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Research on Key Technology of Steel Structure Construction of Hytera Global Headquarters Building

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Abstract With a height of 211.080m, Hytera Global Headquarters adopts eccentric double-angle cylinder + oblique grid structure. The tower and podium floors F3~7 are equipped with multiple large-span trusses and large suspension trusses. The intersection of oblique grid and concrete core barrel floors F11~45 are suspended structures.There are some difficulties in the construction process, such as complicated construction process, complicated force transmission path, cross construction of concrete and steel structure, high installation accuracy requirement, temporary support measures need to be set up before the oblique mesh and suspension structure form a stable force system during construction.In view of the above difficulties, the key technologies of the construction of the complex super high-rise suspended + oblique grid structure are studied, including the overall construction process, tower crane layout and selection, temporary support system design, unloading sequence comparison analysis, fine construction simulation analysis, structural predeformation technology, floor crack control technology, etc., which effectively ensures the installation accuracy and structural safety of the steel structure. It can provide reference for similar projects.

Keywords Steel structure,Oblique grid,Suspension structure,Construction simulation analysis

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1. Introduction

Oblique grid is a structure form of diamond-shaped cylinder with diagonal supports crossing each other. The diagonal columns bear both vertical and horizontal loads at the same time, which provides greater lateral stiffness for the cylinder instead of the traditional form of vertical columns with diagonal supports (Liu et al. 2020).As a complex new structural system, there are great differences in installation technology and stress deformation, and it has been widely used in super high-rise buildings in recent years (Liu and Fang 2022).

Suspension structure refers to a new type of structure in which floor beams and other sub-structures are suspended in the main structure through the suspension rod, which has strong artistic expression (Vosloo 2020). However, a complete force system can only be formed when it is connected with the main suspension system. This feature makes the structural force and deformation of the structure in the process of construction in a large dynamic change. Compared with the structure operation and use stage, there is a big difference (Shi et al. 2017).

However, the supertall suspended + oblique grid structure, which integrates the above two structural forms, has more complex structural system forces. The complete stress system is formed after the main structure and the suspended structure are connected, and the installation process is quite different from that of the traditional frame structure. During the construction process, the stress state of the structure is constantly changing, and there may be tension and compression conversion of internal forces, which makes the construction more difficult.At present, studies on high-rise oblique grid structures mainly focus on design criteria (Montuori et al 2015), static performance (Fang and Liu 2021, Chen et al 2021), lateral stiffness (Liu and Ma 2017), robustness (Mahyar 2023), seismic performance (Liu and Fang 2022), etc. Studies on suspension structures mainly focus on wind performance (Akshat and Hussam 2017), seismic performance and vibration control (Zhang and Wang 2019), construction simulation and monitoring (Shi et al 2017, Sun et al 2016), etc. However, there are few researches on its construction method, process crossing of concrete and steel structure, structural predeformation, floor crack control and so on.

In addition, for long-span suspension and suspension steel structures, the construction process is complicated, the construction period is long, and the structural system is in dynamic change. Before the system is formed,

temporary support system is required to provide additional constraints (Xu et al 2021).Unloading is the process of removing the temporary support system after the structure is installed and welded and forming the structural system, removing the additional constraints and transforming the structure into the design state (Shao et al 2010).As for the unloading sequence, it is necessary to fully consider whether the strength and stability of the temporary support system before and during unloading meet the requirements; Whether the structure deformation is coordinated during unloading, whether the local deformation is too large, and whether the bar meets the requirements during the process of internal force redistribution; Whether the shape state of the structure is consistent with the design after unloading is completed (Wang et al. 2017, Zhao et al 2016, Pan et al 2022).

Therefore, this paper takes the complex super high-rise suspended + oblique grid structure of Hytera Global Headquarters building project as an example to study its key construction technologies, so as to provide reference for the construction of similar projects.



Figure 1. Architectural rendering of Hytera Global Headquarters.

2. Projrct Profile

Located in Nanshan District, Shenzhen, the Global Headquarters building is 119.5 m long from north to south and 50 m wide from east to west. It has a total construction area of 114800m2 with 4 floors underground and 45 floors above ground. The building height is 211.080 m. The tower is located on the south side, and the north side is connected to the 5-storey commercial podium, which is about 32 m high, as shown in Figure 1.

3. Structural Profile

The tower of this project adopts the oblique grid steel tube-reinforced concrete unilateral double-angle tube structure system, and the skirt is the core tube-steel frame structure system, mainly made of Q390GJ and Q355B.The plane dimensions of the tower's double core tubes are 14.3 m × 13.8 m, which are composed of concrete filled steel tube column + reinforced concrete shear wall + steel beam on the floor. The section and wall thickness of steel column and shear wall gradually decrease from bottom to top. The oblique mesh steel cylinder has a plane size of 42 m × 20 m and consists of 22 inclined columns and 6 concrete-filled steel tube columns. Floor steel beams are arranged in the steel cylinder. The maximum cross section of the inclined column is B850X850X100, and the maximum cross section of the concrete-filled steel tube column is B1200X850X50.

