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Analysis and Application of Isolation Layer of a School in Highly Fortified Area

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Abstract. A school complex building is located in an area with a seismic fortification of 8 degrees, with six floors above the ground and two floors below the ground, and has a frame structure. Using YJK calculation program and elastic time history analysis method, the calculation model is established. Through the comparison and verification of the isolated model with the isolated unit and the non-isolated model, the isolation scheme is determined, and the isolation scheme is determined through analysis and research. The isolation layer is arranged on the top of the basement column, and an isolation support is arranged on the bottom surface of each column of the isolation layer to separate the upper structure from the top of the basement column or the top of the beam so as to isolate the seismic energy and reduce the seismic action of the upper structure.

1. Introduction

Isolation is to decouple the building motion and ground motion by using bearings, improve the seismic performance of the building and reduce the horizontal earthquake action of the upper structure. Isolation technology is used to reduce the horizontal earthquake impact coefficient after earthquake isolation. Governments at all levels are paying more and more attention to the safety of school buildings. Relevant standards stipulate that base isolation technology must be adopted in the design of school buildings, student dormitories and other densely populated public buildings with fortification intensity of 8 degrees or above and reconstruction of 4 to 12 floors after disasters. Based on a school complex building project, this paper discusses the feasibility of structural design of isolation layer in 8-degree fortification area, and proposes and determines the layout scheme of isolation layer and isolation bearing.

2. Project Overview

A school complex building construction project, with a construction area of 8,385.83 ㎡, is a cast-in-place reinforced concrete frame structure. The seismic fortification category is Class B. The building height is 23.85 meters, and the indoor and outdoor elevation difference is 0.45 meters. The building has two floors underground and six floors above the ground.

The seismic fortification intensity of this project is 8 degrees, and the designed basic earthquake acceleration is 0.20g. The construction site category is category Ⅱ, the design earthquake is grouped into the third group, and the design characteristic period Tg=0.45s. The peak acceleration is 70.0 cm/s 2 in frequent earthquakes, 200.0 cm/s 2 in fortification earthquakes and 400.0 cm/s 2 in rare earthquakes. This project adopts isolation technology to reduce the horizontal seismic impact coefficient after earthquake isolation to 50% of the standard value.

3. Calculation and Analysis of Seismic Action of Isolated Structures

3.1. Calculation software and calculation method
The program is YJK (version 1.8.1.0) compiled by Beijing yingjianke Software Co., Ltd. The elastic time history analysis method is used to calculate the seismic action of the structure.

3.2. Establishment of computational analysis model
Both isolated and non-isolated structures use spatial finite element models, with the only difference that the isolated model is provided with isolation units at the supports. The three-dimensional diagram of the calculation model of isolated structure established by YJK is shown in Figure 1.

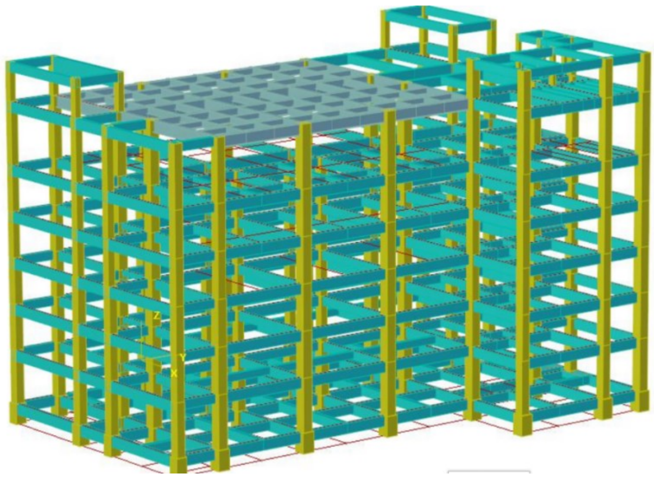


Figure 1. The calculation model of isolated structure built by YJK

The isolation bearing adopts lead-free rubber isolation bearing and lead rubber isolation bearing. For lead-free rubber isolation bearings, the constitutive relation is linear model. For lead rubber isolation bearings, the constitutive relation can be obtained through experiments as shown in Figure 2. In finite element analysis, bilinear model is used to describe the constitutive relation of lead rubber isolation bearings.

