Design and Construction Method of High-low Span Cross Support System for Frame Structures

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Abstract: Taking a high-rise frame-shear wall structure project in Jilin Province as an example, combined with current specifications, standards, and regulations, this paper proposes the design and construction method of the scaffold support system for the high-low span and high formwork between the basement and the main structure； In the construction, the side formwork of the high-low span beam adopts the method of suspending formwork, and the combination of fixing support and drawing bolts on both sides. The floor slab is poured first, followed by the high-low span, and the pouring is carried out in layers and sections, ensuring the quality of the project and shortening the construction period. After construction verification, the various acceptance values are better than the current engineering acceptance evaluation standard values, and it is safe and reliable. This provides a reference for the design and construction of similar high-low span and high-formwork projects in frame structures.

1. Introduction

With the continuous development of society, the construction field has made significant progress. With the improvement of the overall strength of the country, the development of the construction field has also been greatly advanced. Not only are more and more large-scale reinforced concrete structure buildings, super high-rise buildings, and infrastructure appearing in social development but a large number of advanced technical means are also being widely used in them[1]. Basement engineering is an important content in the development of the construction field. In recent years, many engineering teams have increased research and exploration related to basement construction technology, and have innovated and improved related technical means, thus ensuring the overall quality and later safe use of the basement[2][3]. However, through literature investigation and analysis, there is little research on the design and construction methods of high-low span and high-support formwork. This article takes a project in Jilin Province as an example, proposes the design and construction methods of high-low span and high-support formwork, and verifies its design and construction methods through construction monitoring, ensuring engineering quality, shortening the construction period, and ensuring safety and reliability.

2. Project Overview

A certain project in Jilin Province is a frame-shear wall structure with a total construction area of 92,961.38 m^2, a building height of 49.2 m, 13 floors above and below ground, and an underground area of 15,791.38 m^2. The foundation form is a raft foundation and an independent foundation. The section size of the high-low span G axis KL-18 at the intersection of the basement and the main building (the main part of the elevation is -0.1m, and the basement part is -2.1m) is 400mm × 2400mm, with a total length of 57.9m and a template support height of 8m. According to the specifications, concentrated line loads exceeding 20 belong to the scope of ultra-hazardous engineering.

3. Load calculation and design method for high-low span beam and side beam formwork.

3.1 Design and calculation of high-low span beam formwork.

3.1.1 Design method of high-low span beam formwork.

KL-18 concrete beam has a sectional dimension of 400mm ×2400mm, a structural importance coefficient γ0=1.1, and a safety level of Class I for the scaffold. The supporting method for the newly poured concrete beam is with plates on both sides.According to current specifications[4][5][6], the vertical load-bearing capacity determines the horizontal and vertical spacing of the support poles, and the slenderness ratio of the support poles determines the step distance. Through calculation, the obtained values ensure that they comply with the

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allowable range of the current specifications.Thus, the support pole spacing in the beam span direction, l_a=450mm; the transverse spacing of the support poles on both sides of the beam, l_b=1000mm; the step distance, h=1500mm; the length of the support pole extending from the center line of the top horizontal bar to the support point, a= 200mm. The longitudinal spacing of the support poles for the newly poured concrete floor, l'_a=900mm, and the transverse spacing of the support poles for the newly poured concrete floor, l'_b=900mm. The position of the support poles on both sides of the concrete beam is centered, with the left support pole being 500mm from the center line of the beam. The number of support poles added at the beam bottom is increased by 2, and the layout of the additional support poles at the beam bottom is divided equally between the support poles on both sides of the beam. The distance of the additional support poles from the left support pole is 333mm and 667mm in sequence.

3.1.2 Calculation of high-low span beam formwork.

(1)Calculate load parameters:

According to the specification "Building Structural Load Code"[7], the standard value of self-weight for the template and its support is G_{1k}, where the panel is 0.1kN/m^2, the panel and small beam are 0.3kN/m^2, and the floor template is 0.5kN/m^2. The standard value of self-weight for the newly poured concrete G_{2k} is 24kN/m^3. The standard value of self-weight for the reinforcement of concrete beam G_{3k} is 1.5kN/m^3, and the standard value of self-weight for the reinforcement of concrete slab G_{3k} is 1.1kN/m^3. The standard value of construction load Q_{1k} is 3kN/m^2. The standard value of self-weight for materials concentrated on the support scaffolding calculation unit G_{jk} is 1kN. Design plan drawing. As shown in Figure 1.

