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CONSTRUCTION TECHNIQUES AND APPLICATIONS FOR CRACK PREVENTION IN CANTILEVERED MULTI-STORY LARGE-SPAN STEEL-REINFORCED CONCRETE WALLS

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Abstract: This paper proposes a crack-prevention construction method for cantilevered multi-story, large-span steel-reinforced concrete walls, based on a specific multi-story structure with a 23m span. Before construction, the method involves building a three-dimensional finite element numerical model to thoroughly analyze the stress distribution of the cantilevered multi-story steel-reinforced concrete exterior wall under various working conditions. This allows for the optimization of reasonable construction procedures at each stage and the division of the cantilever structure into tension and compression zones. After the multi-story cantilevered steel frame is assembled, the temporary support system at the bottom is removed. The compression zone and wall sections subjected to smaller loads are then cast in a stepped manner, followed by the tension zone. This increases the overall stiffness of the cantilever wall in the compression zone and releases stress in the tension zone to mitigate strain. This cleverly avoids simultaneous deformation of the concrete and steel frame due to excessive tensile stress, thereby reducing the risk of large-area cracks or through-cracks in the cantilever wall.
Keywords: Cantilevered; Multi-story large-span; Steel-reinforced concrete wall; Crack-prevention construction

1 INTRODUCTION

With the continuous development and innovation of modern architectural design, large buildings are increasingly adopting column-free, large-span space designs to meet functional and aesthetic requirements[1-3]. Among these, large-span cantilever structures provide sufficient support for buildings, enabling them to span larger spaces[4-5]. Wu Wenbo conducted cyclic loading tests on different types of shear walls, analyzing the failure modes and load-deformation skeleton curves of the components[6]. Through comparative studies of changes in bearing capacity and energy consumption, he explored the performance advantages of different shear walls. Wu Yuntian et al. conducted seismic performance tests on different forms of built-in steel truss shear walls, studying the influence of factors such as steel section type, shear span ratio, and built-in truss steel ratio on the deformation capacity, hysteresis curves, and stiffness degradation of the shear walls, and explored their failure mechanisms[7]. Cao Wanlin et al. conducted seismic performance tests on concrete shear walls with embedded steel trusses, analyzing the stiffness degradation, bearing capacity changes, and failure characteristics of different specimens, and proposed reasonable seismic design suggestions based on the research conclusions[8].

In the construction of previous multi-story steel-reinforced concrete cantilever wall structures, the design stage generally only focused on the final stress state of the overall structure, neglecting the mechanical performance analysis of each stage during the construction process; and mostly adopted a layer-by-layer hoisting construction method, resulting in excessive investment in temporary supports; during the pouring process, the main method was layer-by-layer overall pouring, without considering the division of tension and compression zones of the cantilever structure, thus increasing the risk of cracking in the cantilever wall. Addressing these problems, this paper, based on a multi-story steel-reinforced concrete cantilever wall structure with a span exceeding 20m, proposes a crack-resistant construction method for cantilevered multi-story large-span steel-reinforced concrete walls, aiming to provide useful reference and guidance for similar projects.

2 PROJECT OVERVIEW

The China Grand Canal Museum project consists of a podium and a tower, forming a comprehensive single building integrating a museum and a cultural exchange center. It has two underground levels and fifteen above-ground levels. The outer ring of levels 1-8 forms the podium, while the inner ring of levels 1-15 forms the mountain-shaped tower. The total building height is 73.5m, and the total construction area is approximately 175,650 m². The building structure has a safety rating of Level 1, a seismic design intensity of 7 degrees, and a basic design seismic acceleration of 0.10g. To achieve a "floating space effect" and meet the functional requirements of the ground-floor urban shared space, the design focuses on both visual hierarchy and structural logic. The upper suspended exhibition hall uses a 49.1m large-span orthogonal steel truss as the suspension component, creating a visual perception of "floating in the air"; the lower structure design adopts the concept of fewer supports and larger spans, relying on CFT columns with a 30m column spacing, 23m large-span cantilevered concrete shear walls, and 50m multi-story trusses to construct the support system, reducing the number of ground-level components and weakening the "presence" of the supporting structure. (Figures 1-2).

