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Seismic Performance Comparison Between Base Isolation and Interlayer Isolation Schemes in Twin-Tower Shear-Wall Structures with Enlarged Basement

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Seismic isolation, an advanced technology, is being progressively applied in various practical projects, including complex yet widely used structures like twin-tower shear-wall structures with an enlarged basement (2TSSLB). However, limited research has been conducted to compare the seismic performance of different isolation schemes in 2TSSLB systems. The main objective of this study is thus to compare the seismic resistance efficiency between the base isolation scheme and the interlayer isolation scheme in a 2TSSLB. Three models were built for a 2TSSLB in this study: Model 1, the non-isolated structure; Model 2, the base-isolated structure; and Model 3, the interlayer-isolated structure (with the isolation layer on top of the enlarged basement). These models were analyzed using ETABS software to compare their maximum story shear force and maximum story drifts under earthquake at the basic fortification intensity within the 8-degree region. The results indicate that seismic performance of the 2TSSLB structure is significantly improved with the application of seismic isolation techniques, including both base isolation (Model 2) and interlayer isolation (Model 3). Notably, the interlayer isolation scheme in Model 3 achieves a lower maximum story drift, showing an average reduction of approximately 17.7% across all floors compared to the base isolation scheme in Model 2. This suggests that the interlayer isolation scheme, which positions the isolation layer above the enlarged basement of the 2TSSLB, provides greater structural safety redundancy and enhanced seismic performance. The findings offer valuable guidance for the practical design of seismic isolation schemes in 2TSSLB structures and recommend prioritizing the interlayer isolation scheme in such designs.

Keywords: Seismic isolation, Base isolation, interlayer isolation, Twin-tower structure, Story drift.

1. Introduction

Earthquakes can have devastating effects on people, resulting in building collapses, damaged roads, ruptured natural gas pipelines, and disruptions to electrical circuits and water systems. Among these, building collapses pose the greatest threat to human lives. The impact of earthquakes has been a major concern for scientists and engineers for many years. Numerous studies have been conducted to reduce the seismic responses of structures to seismic loads [1-19]. To enhance the seismic performance of structures, engineers have implemented a range of measures including conventional approaches such as increasing the cross-sectional area of beams and columns, adding more reinforcement, and optimizing layout configurations. Additionally, novel seismic strategies like energy dissipation techniques and seismic isolation technology have been increasingly adopted. Particularly in regions with high earthquake risks, seismic isolation technology has gained popularity. This technique involves introducing a seismic isolation layer to the middle or bottom level of a structure, which slows down the movement of the structure during an earthquake event and absorbs some of the energy from the earthquake. From the perspective of response spectrum analysis, seismic isolation techniques increase the natural vibration period of structures, thereby reducing their seismic acceleration [20].

Seismic Isolation technology has been applied to a wide range of structures, including not only conventional ones but also various special and complex structures. Numerous studies have been conducted on the application of seismic isolation techniques to complex structures. For example, Lu et al. [21] conducted a study on a roof-isolated structure that features four 230m towers and a top corridor. Wang [22] focuses on the study of a seismic isolation structure that consist of four towers serving as accommodation on top and an enlarged basement serving as a subway station at the bottom. Zhang [23] studied an isolated structure consisting of three towers arranged in a U-shape, which is used as a school. In practical engineering projects, it is common to encounter complex structures with multiple towers and an enlarged basement. This type of structure is referred to as a multi-tower structure with an enlarged basement (MTSLB).

A twin tower structure with an enlarged basement (2TSLB), which is a special case of MTSLB, has been studied by numerous researchers to explore the application of isolation techniques in it. For instance, Xie et al. [24] investigated the impact of different spacing between two towers on the seismic performance of an isolated 2TSLB. Li et al. [25] compared the seismic performance of 2TSLB with other MTSLB by altering their structural configurations, primarily involving changes in the number of towers and floors. Cao et al. [26] compared the seismic performance of a twin-tower shear-wall structure with an enlarged basement (2TSSLB) to its base-isolated version. Building upon the existing models and preliminary conclusions from Cao et al.'s research [26], this study aims to conduct further investigations.

The seismic performance of a structure is influenced by the location of the isolation layer. The two most common schemes for isolation are base isolation and interlayer isolation. However, there have been limited studies comparing the effectiveness of base isolation and interlayer isolation in 2TSLB, especially in twin-tower shear-wall structures with an enlarged basement (2TSSLB). Therefore, this study aims to investigate and compare the seismic performance of a base isolation scheme (with the isolation layer at the bottom) and an interlayer isolation scheme (with the isolation layer at the top of the enlarged basement) in 2TSSLB. This article begins by introducing three models used in this study: model 1 represents a non-isolated structure, model 2 represents a base isolated structure, and model 3 represents an interlayer isolated structure.

The dimensions, structural layout, building functions, as well as the details of isolation layer layout and earthquake intensity are provided for each model. Next, this paper describes the methods employed in this research, including model comparison parameters, calculation methods, standards, selection criteria for seismic waves, and design simplification. Subsequently, the results from this study are presented, with a specific focus on comparing maximum story shear forces and maximum story drifts among all three models under identical earthquake intensities. Finally, in conclusion section, the findings from this research are summarized.

2. Overview

The structure is a typical 2TSSLB, consisting of two towers and an enlarged basement. The towers are 15 stories high (counting from the bottom), with 12 floors dedicated to residential use (excluding the top and bottom two floors). Each floor accommodates two units, and those two units on each level share one elevator entrance. The enlarged basement consists of two levels that can be utilized as a commercial complex. Furthermore, it should be noted that this structure does not have a basement below the ground levels; therefore, the entire structure is above ground. To compare the impact of different positions of isolation layer on its seismic performance while ensuring that its functional requirements are met, this study presents three design models: Model 1(the Non-Isolated model) from previous research [26], Model 2 (the Base-Isolated model) from previous research [26], and Model 3 (the Interlayer-Isolated model).

2.1 Model 1: Non-Isolated Model

The Model 1 is a conventional structure without any isolation layers. As shown in Figure 1[26], the tower has a height of 45m and consists of 15 floors (including two floors within the enlarged basement), with each floor measuring 3m [26]. The tower spans a length of 30.5m and width of 10.1m[26]. The enlarged basement has dimensions of 6m in height, 26.1m in width, and 93m in length [26]. The towers of Model 1 are shear wall structures, including the first two floors within the enlarged basement, while the rest part of the enlarged basement are frame structures. The slenderness ratio (structural height to width) of this 2TSSLB, calculated based on one of its towers, is determined to be approximately 4.46:1.

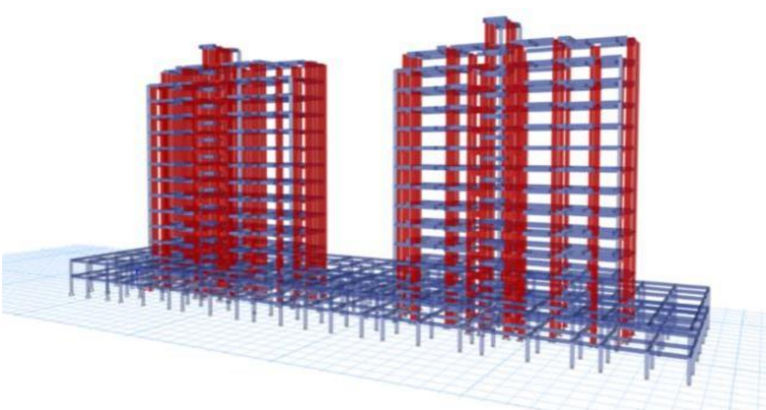

Fig. 1. The 3D illustration of Model 1 the non-isolated 2TSSLB[26]

The arrangement of shear walls and columns on each floor is shown in Figure 2 to 6[26], with yellow elements representing shear walls or columns, and purple ones denoting beams. The diagrams only show half of the symmetrical structure, with the axis of symmetry marked in the figure.