As shown in Figure 2, the structure is vertically equipped with 3 truss layers, F3~7 layer is the first truss layer. The suspension structure consists of 4 longitudinal trusses and 5 transverse trusses, with a maximum suspension length of 13.5 m and a maximum span of 36 m. In addition, F11~15 floors and F41~45 floors are the second and third truss layers, respectively, which are composed of two transverse suspension trusses and two longitudinal edge sealing trusses. There are suspended structures between the truss layers, with a maximum suspension of 13.5 m.

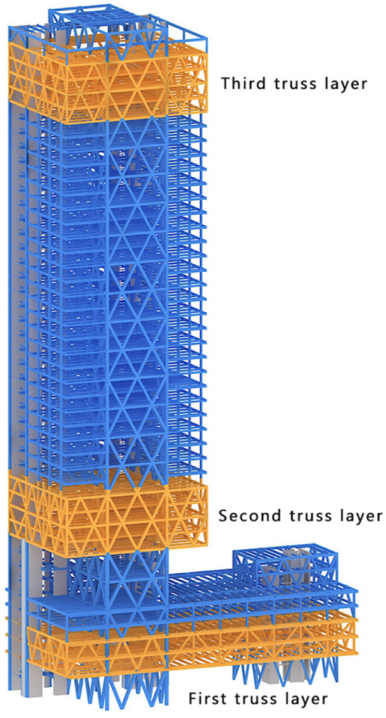


Figure 2. Axial side diagram of the overall structure

4. The Important and Difficult Points of Construction

4.1. Determination of Construction Sequence of Steel Structure

The structure of this project is novel, combining oblique grid structure, large suspension truss and suspension structure. The tower adopts double reinforced concrete core tube and eccentric arrangement, the diamond oblique grid steel tube and the double core tube are orthogonal and embedded between the double core tube. The F3~7 floors are large suspension structure system, and the intersection of the tower oblique grid and concrete core tube F11~45 floors are suspended structure. Therefore, the construction process of the core tube, suspension and suspension structure system and the determination of the floor pouring time are the primary important and difficult points of this project.

4.2. Temporary Support system Design

There are trusses, suspension structures and suspension structures in this project, and temporary supports need to be installed in situ. Due to the large weight of its components, the bearing capacity of the temporary support system is put forward higher requirements. In addition, there are complex supporting conditions such as drop plate, after-pouring belt and automobile ramp in the bottom structure, and the influence of structural internal force redistribution on the support tire frame during unloading should be taken into account. Therefore, the design of temporary support system should not only meet the requirements of strength, stiffness and stability, but also have good controllability. Therefore, the design of temporary support tire frame is another difficulty of this project.

4.3. Unloading Sequence of Temporary Support System

The total amount of steel used in the 3-7 layer structure of this project is 2500t, and 12 temporary support tire frames are arranged in this area. The reaction force of tire frames is large, and the maximum reaction force is close to 850 kN, and the support reaction force changes greatly during unloading. The structure truss is staggered and the stress mode is complicated. Before the structure is formed, the core cylinder, the frame (inclined) column and the temporary support system bear the self-weight. After unloading, the internal force redistribution of the structural members is changed to the design state. Therefore, the unloading sequence has a great influence on the forming of the structure, the internal force distribution of the rod and the load borne by the tire frame. To determine a reasonable and safe unloading sequence, to ensure that the internal force of the structural member does not change too much during the unloading process, to avoid the failure of the member, to ensure that the force transfer path and forming attitude of the structure are consistent with the design state, and to ensure the safety of the structure is the key and difficult point of unloading.

4.4. Steel Structure Installation Precision Control

The tower and podium of this project have a large number of inclined columns, multi-directional leg joints and 3 truss layers, which have high requirements for installation accuracy. Its installation accuracy directly affects the state of the structure forming and the subsequent processes such as the installation of the curtain wall structure, so how to ensure the installation accuracy of the steel structure is one of the important and difficult points of the project.

5. Key Construction Technologies

5.1. Total Construction Procedure

According to the structural characteristics of the project, three construction areas are divided into core tube (zone 1), oblique grid (zone 2) and suspension structure (zone 3), as shown in Figure 3.

Due to the small size of the tower core tube and the eccentric arrangement on both sides of the oblique grid, the out-of-plane stiffness is weak. Oblique mesh steel cylinder has a great contribution to the overall Y-direction (long axis direction of oblique mesh steel cylinder) stiffness of the tower. At the same time, the two boom tower cranes in this project are externally hung on the weak axis side of the ① zone of the tower, so the ① and ② zone of the tower are arranged for flat construction. The concrete shear wall of the next layer of the core tube is constructed while the steel column and steel beam of the core tube are installed. The suspension structure of the zone (3) is about 4 stories behind that of the zone (1) and (2) to reduce the conflict between the floor beam and the