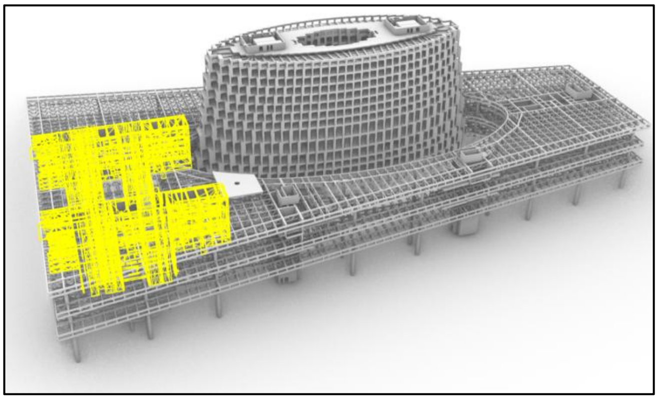


Figure 1 Schematic Diagram of the Structure of a Museum along the Beijing-Hangzhou Grand Canal in China

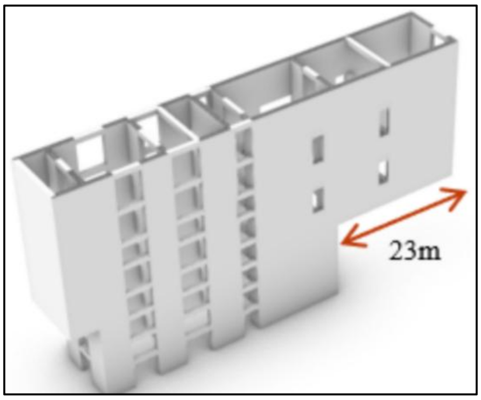


Figure 2 Schematic Diagram of a Large-span Multi-story Reinforced Cantilever Wall

3 TECHNICAL PRINCIPLE

This method describes an active crack prevention construction method for cantilevered multi-story steel-reinforced concrete walls with large spans: Before construction, a three-dimensional finite element numerical model is built to thoroughly analyze the stress distribution of the cantilevered multi-story steel-reinforced concrete exterior wall under various working conditions, optimizing the reasonable construction sequence for each stage and dividing the cantilever structure into tension and compression zones. After the multi-story cantilevered steel frame is assembled, the temporary support system at the bottom is removed. The compression zone and wall sections subjected to smaller loads are then cast in a stepped manner, followed by casting of the tension zone. This improves the overall stiffness of the cantilevered wall in the compression zone and simultaneously releases stress in the tension zone to mitigate strain, thus cleverly preventing simultaneous deformation of the concrete and steel frame due to excessive tensile stress. This significantly reduces the risk of large-area cracks or through-cracks appearing on the cantilevered wall surface. (Figure 3)

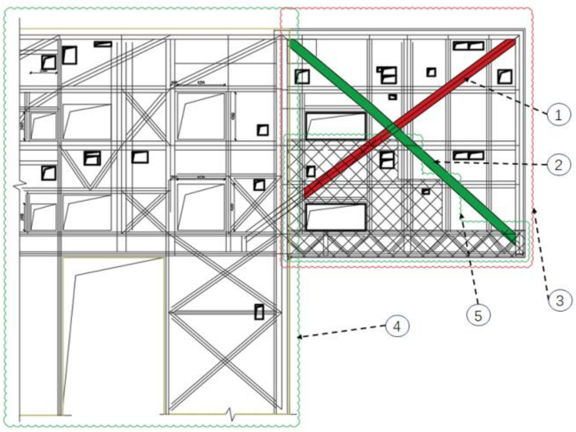


Figure 3 Schematic Diagram of the Segmented Construction Principle of a Large-span Cantilever Wall

