Construction Scheme of the Formwork Support for Overweight Beams

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Abstract. With the rapid increase of the number of high-rise and long-span buildings, oversize and overweight concrete structural beams have emerged. The concrete formwork support for overweight beam faces great risks. To prevent the collapse of formwork support system, it is extremely important to improve the design and construction levels of the formwork support system for overweight beams. Through the actual engineering research, this paper analyzes the material selection and the erection method of formwork and support, and also conducts the mechanics calculation on them. Besides, this paper also introduces the installation and dismantling of the formwork for overweight beams, as well as the construction requirements. This paper proposes to control the design and construction quality of the formwork support system for overweight beams to ensure the stability of the support system. The research results provide references for other similar projects.

1. Project Overview
In recent years, there have been many cases of safety accidents in the construction of the formwork support for oversize and overweight beams. It has become a concern in construction industry about how to control the safety and quality in the construction of formwork support for oversize and overweight beams.

The basement project of the 21#, 22#, 23-1#, 23-2# and 21-23-1# buildings in the Block B of New Scotland Phase III is located at Xiangjiang Road, Zhangzhou Development Zone of China Merchants Group (CMG), Zhangzhou, Fujian Province. The project has a total construction area of 105117.55 m², and the above-ground building area of 93805.85 m². The three high-rise buildings of the project are 21# with 33 floors, 22# with 33 floors, and 23# with 26 floors. For the three buildings, their structural system is frame shear wall, the basement area is 11311.70 m² and floor area of 6385.96 m². The concentrated and line loads of some structural beams of the underground garage of this project exceed 20 kN/m, indicating that the project belongs to the sub-project with high risks. According to the regulations, the concrete formwork support project with total construction load over 15 kN/m² is the formwork project of overweight beams.

The position of the overweight beams in this project is in the X and Y directions of the basement roof between the 21# and 22# to 23-1# buildings in Block B. The plane layout in the X direction is shown in Fig. 1, and the plane layout in the Y direction is shown in Fig. 2, where the beams with thick lines are overweight beams. Among the overweight beams, the beams with cross section of 600×1000 take the majority, and they are located on DB-5 axis, DB-13 axis, DB-14 axis, 23-22 axis and 23-27 axis, with beam numbers of KL13, KL42, KL50, KL52 and KL57, respectively. The beams with cross section of 600×1100 are located on DB-4 axis, DB-9 axis, DB-11 axis and 23-24 axis, with beam
numbers of KL11, KL43, KL48 and KL54, respectively. The beam with cross section of 550×1000 is located on DA-E axis, with beam number of KL10. The beams with cross section of 400×1700 are located on 22-D axis, with beam numbers of KL80 and KL91, respectively. The beam with cross section of 400×1800 is located on 23-G axis, with beam number of KL87.

The cross section b×h of the overweight beam is 600×1100, 400×1700, 400×1800, and the beams with section of 600×1000 and 550×1000 are critical overweight beams. The support height of large beams is as follows: 4.0 m for the attached building, 4.8m for the 21# building, 5.0 m for the 22# building, 5.09 m for the 23# building. The thickness of basement top plate is 180 mm and 200 mm.

Figure 1. Plane layout of the overweight beam in the X direction

Figure 2. Plane layout of the overweight beam in the Y direction

2. Layout of formwork and support

2.1. Material selection for formwork and support

The supporting method of the project's formwork is fastener-type steel tube scaffolding. The panel of the formwork is made of 15 mm-thick plywood for the formwork material of plate bottom and beam bottom board. The pull bolt is made of 12 round steel, and the steel square tube of 50×50×3 is used as the secondary prism of the plate bottom and beam bottom board. The square wood of 100×100 is used as the main prism (joist) of the plate bottom and beam bottom board. The Q345-B steel pipe of φ48.3×3.6 (φ48.0×3.0 is adopted in the calculation) to support the upright tube, tie beam, scissors support, etc.
2.2. Erection of formwork and support
The beam bottom board is 15 mm thick plywood (first layer). The steel square tube of 50×50×3 is used as the secondary (inner) prism (second layer), with five (beam cross section of 600×1100) and four (beam cross section of 400×1800) uniformly distributed along the beam width direction. The square wood of 100×100 is used as the joist (third layer), with longitudinal distance of 1000 mm (beam cross section of 600×1100 beam) and 500 mm (beam cross section of 400×1800). The steel pipe of 4φ48.3×3.6 is used as the upright tube to form a top support structure, with vertical distance of 1000 mm (beam cross section of 600×1100) and 500 mm (beam cross section of 400×1800), and four uniformly distributed at the horizontal distance of 300 mm along the beam width direction. The bottom tube and horizontal tube adopt the steel pipe of φ48.3×3.6, with step of 1500 for the horizontal tube, and it is fixed with the cast reinforced concrete column. The vertical scissors support adopt the steel pipe of φ48.3×3.6, with one arranged under each beam, and it is fully arranged for full-height and full-span cases. The horizontal scissors support adopts the steel pipe of φ48.3×3.6, and is arranged one every two steps.

