International Journal of High-Rise Buildings
www.ctbuh-korea.org/ijhrb/index.php

International Journal of High-Rise Buildings
June 2022, Vol 11, No 2, 103-114
https://doi.org/10.21022/IJHRB.2022.11.2.103

Design and Application of Self-Lifting & Slewing Multi-Cranes Platform

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Abstract Tower crane is of great importance in the construction of high rise buildings. A self-lifting & slewing multi-cranes platform (referred to as crane slewing platform) was developed to optimize the configuration of tower cranes, as well as solve the problems of cooperative operation conflict between multiple cranes and other construction equipment and their respective climbing and occupying of construction period. The design and test of the slewing platform was introduced. By applying the slewing platform in the construction of Chengdu Greenland Center super high rise building project, some key technologies such as the configuration of cranes, the installation, construction and lifting of the slewing platform are implemented and validated. Up to now, the slewing platform has been safely lifted up 98 times in Chengdu Greenland Center project construction, and achieved good social and economic benefits.

Keywords High Rise Building, Tower Cranes Configuration, Slewing Platform, Integrally Lifting, Building Automation

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1. Instruction

Because of the advantages of good mechanical performance and internal space flexibility, giant column frame - core tube structure was widely used by global high rise buildings. As the rising of buildings heights, the sizes and weights of the giant columns increased greatly. Several large-scale movable arm tower cranes were needed to hoist these giant columns during construction.

However, the few giant columns cost 5% of overall hoist times. Lots of light weight structural parts were hoisted by large-scale tower crane in low efficiency. And every crane climbs independently, which cost lots of time.

To solve the problems above, a crane slewing platform was developed and successfully applied in the construction of Chengdu Greenland Center super high rise building project (see Fig. 1).

2. Design of crane slewing platform

2.1 Introduction of crane slewing platform

The crane slewing platform consists of support and power system, slewing driving system, steel frame and monitoring system. The steel frame allows sever tower cranes mounting on it, and rotates in 360 degree. Mutt-cranes shares the steel frame and climbs synchronously. The support and power system employ micro-convex fulcrum to reduce the using of embedded structure parts. The structure and consist were showed in Figure 2.

2.2 Design of various system

2.2.1 Design of steel frame

The steel frame employ space truss structure, which consist of center truss, single chip truss and crane base. The center truss is mounted on the top of slewing driving system. The crane base were mounted at the end of single chip truss.

The central truss is a lattice column structure, and the main structure of the sheet truss is two cross trusses, which are integrated with the central truss as the main bearing frame.In addition, the torsion action of the tower crane perpendicular to the main truss is considered under extreme working conditions. Two secondary trusses connect the ends of the main truss to resist the torsional torque of the tower crane on the main truss under extreme working conditions. Small section bars are used to connect the main and secondary trusses to enhance the integrity of the crane steel frame and improve the stability of the main and secondary trusses. The platform plane is composed of two relative triangles x structure, when the platform is stationary, half of the plane space can be set aside for crane hoisting. Plane layout of crane base is shown in



Figure 1. Crane slewing platform applied in Chengdu Greenland project.

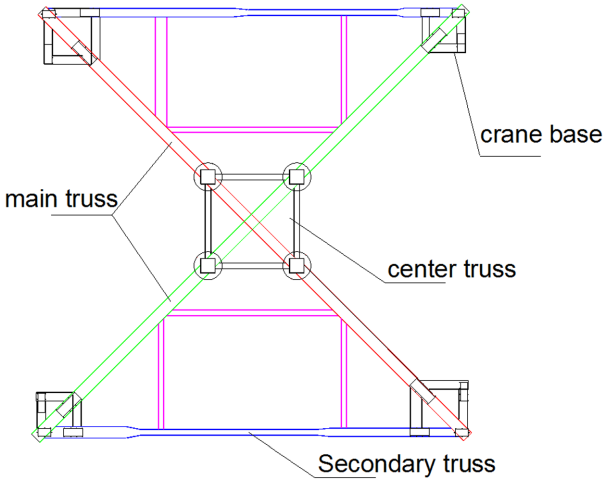


Figure 3. Layout plan of steel frame.