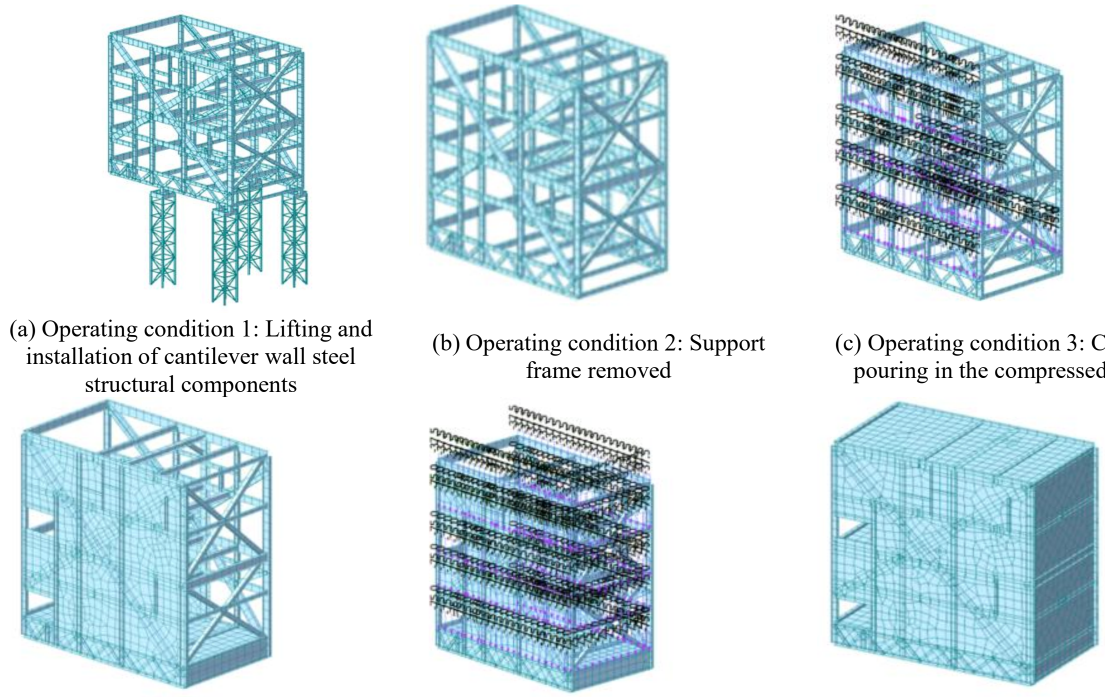
Note: 1.Tension rod, 2. Compression rod, 3. Cantilevered multi-story large-span steel-reinforced concrete wall, 4. Core tube, 5. Stepped pouring area

4 CONSTRUCTION PROCESS AND CONTROL POINTS

The construction process for the cantilevered multi-story large-span steel-reinforced concrete wall is as follows: Finite element full-process construction simulation → Construction preparation → Support frame installation → Steel frame assembly → Support frame removal → Compression zone cantilever wall pouring and curing → Orthogonal truss floor slab construction → Tension zone cantilever wall pouring and curing.

4.1 Finite Element Full-Process Construction Simulation

Through optimization calculations using MIDAS finite element software, the specifications for the horizontal temporary supports and temporary support frames were determined. The bearing capacity and stability of the steel frame of the cantilevered multi-story large-span steel-reinforced concrete wall were simulated at each construction stage, ultimately determining the construction sequence for the large-span reinforced cantilever wall. (Figure 4)



(a) Operating condition 1: Lifting and installation of cantilever wall steel structural components

