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Research on Structural Design of an isolated High-Rise Building with Enlarged Base and Multiple Tower Layer in High Intensity Area

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Abstract: In the high intensity areas, the application of interlayer spacing technology can achieve the unity of quality and seismic performance of high –rise buildings with enlarged base and multiple tower layers. Through the comparison and analysis of structural schemes of an enlarged base multiple tower- layer high rise building, the ultimate seismic isolation scheme was adopted, and its seismic response and seismic performance were analyzed and studied. The results show that the overall seismic isolation effect of the story isolation technique is good, which can greatly reduce the seismic response, and is an effective means to improve the seismic safety of the structure. Considering the structural characteristics of the project, the improvement of the economy and the quality of the building, the use of story isolation technique in the enlarged base multiple tower layer structure in the high intensity region is an optimal scheme. Finally, several key technical issues such as the combined seismic isolation scheme of the enlarged base story isolation technique and the additional bending moment of the isolator and the tensile device of the isolator were discussed, which can provide some references for similar engineering practices.

1. Introduction

Seismic isolation technology is a good solution for high- rise buildings in high intensity areas, and different scholars have carried out a lot of research and engineering practices. In high- rise isolation buildings with various shapes and functions, multitower isolation structure with enlarged base is a typical representative. In the aspect of theoretical research on a large base –isolated structure, Studied that the flag- shaped hysteretic behavior shape memory alloys can be conveniently used for developing efficient isolation systems, providing energy dissipation without implying residual displacements. Studied a common solution for isolating civil engineering structures underground movements. Studied the effects of the over stroke displacement of DCCSS and of displacement restrainers on the seismic response of base isolated buildings considering a case study. Ferraioli and Mandara shows that base isolation proved to be the more appropriate, also for the possibility offered by the geometry of the building to easily create an isolation interface at the ground level. Matsagar and jangid studied the retrofitting of various important structures using seismic isolation technique by incorporation of the layers of isolators at suitable locations. Discussed the seismic performance of multitower base isolation structures. Studied the optimization of base isolation layer stiffness and yield force according to the characteristics of enlarged base and multitower, in the aspect of experimental research, carried out the shaking table test on the large base single tower isolation structure model. All the above results showed that the isolation effect of the base isolation structure with enlarged base is good.

At present, there are some challenges in adopting the base isolation scheme for multitower structure with enlarged base, such as uninterrupted function requirement of vertical elevator shaft and coordination and unification of structure for bottom commercial and upper residential structure. At the same time, the isolation layer at the bottom also makes the overall cost of the structure relatively high. Therefore, more in depth study should be carried out on the location of the isolation layer of the enlarged base structure. So as to obtain a good structural scheme of the coordination and unification of the building use function and the seismic performance of the structure. The seismic response research and engineering design of the multitower story isolation structure with large base are carried out. The results show that the interlayer isolation structure not only has a good isolation effect but also meets the requirements of building function as far as possible. According to the requirement of coordination and unification of building function and seismic performance of large base story isolation structure in the high intensity area, this study takes a high rise building with enlarged base and multitower in the high-intensity area as an example to study its seismic response and seismic performance and design and discuss some key technical problems, which can provide reference for similar engineering practice.

2.Structural Scheme Selection of Enlarged Base and Multitower in the High- Intensity Area:

2.1 Project Overview: The construction area of the project is about 104,858m^2, including apartment, commercial, and basement, there are 2 floors underground for garage and 28 floors above ground. Among them 1-3 floors and 28 floors above ground. Among them, 1-3 floors are commercial supporting podiums and 4-28 floors are two apartment towers. The general plan and effect drawing of the building are shown in figure 1. The roof height of the two towers is 93.8m and the podium height is 15.4m. The plane of the podium is rectangular and the plane size is about 103.2m x 82.3 m, the plane B of the tower is L shaped and the plane a of the tower is T shaped, which are relatively arranged on the east and west sides of the podium plane, As shown in figure 2 the L shaped plane long limb of tower B is retracted once at the elevation of 81.6m, and the T shaped plane long limb of tower A is retreated twice at the elevation of 29.75 and 75.1m. The seismic fortification intensity of the project site is 8degrees and the characteristics period T_g of the site is 0.4 s.

2.2 Structural Features. The reinforced concrete frame core tube structure system is adopted for each tower, and reinforced concrete frame is adopted for podium with large chassis the main structural characteristics of the core tube(shear wall) structure are as follows: 1) The upper two towers B and A are respectively , L shaped and T shaped planes , which belong to the structural torsional irregularity 2) the height direction is generally retracted tower B is retracted once , tower A is twice retracted and the sudden change of tower mass and stiffness is large and the project is located in the strong earthquake area of 8 degree and the sudden change of the mass and stiffness of the tower will bring adverse effects on the overall structure.

2.3 Structural Scheme Selection: According to the structural characteristics of the project three technical schemes are selected in the initial stage, which are the traditional seismic scheme, the first-floor base isolation scheme and the interlayer isolation scheme.

