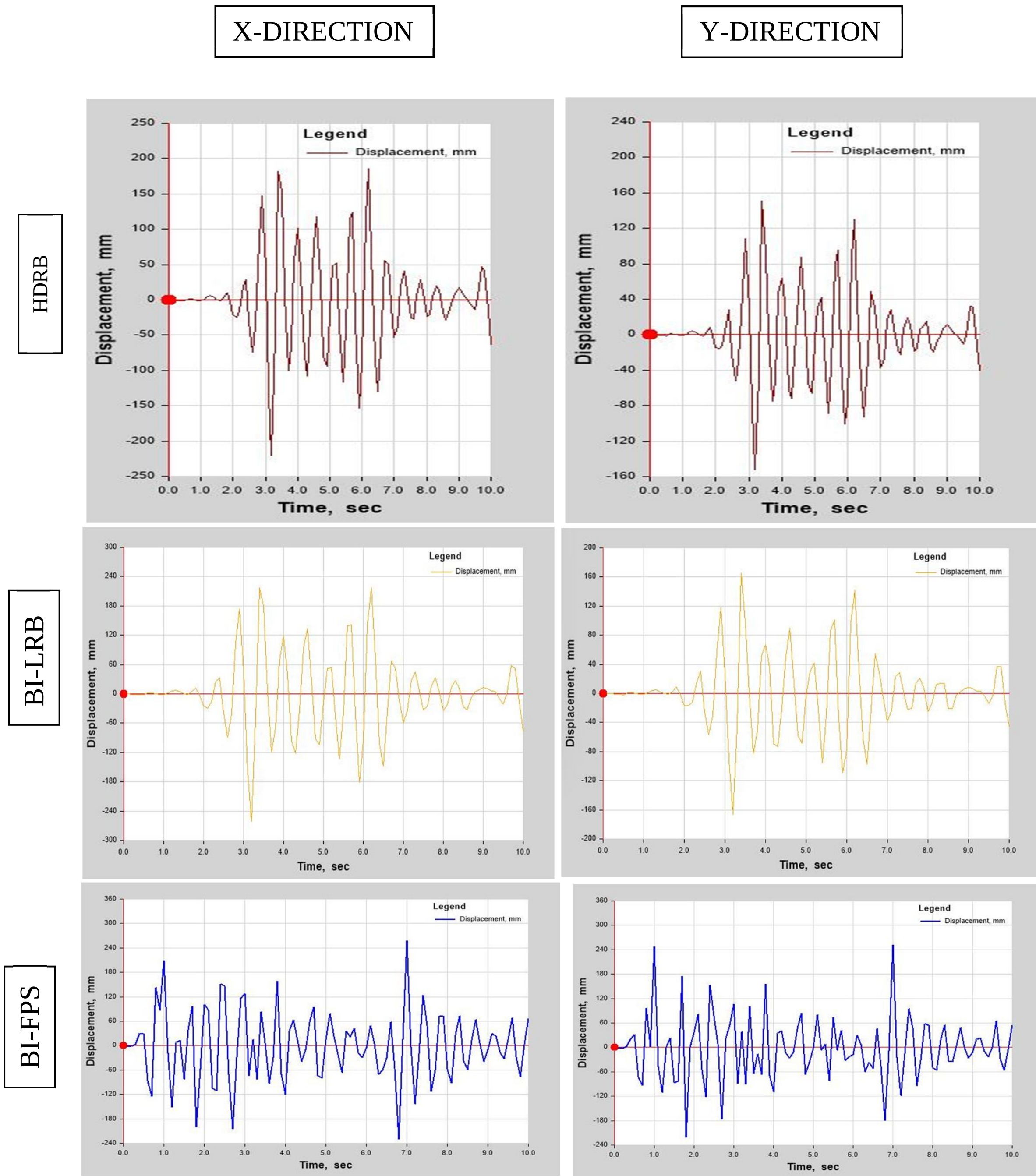
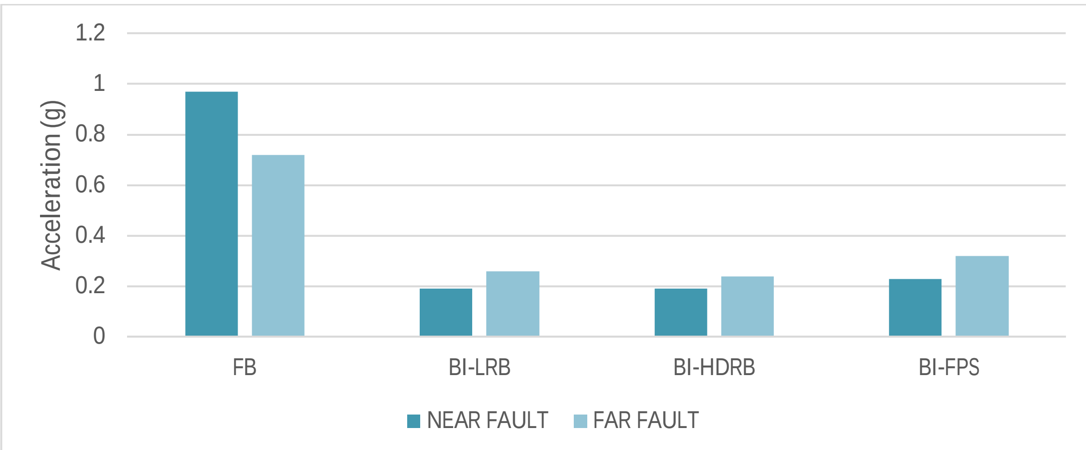


