

VIBRATION AND SEISMIC ISOLATION DESIGN FOR BUILDINGS ON SUBWAY PLATFORM

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ABSTRACT :

This paper introduces the research and application of a three-dimensional (3D) isolation technique for house buildings in Peking, China, which directly built on an existing subway communication hub platform required development of a very effective vibration and seismic isolation system. First, the authors investigate an innovative 3D isolator, which is composed of connecting plate, vertical rubber pad for vibration isolation and the horizontal rubber bearing for seismic isolation. Secondly, this paper presents the design of a building adopted the 3D isolation system in details. Finally, the in situ tests both of the isolated and the non-isolated buildings are carried out. Results from the tests show that the maximum response acceleration of the isolated superstructure reduced ten times as compared to the platform and the maximum attenuation of vibration attend to 25dB. The 3D system explored in this paper is very effective in vibration reduction.

KEYWORDS:

three-dimensional seismic and vibration isolator, vertical vibration isolation, horizontal seismic isolation, application

1. INTRODUCTION

The 1994 Northridge earthquake in the United States, the 1995 Kobe(Hyogo-Ken Nanbu) earthquake in Japan, the 1999 Izmit earthquake in Turkey, the 1999 Chi-Chi earthquake in Taiwan, China and 2008 Wenchuan earthquake in China, all caused significant loss of lives and damage to civil engineering structures. Seismic isolation, as a typical means of response control technology, has been widely used in both new and existing buildings to protect from the devastating effects of earthquakes. The concept of isolation is to prolong natural period and provide higher damping level to traditional structure to avoid resonance with the relatively short period components dominant in earthquake ground motions. Recently, seismic isolation has been utilized in more flexible structures to reduce acceleration or displacement responses.

Today, many buildings have been constructed near subways or other traffic facilities in inner city areas of the world. Transportation systems generate noise and vibration by the wheel-rail contact of the trains, which is transmitted through the ground and the foundations into the neighboring structures and reduce the quality of life of the people living in. Although seismic isolation systems are effective in reduce the responses of horizontal vibrations such as earthquake, while which are not effective in control of the vertical vibrations resulted from traffic operations. To reduce building responses towards seism and transportation vibration, a special 3D isolation system is necessary to investigate.

Some studies have been carried out for 3D seismic isolation of building so far. Fujita research group tested a 3D device which consists of rubber bearings as the horizontal isolation and coned-disc springs as the vertical isolation for 3D seismic isolation of nuclear power plants ^[1]. Yoo et al invented a 3D base isolator with one integral device which composed of lead rubber bearing and dish springs to isolate the lateral and vertical seismic loads ^[2]. The GERB cooperation adopts spring units and visco-elastic dampers as a vibration isolation system to reduce vibration and seismic response of a building. Yabana researched of thick rubber Bearing for three-dimensional seismic Isolation ^[3].

It is the inherent property of 3D isolation system that has a low natural frequency both in horizontal and vertical direction, so it is hard to control the building rotational motion under the three dimensional seismic actions. To solve the problem, author's group investigated an innovative 3D isolator, and applied the 3D isolation system in a building

above a platform of subway to reduce both metro vibration and seismic response.

2. 3D ISOLATOR

To reduce structural responses both from seism and vibration, it's workable by means of changing the horizontal and vertical natural frequencies to avoid resonance with earthquake ground motions and subways or other traffic facilities vibrations. As indicated in Figure 1, an innovative 3D isolator with the properties is being studied, where 1 is connecting plate, 2 horizontal rubber bearing, 3 middle connecting plate, 4 vertical rubber pad and 5 steel pot. For horizontal seismic isolation, the rubber bearing provides a high degree of horizontal flexibility and the horizontal isolation system gives the overall structure a long nature period. For vertical vibration isolation, the vertical stiffness of rubber pad is more lower as compared to rubber bearing, provided the superstructure with a low vertical natural frequency. It is the vertical deformation uncoupled from lateral that controls the rotation motion of substructure under earthquake by the structure of 3D device.

The mechanism of the 3D isolator has been analytically and experimentally conducted, the horizontal properties are the same as horizontal rubber bearing, and the vertical stiffness K_v can be calculated by the following equation with no horizontal deformation.

$$K_v = \frac{K_{vh} * K_{vv}}{(K_{vh} + K_{vv})} \quad (2.1)$$

Where, K_v is vertical stiffness of 3D device, K_{vh} vertical stiffness of horizontal rubber bearings, K_{vv} vertical stiffness of rubber pad.