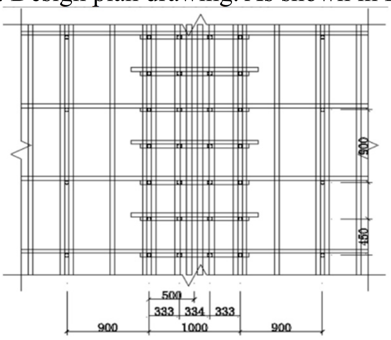

Figure 1. Design schematic plan

(2)Template checking:

According to the “Safety Technical Specification for Building Construction Template”[8], the longitudinal unit width of the beam b=1000mm, is calculated as a continuous beam with three equal spans. Calculate the simplified diagram of the beam bottom template. As shown in Figure 2.

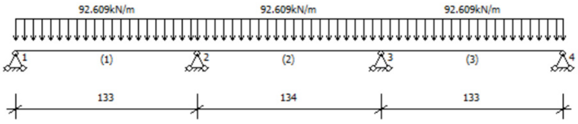

Figure 2.Calculation diagram of beam bottom plate template.

(3)Main beam calculation:

1)Main beam parameters: The type is steel pipe, the main beam section is Φ48.3×3.6mm, the calculated section type of the main beam is Φ48.3×3.6mm, the design value of the main beam's bending strength [f] is 205N/mm^2, the design value of the main beam's shear strength [τ] is 125N/mm^2, the main beam's section moment of resistance W is 4.49cm^3, the main beam's elastic modulus E is 206000N/mm^2, and the main beam's section inertia I is 10.78cm^4.Calculate the load-bearing capacity of the main beam: The design value of the self-weight of a single main beam is q=0.048kN/m.

2)The normal use limit state of a single main beam's self-weight standard value is q' = 0.033 kN/m. As shown in Figure 3.

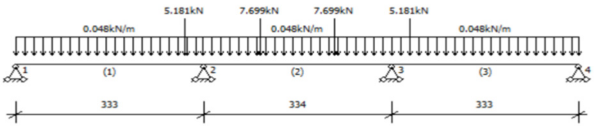

Figure 3. Calculation diagram of main beam

Bending calculation:

$\sigma = \frac{M_{max}}{W} = 86.587\text{N/mm}^2 \leq [\text{f}] = 205\text{N/mm}^2$,

As shown in Figure 4.

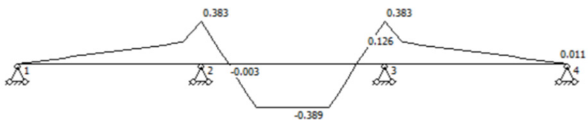

Figure 4. Bending calculation diagram of main beam

Shear calculation：

$\tau_{max} = \frac{2V_{max}}{A} = 36.354\text{N/mm}^2 \leq [\tau] = 125\text{N/}$ mm^2,

As shown in Figure 5.

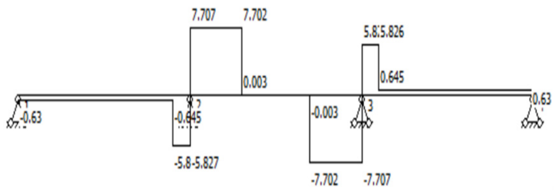

Figure 5. Shear calculation diagram of main beam

Deflection calculation，as shown in Figure 6.

$$V_{max} = 0.0124mm \leq [\text{v}] = \frac{\text{L}}{400} = 0.835\text{mm}$$

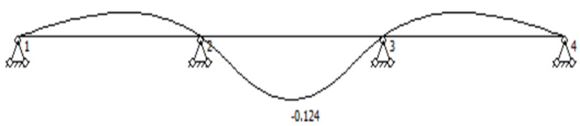

Figure 6. Deflection calculation diagram of the main beam.

