Mechanical performance test of 3-dimensional isolation bearing for horizontal and vertical base-isolated buildings

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ABSTRACT: A new style base isolation device, which is called 3-dimensional isolation bearing (3DIB), is introduced in this paper. 3DIB is composed of lead rubber bearing (LRB) and disk spring bearing (DSB). In order to verify the horizontal and vertical performance of the 3DIB, several mechanical performance tests were conducted. The results show that the LRB is used for horizontal isolation and the DSB is for vertical isolation, and the horizontal properties and vertical properties of the 3DIB are determined by LRB and DSB, respectively. With high load capacity, variable stiffness and high damping, the 3DIB can be used to mitigate the horizontal and vertical seismic responses of base-isolated buildings.

Key words: horizontal isolation, vertical isolation, performance, test

1 INTRODUCTION

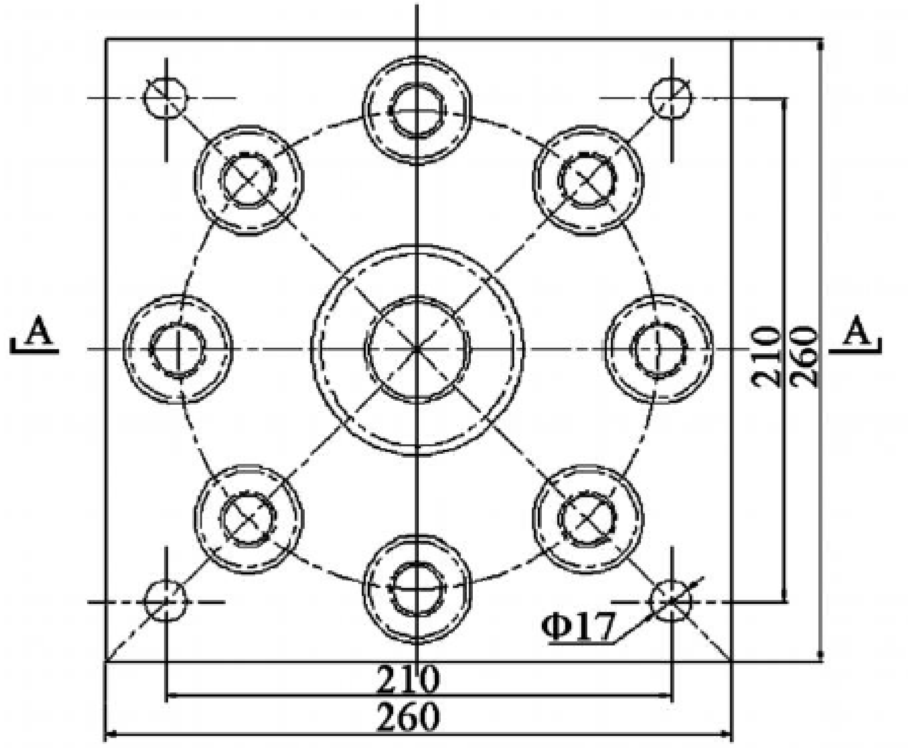
Due to the huge earthquakes occurred frequently in the world, and lateral loads imposed on structures are the primary cause of damage in earthquakes, many base-isolated structures have been constructed to passively control seismic responses in most of the seismic countries(Kelly 1991, Naeim 1999, Asher 1995). In recent years sufficient strong-motion records from large magnitude earthquakes have been recorded by the seismographs, more and more records have larger peak ground acceleration in vertical ground motion than in horizontal ground motion acceleration, which indicate that vertical component of ground shaking should be paid more attention to avoid structural damage(Bommer 2011, Niazi 1992, Ambraseys 2003). The horizontal force of an earthquake ground motion is sufficiently reduced by a base isolation system with lead rubber bearings or other isolators, but the vertical force is transmitted directly. The vertical component of ground shaking can also contribute to the destructive capacity of the motion in many situations. Therefore, development of the effective three-dimensional base-isolated system becomes more and more important. With adding the dampers or active components, the 3-dimensional base isolation systems proposed up to now are very complex and most of them are applied to the nuclear plants (Shimada 2004, Kashiwazaki 1999, Inoue 2004). Additional damper can increase the vertical damping of the three-dimensional isolation bearing, but also increase the vertical stiffness of bearing, which is not conducive to decrease the vertical seismic responses of the base-isolated system. A new 3-dimensional isolation bearing (3DIB), which is combined with lead rubber bearing (LRB) and disk spring bearing (DSB), is introduced in this paper (Zhao 2007).

