**MID-STORY SEISMIC ISOLATION DESIGN AND DYNAMIC RESPONSES OF SOHO GINZA**

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**ABSTRACT**

Mid-story seismic isolation design and dynamic analysis are taken for SOHO Ginza, which is located in Suqian City, Jiangsu Province, China. This building is composed of a large podium with two towers. The isolation story sits between the podium and the two towers, which is composed of rubber bearings and viscous dampers. The control index and the detail arrangement of the isolation story are proposed. The finite element model is established and the time-history analysis is taken. The results indicate that under precautionary intensity earthquake, the story displacements and the story shears of the isolated structure decrease compared with those of the non-isolated structure. The story displacements of the podium and towers can meet the criteria under the rare earthquake. It is concluded that the mid-story isolation technology is feasible in the structure of large podium with two towers. And the isolation effects are significant.

*Keywords: mid-story seismic isolation; large podium with two towers; rubber bearing; viscous damper*

**1. INTRODUCTION**

According to the different location of the isolation story, the seismic isolation building can be divided into two categories: Base Isolation Building and Mid-Story Isolation Building. The mid-story isolation building in which the isolation story is set at the top of the first or other stories has many advantages. Chang (2010) summarized that the mid-story isolation building can practically satisfy architectural concerns, potentially facilitate constructions in site and effectively utilize the limited available space. Li (2002), Xu (2005) and Qi (2006) took the numerical analyses and shaking table tests of mid-story isolation building. Loh (2013) made the system identification of mid-story isolation building using both ambient and earthquake response data. Wang (2013) made the test of the dynamic behavior of a building with base and mid-story isolation systems. [Zhou](https://vpn.just.edu.cn/,DanaInfo=apps.webofknowledge.com+OneClickSearch.do?product=UA&search_mode=OneClickSearch&excludeEventConfig=ExcludeIfFromFullRecPage&SID=8BG1xkVTO2FgJG8HgAa&field=AU&value=Zhou,%20Q.) (2016) made the m[odel reduction and optimal parameters of mid-story isolation systems](https://vpn.just.edu.cn/,DanaInfo=apps.webofknowledge.com+full_record.do?product=UA&search_mode=GeneralSearch&qid=4&SID=8BG1xkVTO2FgJG8HgAa&page=1&doc=9). Based on these studies, the mid-story isolation technology is widely researched. It can be used to design the building with large podium and two towers.

In this paper, the mid-story seismic isolation technology is used in a twenty-story building with a large podium and two towers in China. The design principles for isolation story are introduced. The arrangement of the isolation story and seismic responses of the whole building are studied. It is showed that the seismic responses of towers and podium are both reduced significantly.

**2. DESIGN OF PRINCIPLES OF THE MID-STORY SEISMIC ISOLATION BUILDING**

The design principles of the mid-story seismic isolation building which named SOHO Ginza should be illustrated. The SOHO Ginza is composed of a two-story basement, a four-story large podium and two sixteen-story L-type towers. This building is a frame shear wall structure and its total height is 73.7 m. The building is located in a high intensity zone in Suqian City, Jiangsu Province, China. And its design basic acceleration of ground motion is 0.3g. The site characteristic period is 0.35s. The conventional design is difficult. As a result, the mid-story seismic isolation technology is used in this project with comprehensive consideration of seismic precautionary and economy. The isolation story whose height is 1.8m is set between the podium roof and the bottom of two towers. The architectural drawing of SOHO Ginza is shown in Figure 1.

|  |  |
| --- | --- |
| Figure 1. Architectural drawing of  SOHO Ginza | (a) vertical stiffness (b) lateral stiffness  Figure 2. Mechanical models of the lead rubber bearing |

The key aspect of seismic isolation design is the simulation of rubber bearings. Figure 2 (a) gives the vertical stiffness model of rubber bearings. As shown in the figure, the tensile stiffness is much smaller than the compressive stiffness. The lateral characteristic of natural rubber bearing is assumed to be linear because of its lateral stiffness and damping is smaller. Figure 2 (b) gives the lateral stiffness of lead rubber bearing which is simplified to be a bilinear system.

The eccentric ratio of the isolation story is an important factor for seismic isolation design. Japanese norm clearly defined that the eccentric ratio of isolation story cannot exceed 3% in X and Y directions. As a result, the eccentric ratios of the isolation story in two directions *ρx* and *ρy* are calculated by the following equations:

  (1)

  (2)

 (3)

 (4)

 (5)

 (6)

where *Nl*, *i* is long-term axial compression load taken by the *ith* bearing. *Xi* and *Yi* are the coordinates of *X* and *Y* direction of the *ith* bearing. *Kex*, *i* and *Key*, *i* are the equivalent stiffness of *X* and *Y* direction when the *ith* bearing produce a specified displacement *Δ*.