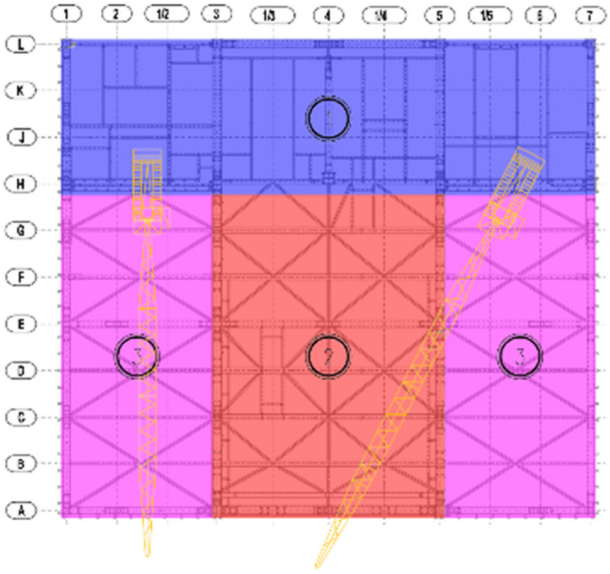


Figure 3. Steel structure construction zoning diagram.

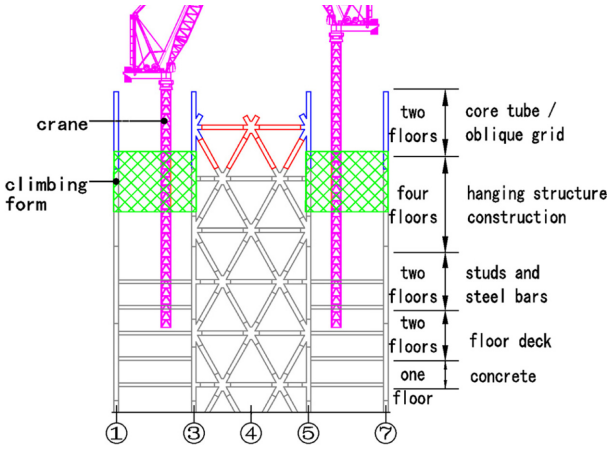


Figure 4. Elevation process diagram.

tower crane, and some steel beams are to be installed after the tower crane climbs. The process of tower facade is shown in Figure 4.

5.2. Tower Crane Layout and Selection

In this project, the diagonal grid and truss members have large sections, so the modular unit hoisting is considered, and the weight of the hoisting unit is about 15~30t. If the tower crane is arranged on the east and west sides of the oblique grid, the performance of the tower crane can be maximized. However, the distance between the nodes of the east-west oblique grid is 8.4m, and the span is too large to be suitable for tower crane attachment. If the floor climbing tower crane is used, the tower crane foundation needs to be added, and the construction conditions are not available. Considering that the two core tubes are small in size and located on the north side, if the tower crane is arranged inside the core barrel, the model of the tower crane needs to be increased. At the same time, due to the limitation of the construction site and horizontal traffic, two ZSL850 tower cranes are finally selected, respectively attached to the shear wall on the south side of the two core tubes. The tower crane layout is shown in Figure 5.

5.3. Design of Complex Temporary Support Systems

There are both large-span trusses and cantilever trusses in the first truss layer of this project. The construction scheme of segmented hoisting is adopted, and a total of 12 temporary support tire frames are set at the end of the cantilever truss and 1/3 of the span of the long-span truss.

The whole structure is installed to the first truss layer of F7 to form a stable system, which can be unloaded. The second truss level provides four lattice temporary support tire frames at the overhanging end. Considering that the support system falls on the first truss layer, in order to avoid excessive load on the first truss layer and the tire frame, F11~15 layers should be unloaded immediately after installation. The third truss layer is located at the top of the tower with a supporting height of only 4.5 m, so four round pipe supports are set at the cantilever end and can be unloaded after installation, welding and acceptance. The temporary support arrangement is shown in Figure 6.

5.4. Comparative Analysis of Unloading Sequence of Temporary Support System

The temporary support will bear a large load before the removal, and the removal of the temporary support will cause the internal force mutation of the structure. If the disassembly method is not proper, it will have a great impact on the final forming state of the structure.

To solve the unloading problem of the temporary support tire frame of the first truss layer, three unloading schemes are proposed (Figure 7): Scheme one is the east-west symmetrical unloading scheme; Scheme 2 is the