(b) Operating condition 2: Support frame removed

(c) Operating condition 3: Concrete pouring in the compressed zone

(d) Operating condition 4: Orthogonal truss floor deck connection

(e) Condition 5: Concrete pouring in the tension zone

(f) Operating condition 6: Usage phase

Figure 4 Finite Element Simulation Diagrams for Various Operating Conditions

Finite element simulation results for each working condition: Analysis of each working condition shows that loading condition 5 has the minimum buckling coefficient of 8.9, and loading condition 6 has the maximum stress ratio of 0.70 (generally, to ensure the safety and reliability of the structure, the maximum stress ratio should be kept below 1. The smaller the value, the safer the material or structure; JGJ7-2010 "Technical Specification for Space Grid Structures" requires a safety factor K≥4.2, and a larger value indicates stronger resistance to instability). (Table 1)

Table 1 Finite Element Simulation Results for each Working Condition

Operating conditions	Maximum stress ratio		Minimum bending coefficient	
	Calculated value	Standard value	Calculated value	Standard value
Operating conditions1	0.20	＜1.0	12.2	≥4.2
Operating conditions2	0.30	＜1.0	11.9	≥4.2
Operating conditions3	0.48	＜1.0	10.6	≥4.2
Operating conditions4	0.55	＜1.0	9.7	≥4.2
Operating conditions5	0.61	＜1.0	8.9	≥4.2
Operating conditions6	0.70<1.0	＜1.0	9.2	≥4.2

4.2 Construction Preparation

The final design of the formwork and temporary horizontal supports will be determined through finite element simulation and then reviewed by the design institute before being used for on-site construction. The detailing unit will then refine and fabricate the formwork and temporary supports according to the simulation results.

4.3 Support Formwork Installation

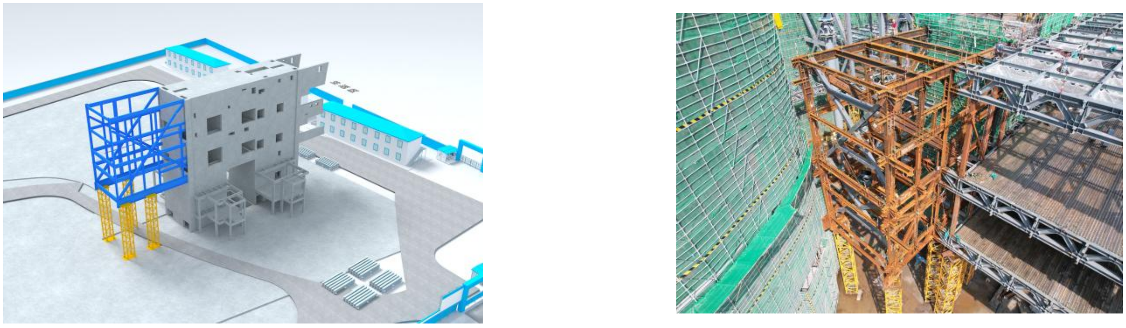
To ensure smooth load transfer between the formwork and the cantilevered wall steel structure and to avoid adverse effects on the cantilevered wall steel structure due to eccentric compression, the formwork supports will be aligned with the control lines after the grid lines are marked on site. The standard sections of the formwork will then be lifted and installed layer by layer, finally completing the support formwork installation. (Figure 5)

(a) (b)

Figure 5 Installation of the Cantilever Wall Support Frame

4.4 Steel Frame Assembly

To ensure the overall structural performance of the cantilever wall steel structure, the steel structure was lifted and welded layer by layer. After each layer was welded, weld inspection was performed. Only after the inspection passed could the next layer of steel components be lifted into place. Temporary horizontal bracing was also installed as the steel structure height increased. (Figure 6)