2.3.1 Traditional seismic Scheme. The irregularity of the structure brings many adverse seismic problems and the high intensity earthquake makes the interstory displacement angle and torsional displacement ratio of the whole structure difficult to meet the requirements of the code. It is necessary to divide the structure into five regular units and set five seismic joints on the corresponding plane. The scheme is technically feasible but there are the following disadvantages:(1) The number of five seismic joints is large, which affects the use of the building: (2) The number of shear wall is large, and the section of frame column is large and (3) The section of frame beam is large which affects the indoor layout.

2.3.2 Base isolation scheme of the first floor. The isolation Layer is set on the basement roof, and the podium and tower above the ground are isolated as a whole to form the first-floor bottom base isolation scheme. The main advantages of this scheme are follows, it can greatly reduce the seismic response of tower and podium, the concept and principle of isolation are clear and the details of isolation structure are easy to handle which is conductive to improving the structure layout and improving the building quantity. However, the whole chassis including the podium needs to be equipped with isolation bearings under each transfer column resulting in a large number of isolation bearings and a total of 148 isolation on the economy of the scheme.

2.3.2 Story Isolation Scheme. The isolation layer is set between the podium roof and the upper tower to from the interlayer isolation scheme. The main advantages of the scheme are as follows, it can greatly reduce the seismic response of the tower and podium and it is helpful to improve the structure layout and the building quantity, In addition as the isolation bearings are only needed to be arranged under the transfer column at the bottom of the

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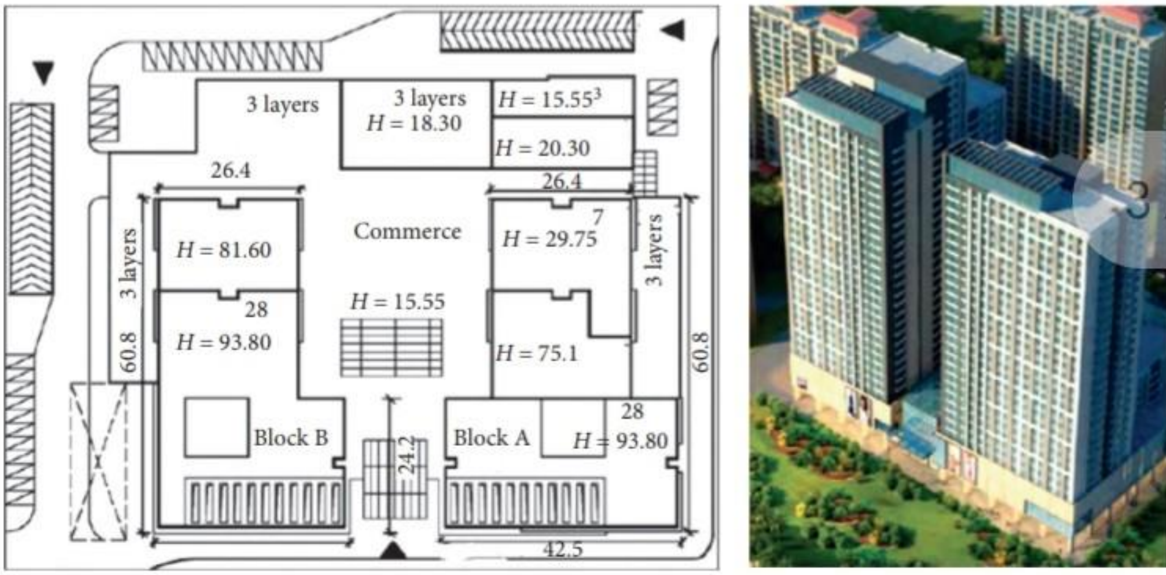


(a) **(b)**

Figure 1 : General plan and the architectural effect drawing of an enlarged base multitower high- rise building (a) General plan of building/m (b) Architectural renderings.

Figure 2 Schematic architectural section of tower B.

Figure 3 Joint drawing of the traditional seismic scheme.

2. Structural Arrangement of the Isolation Layer.

3.1 Staggered Interlayer Isolation System. In order to avoid the elevator track of the vertical elevator shaft from hindering the horizontal deformation of the isolation layer , the isolation bearings are set at different elevations , the isolation bearings beyond the scope of the core tube of the tower are set on the top of the skirt, the shear wall of the core tube of the tower falls directly on the basement base and parr of the isolation bearings are at the bottom of the core tube to from a staggered interlayer isolation structure system as shown in figure 7.

3.2 Combined Isolation Scheme. Due to the high structural height of the project, the structural period before isolation is long. In order to effectively extend the structural period and improve the isolation effect, the elastic plate bearing with large vertical bearing capacity small horizontal

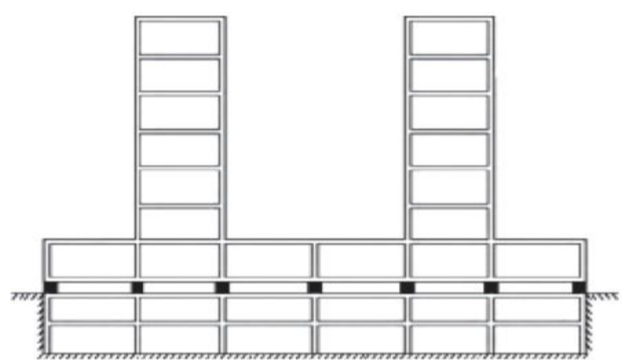


Figure 4 Base isolation diagram of the first floor.

