Multidisciplinary Journal of Engineering and Technology
ISSN: 3007-6900
DOI: 10.61784/mjet3003

MECHANICAL ANALYSIS OF CANTILEVERED RIGID STEEL PLATE SHEAR WALL

Jing Fan[1,2], RuiRong Liang[1,2], BaoAn Zhang[1,2,*], Wei Cao[1,2], YiMing Wang[1,2], XunYin Liu[1,2]
[1]*China Construction Fourth Engineering Bureau Co., Ltd. Guangzhou, Guangdong 510000, China.*
[2]*China Construction Fourth Engineering Bureau Sixth Construction Co., Ltd. Hefei, Anhui 230000, China.*
Corresponding Author: BaoAn Zhang, Email: 19822660870@163.com

Abstract: This paper studies and analyzes the stress characteristics of cantilevered rigid steel plate shear walls in detail. By establishing a mathematical model and using the principles of engineering mechanics, the stress behavior of cantilevered rigid steel plate shear walls under different loading conditions is deeply discussed, mainly analyzing the cracks after pouring concrete in the cantilevered wall. Through simulation analysis and experimental verification, the performance of the structure is evaluated, providing a theoretical basis and reference value for its application in engineering practice.
Keywords: Cantilevered rigid steel plate shear wall; Stress analysis; Cracks; Numerical simulation

1 INTRODUCTION

As a new type of structural system, the performance advantages of cantilevered rigid steel plate shear walls in terms of earthquake resistance and wind resistance have been preliminarily verified [1-2]. However, in-depth research on its stress characteristics is still relatively insufficient. Accurately understanding and grasping the mechanical behavior of cantilevered rigid steel plate shear walls under different stress states is of great significance for the design, construction and performance evaluation of the structure [3-4].

This paper aims to explore the mechanical behavior of cantilevered rigid steel plate shear wall under various stress states through theoretical analysis and simulation, and verify it with actual engineering cases, so as to comprehensively explore the stress behavior of cantilevered rigid steel plate shear wall and provide theoretical basis and technical support for its application in engineering practice.

2 STRUCTURAL CHARACTERISTICS OF CANTILEVERED RIGID STEEL PLATE SHEAR WALL

2.1 Basic Structure

Cantilevered rigid steel plate shear wall is a composite structure composed of steel plate, frame steel member and connector. Steel plate is usually made of high-strength steel with a thickness between 3mm and 6mm, which can be adjusted according to specific design requirements. Frame steel members are usually made of H-shaped steel or box-shaped steel, whose main function is to provide rigidity and support and form an integral structure with the steel plate.

The design of connectors is the key, which includes two main methods: welding and bolt connection. Welding connection is suitable for parts requiring high rigidity and strength, while bolt connection provides a certain flexibility and can better absorb and disperse stress. The arrangement of connectors needs to ensure effective force transmission between steel plate and frame steel member to avoid local stress concentration.

2.2 Working Principle

The main function of the cantilevered rigid steel plate shear wall is to resist horizontal loads, such as wind loads and seismic loads. Its working principle can be analyzed from the following aspects:

(1) Shear action: The steel plate, as the main load-bearing element, bears shear force under horizontal loads. The steel plate provides the main anti-lateral displacement capacity through its shear stiffness and strength.

(2) Bending action: The frame steel members mainly bear bending moment and shear force under horizontal loads. They provide additional lateral stiffness and bearing capacity through bending deformation.

(3) Synergistic effect: The steel plate and the frame steel members form a whole through the connector. The synergistic effect of the two is the key to the excellent seismic performance of the cantilevered rigid steel plate shear wall. The shear deformation of the steel plate and the bending deformation of the frame steel members coordinate with each other to share and resist the external load together.

2.3 Advantages and Applications

Cantilevered rigid steel plate shear walls have the following advantages in high-rise buildings:

(1) High seismic performance: Due to the synergistic effect of the steel plate and the frame steel components, the cantilevered rigid steel plate shear wall can effectively absorb and disperse seismic energy and has high seismic

performance.