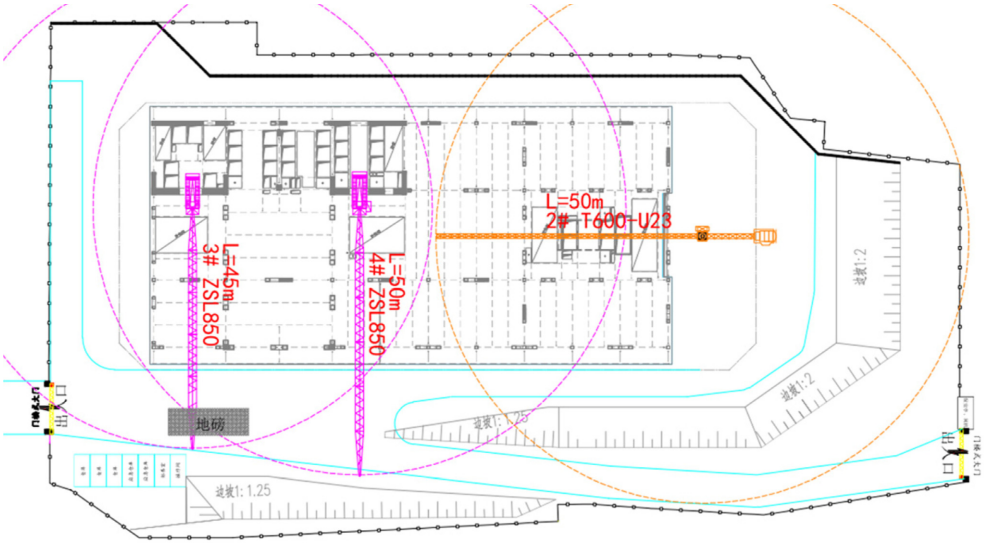
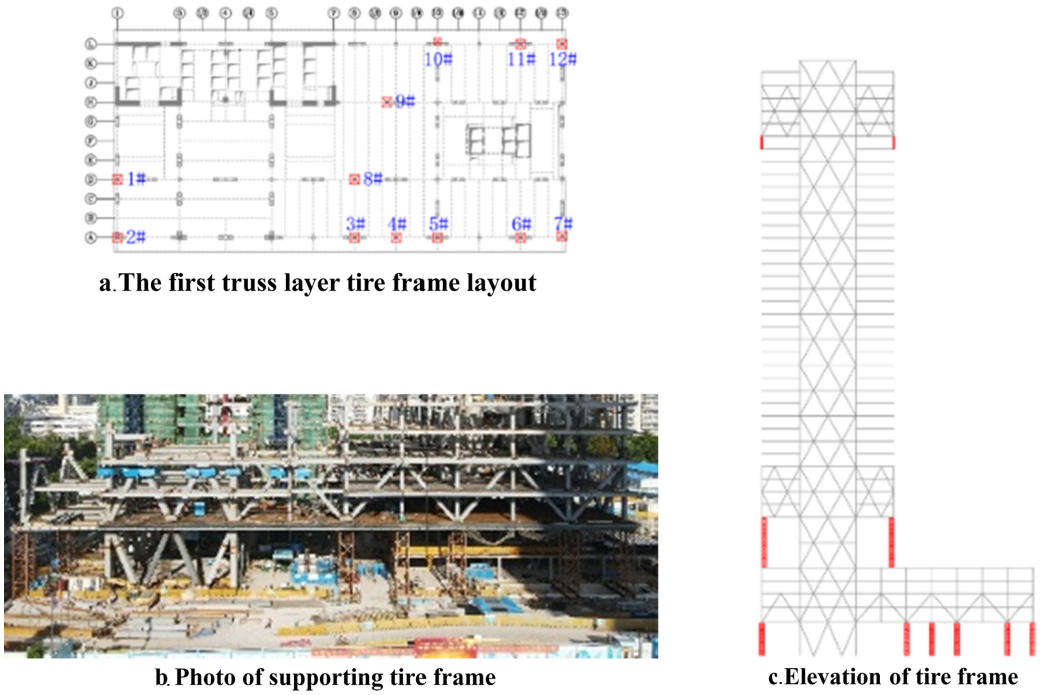


Figure 5. Tower crane layout plan.



a.The first truss layer tire frame layout

b. Photo of supporting tire frame

c.Elevation of tire frame

Figure 6. Layout of temporary support tire frame.

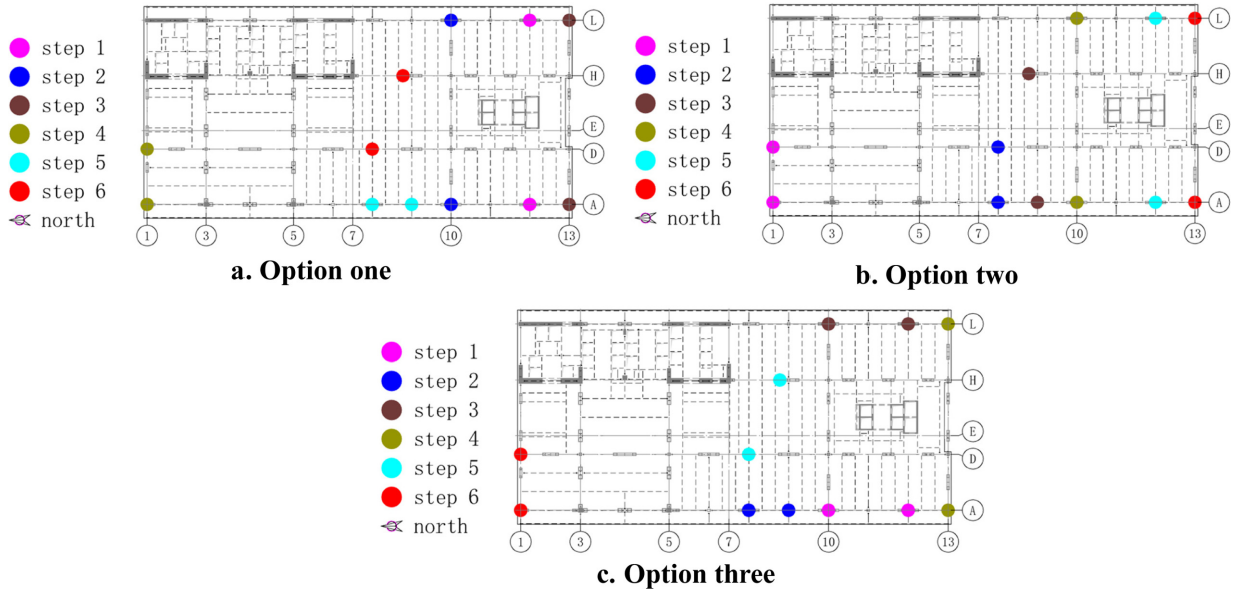
unloading sequence from south to north; Plan three is the sequence from east to west.