2.3. Calculation of formwork and support
Due to the large varieties of cross sections of overweight beams, the calculation is performed on the beams with larger cross section. For the beams with cross section of 600×1100, 600×1000 and 550×1000, the formwork support is set according to the overweight beam with cross section of 600×1100. For the beams with cross section of 400×1700 and 400×1800, the formwork support is set according to the overweight beam with cross section of 400×1800. The thickness of the basement roof is 180 mm and 200 mm, and the thickness of 200 mm is adopted in the calculation.

Taking the overweight beam with cross section of 600×1100 as an example, the thickness of the slab on both sides of the beam is 0.20 m, and the height of the formwork support is 3.99 m. The parameters of the formwork support calculation are: panel thickness is 15 mm, shear strength and bending strength are 1.4 N/mm² and 12 N/mm², respectively, and elastic modulus is 4000 N/mm². The bulk density of the formwork and reinforced concrete are 0.5 kN/m³ and 25.5 kN/m³, respectively, with the live load ignored in construction.

The inner keel is made of the square steel pipe of 50×50×3 mm, and five are evenly arranged according to the width direction of the beam bottom. The beam top is made of the square wood of 100×100, with the shear strength and bending strength being 1.4N/mm² and 13N/mm², respectively, and the elastic modulus being 9 kN/mm², and they are arranged at a pitch of 1 m. The upright tube of the beam bottom is made of the round steel tube of φ48×3, and four are arranged in the width direction, with the distance between the upright tubes on both sides being 0.9 m, the vertical distance of the upright tube being 1 m, and the step of the horizontal tube being 1.5 m.

The beam bottom board is a bent structure, and its bending strength and stiffness need to be checked. The formwork panel is calculated according to the case of multi-span continuous beam. The applied load includes the self-heavy load of the beam and formwork, and the live load in construction, etc. The calculation contents of the formwork include: the calculation of load, the determination of calculation diagram, the calculation of internal force deformation (maximum bending moment, maximum shear force, reaction force of each support, maximum deformation, etc.), and the bending, shear strength and allowable deflection are calculated according to the above calculation results [1]. The calculation results show that the two cross sections of 600×1100 and 400×800 meet the requirements.

3. Installation of the formwork for overweight beams
The project is high-rise residential building with frame and shear structure. The overall layout is irregular, the walls and beams are of various types, and the formwork engineering is complex. Therefore, the rational design and installation of the formwork is the key to the safety and quality of the project.
3.1. Technical scheme for the installation and dismantling of the formwork
The formwork support of the overweight beam is supported on the raft surface. Before the formwork is installed, the floor of the building is leveled. The bottom of each upright tube is provided with a base. The base is provided with a wooden slab of 2000mm×150mm×50mm. When the concrete is poured, the next layer of the formwork support is maintained and not dismantled.

The dismantling scheme adopts the method of support + early dismantling head + wooden keel + bamboo plywood, the top plate is made of 15 mm thick wood plywood, the secondary keel is 100 mm × 100 mm square wood with distance of ≤400 mm, and the main keel is 100 mm×100 mm square wood with distance of 1000~1200 mm. In order to ensure the flatness of the top plate, one side of the contact surface should be planed for all square wood [2].

The support head adopts the early dismantling support head and the adjustable U-shaped support. The beam side form and bottom form adopt the 18 mm thick multi-layer board, with the distance of ≤400 mm for the side form. One pair of Ф12 pull bolts is arranged at the beam height of 600 mm<h<1000 mm, and two pairs of Ф12 pull bolts are arranged at the beam height of >1000 mm. The pull bolts pass through the 16 PVC casing. The beam side adopts the Ф48 steel pipe.

3.2. Construction of the formwork
Firstly, the axis line, the beam position line and the horizontal elevation line are marked on the column. The elevation of the adjustable top support is adjusted according to the designed value, and then 100×100 square wooden joist is placed and fixed on the pallet of the adjustable top support. Then, a 50×50×3 мм square tube is installed on it. The beam bottom board is mounted with plywood and is leveled [3]. When the span of the beam is ≥4 m, the bottom board should be arched, and the arch height is 1‰-3‰ of the span. The arching treatment for the intersection of main and secondary beam is as follows: the main beam arches first, and then the secondary beam arches. The installation order of the formwork for overweight beams is: bottom board, side board, hold-down plate and diagonal support.

