Analysis of Seismic Isolation Effect of Rubber Bearings with Different Periods of Isolated Structures

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Abstract. In order to investigate the isolation performance and economic advantages of different period isolation structures, the isolation design and analysis of different period isolation structures are carried out with an office building as the background, and the related structure, structural design and engineering economy are discussed. Time history analysis shows that under the action of 8 degree earthquake, the isolation performance of short-period isolation structure is better than that of long-period isolation structure; engineering economic analysis shows that when the tensile stress exceeds the limit of the isolation bearing, special measures are needed for adjustment. Will result in a substantial increase in project cost.

Keywords: different periods; isolation; time history analysis, economics.

1. Project Overview

The structural model is designed using a drawing of an office building, and the structural system is a frame structure. The isolation layer is proposed to be built on the top of the foundation, and the foundation roof is simultaneously used as the structural embedded surface and the seismic isolation support surface. The structural design has a service life of 50 years, the engineering seismic fortification intensity is 8 degrees (0.2g), and the design earthquake group is the second group. There is no seismogenic fault within 10Km of the site. The site category is Class II, the characteristic period is 0.4, and the characteristic period of the large earthquake is 0.45. The seismic fortification of buildings is Class C. The basic wind pressure of the construction site is W=0.35KN/m², and the rough category of the site is Class B. The structural member concrete strength grade is C30; the reinforcement grade: the beam and column are grade III steel, and the plate and beam and column stirrup are grade I steel. The structure plane and section are shown in Figure 1-1.
2. Six-Layer Isolation Structure Design Process

2.1. Upper Structure Design
Assume that the horizontal damping coefficient is 0.3, and the horizontal damping coefficient of the isolation technology is between 0.27 and 0.4, which can reduce the one-time fortification, that is, the seismic fortification intensity is reduced from 8 (0.2g) to 7 (0.1g). The design method of the superstructure and substructure (or foundation) of the building is not much different from the traditional seismic structure, except that the horizontal seismic action of the superstructure is reduced due to the isolation and has been constructed and calculated. Supplement and adjustment. Therefore, the calculation and layout of the superstructure can be carried out according to Chapter 6 of the Seismic Code.

2.2 Seismic Support Diameter Primary Selection
According to the “Seismic Code”, the average compressive stress limit of rubber-isolated bearings of Class C buildings is 15 MPa, and for structures with seismic fortification intensity of 9 degrees or 8 degrees and horizontal damping coefficient of less than 0.4, it is necessary to consider vertical. Acting on earthquakes. Take the combination of permanent isolation and variable load (1.35×constant...
load+0.98×live load) and consider the combination of vertical seismic action effects (1.0×constant load+0.5×constrained live load +1.3 vertical load) The disadvantages of the working conditions are designed. The diameter of the isolation bearing is φ400mm and φ500mm.

The larger bearing diameter is selected to ensure that the displacement of the isolation layer is less than 0.55 times the effective diameter of the isolation bearing in the rare earthquake, and the diameter of the bearing is determined to be φ500 mm. There are 34 independent columns in the basement, and one support for each column. In order to make the total horizontal yield strength of the isolation layer reach more than 2%, and increase the overall structural torsion resistance, the lead rubber bearing L500G4 is used. The ratio is 5%, and the layout is shown in Figure 2-1, where the rubber shear modulus is 0.392 MPa. The bearing surface pressure is 5.20~12.44MPa, and the basic parameters of the bearing are shown in Table 2-1.

![Figure 2-1. Support arrangement.](image)

### Table 2-1. Basic parameters of the isolation bearing.

| Model   | Effective diameter (mm) | Horizontal initial stiffness (KN/m) | Horizontal yield (KN) | Post-yield stiffness (KN/m) | Equivalent horizontal stiffness (KN/m) | Equivalent damping ratio (%) |
|---------|-------------------------|------------------------------------|-----------------------|-----------------------------|----------------------------------------|-----------------------------|
| L500G4  | 500                     | 9012                               | 50                    | 912                         | 701                                    | 26.5                        |

3. Calculation Model Establishment

3.1. Establishment of Isolation Model

When establishing the basic fixing model (structural modeling), a standard layer with only one column is added, and the height is 300mm. In the SATWE analysis design, the layer column is set as the isolation bearing column, and the calculation of the isolated structure is obtained model.

