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EARTHQUAKE-RESISTANT CONSTRUCTION

SEISMIC PERFORMANCE OF STRUCTURE WITH ISOLATED FOUNDATION USING U-SHAPE STEEL DAMPER AS AN ISOLATOR

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Hysteretic devices are essential for base-isolated buildings to control the deformation in the isolation system and to dissipate the earthquake-induced energy. U-shaped steel dampers dissipate energy through plastic deformation of specially designed steel elements. This paper investigates the performance of U-shaped steel dampers for the seismic isolation system as well as comparison with lead rubber bearings. For this purpose, both isolators are attached to a 5-storey building. Nonlinear time history analysis is carried out for four different earthquake ground motions. The results show that the response quantities are significantly reduced; therefore structural damages are minimized in both isolation systems.

Introduction

The present design philosophy allows damages in the structure without collapse under seismic action. Earthquake imparts energy to a structure, which is dissipated by inherent damping of the structure. In the past, it was common to ignore the vibration phenomenon while assessing the condition of the structure. It was inconsistent with the present real situation. It was state-of-the art researchers who recognized the importance of this aspect way back in the early seventies and suggested that the installation of flexible and stiff members can help to counter the seismic force. This led to considerable interest in the seismic damage control problem throughout the world. From then onwards, a significant amount of research has been performed on the base isolation process, and relevant research has accelerated in recent years. Recently, many research people have turned towards the civil engineering field and started working on both the approaches available as analytical and experimental. Some of the studies have used the analytical approach, and others have used an experimental approach. During the last twenty years, base isolation is widely used to achieve the higher seismic performance of the structure. Su et al. [1] investigated the effect of variations in the properties of the isolator for shear beam structure. A comparison between the fixed base and isolated base steel structure has been done by Lin and Shenton [2], and similar work was done by Shenton and Lin [3] for concrete frame structure. Erickson and Altoontash [4] studied the design and construction of a base isolation system for industrial structures and also focused on code requirements. Nacamuli [5] has stated the importance of base isolation as a seismic protection system and proposed Ball-N-cone isolations for structure. It also provides an application in data center components like network storage, cooling towers, computer racks, etc. Tavakoli et al. [6], under near and far-fault real ground motions, investigated nonlinear seismic response of the structure with an isolated base and fixed base. The author concluded that reduction in seismic response for the far field is greater as compared to the near field motion. For high damping rubber bear-

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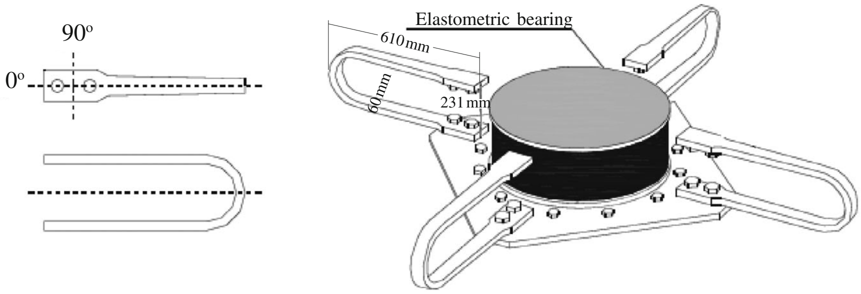

Fig. 1. U-shaped steel damper [17].

ings, the variation in mechanical properties in seismic response of multistorey building was investigated by Gheryani et al. [7]. It is also proposed that the response of the isolator was influenced by variation in properties. Harvey and Gavin [8] introduced a rolling isolation system and examined the earthquake behavior of various structures with varying stiffness and height. Jamalzodeh and Barghian [9] studied a pendulum isolator and also investigated the effect of the vertical and horizontal component of the seismic load. Many researchers studied the behavior of hybrid base isolation systems. Isolators with the addition of other energy dissipation devices are more effective to reduce structural damages. Cancellara and Angelis [10] studied three different isolators with the addition of friction sliders, called hybrid isolation systems. And in further studies, the authors have introduced a new isolator called high damping hybrid isolator and compared it with the lead rubber bearing [11, 12].