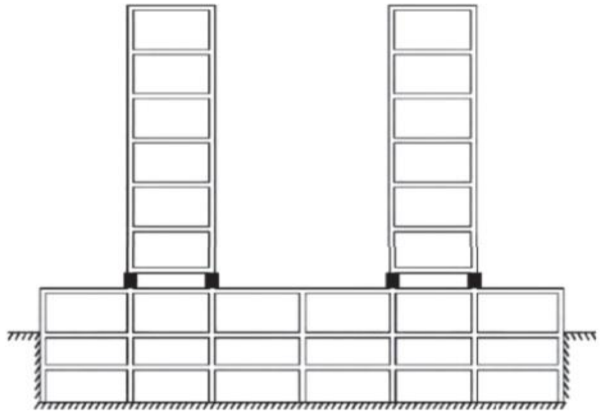


Figure 5 Schematic diagram of interlayer isolation.

Table 1: Optimization of main section of frame column and beam of the layer.

Cross section comparison	Traditional seismic scheme	story isolation scheme
Frame beam	500 x 600 400 x 700	200 x 1050(reverse beam) 250 x 600
Frame column	1000 x 1000 1200 x 1200	900 x 900 1000 x 1000

3.3 Tensile Device. Due to the staggered height difference between the top isolation layer of skirt building and the bottom isolation layer of core tube, during the horizontal movement of the isolation layer , the rubber bearing at the bottom of the core tube connecting the two isolation layers is subjected to tensile stress due to rigid body rotation.

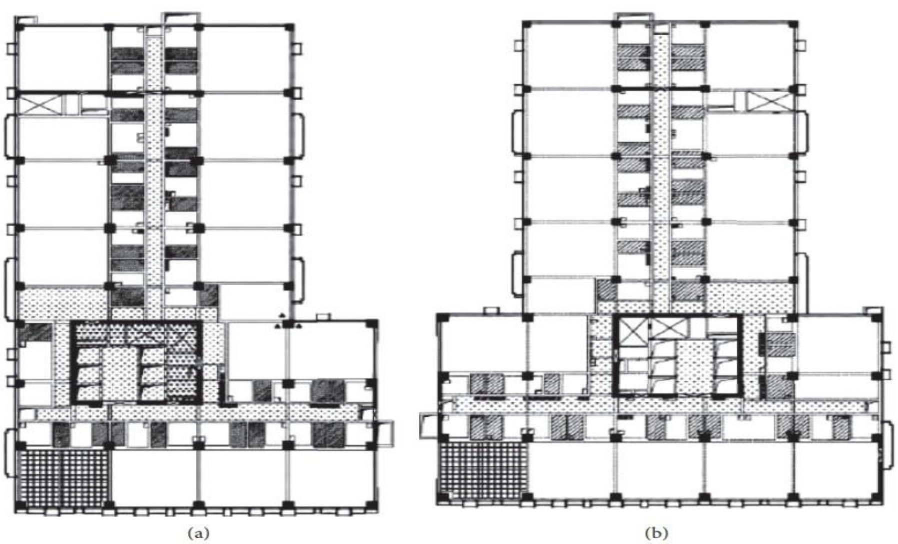


Figure 6 Optimal Layout of standard floor structure of the tower above isolation floor(a) Tower B (b) Tower A

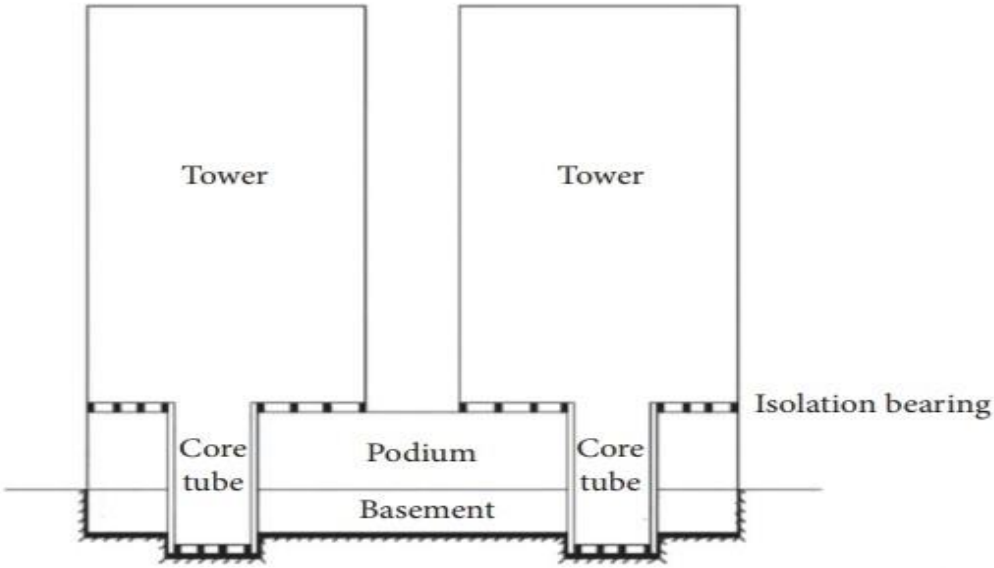


Figure 7: Schematic diagram of the staggered story isolation structure system.

