Research on the Difficulties and Countermeasures of Super High-rise Steel Structure Construction

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Abstract. Steel structures are increasingly used in super high-rise buildings. The construction of super high-rise steel structure projects has many characteristics that are different from conventional steel structure construction. Combined with the actual engineering case, some of the key points, difficulties and countermeasures that may be encountered in the construction of super high-rise steel structure engineering are discussed, which is intended to provide reference for future engineering. Keywords: steel structure, super high-rise, construction

1. Introduction

1.1. Project Basic Profile
This project is located in the Hualong Bridge zone of Yuzhong District, Chongqing City, adjacent to Jibin Road on the north of Jialing River, Hualong Bridge Road in the south, and Jiahua Bridge in the east. The high-end residential area located in its west side is in Chongqing Tiandi. Jiahua Bridge is located in the is an important urban transportation hub connecting the north and south banks of the Jialing River. There are three towers and a podium to be built in the base. The center of the base is a 99-storey super high-rise office and hotel complex (Phase II tower), the southwest of the base is an 47-storey office building (Phase I tower), the east of the base is a 35-storey office building (Phase III tower), the total construction area is 686,420 square meters (including above-ground and underground), and the floor area is 3,150,80 square meters.

The total area of the second-phase project is 391,120 square meters which is including the second-phase tower, podium and basement.

1.2. Steel Structure Basic Profile
This project includes the second-phase tower and surrounding podium and basement. The second-phase tower has 99 floors on the ground, and the height of the ground main structure is 440 meters. An outer frame with a belt truss, a core tube (steel support) and an outrigger truss structure are included, the commercial podium is a six-story structure on the ground, which is cast-in-place reinforced concrete frame junction, the basement has a total of three floors, with partial interfloors, which is a cast-in-place reinforced concrete frame shear wall structure.

The steel structure of this project is mainly distributed in towers and podiums, with a total steel consumption of about 73340 tons. The main steel structure forms of podium are the steel inside the concrete beam and column, the steel beam, the steel column and the truss. The main steel structure of
the tower is a giant steel column with outer frame, steel concealed column in the core tube, concealed beam in the core tube, steel plate shear wall, profiled steel plate, steel frame beam column, outrigger truss, conversion truss, belt truss, and support. The third-phase steel structure mainly includes belt trusses on the 15th and 30th floors. There are six belt trusses in the second-phase tower, which are located on floors 15 to 17, 31 to 33, 47 to 49, 63 to 65, 79 to 81, and 98 to 99. Steel structure of outer frame, steel structure of core tube and steel structure of refuge layer show as Figure 1.

The steel materials used in this project are mainly Q235B, Q345B, Q345GJB, Q345GJC, Q390GJC. The maximum thickness of the steel structure is 130 mm.

![Figure 1. Overall effect drawing of the project: steel structure of outer frame, steel structure of core tube and steel structure of refuge layer.](image)

2. Construction characteristics, construction difficulties analysis and countermeasures

2.1 The tower is high in height, complex in shape, and difficult to construct

The maximum installation height of the steel structure of this project is 468m, and the structure is complicated. The floor plane on the ground of the tower is irregular ellipse, and the outer frame column plane is positioned with two sets of symmetrical arcs. The frame column on the ground is converted from 18 round pipe columns to 18 box columns and 2 round pipe columns (bending and twisting columns) from the fourth layer to the 99th layer through the "dome-like heaven embraces the vast earth" joint and the branching joint. The outer frame column is sloped outward from the 5th floor to the 26th floor, and sloped inwards from the 27th to 98th floors. From the 4th floor to the 99th floor, the floor plan dimensions are constantly changing, and the cross-sectional dimensions and thickness of the members are gradually decreasing. During the construction, the construction cannot be carried out...
according to the simple standard floor, and the measurement and precision control are difficult to perform\[1\].

(2) The engineering task is complicated and the weight is about 70,000 tons. The maximum cross-sectional diameter of the round pipe column reaches 2800mm, and the maximum meter weight reaches 9.09 tons/meter. The maximum cross-section of the joint is 5300×2800, the maximum weight is 330 tons, and the single section after segmentation is 78 tons\[2\]. During the installation for the steel structure of the main building, the simultaneous construction of the podium and basement has a greater impact on the heavy component yard and vertical transportation of the main building. The installation and construction organization for the steel structure is difficult.

(3) Construction countermeasures

1) According to the distribution characteristics of the steel structure of the tower, all construction preparations shall be performed in advance, plans shall be prepared, especially the special measurement plan, and detailed measurement control for each inclined steel column, bending and torsion members, complex joints, and steel truss shall be conducted. And precision control measures should be performed to ensure that the construction accuracy meets the design and specification requirements\[3\].

2) Reasonable segmentation should be performed according to design requirements, large-scale hoisting equipment should be selected for on-site construction, the sequence of tower cranes should be analyzed reasonably to ensure that on-site construction progress meets the requirements of construction period\[4\].