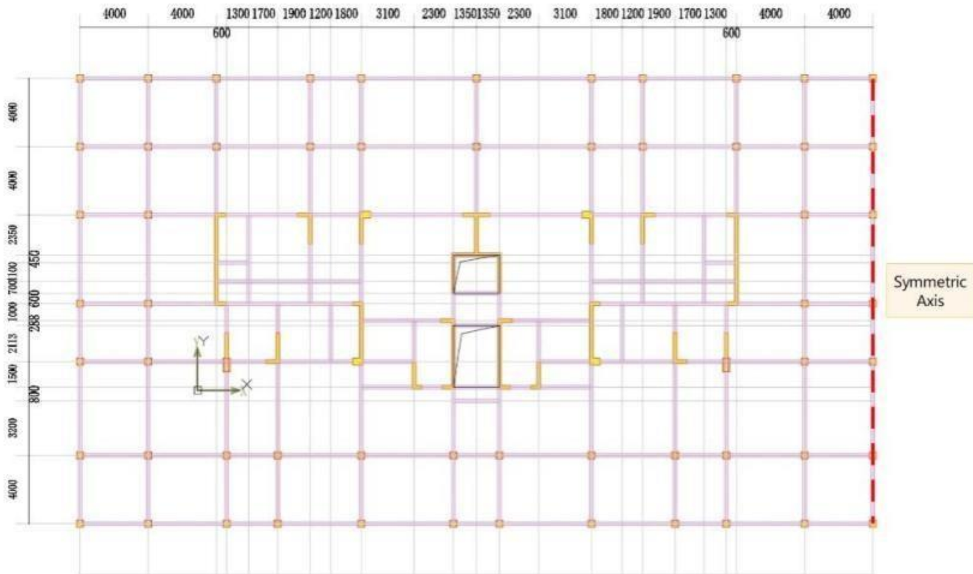

Fig. 2. Half plan view of the enlarged basement for Model 1 (level 1 to 2) [26]

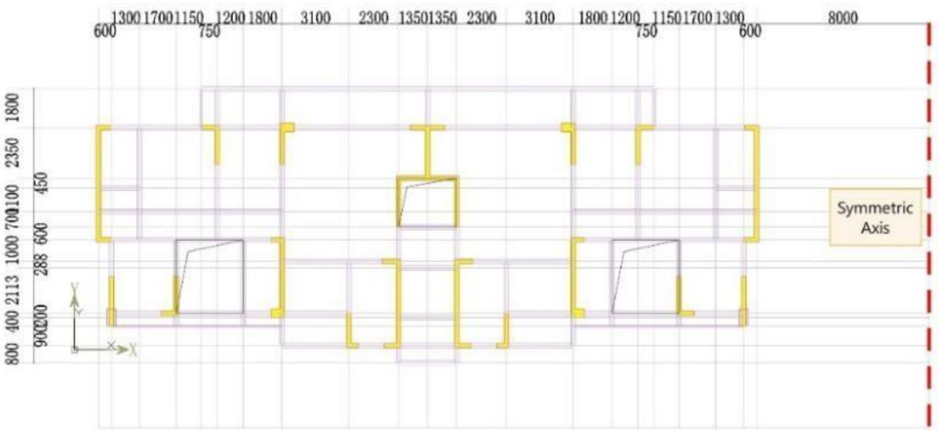

Fig. 3. Half plan view of the towers for Model 1 (level 3 to 12) [26]

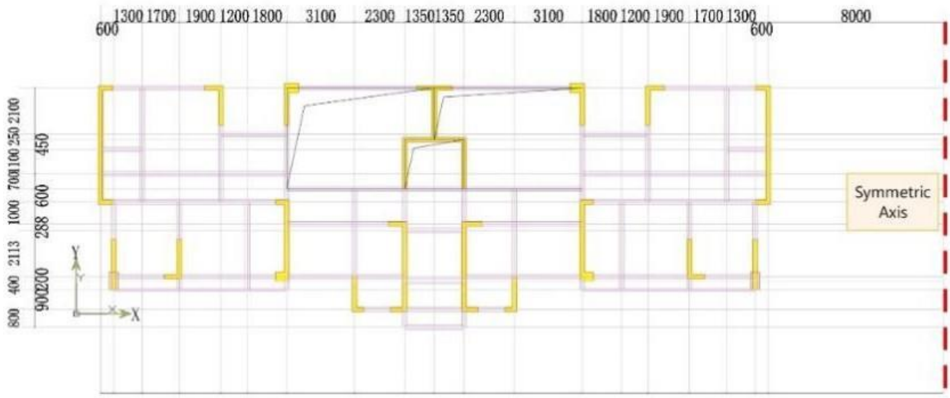

Fig. 4. Half plan view of the towers for Model 1 (level 13) [26]

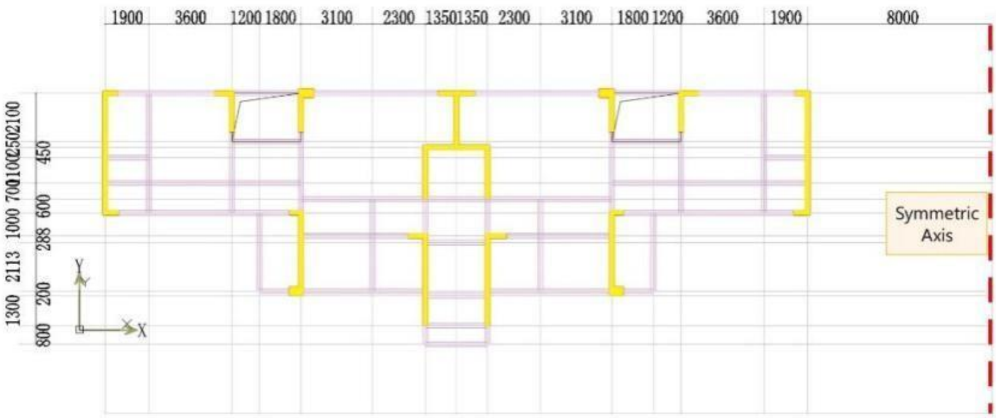

Fig. 5. Half plan view of the towers for Model 1 (level 14) [26]

