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Key Technology of High-Altitude Cantilever Cornice Formwork Support System Construction

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Abstract. The Xianning Yong'an Pavilion scenic spot project is an imitation of the Song Dynasty. There are platform foundations on the first and second floors on the north and south sides of the main building, and there is no platform foundation on the east and west sides. The 4th, 6th, 8th, and 9th floors all have eaves that can be raised outside, and the length of the eaves is about 4 meters. Considering the long construction period and low work efficiency of the antique buildings, the overhanging steel platform support frame is considered as the formwork support for the eaves outside the eaves area, and the full hall scaffolding and protective outer frame are set up on the overhanging platform. The mechanical analysis of the relevant parameters of the support system using the safety calculation software proves the safety of the support system. Considering the long construction period and low efficiency of the antique building, it is considered to set up the cantilever steel platform support frame as the support frame of the eaves outside the cornice area, and set up a full scaffold and protective outer frame on the cantilever platform to ensure the safe production and construction quality.

Keywords. Cornice structure, cantilevered steel platform, support system, construction

1. Project Overview

The main structure of Xianning Pavilion has 4 layers, 6 layers, 8 layers and the roof layer respectively, with a total of 4 layers of cornices, 4 layers, 6 layers and 8 layers of cornices, the length of the cornices is 4.075m, and the roof cornices are 3.823m. ±0.000 corresponds to the absolute elevation of 30.5m, the ridge elevation of 52.690m, and the coreaves elevation of 18.999m, 29.499m, 39.995m, 45.075m. The concrete thickness of the cornice inclined slab is mainly 180mm. The maximum cross-section size of the cornice structural beam is 300 mm×850 mm. Beam, slab and column concrete strength grade is C30.

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2. Scheme Selection

The project needs to set up the cantilever platform support frame. The support floors are respectively the 5th floor and the 7th floor. When the cantilever part of the support frame is set up, it should be reliably connected with the internal full support frame, and the vertical and horizontal scissors braces should be connected through, and the lower struts of the cantilever steel beam should be reliably connected with the structural column at a step distance of 1.5m, and a 60mm horizontal Angle steel should be welded with the lower struts I-steel. The upper surface of the horizontal I-beam is welded with 2 channels of No. 10 steel, and the positions are 500mm away from the root of the frame beam and the end of the cantilever beam, so that the entire cantilever steel beam is connected into a whole. A No. 14 I-beam diagonal brace is arranged at the middle point of the cantilever section of the cantilever, and the bottom end of the diagonal brace is fixed at the intersection of the shear wall and the cornel diagonal plate. The top of the cantilever I-steel is connected with the upper frame beam with steel wire rope. The steel wire rope adopts 6×19, nominal tensile strength 1550Mpa, and the steel wire rope does not participate in the force calculation [1].

The diagonal beam steel adopts No. 14, the steel wire rope adopts 6×19, the nominal tensile strength is 1550Mpa, and the steel wire rope is not involved in the force calculation. The steel pipe of the support frame is Φ48.3×3.0. Three support methods are adopted for different parts:

(1) For the corner beam of the eaves: the spacing of I-beams on both sides of the beam is 800mm, that is, the spacing of vertical rods on both sides of the beam is 0.8m, the spacing of vertical rods in the direction of the beam span is 0.8m, and the step distance is 1.5m. The maximum overhang size of the I-beam is 7300mm, and two diagonal braces are adopted. The first diagonal brace is 2350mm away from the frame beam, and the second diagonal brace is 4750mm away from the frame beam. The end of the steel beam is tied with the upper frame beam with steel wire rope. Horizontal steel beams using 22b I-beams can meet the requirements.

(2) For the part without cantilever structural beam and only the cantilever plate: the I-steel spacing at the cantilever plate is 1000mm, that is, the bar spacing is 1m, the bar spacing along the I-steel direction is 0.8m, and the step distance is 1.5m. The maximum overhang size of the I-beam is 5600mm, the diagonal brace is 3050mm from the frame beam, and the end of the steel beam is tied with the upper frame beam with steel wire rope. Horizontal steel beams using 20b I-beams can meet the requirements [2]. As shown in figure 1.