3.4 Isolation Layer Design: In order to obtain reasonable arrangement of isolation bearings and a good isolation effect, the combined isolation scheme is adopted in the project in which there are 102 isolation bearings of three types lead rubber bearing natural rubber bearing and elastic sliding plate bearing, there are five kinds of the diameter of rubber bearings of elastic slide bearings is 1300mm. The horizontal restoring force of the isolation layer, the eccentricity of the isolation layer and the earth quake reduction coefficient are taken as the control objectives for the arrangement of the isolation bearings,

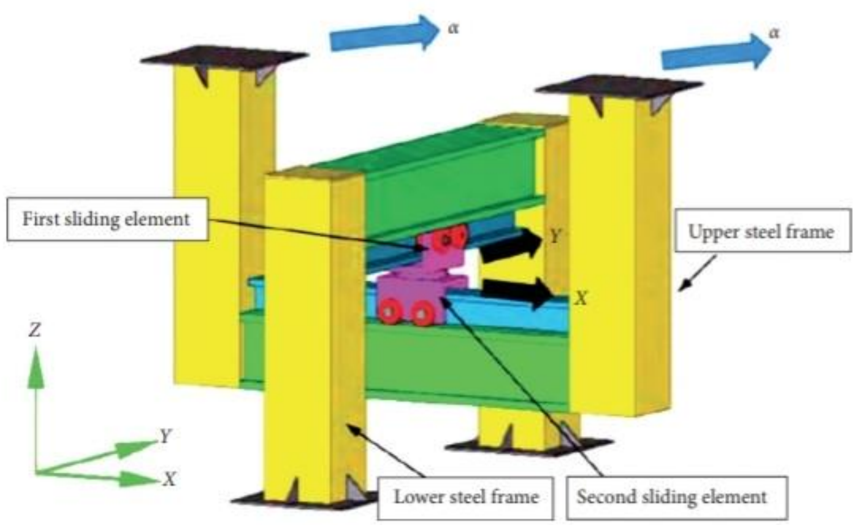
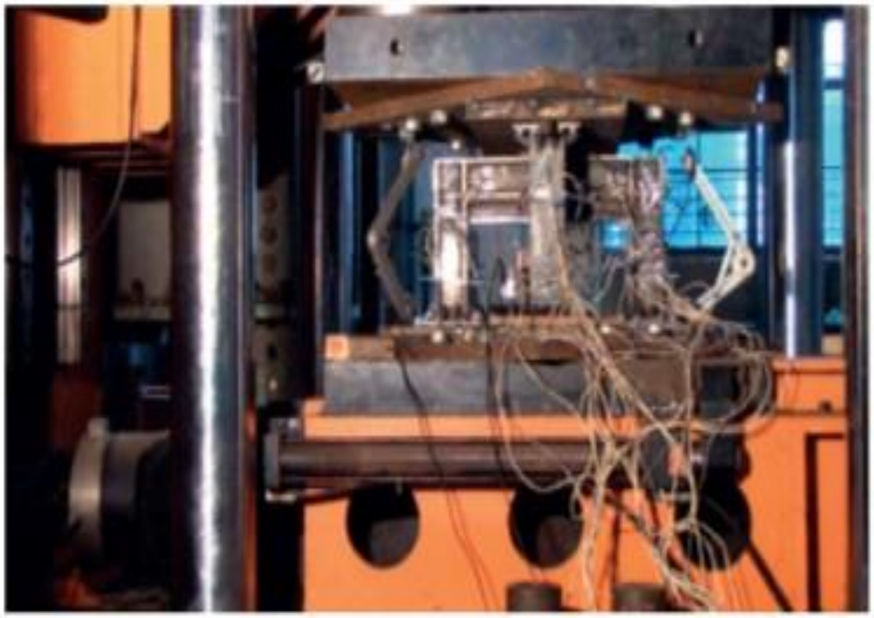


Figure 8 : Structural diagram of the tensile device (a is any angle in XY plane)



4. Seismic Response Analysis of isolated Structures.

4.1. Structural Analysis Model. In order to study the seismic response of multitower story isolation structure with large chassis the finite element analysis was carried out by ETABS software the earthquake intensity was carried out by ETABS software the earthquake intensity is 8 , the damping ratio of structure is 0.05 the peak value of seismic acceleration is 0.2g and the characteristic period is 0.4s the duration and proportion of seismic waves is based on the assumption that the isolation bearing is locally nonlinear and the rest of the structural members are elastic . since the vertical tensile and compressive stiffness of rubber isolator element is equal and the isolation rubber bearing has the characteristic of different vertical tension and compression stiffness the combination of rubber isolator element and gap element is used to simulate its vertical stiffness mechanical constructive model in ETABS and the tensile stiffness is taken as 1/7 of the compression stiffness the elastic sliding plate bearing is simulated by friction isolator element. The Rize method is used to analyze the dynamic characteristics of the structure the FNA method is used to analyze the dynamic time history, and the second order effect of gravity load is considered in each analysis process.

