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Evaluation of Seismic Response of 3D Building Frame with and without Base Isolation Using Finite Element Analysis †

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Abstract: An earthquake is a force which is unpredictable and can cause serious damage to a structure and its structural components. For improved safety, the seismic design of the building should be adequate, and measures should be taken for vibration control. In order to mitigate effects, base-isolation techniques must be provided to counter seismic loads; this is a seismic isolation technique which prevents the transfer of energy from the base of the structure to the upper stories. In the research, two similar 3D frame models were modelled with and without base isolators and analyzed following the provisions and codes. The real ground motion data of the earthquake was selected, then matched to a design spectrum to obtain the matched time history. The story response plots obtained after the time history analysis indicate that base isolation is a reliable and effective technology to improve the seismic performance of the building, particularly with inadequate seismic design.

Keywords: base isolators; seismic base isolation; lead rubber base isolator; time history analysis

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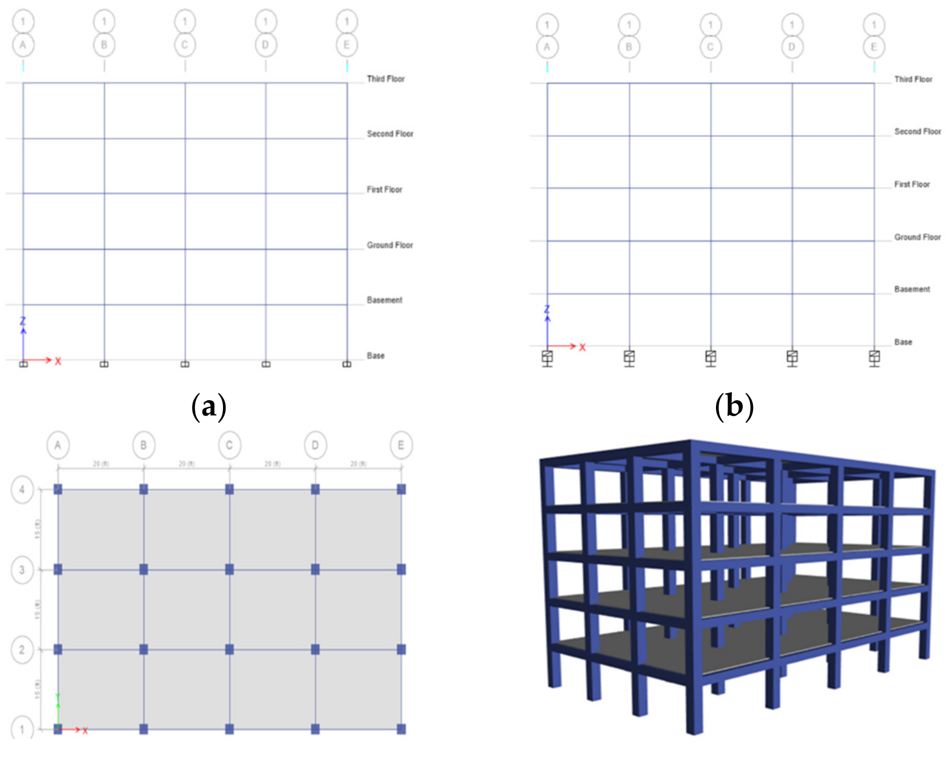
1. Introduction

The health of structures during seismic activity in seismic-prone areas has always been a concern for humanity. An earthquake, which mostly occurs at fault zones, is the shaking of the ground caused by the seismic waves that travel through the Earth's crust. Seismic waves are produced when the energy stored in the Earth's crust is released suddenly, usually when rock masses strain against each other fractures and slip. Nowadays, in the modern construction world, seismic isolation techniques have gained a lot of popularity. This technique has been adopted to protect the structures against the adverse effects of seismic activity [1]. By placing isolation devices between the foundation and super-structure, it effectively decouples the structure from seismic ground vibrations. The base isolation device's primary goal is to reduce the horizontal acceleration which is transmitted to the structure [2]. Earthquakes of lower magnitudes, while perceived as less severe, can still pose significant dangers. The most effective way to protect buildings from seismic forces is to make the structure flexible and increase its stiffness, which is achieved by base isolators.