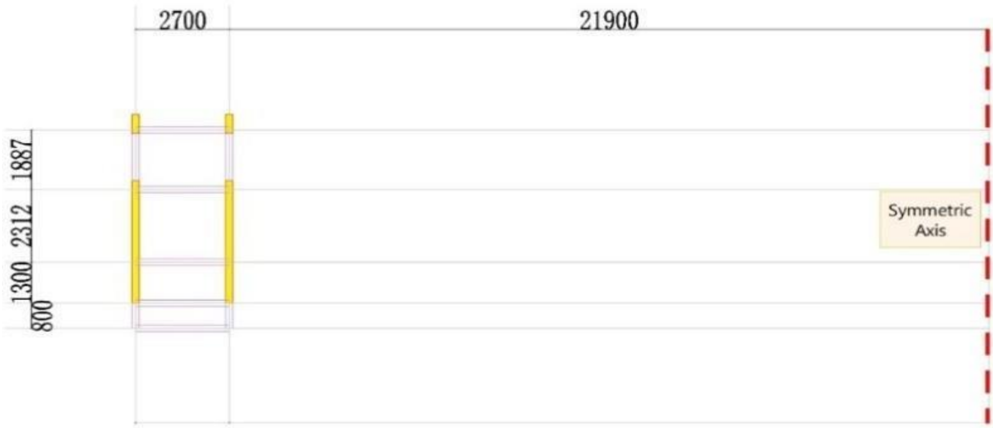

Fig. 6. Half plan view of the towers for Model 1 (level 15) [26]

The seismic precautionary intensity of the area where this structure is located is 8 degrees. The maximum horizontal seismic influence coefficient αmax is 0.16 under frequently occurred earthquake, but it increases to 0.45 under earthquakes at basic fortification intensity according to Code for Seismic Design of Buildings (GB 50011-2010) [27]. This value is associated with the earthquake probability in the region, and it impacts the response spectrum curve. According to Refs. [27], elastic design is required for conventional (non-isolated) structures during frequently occurred earthquake, which means taking αmax=0.16 in Model 1 for design. However, when comparing Model 1 with two isolation models - Model 2 and Model 3 - to ensure consistency in the seismic force calculated using the response spectrum method, a higher value of αmax=0.45 is used. This is because these isolation models are designed based on earthquakes at basic fortification intensity, where αmax=0.45, according to Standard for seismic isolation design of building (GB/T 51408-2021) [28].

Furthermore, according to Refs. [27], the location of the structure is classified as Design Seismic Category I, Class II site. These classifications depend on the geographical characteristics of the location where the structure is situated, including factors such as distance from fault zones and land composition. These classifications have an impact on both the characteristic period and response spectrum curve. In addition, the structure falls under Category C buildings [29]. This categorization method will impact the specific reinforcement requirements and design details of the structure.

The design concept of a conventional (non-isolated) structure aims to enhance structural stiffness to withstand seismic forces. Common practice involves increasing the section size of shear walls, columns, or beams and adding more reinforcement to them. According to Refs. [27], the structure should be designed to withstand frequently occurred earthquake without damage, be repairable after an earthquake at basic fortification intensity, and not collapse during rare earthquakes. However, the reality is that sometimes structures may experience seismic intensities that exceed the local design criteria, resulting in substantial structural damage. In such cases, the implementation of seismic isolation technology becomes one of the most effective solutions.

2.2. Model 2: Base-Isolated Model

The application of seismic isolation technology in the structure can significantly reduce the level of seismic acceleration experienced by the structure. Its design principle incorporates a seismic isolation layer into the structure (either at the bottom or interlayer), effectively absorbing seismic energy and increasing the structural period [1]. According to Refs. [28], seismic isolation structures should be designed to remain undamaged in the earthquake at basic fortification intensity, capable of being repaired during rare earthquakes, and will not collapse in extremely rare earthquakes. It is worth noting that Model 2 and Model 1 have identical seismic precautionary intensity, design seismic category, site class and building category. Specifically, both structures are in a region with an 8-degree seismic precautionary intensity. This region is classified as Design Seismic Category I and Class II site [27]. Both structures are defined as Category C buildings [29]. The consistent site and structure categories enable easy comparison of model calculation results. In addition, according to Refs. [28], Model 2 adopts a maximum horizontal seismic influence coefficient αmax=0.45 in its design.

The seismic resistance effects vary depending on the placement of the isolation layer in different positions within the structure. Model 2 incorporated a seismic isolation layer at the base of the structure. This isolation layer will support the whole structure including both towers and enlarged basement, thus to isolate the structure from the ground, as depicted in Figure 7. [26]

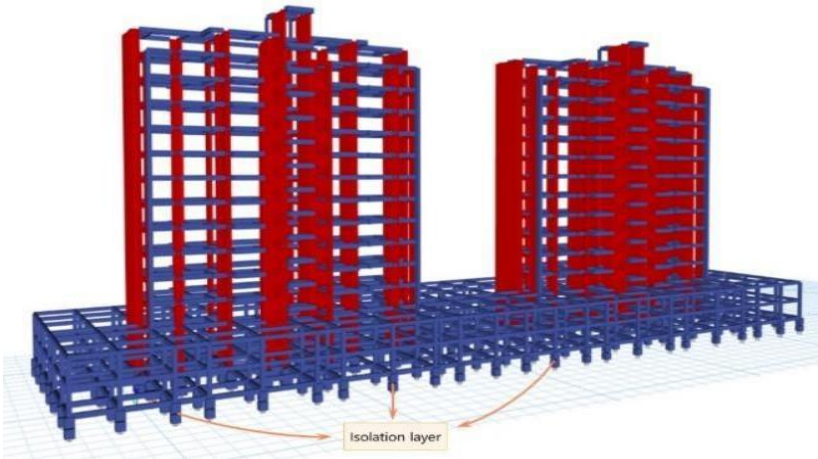

Fig. 7. The 3D illustration of Model 2 the base-isolated 2TSSLB[26]

Model 2 has a 2.2m isolation layer at the bottom, resulting in an increased overall height of the structure from 45m in Model 1 to 47.2m, while keeping the remaining dimensions unchanged. The tower exhibits a height-to-width ratio of 4.67:1. Apart from the floor where isolation layer (including bearings and isolation supporting piers) is located, the layout of shear walls and beams on other floors of Model2 remains identical to that of Model 1. Figure 8[26] shows half of a plan view that illustrates the specific arrangement of the isolation layer, with the axis of symmetry marked in the figure.

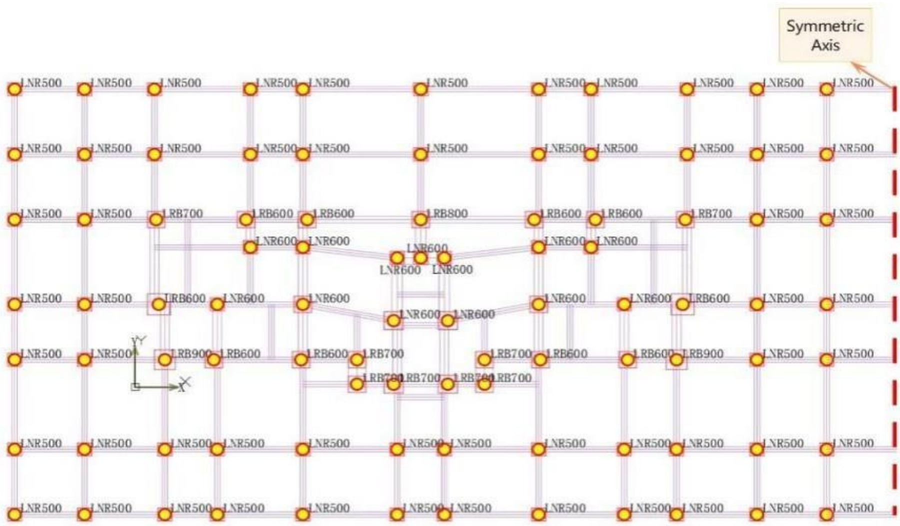

Fig. 8. The details of layouts for isolation layer at the bottom of Model 2 (half plan view) [26]

In this plan view, the yellow circle represents the isolation bearings, including LNR (Linear Natural Rubber Bearing) and LRB (Lead Rubber Bearing). The numbers following each abbreviation represent the diameter of the respective bearing (e.g., LRB500 denotes a 500mm Lead Rubber Bearing). 500 diameter bearings are utilized under the enlarged basement due to the low vertical load, whereas larger ones are employed under the tower section. Furthermore, Lead Rubber Bearings were primarily installed around the perimeter of the tower to enhance lateral stiffness and structural stability [26]. More detailed parameters of these isolation bearings can be found in Table 1.