Figure 3:

The crane bases make full use of the stability of the angle between the main truss and the secondary truss and are arranged at the end of the sheet truss. In this way, the hoisting radius of the crane can be used to the maximum extent, and the external size of the platform can be adjusted according to the structural plane of the project to avoid the influence of the crane on the hoisting area. The number and model of cranes can be selected based on hoisting requirements.

Crane conversion sections are designed to connect the cranes and the steel frame. When the cranes configuration is adjusted according to project requirements, new configuration can be implemented by replacing the crane conversion sections. The crane base is shown in Figure 4.

2.2.2 Design of slewing driving system

Slewing bearing and automatic hydraulic driving

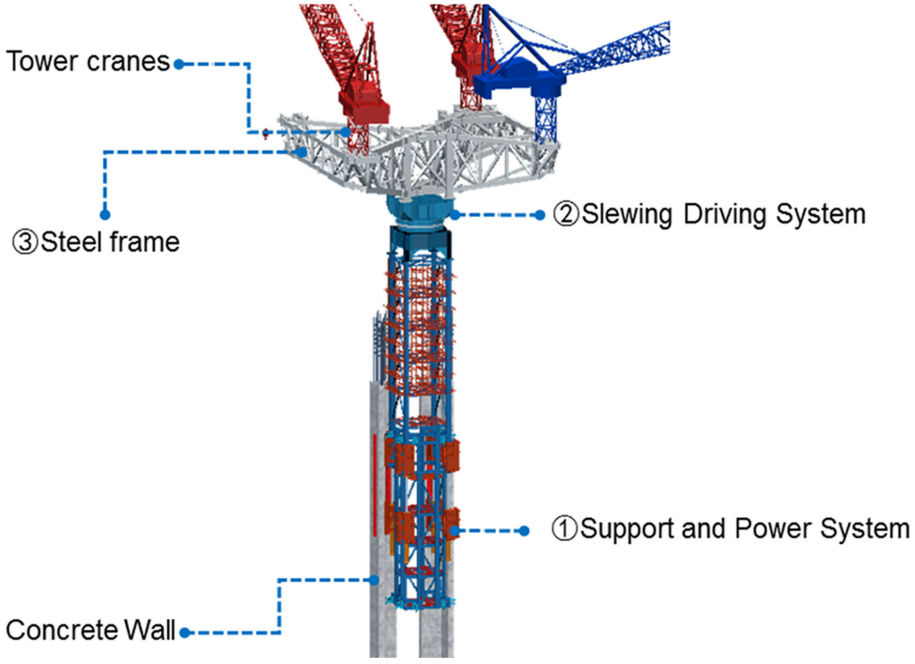


Figure 2. Composition of crane slewing platform.



Figure 4. Crane base

technology were used to realize any rotation angle of the platform.

The slewing driving system consist of upper joint, slewing bearing, lower joint and hydraulic driving system, having the advantages of high load-bearing capacity and safety (see Fig. 5).

Two slewing driving units were mounted straightly inside the upper joint, the external gear match up with the internal gear of the slewing bearing. The steel frame can be rotated by applying driving forces to the external gears of slewing driving units.

The design rotating peried each lap of the platform is 15 minutes, which controlled by PLC(Programmed Logical Controller), along with the direction of rotation, angle and velocity.

2.2.3 Design of support and power system

The support and power system is consist of several fulcrums attached to the wall, hydraulic lifting system, supporting pillar and overturn-preventing system. The fulcrums transmit all the weights and loads of the platform to the concrete wall. The hydraulic lifting system consist of several hydraulic lifting cylinders, pump station and electric control system, which provide power and controlled displacement to lift the platform. The overturn-preventing system can balance the overturning force of the platform by using several overturn-preventing units (see Fig. 7).