4.2 Earthquake Reduction Coefficient. The comparison of the first two translational periods of the structure before and after the isolation is given in Table 2. It can be seen that the

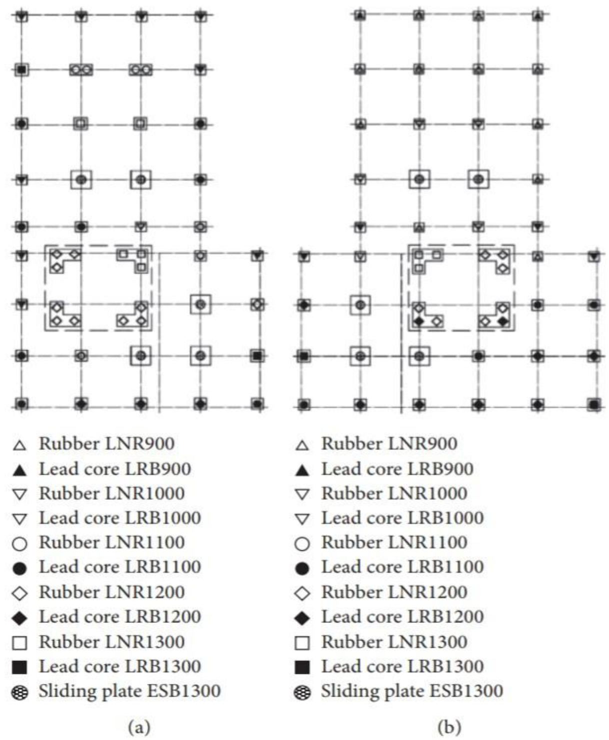


Figure 10 Arrangement of isolation bearing in the isolation layer(a) Tower B (b) Tower A

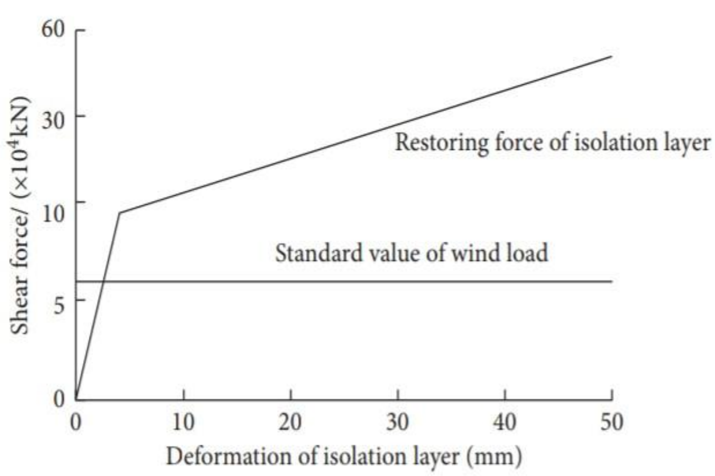


Figure 11 : Horizontal restoring force characteristics of the isolation layer.

Period of the isolated structure is obviously prolonged, which is conductive to reducing the seismic response of the structure, In code for seismic design of buildings the larger values of shear ratio and overturning moment ratio of all floors are used as the evaluation index of the seismic isolation effect of isolated buildings that is the earthquake reduction coefficient,

4.3 Story Drift Angle. The time history analysis of bidirectional horizontal seismic action is used to check the deformation of the structure under the action of earthquake, the analysis method meets the requirements of GB 50011-2010, accidental eccentricity 1.13 in X direction and 1.34 in Y direction and bidirectional seismic actions are considered in the mode response spectrum analysis the average value of two groups of artificial waves and
five.