Fig. 7. Displacement time histories in the X and Y directions for various types of isolators under the NF earthquake as determined using non-linear dynamic analysis.

The displacement time history for the various types of isolators under the NF earthquake is shown in Fig. 7 using results from nonlinear dynamic studies. All of the Base Isolated models have high isolator displacements, which is a frequent problem for isolation systems when subjected to Near Fault ground motions.

In the case of Far Fault and Near Fault earthquakes, Figure. 8 compares the peak values of (a) top acceleration, (b) top drift. The isolation mechanism can reduce the drift during the Far Field earthquake; However, it should be observed that the BI-HDRB model only shows a minor reduction in drift. The Base Isolation -HDRB model exhibits increased drift in the Near Fault earthquake as compared to the Fixed Base model. Such findings suggest that the base isolation system needs enough damping to limit the effects of earthquakes on the structure, especially under Near Fault ground motion. When compared to HDRBs, LRBs have a substantially higher damping ratio but a similar stiffness. The drift under the Far Fault earthquake is not significantly different between the BI-FPS and BI-LRB models, according to numerical data. In Contrast, the BI-FPS model exhibits a greater drift reduction under the Near Fault earthquake than the Base Isolation-LRB model. It is important to make clear that as compared to LRBs, Friction Pendulum System isolators show reduced stiffness and almost similar damping.



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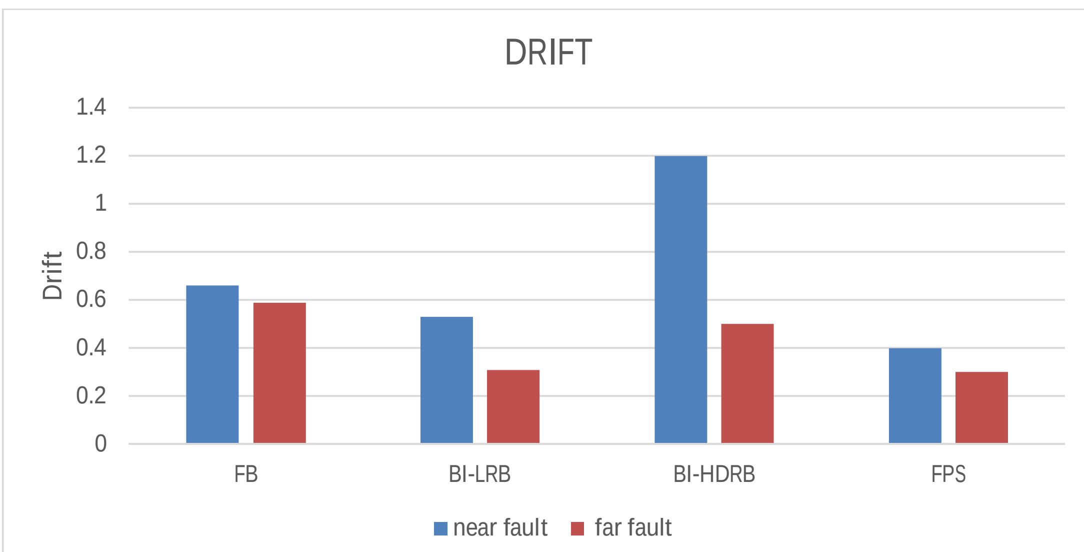

Fig. 8 Peak values of [a] top acceleration, [b] top drift in the case of Far Fault and Near Fault earthquakes

Peak acceleration values for all three BI models are comparable and lower than those for the Fixed Base model, according to numerical results, which also reveal that no notable variation in acceleration response decrement is detected at the top of the BI models for the two earthquakes. It's significant to note that under the Near Fault earthquake, the Fixed Base model exhibits larger peak acceleration values than under the Far Fault earthquake.