**3. seismic isolation story design of soho ginza**

In order to get a good seismic isolation effect, the isolation story should have four basic characteristics:

(1)  It should have a large vertical load capacity, which can support the superstructure safely;

(2) It should have a variable lateral stiffness. Bigger initial shear stiffness can make the isolation story not yield under wind load and micro-vibration. Smaller post-yielding stiffness can turn the isolation floor into a flexible system which can separate earthquake ground motions effectively;

(3) It should have a elastic restoring force, which makes isolation story reset its position quickly after earthquakes;

(4) It should have sufficient damping. As a result, the total structure can have a greater energy dissipation capacity.

In order to achieve the above requirements, rational distribution of rubber bearings and viscous dampers is essential. Lead rubber bearing should be arranged in the isolation story peripheral to control the torsion. The arrangement of natural rubber bearing can coordinate with the eccentric ratio. Viscous dampers can provide large damping force under major earthquakes, so the dampers can be arranged around the structure to control the torsion.

Based on the layout principles, the arrangement of isolation floor of the mid-story isolated building is shown in Figure 3 and Figure 4. LRB900 denotes lead rubber bearing with a diameter of 900mm. RB1000 denotes natural rubber bearing with a diameter of 1000mm. The parameters of the rubber bearings used in this project are shown in Table 1.

Table 1. Parameters of rubber bearings used in the project

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Type** | **LRB900** | **LRB1000** | **LRB1100** | **LRB1300** | **RB1000** | **RB1200** |
| Area (cm2) | 6107 | 7540 | 9157 | 12821 | 7815 | 11271 |
| Diameter of lead (mm) | 180 | 200 | 210 | 240 | / | / |
| Diameter of center hole (mm) | / | / | / | / | 70 | 70 |
| Number of rubber layers | 30 | 33 | 32 | 37 | 29 | 29 |
| Total thickness of rubber (mm) | 180 | 198 | 224 | 259 | 203 | 203 |
| Thickness of steel plate (mm) | 4.4 | 4.4 | 4.4 | 4.4 | 4.3 | 4.3 |
| The first shape factor | 37.5 | 41.7 | 39.3 | 46.4 | 33.2 | 40.4 |
| The second shape factor | 5.0 | 5.1 | 4.9 | 5.0 | 4.9 | 5.9 |
| Vertical stiffness (kN/mm) | 4415 | 5321 | 5476 | 7325 | 4003 | 6803 |
| Lateral stiffness (kN/mm) | 2.52 | 2.83 | 2.90 | 3.41 | 1.49 | 2.15 |
| Initial stiffness (kN/mm) | 18.12 | 20.34 | 21.72 | 26.20 | / | / |
| Post-yield stiffness (kN/mm) | 1.394 | 1.565 | 1.671 | 2.016 | / | / |
| Yield force (kN) | 202.9 | 250.4 | 276.1 | 360.6 | / | / |
| Number used in the building | 24 | 21 | 8 | 3 | 8 | 5 |

Rubber shear elasticity modulus is 0.392N/mm2

Figure 3 and Figure 4 show the isolation story arrangement of tower A. Fifteen LRB900 (LRB means Lead Rubber Bearing and the diameter is 900 mm), five LRB1000 and eight LRB1100 arrange along the structure of peripheral. Five RB1000 (RB means Natural Rubber Bearing and the diameter is 1000 mm) and two RB1200 arrange along the structure of internal. Figure 4 shows the isolation story arrangement of tower B. Nine LRB900, sixteen LRB1000 and three LRB1300 arrange along the structure of peripheral. Three RB1000 and three RB1200 arrange along the structure of internal. Both two towers arrange eight viscous dampers along the structure of peripheral to control torsion effect.



Figure 3. The isolation story arrangement of Tower A Figure 4. The isolation story arrangement of tower B

Figure 5 and Figure 6 give the restoring force of two towers. As shown in the figures, the isolation story has a large yield force to sustain the wind load. The smaller post-yield stiffness ensures the building a good isolation effect.



Figure 5. The isolation restoring force of Tower A Figure 6. The isolation restoring force of Tower B

According to equation (1) - (6), Table 2 gives eccentric ratios of Tower A and Tower B. Figure 7 and Figure 8 give the schematic diagrams of eccentric ratio of two towers.

The results show that eccentric ratios of two towers are both smaller than 3% in X and Y directions. It is indicate that isolation story is arranged regularly. Gravity center and stiffness center are nearly in the same position. And the towers are in a parallel motion state. So the rubber bearings have sufficient stability and safety to keep the towers in a parallel motion state under earthquakes.