Base isolation systems are generally of two types, i.e., elastomeric bearings and sliding isolation bearings. The elastomeric bearing is a type in which synthetic rubber is sandwiched between two mild steel plates as a damping object, while a sliding isolation bearing is a flexible device that allows some movement by the column end which slides over a plate, it deflects the earthquake energy [3]. Studies have shown that the horizontal component of an earthquake plays a major role in the destruction of a structure; it is more responsible for the damage to the structures. It can be reduced by increasing the structure's natural period and decreasing the acceleration response, which can be achieved using base isolators [4]. In 2017, Wankhade studied the behavior of different base isolators in a building and compared peak story shear and displacements with and without base isolators. He concluded that there was a considerable difference in peak story displacements and shear with fixed and isolated bases and that base frequency was reduced by using base isolators. The base isolation system is not physically present in Pakistan, but rather, studies have been conducted on the feasibility and application of lead rubber bearings and different kinds of isolations. There are many earthquake parameters used to determine the ground motion characteristics. Generally, earthquake loading effects are represented by three parameters, that include: peak ground acceleration, time history, and response spectrum. These parameters are used for the design of the structure and are known as the Design Basis Ground Motion Parameters [5].

2. Methodology

The experiment starts with modelling two similar 3D frame models in CSI ETABS version 2016. The elevation, plan, and 3D view of both the frames are shown in Figure 1a–d. Both frames shared the same design parameters and characteristics. Isolation was incorporated at the base of the second frame. The input parameters were complied with the UBC-97 specifications and ACI-318 requirements. The models were analyzed based on a finite element analysis. Moreover, for base isolators, lead rubber bearings were used because they are commonly used in buildings and are easy to install, compared to others. In ETABS base isolator acted as spring element. The input parameters for isolators are given in Table 1.



(**a**) (**b**) (**c**) (**d**)

Figure 1. This figure shows the elevations, plan and 3D views of the frame models: (**a**) shows the elevation of frame without base isolation, while (**b**) shows with base isolation; (**c**) shows plan view of the frame model while (**d**) shows 3D view of the frame model.

Table 1. Stiffness characteristics for the design of lead rubber isolator [6].

Lead Rubber Isolator (LRB) Properties	
Rotational inertia Effective stiffness (Linear)	0.009721 kN/m 889,950.58 kN/m
Effective stiffness (Non-linear) Effective damping (Non-linear)	889.95 kN/m 5%
Stiffness (Non-linear)	8201 kN/m
Yield strength (Non-linear) Post yield strength ratio	26.27 kN 0.1

3. Ground Motion Time History

The earthquake used for analysis was the Northridge—Lassen and Reseda earthquake that occurred in 2007, with a magnitude of 4.66 and having a reverse fault mechanism. The earthquake was matched to the UBC-97 design spectrum using Seismomatch, which was then used in time history analysis to obtain the story response plots. The time history can be seen below in Figure 2.

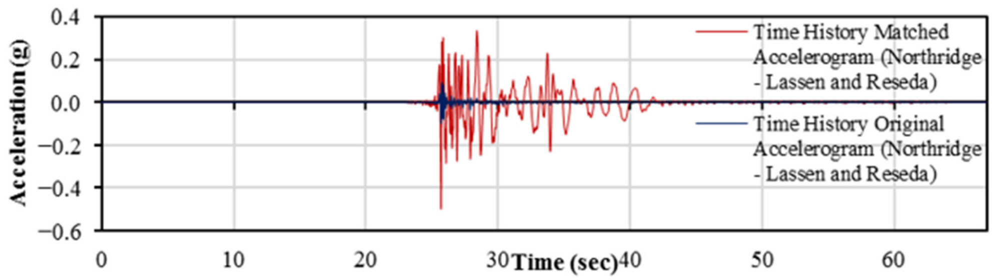


Figure 2. Northridge—Lassen and Reseda time history (acceleration in X-direction).

