

Study on the Influence of Aspect Ratio on the Seismic Response and Overturning Resistance of a New Staggered Story Isolated Structure

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Abstract

The aspect ratio of the structure has a significant impact on the overall stability of the ultra high-rise building. A large aspect ratio of the structure increases the risk of overturning and reduces the lateral stiffness of the structure, leading to significant tensile and compressive stresses in the isolated bearings. To study the effect of aspect ratio on the seismic response and overturning resistance of a new staggered story isolated structure, three models with different aspect ratios were established. Nonlinear time-history analysis of the three models was conducted using ETABS finite element software. The results indicate that the overturning moment and overturning resistance moment of the superstructure in the new staggered story isolated structure increase with an increasing aspect ratio. However, the increase in the overturning moment of the superstructure is much greater than the increase in the overturning resistance moment, resulting in a decrease in the overturning resistance ratio of the superstructure with an increasing aspect ratio. The overturning moment and overturning resistance moment of the substructure in the new staggered story isolated structure decrease with an increasing aspect ratio. However, the decrease in the overturning moment of the substructure is greater than the decrease in the overturning resistance moment, leading to an increase in the overturning resistance ratio of the substructure with an increasing aspect ratio. The decrease in the overturning resistance ratio of the superstructure in the new staggered story isolated structure is much greater than the increase in the overturning resistance ratio of the substructure. Therefore, as the aspect ratio of the overall structure increases, the overturning resistance ratio of the superstructure and the entire structure decreases.

Keywords

Aspect Ratio, A New Staggered Story Isolated Structure, Seismic Response, Overturning Resistance Ratio, Isolated Bearing

1. Introduction

The frame-core tube structure has relatively high lateral stiffness, which can well meet the building functions, and has become one of the most used types for ultra high-rise buildings. Based on this, a new staggered story isolated structure is formed by arranging the isolated layers according to the characteristics of the frame-core tube structure in the lower layer of the core tube and the middle layer of the framework. In the case of a certain height and total weight of an ultra high-rise building, reducing the total weight of the superstructure can improve the overall stability of the structure. Because the isolated layer of the frame part of the new staggered story isolated structure is in the middle of the structure, compared with the traditional seismic isolated structure, the new staggered story isolated structure can effectively reduce the total weight of the superstructure. Therefore, it is necessary to study the seismic response and overturning resistance of the new staggered story isolated structure with different aspect ratios.

Peng Zhizhen *et al.* [1] studied the overall stability of giant frame-core tube structures, and analyzed the influence of aspect ratio, floor mass distribution, and various components on the overall stability of the structure. The results show that the overall stability of the structure decreases with the increase of the aspect ratio and increases with the decrease of the floor mass distribution coefficient, and the installation of giant diagonal braces on the periphery can effectively improve the overall stability of the structure. Tian Wei *et al.* [2] studied the seismic performance of high-rise shear wall structures with large aspect ratios and compared the shear wall damage under frequent earthquakes and rare earthquakes. The results show that the base shear force increases under rare earthquakes, and the bottom of the structure is prone to damage. The reinforcement ratio of the shear wall in the bottom reinforcement area should be appropriately increased to improve the seismic performance of the structure. Yu Wenzheng *et al.* [3] studied the influence of vertical force of the isolated bearing, structural period, and site category on the aspect ratio limit of the seismic isolated structure. The results show that when the compressive stress of the isolated bearing under gravity load is less than the compressive stress at a certain limit point, the aspect ratio limit is controlled by the tensile stress under rare earthquakes, and when the compressive stress is greater than the limit point, the aspect ratio limit is controlled by the compressive stress under rare earthquakes. Du Peng *et al.* [4] [5] studied the overturning of the middle and superstructures in the high-rise shear wall structure with large aspect ratios under earthquakes, and summarized the key points that need to be paid attention to in the design of

such structures, providing a reference for the design of similar structures. Li Feng *et al.* [6] studied the effects of aspect ratio on the seismic performance and hysteresis performance of the steel-braced frame structure with connected columns. The results show that when the aspect ratio is greater than 1.93, the horizontal overturning moment increases under rare earthquakes, and the column base moves upward. The larger the aspect ratio of the structure, the smaller the carrying capacity and lateral stiffness, and the greater the deformation. Zhang Hongmei *et al.* [7]-[9] studied the effects of aspect ratio on the failure mode, strength, energy dissipation capacity, and stiffness degradation of shear walls. The results show that as the aspect ratio decreases, the initial loading fractal dimension is higher, and the deformation of the shear wall changes from shear failure to bending failure, while the “arch” effect inside the shear wall decreases, the carrying capacity of the shear wall decreases, but the deformation capacity significantly increases. Li Xiaojun *et al.* [10] studied the influence of near-fault ground motion on the seismic performance of base-isolated structures with different aspect ratios. The results show that under the near-fault pulse-like ground motions, the seismic response of base-isolated structures gradually increases with the increase of aspect ratio, and the base-isolated structures have a good damping effect with an aspect ratio of less than 3. When the aspect ratio is 4, the base-isolated structures effect is poor. Wang Dong *et al.* [11] studied the dynamic characteristics and seismic response of base-isolated high-rise structures with different aspect ratios and conducted shaking table tests. The results show that the lateral displacement angle of the superstructure in the base-isolated high-rise structure increases with the increase of the aspect ratio, and the overturning resistance of the structure decreases with the increase of the aspect ratio. Feng Shaolin *et al.* [12] studied the seismic response of high-rise base-isolated structures with different aspect ratios. The results show that with the increase in aspect ratio, the seismic response of high-rise base-isolated structures increases, but the change in the horizontal damping coefficient is not significant. Zhang Fuyou *et al.* [13] studied the aspect ratio limit of slip-friction isolated structures under vertical ground motions. The motion differential equations of the slip-friction isolated structure under the coupling of horizontal and vertical ground motions were established, and the calculation formula for the aspect ratio limit under vertical seismic action was derived. Qi Ai *et al.* [14]-[17] studied the aspect ratio limit of base-isolated structures. Two sufficient conditions for the non-overturning of isolated structures under strong earthquakes were summarized, and the calculation formula for the aspect ratio limit of isolated structures was derived. He Wenfu *et al.* [18] conducted shaking table tests on the ordinary steel frame isolated structure with a low aspect ratio under bidirectional earthquakes. The results show that in the case of good ground conditions, the structure will not overturn and the influence of vertical ground motions on the horizontal response of the structure is relatively small. Yang Kang *et al.* [19] [20] analyzed the mechanism of stiffness increase and strong earthquake damage mode

of the concrete frame-core tube structures with a high aspect ratio. The results show that adding frame columns and shear walls can effectively increase the overall stiffness of the structure.