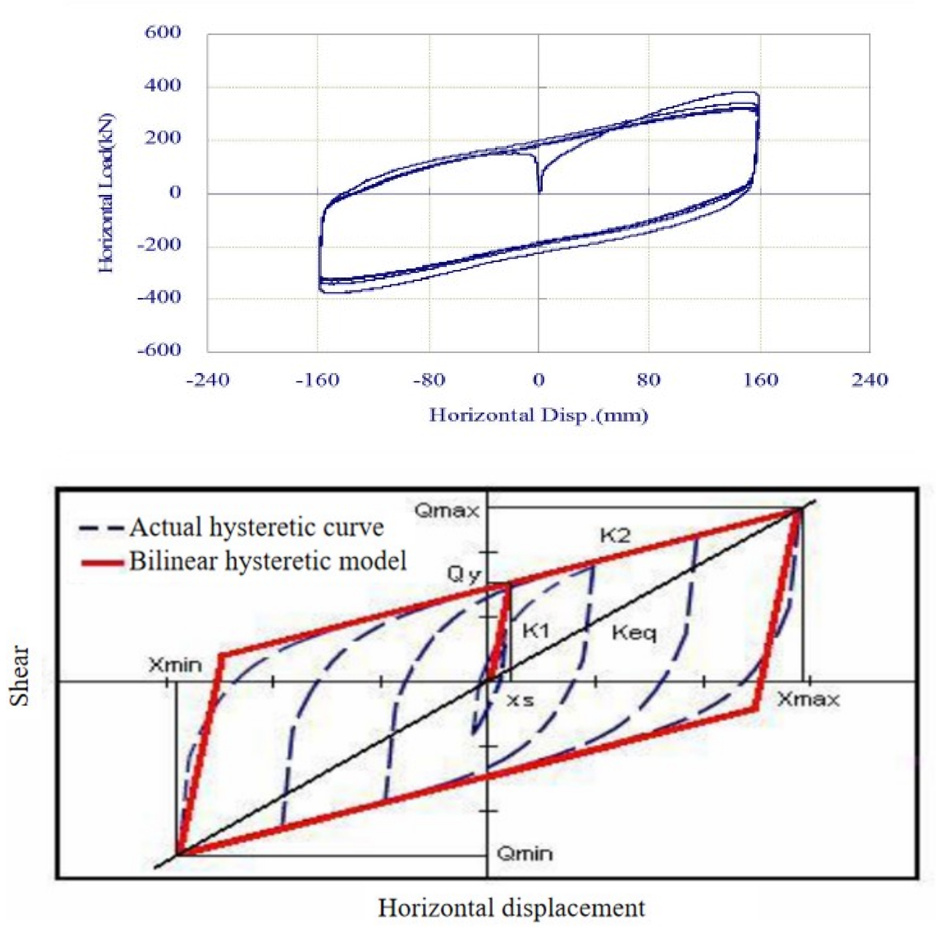


Figure 2. Hysteretic curve and bilinear model diagram of lead rubber bearing

3.3. Verification of conformity of calculation model

In order to ensure the consistency between YJK model used in isolation analysis and calculation and PKPM model used in superstructure calculation by response spectrum method, and to ensure that isolation calculation and analysis structure can effectively act on superstructure, model comparison and verification are carried out. Table 1 shows the comparison of the main parameters of the two models, which shows that the models are in good agreement.