3.2Design and calculation of high and low span beam side formwork

3.2.1High-Low span beam side formwork support design

The layout of the small beams is horizontal, with a main beam spacing of 300mm, a main beam merge number of 2, and a horizontal spacing of 300mm for the pull-out bolts. The thickness of the left side of the beam is 350mm; the thickness of the right side of the beam is 180mm, and the height of the suspended side formwork is 2220mm. The distance of the supports on the left side from the beam bottom is 350mm, 500mm, 1000mm, 1500mm, and 2000mm, with the first support being a fixed support and the other four being pull-out bolts. The distance of the supports on the right side from the beam bottom is 350mm, 500mm, 1000mm, 1500mm, and 2000mm, with the first support being a fixed support and the other four being pull-out bolts. As shown in Figure 7.

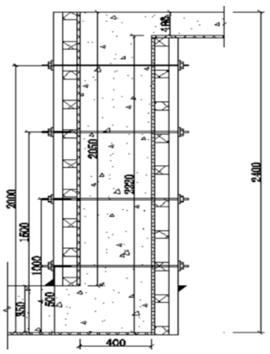

Figure 7. Template design section diagram.

3.2.2Calculation of High-Low span beam side formwork

(1)Calculation of load parameters:

The calculation of the lateral pressure is based on "Safety Technical Specification for Building Construction Formwork"[8], with concrete gravity density γ_c=24kN/m^3, structural importance coefficient γ_0=1.1, variable load adjustment coefficient γ_L=1, initial setting time of new poured concrete t0=4h, correction coefficient for admixture influence β_1=1, and correction coefficient for concrete slump influence β_2=1. The standard value of lateral pressure on the formwork for newly poured concrete, G_{4k} for the suspended formwork under the beam, is calculated as follows: $\min\{0.22\gamma_C t_0\beta_1\beta_2 v^{\frac{1}{2}}, \gamma_c H\} = \min\{0.22\times 24\times 4\times 1\times 1\times 21^{\frac{1}{2}},\ 24\times 2.4\} = 29.868$kN/m^2. The standard value of lateral pressure on the formwork for the left upper-turned formwork G_{4k} is also 29.868kN/m^2. The load standard value on the vertical formwork during the vibration of concrete, Q_{2k}, is 4kN/m^2.In the suspended part, the design value of the load-bearing capacity limit state S_c= 49.311kN/m^2; in the left upper-turned part, the design value of the load-bearing capacity limit state $S_C = \gamma_0(1.3\times G_{4k} + \gamma_L\times 1.5Q_{2k}) = 49.311$kN/m^2; the design value of normal use design value of normal service limit state S_z= G_{4k} = 29.868 kN/m^2 for both the suspended part and the left upper-turned part.

(2)Template checking:

1)Right lower hanging side template:

The width of the beam section is taken as the unit length, b = 1000mm. The area of the beam,

$W = \frac{bh^2}{6} = 37500\text{mm}^3$, $I = \frac{bh^3}{12} = 281250\text{mm}^4$.As shown in Figure 8.

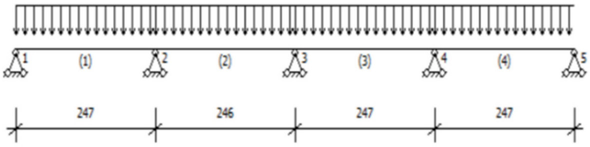

Figure 8. Calculation diagram for the right lower suspended side panel.

2)Left upper flipping side template

The width of the beam section is taken as the unit length, b = 1000mm. The area of the beam,

$W = \frac{bh^2}{6} = 37500\text{mm}^3$, $I = \frac{bh^3}{12} = 281250\text{mm}^4$.As shown in Figure 9.

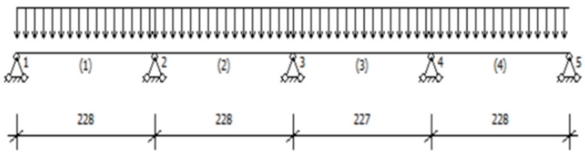

Figure 9. Calculation diagram for left upper flipped side template.

