Seismic Isolation Analysis of a Multi-Story Frame Structure

Yong Sun[a], Shaohong Pan and Yanfeng Zhao*
Yunnan Land and Resources Vocational College, Kunming, Yunnan, China
*

Keywords: Foundation Isolation, FNA Method, ETABS.

Abstract: Taking a nursing home in Yunnan Province as an example, this paper analyzes the isolation control of the superstructure with the base isolation measures.Using the convenience of YJK modeling, the structural model is built in YJK, and the YJK-ETABS model is converted through the built-in interface of YJK software.Using the fast nonlinear analysis FNA method, the nonlinear mode integration method is used to analyze the non-isolated and isolated structures under forcing-resistant earthquakes and rare earthquakes respectively. The results show that:Through horizontal deformation, the isolation bearing can effectively dissipate the seismic force, prolong the basic period of the building structure, increase the damping of the overall structure, greatly avoid the characteristic period of the site, and play an obvious filtering effect on the high-frequency energy in the seismic wave.The structural system is changed into a flexible system, and the seismic isolation idea is changed from the traditional hard seismic resistance to soft seismic isolation, thus isolating the seismic energy transfer to the superstructure to a large extent, reducing the structural dynamic response, and achieving the purpose of seismic isolation control.The isolation effect of the superstructure after using the isolation device is remarkable, which can meet the seismic demand of the structure.

1 INTRODUCTION

With the rapid development of China's society and national economy, infrastructure construction has reached a peak period, and the architectural structure has roughly presented several characteristics, such as large-scale construction, large area, large number, structural growth, towering, and complicated.Now facing a problem, most of the complex buildings in large and medium-sized cities have not been tested by large earthquakes, and China is a country with frequent earthquakes, and there are a lot of infrastructure construction close to or across the earthquake fault, there are still a large number of new and old buildings that do not meet the seismic requirements.In the past earthquake disasters, the probability of damage is often low after the installation of isolation devices, that is, it is more safe and reliable, the isolation effect is obvious, and it has a good advantage of earthquake isolation.

Isolation technology is a typical passive control technology. Since its birth in the 1960s, scholars from all over the world have carried out in-depth research on it, making its application more and more extensive. At present, isolation technology has become mature.It was introduced in China in the 1980s. In 1996, Tang Jiaxiang (Tang et al., 1996) described the design method and principle of foundation isolation based on the actual isolation engineering, and compared the final cost of non-isolation engineering built in the same period. The research shows that the use of isolation measures can save 10% of the total cost of the project.In 2001, China wrote the isolation technology into the seismic code, proposed the concept of shock absorption coefficient, and vigorously promoted its use in practical engineering (GB 50011-2001, 2008), in 2004, Qi Ai (Qi et al., 2004) deduced the height to width ratio limit of the foundation isolation structure under different working conditions. In 2010, Liu Haiqing (Liu et al., 2010) showed through research that considering the interaction of soil structure on soft soil foundation can further improve the isolation effect. In 2013, based on the actual isolation effect of the outpatient complex building of Lushan County People's Hospital, Zhou Yun (Zhou et al., 2013) proposed that the isolation guidance method in the 2010 edition of

[a] https://orcid.org/0009-0001-1832-6100

Sun, Y., Pan, S., Zhao and Y.
Seismic Isolation Analysis of a Multi-Story Frame Structure.
DOI: 10.5220/0013581000004671
In *Proceedings of the 7th International Conference on Environmental Science and Civil Engineering (ICESCE 2024)*, pages 145-151
ISBN: 978-989-758-764-1; ISSN: 3051-701X

the Code for Seismic Design of Buildings is effective and reasonable. Li Zengxin (Li et al., 2013) studied the seismic isolation of multi story frame structures, simplified it into a single point model for theoretical analysis, and compared the frame structures before and after seismic isolation using ETABS. Research has found that in multi-layer seismic isolation structures, the horizontal stiffness of the isolation layer decreases, and the upper acceleration response significantly decreases; As the damping ratio decreases, the upper acceleration response also decreases, but the displacement response increases.In recent years, our country is also vigorously promoting the isolation of buildings, this paper combined with a project example, the isolation of a nursing home in Yunnan was analyzed.