The single fulcrum attached to the wall consist of micro-convex fulcrum, upper supporting frame and lower supporting frame. The upper supporting frame hanged up by the micro-convex fulcrum of upper story wall while the lower supporting frame hanged up by the micro-convex fulcrum of lower story wall. The single micro-convex fulcrum consist of bearing part, backboard, pull rod and concrete micro-convex. The series of micro-convex fulcrums of adjoining story walls formed the track for lifting platform. By stretch out and draw back of the hydraulic lifting cylinders between each upper supporting frame and lower supporting frame, the platform can be lifted up to an upper story.

The overturn-preventing system set two layers of overturn-preventing units, mounting to the middle and the bottom of the supporting pillar. Each overturn-preventing unit contains a self-locking cylinder and a cylinder with scroll wheel, providing overturn resisting force in static and dynamic situations respectively.



Figure 5. Slewing bearing.

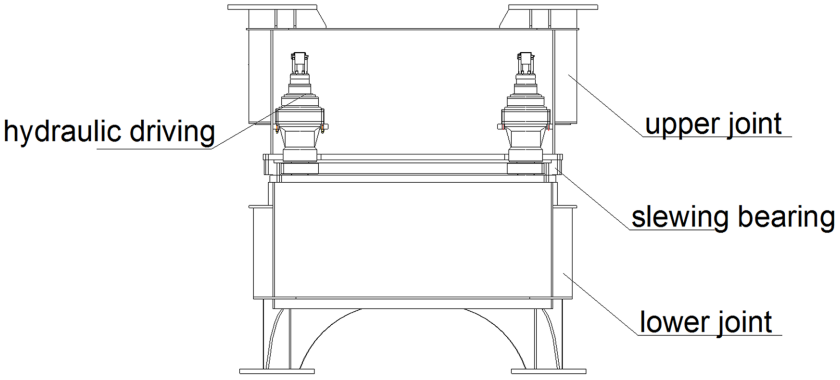


Figure 6. Schematic diagram of slewing driving system.

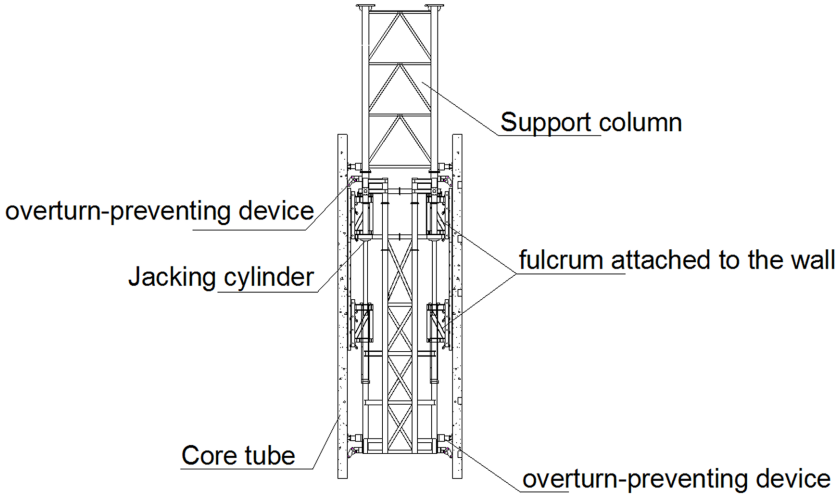


Figure 7. Elevation diagram of supporting and power system.

