



Design of Friction Pendulum Based on the College Dormitory

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Abstract. In order to meet the normal use requirements of the student dormitory building under the action of fortification intensity earthquake, the friction pendulum seismic isolation design was adopted in this project, and the response spectrum analysis and time history analysis under the action of fortification earthquake were carried out. The analysis results show that the arrangement of the bearing of the seismic isolation layer meets the requirements of wind resistance and eccentricity. The shear force of the structural layer is reduced under the action of the fortification earthquake, and the interlayer deformation and the horizontal acceleration of the floor meet the safety threshold, which meets the function of ensuring the normal use of the building under the action of the fortification earthquake and the fortification target that can be repaired under the action of the earthquake.

Keywords: Friction Pendulum Isolation; Response Spectrum; Normal Level of Use.

1 Introduction

On September 1, 2021, the State Council promulgated Order No. 744 "Regulations on the Administration of Earthquake Resistance of Construction Projects" was officially implemented, Article 16 requires that schools, hospitals, elderly care institutions, and emergency shelters located in high-intensity fortified areas and key earthquake monitoring and defense areas shall adopt seismic isolation technology in accordance with relevant national regulations to ensure that the fortified earthquakes in the region can meet the requirements of normal use.^[1-2] On January 18, 2024, the National Development and Reform Commission, the Ministry of Education and other seven departments jointly issued the "Guiding Opinions on Strengthening the Construction of Student Dormitories in Colleges and Universities", Article 15 requires that seismic safety be strengthened, and new university student dormitory buildings in key earthquake monitoring and defense areas should adopt seismic isolation technology to ensure that the area can meet the requirements of normal use under the seismic action of fortification

intensity. [3-5] Friction pendulum isolation bearing, as a rigid sliding isolation bearing with steel as the main body, has been widely used in engineering since the 1980s. This bearing has significant advantages in self resetting ability, isolation period, torsional resistance, durability, and other aspects. This article analyzes the performance of structural isolation and deformation under seismic fortification, and verifies the seismic reduction effect of friction pendulum bearing isolation technology on student dormitory buildings in high-intensity areas.

2 Selection of Seismic Isolation Schemes

2.1 Project Overview

This project is a student dormitory building of a university in Weinan City, with 9 floors, 1 underground floor, and a building structure height of 40.8m. The main design parameters are as follows: 1) the seismic fortification intensity is 8 degrees (0.2g); 2) the design earthquake is grouped into the second group, class II site, and the site characteristic period is 0.4s under the action of fortification earthquake; 3) the basic wind pressure is adopted according to the 50-year event, which is 0.35kN/m², and the basic snow pressure is adopted according to the 50-year event, which is 0.2kN/m²; 4) The seismic fortification category adopts the key fortification category; 5) The reasonable service life of the structural design is 50 years.

2.2 Determination of Seismic Isolation Scheme

According to the Regulations on the Management of Earthquake Resistance of Construction Projects, the project needs to adopt seismic isolation and damping technology to ensure that the fortification in the region can meet the normal use requirements during earthquakes.

The seismic design is to add energy dissipators to traditional earthquake-resistant buildings, and dissipate the seismic energy input to the structure through the deformation of the energy dissipators. The seismic isolation design is to set up a seismic isolation layer with little horizontal stiffness and great vertical stiffness between the traditional seismic building and the foundation, and reduce the horizontal seismic action input to the superstructure by extending the natural vibration period of the structural system. The change of vertical pressure on the support will alter the recovery force displacement curve of the support, as well as the equivalent stiffness and equivalent radius of the support. To address these effects, a refined model is established, and a limit device is installed at a distance of 160mm from the center to avoid excessive displacement of the sliding block from the support during earthquakes. Compared to above ground structures, due to the constraints of surrounding soil, the deformation of underground structures during earthquakes is generally smaller than that of above ground structures. Friction pendulum mainly achieves shock absorption effect through the swinging of sliding blocks rather than deformation during earthquakes, so the material is usually maintained in the elastic deformation stage. Choose a linear elastic constitutive model to simulate the material properties of the support.