2 ISOLATION DESIGN PROCESS

(1) Initially determine the target of seismic isolation fortification, usually by reducing the intensity of fortification by one degree, with the isolation layer as the boundary, which is divided into three parts: substructure, superstructure and isolation layer.
(2) Model conversion: convert YJK model or PKPM model into ETABS model, and make model comparison to compare its quality, period, and floor shear to test the reasonable feasibility of the model.
(3) The ETABS isolation model is established. Under the representative value of gravity load, the isolation model under forced-earthquake is obtained through the reasonable arrangement of rubber isolation supports with lead core and without lead core.
(4) The horizontal damping coefficient is calculated, 7 seismic waves are selected, and elastic time history analysis and FNA time history analysis are carried out on the medium earthquake non-isolation model and the medium earthquake isolation model respectively.The ratio of shear force and overturning moment before and after seismic isolation is calculated. Finally, the maximum ratio of the two above the seismic isolation layer is taken as the damping coefficient.
(5) Judging whether the fortification target is satisfied by the horizontal damping factor.
(6) Check calculation of isolation support, check whether the tensile stress, compressive stress and displacement index of isolation support meet the requirements of the code, and use the obtained support reaction force to reinforce the pier.

3 VERIFICATION OF ETABS ANALYTICAL MODEL

The project is a multi-storey frame structure nursing home, a total of 7 floors, of which, six floors above the ground, an underground basement (isolation layer) 4.2m high, the first layer is 5.4m high, the rest are 3.6m high, building height: 23.70m.The fortification intensity is 0.3g, the earthquake group is the third group, the fortification category is the key fortification category (Class B), the construction site category is Class III, the characteristic period is 0.65s, and the earthquake resistance is unfavorable.
In this project, a large finite element software ETABS is used to establish the model of isolated and non-isolated structures, and the calculation and analysis are carried out.The ETABS software has convenient and flexible modeling functions and powerful linear and nonlinear dynamic analysis functions, in which the connection unit can accurately simulate the rubber isolation bearing.The structure model is based on YJK modeling.The ETABS model is shown in Figure 1.

In order to verify the accuracy of the ETABS model, the mass, period and seismic shear calculated by EATBS and YJK non-isolation models are compared, as shown in the following table (Tables 1-3). The error algorithm in the table is as follows:

$$\text{Error} = (|\text{ETABS-YJK}|/\text{YJK})*100\% \quad (1)$$

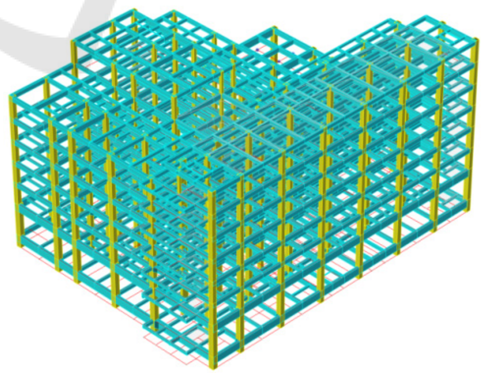

Figure 1: Structure 3D model diagram.

Table 1: Quality comparison of non-isolated structures.

YJK(ton)	ETABS(ton)	Difference value(%)
16388.797	16267.01	-0.74

Table 2: Cycle comparison of non-isolated structures.

Mode of vibration	YJK(s)	ETABS(s)	Difference value(%)
1	1.0255	1.0311	0.55
2	0.982	0.9824	0.04
3	0.8418	0.8413	-0.06

Table 3: Comparison of seismic shear forces of non-isolated structures under multiple earthquakes.

Number of floors	YJK(kN)		ETABS(kN)		Difference value(%)	
	X	Y	X	Y	X	Y
7	881.73	889.59	722.46	731.44	-18.06	-17.78
6	3729.07	3855.83	3661.08	3774.89	-1.82	-2.10
5	5939.85	6168.07	5923.98	6133.78	-0.27	-0.56
4	7761.7	8086.79	7802.58	8104.09	0.53	0.21
3	9868.31	10281.25	9960.49	10373.38	0.93	0.90
2	11019.27	11488.77	11138.72	11608.75	1.08	1.04
1	12189.5	12724.01	12291.83	12839.73	0.84	0.91
Isolation layer	12451.38	13000.16	12554.16	13126.99	0.83	0.98

It can be seen from the above table that the structural mass, calculation period and seismic shear force (except the top layer) of ETABS non-isolated structure model and YJK model have little difference.Therefore, ETABS model, as a finite element model for seismic isolation analysis of this project, is accurate and can reflect the basic characteristics of the structure.