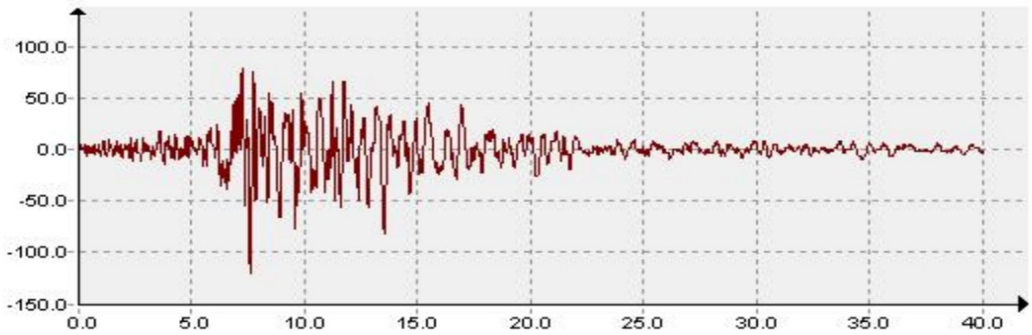
Table 1 Comparison of main parameter characteristics between PKPM model and YJK model

Projects		PKPM model	YJK model	Error
Quality		8956.5	8954.4	0.02%
The first 3 natural vibration periods	T1	1.0465	1.0465	0%
	T2	0.9168	0.9170	0.02%
	T3	0.8817	0.8809	0.09%
Base shear (KN)	X direction	6482.4	6467.1	0.2%
	Y direction	7600.3	7581.1	0.3%

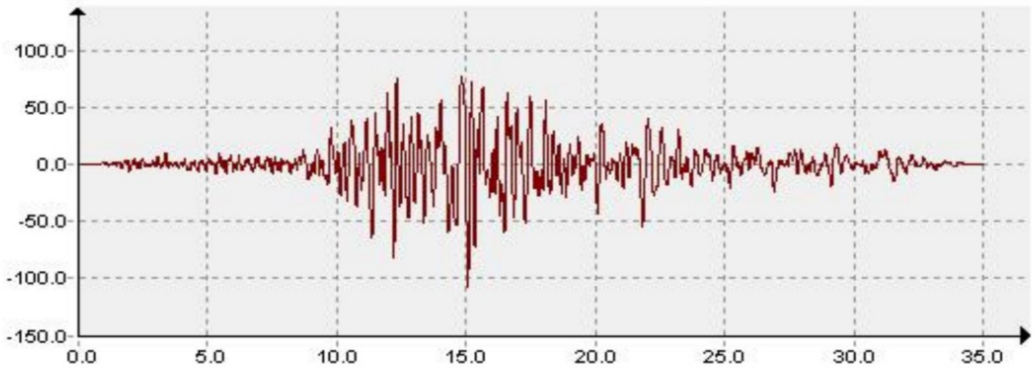
3.4. Selection of seismic waves

The selection of seismic waves in Code for Seismic Design of Buildings GB50011-2010(2016 Edition) shall meet the following requirements: (1) actual earthquake records and artificially simulated acceleration time-history curves shall be selected according to construction site category and design earthquake grouping, wherein the number of actual earthquake records shall not be less than 2/3 of the total; (2) The average seismic impact coefficient curve of multi-group time history curves should be consistent with the seismic impact coefficient curve adopted by the mode decomposition response spectrum method in statistical sense; (3) The calculated bottom shear force of each time-history curve shall not be less than 65% of the calculated results by the mode decomposition response spectrum method, and the average value of the bottom shear force of the structure calculated by multiple time-history curves shall not be less than 80% of the calculated results by the mode decomposition response spectrum method; (4) The duration of seismic wave should not be less than 5 times and 15s of the basic natural vibration period of the building structure, and the time interval of seismic wave can be 0.01s or 0.02s.

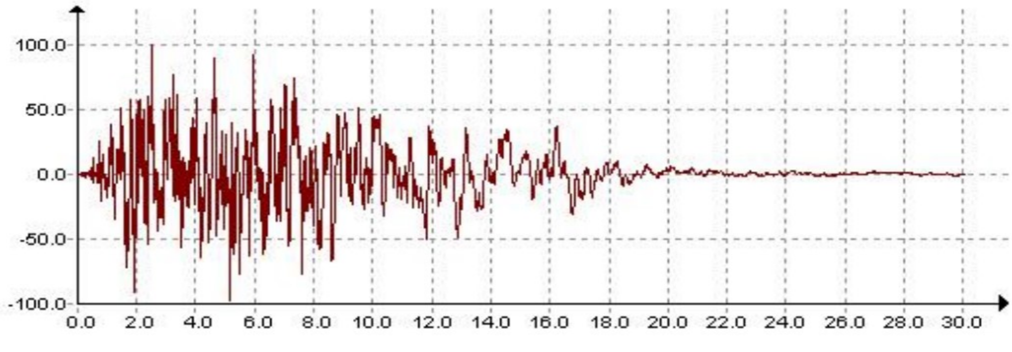
Two natural waves TH1, TH2 and one artificial wave RH1 provided by the software are selected according to the characteristic period of 0.45 seconds that the class II site and the design earthquake are grouped into the third group. See Figure 3 for seismic wave time history curve.