Table 1. The details of isolation bearings [30]

Types With diameter in mm.	Heights of isolators (mm)	Directions	Linear Properties			Non-Linear Properties			GAP Unit
			Effective stiffness for compression (kN/mm)	Effective stiffness for Tension in kN/mm	Effective stiffness at 100% deformation (kN/mm)	Stiffness in kN/mm	Yield Strength in kN	Post Yield Stiffness Ratio	Effective stiffness in kN/mm
		U1	1600	160					1440
LNR500	140	U2			0.81				
		U3			0.81				
		U1	1900	190					1710
LNR600	165	U2			0.98				
		U3			0.98				
		U1	2200	220					1980
LRB600	165	U2			1.58	13.11	63	0.077	
		U3			1.58	13.11	63	0.077	
		U1	2600	260					2340
LRB700	195	U2			1.87	15.19	90	0.077	
		U3			1.87	15.19	90	0.077	
		U1	2900	290					2610
LRB800	225	U2			2.05	17.35	106	0.077	
		U3			2.05	17.35	106	0.077	
		U1	3500	350					3150
LRB900	250	U2			2.37	19.67	141	0.077	
		U3			2.37	19.67	141	0.077	

2.3 Model 3: Interlayer-Isolated Model

The seismic precautionary intensity, design seismic category, site class and building category of the area where Model 3 is situated are consistent with those of Model 1 and Model 2. Furthermore, according to Refs. [28], the design of Model 3 incorporates a maximum horizontal seismic influence coefficient (αmax) of 0.45. The Model 3 also incorporates seismic isolation technology, similar to the Model 2. However, in the Model 3, the isolation layer is located on the floor where the tower connects with the enlarged basement, rather than at the bottom of the structure, as illustrated in Figure 9.

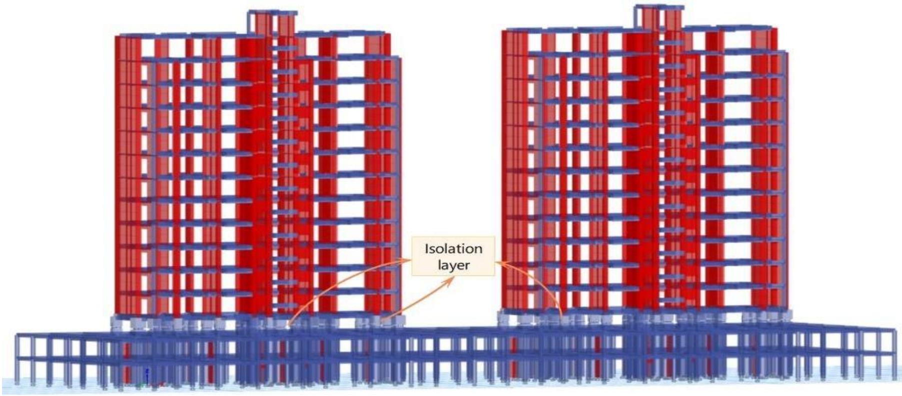

Fig. 9. The 3D illustration of Model 3 the interlayer-isolated 2TSSLB

Due to the 2.5m isolation layer set at an elevation of 6m (measured from the bottom ±0m) of the structure, the overall height of Model3 is adjusted to 47.5m, while keeping other dimensions unchanged, compared to the original non-isolated Model 1. Consequently, the height-to-width ratio (calculated by tower) becomes about 4.70:1.

As depicted in Figure 10 (half of the symmetrical plan view), there are notable differences in the structural configuration of the bottom two floors of Model 3 compared to Model 1 and Model 2, particularly in the section below the tower within the enlarged basement. The first two levels of the towers in Model 3 have been modified from their original shear-wall structure to a mixed structure with both shear walls and columns. These additional 6m height columns serve as lower isolation supporting piers beneath the isolation bearings, while also enhancing the stiffness of the first two levels of the structure.

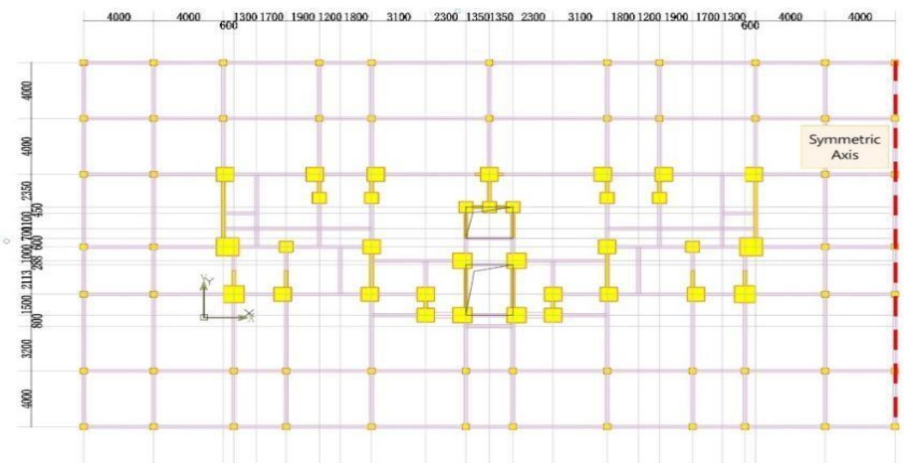

Fig. 10. Half plan view of the enlarged basement for Model 3 (level 1 to 2)

Figure 11 depicts the half plan view of Model 3's isolation layer at 6m, with the axis of symmetry indicated. In comparison to the arrangement of isolation bearings at the tower bottoms in Model 2, the stiffness of the northern bearings is increased by using larger diameter isolation bearings in Model 3, while the stiffness of the southern bearings is reduced by employing smaller diameter isolation bearings. This adjustment is made to ensure that the eccentricity of the structure remains below 3%, as per requirements outlined in Standard for seismic isolation design of building (GB/T 51408-2021) [28].