2.3 Determination of the Type of Seismic Isolation Bearing

The main isolation bearings are rubber bearings and friction pendulum isolation bearings. Rubber bearing is a type of bearing formed by high temperature and high pressure vulcanization of thin steel plate layer and thin rubber layer; The friction pendulum isolation bearing is a bearing that realizes the seismic isolation function by extending the natural vibration period of the structure by spherical oscillation and the friction consumption of seismic energy at the sliding interface, and the service life of this project is 50 years, and the rubber bearing has aging problems. The swing period of the friction pendulum isolation bearing depends on the equivalent radius of curvature, has nothing to do with the weight of the seismic isolation building, the steel core of the bearing coincides with the center, there is no need to consider the torsional deformation, the seismic isolation effect is good, and it has the advantages of simple processing, stable performance, good durability, high bearing capacity, and large deformation without damage, so this project adopts the friction pendulum isolation bearing for seismic isolation design.

3 Friction Pendulum Isolation Bearing Design

3.1 Fortified Targets

The basic fortification objectives of this project: when suffering a fortification earthquake equivalent to the basic intensity of the region, the main structure is basically not damaged or does not need to be repaired to continue to use; In the unlikely event of an earthquake, the structure may be damaged and can be repaired to continue to be used.

According to Clause 4.4.6 of the Design Standards for Seismic Isolation of Buildings, it is necessary to classify the performance objectives of the components for the seismic isolation buildings, and the types, compositions and performance objectives of the components are shown in Table 1.

Table 1. Structural component types, composition, and performance targets

Build type	Component composition	Performance targets	
		Medium earthquake	Great earthquake
1 Pier pillars and connected members	The lower pier and the lower pier are connected to the main beam	elasticity	Shear elasticity, bending resistance and no yield
2 Key building blocks	The upper and lower buttresses and the connected main beams	elasticity	---
3 Ordinary vertical members	Columns on the ground floor and above, seismic walls	Shear elasticity, bending resistance and no yield	---
4 Ordinary horizontal members	General frame beams, seismic wall beams	bending without yielding, and considering the super-strength coefficient of the reinforcement	---

3.2 Seismic Isolation Model

The large-scale finite element software ETABS was used to establish the seismic isolation and non-seismic isolation structural models, which were converted from the PKPM model, and the ETABS model is shown in Figure 1.

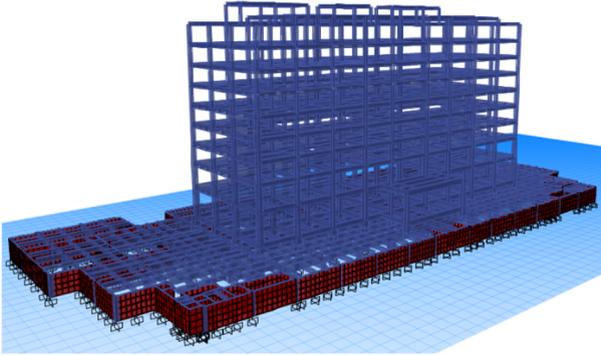


Fig. 1. Schematic representation of the structural finite element model

3.3 Constitutive Design of Friction Pendulum Isolation Bearing

The seismic isolation layer is located between the first floor and the basement floor, and the seismic isolation layer is independent and does not have the function of use. The superstructure system is a concrete frame-shear wall, and the superstructure transfers the load to the upper support plate by means of a conversion beam at the roof of the seismic isolation layer. The basic structure and working state of friction pendulum isolation are shown in Figure 2, the bearing is composed of the upper support plate, the hinged slider, the slide plate, the lower support, when the external load excitation arrives, when the shear force exceeds the static friction force, the slider begins to do a single pendulum movement, the upper and the substructure are separated to weaken the earthquake transmission, the slider and the sliding surface consume a certain amount of energy in the process of contact friction, and after the excitation is over, the upper structure recovers to the initial position under the action of gravity[6-9].