According to the construction drawing and the layout of the tire frame, a fine model of the main structure and temporary supporting tire frame of layers 1 to 11 was established. According to the above three unloading schemes, the unloading process was simulated and analyzed. The unloading simulation analysis model was shown in Figure 8.

Table 1 shows the peak reaction force of the support points of each tire frame during the dismantling process. It can be seen from Table 1:

(1) From the perspective of the maximum vertical reaction in the unloading process, the maximum vertical reaction of Scheme 1, Scheme 2 and Scheme 3 is 851.9 kN, 954.8 kN and 777.2 kN respectively. The maximum vertical reaction of Scheme 2 is the largest, followed by Scheme 1 and Scheme 3 is the smalles.

(2) From the point of view of the change of tire frame reaction before and after unloading, the maximum change



a. Option one

b. Option two

c. Option three

Figure 7. Sequence of unbracing of three schemes.

Table 1. Comparison of peak reaction force of support points during unloading

Frame number	Support reaction peak during unloading （kN）			
	before unload	Option one	Option two	Option three
1#	541.4	541.4	541.4	541.4
2#	486.5	486.5	486.5	486.5
3#	675.3	714.1	675.3	728.5
4#	683.8	751.7	683.8	773.5
5#	372.5	391.1	373.1	384.0
6#	577.1	711.9	715.4	750.6
7#	765.7	851.9	765.7	765.7
8#	723.6	796.5	954.8	723.6
9#	777.2	777.2	829.8	777.2
10#	738.8	738.8	897	738.8
11#	435.9	591.4	573.4	573.0
12#	405.0	541.0	562.8	630.6

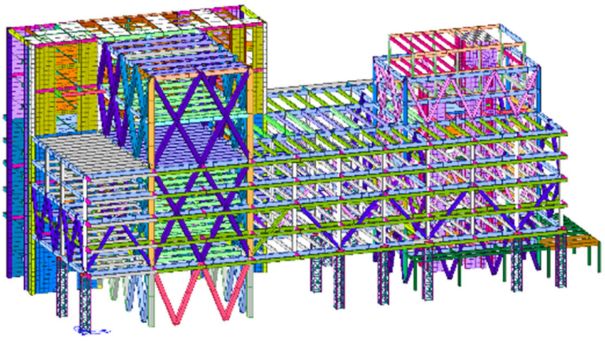


Figure 8. Unload simulation analysis model.

of reaction of Plan 1, Plan 2 and Plan 3 is 155.5 kN, 233.6 kN and 225.6 kN respectively, indicating that for each support tire frame, the vertical reaction of the tire frame obtained by plan 1 is the least and more stable.

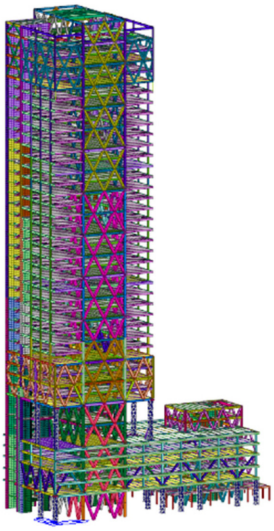
By comprehensive comparison of the calculation results of the three schemes, such as the forming state of the main structure, the change of equivalent stress of the member during unloading, the change of vertical displacement and the change of vertical reaction of the support point are more stable than that of the two schemes and the three schemes. The stress of the main structure during unloading is far less than the design strength, which meets the specification requirements. The main structure is in a safe stress state. Therefore, this project adopts the sequence of scheme 1 to unload the support tire frame.