2 3DIB TEST MODEL

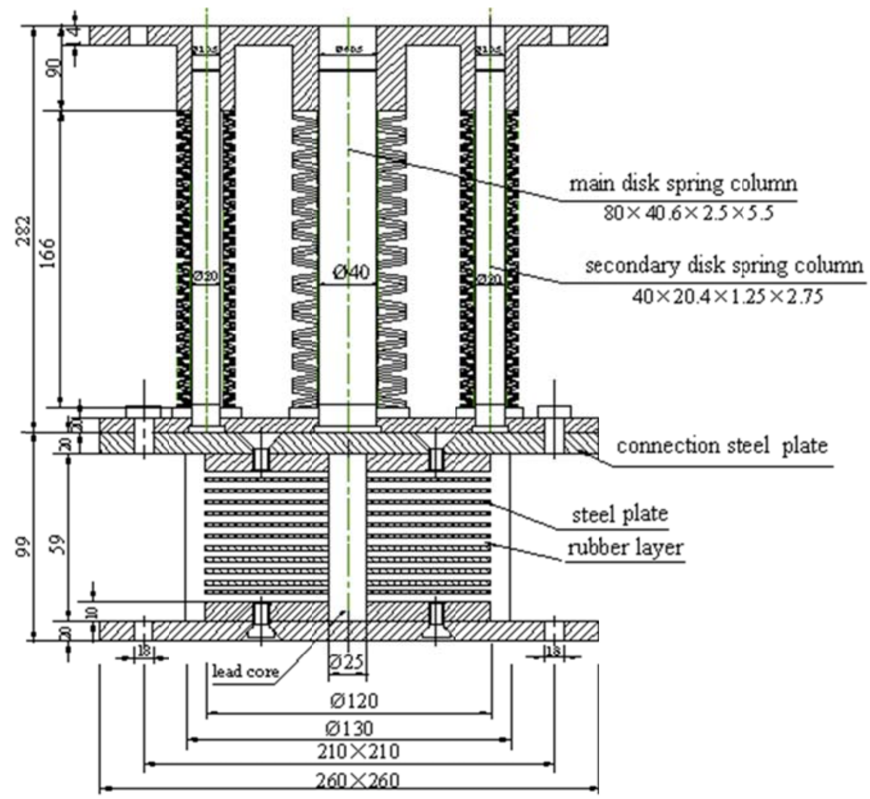
The 3-dimensional isolation bearing (3DIB), proposed in this paper, is combined with lead rubber bearing (LRB) and disk spring bearing (DSB). LRB is effective to decrease seismic responses of building in horizontal directions. Disk spring is chosen to design DSB as the vertical isolator, because it has the following features (Almen 1936).

1. The restoring force characteristics of the disk spring show nonlinearity.

2. The effect of the friction becomes remarkable when large number of disk springs stacked (Niepage 1984).



(a) 3DIB plan view



(b) A-A section

Figure 1 Typical plan and elevation of 3-dimensional isolation bearing (3DIB)

A schematic drawing of the 3DIB is shown in Figure 1a and Figure 1b. DSB is consisted of one main disk spring column and eight secondary disk spring columns. Dimensions of the main disk spring are 80 mm in outside diameter, 40.8 mm in inside diameter and 2.8 mm in thickness. By stacking two disks in parallel and 24 sets in series, the DSB is made up 48 main disks in a main disk spring column. In addition, Dimensions of the secondary disk spring are 40 mm in outside diameter, 20.4 mm in inside diameter and 1.4 mm in thickness. By stacking two disks in parallel and 48 sets in series, the DSB is made up 96 secondary disks in a secondary disk spring column. The centre guide is installed inside of disks.

The diameter of the LRB was 130mm. The bearing was composed of 16 rubber layers and 15 steel shim plates. The thickness of each rubber layer was 1.5mm, and the thickness of the steel plates was 1mm. The diameter of the lead plug was 25mm.