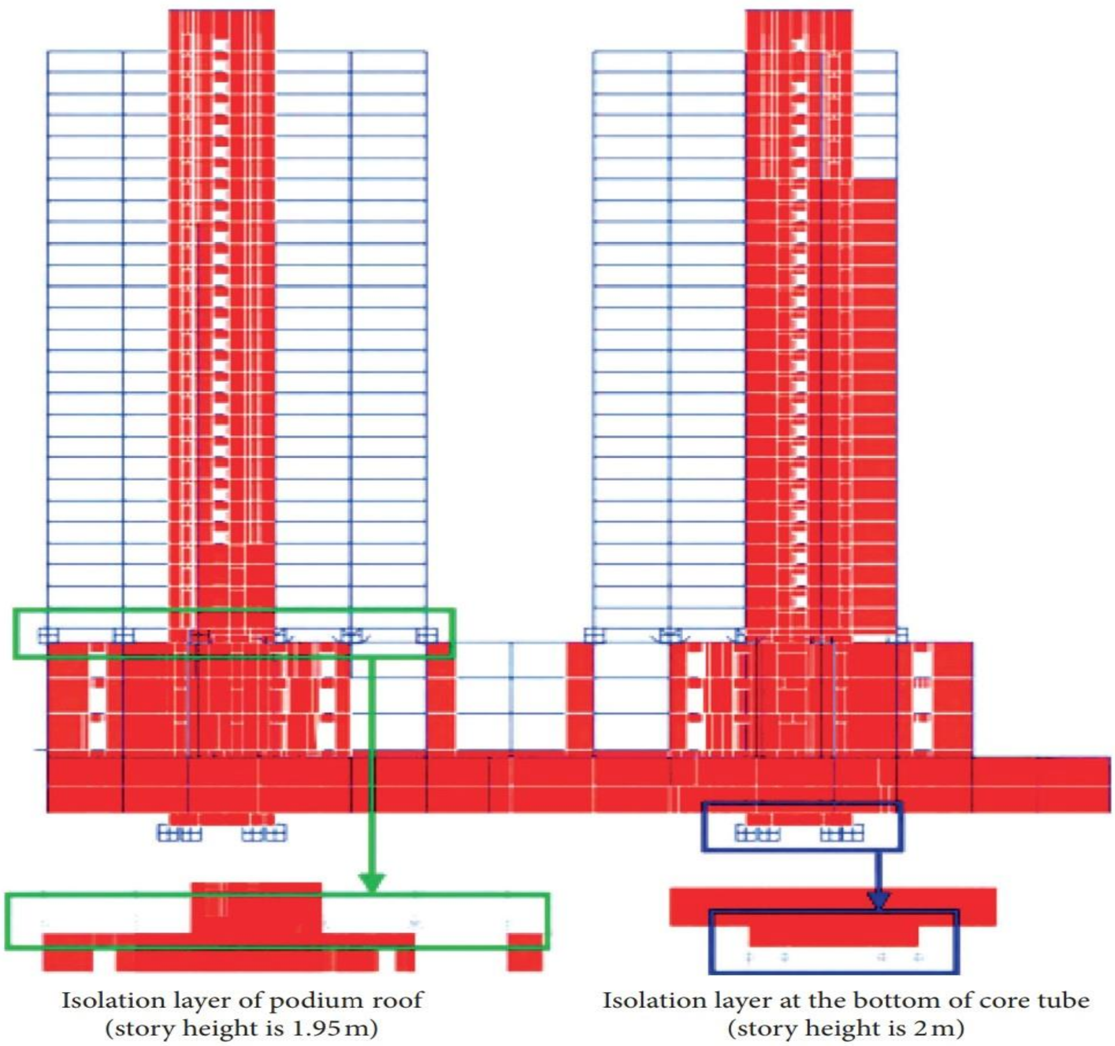


Figure 12 Comparison of the project of the structure before and after isolation

4.4 Bearing Capacity and deformation Checking Calculation of Isolation Bearing.

The two way horizontal and vertical seismic action time history analysis is used to check the bearing capacity of isolation bearing under rare earthquake, the average value of two groups of artificial waves and five groups of natural waves is taken as the calculation results of the isolation bearing are given in Table 4