VI. CONCLUSIONS

The efficiency of base isolation for the earthquake protection of a stepped building has been thoroughly evaluated in this study. We've looked at and taken into consideration three different types of isolators (LRB, HDRB, and FPS), each of them has a different damping ratio or effective stiffness. Nonlinear dynamic analyses using near fault and far fault ground motion have been used to study the earthquake response of stepped structure in various configurations (base isolated and fixed-base). The following observations were made based on an overall analysis of the study's findings:

1) Despite having a different horizontal stiffness, the BI-Lead Rubber Bearing and BI-Friction Pendulum System models perform well under the Far Fault earthquake: The residual displacements of the structure are minor, and the displacements of the isolators are within the limit values. The BI-Lead Rubber Bearing model exhibits a substantially higher top displacement under the Near Fault earthquake than the BI-Friction Pendulum System model. In any circumstance, in terms of isolator displacements and drifts, neither the BI-LRB nor the FPS models provide enough seismic protection during the NF earthquake.
2) According to the results, base isolation system along with stronger damping & a greater dimension is needed in the event of Near Fault earthquakes in order to prevent drifts and adjust the significant displacements of the isolators. In order to significantly increase the isolation system's capability for dissipation, a supplementary damper system can be considered.
3) Lastly, it's critical to note that the base isolation intervention for the structure may have greater estimated costs than more conventional strengthening techniques. Base isolation, however, may be much more practical than conventional strengthening interventions in terms of seismic protection and damage prevention, keeping the building's unique aesthetic and structural features of the construction.

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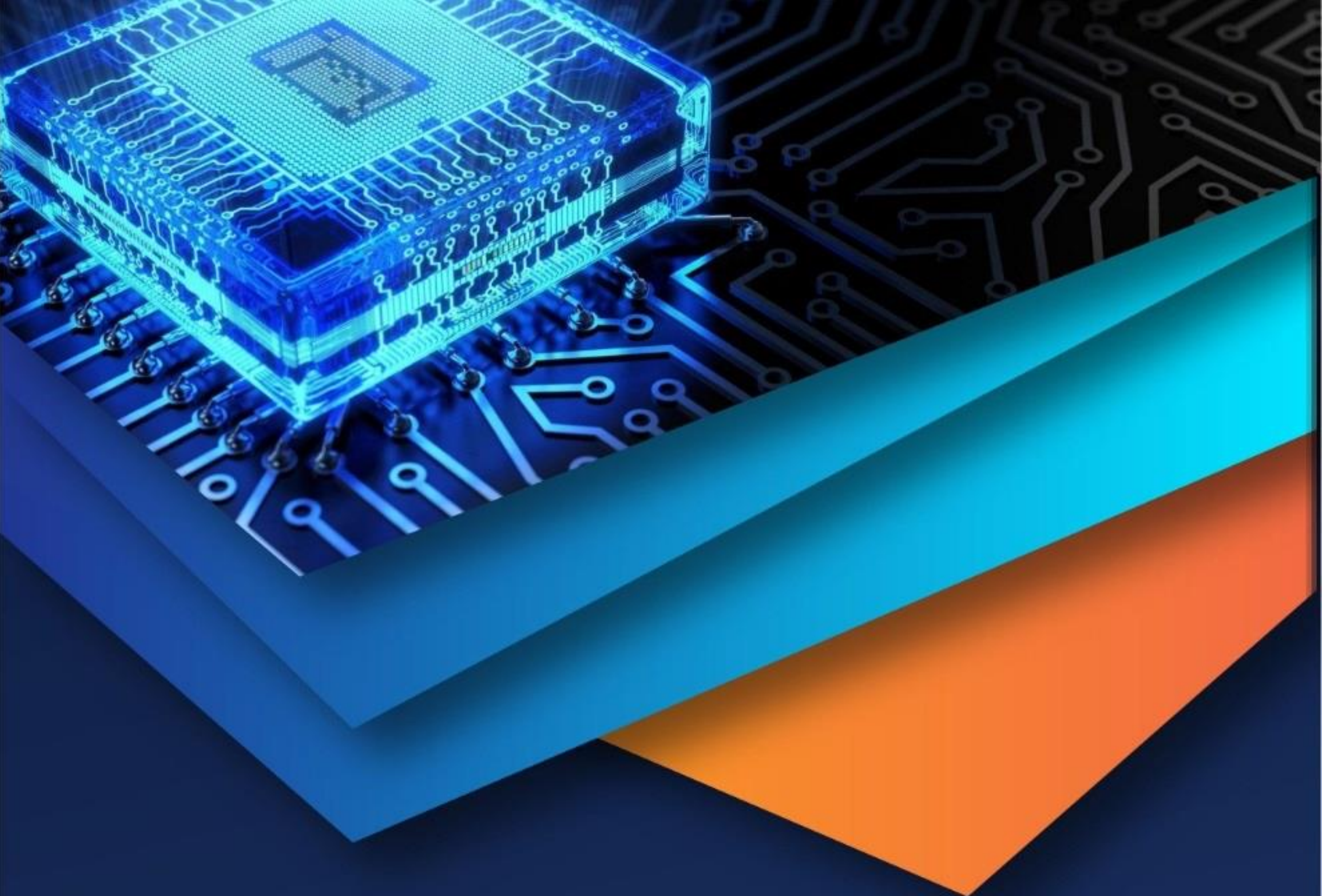

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