3) The yard should be set to meet the requirements of the lifting range and transportation roads near the tower crane. For the above-ground construction stage, due to the lack of on-site construction site, considering the large number of components, it is selected to set up the yard above the tower and the construction road. The north side is set on the ground floor, and the south side is set on the flat top floor. For the construction stage above 83 floors, in order to facilitate the lifting of steel members and meet the requirements of early operation, a storage yard is set on the south side of the 83 floor.

4) The construction of complex components is mainly controlled from three aspects: component production, on-site measurement and welding.

2.2 Deepening steel structure design

Deepening design is the premise of steel structure construction. The quality of deepening design directly determines the difficulty of engineering construction.

(1) The engineering structure is complex, the forms of joints are diverse, and the design for some joints is imperfect (the steel structure conflicts with civil works and curtain walls).

(2) The selection of design units shall be deepened. There are not many domestic units that have the ability to deepen the design for such super high-rise projects, which is not conducive to the development of deepening design.

(3) Preventive solution

1) The drawings and modeling shall be familiarized in advance, the drawings shall be reported and deepened as early as possible before construction, in the joint design process, the project department and the technical department are responsible for the production and installation feasibility review on the joint, and the ministry of commerce is responsible for the coordination between the design and the contract review.

2) The "technical conditions" attached to the design unit should be analyzed in-depth, and some of these requirements should be communicated in advance.

3) Two or three deepening units for technical cooperation shall be selected in advance and work shall be carried out in advance.

In addition to some conventional joints, there are many complex joints in this project joint design deepening design. The design institute should be deepened, the existing deepening design software should be adopted, we should have the ability to deepen it reasonably according to the deepening principles and design intent for production and installation.
The structure of this project is complex and the task is complicated. It is important to deepen the design work. In the process of deepening the design, it is necessary to consider comprehensively and to establish a good foundation for the subsequent construction. It is recommended that the following factors should be considered in the process of deepening the design:

A. Pre-adjusted value of structural construction

The structural pre-adjustment value during construction is always a dynamic adjustment process. Part of the structural pre-adjustment (making the pre-adjustment value) will be carried out during the construction detailed design and component processing stage, so that the staged completion state of the structure meets the initial configuration required by the structural analysis.

B. Installation method and construction measures of steel structure

The steel structure installation method and construction measures are reasonably divided (segmented) according to the selection and installation methods of the lifting equipment, including: additional connection plates required for tower crane installation and climbing, lifting ears and temporary connection plates, temporary deformation and reinforcement structures, reasonable joint forms and weld forms that meet the site installation conditions, additional connection plates and bolt holes required for hoisting temporary safety measures.

C. Connection measures with civil construction

Including reinforced connectors required by the civil engineering profession, holes through the reinforcement, studs that are not easy to weld on site, connections that may be needed to fix the formwork, steel column bottom grouting needs to be designed with holes, and steel supports (including permanent and temporary) that need to be added during the construction of floor concrete.

D: The needs for various electromechanical professions

Including the reserved holes and openings the reinforced electromechanical pipeline through the component, the pre-needed connection parts, the plate parts of the electromechanical equipment base connected to the steel structure, the plate parts temporarily connected to the steel structure required for equipment lifting, and connection plate and fixed plate of elevator system and steel structure.

E. Needs of curtain wall system and decoration professional

The connection between curtain wall system and decoration works with steel structure, fixing plates, eyelets, etc. are limited to the parts whose dimensional accuracy meets the accuracy of steel structure fabrication and installation construction.

F. Demand for other construction measures

Including connection plates for construction elevators and steel structures, plates for connecting concrete delivery pump pipes and steel structures, plates for connecting unloading platforms and structures, and connecting plates for safety measures that need to be temporarily fixed on the steel structure.

2.3 Procurement of American standard materials

This project contains about 4000t of American standard materials. It is learned that at present, purchasing American standard materials takes about 140 days from order to receipt, and some of the American standard materials involved in the project are not in stock in the market and need to be reserved in advance. However, the foreign rules are to pay first and then produce, which puts great pressure on the project management schedule and capital. The responses are:

(1) According to the drawings, the required American standard materials shall be separately listed, and the construction schedule order shall be combined to deepen the partial structure of the designed American standard materials in advance (the necessary raw material procurement, production, and transportation cycle should be considered) and it shall be reported to the designer to confirm American standard material order list. For materials that cannot be procured, communicating with the designer in advance shall be performed, and the national standard welded steel shall be used for replacement.
(2) The welding process of American standard steel and national standard steel should be evaluated in advance, and the welding of American standard steel can only be carried out after the evaluation result is qualified.