Based on the average axial load exerted on the isolation system by the dead load of the superstructure, an axial load of 50kN is imposed to DSB, LRB, and 3DIB for the performance test conducted in pseudo dynamic test equipment, respectively.

3 TEST RESULTS

3.1 Horizontal properties of 3DIB

The shear-compression tests up to25%, 50%, 100%,150%,200% and 250% shear strain at the vertical compressive load of 50kN were carried out to characterize the mechanical properties of the 3DIB and LRB. The corresponding maximum shear displacements were 6mm, 12mm, 24mm, 36mm, 48mm and 60mm.

Figure 2 shows that the hysteretic curves up to 20%, 50%, 100% shear strain for 3DIB. It is seen that with the increase of horizontal shear deformation, the hysteresis curve is more and more full.

The equivalent stiffness and damping ratio at several strain points are shown in Figure 3a, 3b. It is seen that as the shear strain of 3DIB increases, the horizontal equivalent stiffness decreases more than 30% from 0.26kN/mm to 0.17kN/mm at 50% and 250% shear strain (0.05Hz), and the equivalent damping increases from 15% to 21% at 50% and 250% shear strain (0.1Hz). Meanwhile with the increase of loading frequency (from 0.05Hz to 1.0Hz), the equivalent stiffness and damping ratio varied slightly (about 20%).

Figure 4 displays the horizontal equivalent stiffness and damping ratio comparative curves of LRB and 3DIB at 25%, 50% and 100% shear strain when the load capacity is 0.1Hz and 0.2Hz. It is proven that each equivalent stiffness and equivalent damping ratio of LRB is in good agreement with that of 3DIB, which could be confirmed that the horizontal hysteretic characteristics of 3DIB is mainly decided by LRB.

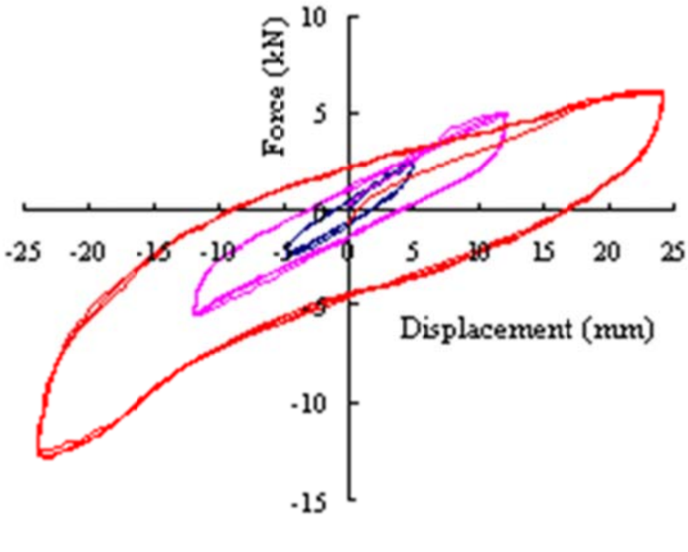


Figure 2 20%, 50% and 100% shear strain hysteresis for 3DIB (0.1Hz)

