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Comparative Seismic Response Analysis of a Multi-Storey Building with and without Base Isolators under High Magnitude Earthquake †

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Abstract: Earthquakes can induce structural failure, the vertical collapse of a structure, or can result in the breaking and falling of non-structural components of the structure. Most of the region of Pakistan has a high risk of seismic activity and the country lacks seismic-resistant structures. The effectiveness of the base isolation technique has been studied by many researchers, but significant research has not been conducted particularly for high earthquake-prone regions of Balochistan. This study includes the comparative seismic response analysis of the two multi-storey reinforced concrete 3D frames, with and without base isolation under the effect of seismic loads. This study indicates the effectiveness of base isolators in reducing the seismic response of buildings in the earthquake-prone regions of Balochistan.

Keywords: base isolation; FEM; seismic analysis; Uniform Building Code (UBC-97)

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1. Introduction

An earthquake is a disruptive and unpredictable force that causes the Earth's surface to shake along a fault plane. They are the costliest disasters in history [1,2]. The 1935 Quetta earthquake destroyed the city completely, killing 30,000 to 60,000 in impact. Moreover, more than 450,000 buildings were damaged in the Kashmir Earthquake in 2005 [3]. Recently, two major quakes of magnitudes 7.5 and 7.8 occurred in south-central Turkey on 6 February 2023, near the Syrian border killing over 50,000 people [4]. The principal reason for structural failure during an earthquake is poor-quality construction materials, faults in construction methods, soil and foundation failure, mass irregularities, and inadequate design. With population growth, the demand for tall buildings is increasing. Worldwide, Reinforced Concrete (RC) multi-storied buildings have been affected by earthquakes drastically, and shear walls and steel bracing are used to reduce the earthquake effects but emerging technologies such as base isolators and dampers are found to be relatively more effective [5]. In earthquake-prone areas, there is always a risk of dangerous seismic activities. Several structures could collapse at magnitudes 6 to 7, with cracks on the ground. Many buildings may fall during earthquakes of magnitude 7 to 8 with significant damage [6]. Therefore, while designing a medium-to-high-rise building, vibration control should be considered along with the seismic design of the building. The effects of the horizontal component of an earthquake can be reduced by increasing the structure's natural period and decreasing the acceleration response which can be achieved utilizing seismic isolation [7]. Base isolators decouple the superstructure from the foundation, consisting of flexible or sliding materials placed between the building and its foundation. Extensive research shows that base isolation works properly for medium to high-rise buildings [8]. However, the novelty of this research is its focus on the response analysis of multi-storey buildings in regions of Balochistan, with high risk of seismic activity. The significance of this work lies in its potential to contribute to future research and base isolator usage for earthquake protection in Balochistan.

2. Research Methodology

2.1. Modelling of Frame

Two five-storey identical building frames were modeled with and without base isolators shown in Figure 1a,b. The Lead Rubber Bearing (LRB) base isolator was modeled in ETABS by applying springs in the model at the location of joints. The link/support properties used in defining the springs are shown in Table 1 [9].


(**a**) (**b**)

Figure 1. 3D View of the SMRF frame: (**a**) without base isolation; (**b**) with base isolation.

Table 1. Lead rubber base isolator properties [9].

Lead Rubber Isolator Properties			
Rotational inertia	0.016603 kN/m	Distance from the end (Non-linear)	0.00318 m
Effective stiffness (Linear)	1,175,418.57 kN/m	Stiffness (Non-linear)	10,831 kN/m
Effective stiffness (Non-linear)	1175.42 kN/m	Yield strength (Non-linear)	34.70 kN
Effective Damping (Non-linear)	5%	Post-yield strength ratio	0.1

2.2. Ground Motion Data

A large magnitude earthquake, Tabas, Iran was used in seismic response analysis, obtained by selection of the best matched ground motion amongst different ground motions selected initially from PEER Ground Motion Database and through SeismoSignal. The properties of the ground motion used are shown in Table 2.

Table 2. Ground motion data [10].

Earthquake	**Year**	**Magnitude**	**Fault Mechanism**
Tabas, Iran	1978	7.35	Reverse

2.3. Ground Motion Parameters

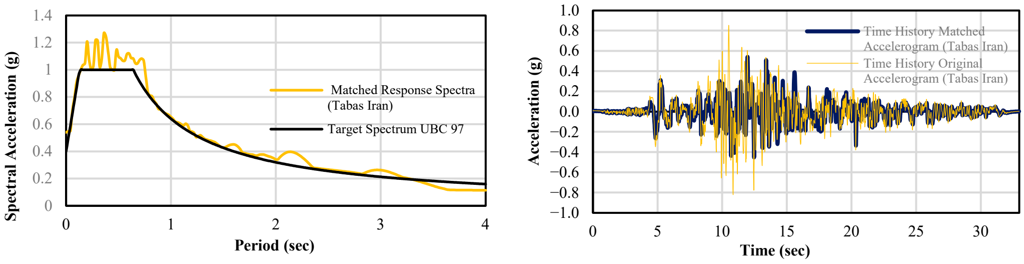
Ground Motion parameters used for the seismic analysis and matching of the ground motion are selected based on UBC-97, which are according to the regions lying in the most critical zones of Balochistan, i.e., Zone 4. The parameters are shown in Table 3.

