Engineering Advances, 2023, 3(6), 477-482
https://www.hillpublisher.com/journals/ea/
ISSN Online: 2768-7961

Optimization of Seismic Performance of Staggered Layer Structures Based on SATWE Software Plate Thickness

Haojie Zhang*, Xinpan Xia, Xiaopan Gao

Zhengzhou Business University, Zhengzhou, Henan, China.

How to cite this paper: Haojie Zhang, Xinpan Xia, Xiaopan Gao. (2023) Optimization of Seismic Performance of Staggered Layer Structures Based on SATWE Software Plate Thickness. *Engineering Advances*, 3(6), 477-482.
DOI: 10.26855/ea.2023.12.007

Received: November 30, 2023
Accepted: December 27, 2023
Published: January 19, 2024

***Corresponding author:** Haojie Zhang, Zhengzhou Business University, Zhengzhou, Henan, China.

Abstract

In this paper, based on the seismic effect, the influence of the change of floor thickness on the seismic performance of high-rise staggered-story buildings is studied. Taking an engineering example as the research object, the structure model is established by SATWE software. Four kinds of finite element analysis models with thicknesses of 110 mm, 120 mm, 130 mm, and 150 mm are established. The elastodynamic time history analysis method is used to compare the maximum floor displacement of each structural scheme, the floor displacement angle of each structural scheme, and the lateral stiffness of each structural scheme. The analysis results show that with the increase in floor thickness, the maximum floor displacement, floor displacement angle, and lateral stiffness of the structure tend to increase. The following conclusions can be drawn.: the structure must not be too thin behind the slab, nor the thicker the better to meet the seismic requirements. In this project, the floor thickness of 130mm can meet the seismic requirements and is comparatively economical.

Keywords

Staggered floor, Aseismatic performance, Maximum floor displacement angle, Lateral stiffness

Staggered structure refers to a type of structure in a building where the floor slabs on the same floor are not at the same height, and the height difference is greater than the beam height or greater than 500mm. Due to the discontinuity of the floor slab, staggered structures can complicate the distribution of internal forces and seismic effects along the floor height. The staggered parts can also easily form short columns and low walls that are not conducive to earthquake resistance, making them complex multi-story and high-rise structures. Therefore, staggered structures have their unique characteristics in various design stages such as modeling, calculation, and drawing, which are much more difficult than the design of flat story structures.

At present, there is no standardized and unified theory for the selection of floor thickness in the research and optimization design of seismic performance of staggered structures both domestically and internationally. However, in recent years, China has gradually improved the design and seismic analysis of staggered structures. Scholars at home and abroad have proposed their own views on the seismic optimization analysis of staggered structures. In 2017, Zhang Xiao used PKPM structural design software as an example to model and evaluate the overall seismic performance of a frame-supported shear wall structure with staggered story conversion. The experiment proved that the structure of this project has a good yield mechanism and bearing capacity, achieving the seismic target [1]. In 2016, Tian Xuan used ANSYS finite element software to establish three-dimensional spatial models of different structural forms for structural seismic analysis in his graduation thesis, which was based on the seismic performance analysis of beam transfer floors with different structural forms using ANSYS [2]. This article is based on the study of the impact and optimization analysis of floor thickness on the seismic performance of staggered structures under earthquake action, with floor thickness as a variable and other component sizes being the same.

1 Scheme selection

1.1 Scheme Design

A commercial and residential integrated high-rise building with a prefabricated spiral staggered building structure, including a main structure and a glass curtain wall structure. The main building adopts a tube-in-tube structure, and the main building is composed of multiple building bodies, with multiple building bodies forming staggered structures. The structural design of glass curtain walls is a spiral structure, which is divided into upper building, middle building, and lower building. The upper building and lower building have symmetrical axes and are mutually symmetrical. Effectively connecting the staggered structure and spiral glass curtain wall building together, and setting friction dampers or friction energy dissipation cross support damping devices at adjacent staggered structures of different heights in two adjacent areas, solves the problem of contradiction between structural design and ornamental function in high-rise buildings in existing technology, making the internal structure of the building unique, improving visual enjoyment effect, and having good seismic performance.

The structural system of this project adopts a frame structure, consisting of 23 floors, and adopts a staggered structure form. The grid size is 8m * 6 and 7.2m * 4, and the staggered layout form is that the middle two spans are 1.2m lower than the left and right two spans. The thickness of the four types of structures is different from that of other structures, of the same size. Option 1 selects 110mm for the thickness of the floor, Option 2 selects 120mm for the thickness of the floor, Option 3 selects 130mm for the thickness of the floor, and Option 4 selects 150mm for the thickness of the floor.