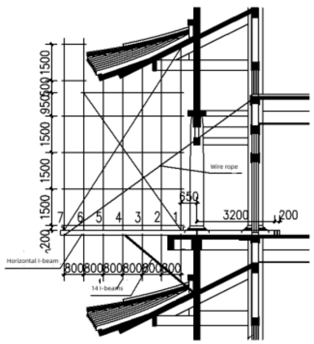

Figure 1. Section view of the frame erection at the waist beam of the cornice.

3. Main Beam Checking Calculation

The maximum section size of the eaves corner beam of this project is 300mm×850mm, and the maximum overhang length is 4.075m. The most unfavorable part is selected and the main beam is checked and calculated as follows:

(1) The distance between I-beams on both sides of the beam is 800mm, that is, the distance between vertical rods on both sides of the beam is 0.8m, the distance between vertical rods in the direction of the beam span is 0.8m, and the step distance is 1.5m.

(2) This project uses φ48.3×3.0 steel pipe, dead weight =3.33kg/m, steel pipe moment of inertia $Ix=10.78cm^4$, ix=1.59cm, section area $A=4.24cm^2$, steel pipe slenderness ratio λ=1500/15.9=94, The concentrated force of I-beams on both sides of the beam is N1, N2, N3, N4, N5, N6, N7, N8, N9. The suspended I-beams bear the vertical rod transfer load and self-weight load. The variable load and permanent load effect control combination are considered respectively in calculation, and the two values are compared and the maximum value is taken to check the calculation [3].

According to the calculation book of the beam and plate mold support system in the 6-story cornel area, the concentrated force is the sum of the axial force of each beam and plate:

$N_1=N_2=N_3=N_4=N_5=N_6=N_7=21.417kN$, $N_8=20.098kN$, $N_9=5.244kN$.

(3) Load calculation of cantilever I-beams

The cantilever I-steel adopts 22b I-steel, E=2.06× $105N/mm^2$, $I=3.57\times107mm^4$, $W=3.25\times105mm^3$, Ix/Sx=187mm, d=9.5mm, $A=46.53cm^2$, and its own weight is 33kg/m.

$$EI = 7354.2\ kN \cdot m^2 \tag{1}$$

$$EA = 958518kN \tag{2}$$

The cantilever length of the I-steel is 7300mm, the anchoring length is 4500mm, and the I-steel is carried by the pull-down brace. The calculation diagram is shown in figure 2 below.

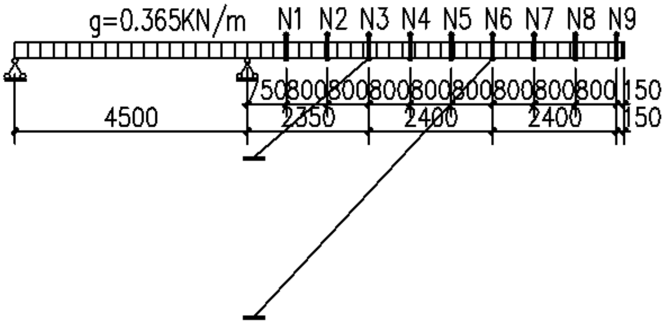

Figure 2. Schematic diagram of Angle beam calculation.

The Structural Mechanics Solver of Tsinghua University was used for internal force calculation. According to the calculation results, Mmax=58.64kN·m, Vmax=45.98kN, and the bearing reaction forces were -0.51kN, 26.89kN, 38.179kN and 112.31kN respectively, then:

Section stress:

$$\sigma = M_{max}/W\ < [f] \tag{3}$$

Mmax is the maximum bending moment of section; W is the net section modulus (resistance moment) of I-steel (cm^3); [f] is the design value of compressive strength of I-steel: [f] =205 N/mm^2.

Shear stress:

$$\tau = V_{max}/(d \times I_x/S_x) < 125.0N/mm^2 \quad (4)$$

It can be obtained by calculation that the deflection is small and meets the requirements of use [4].