From all the above studies, it is clear that the lead rubber bearing is mostly used for isolation systems. In the present study, the behavior of a 5-storey RC building under different earthquakes is studied without and with isolated foundation. For this purpose, a new attempt has been made, i.e., a U-shaped steel damper is used for the isolation system and compared with the lead rubber bearing system, whereas in the previous study of U-shape dampers, the authors have checked its effectiveness experimentally only. Nonlinear time history analysis is being performed by using four different earthquakes.

U-Shaped Damper

During an earthquake, the building vibrates in all directions and it greatly deforms in the horizontal direction. Thus, in the horizontal direction, homogeneous damping is required. Nippon steel has manufactured a steel damper for seismic isolation. Due to the plasticity of steel material, it actively absorbs seismic energy by the hysteresis property. This damper is plasticized in any direction of 360° for the horizontal force. The first idea of utilization of the U-shaped damper for the isolation system was introduced by Suzuki et al. [13]. They have also described the features of U-shaped damper and its properties. Konishi et al. [14] investigated the fatigue performance of the U-shaped damper experimentally. Oh et al. [15] and Jiao et al. [16] experimentally investigated the seismic response of the U-shaped isolator using shake table tests. Ene et al. [17] studied the reliability of the U-shaped damper using analytical models. The configuration of a U-shaped steel damper is shown in Fig. 1 with low damping rubber bearing and 4 arms. The nonlinear properties of the U-shaped isolator UD40 are: yield force 112 kN; initial stiffness 5920 kN/m; post stiffness 100 kN/m; and yield deformation 0.0189 m.

Lead Rubber Bearing

Initially, lead rubber bearing (LRB) was introduced in New Zealand in 1975 and after that widely used in Japan and the USA [1]. It works like a laminated rubber bearing. The lead core provides more rigidity to the system, which is placed at the center. Due to the lead core, more energy gets

TABLE 1

Location	K_{eff}, kN/m	K_p, kN/m	F_y, kN
Internal	779.099	622.222	112
Outer	548.361	622.222	112
Corner	377.542	622.222	112

TABLE 2

Models	Fundamental time periods for			
	3-storey building		5-storey building	
	T_x, sec	T_y, sec	T_x, sec	T_y, sec
Fixed Based	0.47	0.42	0.715	0.63
LRB	2.43	2.42	2.48	2.47
U-shaped	2.41	2.44	2.49	2.42

absorbed because the lateral stiffness is significantly increased. The LRB is modelled as a nonlinear element. The post-elastic stiffness K_p is obtained by Naeim and Kelly [18] as

$$K_p = \frac{GA_b}{T}, \tag{1}$$

where A_b is the area of rubber; the rubber thickness $T = 2\pi\sqrt{M / K_p}$, where M is the total mass, G is the shear modulus of rubber.

The effective stiffness K_{eff} is given by

$$K_{eff} = K_p + \frac{Q}{D}, \tag{2}$$

where Q is yield strength and D is design displacement. The effective stiffness of isolation is mostly designed in such a way as to give a considered value of the isolator period:

$$Q = \frac{\pi\beta_{eff} K_p D^2}{(2 - \pi\beta_{eff})D - 2D_y}, \tag{3}$$

where D_y is yield displacement, β_{eff} is assumed to be 0.05. From the experimental investigation of some of the researchers, it is suggested that D_y is approximately 0.05-0.1 times the rubber thickness [18]. The yield force of bearing can be found as

$$F_y = Q + K_p D_y; \tag{4}$$

$$K_u = F_y / D_y. \tag{5}$$

The mechanical properties of the LRB for application in a 5-storey structure are shown in Table 1. Yield force and yield deformation are assumed to be equal to yield force and yield deformation of the U-shaped isolator respectively.

Numerical Study

A 5-storey reinforced concrete building is considered in this work. Two bays of 4 m are in the *X*-direction and four bays of 3 m are in the *Y*-direction. A constant storey height of 3 m is considered. A building is located in the seismic zone V with PGA of 0.36*g*. A reinforced concrete slab of 120 mm thickness and infill as thick as 230 mm are taken. All beams are 300 × 600 mm and columns are 600 × 600 mm [19, 20]. The dead load and live load are considered according to [21-22]. The compressive strength of concrete is 30 MPa, and reinforcing steel has a yield strength of 415 MPa. A 3-D building with and without isolator is modelled and analyzed by SAP2000NL [23]. Table 2 shows fundamental periods of the building for three different cases.