5.5. Fine construction simulation analysis

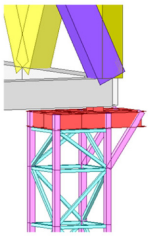
In this project, midas Gen was used to establish the construction finite element model. The analysis and

Table 2. Overall structure construction steps

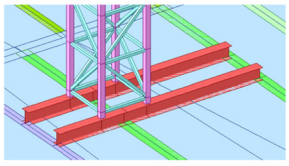
Serial Number	Construction procedure
CS1	7 layers of core cylinder and oblique mesh were installed, and the podium and the steel structure of the first truss layer were completed.
CS2	First truss level unloaded
CS3	Core cylinder and oblique mesh installed to level 10
CS4	Core cylinder and oblique mesh are installed to the 15th floor; The suspension structure is installed to the 12th floor
CS5	The core cylinder and oblique mesh are installed to the 17th floor; Suspension structure installed to 15th floor (second truss level installed completed)
CS6	Second truss level unloaded
CS7-12	From the bottom up, the core tube and oblique mesh are installed on floors 17-45, and the suspension structure is installed on floors 15-42
CS13	Suspension structure installed to 45th floor
CS14-16	The third truss layer is unloaded, the main structure floor pouring is completed, and the after-pouring plate pouring is completed



a.Overall model



b.Computational model details 1



c.Computational model details 2

Figure. 9 Whole process construction simulation analysis model of the overall structure.

calculation model was modeled according to the design drawings, considering the unloading process of the temporary support system, the attached load of the tower crane, the order of floor pouring and the post-pouring area, and the detailed modeling was carried out according to the specific structural form and arrangement of the scaffolding in actual construction. The simulation analysis and calculation were carried out together with the overall structural model, and the construction phase was defined according to the steps in Table 1. Oblique mesh, frame columns, trusses, frame beams and temporary support vertical rods all use beam elements, temporary support ribs use truss elements, shear walls are wall elements, floor slabs are plate elements, and column bottom constraints are set as rigid joints. The construction simulation and analysis calculation model is shown in Figure 9.

As can be seen from the results of construction simulation analysis in Table 3:

(1) The maximum vertical displacement of the completed structure is –39.7 mm, and the maximum vertical displacement of the primary form is –63.7 mm. The vertical displacement of the completed construction state increases first and then decreases from the low floor to the high floor, and the maximum vertical displacement occurs at 27F in the middle, which is the result of taking into account the leveling to the design elevation during layered construction. The maximum cumulative vertical deformation occurs in the overhanging area of the middle layer of the structure. However, the vertical displacement of the primary form increases along the floor, because the load is loaded at one time instead of in stages, and the leveling of the construction process is not considered, which makes it different from the result of considering the construction process. For high-rise building structure, considering the accumulation of construction process and the impact of layer by layer leveling is closer to the actual construction state.

(2) The maximum horizontal displacement of the completed structure is –54.7 mm, and the maximum horizontal displacement of the primary form is –101.6 mm. The maximum horizontal displacement occurs in the roof layer, and there is a large difference between the two, which is the result of the correction to the design coordinate during the layered construction.

(3) The maximum equivalent stress of the completed construction state is 108.5 MPa, and the maximum equivalent stress of the primary forming state is 116.7 MPa, which is relatively close and the distribution trend is basically the same. The stress of the structural members in the construction

Table 3. Comparison of construction simulation analysis results

Project	Construction completed state	Single form condition
Maximum vertical displacement	–39.7 mm	–63.7 mm
Maximum vertical displacement floor	27F	ROOF
Maximum horizontal displacement	–54.7 mm	–101.6 mm
Maximum horizontal displacement floor	ROOF	ROOF
Maximum equivalent stress	108.5 MPa	116.7 MPa

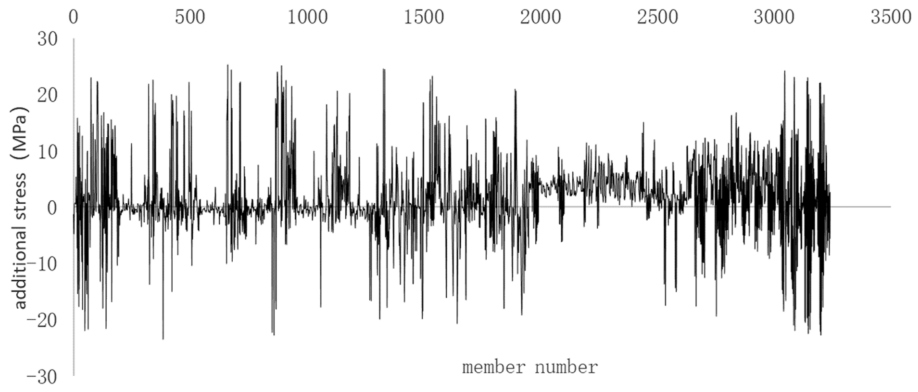


Figure 10. Additional stress of main components.

process does not exceed the design strength, and is in a safe state.

By comparing the completed construction state with the primary forming state, the stress difference of the main components of the three-way truss layer steel column, truss and oblique mesh is calculated to the additional stress as shown in Figure 10. The maximum value is 24.8 MPa, and most of the difference value is less than 10MPa, indicating that the construction process adopted has little influence on the structure, and the stress state of the structure is basically consistent with the design.