The new staggered story isolated structure is developed from the base isolated structure and the inter-layer isolated structure. The above scholars mainly studied the aspect ratio limits of base isolated structures, high-rise shear wall structures, and ultra high-rise structures. They also studied the influence of the near-fault pulse-like ground motion and vertical ground motion on the aspect ratio of structures. There is relatively little research on the effect of aspect ratio on the seismic response and overturning resistance of the new staggered story isolated structure. Therefore, in this paper, three new staggered story isolated structure models with different aspect ratios are established, and the seismic response of the three models as well as the overturning resistance of the superstructure, substructure, and the overall structure are studied. The weak points of the new staggered story isolated structure with a larger aspect ratio are found, providing a reference for the design of the aspect ratio and overturning resistance of the structure.

2. The Establishment of Finite Element Models

2.1. Project Overview

With the same plan layout, the height of the structure is changed by increasing and decreasing the number of superstructure floors (the superstructure of each model differs by 9 floors), and three new staggered story isolated structure models with different aspect ratios are established. The plan dimensions are 33.6 m × 33.6 m, with a floor height of 4.5 m for the 1st to 3rd floors and a standard floor height of 3.9 m. The core tube isolated layer is located at the bottom of the core tube, and the frame isolated layer is located between the 8th and 9th floors of the frame, with a height of 1.6 m and a floor thickness of 160 mm. The thickness of the other floors is 120 mm. The seismic precautionary intensity is VIII, the design basic seismic acceleration value is 0.20 g, the seismic design grouping is the second group, the construction site classification is II, the characteristic period of the seismic response spectrum is 0.4 s. The aspect ratios of the three new staggered story isolated structures models are 2.122, 3.167, and 4.211, with total heights of 71.3 m, 106.4 m, and 141.5 m, and total floors of 17, 26, and 35, respectively. The 3D diagrams of the three models are shown in **Figure 1**. The design of the three models meets the requirements of “Code for Seismic Design of Buildings” (GB 50011-2010) and “Technical Specification for Concrete Structures of Tall Building” (JGJ 3-2010), and complies with the requirement that the aspect ratio of a frame-core tube structure should not exceed 6 when the seismic fortification intensity is 8 degrees. Therefore, the design of the aspect ratio for the new staggered story isolated structure is reasonable. The concrete strength grade of the columns and beams is C40, and the grade of steel bars and stirrups is HRB400. The shear walls in the core tube are connected by coupling beams, and the frame element and layered shell element are connected by embedded beams. The section information of beams and columns is shown in **Table 1**.

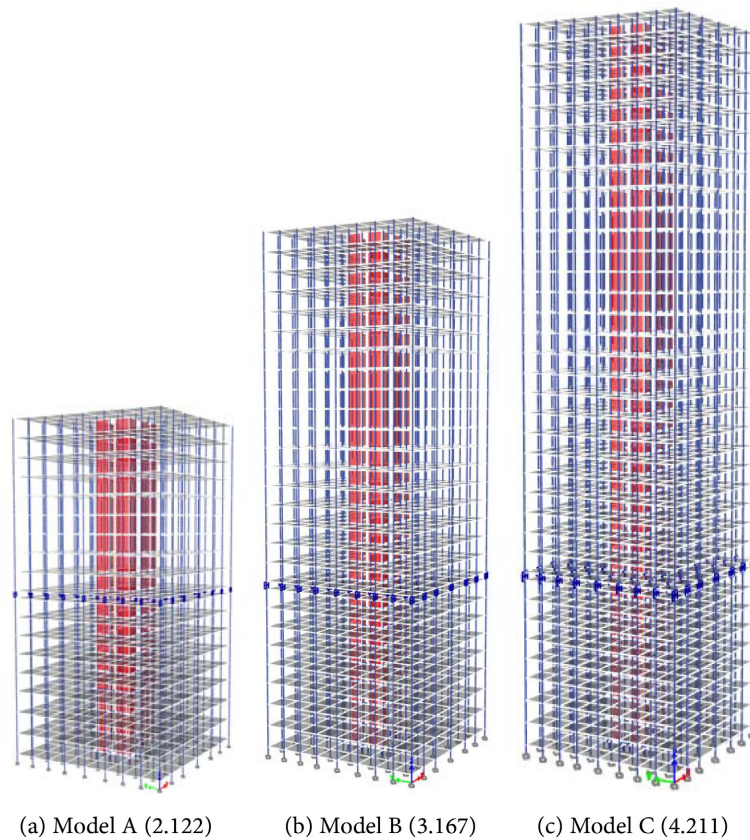


Figure 1. Schematic diagram of 3D model.

Table 1. Section dimensions of beams and columns.