(4) Check calculation of lower support member

1) Check calculation of the first lower support member

According to the above calculation results, the top vertical force of the lower braced member is 38.17kN, then the axial force of the inclined braced member is:

$$N = V/cosarctan\left(\frac{2.225}{1.928}\right) = 58.29kN \quad (5)$$

The project adopts 14# I-steel as the lower strut member, and the direction of the lower strut I-steel web is the same as that of the cantilever I-steel. Ix=712cm^4, iy= 64 cm^4, Wx=102cm^3, Wy=16.1cm^3, radius of rotation ix= 5.79cm, iy= 1.73cm, cross-section area A= 21.5cm^2

The stability calculation formula of inclined top I-steel:

$$\sigma = \frac{N}{\varphi A} \leq [f] \quad (6)$$

Wherein: the design value of the axial pressure of N-I-steel (kN): N = 58.29kN;

φ- The stability coefficient of the axial compression vertical rod, obtained from the slenderness ratio lo/i;

i - Calculate the radius of rotation (cm) of the section of the I-steel;

A-i-steel net section area (cm^2);

W-i-steel net section modulus (resistance moment)(cm^3);

σ- The maximum stress calculated value of I-steel (N/mm^2);

[f] -I-steel compressive strength design value: [f] =205 N/mm^2;

L0 - calculated length (m) (the upper and lower ends of the lower braced member are simplified as hinged, and the calculated length is the length of the member)

The calculation result of the above formula: the length of the vertical rod is calculated

L_0=$(2.2252+1.9282)^{1/2}$=2.94m;

L_0/i_x=294/5.76=51.04<[λ]=150, meet the requirements.

L_0/i_y=294/1.73=169.9>[λ]=150, do not meet the requirements.

According to GB 50017-2017[4] Standard for Design of Steel Structures, it can be seen that the 14# I-steel is a Class A section for X-axis and b section for Y-axis (X-axis is perpendicular to the web and Y-axis is parallel to the web). Moreover, the stability coefficient of the axial compression member of the section of the inclined top member is φx=0.913, then:

Stability of I-beam:

$$\sigma_x = 29.70N/mm^2 < [f] = 205\ N/mm^2$$

I-beams strength:

$$\sigma = 27.11\ N/mm^2 < [f] = 205\ N/mm^2$$

Along the length of the skew I-steel, one channel L60 Angle steel is evenly divided in the middle and welded with the skew I-steel, then L0/iy=147/1.73=84.97. It can be seen from the stability coefficient of the axial compression member of the section of the skew top member is φy=0.655, then:

I-beams stability:

$\sigma_y = 41.39N/mm^2 < [f] = 205\ N/mm^2$, meet the requirements.

2) The second check calculation of the lower support member

According to the above calculation results, the top vertical force of the lower braced member is 112.31kN, then the axial force of the inclined braced member is:

$$N = \frac{112.31}{cosarctan(\frac{4.625}{5.21})} = 150.18kN \quad (7)$$

The stability calculation formula of the inclined top I-beam is used to calculate the length of the vertical bar: L_0=(4.6252+5.212)1/2= 6.97m;

L_0/i_x=697/5.76=121＜[λ]=150, meet the requirements.

L_0/i_y=697/1.73=402.89＞[λ]=150, do not meet the requirements.

(5) Calculation of embedded parts

1) The first understay embedded part

The embedded parts were embedded at the junction of the fourth floor concrete structure and the shear wall, and the lower support members were welded with the embedded steel plates. The embedded parts were calculated according to the "Straightening Structure Design Toolbox Software 6.5".

The size of the embedded parts is 250×300mm, the thickness of the anchor plate is 12mm, and the anchor bars are in the form of straight anchor bars. The anchor bars are in 2 layers and 2 columns. The layer spacing is 75mm and the column spacing is 100mm. The anchor bars are made of HRB400 diameter 14mm steel bars and the anchoring length is 500mm.

2) The second understay embedment

The embedded parts are embedded on the top surface at the junction of the corner beam and shear wall on the fourth floor, and the lower support members are welded with the embedded steel plates. The layout is the same as that of the first lower support embedded parts.

(6) Check calculation of fillet weld between the lower support member and the anchor plate (cantilever I-steel)

As the second lower braced member has greater force, the second lower braced member is selected to check the calculation, and the weld of the first lower braced member is the weld of the second lower braced member. The lower strut I-steel and anchor plate (cantilever I-steel) are connected by fillet weld at the flange. Weld thickness he=10mm, weld length lw=100mm, design value of fillet weld strength ffw=160N/mm^2, then:

$$\sigma_f = \frac{N_S}{(he \times lw)} \leq \beta_f f_{fw} \quad (8)$$

(7) Calculation of the connection between the cantilever I steel anchorage section and the floor slab

The anchoring length of the pressure ring in the main beam building Lm=1500 mm, the grade of the beam slab concrete is C30, the diameter of the pressure ring reinforcement is 20mm, and the inner end pressure ring is double pressure ring. According to the above calculation results, only the inner anchoring pressure ring is strained, which needs to be checked.