5.6. Analysis of construction monitoring results

The temporary support system shall be dismantled according to the dismantling sequence of Scheme 1 and the site construction situation. Measuring points are arranged on the lower chord members of the truss corresponding to the key points before the dismantling, and deformation monitoring is carried out during the dismantling process to ensure the structural safety during the dismantling process. The key point arrangement is shown in Figure 11, and the data of each key point is compared and analyzed with the data of the dismantling construction simulation in Figure 12. As can be seen from Figure 12:

(1) The measured deformation values of each measuring point are small, the overall deformation trend is basically the same, and the structural deformation

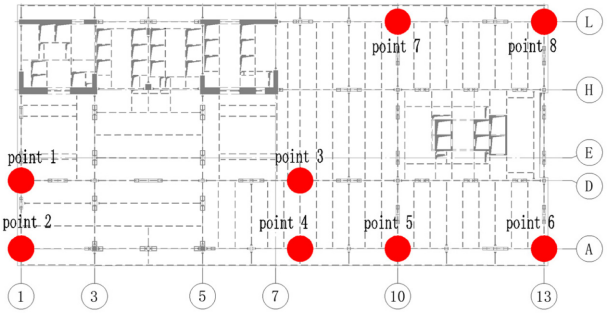


Figure 11. Layout of key measuring points.

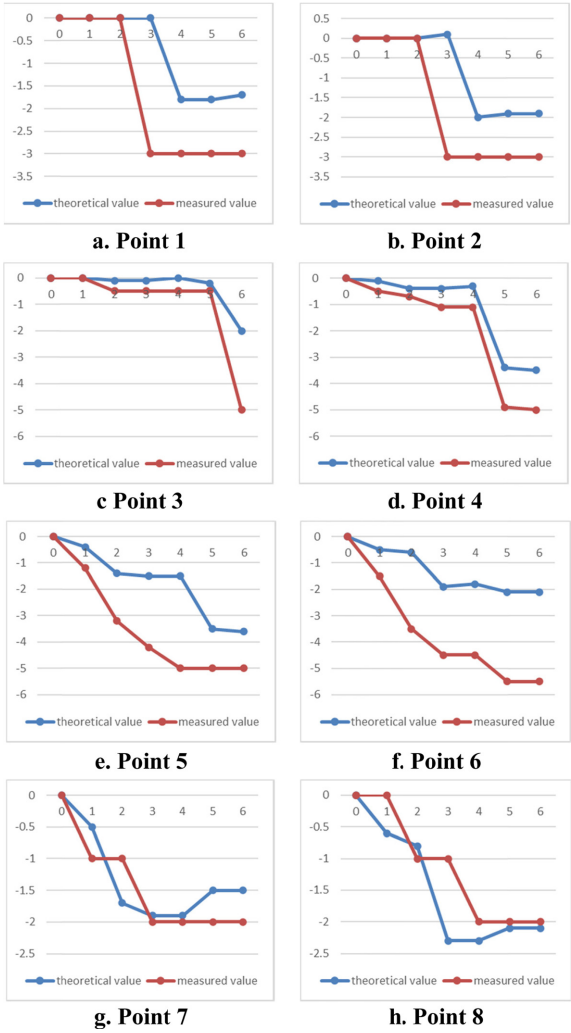
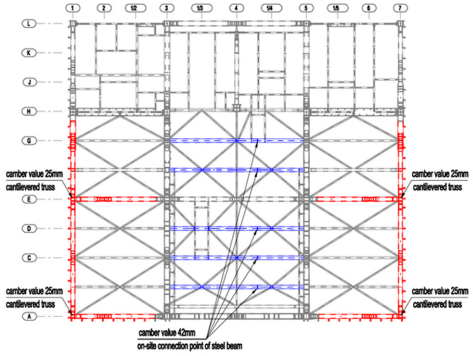


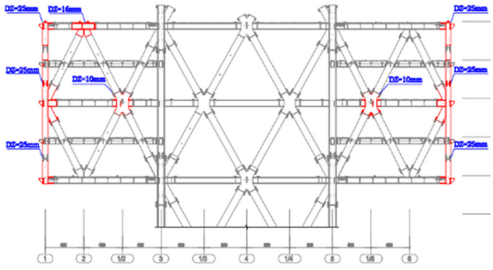
Figure 12. Comparison between monitoring data and simulation data.

during the dismantling process is relatively mild, indicating that the dismantling sequence is reasonable, and the construction simulation results are basically consistent with the actual.

(2) Key points 1, 2 The actual construction of the site



a. Layout of the prearch values for the 15th floor



b. Distribution of arch value of cantilever truss

Figure 13. Pre-deformation measures of cantilever truss.

is unloaded one stage ahead of time, so the inflection point of the measured value curve is inconsistent with the theoretical value.

(3) Compared with the results of construction simulation, the measured value is generally larger, which is due to the fact that the floor slab laying and reinforcement binding before the structure unloading in actual construction, coupled with the steel structure installation deviation, structural settlement and other factors, resulting in a certain deviation between the measured value and the theoretical value.