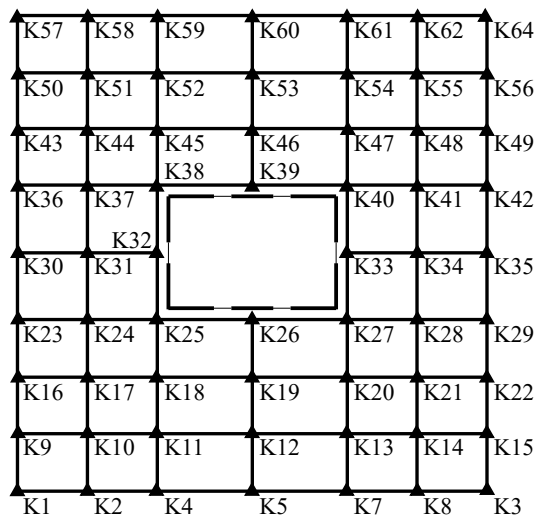
Model	Component type	Floor	Section dimension (mm × mm)
Model A (2.122)	Framework column	1 - 10	800 × 800
		11 - 17	700 × 700
	Framework beam	1 - 17	800 × 400
	Coupling beam	1 - 3	400 × 750
		4 - 17	300 × 750
Embedded beam	1 - 3	400 × 750	
Model B (3.167)	Framework column	1 - 10	800 × 800
		11 - 26	700 × 700
	Framework beam	1 - 26	800 × 400
	Coupling beam	1 - 3	400 × 750
		4 - 26	300 × 750
Embedded beam	1 - 3	400 × 750	
Model C (4.211)	Framework column	1 - 10	800 × 800
		11 - 35	700 × 700
	Framework beam	1 - 35	800 × 400
	Coupling beam	1 - 3	750 × 400
		4 - 35	750 × 300
Embedded beam	1 - 3	750 × 400	

2.2. Models Information

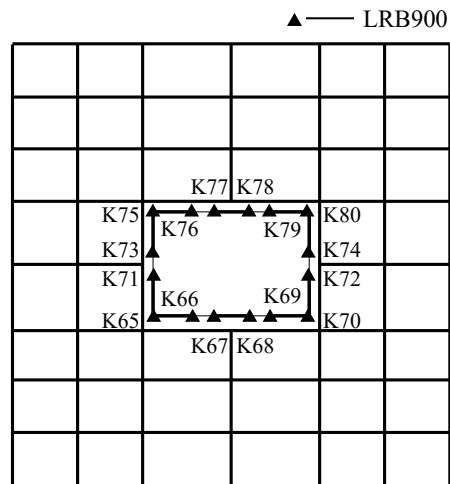
In this paper, the finite element software ETABS is used to establish the new staggered story isolated structure models. The bottom reinforcement area of the core tube is 1 to 3 floors, which is simulated by layered shell elements with a thickness of 400 mm; The non-bottom reinforcement area is simulated by elastic thin shell elements with a thickness of 300 mm. The embedded beams are placed between the frame and the layered shell elements. The Tekeda hysteresis model is used to simulate the nonlinear properties of C40 concrete, and the Kinematic hysteresis model is used to simulate the nonlinear properties of HRB400 steel bars. The frame columns are all equipped with fiber P-M2-M3 hinges, and the frame beams and connecting beams are equipped with M3 hinges. The number of seismic isolation bearings is determined according to the total horizontal yield force being 2% of the base vertical reaction force under the standard value of gravity load. A total of 78 isolated bearings with a diameter of 900 mm are set, of which 62 lead rubber isolated bearings are set in the frame isolated layer, and 16 lead rubber isolated bearings are set in the core tube isolated layer, which is simulated by nonlinear connection elements “Rubber Isolator”. The parameters of the isolated bearings are listed in **Table 2**, and the layout of the isolated bearings is shown in **Figure 2**. A schematic diagram of the lead rubber isolated bearing is shown in **Figure 3**.

Table 2. Parameters of isolated bearing.

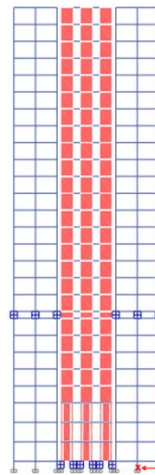
Type	Effective diameter (mm)	Total rubber thickness (mm)	Stiffness before yielding (kN/m)	Stiffness after yielding (kN/m)	Equivalent stiffness (kN/m)		Vertical stiffness (kN/mm)	Yield force (kN)
					100% horizontal shear deformation	250% horizontal shear deformation		
LRB 900	900	166	18690	1440	2290	1760	3200	141



(a) The isolated bearings in frame isolated layer



(b) The isolated bearings in core tube isolated layer



(c) The cutaway view of isolated layers

Figure 2. Layout of isolated bearings.

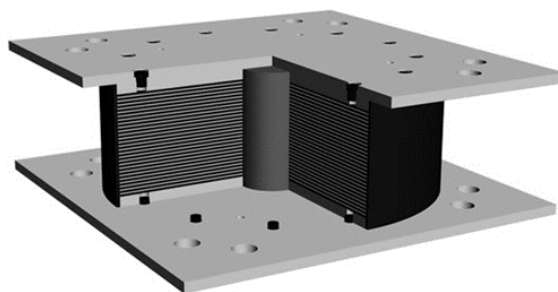


Figure 3. Schematic diagram of lead rubber isolated bearings.

2.3. Selection of Ground Motions

In accordance with the “Code for Seismic Design of Buildings” (GB50011-2010), based on the response spectrum, seismic intensity, seismic grouping, seismic frequency, site category, etc., two natural ground motions were selected from the Pacific Earthquake Engineering Research Center. According to the response spec-

trum, seismic parameters, and the first three natural periods of the structure, an artificial ground motion was generated using the GM-Tool software. The base shear force calculated using the time-history method under each ground motion is greater than 65% of the base shear force calculated using the mode-superposition response spectrum method. The average of the base shear forces calculated using the time-history method under the seven ground motions is greater than 80% of the base shear force calculated using the mode-superposition response spectrum method. Therefore, the selected ground motions are reasonable and effective, meeting the requirements of the code, and can be used for the analysis and calculation of the seismic response and overturning resistance of new staggered story isolated structures. The information on the two natural ground motions is listed in **Table 3**, and the acceleration response spectra are shown in **Figure 4**.

Table 3. Information of ground motions.