4 SUPPORT ARRANGEMENT

The foundation isolation method is adopted, and the basement is used as the isolation layer. Considering the near-field amplification effect, three types of supports, namely lead core rubber bearing LRB1000, LRB900 and natural rubber bearing LNR900, are adopted after repeated trial and calculation from the aspects of economy, rationality and feasibility. The mechanical performance parameters of rubber isolation supports are shown in Table 4. Its support layout is shown in Figure 2. Among them, the following principles are mainly followed when the isolation bearing is arranged:

(1) The Code for Seismic Design of Buildings (GB50011, 2010) stipulates that the compressive stress value of the isolation mat under the representative value of gravity load should be uniform, and should not exceed the limit value of 12Mpa for Class B buildings.

(2) In rare cases, the isolation pad should not be in a tension state, and when it is inevitable, its tensile stress should be checked to make it less than the limit value 1.0MPa, so as to control the isolation support will not be damaged by tension.

(3) In rare cases, the horizontal displacement of the isolation support should not be too large and exceed the limit value, the limit value is min(0.55D, 3Tr), D: the minimum isolation mat, Tr: the total thickness of the rubber layer).

Table 4: Mechanical property parameters of rubber isolation bearing.

Design parameter		symbol	unit	With lead core isolation support	Lead-free isolation mount	Lead-free isolation mount
				LRB900	LRB1000	LNR900
Quantity used		N	piece	37	4	16
First form factor		S1		36.9	37.0	35.0
Second form factor		S2		5.27	5.49	5.27
Design bearing capacity (12MPa)		P0	KN	7634	9425	7634
Vertical compression stiffness		Kv	KN/mm	4450	5150	3850
γ100	Yield force	Qd	KN	141.3	171.1	

%	Post-yield stiffness	K2	KN/mm	1.289	1.491	
	Horizontal equivalent stiffness	Kh	KN/mm	2.116	2.429	1.283
	Equivalent damping ratio	heq	%	24.9	24.6	
Γ25 %	Yield force	Qd	KN	149.4	180.9	
	Post-yield stiffness	K2	KN/mm	1.082	1.252	
	Horizontal equivalent stiffness	Kh	KN/mm	1.445	1.654	
	Equivalent damping ratio	heq	%	16.0	15.5	
Total thickness of rubber layer		Tr	mm	165	180	165
Total support height		H	mm	344.0	380	344.0

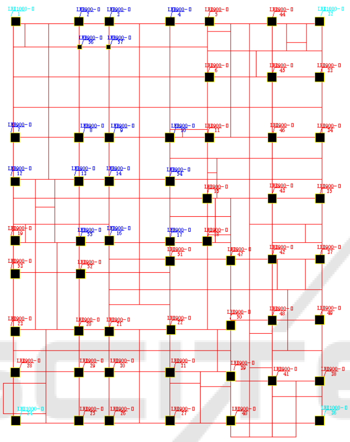
Figure 2: Support plane layout.

Table 5: Comparison of structural natural vibration period before and after isolation.

Mode of vibration	non-isolation(S)	Shock isolation(S)	Difference in X and Y directions(%)	
			non-isolation	Shock isolation
1	1.0311	2.6081	4.96%	0.53%
2	0.9824	2.5945		
3	0.8413	2.0214		

5 ISOLATION ANALYSIS

5.1 Comparison of Natural Vibration Period of Structure before and after Isolation

By comparing the period of the building structure before and after earthquake isolation, it can be found from Table 1 that the isolation bearing significantly amplifies the period of the overall structure and becomes a flexible system. Among them, the first period extends from 1.0311s to 2.6081s, enlarging 2.53 times, effectively avoiding the characteristic period of the site of 0.65s, thereby inhibiting the dynamic response of the superstructure and isolating part of the earthquake energy (Table 5).

5.2 Isolation Analysis under Multiple Earthquakes

When using the time-history analysis method, the actual strong earthquake records and artificial simulated acceleration time-history curves should be selected according to the type of building site and the design earthquake group, in which the number of actual strong earthquake records should not be less than 2/3 of the total number, and the average seismic impact coefficient curves of multiple groups of time history curves should be statistically consistent with the seismic impact coefficient curves adopted by the response spectrum method of vibration mode decomposition.In this paper, 2 groups of artificial waves and 5 groups of actual seismic records are selected. Among them, the comparison between the response spectrum curve of standard design and 7 time-history wave response spectra and their average values is shown in Figure 3, and the time-history curve is shown in Figure 4. By using ETABS software, the linear modal time-history analysis of the non-isolated structure is carried out, and the base shear is compared.

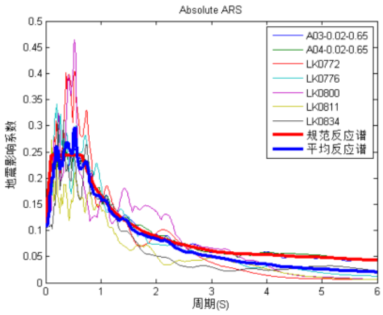

Figure 3: The average of 7 time history response spectra and the standard response spectrum curve.