4. Seismic Response

The comparison of the story displacement of both the fixed base and the isolated base is shown in Figure 3. The base isolation systems cause the superstructure to move rigidly, which reduces the relative structural element displacement and, in effect, reduces internal forces on beams and columns. For the earthquake, i.e., the Northridge—Lassen and Reseda, a significant reduction of 85.9% in roof story displacement was observed, as shown in Figure 1a. When comparing the base-isolated frame to the fixed base frame, it can be seen in Figure 3b that the story drift ratio is higher on lower floors, and then it becomes constant on upper floors. However, in the fixed base frame, the story drift starts at zero at the ground level and increases nonlinearly with height. A reduction of 94.5% in roof story drift has been observed. Story shear refers to the lateral or horizontal force exerted on each level or story of a building during an earthquake event. Compared to the fixed base frame, a significant reduction in shear at each story is observed, and a reduction in roof story shear of 80.7% was observed in the base-isolated frame, as shown in Figure 3c.

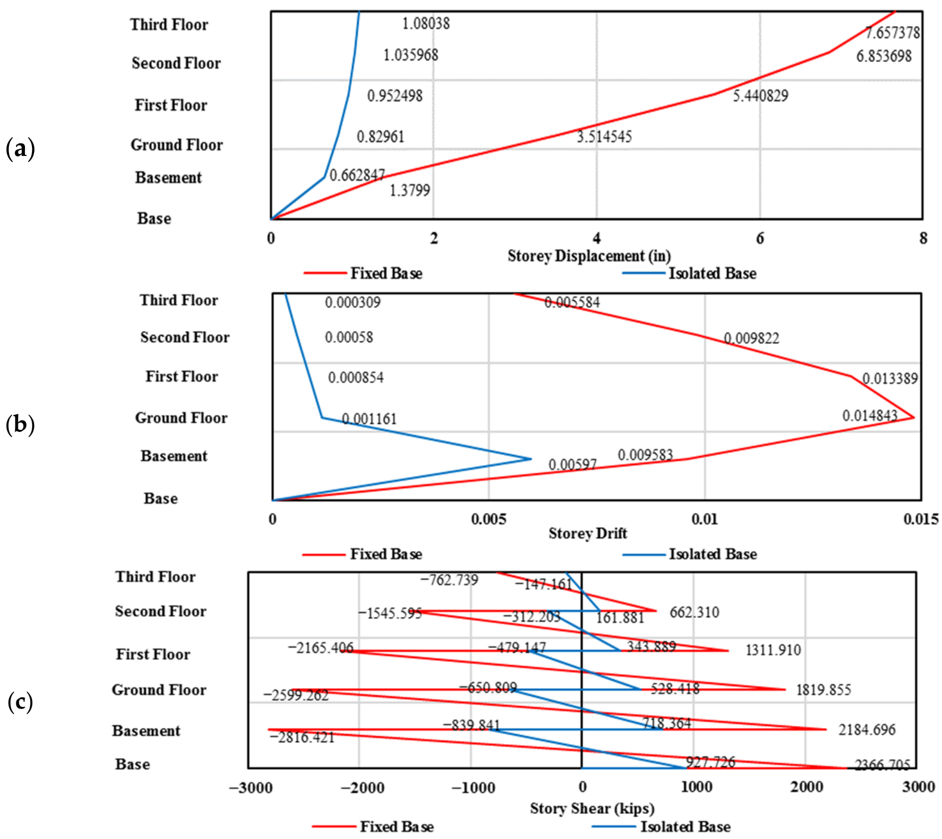


Figure 3. This figure shows the seismic response of the building frame in terms of story response plots: (**a**) shows the story displacement for Northridge—Lassen and Reseda for fixed and isolated base models (X-direction), (**b**) shows the story drift, while (**c**) shows the story shear.

5. Conclusions

The conclusions drawn from the results of seismic response analysis are as follows:

- In comparison to a fixed-base frame, the frame with base isolation shows a significant decrease in story displacement, i.e., by 85.9%; a story drift of 94.5%; and story shear, which is 80.7% because of the reduction in seismic effect after the provision of lead rubber base isolators.
- The results indicate that for earthquakes of relatively lower magnitudes, base isolators have been proven to be very effective and important, especially for buildings which have not been designed according to the seismic demand.
- This study demonstrates that base isolation can be successfully used in mid-rise buildings to mitigate the effects of earthquakes and can be used for retrofitting to prevent structural damage.

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