TABLE 3

Earthquake	ID	PGA (*g*)
Hector Mine, USA (1999)	120522	0.34
Imperial Valley, Mexico (1979)	120612	0.35
Kocaeli, Turkey (1999)	120812	0.36
Superstition Hills, USA (1987)	121211	0.36

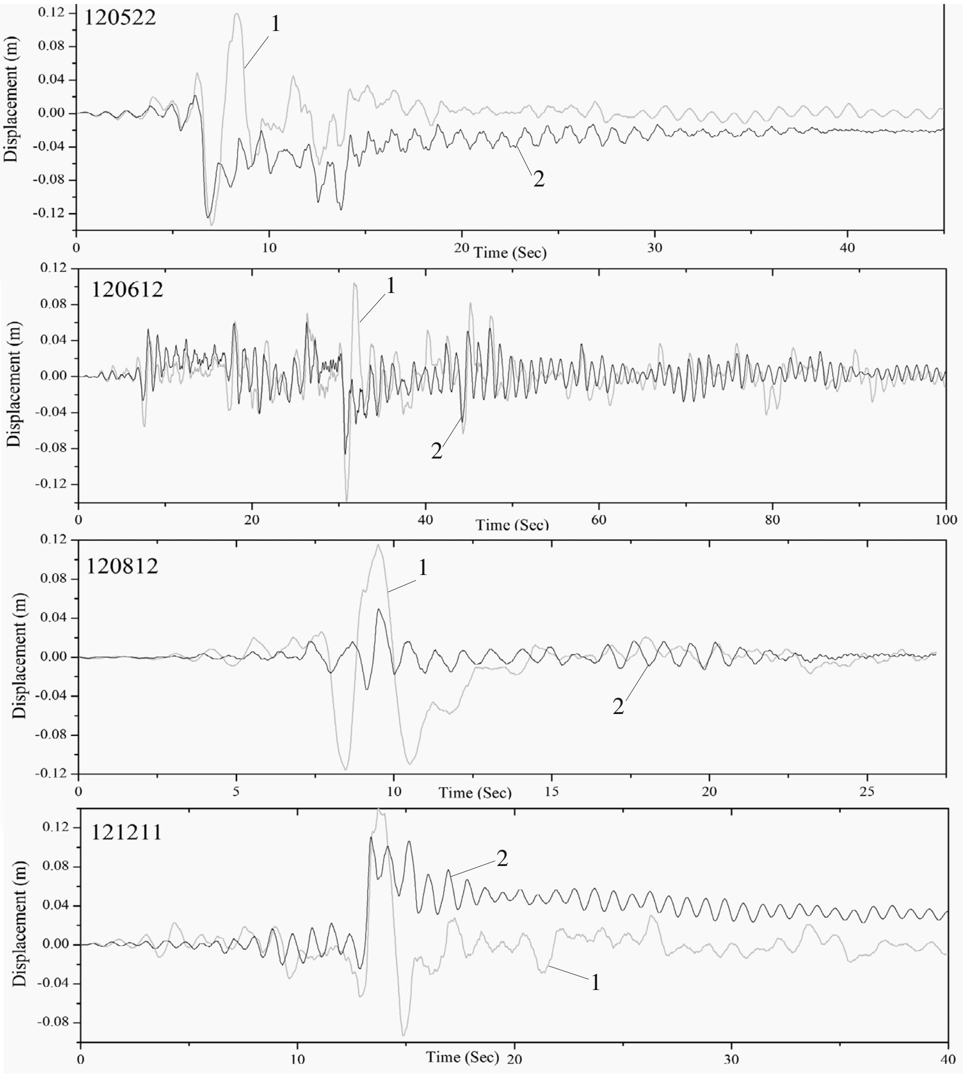

Fig. 2. Bearing displacement of 5-storey building for four earthquakes: 1) LRB; 2) U-shape.

