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STABILITY AND UNLOADING CALCULATION ANALYSIS OF TEMPORARY SUPPORT FRAME OF RING-LAYERED HOLIER-WEB TRUSS

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Abstract: This paper takes the Beijing-Hangzhou Grand Canal Museum project in China as the background, introduces the stress characteristics of the ring-layered holier-web truss of the project, and designs a temporary support frame structure based on its stress characteristics to ensure the safe construction of the project. Yingjianke software is used to verify the overall stability and floor shear bearing capacity of the temporary support frame, and the support frame during the construction process is subjected to stress analysis. In addition, the active control method is used for unloading to realize the conversion of the force system, and the stress and strain measurement points are arranged in the key sections to monitor the stress and strain in real time during the structure construction and unloading process. The construction method of this project can provide a technical reference for the construction of similar projects.
Keywords: Annular laminated holier-web truss; Temporary support frame; Yingjianke software; Force analysis

INTRODUCTION

The holier-web truss consists of upper and lower chords and vertical webs. It is evenly stressed, has good lateral stiffness, and has a high energy dissipation capacity. In recent years, for buildings with large-span discontinuous vertical components and high requirements for facade effects, holier-web trusses have been widely selected [1-3].

The laminated holier-web truss can further reduce the internal force of the rod, reduce the cross-section of the rod, and make the force more uniform, effectively solving the problem of weak layers and weak layers [4-5]. Sun Yongzhi [6]'s research shows that the overall bending of the large-span laminated holier-web truss structure system causes the plate grid at the end of the floor slab to produce a large negative bending moment, and the plate grid at the middle of the floor slab to produce a large positive bending moment. This additional stress cannot be ignored. Li Yuying[7] and Wang Hongchang[8] believed that when the constraint of the truss column on the truss beam is very small, the truss column mainly transmits axial force, and the upper and lower truss beams work independently and mainly bear bending moment; when the constraint of the truss column on the truss beam gradually increases, the truss effect is obvious. At this time, the truss beam not only bears bending moment, but also bears tension (lower truss beam) and compression (upper truss beam); when the constraint of the truss column on the truss beam is extremely large, the stress characteristics of the laminated hollow truss are mainly bending deformation, reflecting the stress characteristics of the beam and the stress characteristics of the truss, that is, in addition to bearing bending moment and shear force, it also bears axial force. The upper chord is a compression, bending and shearing member, and the lower chord is a tension, bending and shearing member.

For large-span laminated hollow trusses, Duan Yongfei[9] believed that the hollow truss beam needs to be supported at the bottom during construction. When the upper and lower chords and vertical bars of the hollow truss reach the design strength, the vertical support can be removed.

Based on the Grand Canal Museum project in Hangzhou, Zhejiang Province, this paper uses YJK (5.2.1) software to study the stability of the temporary support frame of the annular laminated pierced truss, and gives the unloading construction method, which can provide a design basis for similar projects.

1 PROJECT OVERVIEW

This project is located on the bank of the Grand Canal in Hangzhou. It adopts the form of "one museum and multiple museums", covering multiple functions such as museums, conference centers, and the Grand Canal International Exchange Center, creating a new world-class cultural landmark.

This project has 2 underground floors and 15 above-ground floors, of which floors 1-8 are podiums and floors 9-15 are towers. The total height of the building is 73.5m and the total construction area is about 175650m^2. The project effect is shown in Figure 1.

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Figure 1 Project Effect Diagram

2 STRUCTURAL SYSTEM

The tower is a frame-shear wall system, mainly composed of an outer "mountain"-shaped column tube, an inner "mountain"-shaped column tube, and a concrete core tube. The "mountain"-shaped column tube is a frame structure composed of folded beams and stepped lap columns. Among them, the beams and columns of the inner "mountain"-shaped column tube (9F-15F) are all supported on the 9F conversion ring beam, and the conversion ring beam is supported on the cantilever wall (7F-8F) at the core tube through four conversion columns (8F floor-9F floor). The structure is converted layer by layer, the force transmission is complex, and the overall redundancy of the structure is small.

In order to improve the integrity and safety of the inner courtyard structure and reduce the bending moment of the conversion ring beam, the inner courtyard is considered as a hollow truss structure system during the design, that is, the roof ring wall is used as the upper chord, the 9F conversion ring beam is used as the lower chord, the 10-15F floor frame beam is used as the middle chord, and the 9-roof layer lap columns are used as vertical webs to form a spatial structure system. Therefore, during the construction process layer by layer, the hollow truss cannot be stressed as a whole, and the conversion ring beam bears the load transmitted by the upper columns, and each side under the ring beam is supported by only 2 conversion columns, with a maximum span of 20m.