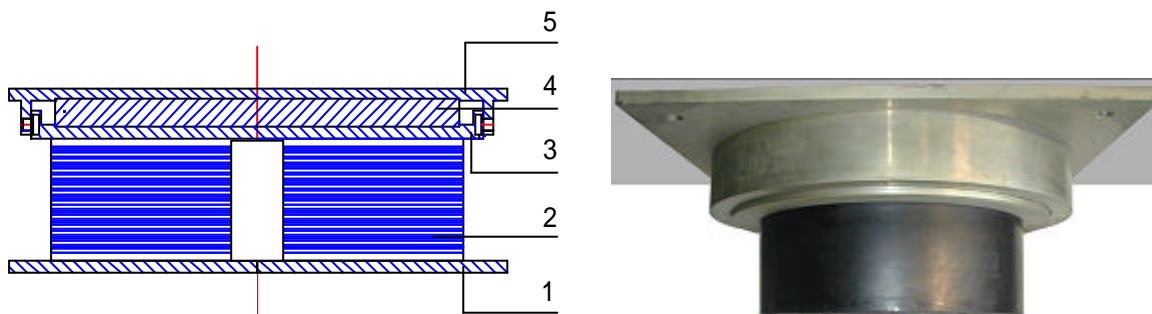


Figure 1 Three dimensional isolator

To verified the properties of 3D isolator, the routine tests of a specimen 600 mm in diameter are carried out. The details of isolator shown in Table 1. For horizontal tests, Figure 2 shows the force-displacement hysteresis loops of the 3D isolator and the horizontal lead-rubber bearing at the test condition of axial load 2800kN(10MPa) and a horizontal amplitude of 120 mm(100% shear strain). For vertical tests, the vertical displacements of 3D isolator, horizontal rubber bearing and vertical rubber pad are measured with vertical compressive stress 10 MPa±30% and the test curves are shown in Figure 3. As indicated in Table 2 the experiment results of vertical stiffness are good agreement with the Eqn.2.1.

Table 1 Details of test piece

	LRB600	VP600
inner rubber plate/mm	24×5 mm=120	5×15 mm=75
inner steel plate n* t_s /mm	23×2.5 mm=52.9	4×2.5 mm=52.9
diameter of hole or lead /mm	100	120
1 st shape coefficient S_1	30	8
2 nd shape coefficient S_2	5	8

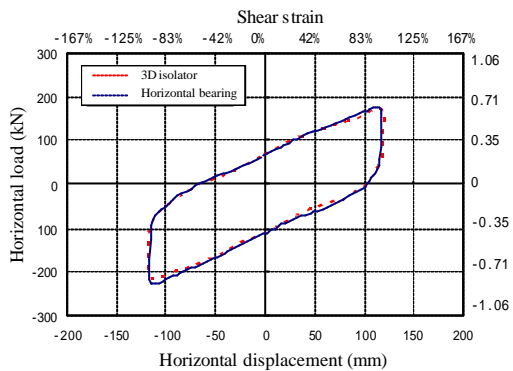


Figure 2 Hysteresis loops of 3D isolator and horizontal lead-rubber bearing

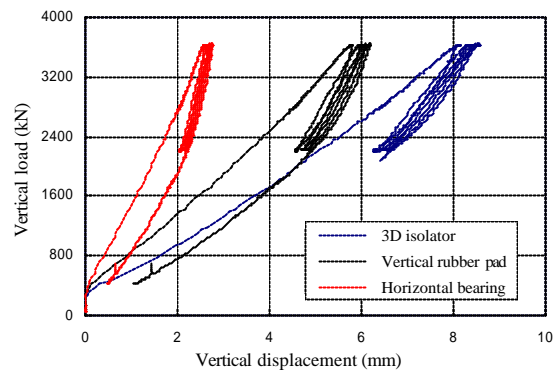


Figure 3 Vertical stiffness curves of 3D isolator, horizontal rubber bearing and rubber pad

Table 2 Test results of vertical stiffness (10 MPa± 30%)

K_{vv} (kN/mm)	K_{vh} (kN/mm)	K_v (kN/mm)
1131	2525	774

To master the performance of 3D isolator under earthquake, the vertical properties are tested with the design compressive force in practice and levels of shear strain, 0%, 50% and 100%. The test results are shown in Table 3. As previously mentioned, the vertical stiffness is very low under no horizontal deformation for vibration condition, however, the vertical stiffness is increased to the level of the horizontal rubber bearing when the isolator subjected to multiple levels of shear displacement, such as caused by earthquakes. This feature is useful to control the rational motion of structure and make it feasible for 3D technique applied in building .