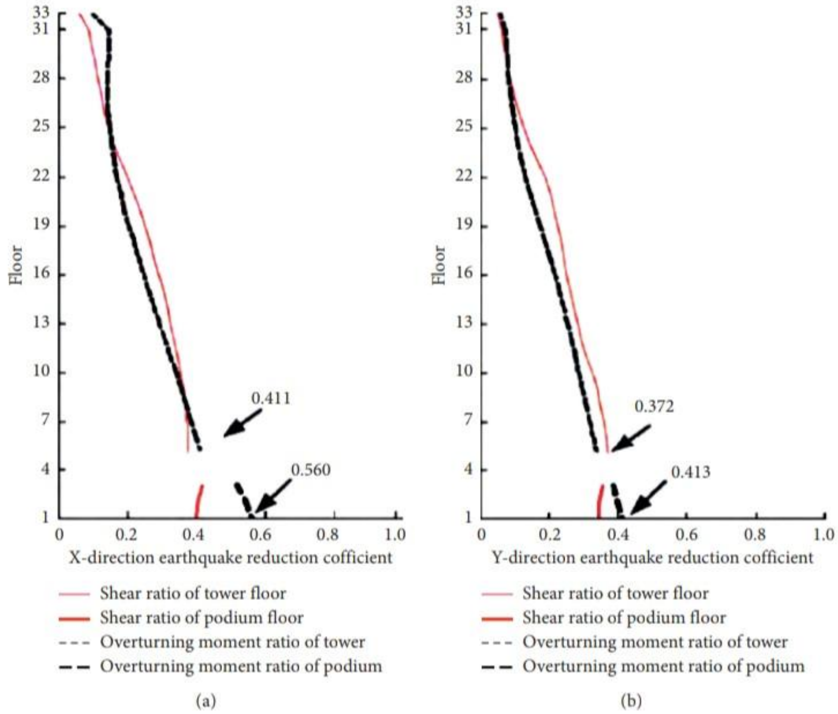


Figure 13 Horizontal earthquake reduction coefficient of tower A

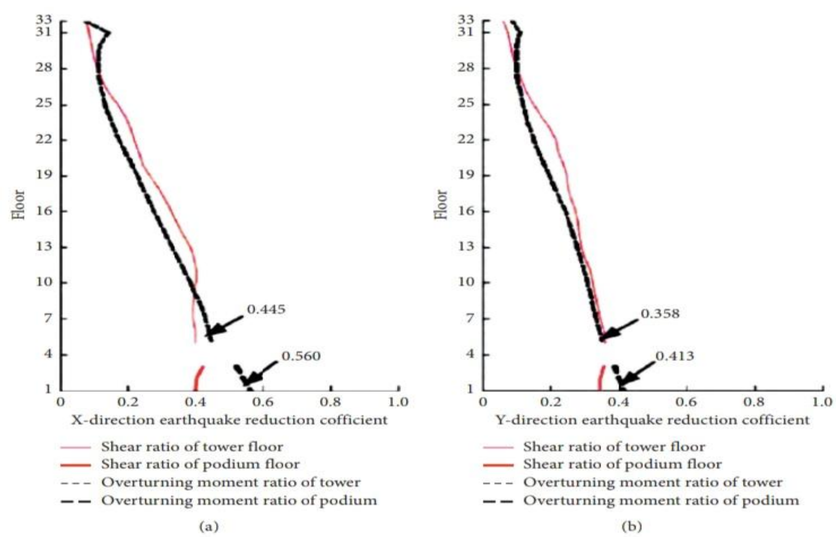


Figure 14 : Horizontal earthquake reduction coefficient of tower

Table 3: Interstory displacement angle of structure curve under fortification earthquake.

Interstory displacement angle	X direction	Y direction
Tower A	1/690	1/830
Tower B	1/685	1/991
Podium	1/1122	1/1408

Table 4: Isolation bearing pressure, tensile stress and deformation

Location and type of support	compressive stress	Tensile stress	Max deformation
Podium roof Rubber bearing	25.1	0.32	466
Elastic slide plate support	20.9	0.70	448
Rubber bearing at the bottom of core Tube	22.9	0	431

4.5 Mechanical Performance under Rare Earthquake: In this project the dynamic elastoplastic time history analysis is carried out by using the high-performance non-linear analysis software SAUSAGE. The mechanical model of the isolation rubber bearing vertical tension and compression stiffness and the mechanical model by the friction pendulum bearing element.

Table 5: Interstory displacement angle of structure under rare earthquake.

Interstory displacement angle	X direction	Y direction
Tower A	1/166	1/172
Tower B	1/142	1/181
Podium	1/221	1/294

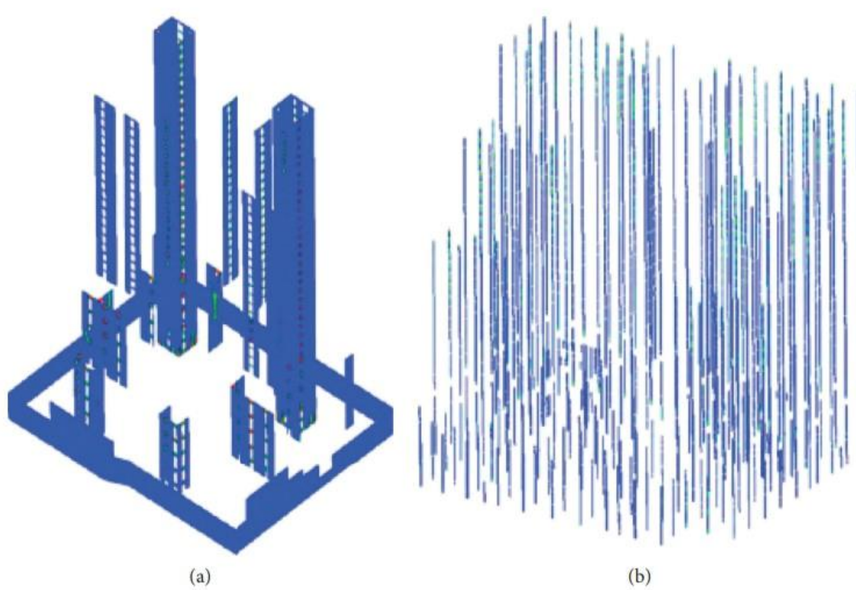


Figure 16 Damage of shear walls and frame columns under artificial wave y direction earthquake (a) overall damage of shear wall . (b) Damage of frame column.

4.6 Other Key Technical Issues

4.6.1 Advantages of Combined Isolation Scheme. Elastic sliding plate bearing is an isolation bearing composed of rubber bearing part , sliding material , sliding panel and upper and lower connecting steel plate, the friction pair composed of PTFE plate and stainless steel plate provides good friction energy consumption , compared with the isolation rubber bearing the elastic sliding plate bearing has the advantages of layer vertical bearing capacity small horizontal stiffness large sliding displacement and strong energy dissipation capacity.