In order to ensure the safe construction of the ring-layered hollow truss structure and effectively control its mid-span deflection, ensure the flatness of the finished surface of the building and do not affect the use effect of the building. A concrete frame structure is set up from the negative second floor to the eighth floor below the ring-layered hollow truss as its temporary support until the hollow truss structure is completed and the overall force is applied, and then the temporary support frame is removed. The force transmission path of the ring-layered hollow truss is shown in Figure 2.

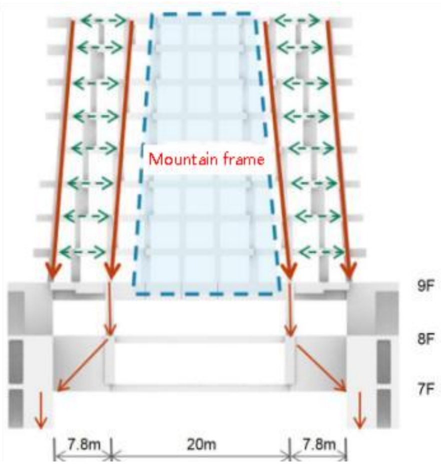

Figure 2 Force Transmission Path of Annular Laminated Open-Web Truss

3 SUPPORT STRUCTURE DESIGN AND FORCE ANALYSIS

3.1 Support Frame Design

The support frame is equipped with 12 frame columns, of which: 4 are set under the conversion ring beams on the east and west sides, a total of 8 as the main load-bearing frame columns (the cross-sectional dimensions of frame columns below the elevation of 31.355m are all 900mm×900mm, and above the elevation of 31.355m, the cross-sectional dimensions of corner columns are 900mm×1125mm, and the cross-sectional dimensions of side columns are 900mm×1070mm); 4 frame columns with a cross-sectional dimension of 700mm×700mm are set in the middle, which mainly play a role in tensioning. The 12 frame columns are connected together by frame beams to ensure the overall stability of the support frame. There are 9 frame beams in total, which are located at elevations of -5.500m, 0.850m, 5.940m, 11.290m, 16.805m, 21.855m, 26.955m, 32.155m, and 37.832m. The frame columns of the support frame are only connected to the floor beams and slabs of the first and second floors of the main structure, and are separated from the floor beams and slabs of the other floors of the main structure. The relative relationship between the support frame and the main structure is shown in Figure 3.

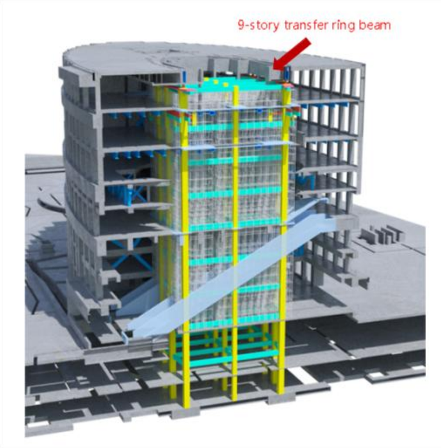

Figure 3 Relative Relationship between the Support Frame and the Main Structure

3.2 Force Analysis of the Support Frame

3.2.1 Establishment of the support frame model

The structural calculation program of this project uses Yingjianke Building Structure Design Software (YJK5.2.1) to analyze the support frame. Among them: wind load is calculated according to the windproof area of the component, and the corrected basic wind pressure is $0.45kN/m^2$; seismic action is not considered; the structural importance coefficient is 1.0; the self-weight of the cast-in-place slab is automatically calculated.

Load value: The constant load is $2kN/m^2$; the live load is $2kN/m^2$; the upper hollow truss load is converted into a concentrated force and acts on the top of the support frame column. The load arrangement diagram and the support frame model diagram are shown in Figures 4 and 5.