TH1



TH2



RH1

Figure 3 Seismic wave time history curve

The comparison between the response spectrum of the three groups of seismic waves and the standard response spectrum is shown in fig. 4., which basically conforms to the "statistical significance" at the main periodic points. For non-isolated structures subjected to frequent earthquakes, see Table 2. for checking the base shear of the results calculated by time history analysis and response spectrum method. It can be seen that the selection of seismic wave meets the specification requirements.

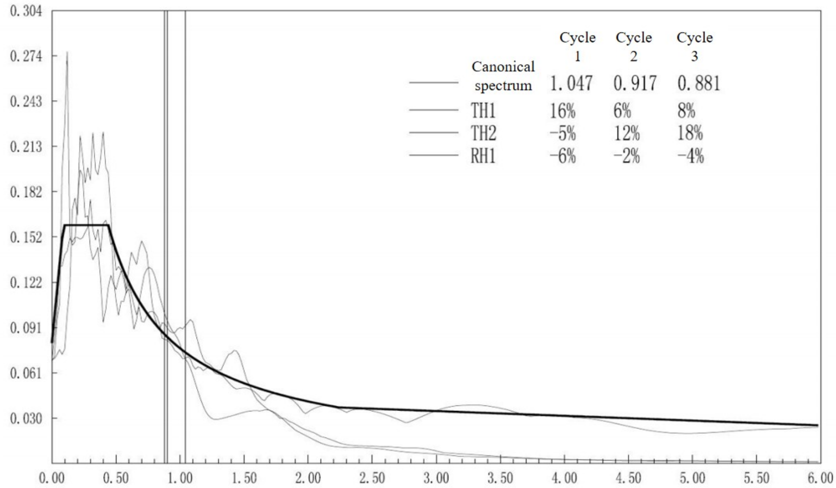


Figure 4 Comparison between normal spectrum and reaction spectrum

Table 2. Time history analysis and base shear check of response spectrum

		Reaction spectrum method	Time history analysis			
			TH1	TH2	RH1	Average
Base shear (KN)	X	6467.1	6544.9	5808.2	5156.5	5836.5
	Y	7581.1	6086.0	7127.0	5895.9	6369.6
Time history analysis/response spectrum (%)	X	--	101	89	79	90
	Y	--	80	94	77	84

3.5. Compressive stress of rubber isolation bearing

The calculation results of vertical compressive stress of rubber isolation bearing under the representative value of gravity load are shown in table 3, which are not more than the limit value of table 12.2.3 in GB 50011-2010(2016 edition) of "code for seismic design of buildings": (class b buildings) 12MPa.

Table 3 Vertical compressive stress of rubber isolation bearing under gravity load representative value

Bearing number	Effective diameter	Pressure (KN)	Compressive stress(MPa)
1	LRB600	1846.9	6.5
2	LRB600	2286.0	8.1
3	LRB700	1993.4	5.2
4	LRB800	1502.0	3.0
5	LRB600	3152.0	11.2
6	LNR700	4309.7	11.2
7	LNR700	3907.2	10.2
8	LRB600	2723.0	9.6
9	LRB700	4272.9	11.1
10	LNR700	3928.4	10.2
11	LNR700	3871.8	10.1
12	LRB700	4147.8	10.8
13	LRB700	4167.9	10.8
14	LNR700	3769.7	9.8
15	LNR700	3711.7	9.6
16	LRB700	4068.8	10.6
17	LRB700	3758.0	9.8
18	LRB900	5432.6	8.5
19	LNR800	5147.9	10.2
20	LRB900	6133.	9.6
21	LRB700	2441.6	6.3
22	LRB600	3012.3	10.7
23	LNR800	5126.7	10.2
24	LRB900	6487.9	10.2
25	LRB700	3413.5	8.9
26	LRB700	2013.3	5.2
27	LRB600	3241.4	11.5
28	LRB700	3445.3	9.0
29	LRB900	2195.3	3.5