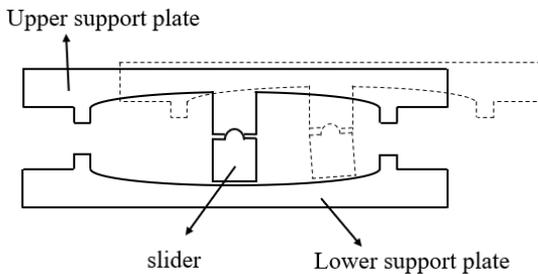


Fig. 2. Friction pendulum isolation bearing

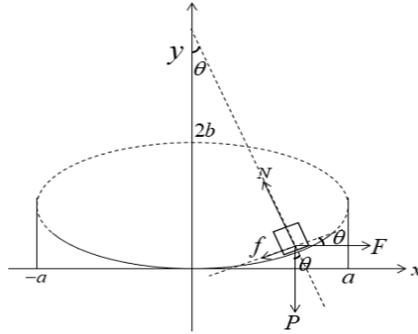


Fig. 3. Schematic diagram of the force of the support slider

The sliding surface of the friction pendulum bearing is an elliptical surface, and the center of the bottom of the sliding surface is the origin of the Cartesian coordinate system, and the elliptic curve is shown in Figure 3, and the functions of the elliptic curve and the elliptical sliding surface are respectively

$$\frac{x^2}{a^2} + \frac{(b-y)^2}{b^2} = 1 \tag{1}$$

$$y = b - \frac{b}{a} \sqrt{a^2 - x^2} \tag{2}$$

where a and b are the lengths of the major and minor semi-axes of the ellipse, respectively. The tangent slope of the elliptical surface in contact with the slider is $\tan \theta = dy/dx$, and the substitution(2) is:

$$\tan \theta = d[b - \frac{b}{a} \sqrt{a^2 - x^2}] / dx = \frac{bx}{a\sqrt{a^2 - x^2}} \tag{3}$$

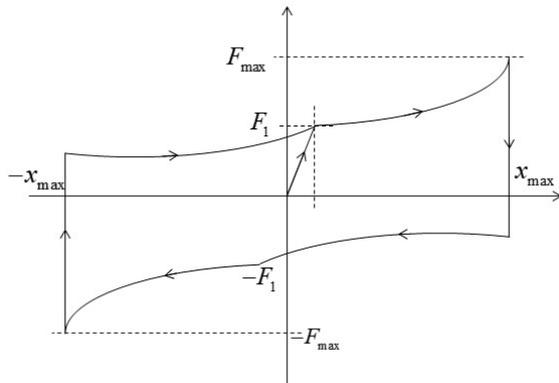


Fig. 4. Support shear-displacement hysteresis curve

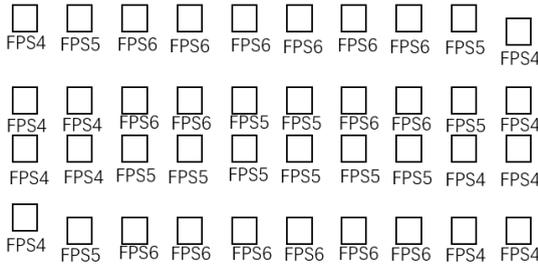


Fig. 5. Diagram of the support arrangement

The slider bears the positive pressure N from the lower support plate, the tangential friction force f , the horizontal force F and the vertical load P from the superstructure, and the force balance equation from the contact surface is:

$$N = P \cos \theta + F \sin \theta \tag{4}$$

$$F \cos \theta - P \sin \theta - f = ma_0 \tag{5}$$

where θ is the chamfer angle of the sliding surface, a_0 is the tangential acceleration of the slider, and m is the mass of the slider. The tangential inertia force of the slider in practice is ignored, and equations (4)(5) can be obtained by ignoring the inertial force:

$$F = P \tan \theta + f \sqrt{1 + \tan^2 \theta} \tag{6}$$

$$N = f \tan \theta + P \sqrt{1 + \tan^2 \theta} \tag{7}$$

The expression formula of sliding friction is $f = \text{sgn}(\dot{x})\mu N$, the expression of sliding friction can be further obtained by simultaneous equation (6), because the slope and dynamic friction coefficient of the sliding surface are much less than 1, so the high power of the slope and dynamic friction coefficient is no longer considered, so the sliding friction can be expressed as:

$$f = \text{sgn}(\dot{x})\mu P \left(\frac{\sqrt{1 + \tan^2 \theta}}{1 - \text{sgn}(\dot{x})\mu \tan \theta} \right) \approx \text{sgn}(\dot{x})\mu P \tag{8}$$

$$\text{sgn}(\dot{x}) = \begin{cases} 1, & \dot{x} > 0; \\ 0, & \dot{x} = 0; \\ -1, & \dot{x} < 0; \end{cases} \tag{9}$$