3.3. Dismantling of the formwork
The principle of the dismantling of the formwork is as follows: the first installed formwork is dismantled later, and the rear-installed formwork is dismantled first. During the dismantling process, the formwork should not be damaged. After the formwork is dismantled, the planer is used to remove the debris on the board surface, the damaged surface of the formwork is repaired with cement putty, and the mold release agent is applied to facilitate the dismantling step. The structure of the dismantled formwork and its support can bear the full load only after the concrete strength reaches the designed concrete strength. When the effect of the construction load is more unfavorable than that of the working load, calculation must be performed and temporary support should be added [4].

4. Construction requirements for the formwork support of overweight beams
The construction requirements for the formwork support of overweight beams should be formatted as follows:

- The upright tubes are placed on the top plate of the basement. The bottom of each upright tube is provided with a wooden mat with a thickness of >50 mm and a size of >500×500. The upright tubes must be butt jointed and overlap joint is prohibited. The force point at the top of the upright tube is a U-shaped top support, and the horizontal tube should not be stressed. The U-shaped top support (including the screw) has a protruding length of ≥150 mm. The verticality deviation of the upright tube is ≥1/500 H of the total height of the support body, and ≥±50 mm.
- The support body must be continuously set with vertical and horizontal bottom tubes as well as horizontal tube. The vertical bottom tube should be fixed on the upright tubes with the right-angle couplers, and is not more than 200 mm from the base. The horizontal bottom tube should be fixed on the upright tube below the vertical bottom tube using the right-angle couplers [5].
The support body must be firmly connected with the constructed stable structure. The beam bottom should be provided with scissors support along the span direction. Each pair of scissors supports satisfy $\leq 4$ spans and $\leq 6$ m. The angle between the inclined tube and the horizontal plane is 45-60 degrees. At the intersection of the scissors inclined tube and all the tubes, the rotating couplers are used for fixing.

A reliable connection should be formed around the support body and the building to reduce the adverse effect of the height of the support body on the stability. In the vertical direction, a connecting tube is set along the vertical direction according to the requirement that the height of each floor or the column should not be more than 4 m, and a connecting tube is set along the horizontal direction every 3 spans [6].

The joints of the upright tube, horizontal tube and scissors inclined tube should be staggered in different sash layers. The joints of two adjacent upright tubes should not be set in the synchronization. The distance between the joints in the height direction is not less than 500, and the distance from the center of each joint to the main node is not more than 1/3 of the step. The tubes in the formwork support system must not be connected with the outer support frame, or the unloading platform, etc.[7].

All the connection nodes of the formwork support system must be connected by couplers. The quality of the couplers and whether they are tightened are essential for the safety. In practice, there is often the phenomenon that the quality of the couplers does not meet the requirements and the torque is not enough which should be controlled at 45-60N·m.

5. Conclusion
In this project, the construction scheme of the formwork support for overweight beams has been examined and proved by experts. Through the research on actual engineering projects, this paper analyzes the material selection and erection method of formwork and supports. Based on the calculation results of the formwork support, the installation and dismantling process of the formwork, and the structural requirements, etc., the installation and erection is performed strictly in accordance with the requirements. No phenomenon of instability or deformation occurs in the subsequent construction of formwork support, which greatly improves the reliability of the scheme. Practice has shown that only the strict implementation of designed technical parameters, construction schemes, construction requirements, etc., can we ensure the safety of formwork construction for overweight beams, thus ensuring the construction quality of projects.

References
[1] Wu C.H. (2006) Design and Construction of Extra High and Heavy Formwork Supporting System. Building Construction. pp. 81-84.
[2] Cao L.T, Chang H.L, Zhao Q.X.(2008) Several Questions of the Multi-erecting Poles Buckle Type Steel Pipe Scaffold.Journal of Lanzhou Polytechnic College.pp.52-56.
[3] Huang B.W, Cheng Y.H, Zhu S.Q.(2014) Practical calculation methods of high formwork fastener steel pipe (support) vertical pole and so on. Shaanxi Architecture.pp.46-48.
[4] Wu C.H. (2013) Stress and Deformation Monitoring and Analysis of Formwork Support System of Heavy-duty Elevated Frame[J].Anhui Architecture.pp.91-95.
[5] Zheng W.G, Su P.F, Huang Q.J.(2008) Discussion on construction of fastener-type steel pipe scaffold high support. Construction. PP. 103-106.
[6] Li J.X. (2009) Stability analysis and Engineering Application Research of high formwork steel pipe support frame. Huaqiao University.
[7] Chen Zhengyi. (2009) Safety Technology of Overweight, High Clearance and Large Span Formwork Support System. Architecture. PP. 102-104.