The basic design conditions are as follows:

Basic earthquake information: fortification intensity, 7 (0.15g); Site category, Class III; Seismic fortification group, second group; Structural rule-based information, irregular; Concrete frame seismic rating, Level 2; The seismic level of seismic construction measures shall not be changed; Characteristic period (seconds), 0.55; The maximum seismic impact coefficient used for checking weak floors of regular concrete frame structures below 12 floors, 0.7200; The selection method of structural damping ratio is unified throughout the building; Damping ratio of the structure (%), 5.00; Maximum additional damping ratio, 0.50; Iterative determination of equivalent stiffness and equivalent damping ratio, no.

The wind load information is, ground roughness category, A; Corrected basic wind pressure (kN/m^2), 0.90; The basic period of X-direction structure (seconds) and Y-direction structure (seconds), 1.24; Damping ratio of the structure under wind load (%), 5.00; Amplification coefficient of wind load effect during bearing capacity design, 1.00; Wind pressure for comfort calculation (kN/m^2), 0.90; Structural damping ratio (%) for comfort calculation, 2.00.

Adjustment information: negative bending moment adjustment coefficient at the beam end, 0.85; Beam end bending moment amplitude modulation method, using vertical components to determine the support of the amplitude modulation beam; Beam end bending moment amplitude modulation method, using vertical components to determine the support of the amplitude modulation beam; Automatically consider Article 5.2.5 of the seismic code (adjustment of shear weight ratio), and adjust the seismic internal forces of each floor according to the seismic code (5.2.5); The method of judging weak layers based on stiffness ratio, and strict judgment based on compliance and high regulations.

1.2 Seismic wave selection

This article adopts the spatial finite element analysis software—SATWE for multi-layer and high-rise structures [3].

The basic principle for selecting seismic waves [4]: The influence of the site category where the building structure is located should be fully considered so that the spectral characteristics of the selected seismic waves are as consistent as possible with the site category. Therefore, the shape of the function curve in this part should be as consistent as possible.

The basic principle for selecting seismic waves [4]: The influence of the site category where the building structure is located should be fully considered so that the spectral characteristics of the selected seismic waves are as consistent as possible with the site category. Therefore, the shape of the function curve in this part should be as consistent as possible.

According to the "Code for Seismic Design of Buildings" [5], when three seismic waves are used, the number of natural waves shall not be less than 2/3 of the total wave number. The seismic wave selected in the article is TH001TG045 (as shown in Figure 1), a natural wave with a characteristic period of 0.45 seconds and a peak acceleration of 116.8 in the main direction, 113.7 in the secondary direction, and 48.7 in the vertical direction; TH002TG055 (as shown in Figure 2) is a natural wave with a characteristic period of 0.55 seconds and a peak acceleration of 265.3 in the main direction, 261.3 in the secondary direction, and 123.3 in the vertical direction; RH2TG065 (as shown in Figure 3) artificial wave, with a characteristic period of 0.65 seconds and peak acceleration of 100 in the main direction, 100 in the secondary direction, and 100 in the vertical direction.

2. Maximum floor displacement angle of the structure

The interlayer displacement angle refers to the ratio of the maximum horizontal displacement between floors and the height of floors under the action of wind load or frequent earthquake standard values calculated using elastic methods $\Delta u/h$ According to the requirements of the "Seismic Code", the limit values for the ratio of maximum inter-story displacement to story height of building structures are 1/1000 for shear walls, 1/800 for frame shear structures, and 1/550 for frame structures. According to Article 4.3.5-4 of the "High Regulation" [6], when calculating three sets of time history curves, it is advisable to take the larger value of the envelope value of the time history method calculation result and the mode decomposition response spectrum method calculation result for the structural seismic effect; When calculating seven or more sets of time history curves, the seismic effect of the structure can be calculated using the average value of the time history method and the larger value of the mode decomposition response spectrum method. Three seismic waves were selected for the structure, and the envelope values of all seismic wave floor shear forces were compared with the CQC results. The value of the interlayer displacement angle in the text is taken as the envelope value of three seismic waves. The floor displacement angles of each structural scheme are shown in Table 1:

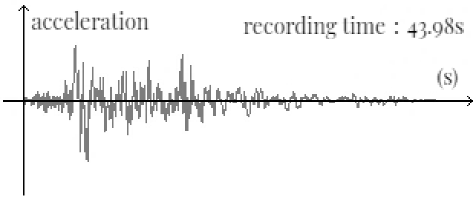


Figure 1. Natural wave TH001TG045.