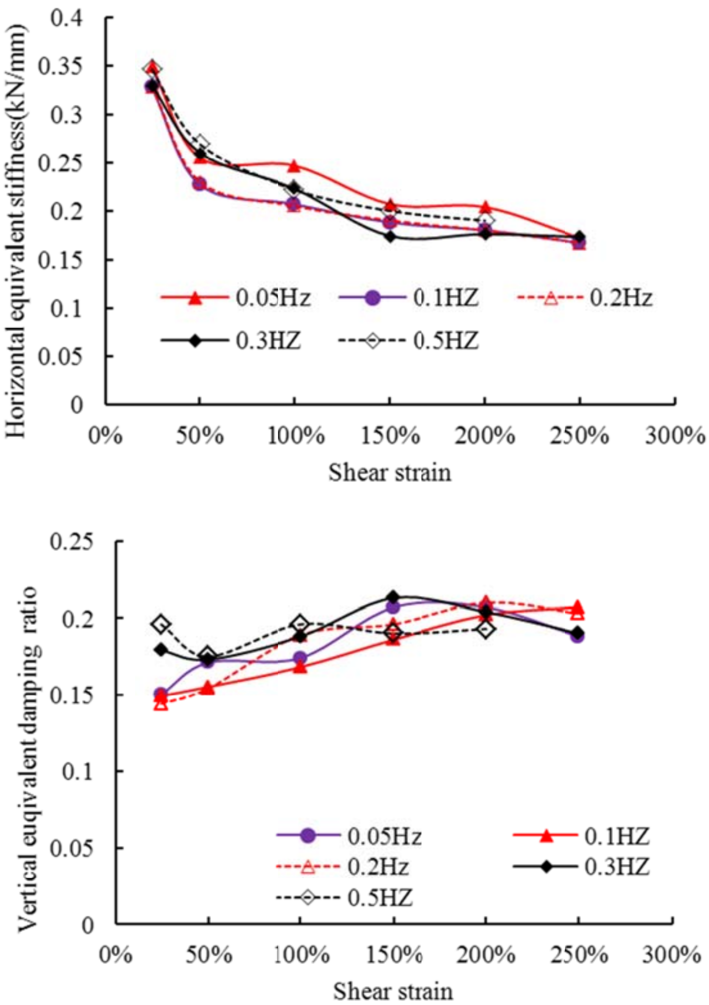
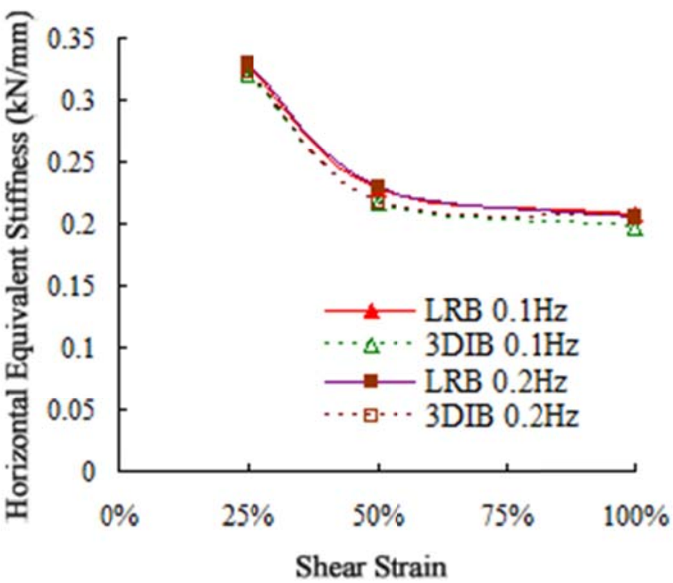


Figure 3 Horizontal equivalent stiffness and equivalent damping ratio of 3DIB



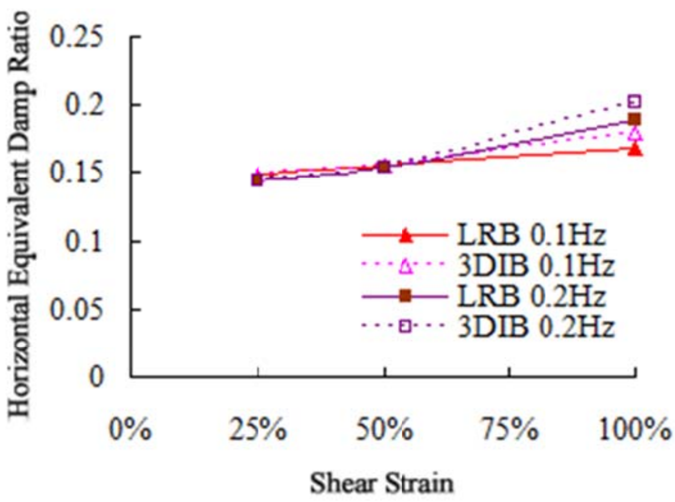


Figure 4 horizontal equivalent stiffness and damping ratio comparative curves of LRB and 3DIB