4. Seismic Response Analysis of Isolated Structures

According to article 12.2.4 of "code for seismic design of buildings" GB50011-2010(2016 edition), the design parameters of isolation bearings are determined by tests: for the calculation of horizontal damping coefficient, the equivalent stiffness and equivalent viscous damping ratio with shear deformation of 100% shall be taken; For checking computations of rare earthquakes, the equivalent stiffness and equivalent viscous damping ratio when the shear deformation is 250% should be adopted, while the equivalent stiffness and equivalent viscous damping ratio when the shear deformation is 100% can be adopted when the diameter of isolation bearing is large. The equivalent natural vibration characteristics of the isolated structure are estimated by elastic method, and the equivalent stiffness is calculated by the performance parameters when the horizontal shear strain of the isolated support is 100%. Table 4 shows the comparison of natural vibration characteristics between non-isolated structure and isolated structure.

4.1. Natural vibration characteristics of isolated structures

Table 4 Comparison of natural vibration characteristics between non-isolated structure and isolated structure

Mode of vibration	Non-isolated structure			Isolation structure			Periodic amplification factor
	Cycle	Quality participation coefficient		Cycle	Quality participation coefficient		
		X direction	Y direction		X direction	Y direction	
1	1.0465	73.02	0.18	2.5119	97.51	0.3	2.40
2	0.9170	3.59	57.71	2.4643	0.48	97.30	2.69
3	0.8809	4.86	23.77	2.2485	1.17	1.86	2.55

4.2. Horizontal damping coefficient

This project is a multi-storey building. According to the second paragraph of Article 12.2.5 of "Code for Seismic Design of Buildings" GB 50011-2010(2016 Edition), elastic time-history analysis method is adopted. See table 5 for floor shear force X direction and table 7 for Y direction of non-isolated structure and isolated structure calculated according to design basic acceleration input. see table 6 for ratio X direction of floor shear force of isolated structure and floor shear force of non-isolated structure and table 8 for Y direction.

Table 5 Time-history shear of X-direction floors

Floor	X-direction interlaminar shear between non-isolated structure and isolated structure					
	TH1		TH2		RH1	
	Non-isolated structure	Isolation structure	Non-isolated structure	Isolation structure	Non-isolated structure	Isolation structure
7	1692.7	508.4	1648.2	545.7	1366.7	481.1
6	8242.2	2341.0	7202.6	2451.0	5376.2	1844.
5	11947.1	3395.6	11278.9	3857.9	9429.4	3121.1
4	13817.9	3622.6	13446.7	4246.6	11530.8	3845.0
3	17206.0	4287.5	13234.3	4331.3	12650.6	4080.7
2	18712.8	5416.6	14773.4	4979.8	13442.8	4600.1
1	18699.8	5456.4	16594.8	4994.9	14732.7	4942.5

Table 6 Time-history shear of X-direction floors

Floor	X-direction interlayer shear of isolated structure/X-direction interlayer shear of non-isolated structure			
	TH1	TH2	RH1	Maximum value
7	0.3	0.33	0.35	
6	0.28	0.34	0.34	0.35
5	0.28	0.34	0.33	
4	0.26	0.32	0.33	
3	0.25	0.33	0.32	
2	0.29	0.34	0.34	
1	0.29	0.30	0.34	