4.6.2 Reasonable Consideration of Additional Bending Moment of Isolation Bearing. Due to the large deformation of the isolation bearing the additional bending moment of the isolation bearing and the eccentric bending moment formed by the gravity load of the upper structure constitute the additional bending moment of the isolation bearing

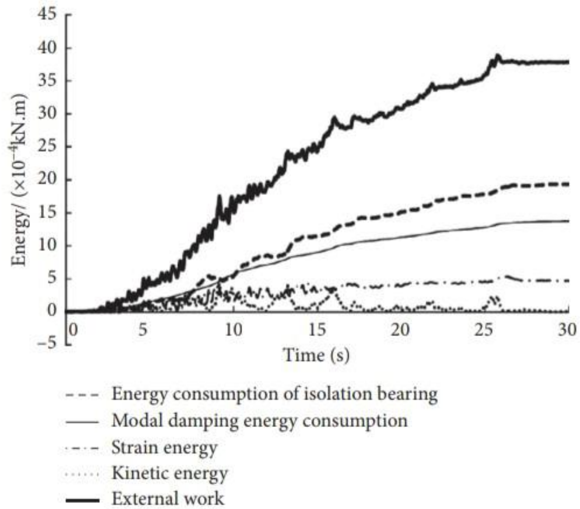


Figure 17: Energy curve of structure under artificial wave Y main direction earthquake action

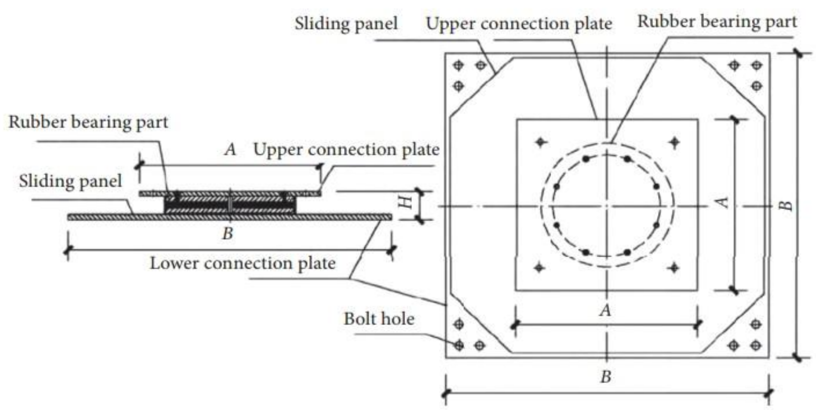


Figure 18: Structural diagram of elastic sliding plate support

Table 6 : Comparison of different isolation schemes

Comparison of isolation schemes	isolation period	Earthquake reduction coefficient
Natural rubber bearing+ lead rubber bearing	4.49	0.484
Natural rubber + lead rubber bearing+ elastic Plate support	4.77	0.445

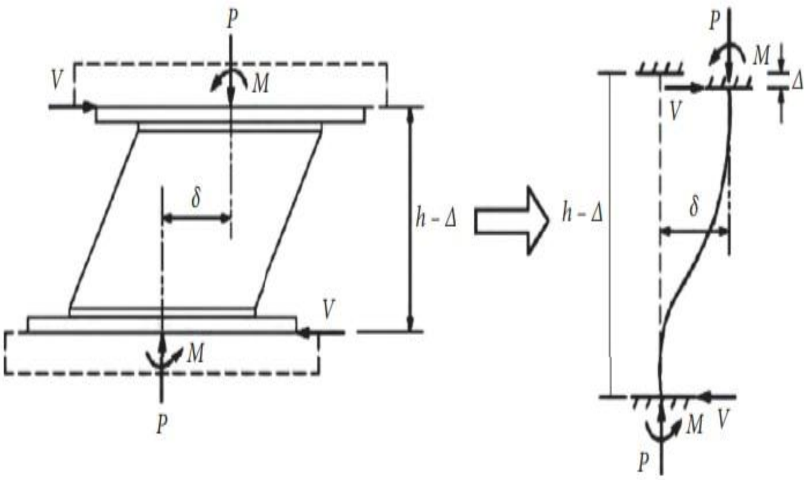


Figure 19: Calculation diagram of additional bending moment of isolation bearing

5. Conclusion

In this study the story isolation technology is applied to a high- rise building with enlarged base and multitower in the high-intensity area. The isolation layer is designed the seismic response of the whole structure is analyzed and the following conclusions are obtained:

(1) In the high-rise building structure with enlarged base and multitower in the high intensity area the application of isolation technology which is an effective means to improve the seismic safety of the structure,

(2) Considering the structural characteristics economy and building quality of the project it is a preferred implementation scheme to adopt the interlayer isolation technology in the multitower structure with enlarged base in the high intensity area.

(3) The eccentricity and earthquake reduction coefficient of the isolated structure are reasonable and the overall earthquake reduction effect is good, Tthe bearing capacity deformation and elastic requirements of the code under rare earthquake which further verifies that the application of interlayer isolation technology in the high-intensity area is safe and feasible.

(4) The design and discussion of the combined isolation scheme, the additional bending moment of the isolation bearing and the bearing tension device are carried out which can provide references for similar engineering practice.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest:

The authors declare that they have no conflicts of interest.

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