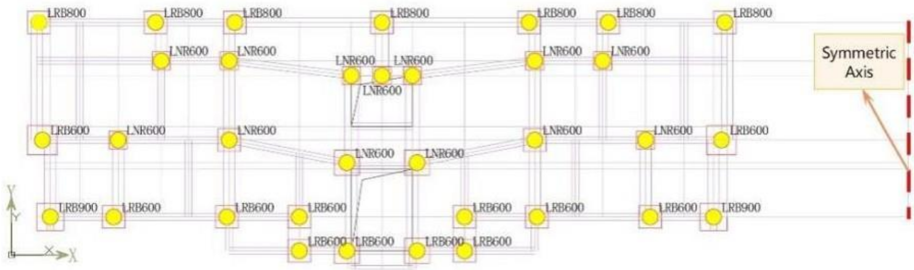

Fig. 11. The details of layouts for isolation layer of Model 3 (half plan view)

3. Methodology

3.1. Analysis Method

3.1.1. Models and Parameters for Comparison

In this study, three twin-tower shear wall structures with enlarged basement(2TSSLB), namely Model 1, Model 2, and Model 3, are investigated. Model 1 represents a conventional (non-isolated) structure while Model 2 incorporates a seismic isolation layer at the base of the 2TSSLB to achieve base isolation [26]. On the other hand, Model 3 features an interlayer isolated structure with a seismic isolation layer installed at the junction between the tower and the enlarged basement of the 2TSSLB. By comparing the seismic performance of these three models, the determination of which one offers greater advantages in terms of seismic effects for this 2TSSLB can be made.

In this study, two parameters, namely maximum story shear force and maximum story drift, will be utilized for model comparison. The maximum story shear force represents the maximum seismic force experienced by each floor of the model. Under identical structural arrangements, a smaller maximum seismic force indicates a more favourable seismic effect on the corresponding structure.

Normally, the columns are added below the isolators as supporting piers to achieve their isolation functionality. However, in some case, these additional columns can be excessively tall, thereby increasing the stiffness of the structure and subsequently raising the maximum story shear force. For example, Model 3 incorporates 6m tall columns as lower isolation supporting piers through its first and second floors, which increases the stiffness and enhances the maximum story shear force at these levels. In this case, the maximum story shear force may no longer accurately reflect the true seismic performance and safety of the structure.

Consequently, another crucial parameter emerges - maximum story drift - which directly indicates the structural deformation. If deformation exceeds a certain limit value, structural collapse may occur; hence controlling maximum story drift has become one of the primary objectives for earthquake resistance.

3.1.2. Response Spectrum Method and Time History Analysis

In this study, the software ETABS will be used to determine the maximum story shear force and maximum story drift of the model through two calculation methods: response spectrum method and time history analysis method. The response spectrum method will be employed by Model 1, while both Model 2 and Model 3 (due to their isolated structure) will utilize both the response spectrum method and the time history analysis method, according to Refs. [28]. For Model 1, the result obtained from the response spectrum method will be directly used. However, for Model 2 and Model 3, an envelope value approach will be employed by comparing the average values of calculated results from seven selected seismic waves with those obtained from the response spectrum method, taking their maximum value as the final value. The aim is to improve the accuracy of drawing outcomes.

The maximum horizontal seismic influence coefficient under frequently occurred earthquake($\alpha max=0.16$) is used in the response spectrum method during the design of Model 1 [27]. However, for consistency with Models 2 and 3, a value of $\alpha max=0.45$ is used in Model 1 for comparison after completing the design. In Models 2 and 3, the maximum horizontal seismic influence coefficient under earthquakes at basic fortification intensity($\alpha max=0.45$) is used [28]. Additionally, a peak ground acceleration of 200 cm/s^2 is used in time history analysis for the design of Model 2 and 3, while a peak ground acceleration of 400 cm/s^2 is utilized to evaluate certain parameters of the isolation structure during rare earthquakes [28].

3.1.3. Standards and Economic Efficiency

Regarding the standards, Model 1, as conventional(non-isolated) structure, is designed based on the Code for Seismic Design of Buildings (GB 50011-2010) [27], while Model 2 and 3, as isolated structures, comply with the Standard for seismic isolation design of building (GB/T 51408-2021)[28]. Comparatively, the Standard for seismic isolation design of building (GB/T 51408-2021) [28] imposed on Model 2 and model 3 is more stringent. For example, under earthquakes of basic fortification intensity, conventional structures are expected to experience plastic deformation that can be repaired according to the Code for Seismic Design of Buildings (GB 50011-2010) [27], while isolated structures should maintain structural elasticity during earthquakes at basic fortification intensity based on the Standard for seismic isolation design of building (GB/T 51408-2021) [28]. In addition, during rare earthquakes, the isolated structure will then be allowed to undergo elastoplastic deformation [28].

Specifically, the Standard for seismic isolation design of building (GB/T 51408-2021) [28] stipulates requirements for the maximum story drift of the main structure in an isolation system. Under earthquakes of basic fortification intensity, the maximum story drift of the shear wall structure above the isolation layer should be less than 1/600, while for the frame-shear wall structure it should be less than 1/500 [28]. Additionally, the maximum story drift of frame-shear wall structure below the isolation layer under earthquakes of basic fortification intensity must not exceed 1/600 [28]. On the other hand, the Code for Seismic Design of

Buildings (GB 50011-2010) [27] requires that non-isolated structures during frequently occurred earthquake should have a maximum story drift of 1/550 for frame structures and 1/1000 for shear wall structures. Furthermore, the Standard for seismic isolation design of building (GB/T 51408-2021) [28] also provides specifications regarding the isolation layers and isolators. These specifications include the eccentricity of the isolation layer, the long-term surface pressure on isolators, maximum tensile and compressive stresses on isolators during rare earthquakes, as well as horizontal displacement of isolators during rare earthquakes [28].

The model design for this project will adhere to both standards' requirements while also considering the building's economic efficiency. In other words, the design aims to minimize the section size of shear walls or frames, reduce the dimensions of isolation supports as much as possible, and optimize the steel content in the structure while fulfilling code requirements. However, there are instances where considerations must be given to factors like the impact of an isolation layer. For example, in Model 2 and Model 3, columns of a larger size are needed to support isolation bearings, requiring them to be at least 200mm larger than the diameter of the bearing to ensure sufficient installation space. In Model 3 specifically, since the isolation bearings need to be accommodated at a height of about 6m, an increase in the height of the lower isolation supporting piers is necessary accordingly. In general, it is essential to control the construction costs of these design schemes as much as possible while still meeting these standards to make them closer to real-world designs. Consequently, the findings from this research can be considered more reliable.

3.2. Earthquake Wave Selection

According to the requirements of the Code for Seismic Design of Buildings (GB 50011-2010) [27], it is optimal to supplement the seismic isolation structure calculation with time-history analysis. Therefore, in addition to the response spectrum method, model 2 and model 3 are also analyzed using time-history method. For each model, seven seismic waves (including two artificial ones) were utilized. The selection of these seismic waves refers to the Code for Seismic Design of Buildings (GB 50011-2010) [27], which specifies criteria for the number and proportion of actual seismic waves, the duration of seismic waves, as well as calculated structural base shear force and response spectrum curve. These specifications ensure an adequate number of actual seismic waves with sufficient duration, as well as a mathematical sense of similarity and compatibility between the land where the project is built and the locations where these selected seismic waves occur. Hence, the use of these selected seismic waves allows for a more precise assessment of structures and their true response during seismic events.

3.3. Simplifications

In this study, for easier model comparison, certain simplifications have been made.

3.3.1. Simplification of Structure Levels

Firstly, the height and floor number of the models are simplified. Although there may be variations in height due to the installation of seismic isolation layers, these differences do not exceed 2.5m, and the difference in height-to-width ratio does not exceed 5.5%. Furthermore, all models can achieve the same building function. Thus Model 1, Model 2, and Model 3 can be considered as different design schemes for the same 2TSSLB.