Table 7 Y-direction floor time-history shear force

Floor	Y-direction interlayer shear of isolated structure/Y-direction interlayer shear of non-isolated structure					
	TH1		TH2		RH1	
	Non-isolated structure	Isolation structure	Non-isolated structure	Isolation structure	Non-isolated structure	Isolation structure
7	2051.3	565.5	2075.6	522.6	1560.2	490.2
6	7937.7	24.1.8	10070.8	2431.1	7104.9	2106.8
5	11832.9	3494.7	14963.8	3507.6	10632.8	3349.9
4	14819.9	3782.4	17699.7	4054.2	13104.4	3902.5
3	16679.5	4232.5	18221.5	3616.3	15136.3	4230.1
2	17273.7	5308.6	19559.7	4296.2	16258.5	5111.4
1	17388.4	5436.9	20362.9	4628.9	16845.3	5354.6

Table 8 Y-direction floor time-history shear ratio

Floor	Y-direction interlayer shear of isolated structure/y-direction interlayer shear of non-isolated structure			
	TH1	TH2	RH1	Maximum value
7	0.28	0.25	0.31	
6	0.30	0.24	0.30	0.32
5	0.30	0.23	0.32	
4	0.26	0.23	0.30	
3	0.25	0.20	0.28	
2	0.31	0.22	0.31	
1	0.31	0.23	0.32	

Through the above calculation and analysis, it is shown that after the isolation support is installed on the top of the basement column, the seismic effect of the superstructure is greatly reduced, the horizontal damping coefficient = 0.35, and the horizontal seismic impact coefficient after isolation is max1max/ 0.35*0.16/0.8= 0.07. Achieve the shock absorption target of this project: the horizontal earthquake impact coefficient is 50% of the standard value of 0.16.

4.3. Checking calculation of bearing displacement under rare earthquake

Time history analysis method is used for displacement calculation under rare earthquake, and two-dimensional input is used for earthquake input. The horizontal displacement limit value of isolation bearings is 0.55 times the effective diameter of each isolation bearing and 3.0 times the total rubber thickness inside the bearing (Article 12.2.6 of Code for Seismic Design of Buildings GB50011-2010). It can be seen from this that under rare earthquake, the maximum deformation of isolation bearing meets the specification requirements.

Table 9 Calculation of deformation of isolated bearings in rare earthquakes

Seismic wave/direction	Maximum horizontal displacement of isolation layer (mm)				Horizontal displacement limit (mm)
	TH1	TH2	RH1	Envelope value	
X direction	67.7	65.1	162.3	162.3	330
Y direction	77.5	74.2	158.7	158.7	330

4.4. Seismic response of isolation layer under rare earthquake

(1) See Table 10 for seismic time-history response of isolation bearing under rare earthquake. The load term is the envelope value of the combination of gravity 17 load representative value and three groups of earthquake time-history response values, P, V, represents axial force and shear force, U represents the maximum displacement of the bearing and represents the vertical stress of the bearing. Positive values of axial force and stress indicate pressure, while negative values indicate tension.

(2) The tensile stress generated by each support under rare earthquake is not more than 1MPa, which conforms to the provisions of Article 12.2.4 of Code for Seismic Design of Buildings GB 50011-2010(2016 Edition).