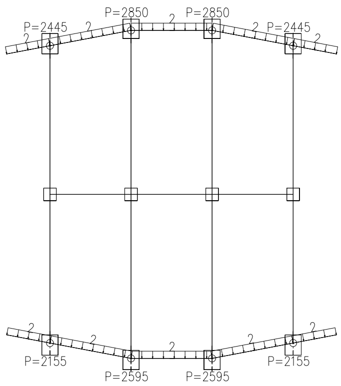

Figure 4 Load Arrangement Diagram

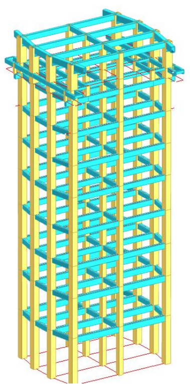

Figure 5 Support Frame Model Diagram

3.2.2 Overall stability verification of the support frame structure

The overall stability calculation results of the support frame structure are shown in Table 1.

Table 1 Stability of Supporting Frame Structure

Layer number	X-direction Stiffness/10^5	Y-direction Stiffness/10^5	Floor height	Upper part Weight	X-stiffness to weight ratio	Y-stiffness to weight ratio
3	2.78	2.25	5.090	48201	29	24
4	2.33	1.86	5.350	45848	27	22
5	2.13	1.74	5.515	43559	27	22
6	2.40	1.95	5.050	41098	29	24
7	2.20	1.96	5.100	38886	28	25
8	2.17	1.91	5.200	36615	30	27
9	1.86	1.48	5.677	31824	33	26

It can be seen from Table 2 that the rigidity-to-weight ratio of the support frame structure Di×Hi/Gi＞20, which meets the requirements of the "High Code", can pass the overall stability verification and can ignore the second-order effect of gravity.

3.2.3 Verification of shear bearing capacity of support frame floors

The calculation results of the shear bearing capacity of the support frame structure floors are shown in Table 2.

Table 2 Shear Bearing Capacity of Supported Frame Floors

Layer number	X-axis bearing capacity	Y-axis bearing capacity	Ratio_X	Ratio_Y
9	7.17×10^3	8.46×10^3	1.00	1.00
8	7.67×10^3	7.84×10^3	1.07	0.93
7	8.13×10^3	8.33×10^3	1.06	1.06
6	8.32×10^3	8.72×10^3	1.02	1.05
5	7.97×10^3	8.14×10^3	0.96	0.93
4	8.34×10^3	8.71×10^3	1.05	1.07
3	9.32×10^3	9.53×10^3	1.12	1.09
2	7.48×10^3	7.75×10^3	0.80	0.81
1	6.25×10^3	6.43×10^3	0.84	0.83

Ratio_X, Ratio_Y: represents the ratio of the bearing capacity of the current layer to the previous layer.

Table 2 shows that the interlayer shear bearing capacity of the floor lateral force resistance structure and the shear bearing capacity of the adjacent previous layer are both ≥0.8, which meets the provisions of Article 3.5.3 of the Technical Code for High-rise Concrete Structures JGJ3-2010.

3.3 Construction Condition Analysis

Due to the large stiffness of the cantilever wall under the conversion column, in order to prevent the conversion beam from arching during the construction process, which affects the open-web truss structure, Yingjianke software (YJK5.2.1) is used to perform layer-by-layer construction simulation analysis, mainly analyzing the column top reaction force and compressive deformation of the conversion column and supporting frame column.

The floor load values for 9 floors (transfer floors) and above are: additional dead load 1kN/m^2, construction live load 2kN/m^2, and concrete pouring live load 4kN/m^2. Beam and wall loads: except for the core tube, which is the original design load, others: 0kN/m. The compressive deformation of the top of the supporting frame column and the column top reaction force are shown in Figures 6 and 7.

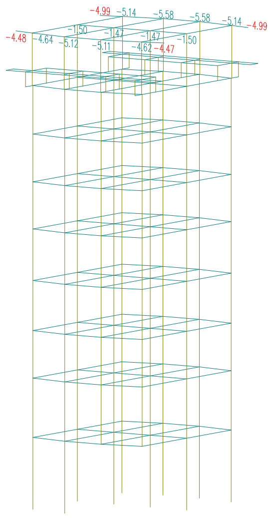

Figure 6 Compressive Deformation Diagram of the Top of the Supporting Frame Column

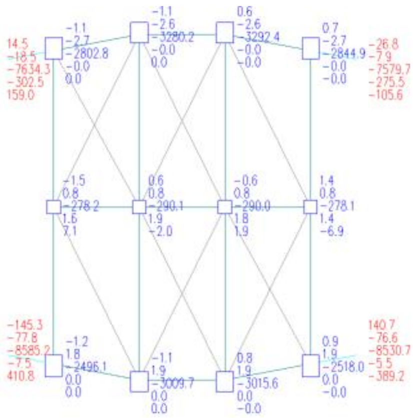

Figure 7 Reaction Diagram of the Top of the Supporting Frame Column

It can be seen from Figures 8 that during the loading process, the column top reaction force of the conversion column is greater than that of the adjacent frame column, and the compressive deformation of the conversion column is less than that of the frame column. Therefore, the conversion beam will not produce an upward arch phenomenon during the loading process, which is consistent with the design intention of the main structure and meets the design requirements.