3.2 Vertical properties of 3DIB

Performance tests of DSB and 3DIB were conducted under static and dynamic loading. Figure 5 presents vertical force-displacement hysteresis loops for the3DIB from a test consist of four fully reversed cycles of sinusoidal input to different displacement amplitude of 5mm, 7mm and 10mm at a frequency of 1.0Hz with the initial displacement of 40mm. Vertical equivalent stiffness and damping ratio changed with different loading frequency and displacement amplitude of 3DIB are shown in Figure 6. It was confirmed that the 3DIB has good property of variable vertical stiffness and the vertical damping ratio was about 20% without adding any dampers. As shown in Figure 6 (the initial displacement is 40mm), with the increasing displacement amplitude(5mm,7mm,and 10mm), the vertical equivalent stiffness of 3DIB decreased from 25% at 5mm to 42% at 10mm. The vertical equivalent damp ratio of 3DIB is not less than 20% when the vertical displacement amplitude is 5mm, 7mm and 10mm.

Figure 7 displays the vertical equivalent stiffness and damping ratio comparative curves of DSB and 3DIB at different displacement amplitude (5mm, 7mm and 10mm) from 0.1Hz to 1.0 Hz when the initial displacement is 40mm. It is proven that each vertical equivalent stiffness and equivalent damping ratio of DSB is in good agreement with that of 3DIB, which could be confirmed that the vertical hysteretic characteristics of 3DIB are mainly decided by DSB.

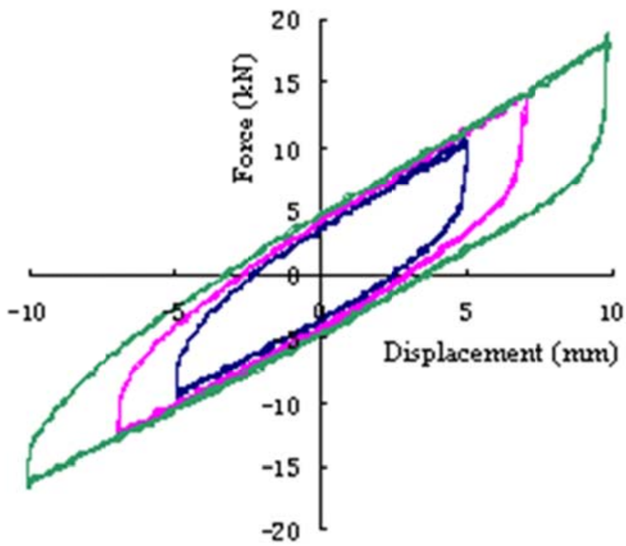


Figure 5 Vertical force-displacement hysteresis loops of 3DIB

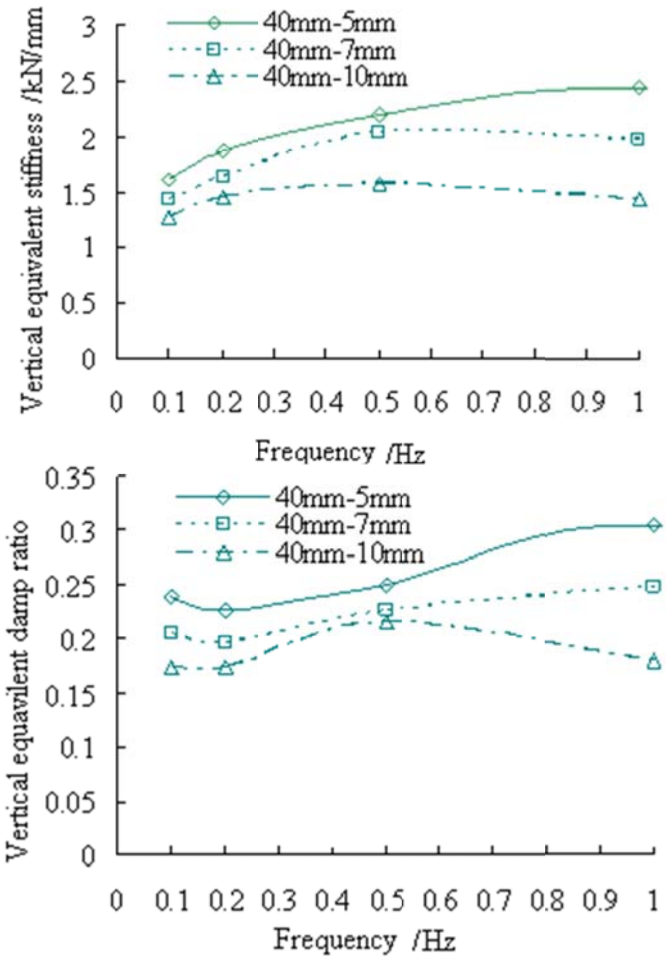
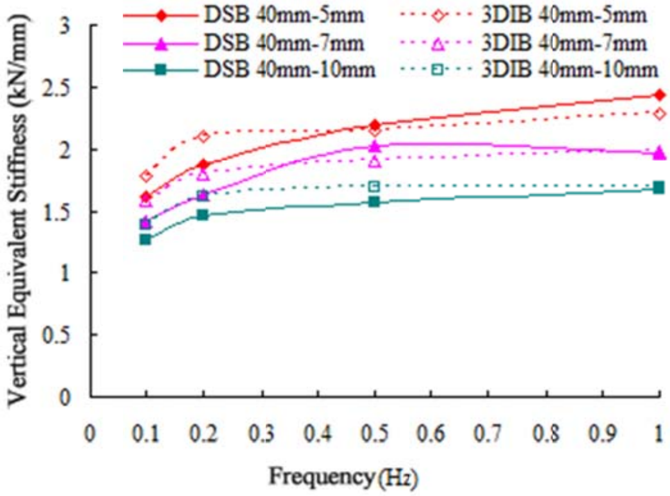