Table 10 Time-history response of isolated bearing under rare earthquake

Support seat serial number	Effective diameter	Load	P(KN)	Vx(KN)	Vy(KN)	Ux(mm)	Uy(mm)	(MPa)
1	LRB600	Max	2979.71	264.54	247.63	176.34	161.76	10.54
		Min	217.84	-272.51	-261.33	-189.87	-176.15	0.77
2	LRB600	Max	3794.17	262.34	245.75	178.29	159.77	13.43
		Min	74.94	-278.82	-259.84	-191.90	--174.92	0.27
3	LRB700	Max	3534.22	357.56	331.34	177.95	158.75	9.19
		Min	-295.33	-374.27	-350.95	-191.53	-174.19	-0.77
4	LRB800	Max	2628.77	260.16	241.89	176.55	155.29	9.30
		Min	-138.22	-277.36	-257.69	-190.10	-172.39	-0.49
5	LRB600	Max	4291.35	354.22	335.57	172.11	161.84	11.16
		Min	1435.20	-365.30	-353.96	-188.29	-176.24	3.73
6	LNR700	Max	6630.54	387.59	359.33	173.55	159.42	13.20
		Min	2085.90	-430.39	-392.36	-189.83	-174.51	4.15
7	LNR700	Max	5850.92	392.79	357.54	173.66	158.64	11.65
		Min	1960.21	-425.67	-391.34	-189.94	-174.05	3.90
8	LRB600	Max	3837.41	255.28	242.81	172.72	157.02	13.58
		Min	969.02	-277.31	-258.39	-188.95	-173.20	3.43
9	LRB700	Max	6312.63	405.92	395.04	164.82	161.51	12.56
		Min	2322.66	-426.26	-416.71	-186.38	-175.85	4.62
10	LNR700	Max	4779.47	371.58	359.45	166.62	159.84	9.51
		Min	2162.16	-426.95	-394.30	-188.12	-175.02	4.30
11	LNR700	Max	4535.72	377.70	357.39	166.62	158.91	9.03
		Min	2033.10	-420.82	-392.85	-188.12	-174.38	4.05
12	LRB700	Max	6124.11	394.95	387.13	164.86	156.21	12.1918
		Min	2279.54	-437.29	-411.40	-186.42	-172.30	4.54
13	LRB700	Max	6242.86	394.26	395.36	157.34	161.57	12.43
		Min	2231.19	-423.06	-416.64	-184.12	-175.92	4.44
14	LNR700	Max	4658.92	355.07	359.81	159.16	159.87	9.27
		Min	2044.86	-421.59	-394.11	-185.87	-175.05	4.07
15	LNR700	Max	4382.46	361.11	357.59	159.19	158.96	8.72
		Min	1918.30	-415.70	-392.89	-185.91	-174.44	3.82
16	LRB700	Max	5844.98	383.63	386.89	157.35	156.32	11.63
		Min	2185.20	-433.69	-412.04	-184.13	-172.43	4.35
17	LRB700	Max	5312.34	324.83	335.49	150.25	161.92	13.81
		Min	1542.01	-357.45	-354.68	-182.28	-176.35	4.01
18	LRB900	Max	7678.56	612.98	642.27	150.59	158.92	12.08
		Min	2752.91	-714.88	-683.98	-182.67	-173.97	4.33

19	LNR800	Max	6745.25	342.01	356.69	151.04	158.11	13.43
		Min	2565.91	-410.43	-389.69	-183.23	-173.46	5.11
20	LRB900	Max	7125.01	613.23	635.98	150.21	155.43	11.21
		Min	3960.48	-711.55	-673.56	-182.18	-171.44	6.23
21	LRB700	Max	3837.81	236.99	242.42	151.48	154.41	13.58
		Min	235.28	-269.02	-254.39	-183.60	-170.97	0.83
22	LRB600	Max	4311.21	313.28	334.73	143.31	161.73	11.21
		Min	1315.69	-354.02	-354.65	-179.37	-176.12	3.42
23	LNR800	Max	5698.67	368.16	392.20	144.44	160.01	11.34
		Min	3403.65	-423.76	-415.98	-180.70	-175.20	6.77
24	LRB900	Max	7133.43	474.52	496.16	144.22	156.74	11.22
		Min	3683.70	-543.81	-533.81	-180.42	-172.64	5.79
25	LRB700	Max	4834.91	324.64	306.55	143.90	155.21	12.57
		Min	1219.28	-362.38	-350.43	-180.08	-171.86	3.17
26	LRB700	Max	2716.30	227.32	247.17	141.41	161.76	9.61
		Min	-0.76	-261.83	-261.68	-178.96	-176.15	0.0019
27	LRB600	Max	4938.54	305.19	330.96	141.80	158.94	12.84
		Min	695.74	-358.78	-351.48	-179.44	-173.99	1.81
28	LRB700	Max	4796.78	305.15	327.66	141.77	156.07	12.47
		Min	746.24	-358.66	-348.31	-179.42	-171.87	1.94
29	LRB900	Max	3270.16	302.93	325.37	141.49	154.67	8.50
		Min	-346.32	-359.79	-348.05	-179.03	-171.26	-0.90

4.5. Design of substructure of isolation layer

According to article 12.2.9 of "code for seismic design of buildings" GB50011-2010(2016 edition), the bearing capacity of piers, struts and connected components of the isolation layer shall be checked by the vertical force, horizontal force and moment at the bottom of the isolation bearing under rare earthquake of the isolation structure.