Where \dot{x} is the first derivative of time and μ is the coefficient of dynamic friction. Considering that the dynamic friction coefficient on the sliding surface is uneven, and the slope and the high power of the dynamic friction coefficient are ignored and do not affect the result, the total shear force of the support can be obtained by substituting the formula (3) and the formula(8) into the formula(6).

$$F(x) = P \tan \theta + \text{sgn}(\dot{x})\mu P = \frac{bx}{a\sqrt{a^2 - x^2}} P + \text{sgn}(\dot{x})\mu(x)P \quad (10)$$

where $F(x)$ is the shear force; $\mu(x)$ is the coefficient of friction, which is related to the position of the slider; $bxP/a\sqrt{a^2 - x^2}$ is the restoring force component; $\text{sgn}(\dot{x})\mu(x)P$ is the dynamic friction component. The static friction needs to be overcome before the support can slide, during this stage, $F(x)$ is proportional to x , and the shear-displacement hysteresis curve of the support under cyclic load is shown in Figure 4. The shear force of the friction pendulum isolation bearing of the building is calculated according to the formula(10), and the support parameters are shown in Table 2. The principle of seismic isolation bearing arrangement: (1) uniform distribution of compressive stress, (2) mechanical performance indexes and deformation indexes meet the requirements of standard design; (3) Maximize the seismic isolation effect, and the seismic isolation bearing arrangement is shown in Figure 5.

Table 2. Mechanical properties parameters of friction pendulum isolation bearings

Bearing model	Vertical loads P (kN)	The equivalent radius of curvature of the support R (mm)	Horizontal displacement of the support D (mm)	Coefficient of dynamic friction μ	Support recovery force (kN)
FPS1a	2000	4800	350	0.02	186
FPS2b	4000	4800	350	0.05	492
FPS3b	6000	4800	350	0.05	738
FPS4b	8000	4800	350	0.05	983
FPS5a	10000	4800	350	0.02	929
FPS6b	12000	4800	350	0.05	1475
FPS7a	14000	4800	350	0.02	1301
FPS8a	16000	4800	350	0.02	1487
FPS9a	18000	4800	350	0.02	1673
FPS10a	20000	4800	350	0.02	1858
FPS11a	22000	4800	350	0.02	2044
FPS12a	24000	4800	350	0.02	2230
FPS13a	26000	4800	350	0.02	2416

4 Analysis of Seismic Isolation Effect under the Action of Fortification Earthquake

4.1 Comparison of Support Periods before and after Seismic Isolation

As shown in Table 3, it can be seen that the period of the structure after seismic isolation is significantly extended, and the period of the structure after seismic isolation is magnified by about 2.21 times, which avoids the excellent period of the site, and the seismic action of the superstructure can be greatly reduced from the perspective of response spectrum. If the difference between the basic period of the seismic isolation house in the two directions is too large, it will lead to a large difference in the seismic isolation effect in the two directions, and it is necessary to limit the error between the two to no more than 30% of the smaller value. It can be seen from Table 3 that after the seismic isolation technology is adopted, the basic period of the two directions is not much different, which meets the requirements.

Table 3. Comparison of the first three periods of seismic isolation and non-seismic isolation structures under the action of ETABS

Mode shapes	Non-seismic isolated (s)	Seismic isolation (s)	ratio	Non-seismic isolation difference in both directions (%)	Difference between the two directions of seismic (%)
1	1.7439	3.5761	2.05		
2	1.5968	3.5330	2.21	9.21	1.22
3	1.495	3.3245	2.22		

4.2 Comparison of the Shear Force of the Structural Layer before and after Seismic Isolation

The evaluation of the damping effect can be determined by the ratio of the maximum layer shear force of the isolated and non-isolated structures under the action of the fortified earthquake, and the shear force of the isolated and non-isolated floors is shown in Figure 6, and the ratio of shear force is shown in Figure 7. As can be seen from Figure 7, the maximum shear force ratio of the bottom of the structure before and after the isolation is 0.493, which is less than 0.5, and it can be concluded that according to Article 6.1.3 of the "Isolation Standard", the structural seismic measures of the upper structure can be reduced by one degree, and the part of the seismic measures below the seismic isolation layer is still used according to the fortification intensity.