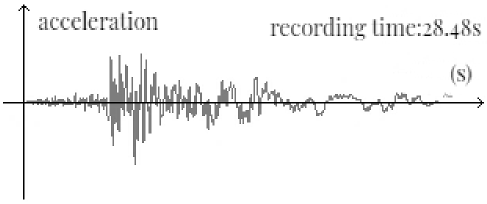


Figure 2. Natural wave TH002TG055.

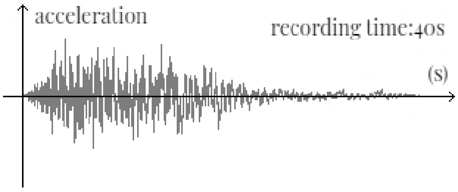


Figure 3. Artificial wave RH2TG065.

Table 1. Comparison of floor displacement angles of different structural schemes

Floor	Programme 1		Programme 2		Programme 3		Programme 4	
	X direction	Y direction	X direction	Y direction	X direction	Y direction	X direction	Y direction
23	1/2712	1/3185	1/2710	1/3198	1/2702	1/3226	1/2687	1/3242
22	1/2212	1/2394	1/2211	1/2398	1/2204	1/2408	1/2195	1/2422
21	1/1781	1/1892	1/1779	1/1895	1/1772	1/1903	1/1765	1/1915
20	1/1550	1/1622	1/1549	1/1625	1/1541	1/1635	1/1536	1/1643
19	1/1285	1/1309	1/1282	1/1310	1/1272	1/1312	1/1268	1/1312
18	1/1173	1/1163	1/1167	1/1161	1/1159	1/1159	1/1153	1/1156
17	1/1022	1/984	1/1017	1/982	1/1008	1/979	1/998	1/973
16	1/968	1/912	1/962	1/911	1/950	1/908	1/939	1/901
15	1/868	1/807	1/862	1/805	1/849	1/801	1/836	1/795
14	1/844	1/777	1/838	1/775	1/824	1/772	1/811	1/766
13	1/773	1/710	1/767	1/708	1/754	1/704	1/743	1/700
12	1/768	1/703	1/762	1/701	1/750	1/697	1/739	1/692
11	1/716	1/657	1/710	1/655	1/700	1/651	1/689	1/646
10	1/724	1/660	1/719	1/658	1/707	1/654	1/698	1/649
9	1/684	1/624	1/679	1/623	1/669	1/618	1/659	1/612
8	1/703	1/634	1/697	1/631	1/686	1/626	1/676	1/621
7	1/672	1/604	1/666	1/602	1/655	1/597	1/644	1/591
6	1/692	1/617	1/686	1/614	1/673	1/609	1/661	1/604
5	1/659	1/595	1/654	1/592	1/642	1/587	1/631	1/582
4	1/673	1/620	1/669	1/618	1/660	1/613	1/652	1/608
3	1/651	1/610	1/647	1/608	1/638	1/603	1/631	1/598
2	1/698	1/664	1/693	1/661	1/683	1/655	1/675	1/649
1	1/1041	1/1008	1/1032	1/1003	1/1017	1/992	1/1003	1/982

The floor displacement angle diagram of each structural scheme is shown in Figure 4 below:

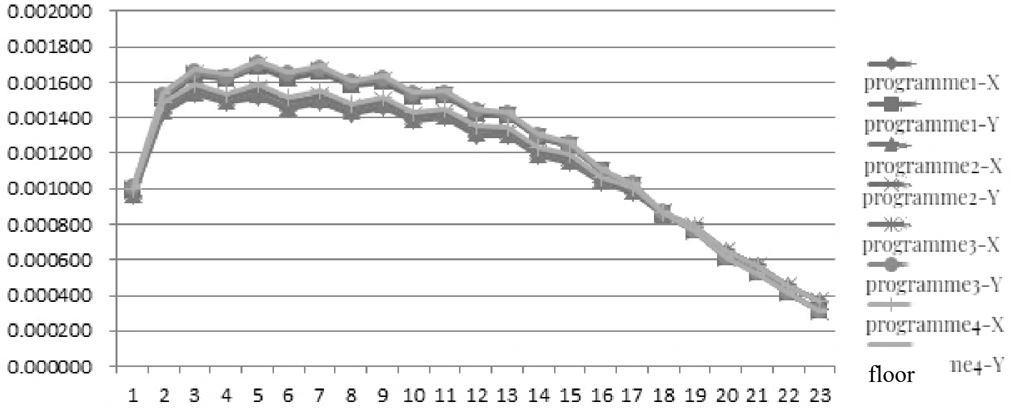
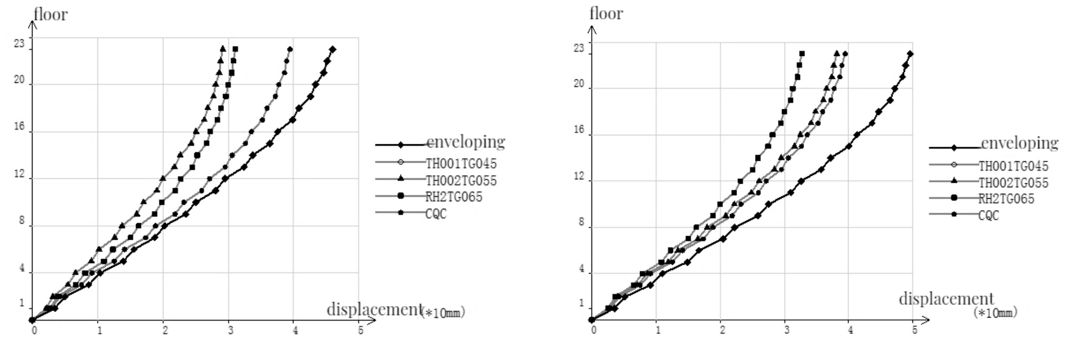


Figure 4. The structure scheme of floor displacement angle diagram.

According to Table 1 and Figure 4, it can be seen that these four schemes, both in the X and Y directions, meet the limit value of the ratio of maximum inter-story displacement to story height of the building structure specified in the specification: 1/550 for frame structure. However, as the thickness of the floor slab increases, there is a trend of increasing inter-story displacement angles in both the X and Y directions for these four schemes. Scheme 1 is the smallest, Scheme 2 is the second, Scheme 3 is the third, and Scheme 4 is the largest. This is because as the thickness of the floor increases, the overall self-weight of the structure increases, resulting in an increase in the seismic shear force and seismic moment of inertia of the structure, resulting in an increase in the maximum floor displacement of the structure and an increase in the inter-story displacement angle of the structure.

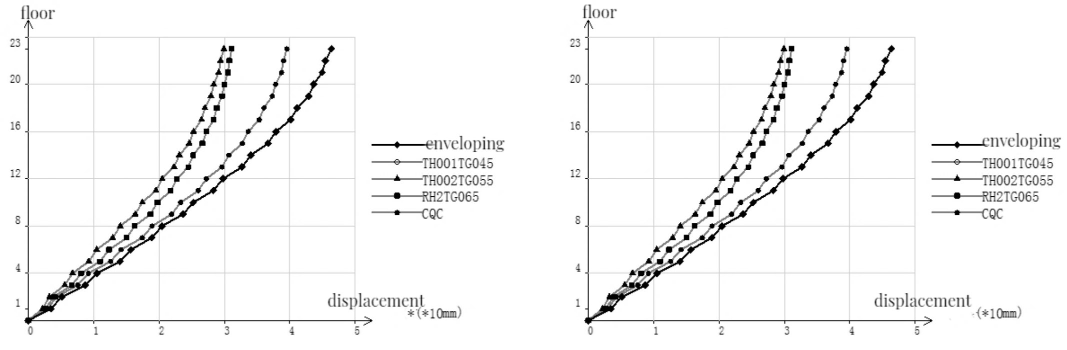
3. Maximum floor displacement of the structure

According to Article 4.3.5-4 of the "High Regulation" [5], when calculating three sets of time history curves, it is advisable to take the larger value of the envelope value of the time history method calculation result and the mode decomposition response spectrum method calculation result for the seismic effect of the structure. The maximum floor displacement in the X and Y directions of seismic waves for each structural scheme is shown in Figure 5:



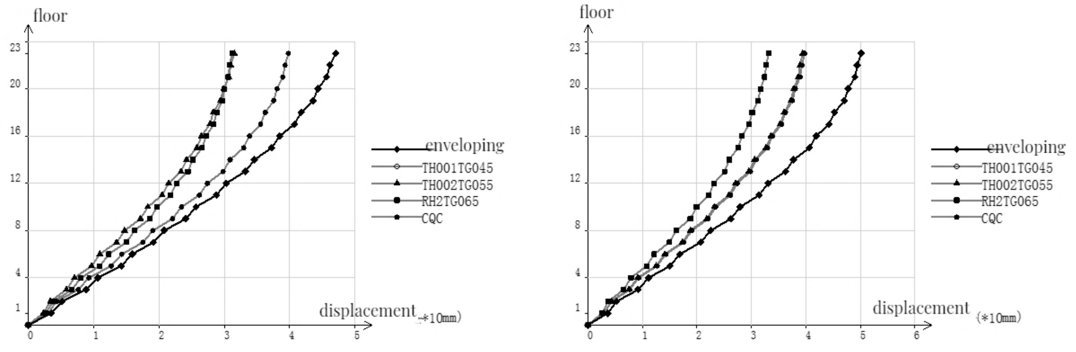
(a) Option 1 X direction

(b) Option 1 Y direction

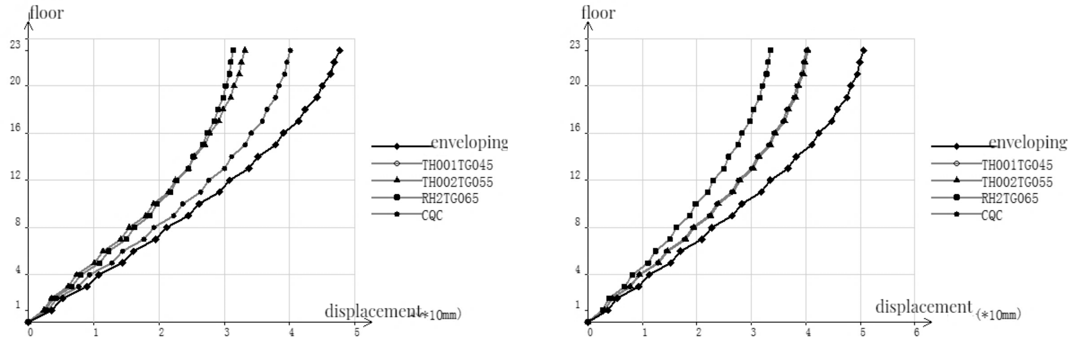


(c) Option 2 X direction

(d) Option 2 Y direction



(e) Option 3 X direction (f) Option 3 Y direction



(g) Option 4 X direction (h) Option 4 Y direction

Figure 5. Maximum floor displacement diagram of structural schemes.

From Figure 5, it can be concluded that as the thickness of the floor increases, the maximum floor displacement of each structure in both the X and Y directions shows an increasing trend. This is because the increase in floor thickness increases the overall self-weight of the structure, as well as the seismic shear force and seismic moment of inertia of the structure. As a result, the maximum floor displacement and deformation of the structure increase, making it more prone to failure. Therefore, it can be seen that the larger the size of structural components, the better the seismic performance. Sometimes, it can have the opposite effect, causing waste and affecting the seismic performance.

4. Conclusion

(1) The inter-story displacement angle, all four schemes meet the limit value of the ratio of maximum inter-story displacement to story height for building structures specified in the specification: 1/550 for frame structures. However, these four schemes show an increasing trend in the interlayer displacement angle in both the X and Y directions as the thickness of the floor increases.

(2) The maximum floor displacement of each structure shows an increasing trend as the thickness of the floor increases.

(3) The lateral stiffness of each floor structure tends to increase with the increase of floor thickness.

From the overall analysis, the following conclusion can be drawn: to meet the seismic requirements of the structure, the thickness of the floor slab must not be too thin, and the thicker the better. Choosing a floor thickness of 130mm in the structure of this project is sufficient, which can meet seismic requirements and is relatively economical.

Funding

2023 Henan Province National College Student Innovation and Entrepreneurship Training Program Project (Project Name: Development of a New Type of Assembled Spiral Staggered Building Staircase Isolation Component; Research Number: 202314040016).

References

[1] Southeast University, et al. Principles of Concrete Structure Design Volume I [M]. China Construction Industry Press, 2022.

[2] Yang Zhen, et al. PKPM Structural Design and Application Example [M]. China Machinery Industry Press, 2022.

[3] Standards of the People's Republic of China General Code for Concrete Structures GB55008-2021 [S]. Beijing: China

Construction Industry Press, 2021.

[4] Standards of the People's Republic of China General Code for Engineering Structures GB55001-2021 [S]. Beijing: China Construction Industry Press, 2021.

[5] Standards of the People's Republic of China General Code for Seismic Design of Buildings and Municipal Engineering GB55002-2021 [S]. Beijing: China Construction Industry Press, 2021.