3.2. Rationality Check

3.2.1. Horizontal Damping Coefficient Since the structure is elastically deformed under the design earthquake, the horizontal spectrum damping coefficient can be calculated by the response spectrum method. The SATWE program is used to generate the two sub-models of the medium-seismic model and the medium-seismic non-isolated model. According to the Earthquake Code, the maximum seismic influence coefficient of the 8 degree (0.2g) mid-seismic level is 0.45, and the envelope calculation is performed to obtain the inter-layer shear force. And the inter-layer overturning moment,
the horizontal damping coefficient is 0.37. Calculated by the formula 12.2.5 of the seismic code, the maximum horizontal seismic influence coefficient of the upper structure basic earthquake is 0.21, and the seismic action of the superstructure is converted to 7 degrees (0.1g) based on structural safety considerations (the horizontal seismic influence coefficient of the basic earthquake is the largest). The value is 0.24, which is designed to be lowered by 1 degree, which is consistent with the initial design.

3.2.2. Checking the Wind Bearing Capacity of the Isolation Layer: The seismic code requires that the total horizontal force generated by the wind load is less than 10% of the total gravity of the structure. The basic wind pressure of the building site is 0.35N/m², and the external wall is added to the structural modeling to calculate the horizontal wind load. The X and Y wind loads are calculated, and the total horizontal force is 986KN, and the total weight of the structure is 57060KN. The total horizontal force generated by wind load and the total weight ratio of the structure are 1.7%, which meets the requirements of anti-regulation.

4. Rare Earthquake Verification

4.1. Selection of Seismic Waves
According to the provisions of 5.1.2 of the Code for Seismic Design of Buildings, the two sets of actual strong earthquake records applicable to Class II sites are selected, namely TH103 and TH010 and a set of artificial waves RH4. In order to test the rationality of seismic wave selection, the bottom shear force under the action of 8 degrees (0.2g) multiple earthquakes was calculated by two methods of time history analysis and mode decomposition reaction spectrum, and the comparison is shown in Table 4-1.

| Types of response spectrum | X direction | Y direction |
|----------------------------|-------------|-------------|
|                            | Base shear (KN) | Time course/response spectrum | Base shear (KN) | Time course/response spectrum |
| Response spectrum          | 2024        | —           | 2030        | —           |
| TH103                      | 2388        | 117.98%     | 2385        | 117.49%     |
| TH006                      | 1476        | 72.92%      | 1490        | 73.40%      |
| RH2                        | 1373        | 67.84%      | 1371        | 67.54%      |
| average                    | 1746        | 86.25%      | 1749        | 86.16%      |

According to Table 4-1, the shear force at the bottom of each seismic wave is greater than 65% of the response spectrum method. The average value of the bottom shear force calculated by the three seismic waves is greater than 80% of the response spectrum method. The selected seismic wave is reasonable.

4.2. Degree Rare Earthquake Check
In order to verify the safety of the superstructure under the action of large earthquakes and the sufficient safety and stability of the isolation layer (maximum horizontal displacement 236.06), the seismic isolation model and the non-isolated structure model are converted to the earthquake with an intensity of 8 degrees (Gmax). Time-history analysis was carried out under the action of | = 400 cm/s². The displacement between layers and the displacement angle between layers were listed in Table 4-2.
Table 4-2. Displacement between structural layers.

| Layer number | X direction Displacement | Y direction Displacement | Inter-layer displacement angle | Inter-layer displacement angle |
|--------------|--------------------------|--------------------------|-------------------------------|-------------------------------|
| 6            | 221.711                  | 140.595                  | 1/1222                        | 1/1959                        |
| 5            | 219.134                  | 138.980                  | 1/766                         | 1/1231                        |
| 4            | 215.010                  | 136.395                  | 1/614                         | 1/984                         |
| 3            | 209.819                  | 133.321                  | 1/638                         | 1/1011                        |
| 2            | 204.656                  | 130.207                  | 1/564                         | 1/887                         |
| 1            | 198.701                  | 126.601                  | 1/530                         | 1/836                         |
| Isolated layer | 191.114                | 121.899                  | -                             | -                             |
| Substructure | 0.118                    | 0.118                    | 1/6757                        | 1/10594                       |

From Table 4-2, under the action of 8-degree rare earthquake: the displacement angle between the layers of the isolated structure changes uniformly, the main formation is the overall horizontal translation, and the inter-layer displacement angle balance is 1/530-1/1222, which satisfies the earthquake resistance. The requirement of less than 1/500 in the specification is basically elastic deformation; the horizontal deformation of the structure is concentrated in the isolation production, and the maximum horizontal displacement is 191.114mm, less than 0.55D=275mm (D is the minimum isolation bearing diameter) and 3Tr = The smaller of 288 mm (Tr is the total thickness of the rubber layer of the minimum isolation bearing). The tensile stress of the bearing is 0.31 MPa, and the maximum tensile stress that meets the requirements of the anti-regulation should not be less than 1.0 MPa. From the above numerical values, it is proved that the isolation layer has sufficient stability and safety, and it is also feasible to surface the model and arrangement requirements of the isolation bearing.