Additionally, the installation of seismic isolation layers in Model 2 and Model 3 has resulted in a change in the number of floors. In this study, data from each floor will be compared, excluding those with seismic isolation layers. Furthermore, floors will be named based on their respective building functions. This means that the level where isolation layer located are not included in floor sequencing for comparison purposes. For instance, level 3 of Model 3 in the "results and discussion" section is defined based on its building functions, which is considered as the fourth floor physically speaking. This is because, physically, the third floor in Model 3 is the isolation layer, which is excluded from the floor sequences. Similarly for Model 2 where the level 1 in “results and discussion” section corresponds to actual second level since first level is the seismic isolation layer. In summary, floors are defined based on their building functions, and those floors with the same functions across all models (Model 1-3) are assigned identical floor numbers.

3.3.2. Simplification of Concrete Using

The second aspect involves the simplification of the concrete materials utilized in the structure. In this case, all three models (Model 1-3) employ C85 concrete. This high-strength concrete possesses a standard compressive strength value of Fck=53.4Mpa, with a shear modulus G=15975Mpa and an elastic modulus E=38340MPa. By employing high-strength concrete throughout the entire structure, it becomes possible to reduce the dimensions of shear walls, beams, and columns while simultaneously preserving the seismic performance of the structure. Thus, this approach better caters to the functional requirements of this structure.

3.3.3. Simplification of Elevators and Enlarged Basement

In practical engineering, the bottom floor of the elevator shaft is often situated below the first floor of the main structure, serving primarily as an equipment room. However, for this experiment, it is assumed that the first floor of the elevator shaft and the bottom of the structure are at equal heights. Furthermore, this research assumes that there is sufficient space for an elevator shaft; therefore, there is no need to shift the isolation supporting piers surrounding the shaft on both the first and second floors.

Finally, the design of the enlarged basement is simplified by adopting a fully symmetrical frame structure. This approach ensures a more regular and representative structure for comparative studies. In practical engineering, the shape of the enlarged basement could be more flexible, allowing for asymmetrical arrangements of internal beams and columns.

4. Comparison Results and Discussion

This study aims to compare the seismic performance of Model 1, Model 2, and Model 3 in terms of two aspects: maximum story shear force and maximum story drift. The Model 1 will be evaluated solely using the response spectrum method, and its result will be considered as the outcome. On the other hand, Model 2 and Model 3 will utilize both the response spectrum method and time history analysis method. The time history analysis results of 7 seismic waves are averaged and then compared with those obtained from the response spectrum method. The final calculation results are determined by selecting the larger values.

4.1 Maximum story Shear Force

The maximum shear forces (in the X and Y directions) of each floor in both towers are illustrated in Figure 12 to 15 for this 2TSSLB, as well as the maximum shear forces of the two floors which forms the enlarged basement.