2.4. Matched Response Spectra and Time History

Initially, the UBC-97 design spectrum was generated in Seismomatch with a PGA value of 0.32 g, then matched to the UBC-97 design spectrum from which the response spectra and matched time history were obtained, as shown in Figures 2a and 2b, respectively.

Table 3. Ground motion parameters.

Soil Profile	SD	Stiff soil
Seismic zone factor	ZONE Z	4 0.4
Seismic Coefficient "Ca"	Soil Profile Type SD	Seismic zone factor, Z (Z = 0.4) 0.44Na
Seismic Coefficient "Cv	Soil Profile Type SD	Seismic zone factor, Z (Z = 0.4) 0.64Na
Near Source factor "Na"	Seismic source type B Na	Closest distance to the known seismic source ≥10 km 1.0
Near Source factor "Nv"	Seismic source type B Na	Closest distance to the known seismic source ≥15 km 1.0



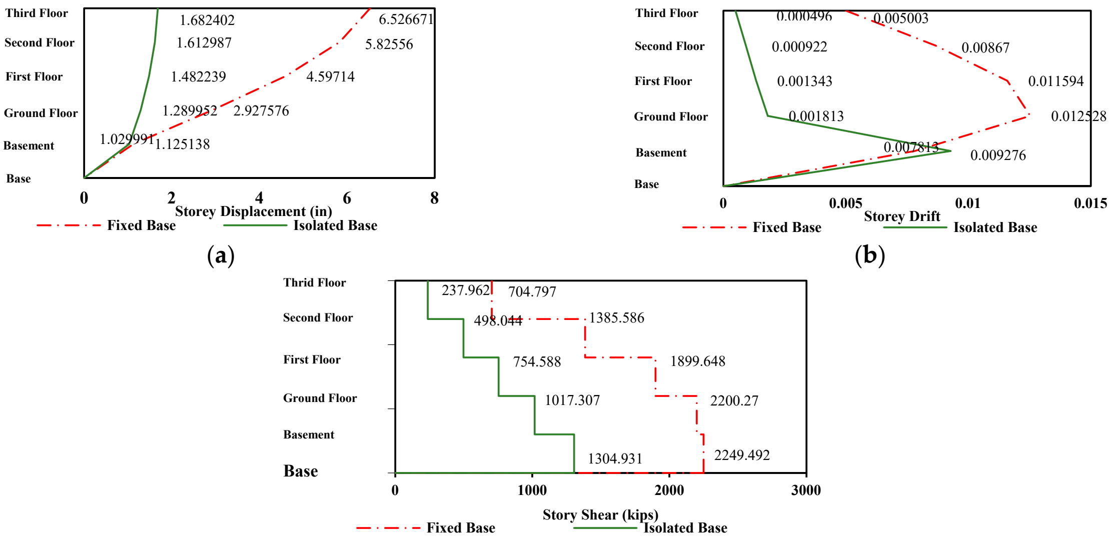
(**a**) (**b**)

Figure 2. (**a**) Spectral acceleration (X-direction); (**b**) Tabas, Iran time history (X-direction).

3. Results and Discussions

3.1. Storey Displacement

The storey displacement is the absolute value of displacement of the storey with respect to the base. Figure 3a shows that the overall maximum inter-storey displacement has been significantly reduced. Hence, a reduction of 74.3% in roof storey displacement is observed.



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

Figure 3. (X-direction) (**a**) Storey displacement; (**b**) Inter-storey drift; (**c**) Storey shear.

3.2. Inter-Storey Drift Ratio

Inter-storey drift ratio is the difference of displacements between two consecutive stories or storey drift, divided by the height of the story. The non-structural damage has a direct connection with the story drift [11]. At the roof storey, a reduction of 90.1% in the inter-storey drift ratio is observed. The following pattern can be seen in Figure 3b below.

3.3. Storey Shear

Storey shear is the lateral force caused by seismic and wind forces that are acting on a storey. Base isolation increases time period and storey drift while decreasing storey shear and acceleration, making stiffer structures more flexible by directing energy to the foundation [12]. Hence, a reduction of 66.2% in roof storey shear is observed in Figure 3c.

4. Conclusions

This study proves that base isolators significantly reduce storey displacements, drifts, and shear in multi-storey buildings in Balochistan's high-seismic-risk Zone 4. LRB isolators effectively increased stiffness, energy dissipation, and building time period from 0.8 s to 2.03 s, mitigating the earthquake impact by preventing resonance and reducing deformations.

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