(3)Template checking

1)Main beam parameters: The main beam type is pipe, the main beam section type is Φ48.3×3.6 (mm), the main beam calculated section type is Φ48×3 (mm), the number of main beams merged is two, the Young's modulus E = 206000N/mm^2, the design value of beam bending strength [f] = 200N/mm^2, the design value of beam shear strength [τ] = 115N/mm^2, the section moment of inertia I = 10.78cm^4, the section modulus W = 4.49cm^3, and the uneven loading coefficient of the main beam is 0.6.

2)The load-bearing capacity of the right lower hanging side template: Due to the merger of the two main beams, the uneven loading coefficient for the main beam during calculation is 0.6.As shown in Figure 10.

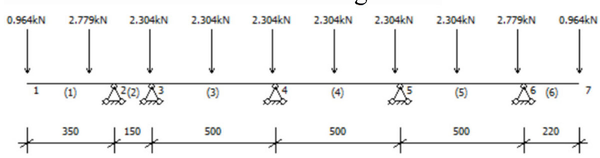

Figure 10. Calculation diagram for load-bearing capacity of right lower suspended side template.

Bending calculation:

$\sigma = \frac{M_{max}}{W} = 139.049\text{N/mm}^2 \le [f] = 200\text{N/mm}^2$, As shown in Figure 11.

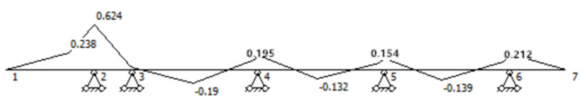

Figure 11. Calculation diagram for bending resistance of right lower suspended side template.

Shear calculation:

$\tau_{max} = \frac{2V_{max}}{A} = 18.972\text{N/mm}^2 \le [\tau] = 115\text{N/mm}^2$, As shown in Figure 12.

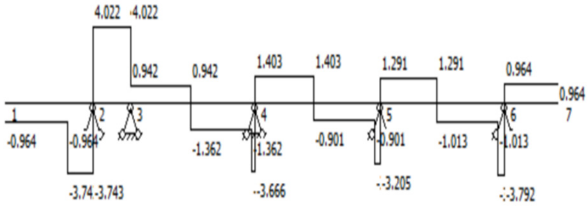

Figure 12. Calculation diagram for shear resistance of right lower suspended side template.

Deflection calculation， As shown in Figure 13.

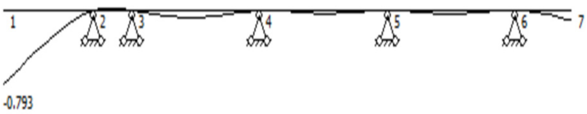

Figure 13. Calculation diagram for deflection of right lower suspended side template.

3）The carrying capacity of the left upper corner template： Due to the merger of the two main beams, the uneven loading coefficient for the main beam during calculation is 0.6. As shown in Figure 14.

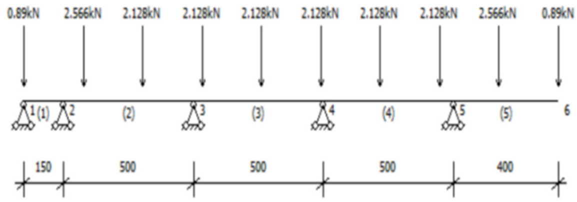

Figure 14. Calculation diagram for carrying capacity of left upper flipped side template.

Bending calculation：

$\sigma = \frac{M_{max}}{W} = 177.813\mathrm{N/mm^2} \leq [\mathrm{f}] = 200\mathrm{N/mm^2}$ ， As shown in Figure 15.

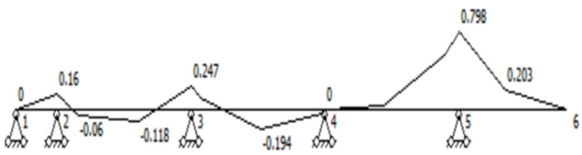

Figure 15. Calculation diagram for bending resistance of left upper flipped side template.

Shear calculation：

$\tau_{max} = \frac{2V_{max}}{A} = 20.799\mathrm{N/mm^2} \leq [\tau] = 115\mathrm{N/mm^2}$， As shown in Figure 16.

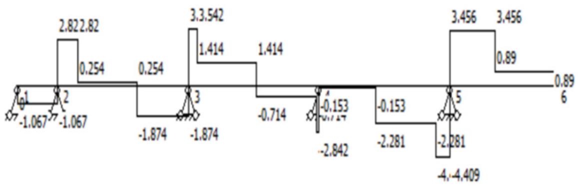

Figure 16. Calculation diagram for shear resistance of left upper flipped side template.