4 UNLOADING OF THE SUPPORTING FRAME

The unloading process of the supporting frame is to gradually transfer the load borne by the temporary support to the structure, realize the self-stressing of the hollow truss structure, and finally the temporary support withdraws from work. In this project, sand boxes are used as temporary supports, which are set at the top of the east-west frame columns (columns A-H), with a total of 8 groups. 300t hydraulic jacks are set on the top of the axil beams on both sides of the sand box to cooperate with unloading. See Figure 8 for details of the unloading support.

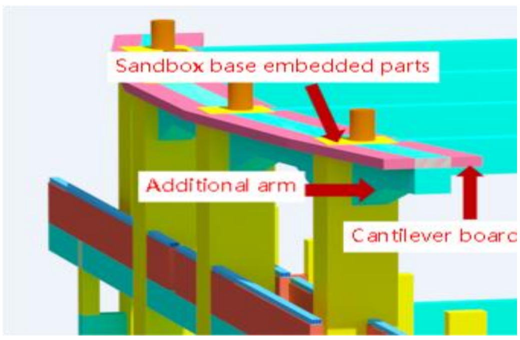

Figure 8 Sectional View of Unloading Support

Unloading adopts the principle of grading and symmetry. When unloading, first apply a top force to the jacks on both sides (the top force value on each side is 1/2 of the residual load value after unloading at this level). At this time, the entire load after unloading at this level is actively borne by the jacks, and then the sand is released by turning the sand box nut to separate the sand box from the conversion ring beam. The unloaded load is borne by the hollow truss itself. Finally, the lifting force of the jacks on both sides is slowly unloaded, so that the unloaded load is transferred to the sand box again. At this time, the first level of unloading is completed. Unloading is carried out step by step in this way until the hollow truss structure is self-stressed. Finally, the sand box and the jack are removed, and the unloading is completed. Unloading is divided into five levels, and the graded unloading amount is shown in Table 3.

Table 3 Gradual Unloading Amount

Unloading grade	Unloading amount
First-level unloading	Support columns B, C, F, G unload 30% of the reaction force FN; support columns A, D, E, H unload 20% of the reaction force FN.
Second-level unloading	Support columns B, C, F, G unload 50% of the reaction force FN; support columns A, D, E, H unload 50% of the reaction force FN.
Third-level unloading	Support columns B, C, F, G unload 70% of the reaction force FN; support columns A, D, E, H unload 65% of the reaction force FN.
Fourth-level unloading	Support columns B, C, F, G unload 90% of the reaction force FN; support columns A, D, E, H unload 80% of the reaction force FN.
Fifth-level unloading	Support columns B, C, F, G unload 100% of the reaction force FN; support columns A, D, E, H unload 100% of the reaction force FN.

4.1 Monitoring Frequency

Loading condition monitoring frequency: Monitor and collect data once 30 minutes before each concrete pouring of the AH-AK axis atrium area of the 9th floor and above, monitor in real time during the pouring process and collect data every 15 minutes, monitor and collect data once 30 minutes after the concrete pouring is completed; monitor and collect data every 2 days for the rest of the time.

Unloading condition monitoring frequency: Monitor and collect data once 10 minutes before each level of unloading, monitor in real time during the current level of unloading and collect data every 5 minutes, collect data at the 5th minute, 15th minute, 30th minute, 45th minute, and 60th minute after each level of unloading is completed, and collect data every 30 minutes thereafter, until the last level of unloading is completed and all monitoring data are stable for 24 hours, then the monitoring can be ended.

5 CONCLUSION

This paper takes the Beijing-Hangzhou Grand Canal Museum project in China as the background, introduces the stress characteristics of the ring-laminated venter truss of the project, and designs a temporary support frame structure based on its stress characteristics to ensure the safe construction of the project. Yingjianke software is used to verify the overall stability and floor shear bearing capacity of the temporary support frame. In addition, the active control method is used for unloading to realize the transformation of the force system, which can provide technical support and reference for the construction of similar projects.

COMPETING INTERESTS

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

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