Under rare earthquake, the shear standard value and maximum displacement of isolation layer are shown in Table 5.5.1. Figure 3.6.1 shows the load transferred from the support to the lower buttress. In the figure, P is the axial force generated under the design combination working condition when there is a rare earthquake. V is the horizontal shear force (Vx, Vy) generated under the design combination working condition when there is a rare earthquake. U is the horizontal displacement (Ux, Uy) of the isolation bearing under the action of rare earthquake. H is the height of the isolation bearing. The bending moment generated at the bottom of the lower abutment of the isolation bearing is MX

$$M_x = P \times U_x + V_x \times (h + H) \text{、}$$

$$M_y = P \times U_y + V_y \times (h + H)$$

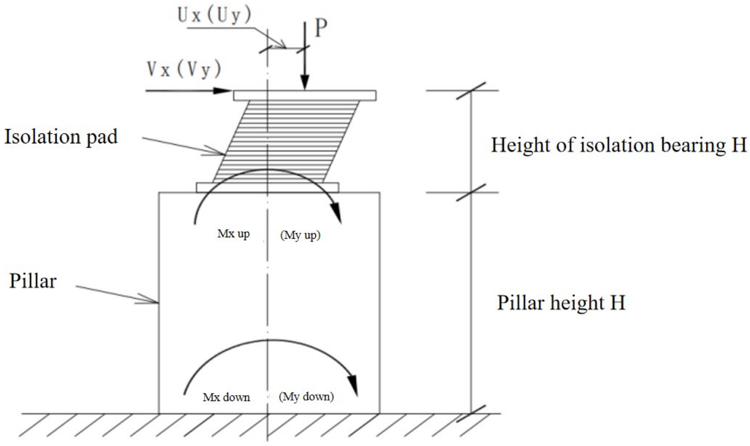


Figure 5 Schematic diagram of design load for substructure of isolation bearing

According to the provisions of "code for seismic design of buildings" GB50011-2010(2016 edition), the axial force p shall be the maximum combined axial force of the column at the top section of the seismic isolation support, and the standard value of shear force v and displacement u shall be the values of 8 degrees (0.20g) in rare earthquakes. the specific values are shown in table 3.5.1. In addition, the relevant components directly supporting the structure above the isolation layer in the structure below the isolation layer shall meet the requirements of the embedded stiffness ratio and the anti-bearing capacity of the earthquake prevention after the earthquake, and the anti-shear bearing capacity shall be checked according to the rare earthquake. (Code for Seismic Design of Buildings GB50011-2010(2016 Edition) Article 12.2.9. Seismic checking calculation and foundation treatment of base-isolated building foundation are still carried out according to the seismic fortification intensity of the region.

5. Application Evaluation and Application Example of Isolation

(1) After the isolation foundation is adopted, the period of the structure is prolonged by 2.13 times, and the earthquake action is greatly reduced; After the earthquake, the horizontal displacement of the structure is concentrated in the isolation layer, the base shear force and interlayer acceleration are greatly reduced, and the structure is translational.

(2) The maximum ratio of shear force between isolated structure and non-isolated structure is 0.35 under seismic fortification intensity.

(3) Under rare earthquake, the deformation value of the isolation bearing is less than the allowable horizontal displacement of the isolation bearing.

(4) The vertical compressive bearing capacity and tensile bearing capacity of the isolation bearing meet the specification requirements and will not overturn.

(5) Precautions for Installation of Isolation Bearings

1) At the bottom of the bearing center elevation deviation is not more than 5mm, plane position deviation is not more than 3mm.

2) The inclination of a single support is not more than 1/300.

3) The installation sequence must conform to the specifications and design requirements.

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