Deflection calculation， As shown in Figure 17.

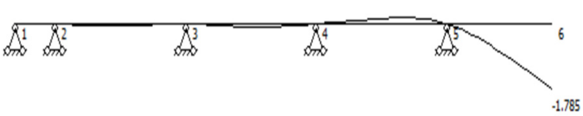

Figure 17. Calculation diagram for deflection of left upper flipped side template

4. The construction method and construction verification of high-rise formwork and high-low span.

4.1 The construction process diagram and key quality control points of high-rise formwork and high-low span template construction.

In response to the structural characteristics and formwork scheme of this project, based on current specifications, the clip-type full-floor support system is adopted， and construction process flow diagram is created using Visio[10].As shown in Figure 18.

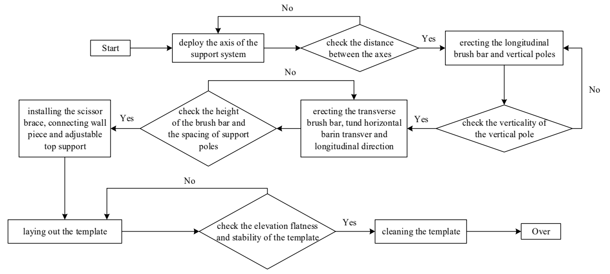

Figure 18. High and low-span formwork construction process flow chart and key points of quality control.

4.2 The construction methods of high-rise formwork and high-low span.

The construction method involves using a suspended formwork on one side, with fixed support for the first layer and a combination of pull-out bolts for the others. The concreting process utilizes a truck-mounted pump for delivery. The pouring sequence begins with the lower span section, followed by the high-low span and high span sections before the concrete sets initially.Due to the significant difference in height between the high-low span in this article (2400mm) and the conventional high-low span, the concreting method differs greatly[11]. A segmented and layered pouring method should be adopted, starting with a 300mm-high section. After sufficient vibration of the concrete, another 300mm-high section should be poured before the concrete sets. This construction method will complete the pouring of the high-low span.During the concreting process, it is necessary to survey the floor slab elevation every 30 minutes and monitor the settlement value of the fastener-type full-height scaffolding every 12 hours. Additionally, concrete specimens should be retained according to requirements, without leaving construction joints, and pouring continuously in one go.

4.3Construction verification.

According to this construction method, attention should be paid to the following: after the concrete pouring of high-rise formwork and high-low span, there was no occurrence of inflation, and the template joints were smooth without concrete slurry leakage. After demolding, the concrete surface was smooth, with a vertical deviation of ±3mm, and there were no phenomena such as bending, deformation, and fracture. There were also no problems such as insufficient vibration, honeycombing, and cracks, which are common quality problems. All acceptance values are better than the evaluation criteria of the "Construction Specification for Concrete Structures" [9]. The settlement value of the cylindrical steel tube scaffold with fasteners is 2mm, and the vertical deviation is 2mm, which is better than the evaluation criteria of current specifications.

5. Conclusion

1. This article proposes the construction process flow and three-step construction method for high-rise formwork and high-low span template, as well as four key quality control points. The setting of these control points provides better assurance for the safety and quality of construction in large-scale high-rise formwork and high-low span projects.

2.This article suggests that taller high-low span structures should adopt a segmented and layered casting method. This ensures that the concrete is thoroughly vibrated, preventing any voids or defective vibrations, and can guarantee the integrity of the high-low span, eliminating construction joints.

3. The design of the formwork for high-low span should be divided into beam template design and beam side template design. In the design of beam templates, it is important to consider the load parameters such as the weight of the template, support, newly poured concrete, and reinforcement; followed by the calculation of the bending, shear strength, and elastic modulus of the template; and finally, the cross-sectional dimension, elastic modulus, and bending, shear, and deflection calculation of the main beam. When designing the beam side template, the load parameters are considered first, followed by the calculation of the suspended template on the right and the inverted template on the left, and finally, the bending, shear, and deflection calculation of the main beam to ensure its stability.

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