For the numerical analysis, four earthquake records were taken from ATC-40 (Table 3). These time histories have been scaled to spectral compatible data with peak ground acceleration of 0.36*g* with the help of a wavelet transform based software WAVEGEN [24].

Dynamic Response of Isolated Foundation

The bearing displacement is a very important parameter in the design of an isolator to avoid pounding with an adjacent structure. A comparison between bearing deformations is shown in Fig. 2. The isolator displacement for a U-shaped isolator is less compared to the LRB. There is a significant decrease in peak displacement due to the U-shaped isolator.

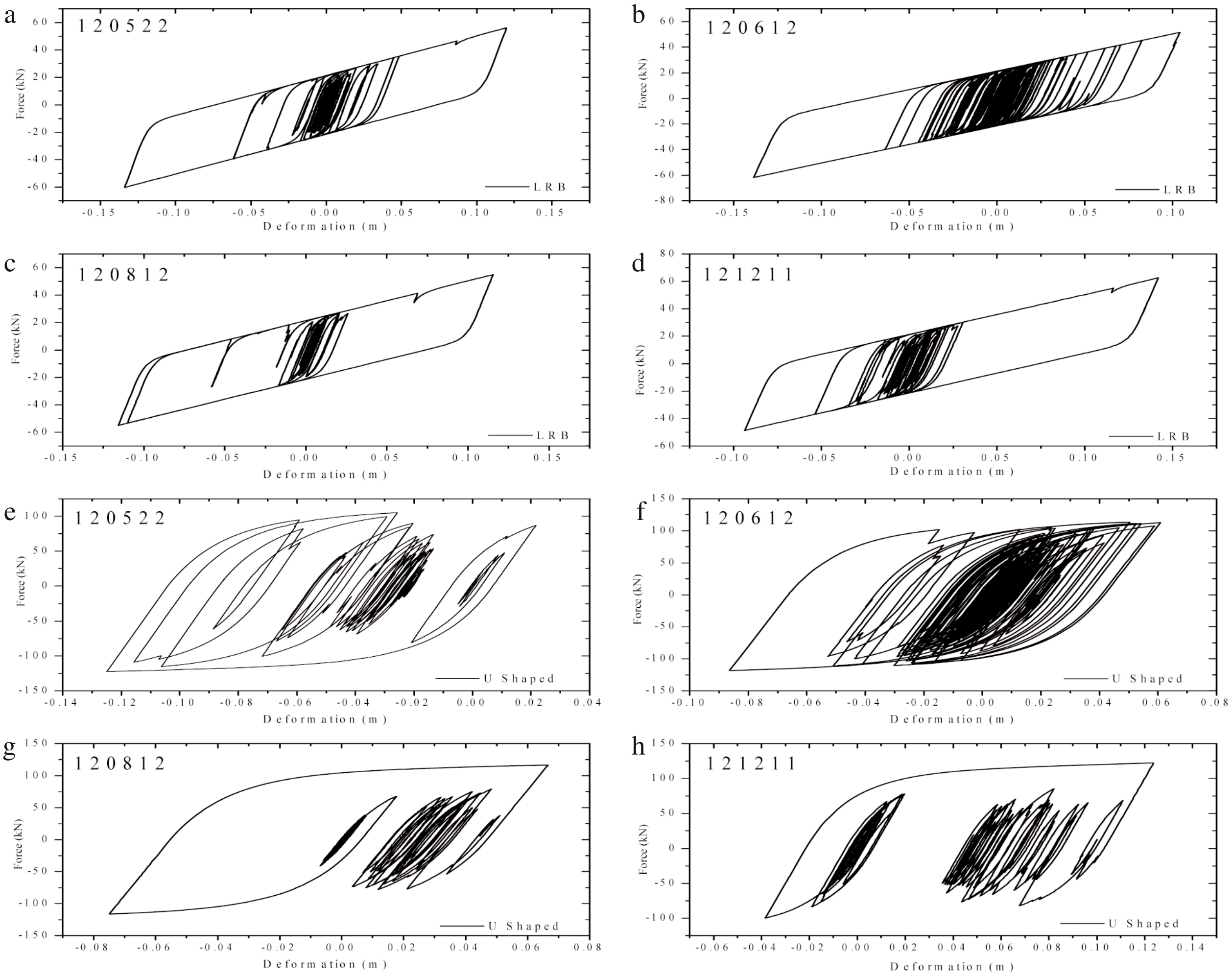

Fig. 3. Hysteresis curve of the LRB (a-d) and U-shaped isolator (e-h) for a 5-storey building.