Number	Ground motion	Time	Station	Earthquake magnitude
1	Hollister-01	1961	Hollister City Hall	5.6
2	Parkfield	1966	Cholame-Shandon Array #12	6.19

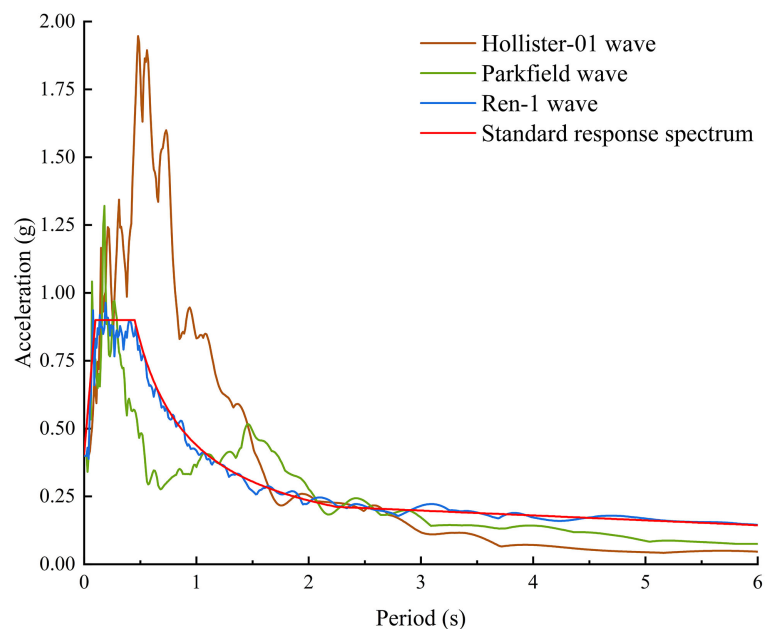


Figure 4. Acceleration response spectra.

3. Seismic Response Analysis of New Staggered Story Isolated Structures with Different Aspect Ratios

3.1. Comparative Analysis of Base Shear Force and Inter-Layer Shear Force under Rare Earthquakes

The envelope values of the base shear forces of the new staggered story isolated structures with aspect ratios of 2.122, 3.167, and 4.211 under rare earthquakes are 38193.949 kN, 36478.754 kN, and 42667.013 kN, respectively. With the increase of the aspect ratio, the base shear force increases. A larger base shear force

requires larger isolated bearings to ensure the stability of the overall structure, thus reducing the risk of overturning the superstructure. As shown in **Figure 5**, as the aspect ratio of the new staggered story isolated structure increases, the inter-layer shear force of the substructure increases. When the aspect ratio increases from 2.122 to 3.167, the average increase rate of the envelope value of the inter-layer shear force for each floor of the substructure is 6.036%. When the aspect ratio increases from 2.122 to 4.211, the average increase rate of the envelope value of the inter-layer shear force for each floor of the substructure is 43.166%. Therefore, as the aspect ratio of the new staggered story isolated structure increases, the substructure will bear a larger inter-layer shear force. Therefore, when designing new staggered story isolated structures with a larger aspect ratio, the substructure should be strengthened to avoid the substructure bearing excessive seismic forces, which could increase the risk of damage to the substructure and the risk of overturning the superstructure.

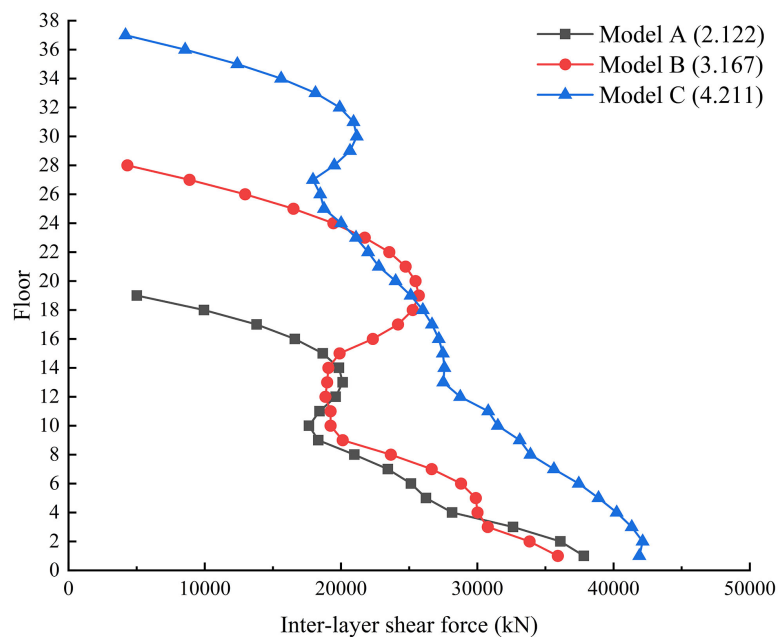
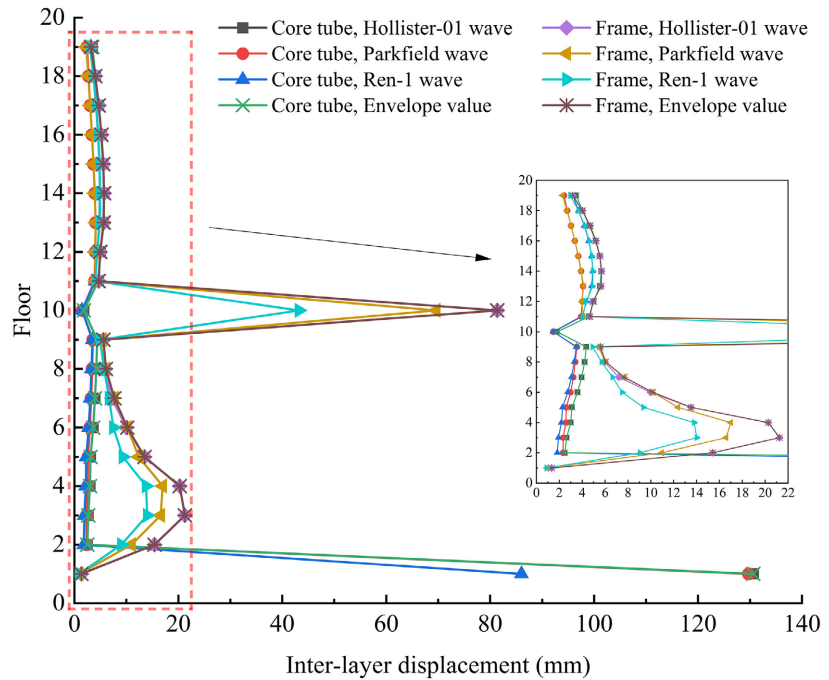


Figure 5. Comparison diagram of inter-layer shear forces of new staggered story isolated structures with different aspect ratios.