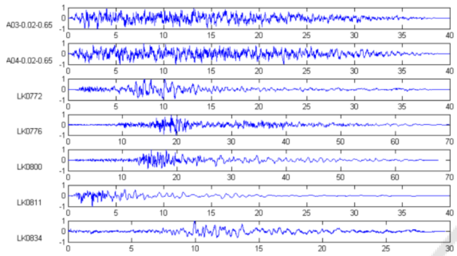

Figure 4: Time history curve.

5.3 Analysis of Isolation under Fortification of Earthquake

In the design of the isolation layer of this project, the influence of vertical seismic action is considered, and the isolation supports are arranged according to the principle of meeting the vertical bearing capacity in part and as a whole. After review, the isolation supports meet the relevant requirements of the Code for Seismic Design of Buildings and the Technical Regulations for Isolation of Laminated rubber Supports (CECS 126, 2001). The shear ratio and bending moment between layers under earthquake protection are shown in Table 6 and Table 7:

Table 6: The maximum values in the X, Y, and X/Y directions——Inter story shear ratio of non isolated and isolated structures.

Interstory shear force of isolated structure								Shear ratio between isolated and non-isolated layers								
R1	R2	T1	T2	T3	T4	T5	X-AVE	R1	R2	T1	T2	T3	T4	T5	Y-AVE	X,Y-MAX
0.15	0.16	0.10	0.07	0.12	0.19	0.08	0.13	0.15	0.14	0.10	0.08	0.16	0.22	0.07	0.13	0.13
0.18	0.18	0.12	0.09	0.14	0.22	0.10	0.15	0.16	0.16	0.12	0.09	0.19	0.24	0.08	0.15	0.15
0.20	0.20	0.13	0.11	0.16	0.24	0.11	0.16	0.18	0.17	0.13	0.10	0.20	0.25	0.09	0.16	0.16
0.24	0.22	0.14	0.13	0.19	0.26	0.13	0.19	0.20	0.20	0.14	0.12	0.23	0.28	0.11	0.18	0.19
0.28	0.26	0.17	0.15	0.24	0.29	0.14	0.22	0.24	0.25	0.15	0.14	0.27	0.31	0.13	0.21	0.22
0.29	0.28	0.19	0.17	0.25	0.31	0.16	0.23	0.27	0.29	0.16	0.17	0.27	0.32	0.15	0.23	0.23
0.30	0.32	0.23	0.18	0.27	0.35	0.18	0.26	0.32	0.33	0.18	0.20	0.29	0.35	0.17	0.26	0.26
0.36	0.39	0.28	0.22	0.32	0.43	0.22	0.32	0.39	0.39	0.22	0.24	0.34	0.42	0.20	0.32	0.32

Table 7: The maximum values in the X, Y, and X/Y directions——The ratio of interlayer bending moment between non isolated and isolated structures.

Interlayer bending moment of isolated structure								Interlayer bending moment of isolated structure								
R1	R2	T1	T2	T3	T4	T5	X-AVE	R1	R2	T1	T2	T3	T4	T5	Y-AVE	X,Y-MAX
0.13	0.13	0.09	0.06	0.14	0.19	0.07	0.12	0.18	0.15	0.11	0.08	0.13	0.20	0.09	0.13	0.13

0.16	0.16	0.12	0.09	0.18	0.24	0.09	0.15	0.18	0.17	0.13	0.08	0.13	0.21	0.10	0.14	0.15
0.17	0.17	0.13	0.10	0.20	0.25	0.09	0.16	0.18	0.18	0.12	0.09	0.14	0.22	0.10	0.15	0.16
0.19	0.18	0.14	0.11	0.21	0.26	0.10	0.17	0.20	0.19	0.13	0.10	0.15	0.23	0.11	0.16	0.17
0.21	0.20	0.15	0.12	0.24	0.29	0.12	0.19	0.24	0.22	0.14	0.12	0.18	0.25	0.13	0.18	0.19
0.23	0.23	0.15	0.13	0.27	0.31	0.13	0.21	0.27	0.25	0.15	0.14	0.21	0.27	0.13	0.20	0.21
0.26	0.27	0.17	0.15	0.28	0.33	0.15	0.23	0.30	0.27	0.17	0.16	0.26	0.29	0.15	0.23	0.23
0.27	0.29	0.17	0.16	0.29	0.34	0.16	0.24	0.31	0.29	0.18	0.16	0.27	0.31	0.16	0.24	0.24

As can be seen from the above table, the ratio of shear force before and after isolation of building structure is mainly calculated under earthquake prevention, and the ratio of overturning 6 bending moments is also needed to be calculated for high-rise building structures.The maximum ratio except the isolation layer is selected as the final horizontal damping coefficient 0.26. Considering the effect of near-field amplification, the horizontal seismic effect influence coefficient of the building structure can be obtained by the formula as 1.5×0.24×0.26/0.85 = 0.110.Considering comprehensively, the horizontal seismic influence coefficient of the structure is 0.12, which meets the requirement of lowering the fortification intensity by one degree.