Figure 3 shows the hysteresis curve of the LRB and a U-shaped isolator for a 5-storey structure. The area under the hysteresis curve shows the energy dissipated, and from the figure it is clearly observed that the energy dissipated by the U-shaped isolator is greater compared to the LRB.

Dynamic Response of Super-structure

The acceleration of structure indicates the amount of force exerted on the structure due to earthquake motion. The top acceleration of the superstructure for four different earthquakes is shown in Fig. 4, which also gives a comparison of the fixed base and the isolated building. Both isolation systems give a remarkable reduction in top floor acceleration of the superstructure. Thus the U-shaped damper is also capable of working as an isolator.

Due to the application of the LRB isolator, the drift and acceleration of the joints have decreased as compared to the fixed base conditions when subjected to ground motion. As the base isolators get deformed itself at the base of the structure due to the high energy seismic waves, a lesser amount of the energy is transmitted in the superstructure. Hence, the amount of storey drift gets reduced which can be seen from Fig. 5 for 5-storey buildings. A similar trend is observed in the U-shaped isolator case with less flexibility of the U-shaped isolated building as compared to the LRB isolated building.

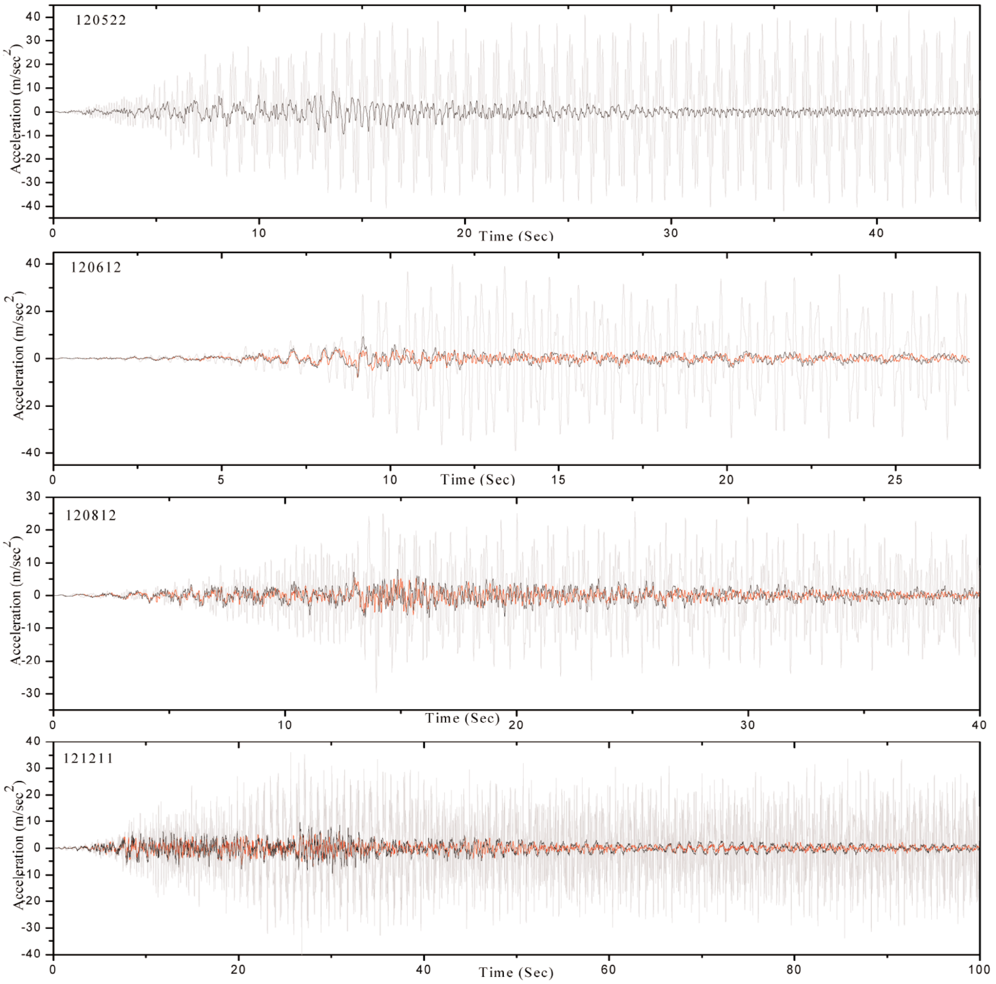

Fig. 4. Top floor acceleration comparison for a 5-storey building: ——) fixed; ——) U-shape, and ---) LRB.

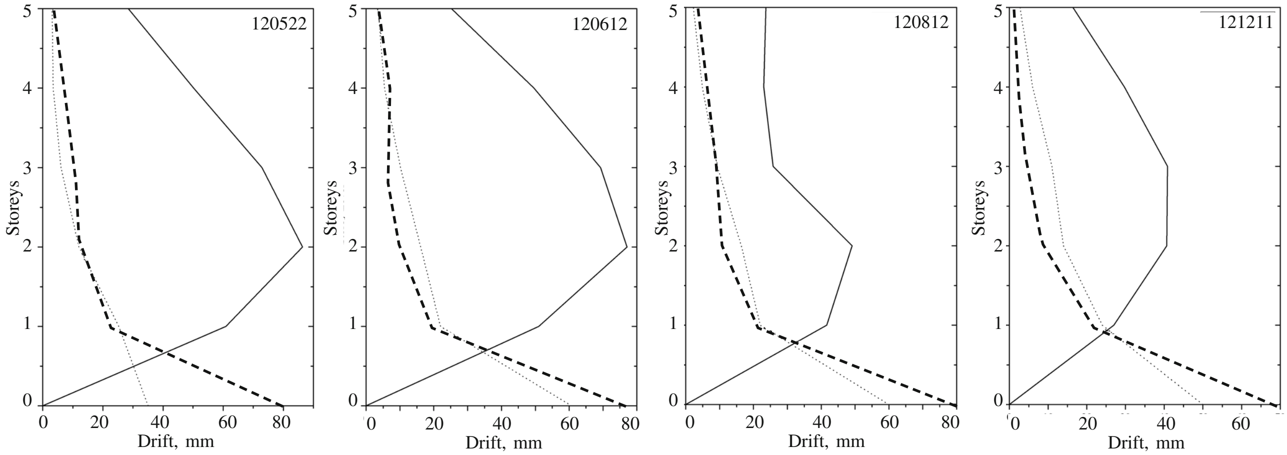

Fig. 5. Storey drift comparison for a 5-storey building: ——) fixed; ····) U-shape; and - - -) LRB.

Figure 5 compares the drift of each storey for the fixed base and isolated building. In the 5-storey building, base deformation with the LRB is greater compared to the U-shape isolator, but the storey drift for both isolators is approximately the same.

Conclusion

The results of the present analytical work show a trend between the fixed base and isolated foundation conditions. The use of the LRB and U-shaped isolators as methods for isolated foundation have proved effective as it reduces the general response of the structure due to any seismic activity. An attempt through this study certainly emphasizes the effectiveness of the U-shaped damper as an isolator and as an upcoming tool.

The following observations are made from the analytical study:

1. While comparing the two isolators, the maximum bearing displacement of the U-shaped isolator is reduced by the range 50 - 60% as compared to the LRB for all earthquakes. For this aspect, the U-shaped steel isolator is more effective than the LRB.
2. The energy dissipation capacity of the U-shaped isolator is greater compared to the lead rubber isolator.
3. In the case of the U-shaped isolator, the reduction in top floor acceleration of the superstructure is similar to the LRB. The U-shaped isolator also gives a large reduction in acceleration. Hence, this new device is one of the most effective seismic base isolation method for reducing the seismic effect on a structure.
4. From the present study, it is noted that the U-shaped isolator displacement is less compared to the LRB, but the building acceleration is approximately the same.

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