(2) Light weight: Compared with traditional reinforced concrete shear walls, steel plate shear walls are lighter, which helps to reduce the self-weight of the building structure and reduce the bearing requirements of the foundation.

(3) Convenient construction: The construction process of steel plate shear walls is relatively simple, and modular components can be prefabricated in the factory and assembled on site, shortening the construction period and improving construction efficiency.

(4) High space utilization: Due to the thin thickness of the steel plate shear wall, it can provide more available space than traditional shear walls, improving the use efficiency of the building.

3 FORCE ANALYSIS

3.1 Theoretical Analysis

Under the action of horizontal load, the cantilevered rigid steel plate shear wall, as an integral structure, bears shear force, bending moment and axial force. It can be analyzed using the classical plate-shell theory and beam-column theory.

The steel plate mainly transmits shear force through shear deformation, and its shear stiffness is an important factor in determining the overall shear resistance of the shear wall. The shear stress of the steel plate can be calculated by the following formula:

$$\tau = \frac{V}{A_s} \tag{1}$$

The frame steel member mainly bears the bending moment, and its stiffness and strength determine the lateral stiffness of the shear wall. The distribution of the bending moment can be calculated by the following formula:

$$M = \frac{EI}{L^2} \tag{2}$$

Where M is the bending moment, E is the elastic modulus of the steel, I is the section moment of inertia of the frame steel member, and L is the height of the shear wall.

3.2 Concrete Crack Verification after the Cantilever Wall Support Frame is Removed

As shown in the figure 1 and 2 below, after the support frame is removed, the maximum internal force occurs at the GHJ3 support position, and the maximum internal force of the shear wall at the truss support is 171.28kN.

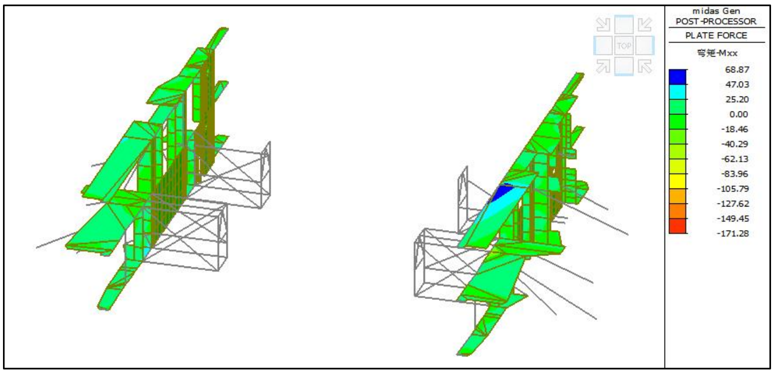

Figure 1 Internal force cloud diagram of concrete wall slab after support frame removal

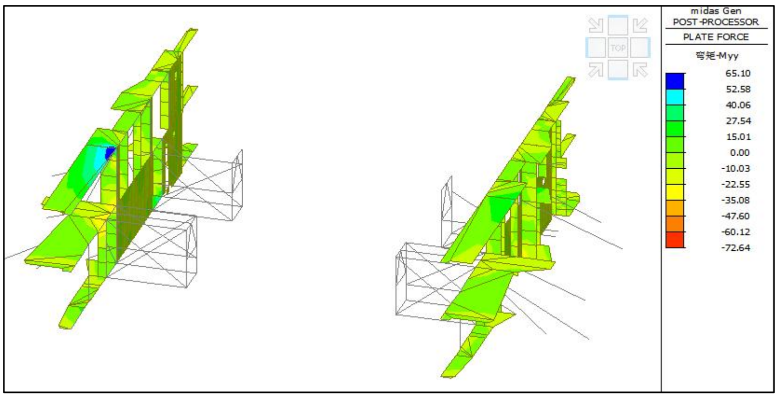

Figure 2 Internal force cloud diagram of concrete wall slab after support frame removal

Cantilever wall truss and internal extension structure are shown below Figure 3:

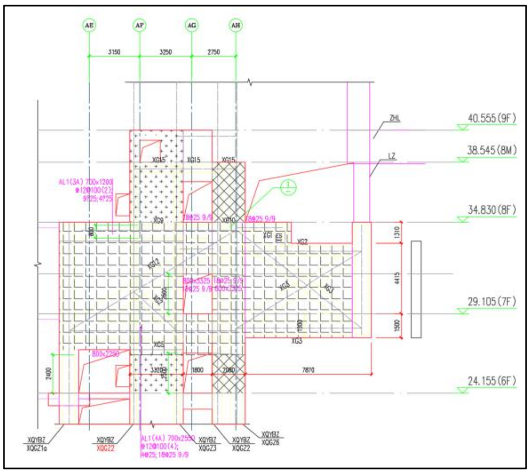

Figure 3 Cantilever wall truss and inward extension structure

The beam size at the support is: 700×2550, reinforcement information: tensile reinforcement: 18φ25, tensile reinforcement area: 3.14×252×18/4=8831mm2.
It can be calculated that the concrete crack is 0.026mm<0.4mm, which meets the requirements of the specification. The removal of the support frame has little impact on the structure.

3.3 Calculation of Strain Value of Cantilever Shear Wall

According to the common concrete structure steel content and reinforcement ratio in the cantilever wall of this project, the corresponding strain of steel can be calculated when the crack width of the typical section concrete reaches 0.2mm-0.3mm. Assuming that there is no slip between steel and concrete, the strain of steel at this time is equal to the strain of concrete. The calculation statistical results are detailed in the table 1 below.

Table 1 Statistics of Axial Tensile Strain of Concrete (Crack Width 0.25mm)

When the width of the concrete axial tensile crack is 0.25mm, the nominal strain value of the steel				
section600×1000			The specification allows cracks	0.3mm
Strain value	Steel content 0%	Steel content 2%	5%	10%
Reinforcement ratio2.05%	9.30E-04	8.92E-04	9.23E-04	8.92E-04
Reinforcement ratio1.63%	9.90E-04	1.02E-03	9.19E-04	8.74E-04
Reinforcement ratio1%	1.27E-03	8.52E-04	9.05E-04	1.04E-03

The cantilever wall goes through two most unfavorable stages:
(1) Before the cantilever wall concrete is poured, the internal force at the cantilever truss support reaches the extreme value, and crack verification is required;
(2) After the cantilever wall is poured, the subsequent design load (design dead load and design live load) further causes the cantilever wall internal force to reach the extreme value, and crack verification is required for the cantilever strong support and the newly poured concrete.
The verification results are as follows Figure 5 and 6:

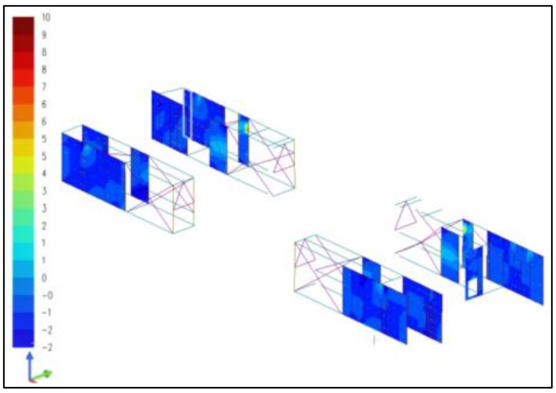
Figure 5 Shear wall stress without concrete pouring