The 9-layer isolation structure and the 12-layer isolation structure are designed under the same conditions, and the design methods and steps are the same as before, and will not be described here.

5. Analysis of Seismic Absorption Effects of Different Period Isolation Structures

The total height of the 6-story isolated building is 19.1m, the total height of the 9-story isolated building is 29.5m, and the total height of the 12-story isolated building is 39.7m. The height of the isolation layer above the isolation layer is 3.4m.

5.1. Horizontal Damping Coefficient

Adjust the horizontal damping coefficient of the isolated building to a similar value to facilitate analysis of the upper structure. By comparing the horizontal building coefficient between the seismic code and the seismic intensity corresponding to the post-isolation structure level, it can be seen that the designed different period buildings are reduced by 1 degree (Table 5-1).

Table 5-1. Horizontal damping coefficient table.

| Analysis model | 6-layer structure | 9-layer structure | 12-layer structure |
|----------------|-------------------|-------------------|-------------------|
| Damping coefficient | 0.37              | 0.38              | 0.37              |

Earthquakes have strong randomness. A seismic wave is only a sample of data obtained from an earthquake. Even in the same earthquake, the seismic records obtained under the same site conditions are different. The seismic response of different seismic waves is input during structural analysis. It is also very different, directly affecting the correctness of the analysis results. Therefore, the same three seismic waves meeting the requirements of the specification are selected, and the time-separated analysis of the isolated structure is carried out.
Table 5-2. Equivalent period of each structure under small earthquake.

| Analysis model | 6-layer structure | 9-layer structure | 12-layer structure |
|----------------|-------------------|-------------------|-------------------|
| Non-isolated   | 0.8493            | 0.8895            | 1.0437            |
| Isolated       | 2.0547            | 2.0754            | 2.4939            |

It can be seen from Table 5-2 that the 6-story isolated structure is extended by 141.93% compared with the non-isolated structure, the 9-story isolated structure is extended by 133.32% compared with the non-isolated structure, and the 12-story isolated structure is extended by 138.95 compared with the non-isolated structure.

5.2. Comparison of the Bottom Shear Force

It can be seen from Table 5-3 that the maximum displacement between the 6-story isolated structure and the non-isolated structure is reduced by 75.28%, and the maximum displacement between the 9-story isolated structure and the non-isolated structure is reduced by 67.00%. The maximum displacement between the layers of the non-isolated structure is reduced by 63.66%. The maximal displacement between the layers of the 6-story isolated structure has the largest reduction. In terms of interlaminar shear, the isolation effect is better than the other two periodic buildings.

Table 5-3. Bottom Shear Force (KN) of each structure under small earthquake.

| Analysis model | 6-layer structure | 9-layer structure | 12-layer structure |
|----------------|-------------------|-------------------|-------------------|
| Non-isolated   | 5.58              | 4.03              | 3.66              |
| Isolated       | 1.36              | 1.33              | 1.33              |
| Maximum displacement between layers of superstructure | 34.82 | 30.11 | 49.50 |
| Inter-layer displacement | - | - | - |

It can be seen from the above analysis that after the isolation layer is installed, the horizontal stiffness of the isolation layer is much smaller than that of the upper structure. Therefore, the deformation of the base isolation structure is mainly concentrated on the isolation layer, and the displacement of the isolation layer is higher than that of the upper part. The displacement of the structure is much larger, which effectively reduces the displacement between the layers of the upper structure during horizontal earthquake action. Compared with the non-isolated structure, the upper structure is approximately similar to the overall motion. However, the short-period isolation building is better than the long-period isolation building, and the isolation effect obtained by the isolation technology is better.

6. Analysis of Isolated Building Structures with Different Periods

Compared with short-period buildings, long-period buildings have obvious overturning effects under horizontal earthquakes. After isolation technology, when subjected to large earthquakes, tensile stress may occur in seismic isolation bearings, and laminated rubber used in engineering. The bearing has a low tensile strength. The problem of the isolation of the isolation bearing has always been one of the main obstacles to the application of seismic isolation technology in long-period construction. The reason why the isolation bearing is pulled can be seen as the overturning force of the horizontal seismic load and the upward force of the vertical seismic vibration exceeding the pressure applied to the support by the self-weight of the structure. Therefore, it is possible to solve the tension problem of the isolation bearing by increasing the gravity load range of the seismic isolation bearing, reducing the overturning force caused by seismic action or using other basic methods of isolation bearing with high tensile strength. In order to make the tensile stress of the isolation bearing not exceed the limit, in the case of not changing the structural plane design and not using the seismic isolation bearing with high tensile strength (to facilitate comparison with short-period buildings), the 12-story isolation structure
is increased. The gravity load on the large bearing reduces the tensile stress of the isolation bearing. The following figures show the standard layer plan and the 12-story isolation structure of the 9-story isolated structure. Standard floor plan.