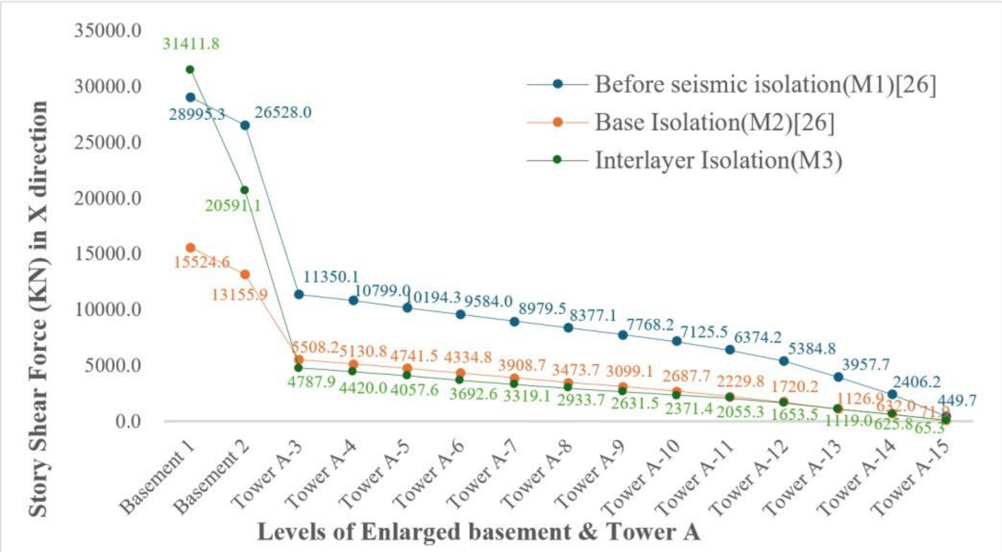

Fig. 12. The story shear force in X direction for Tower A & Enlarged basement

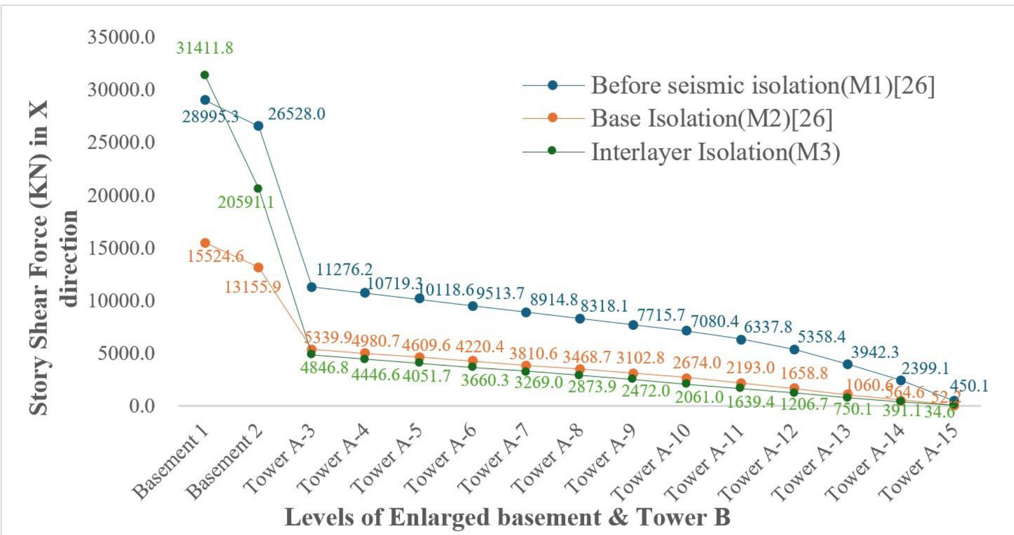

Fig. 13. The story shear force in X direction for Tower B & Enlarged basement

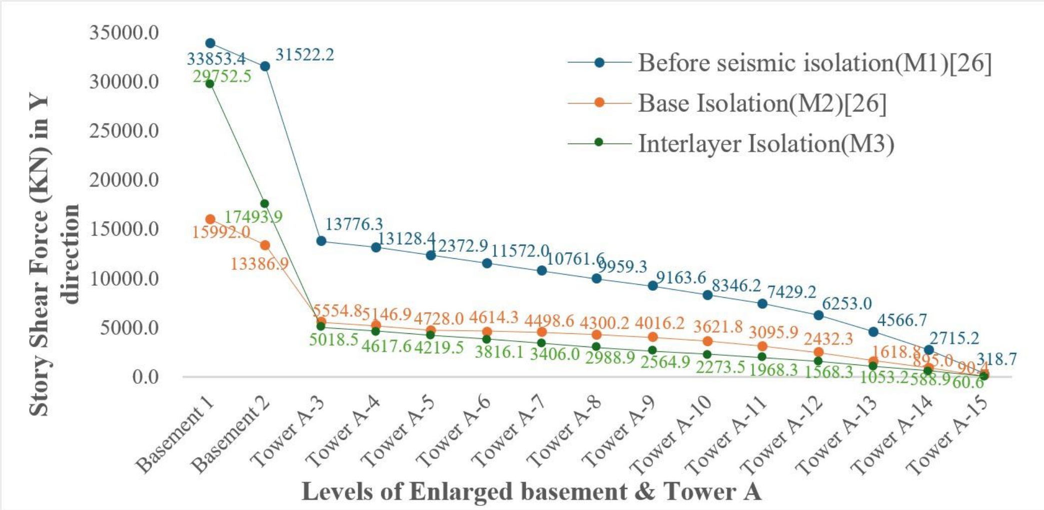

Fig. 14. The story shear force in Y direction for Tower A & Enlarged basement

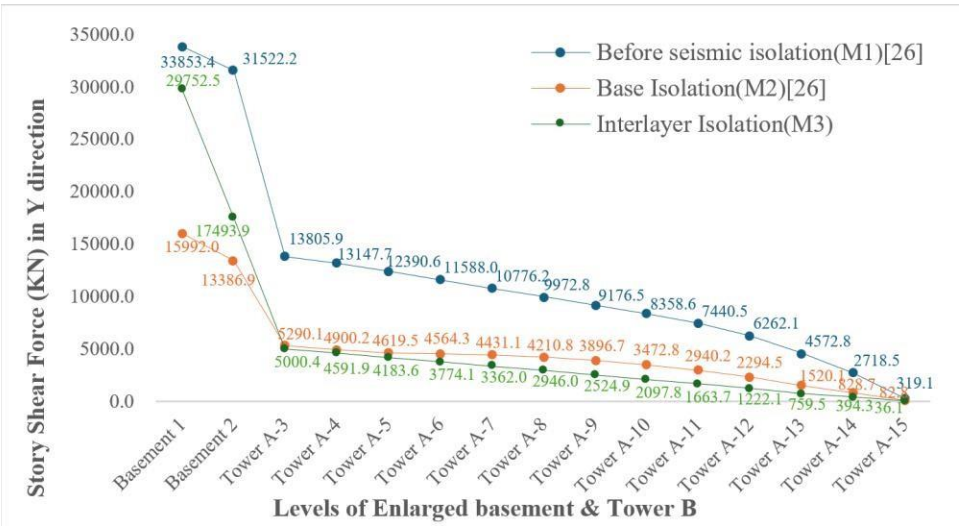

Fig. 15. The story shear force in Y direction for Tower B & Enlarged basement

The tower section (level 3 to level 15) exhibits the same arrangement of shear walls and beams for Model 2 and Model 3. Compared to the non-isolated structure (Model 1), both isolation design schemes (Model 2 and 3) effectively reduce the maximum story shear force exerted on the towers within the structure. Notably, Model 3, as an interlayer isolated structure, demonstrates a lower maximum story shear force than Model 2, the base isolated structure, in the towers (from level 3 to level 15), with an average decrease of approximately 22.5%.

For the two levels of the enlarged basement in this 2TSSLB, Model 2 with base isolation system can reduce the maximum story shear force of it [26]. However, the maximum story shear force of the enlarged basement in Model 3 does not decrease and may even increase in some cases, such as the maximum shear force on the first floor in the X direction. This is because additional columns have been installed as lower seismic isolation piers on the first two floors to support isolators for this interlayer isolated structure (Model3), which enhances structural stiffness and consequently increases maximum story shear forces. Thus, the final judgment regarding structural safety should be based on maximum story drift.

4.2 Maximum Story Drift

The maximum story drift of each floor in the X and Y directions of this 2TSSLB are illustrated in Figure 16 to 19.