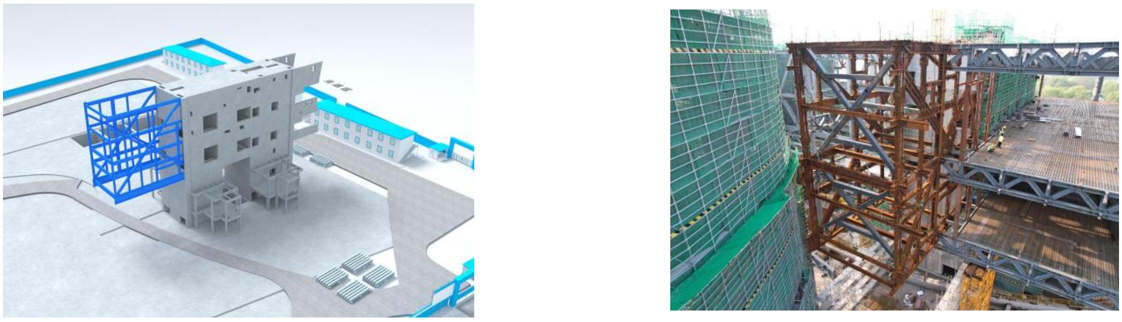


(a) (b)

Figure 6 Welding of the Steel Structure of the Cantilever Wall

4.5 Removal of Support Scaffolding

After the cantilever wall steel structure is installed and welded, the cantilever wall steel structure will be inspected. Weld joints will undergo third-party non-destructive testing as required, and a formal third-party inspection report will be issued. After the inspection, the support scaffolding will be unloaded and removed, allowing the entire cantilever wall steel structure to participate in its own structural stress and deformation. (Figure 7)



(a) (b)

Figure 7 Removal and Dismantling of the Support Frame

4.6 Casting and Curing of the Compression Zone Cantilever Wall

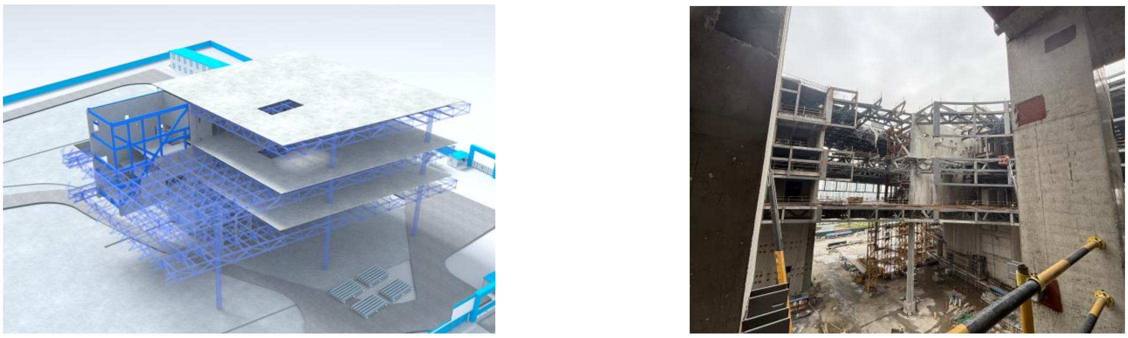
After the removal of the support scaffolding, concrete casting of the compression zone was carried out in sections according to the construction simulation and analysis results from the finite element software. The concrete was then covered with a curing membrane. One side was cast up to the 8th layer (low-stress area), while the other side was cast in a stepped manner (compression zone: below the downward diagonal tie rods of the 4th-6th layers of the cantilever wall). The concrete in the low-stress and compression zones of the cantilever wall was cast earlier to ensure overall rigidity. The concrete in the high-stress and tension zones of the cantilever wall was cast later to ensure that the steel reinforcement in the tension zone of the cantilever wall experienced stress and deformation beforehand. No cracks were observed in the wall during observation. (Figure 8)

(a) (b)

Figure 8 Concrete Pouring in the Compression Zone

4.7 Construction of Orthogonal Truss Floor Slabs

After the concrete in the first section reached 100% strength, the orthogonal truss connections for the cantilever sections of floors 4, 6, and 8 were installed, and the concrete for the orthogonal truss floor slabs was poured. This connected the cantilever walls to the entire structure, allowing them to bear load, after which the remaining concrete for the cantilever walls on floors 4-6 was poured. No cracks were observed in the walls. (Figure 9)