2.4 Complex structure and difficulty in making components

1) The internal structure of the steel member is complex, and there are many rigid plates. The steel tubular column and the “+” shaped rigid plate are arranged inside the round pipe column, and there are many welding contact surfaces. The box-shaped column is provided with a “+” shaped rigid plate, the minimum cross-section is 2000mm×2000mm, the welding space is narrow, and the large-diameter thick-walled round tube (the maximum cross-section is Φ2800×70), square tube members and cast steel members High precision is required.

2) The project joints are complex and large in number. Complex joints include 4 split-joints, and 16 joints that dome-like heaven embraces the vast earth. The typical complex components show as Table 1.

| Component name                        | Diagram                              | Location in structure                                                                 |
|----------------------------------------|--------------------------------------|----------------------------------------------------------------------------------------|
| Truss                                  |                                      | Mainly used for tower belt truss, outrigger truss, conversion truss                     |
| Eccentric joints of bending and torsion columns |                                      | Mainly used in the variable cross section of the outer cylinder steel column in the tower |
| Joints that dome-like heaven embraces the vast earth |                                      | Mainly used in the variable cross section of the outer cylinder steel column in the tower |
| Pillar joint                           |                                      | Mainly used in the variable cross section of the outer cylinder steel column in the tower |

(3) Construction countermeasures

1) 3D software modeling shall be used to simulate the processing sequence, a reasonable processing plan and operation instructions should be performed, and pre-arching, welding shrinkage and deformation shall be fully considered.

2) CNC plane drilling, three-dimensional CNC drilling machine and other hole-making equipment shall be adopted. In the pre-assembly process, precise pay-off shall be performed, total equipment and
other advanced equipment and measurement methods shall be used to ensure the accuracy of components.

3) There should be special staff to supervise the manufacturing in the factory, strictly monitor the production process of the components, the quality and progress of the components should be ensured, and the components should be adjusted in time according to the specific conditions on the site.

2.5 On-site construction precision control is difficult

(1) The cross-sectional size and weight of some components of the tower in this project are large, and the height of the working surface is high, which causes inconvenience to on-site installation.

(2) There are large cross-section and plate thickness of the component, the stress is reduced after welding, and there are high deformation control requirements.

(3) The tilt angle of the outer frame column of the tower is different and the bending and torsion column is tilted in both directions, which requires high measurement and control requirements. The deformation and settlement of the steel structure have a greater influence on the installation accuracy of the steel structure[7].

(4) Construction countermeasures

1) On the premise of ensuring the safe operation of the tower crane, the steel structure system and construction characteristics should be combined, the steel members should be segmented reasonably to ensure construction safety and construction period.

2) Extra-thick steel plates should be left for welding, and preheating and heat preservation methods should be used to reduce residual stress. Reasonable segmentation and welding process should be adopted to decrease welding deformation of ultra-thick steel plates of components.

3) Plane and elevation accuracy shall be strictly controlled. Steel columns should be monitored to control structural deformation.

4) The temperature in Chongqing is high in summer, and temperature deformation control is also an important aspect for measurement control.

2.6 For ultra-high-altitude operations, safety protection is particularly important

(1) When the building exceeds the specified height, there is a high safety risk when working at height.

(2) The outer frame column is a large-section steel pipe column, and the vertical stiffening plates inside the column need to be welded on site to ensure good ventilation on site, ensure the safety of the operator, and do not affect the welding quality, which is a major difficulty in site construction.

(3) The tower below the 17th floor and the podium need to be operated in advance, and the construction of the upper steel structure has a great impact on its safe use.

(4) Construction countermeasures

1) Special safety protection measures should be formulated and safety protection measures should be deepened for construction on the sidelines.

2) The safety supervision and management of high-altitude operations should be strengthened, safety patrols and safety construction side station management shall be added to construction operations with high safety risks, and hidden dangers shall be dealt with in time.

3) The steel structure yard and safety protection measures shall be reasonably arranged before construction to ensure the safety of early operation.

2.7 Complex construction of multi-specialty cross construction

(1) The steel structure construction and other major constructions are carried out at the same time on the plane and the facade. Affected by many factors such as civil construction top formwork and the characteristics of the steel structure, steel structure construction cannot be carried out separately from other professions on the facade, which will inevitably cause the working surface to be jointly occupied, and even the work will be constrained by civil engineering-related work, multiple professionals perform construction at the same time, there will be complex organization.

(2) Construction countermeasures
1) The steel structure construction deployment should be implemented according to the overall construction deployment and adjusted in time.

2) Close contact with other majors should be kept, and for specialty construction, special personnel shall be sent to contact and communicate to formulate the site plan of each stage of the steel structure construction, so that the process overlap can be reasonable and the construction procedure can be smooth.

3. Conclusion
The steel structures in super high-rise buildings has become the mainstream. Only by continuously summarizing, researching and innovating the installation technology of super high-rise steel structures can progress and accumulate experience for faster and better super high-rise steel structure installation be made in the future.

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