Pressure ring check calculation:

$$\sigma = N/(4A) \leq 0.85 \times [f] \quad (9)$$

Meet the requirements.

The pull ring of the horizontal steel beam and the pressure point of the floor must be pressed under the lower steel bar of the floor, and the anchoring length on both sides must meet the requirements [5].

(8) Check the strength of concrete under the hanging steel beam

Because the cantilever steel beam is suspended on the floor, the front end of the cantilever steel beam is subjected to the largest load, that is, the concentrated force, and the acting area here is b×b (b is the width of the I-steel flange, 22b I-steel b= 112mm), which conforms to the actual situation. The I-steel will be installed and the cantilever support frame will be set up 15d after the layer is poured, assuming that the average temperature of construction is 20℃. At 15d, the strength grade of C30 concrete is fc=14.3×80%=11.44N/mm^2, R1=36.41kN.

According to Article 6.6 of the Code for Design of Concrete Structures, take βc=1.0, βl=, A1n=b2=12544 mm^2, then

$$R_1 \leq 1.35\beta c\beta_l fcA_l n \quad (10)$$

(9) Check the overall stability of cantilever I-steel

Axial force of the lower support member on the cantilever I-steel:

$$N_{xcz} = Ntanarctan\left(\frac{2.225}{1.928}\right) + 150.18\ tanarctan\left(\frac{4.625}{5.21}\right) = 200.59KN$$

Tensile bending member strength:

$$\sigma_{max} = \frac{M_{max}}{\gamma W} + \frac{N}{A} \leq [f] \quad (11)$$

Overall stability analysis of flexural components:

Where - the overall stability coefficient of uniformly bending bending member;

Refer to "Steel Structure Design Standard" (GB50017-2017), =2, because

$$\sigma = \frac{Mmax}{Wx} \leq [f] \quad (12)$$

To sum up, meet the requirements.

4. Structural Measures and Construction Requirements to Ensure the Stability of the Support System

4.1. Structural Measures of Formwork Support System

(1) The step distance of the top shelf supported by the project is set in half, that is, the step distance of the top step shelf does not exceed 0.75m [6].

(2) The frame is connected with the pre-poured column and wall hoop around the frame, the horizontal spacing is not more than 6 m, and the vertical spacing is synchronized.

(3) The outer facade and inner side of the high-altitude support die bracket should be continuously filled with longitudinal scissors. In the middle of the frame, one horizontal vertical scissor brace is arranged every 5 m, and one horizontal scissor brace is arranged at the top, middle and root between the two vertical scissor braces.

4.2. Construction Requirement

(1) The bottom mold of the high-altitude suspended concrete structure must be removed after the concrete strength reaches 100% [7].

(2) Strengthen the monitoring of the deformation of the frame during the construction process, and arrange a monitoring profile every 10~15m spacing. Each monitoring profile shall be arranged with no less than 2 monitoring points for horizontal displacement and deformation of the support and 3 observation points for

settlement of the support. The warning value of horizontal displacement at the top of the frame is 25mm, the warning value of verticality change is 20mm or the warning value of settlement is 20mm. The maximum deformation monitoring value of the steel platform is 10mm. When the monitoring data exceeds the warning value, the construction must be stopped immediately, the personnel must be evacuated, and the reinforcement process must be carried out in time [8].

5. Peroration

In this paper, the cantilever with the most unfavorable position is selected and the main beam of the cantilever is checked. The results show that the scheme is feasible. The subsequent engineering practice also further proves that the construction in strict accordance with this scheme can effectively and safely ensure the smooth progress of construction. There is no abnormal situation in the construction process, and the formwork and support frame are stable and reliable, ensuring the safety and quality of the structure construction [9]. At present, the project has been rated as the high-quality construction project of Hubei Province, and it is planned to apply for the high-quality project of Hubei Province "Chutian Cup". This paper not only guides the construction, but also provides good practical experience for the construction of similar projects in the future.

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