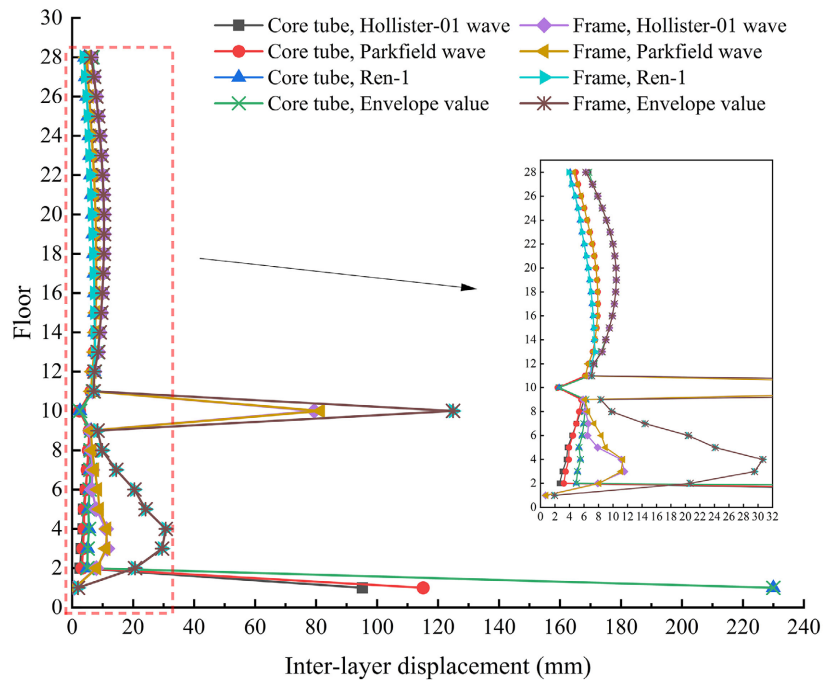
3.2. Comparative Analysis of Inter-Layer Displacement and Inter-Layer Displacement Drift under Rare Earthquakes

As shown in **Figure 6**, the envelope values of the inter-layer displacements of the frame isolated layer and the core tube isolated layer in the new staggered story isolated structure with an aspect ratio of 2.122 are 130.648 mm and 81.368 mm, respectively; For the aspect ratio of 3.167, the envelope values are 229.99 mm and 124.905 mm, respectively; For the aspect ratio of 4.211, the envelope values are 310.543 mm and 235.013 mm, respectively. These values are less than the limit displacement of the isolated bearings specified in the “Code for Seismic Design of Buildings” (GB50011-2010), which is $\mu_i \leq [0.55R; 3H]$, that is, less

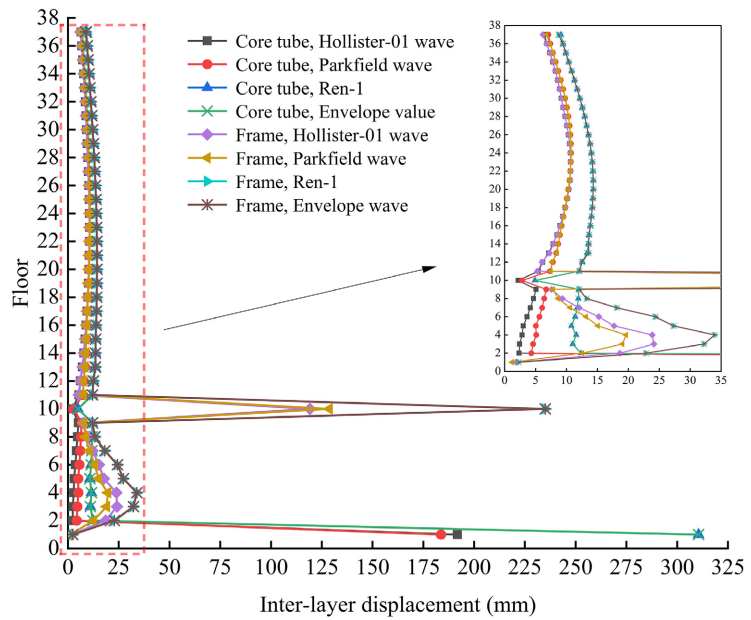
than 495mm. As shown in **Figure 7**, the inter-layer drift of the new staggered story isolated structures with different aspect ratios satisfies the requirement specified in the “Code for Seismic Design of Buildings” (2010) that the elastic-plastic inter-layer drift of the substructure should be less than 1/130 under rare earthquakes, and the elastic-plastic inter-layer drift of the superstructure should be less than 1/100 under rare earthquakes.



(a) Comparison diagram of inter-layer displacement when the aspect ratio is 2.122



(b) Comparison diagram of inter-layer displacement when the aspect ratio is 3.167



(c) Comparison diagram of inter-layer displacement when the aspect ratio is 4.211

Figure 6. Inter-layer displacement comparison of new staggered story isolated structures with different aspect ratios.