(a) (b)

Figure 9 Orthogonal Truss Connection of the Cantilever Section

4.8 Casting and Curing of the Tension Zone Cantilever Wall

After the remaining concrete is poured for floors 4-6, and once the concrete strength in this area reaches 100%, the concrete for the orthogonal truss floor slab of the 8th floor is poured and covered with a curing membrane. This ensures that all the load from the adjacent areas is transferred to the cantilever wall structure before the remaining concrete for floors 6-8 is poured. Once the cantilever wall concrete reaches 100% strength, the horizontal bracing is removed. Observation showed no cracks in the wall. (Figure 10)

Figure 10 Casting and Curing of the Cantilever Wall in the Tension Zone

5 COST-BENEFIT ANALYSIS

Taking the China Grand Canal Museum project as an example:
Traditional cantilevered multi-story large-span steel-reinforced concrete wall support scaffolding construction method: Each cantilevered wall requires 5 support scaffolds to support the entire cantilevered wall steel frame hoisting and concrete load. At each scaffold location, counter-support measures are required from the basement floor slab to the top slab. The scaffolds use 15.6m long, 1.8m x 1.8m standard tower crane sections, totaling 5 x 5 x 4 = 100 sections; the counter-support components use P299x10 round steel pipes, with a total of 20 scaffolds and 264m of round steel pipes, weighing 264m x 69 kg/m = 18,216 kg (18 tons). The construction period is 120 days. The total rental cost is: standard section rental fee: 100 x 280 x 4 = 112,000 yuan; round steel pipe rental fee: 264 x 2 x 120 = 63,360 yuan. Mechanical and labor costs are approximately 300,000 yuan. Due to the counter-support in the basement, secondary structure construction cannot be carried out simultaneously, resulting in a serious delay of 30 days in the basement structure construction. The resulting delay costs, finished product maintenance costs, and large personnel management costs total approximately 100,000 yuan. Total cost: 112,000 + 63,360 + 100,000 + 300,000 = 575,360 yuan.
Optimized cantilevered multi-story large-span steel-reinforced concrete wall support scaffolding construction method: Only 2 support scaffolds are used under each cantilevered wall to support the entire cantilevered wall steel frame hoisting, without counter-support measures. The scaffolds use 15.6m long, 1.8m x 1.8m standard tower crane sections, totaling 2 x 5 x 4 = 40 sections. The construction period is 90 days. Rental cost: 40 x 280 x 3 = 33,600 yuan. Mechanical and labor costs are approximately 200,000 yuan. Total cost: 33,600 + 200,000 = 233,600 yuan. Based on the above analysis, the cost savings would be: 57.536 - 23.36 = 34.176 million yuan.

6 CONCLUSION

This paper proposes a crack-prevention construction method for cantilevered multi-story, large-span steel-reinforced concrete walls, based on a specific multi-story structure with a 23m span. Before construction, the method involves building a three-dimensional finite element numerical model to thoroughly analyze the stress distribution of the cantilevered multi-story steel-reinforced concrete exterior wall under various working conditions. This optimizes the reasonable construction sequence for each stage and divides the cantilever structure into tension and compression zones. After the multi-story cantilevered steel frame is assembled, the temporary support system at the bottom is removed. The compression zone and wall sections subjected to smaller loads are then cast in a stepped manner, followed by casting of the tension zone. This enhances the overall stiffness of the cantilever wall in the compression zone and releases stress in the tension zone in advance to mitigate strain. This cleverly avoids simultaneous deformation of the concrete and steel frame due to excessive tensile stress, thereby reducing the risk of large-area cracks or through-cracks in the cantilever wall.

COMPETING INTERESTS

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

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