Table 3 Test results of vertical stiffness under different shear strains (5 MPa± 30%)

Shear strain	$\gamma=0\%$	$\gamma=50\%$	$\gamma=100\%$
K_v (kN/mm)	577	2780	3161

3. APPLICATION OF 3D TECHNIQUE

A subway communication hub platform is a 2 stories RC frame structure, with a large size of 1500 m wide and 2000 m long in Peking, China. There are 48 seismic isolation buildings built on it, and two house buildings along the railway adopted the 3D isolation technique for the problems of subway vibration and earthquake action. The superstructure of the 3D isolated building is nine-story reinforced concrete building. The fortification intensity is for Beijing and the site category is . Figure 4 is a photograph showing the 3D isolated building on the platform.

The 3D isolation layer is located on the top of the platform, which consists of 103 rubber bearings in horizontal isolation, and the vertical rubber pad is 700 mm in diameter with the same as the horizontal rubber bearing. Figure 5 and 6 show the isolation layer and the structure of rubber pad. The isolator details are shown in Table 4.

A static routine test of 3D isolator was carried out, the vertical test curve is shown in Figure 7. The vertical stiffness of isolation layer is $37193 \text{ kN}\cdot\text{mm}^{-1}$ and the vertical natural frequency is 8.61 Hz which achieves good isolation for the entire frequency range of vibration.



Figure 4 Photo of buildings on the platform

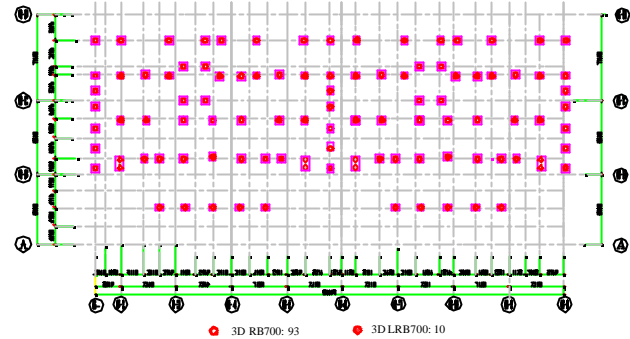


Figure 5 Plan view of isolation layer

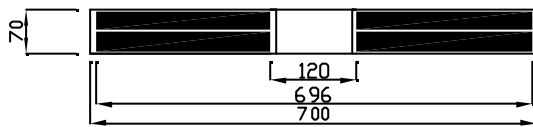


Figure 6 Vertical rubber pad

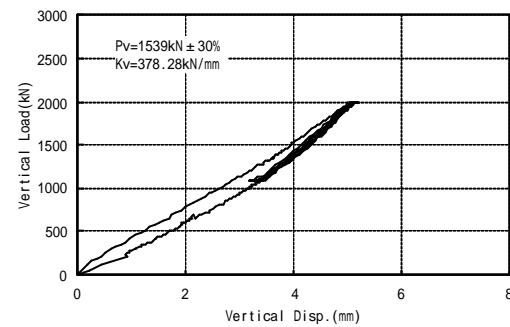


Figure 7 Vertical properties of 3D isolator

Table 4 Details of all isolators

isolator type	diameter of hole or lead	inner rubber plate $n * t_r$	inner steel plate $n * t_s$	1st shape coefficient S_1	2nd shape coefficient S_2
RB700	35 mm	17×7 mm=119	16×2.5 mm	23.75	5.88
LRB700	120 mm	17×7 mm=119	16×2.5 mm	25	5.88
VP700	120 mm	2×29.75 mm=56	3×3.5 mm	4.84	11.7

4. VIBRATION MEASUREMENTS

The in situ comparing tests of isolated and traditional buildings were carried out in 1995, shortly after the completion of the building substructure with not yet used. Figure 8 and 9 show photo of 3D isolator in practice and the measurement points location. The test results show that the natural frequency of the non-isolated structure is 24.7 Hz, however, the entire isolated structure is 11.5 Hz. For the live load no acting and the dynamic vertical stiffness may differing to static test, the test result of isolated building is larger than the design. Acceleration time histories are shown in Figure 10. The acceleration magnitude responses of the isolated super-structure can be reduced to 10% of the sub-structure, with a significant isolation effect, but for the non-isolated building, the super-structure amplify the vibration slightly. The one-third octave vibration spectra measure results are shown in Figure 11 and indicate that the maximum vibration attenuation of the isolated superstructure attend to 25dB in high frequency domain. The metro vibration limit has been met and the 3D isolation system has achieved the expected performance.