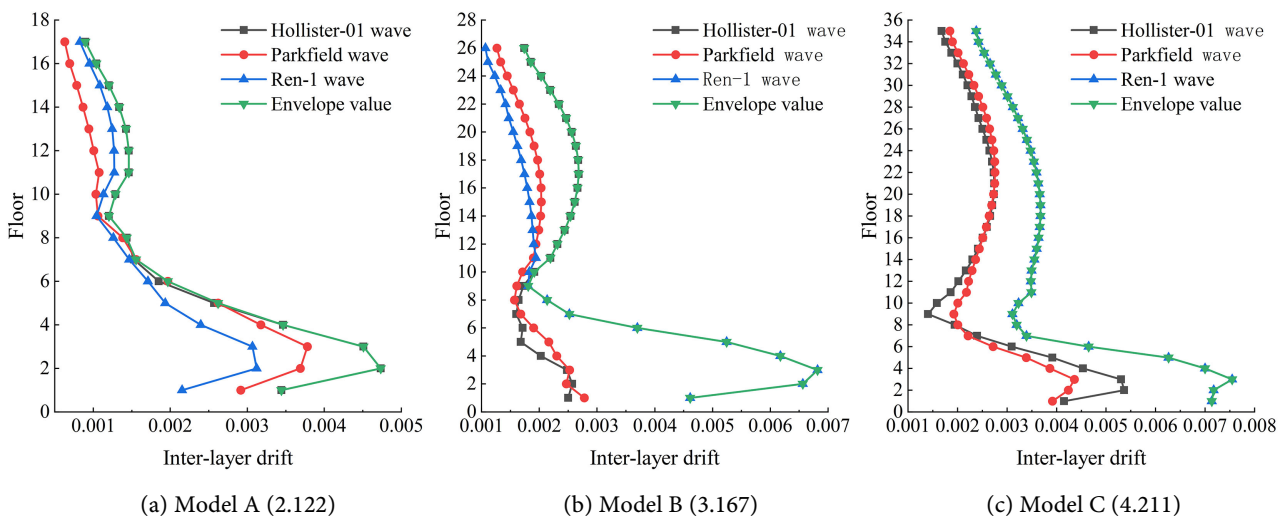


Figure 7. Inter-layer drift comparison of new staggered story isolated structures with different aspect ratios.

The larger inter-layer displacements indicate a greater influence of seismic action on the structure, and larger inter-layer displacements can lead to structural damage, reduce the overall stability of the structure, and increase the risk of overturning. With the increase of the aspect ratio of the new staggered story isolated structure, both the inter-layer displacements and inter-layer drift of the core tube and frame at each floor gradually increase, indicating that a larger aspect ratio will result in a greater seismic impact on the structure. The inter-layer displacements of the core tube isolated layer are greater than those of the frame isolated layer. Furthermore, as the substructure of the new staggered story isolated structure acts as the non-isolated structure, the inter-layer displacements

and inter-layer drift of the core tube below the frame isolated layer are less than those of the frame at each floor.

4. Comparative Analysis of Overturning Resistance of New Staggered Story Isolated Structures with Different Aspect Ratios

4.1. Comparative Analysis of Tensile and Compressive Stresses of Isolated Bearings

As shown in **Figure 8**, the compressive stress of the isolated bearings in the frame isolated layer and the core tube isolated layer of new staggered story isolated structure increases with the increase of aspect ratio, and both are less than the specified limit of 30 MPa. When the aspect ratio increases from 2.122 to 3.167, the average increase in compressive stress for the isolated bearings in the frame isolated layer and core tube isolated layer are 93.900% and 47.907% respectively; when the aspect ratio increases from 2.122 to 4.211, the average increase in compressive stress for the isolated bearings in the frame isolated layer and core tube isolated layer are 189.109% and 98.267% respectively. As shown in **Figure 9**, the isolated bearings of the frame isolated layer in the new staggered story isolated structure do not experience tensile stress, only the isolated bearings of the core tube isolated layer experience tensile stress. The tensile stress and the number of isolated bearings experiencing tensile stress increase with the increase in aspect ratio. When the aspect ratio is 2.122 and 3.167, the tensile stress of the isolated bearings in the core tube isolated layer is less than the specified limit of 1 MPa, but when the aspect ratio increases to 4.211, some of the isolated bearings in the core tube isolated layer exceed the specified limit of 1 MPa for tensile stress.

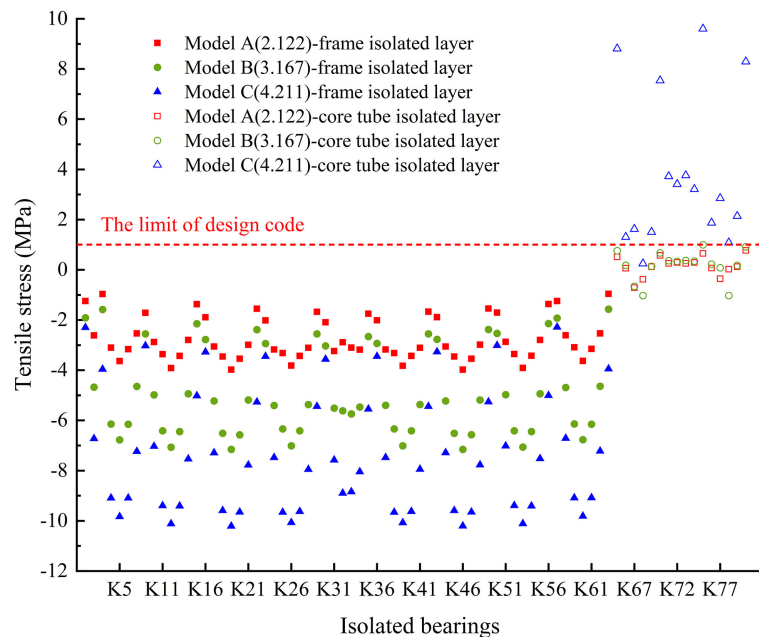


Figure 8. Comparison diagram of compression stress envelope values of isolated bearings of new staggered story isolated structures with different aspect ratios.