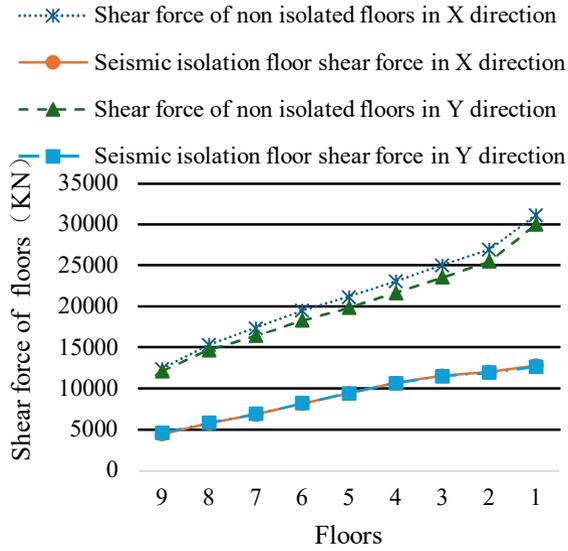


Fig. 6. Seismic isolation and non-seismic isolation floor shear force

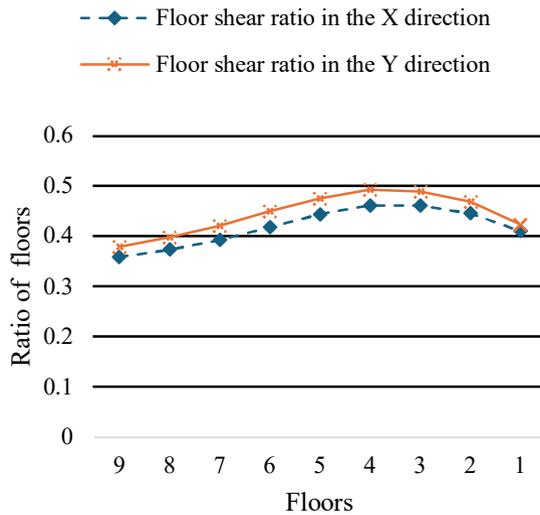


Fig. 7. Ratio of shear force to floor under seismic isolation to non-seismic isolation conditions

4.3 Displacement Angle of the Structural Layer after Seismic Isolation

The inter story displacement angle of the structure under the action of fortification earthquake is shown in Figure 8. It can be seen from Figure 8 that the maximum inter story displacement angle in both directions is less than 1/500, which meets the deformation requirements.

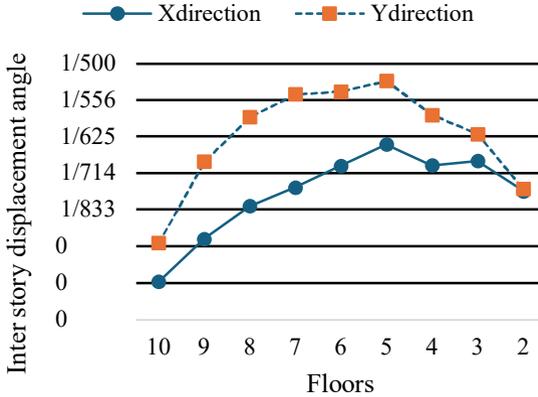


Fig. 8. Inter story displacement angle

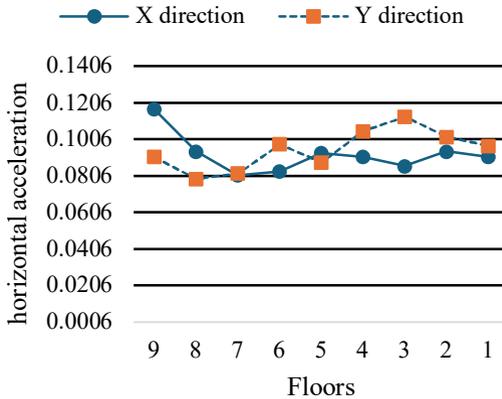


Fig. 9. Horizontal acceleration of the floor/g

4.4 Horizontal Acceleration of the Floor

Figure 9 shows the resulting data for the top-level horizontal acceleration calculated by time history. It can be seen from Figure 9 that the horizontal acceleration of the first floor under the seismic isolation bearing is reduced a lot, and the maximum acceleration

appears on the top floor, which is less than 0.25g, which meets the control requirements of sensitive components for acceleration.