Figure 6 Vertical equivalent stiffness and damping ratio of 3DIB at different frequencies and displacement amplitude



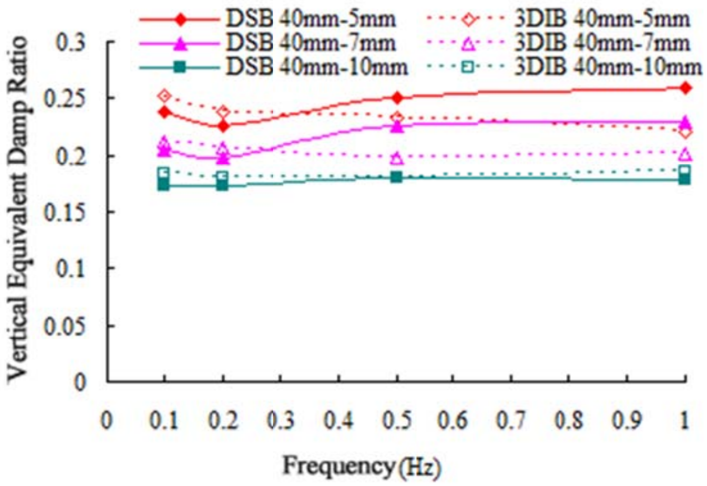


Figure 7 Vertical equivalent stiffness and damping ratio comparative curves of 3DIB and DSB

4 CONCLUSIONS

A new 3-dimensional isolation bearing (3DIB), which is composed of lead rubber bearing (LRB) and disk spring bearing (DSB). From the mechanical performance tests of 3DIB, main conclusions of the research are as follows:

1. The horizontal equivalent stiffness and damping ratio of 3DIB is similar with those of LRB. With the increase of horizontal shear deformation, the hysteresis curve is more and more full. The horizontal equivalent stiffness of 3DIB is decreasing with the increasing shear strain, and the horizontal equivalent damping ratio of 3DIB is about 20%. The horizontal hysteretic characteristics of 3DIB is mainly decided by LRB.

2. The vertical equivalent stiffness and damping ratio of 3DIB is similar with those of DSB. The vertical equivalent stiffness of 3DIB is decreasing with the increasing displacement amplitude, and the vertical equivalent damping ratio of 3DIB is about 20% without adding a damper. The vertical hysteretic characteristics of 3DIB are mainly decided by DSB.

With high load capacity, variable stiffness and high damping, the 3DIB can be used to mitigate the horizontal and vertical seismic responses of base-isolated buildings.

5 ACKNOWLEDGEMENTS

This work is supported by the Beijing Nova Program (Z121106002512059), the National Natural Science Foundation of China (51108428), and research grant from Institute of Crustal Dynamics, China Earthquake Administration (No. ZDJ2013-03).

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