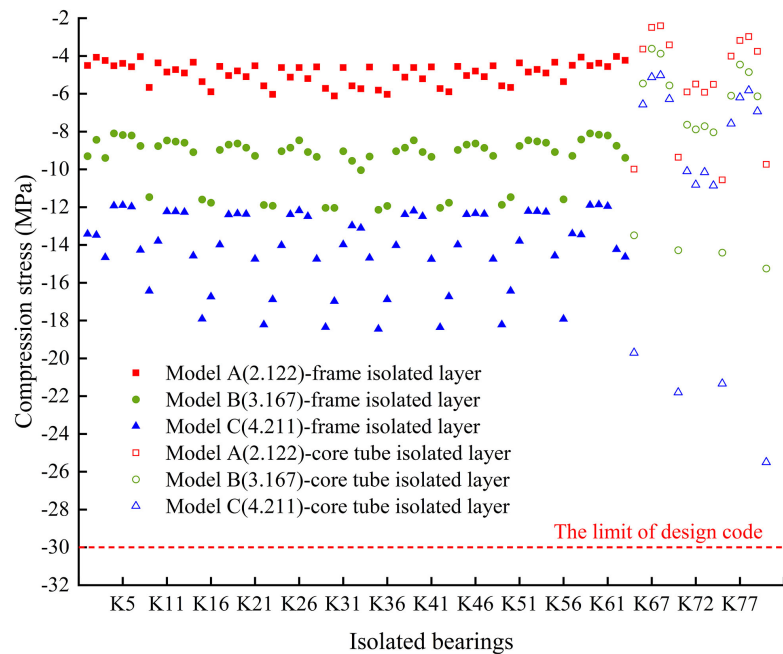


Figure 9. Comparison diagram of tensile stress envelope values of isolated bearings of new staggered story isolated structures with different aspect ratios.

4.2. Comparative Analysis of Overturning Resistance Ratio

As shown in **Figure 10** and **Table 4**, with the increase in aspect ratio, the height of the superstructure increases, which causes the overturning lever arm of the superstructure to increase, so the overturning moment of the superstructure increases with the increase of the aspect ratio. In addition, when the height of the superstructure increases, the number of floors increases, so the permanent load standard value of the superstructure also increases with the increase of the aspect ratio. Because the permanent load standard value of the superstructure is proportional to the overturning resistance moment of the superstructure, and the width of the structure remains constant, the overturning resistance moment of the superstructure also increases with the increase in aspect ratio as the overturning resistance lever arm remains constant. When the aspect ratio increases from 2.122 to 3.167, the overturning moment and overturning resistance moment of the superstructure increase by 239.565% and 87.817% respectively. When the aspect ratio increases from 2.122 to 4.211, the overturning moment and overturning resistance moment of the superstructure increase by 619.634% and 174.581% respectively. Although both the overturning moment and overturning resistance moment of the superstructure are increasing, the increase in overturning moment is much greater than the increase in overturning resistance moment. Therefore, as the aspect ratio of the new staggered story isolated structure increases, the overturning resistance ratio of the superstructure will decrease with the increase in aspect ratio. When the aspect ratio of the new staggered story isolated structure increases, the absolute horizontal acceleration of the substructure decreases. Since the absolute horizontal acceleration of the

floors is proportional to the overturning moment, the overturning moment of the substructure decreases as the aspect ratio of the structure increases. In addition, when the aspect ratio of the structure increases, the horizontal displacement of the floor increases. Since the horizontal displacement of the floor is inversely proportional to the overturning resistance moment, the overturning resistance moment of the substructure decreases as the aspect ratio of the structure increases. However, the decrease in the overturning moment of the substructure is greater than the decrease in the overturning resistance moment, so the overturning resistance ratio of the substructure of the new staggered story isolated structure increases as the aspect ratio of the structure increases.

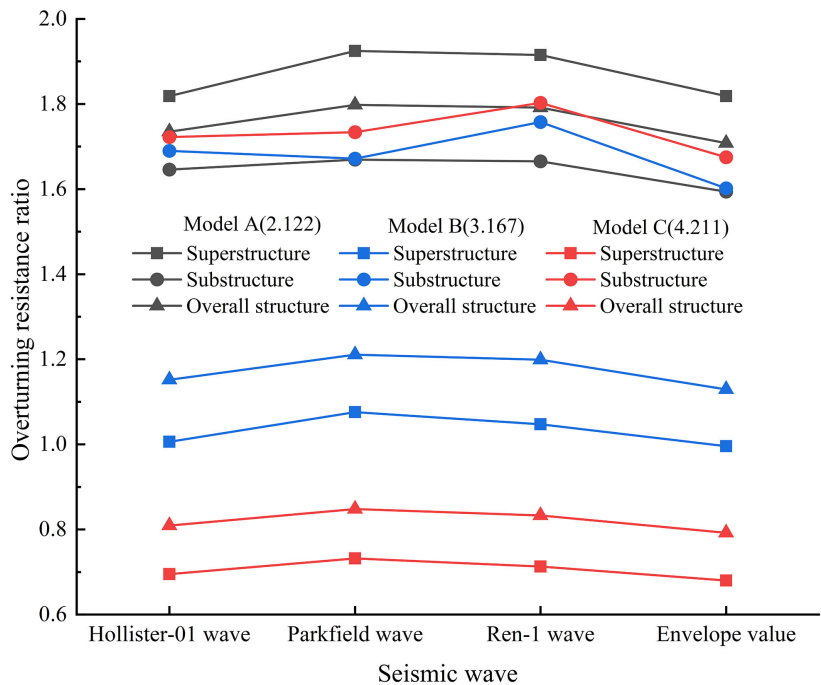


Figure 10. Comparison diagram of the overturning resistance ratio of new staggered story isolated structures with different aspect ratios.

Table 4. The overturning resistance ratio of new staggered story isolated structures with different aspect ratios.