5.7. Structure predeformation technology

According to the construction simulation analysis of the whole structure, the difference value of the deformation between the completed construction state and the designed primary form of each component of the truss, long-span steel beam and suspension structure is obtained. The actual deformation value of the structure is obtained by combining the vertical deformation of the temporary support. The corresponding component is pre-deformed in the deepening stage. Pre-deformation of long-span steel beams can be realized by multi-point camber during member processing. The truss achieves structural predeformation by adjusting the vertical component Z-elevation, as shown in Figure 13. In the deepening stage, the factory length and port shape of each component are corrected, and the bolt hole position is adjusted to improve the installation accuracy of on-site components and avoid

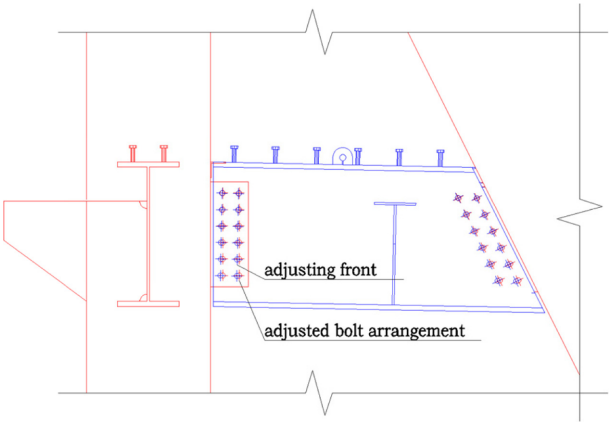


Figure 14. Schematic diagram of adjusting the hole position of the interface bolt of the predeformed member.

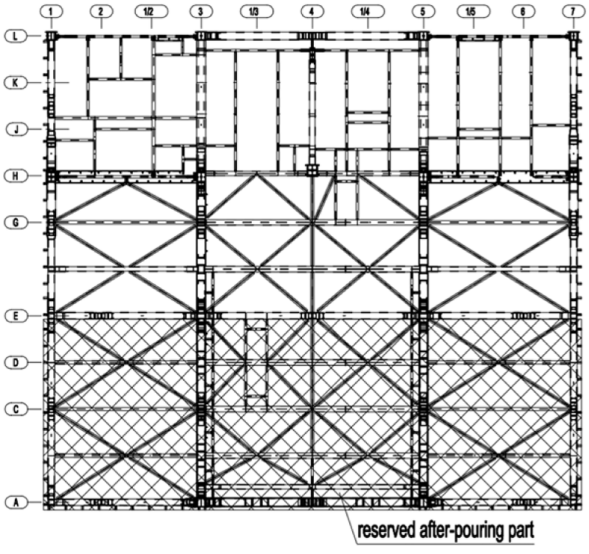


Figure. 15 Layout plan of the after-pouring area of the tower.

reaming and flame cutting of components caused by dislocation of bolt holes and misopenings of components, as shown in Figure 14.

5.8. Control technology of floor cracks

The tower floors are poured in the order of ①→②→③ zones. F3~7 layers and F11~15 layers are truss layers. With the construction of the structure, the load and vertical deformation of the truss layer gradually increase. If the floor is poured with the construction of the structure, the truss floor will produce a large negative bending moment and deformation, which will cause the cracking of the floor. In order to prevent excessive additional stress on the floor after the completion of construction, the position with large bending moment on the 3/5/7/11/13/15 floor is set as the post-pouring area, which will be poured after the structure is capped. The placement of the after-pouring area is shown in Figure 15.

6. Conclusions

Taking Hytera Global Headquarters building as an example, this paper conducts corresponding research on the key technologies of complex super high-rise suspension & oblique grid structure construction, and draws the following conclusions:

(1) Based on the characteristics of the super high-rise suspended + oblique grid structure system, plan the plane partition of the core cylinder, oblique grid cylinder, suspension structure and apron, plan the split-level relationship of facade construction, ensure the safety of the steel structure construction process, and form flow construction to shorten the construction period.

(2) The whole fine calculation model is established, and the simulation analysis is carried out according to the actual construction technology, which effectively verifies the feasibility of the construction scheme and ensures the safety of the main structure construction process.

(3) According to the calculation and analysis of the whole construction process and the deformation value of the temporary support tire frame, and combined with the design requirements, the specific plan of pre-deformation is formulated and the area of the floor after pouring is determined to ensure that the completion status of the structure construction is consistent with the design drawings.

(4) Through the construction simulation of the three dismantling schemes, the change of stress of the main structure, the vertical displacement of key points and the change of reaction force of support points are comprehensively compared, and scheme 1 is finally adopted: according to the principle of east-west symmetry, the supporting tire frame of the cantilever truss of the podium is first unloaded, and then the supporting tire frame of the cantilever truss of the tower is unloaded, and the supporting tire frame between the podium and the tower is finally unloaded;

(5) After unloading the podium, the maximum stress at the measuring point increases by 12.6 MPa, and the maximum vertical displacement does not exceed 6mm, which is basically consistent with the theoretical value of construction simulation, and the construction stage is in a safe and controllable state. The depropping sequence is reasonable and feasible, effectively ensuring the security of the depropping process.

In summary, the proposed key construction technologies effectively ensure the installation accuracy and structural safety of steel structures, and can provide reference for similar projects.

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