5 Conclusion

In this paper, the dynamic analysis model of the seismic isolation bearing is established based on ETABS and PKPM software for the typical frame structure of the university dormitory, and the seismic performance of the dormitory building under the traditional seismic bearing and friction pendulum isolation bearing is studied, and the seismic isolation effect of the support period, structural layer shear force, structural layer displacement angle and horizontal acceleration on the seismic isolation bearing is discussed, and the following main conclusions are obtained:

(1) By controlling the inter story deformation of the structure, the damage of structural components and non-structural components of the building can be reduced; By controlling the acceleration, the normal operation of the building's non-structural components and equipment can be guaranteed.

(2) The reasonable arrangement of the friction pendulum bearing of the isolation layer can make the isolation bearing meet the surface pressure requirements under the representative value of gravity load, meet the wind resistance requirements of the isolation layer, ensure that the center of mass and the center of rigidity basically coincide, and reduce the eccentricity.

(3) Under the action of fortification earthquake, the structural period under the seismic isolation bearing is extended to about 2.2 times, and the shear force of the structural layer meets the requirements, which greatly reduces the seismic energy input to the superstructure. The structural damage in this project is small, the performance is good, and it meets the requirements of the normal use of the building under the action of fortification earthquake.

(4) In this paper, the damping effect of friction pendulum isolation bearings is studied, but there is no suggestion on the parameter range to optimize the friction pendulum isolation effect.

References

1. Regulations on the management of earthquake resistance of construction projects: State Council Decree No. 744[A]. Beijing: China Rule of Law Publishing, 2021.
2. Guiding Opinions on Strengthening the Construction of Student Dormitories in Colleges and Universities[R]: The National Development and Reform Commission, the Ministry of Education and other 7 departments jointly issued, 2024
3. Qiao-yun, W.U., W. Hong-wei, F. Hai, H. Ying-hong, J. Guo-qiang and D. Lan. 2024. "Frequency based damage identification of laminated rubber isolation bearing," *Journal of Vibration Engineering*, 37 (7): 1230-1238. 10.16385/j.cnki.issn.1004-4523.2024.07.015.
4. Longfei, Z., L. Xiangyu, D. Yiqiao, L. Bang and L. Zhiqiang. "Integrated Design and Performance Analysis of Seismic Isolation Structure for a Special Fortified Building in Kunming City," *J. Earthq. Eng.* 1-11.

5. Hai-long, Z., Z. Yong-liang, Z. You-quan and L. Hai-tao. 2024. "Analysis of vibration isolation effect of friction pendulum bearings on simple-supported girder bridges for high-speed railroad," *Earthquake Resistant Engineering and Retrofitting*. 46 (1): 69-76. 10.16226/j.issn.1002-8412.2024.01.011.
6. Zhiyi, C., J. Peng and L. Zhiqian. 2022. "Parameter analysis of friction pendulum bearings in underground stations during the earthquake," *China Civil Engineering Journal*. 55 (4): 12-22.
7. N, H., Z. Zhipeng, T. Yuanchen, C. Qingjun and D. Yongfeng. Performance design and seismic analysis of negative stiffness-friction pendulum system in soil-to-d interaction systems. in The 33rd National Conference on Structural Engineering. 2024. Fuxin, Liaoning, China.
8. Li, J. and L. Qiqi. Friction pendulum isolation design for college student dormitories based on maintaining building normal functionality. in 2024 Engineering Structure Seismic Technology Exchange Conference. 2024. Kunming, Yunnan, China.
9. Changzheng, S., W. Tingchao, X.U. Yuwang, W.U. Hegao and B. Rui. 2024. "Seismic isolation analysis of exposed steel penstock based on a simplified model of a friction pendulum bearing," *Journal of Tsinghua University (Science and Technology)*. 64 (7): 1126-1135. 10.16511/j.cnki.qhdxxb.2024.26.022.

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