5.4 Analysis of Isolation under Rare Earthquakes

The vertical seismic force of this project is 0.3 times the representative value of gravity load.Under rare earthquakes, the load combinations are selected as follows:

①Displacement calculation:

1.0×Dead load ＋ 0.5×live load ＋ 1.0×horizontal seismic action，i.e.1.0D+0.5L＋1.0 Fek；

②Tensile stress calculation:

1.0×Dead load±1.0×horizontal seismic action － 0.5×Vertical seismic action，

i.e.1.0D ±1.0 Fek -0.5×0.3×(1.0D+0.5L)=0.85D-0.075L±1.0Fek。

③Compressive stress calculation:

1.0×Dead load+0.5live load+1.0×horizontal seismic action+0.5×Vertical seismic action，

i.e.1.0D+0.5L+1.0Fek+0.5×0.3(1.0D+0.5L)=1.15D+0.575L+1.00Fek；

④Shear force and axial force calculation:

1.2(1.0×Dead load ＋ 0.5×live load) ＋ 1.3×horizontal seismic action+0.5×Vertical seismic action，

i.e.1.2(1.0D+0.5L)+1.3 Fek +0.5×0.3×(1.0D+0.5L)=1.35D+0.675L+1.3 Fek；

The calculation results show that under rare conditions, the most unfavorable horizontal displacement in both directions (X, Y) of the isolation support is 480mm, which is less than the horizontal displacement limit of the isolation mat of this project of 495mm, and there is a certain safety reserve space to ensure that the isolation device can isolate and dissipate most of the seismic energy and achieve the expected isolation target.

Under rare conditions, some side supports are strained, and the maximum tensile stress value is 0.33MPa<1MPa.The maximum compressive stress is 13.39MPa<30MPa, that is, both tensile and compressive stresses meet the specifications, indicating that the isolation performance of the large-diameter isolation mat will not be damaged due to excessive tension.

6 CONCLUSIONS

This paper describes the basic flow and steps of seismic isolation analysis, and provides some empirical guidance for the isolation of multi-story frame structures.The results show that:

(1) After the isolation technology is adopted, the isolation bearing extends and amplifies the basic period of the structure, effectively avoids the high-frequency part of the seismic wave, weakens the isolation earthquake action, and thus reduces the structural response.The section of the component is reduced, the building space is increased, and the total cost of the project is saved.

(2) The isolation device dissipates seismic energy through deformation and isolates seismic transmission. The upper main structure is in a

flexible working state, and the movement is mainly translational.

FUNDING RESOURCES

Scientific Research Fund project of Yunnan Education Department in 2023(2023J1611);
The second batch of vocational education teacher teaching innovation team in Yunnan Province - Civil engineering inspection technology professional team of Yunnan Land and Resources Vocational College.

REFERENCES

Tang, J., Li, L., Li, Y., et al., 1996. Design and Research of Base-Isolated Building with Laminated Rubber Bearings[J]. *Journal of Building Structures*, (02): 37-47+79.

GB 50011-2001, 2008. *Code for Seismic Design of Buildings*[S].

Qi, A., Fan, H., 2004. Research on the height-width ratio of base isolated structure[J]. *Journal of Building Structures*, (06): 52-58.

Liu, H., Sha, Z., 2010. In fluence of soil-structre dynamic in teraction on isolation effect of lead-rubber bearing[J]. *Earthquake Engineering and Engineering Vibration*, 30(03): 161-165.

Zhou, Y., Wu, C., Zhang, C., Yang, G., 2013. Analysis and design of seismic isolation structure in outpatient building of the Lushan County People's Hospital[J]. Building Structure, 43(24): 23-27.

Li, Z., Dong, Y., 2013. Analysis on frame structure with base isolation[J]. *Building Structure*, 43(S2): 395-398.

GB50011, 2010. *The 2016 edition of the Code for Seismic Design of Buildings*.

CECS 126, 2001. *Technical specification for seismic-isolation with laminated rubber bearing isolators*.