Figure 8 Photo of 3D isolator in application

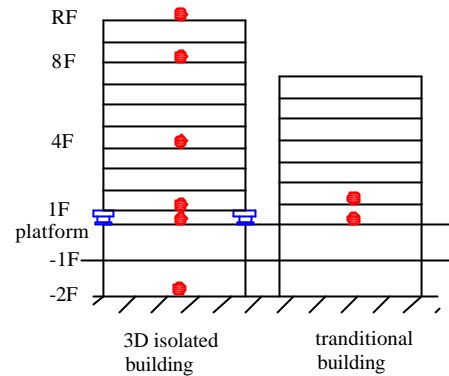


Figure 9 Measurement points location

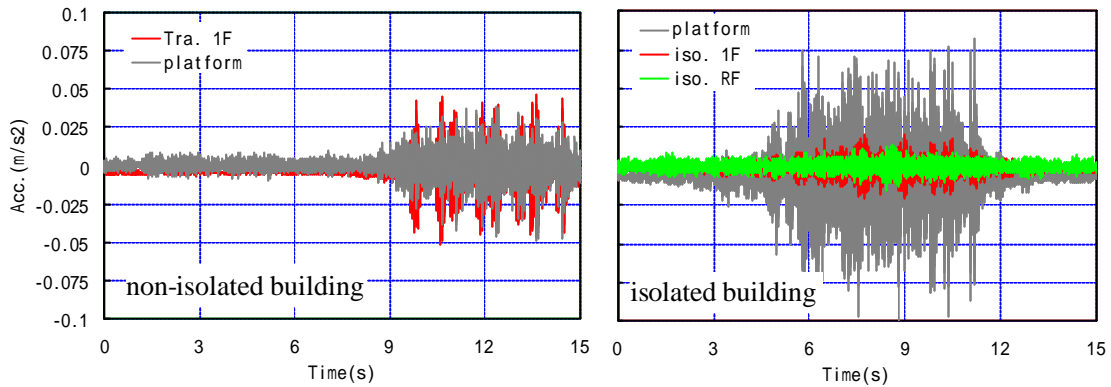


Figure 10 The comparison of acceleration time histories of isolated and non-isolated buildings

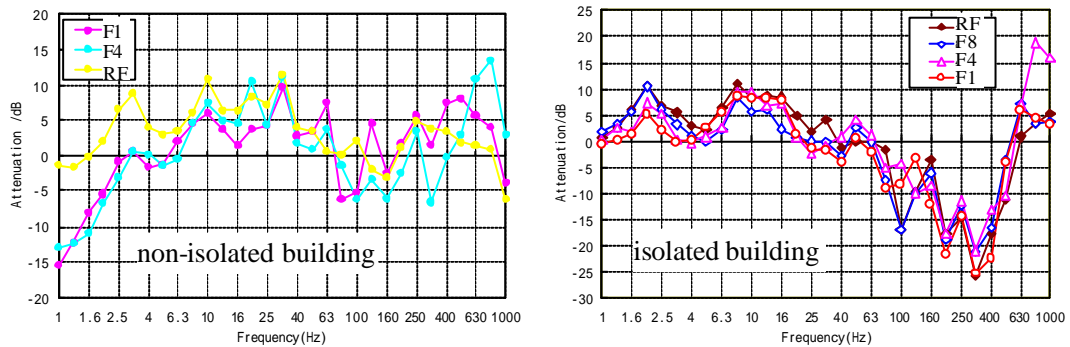


Figure 11 Vibration attenuation to platform

5. CONCLUSIONS

It's effective to uncouple the lateral and vertical deformations for 3D technique in vibration and seismic isolation, the innovative 3D isolator investigated in this paper is achieved the performance to control the rotation action under earthquake by mechanism of the device.

The overall isolation test results of this project are notable by the measured time histories and vibration attenuation values. The 3D isolation system applied in the house buildings in Peking has successfully protected the super-structure form disturbance due to vibration from the metro railway.



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