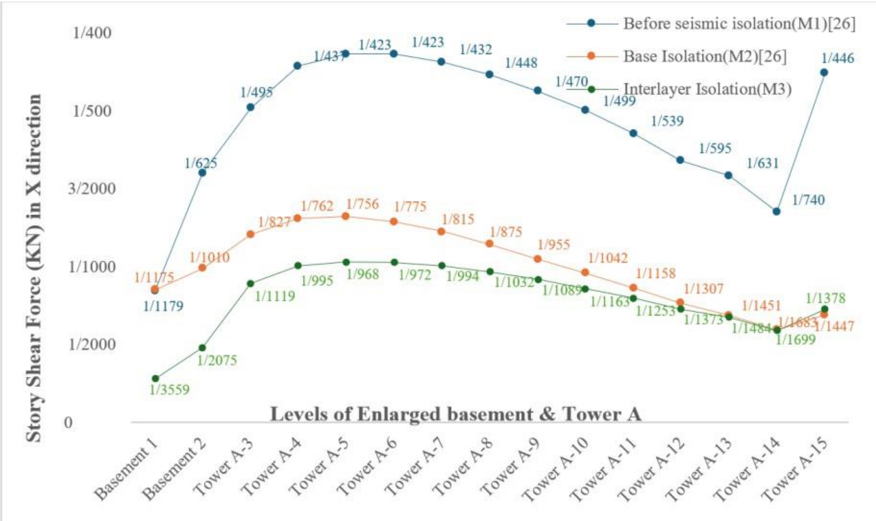

Fig. 16. The story drift in X direction for Tower A & Enlarged basement

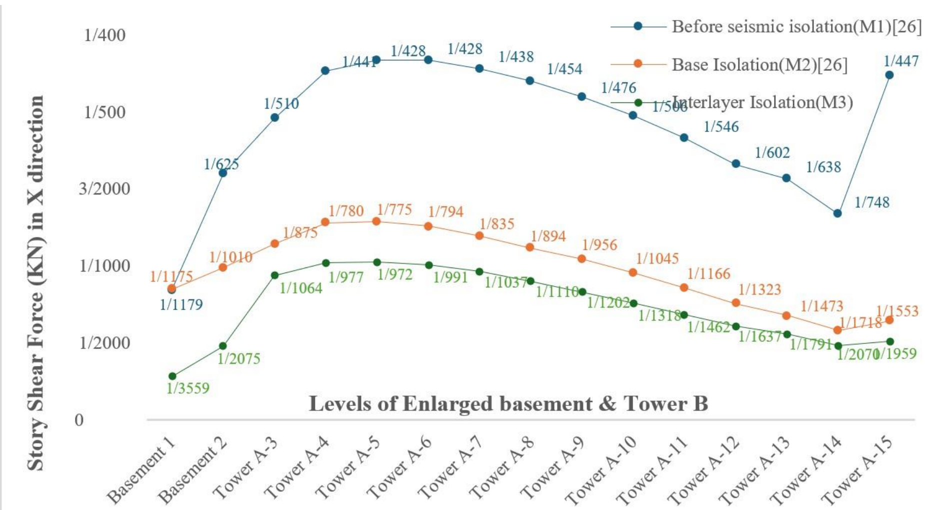

Fig. 17. The story drift in X direction for Tower B & Enlarged basement

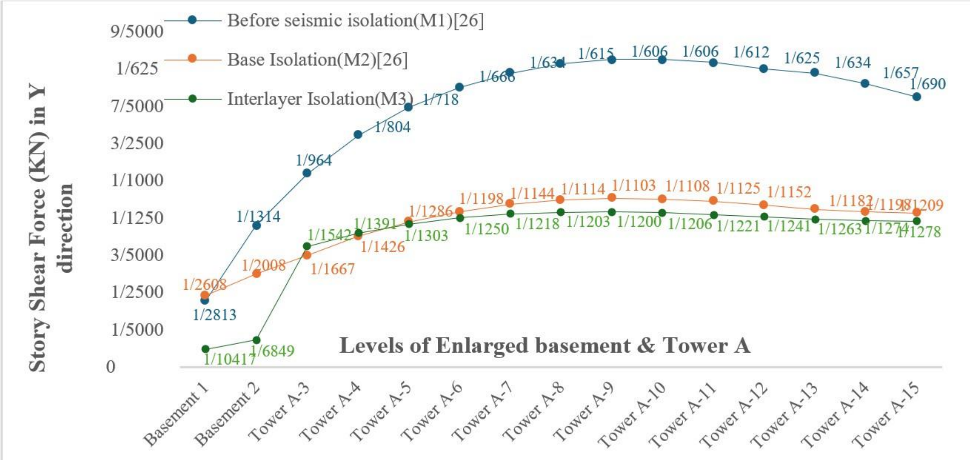

Fig. 18. The story drift in Y direction for Tower A & Enlarged basement

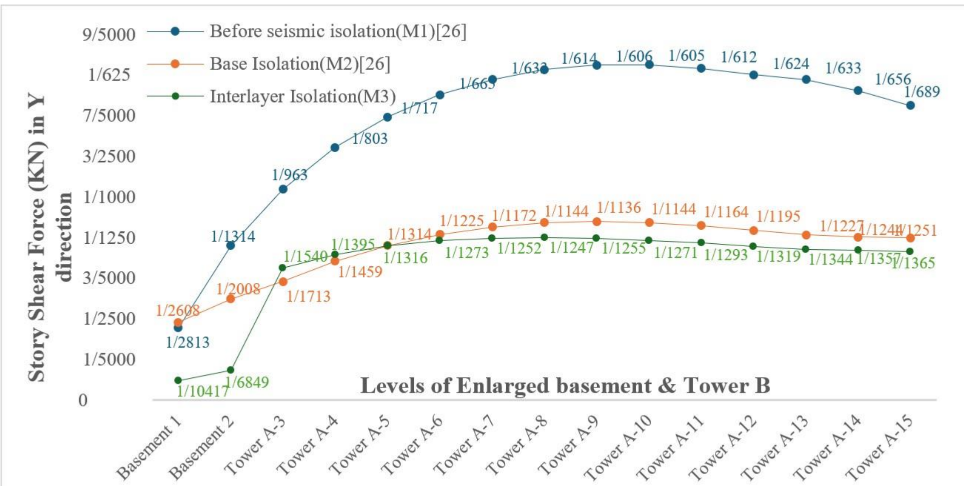

Fig. 19. The story drift in Y direction for Tower B & Enlarged basement

The results depicted in Figure 16 to 19 demonstrate a significant reduction in the maximum story drift for each level of the tower (from level 3 to level 15) when comparing Model 2 and 3 (isolated structures) with Model 1 (a non-isolated structure). Notably, Model 3 (with an interlayer isolated system) exhibits a lower maximum story drift within the tower (from level 3 to level 15) compared to Model 2 (with a base isolated system), showing an average decrease of approximately 12.6%. Furthermore, it is observed that there is an increase in the maximum story drift at the top floor (level15) of the non-isolated structure in its X direction, potentially attributed to the whipping effect; however, implementing isolated technology can effectively mitigate this phenomenon [26].

The maximum story drift of Model 3's enlarged basement is approximately 66% lower than that of Model 2. This means that the safety of Model 3 is not compromised despite an increase in maximum story shear force due to the addition of some lower isolation supporting piers within the enlarged basement. On the contrary, it indicates that the safety redundancy for level

1 and level 2 in Model 3 surpasses that of Model 2.

5. Conclusions

In this study, three design schemes of 2TSSLB are analyzed: Model 1, the non-isolated structure from previous research [26]; Model 2, the base isolated structure from previous research [26]; and Model 3, the interlayer isolated structure. The objective of this paper is to compare the seismic effects of these two isolation techniques to provide guidance for the design of practical isolation projects. By analyzing their maximum story shear force and maximum story drift, the following conclusions are drawn:

In the tower section (from level 3 to level 15), the use of seismic isolation technology significantly reduces the maximum story shear force and maximum story drift for this 2TSSLB. Furthermore, Model 3 with an interlayer isolation system exhibits a more pronounced effect in reducing seismic effects in these towers compared to Model 2 with a base isolation system.

When compared to the non-isolated structure of Model 1, Model 2 with a base isolation system achieves an average reduction of 62.4% in maximum story shear force and an average reduction of 48.3% in maximum story drift within the tower section. Similarly, when compared to Model 1, Model 3 with an interlayer isolation system achieves an average reduction of 70.7% in maximum story shear force and an average reduction of 53.6% in maximum story drift in towers. It is also noteworthy that the arrangement of shear walls and beams remains consistent in the tower section across all three models.

In the enlarged basement (from level 1 to level 2) for this 2TSSLB, Model 3 with an interlayer isolation system has superior safety redundancy than Model 2 with a base isolation system, despite experiencing higher maximum story shear force.

Specifically, Model 2 exhibits an average reduction of 51.8% in the maximum story shear force and an average reduction of 16.1% in the maximum story drift, compared to Model 1. The maximum shear force for the enlarged basement of Model 3 does not decrease significantly (with an average reduction of only 17.7% to Model 1), and it is even higher than that of Model 1 in the X direction of tower A (8.3% higher). However, this can be attributed to the increased stiffness of Model 3's enlarged basement due to the addition of columns serving as isolation supporting piers, resulting in higher seismic forces. In such cases, the maximum story drift will more accurately indicate the structural collapse risk. Due to the greater stiffness of its enlarged basement with additional columns compared to Models 1 and 2, Model 3 demonstrates even smaller maximum story drifts compared to Model 2 (72.6% lower than that in Model 1) in the enlarged basement, proving that the enlarged basement in Model 3 has superior safety redundancy.

In general, for 2TSSLB, regardless of whether the base isolation system (as in Model 2) or the interlayer isolation system (as in Model 3) is employed, the seismic performance surpasses that of non-isolation structures (as in Model 1). Especially, when compared to Model 2, Model 3 exhibits a lower overall maximum story drift (on average 17.7% less than Model 2), resulting in a more advantageous overall isolation effect.

In practical engineering design, seismic isolation technology can be employed to enhance the seismic performance of 2TSSLB. This article also suggests that the interlayer isolation scheme should be prioritized or at least considered as one of the options when designing a 2TSSLB, while ensuring the fulfilment of building function. Additionally, factors such as economization, ease of maintenance for isolation bearings, and others should also be taken into consideration.

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