Aspect ratio	Structure	Overturning resistance ratio	Hollister-01 wave	Parkfield wave	Ren-1 wave	Envelope value
2.122	Superstructure	Overturning moment (N·m)	1389493418	1312902136	1322942855	1389493418
		Overturning resistance moment (N·m)	2527139253	2526750495	2533938520	2526746358
		Overturning resistance ratio	1.818748632	1.924553572	1.915380176	1.818465871
	Substructure	Overturning moment (N·m)	1308379190	1289956815	1296821969	1350849126
		Overturning resistance moment (N·m)	2153453629	2153365270	2159283953	2153320914
		Overturning resistance ratio	1.64589413	1.669331287	1.665058122	1.594049899
	Overall structure	Overturning moment (N·m)	2697872608	2602858950	2619764825	2740342545
		Overturning resistance moment (N·m)	4680592881	4680115765	4693222472	4680067272
		Overturning resistance ratio	1.734919902	1.798067377	1.791467092	1.707840241

Continued

		Overturning moment (N·m)	4718239982	4405164879	4485588467	4718239982
	Superstructure	Overturning resistance moment (N·m)	4746409313	4738891311	4697595224	4697595224
		Overturning resistance ratio	1.005970305	1.075757989	1.047263978	0.995624479
3.167		Overturning moment (N·m)	1277067485	1289046240	1216899831	1335168997
	Substructure	Overturning resistance moment (N·m)	2158205262	2154968701	2138862490	2138862490
		Overturning resistance ratio	1.689969628	1.671754383	1.757632334	1.601941399
		Overturning moment (N·m)	5995307467	5694211118	5702488298	6053408978
	Overall structure	Overturning resistance moment (N·m)	6904614574	6893860012	6836457714	6836457714
		Overturning resistance ratio	1.151669804	1.210678682	1.198855194	1.129356655
		Overturning moment (N·m)	9981439457	9418863426	9520341482	9981439457
	Superstructure	Overturning resistance moment (N·m)	6939042838	6893148472	6788417296	6788417296
		Overturning resistance ratio	0.695194603	0.731845039	0.713043467	0.68010404
4.211		Overturning moment (N·m)	1245526796	1237360658	1178813169	1269026393
	Substructure	Overturning resistance moment (N·m)	2145371585	2145094798	2125118113	2125118113
		Overturning resistance ratio	1.722461205	1.733605141	1.80276075	1.674605134
		Overturning moment (N·m)	11226966252	10656224084	10699154651	11250465850
	Overall structure	Overturning resistance moment (N·m)	9084414422	9038243270	8913535408	8913535408
		Overturning resistance ratio	0.809160215	0.848165654	0.833106512	0.792281451

When the aspect ratio of the structure increases from 2.122 to 3.167 and 4.211, the overturning resistance ratio of the superstructure in the new staggered story isolated structure decreases by 45.323% and 62.773% respectively. The overturning resistance ratio of the substructure in the new staggered story isolated structure increases by 5.560% and 8.270% respectively. It is apparent that the decrease in the overturning resistance ratio of the superstructure is much greater than the increase in the overturning resistance ratio of the substructure. When the aspect ratio increases from 2.122 to 3.167 and 4.211, the overturning resistance ratio of the overall structure decreases by 33.618% and 53.496% respectively. Therefore, with the increase in the aspect ratio, the overturning resistance ratio of the superstructure and the overall structure decreases, leading to an increased risk of overturning for the superstructure and the overall structure. Therefore, in the design of the new staggered story isolated structure with a larger aspect ratio, particular attention should be paid to the superstructure. This can be achieved by altering the arrangement of the isolation layer to reduce the overturning lever arm of the superstructure, thus reducing the risk of collapse of the overall structure due to the overturning of the superstructure. In addition, special attention should be given to the state of the isolated bearings in the core tube isolated layer, and the tensile stress and the number of isolated bearings that generate tensile stress should be reduced as much as possible. By altering the arrangement of the isolated layer, the parameters of the isolated bearings, or uti-

lizing combined seismic mitigation isolation methods, it is possible to reduce damage to the weak positions of the new staggered story isolated structure and consequently reduce the risk of overturning and collapse of the structure.

5. Conclusions

In this paper, the base shear force, inter-layer shear force, inter-layer displacement, and inter-layer displacement drift of three new staggered story isolated structure models with different aspect ratios under rare earthquakes are analyzed. In addition, the transformation of tensile and compressive stresses of the isolated bearings and the variation of the superstructure, substructure, and overall structure with the aspect ratio are analyzed. The conclusions are as follows:

1) With the increase in the aspect ratio of the new staggered story isolated structure, the base shear force and inter-layer shear force borne by the substructure increase. The inter-layer displacement and inter-layer drift of each floor in the core tube and frame increase, indicating that a larger aspect ratio will result in a larger seismic response of the structure. The inter-layer displacement of the core tube isolated layer is greater than that of the frame isolated layer. Below the frame isolated layer, the inter-layer displacement and inter-layer drift of each floor in the core tube are smaller than those of the frame.

2) When the aspect ratio of the new staggered story isolated structure increases to 4.211, the isolated bearings on the four sides of the core tube isolated layer are prone to generate tensile stress, exceeding the code limits. Therefore, when designing the new staggered story isolated structure with a larger aspect ratio, special attention should be paid to the core tube isolated layer to avoid generating significant tensile stress in the isolated bearings, which could reduce the overall structural stability and increase the risk of overturning.

3) The overturning moment and overturning resistance moment of the superstructure in the new staggered story isolated structure increase with the increase in aspect ratio. However, the increase in overturning moment of the superstructure is much greater than the increase in overturning resistance moment, resulting in a decrease in the overturning resistance ratio of the superstructure with the increase in aspect ratio. The overturning moment and overturning resistance moment of the substructure of the new staggered story isolated structure decrease with the increase in aspect ratio. However, the decrease in overturning moment of the substructure is greater than the decrease in overturning resistance moment, leading to an increase in the overturning resistance ratio of the substructure with the increase in aspect ratio.

4) The decrease in the overturning resistance ratio of the superstructure in the new staggered story isolated structure is much greater than the increase in the overturning resistance ratio of the substructure. Therefore, with the increase in the aspect ratio of the structure, the overturning resistance ratio of the superstructure and the overall structure decreases. Thus, when designing the new staggered story isolated structure with a larger aspect ratio, special attention

should be given to the superstructure, and the arrangement of the isolated layer could be altered to reduce the overturning lever arm of the superstructure, thereby reducing the risk of collapse of the overall structure due to the overturning of the superstructure.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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