Table 2. Eccentric ratio of the isolation story

|  |  |  |  |
| --- | --- | --- | --- |
| **Parameters** | **Layout direction** | **Tower A** | **Tower B** |
| Center of gravity (m) | X = | 24.628 | 73.576 |
| Y = | 19.769 | 34.698 |
| Center of rigidity (m) | X = | 24.624 | 73.428 |
| Y = | 19.895 | 34.679 |
| Eccentric distance (m) | X = | 0.004 | 0.149 |
| Y = | -0.127 | 0.019 |
| Torsion stiffness (kN/m) | *Kt* = | 2.88E+11 | 3.96E+11 |
| Gyration radius (m) | *Rx* = | 18.201 | 21.075 |
| *Ry* = | 18.201 | 21.075 |
| Eccentric ratio | *ρx* = | -0.007 | 0.001 |
| *ρy* = | 0.000 | 0.007 |

 

|  |  |
| --- | --- |
| Figure 7. Eccentric ratio of isolation story of tower A | Figure 8. Eccentric ratio of isolation story of tower B |

**4. seismic response analysis of mid-story isolation building**

In order to study the seismic behavior of mid-story isolation building, four earthquake ground motions (EGM) were selected to start nonlinear time history analysis. The load cases are bidirectional ground motion input. And primary and secondary direction of ground motion intensity ratio is 1:0.85. In this paper, the seismic responses of isolated and non-isolated building under intensity earthquakes and major earthquakes are investigated. Figure 9 gives the acceleration spectrum of four major earthquake ground motions used in this project.



Figure 9. Acceleration spectrum of major earthquake ground motion

Figure 10 (a) - (d) give the story shears of towers under precautionary intensity earthquake between isolated and non-isolated building. As shown in the figure, the story shears of towers of mid-story isolation building is one third of the non-isolated building.

 

(a) (b)

 

(c) (d)

Figure 10. Story shears of towers under precautionary intensity earthquake

Figure 11 (a) and (b) give the story shears of podium under precautionary intensity earthquake between isolated and non-isolated building. The figure shows the story shears of podium of mid-story isolation building is half of the non-isolated structure. Figure 11 (c) and (d) give the story displacements of podium of mid-story isolation building under precautionary intensity earthquake. The figures show that story drifts of podium are less than 1/1000 in two directions which is from Code for seismic design of buildings (Code for seismic design of buildings 2016 Edition).

 

(a) (b)

 

(c) (d)

Figure 11. Seismic responses of podium under precautionary intensity earthquake

Figure 12 (a) - (d) give the story displacements of mid-story isolation building towers under precautionary intensity earthquake. The figures show that story drifts of towers are less than 1/500 in two directions.

 

(a) (b)

 

(c) (d)

Figure 12. Story displacements of towers under precautionary intensity earthquake

Figure 13 and 14 give the story displacements of mid-story isolation building under rare earthquake. As shown in Figure 13, the story drifts of towers are less than 1/200 in two directions under rare earthquake. Figure 14 shows the story drifts of podium are less than 1/500 in two directions under rare earthquake.

 

(a) (b)

 

(c) (d)

Figure 13. Story displacements of towers under rare earthquake

 

(a) (b)

Figure 14. Story displacements of podium under rare earthquake

Compared with non-isolated structure, story displacements of isolated structure are very small, and the deformations are mainly concentrated in the isolation layer. So the two towers are in a parallel motion under earthquake. story shears of isolated structure are smaller than non-isolated structure. The story shears of two towers are significantly reduced, while the shears of the podium also decrease.

**5. Conclusions**

In this paper, the isolation story design of mid-story isolation building with large podium and two towers is analyzed. And the seismic responses of isolated and non-isolated structures are studied by nonlinear time history method. The conclusions are as follows:

(1) Using the bilinear system to simulate the lateral characteristic of isolation story is reasonable. Variable lateral stiffness ensures the isolation story not yield under wind loads or micro-vibration. And when earthquakes come, the isolation story has a good isolation effect. In the design process, the eccentric ratio of isolation story is an important factor which cannot exceed 3% in X and Y directions. As a consequence, the towers can move in a parallel motion.

(2) Analysis showed that story shears of mid-story isolation building are smaller than the non-isolated building under precautionary intensity earthquake. story displacements of mid-story isolation building are also within the limit.

(3) Story displacement of mid-story isolation building is smaller than interstory drift limit of China code under major earthquakes. The mid-story isolation technology can reduce the seismic responses of the whole structure, when it is used in the structure of two towers and large podium in high-intensity zone. The technology makes the structure in a flexible state and protects the building effectively.

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