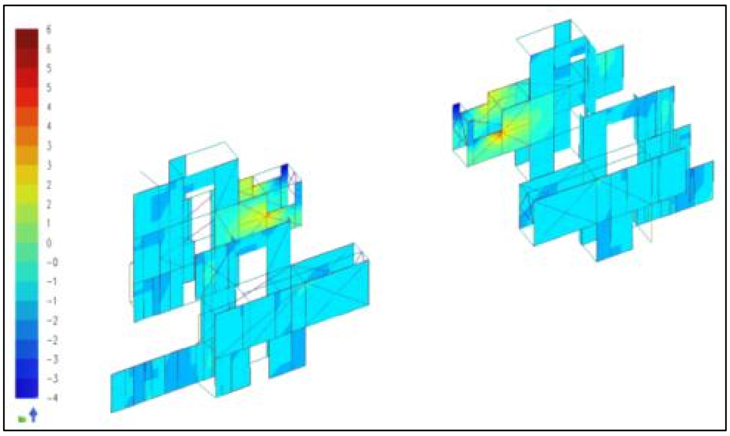

Figure 6 Shear wall stress after concrete pouring

It can be seen from the above figure that the peak stress of the shear wall in the above two stages is less than or equal to 16N/mm2, and the comprehensive strain of concrete is 4.44×10-4<8×10-4. It can be seen that the comprehensive strain of the shear wall meets the nominal strain control value, and cracks can be effectively controlled.

4 DESIGN SUGGESTIONS AND OPTIMIZATION MEASURES

4.1 Design Suggestions

(1) The thickness of the steel plate has a significant impact on the shear resistance and overall stiffness of the shear wall. During design, the appropriate steel plate thickness must be selected based on the load conditions and seismic resistance requirements of the actual project.
(2) The cross-sectional form and size of the frame steel components directly affect the overall stiffness and load-bearing capacity of the shear wall. It is recommended to give priority to high-strength, lightweight H-shaped steel or box-shaped steel as frame steel components.
(3) The connector plays a key force transmission role in the cantilevered stiff steel plate shear wall. Its stiffness and strength should ensure effective force transmission between the steel plate and the frame steel components to avoid local stress concentration.

4.2 Optimization Measures

(1) Use high-strength, lightweight steel to improve the load-bearing capacity and seismic performance of the shear wall.
(2) Optimize construction technology and adopt advanced construction technology and equipment to improve construction efficiency and quality. It is recommended to adopt the process of modular prefabrication + automated welding.
(3) Use topology optimization methods to optimize the structural form and component arrangement of the shear wall to improve material utilization and structural performance.

5 CONCLUSION

5.1 Conclusion

Through theoretical analysis, numerical simulation and experimental verification, this paper systematically studies the stress characteristics of cantilevered stiff steel plate shear walls and puts forward corresponding design suggestions and optimization measures. The main conclusions are as follows:
(1) Cantilevered stiff steel plate shear walls exhibit good mechanical properties under horizontal loads and have high load-bearing capacity and stiffness.
(2) The experimental results are reliable: Through experimental verification, the stress-strain relationship and deformation mode of the cantilevered stiff steel plate shear wall under different load conditions are highly consistent with the theoretical analysis and numerical simulation results, verifying the reliability of the model.

5.2 Shortcomings

Although this paper systematically studies the stress characteristics of cantilevered stiff steel plate shear walls, there are still some issues that need further discussion. Future research can be conducted in depth from the following aspects:
(1) Further study the mechanical properties of cantilevered stiff steel plate shear walls under complex loads, especially the combined effects of wind load and earthquake load.
(2) Explore the application of new high-performance materials in cantilevered stiff steel plate shear walls, such as

high-strength composite materials and ultra-high-strength steel, to further improve structural performance and reduce structural weight.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

REFERENCES

[1] Kan Zhihao. Seismic performance design and verification of cantilever conversion structure residential buildings. Sichuan Cement, 2024(05): 124-128.

[2] Li Hongqiang, Zhang Mingchao, Li Jie, et al. Design analysis of long cantilever steel structure - taking Zhengzhou International Cultural Exchange Center Hotel as an example. Group Technology and Production Modernization, 2024, 41(01): 42 -46.

[3] Feng Xiaotian, Hao Jiping, Yu Jinguang. Research on the seismic performance of sandwich corrugated CFRP-steel composite plate shear walls. Journal of Building Structures, 2024, 45(09): 69-82.

[4] Cao Zezheng. Research and application of steel plate concrete composite shear wall construction technology. Construction Mechanization, 2024, 45(05): 102-103.