![Figure 6-1. Plan view of the standard floor of a 9-story isolated building.](image)

![Figure 6-2. Plan view of the 12-story isolated building standard floor.](image)

| Structure       | 6-layer structure | 9-layer structure | 12-layer structure |
|-----------------|-------------------|-------------------|-------------------|
| Maximum tensile stress (MPa) | 0.31              | 0.92              | 3 stairs          |
|                 |                   |                   | 5 stairs          |
|                 |                   |                   | 1.45              |
|                 |                   |                   | 0.85              |

Table 6-1. Maximum tensile stress table of seismic isolation bearing.

It can be seen from Table 6-1 that when the short-period isolation structure reaches the 9th floor (the total height of the building is 29.5m), the tensile stress of the isolation bearing is nearly 1MPa. When the isolated structure reaches 12 stories (the total height of the building is 39.7m), the tensile stress of the isolation bearing is 1.45MPa, which is already exceeded. If the structure is regular, the tensile stress of the seismic isolation bearing generally appears in the corner bearing. Therefore, by adding stairs at the four corners of the building, the gravity load on the corner bearing is increased, and the seismic isolation bearing is increased. The tensile stress is reduced to 0.85 MPa, but this undoubtedly increases the project cost and loses part of the building's use area. However, in terms of safety performance, the addition of stairs has improved the evacuation of personnel.

In summary, the design of long-period isolation structures is more complicated than that of short-period isolation structures.
7. Economic Analysis of Different Period Isolation Structures

7.1. Superstructure Costs
In order to compare and analyze the direct engineering cost of different period isolation structures, in the PKPM software, different period isolation structures are designed according to 8 degrees (0.2g), and the calculation results are used as the main materials in the cost comparison and engineering quantity data. Data such as the base price of materials are derived from the “Architectural and Materials Engineering Price List of Construction and Decoration Engineering Estimates” (2010) and market quotes from suppliers. The material cost comparison of the upper structure of different period isolation structures is shown in Table 7-1.

| Material          | Base price/yuan | 6-layer structure | 9-layer structure | 12-layer structure |
|-------------------|----------------|-------------------|------------------|-------------------|
| C30               | 380            | 1366.7            | 2083.1           | 2870.7            |
| Reinforcement (t) | 4200           | 91.82             | 154.86           | 237.35            |
| Total price / million yuan | -         | 90.5              | 144.2            | 208.8             |
| Total cost / million yuan | -         | 139.23            | 221.85           | 379.64            |

According to engineering experience, multi-storey building materials costs account for 65% of the total cost, and high-rise building materials costs account for 55% of the total cost.

7.2. Seismic Layer Cost
According to the “Basic Seismic Structure Design and Construction Guide”, the cost estimates of China’s isolated isolators and dampers are estimated according to the building area. When the upper structure is a reinforced concrete frame, the price of the laminated rubber isolation bearing is 50 yuan/m². Table 7-2 can estimate the cost of the isolation layer for different period isolation structures.

| Construction area /m² | 6-layer structure | 9-layer structure | 12-layer structure |
|-----------------------|-------------------|-------------------|-------------------|
|                       | 4199.0            | 6298.6            | 8398.1            |
| Total price /million yuan | 21.0          | 31.5              | 42.0              |

7.3 Total Cost of Isolated Structures with Different Periods
It can be obtained from Table 7-3 that the 9-story isolated structure is only increased by 20.64 yuan per square meter compared with the 6-story isolated structure, but the 12-story isolated structure is increased by 106.19 yuan per square meter compared with the 9-story isolated structure. The reason is that the high-rise structure has tensile stress due to the isolation bearing, and it is necessary to make the structure more complicated and consumable design (adding stairs), which leads to a large increase in engineering cost.

| Total cost / million yuan | 6-layer structure | 6-layer structure | 6-layer structure |
|--------------------------|-------------------|-------------------|-------------------|
| 160.23                   | 253.35            | 421.64            |
| Cost per square meter / yuan | 381.59         | 402.23            | 508.42            |

8. Conclusion
The short-period isolation structure is more sensitive to seismic response than the long-period isolation structure, and the isolation effect is superior.
Long-period isolation structure, because the bearing tensile stress exceeds the limit, special measures are needed to adjust the tensile stress of the isolation bearing, the project cost increase is relatively large, so the isolation structure should avoid special measures for the isolation bearing Adjustment of tensile stress.

Acknowledgement
National Natural Science Foundation of China (51578029); Hebei Province Housing and Urban-Rural Development Program (2017-130).