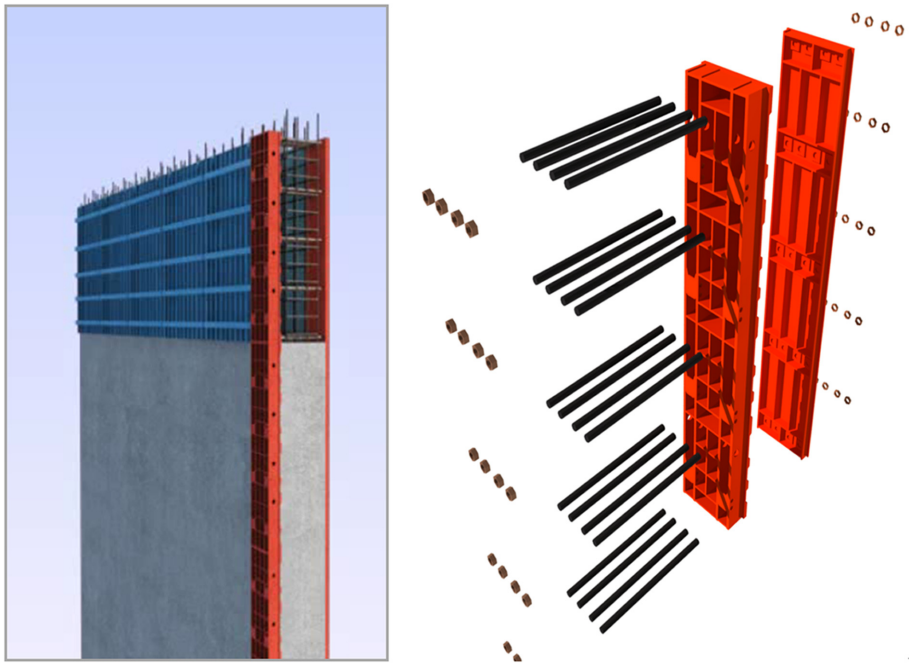


Figure 8. Structural diagram of micro convex fulcrum.

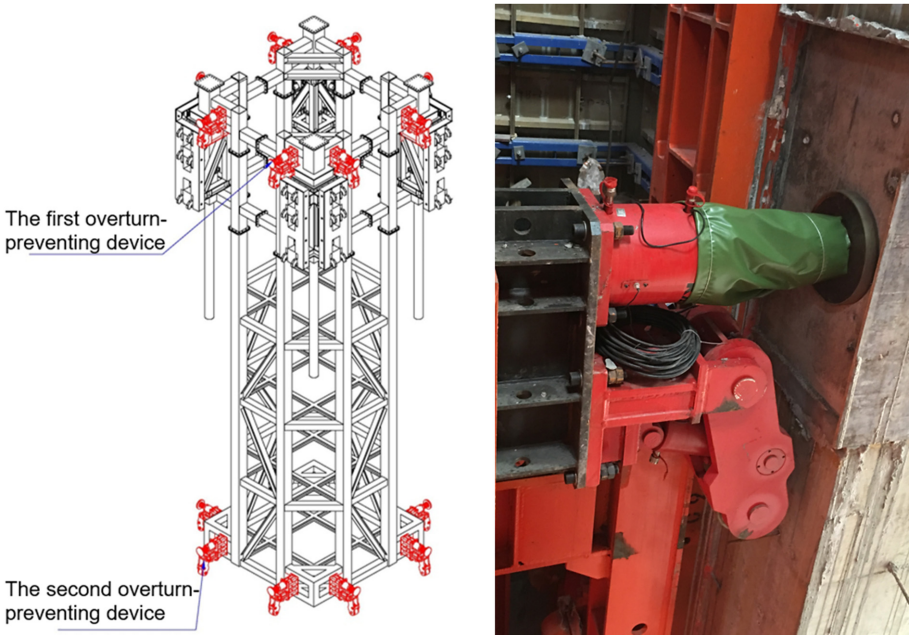


Figure 9. Schematic diagram of overturn-preventing device.

2.2.4 Monitoring system

Key information were measured and monitored by the monitoring system, including movement situations, wind speed, stress-strain, levelness and perpendicularity of platform.

Smart cameras were used to observe the working conditions of the support and power system as well as the fulcrums attached to the wall.

Stress and strain sensors were used in the area of stress concentration of steel structure. Hydrostatic leveling sensors were arranged at the center of platform and bases of each crane. Verticality detection sensors were used at the supporting pillar.

By using the cameras and sensors mentioned above, key operation parameters of the platform can be acquired in real-time, and the safety of the platform is guaranteed. The monitoring interface of the platform is shown in Figure 10.

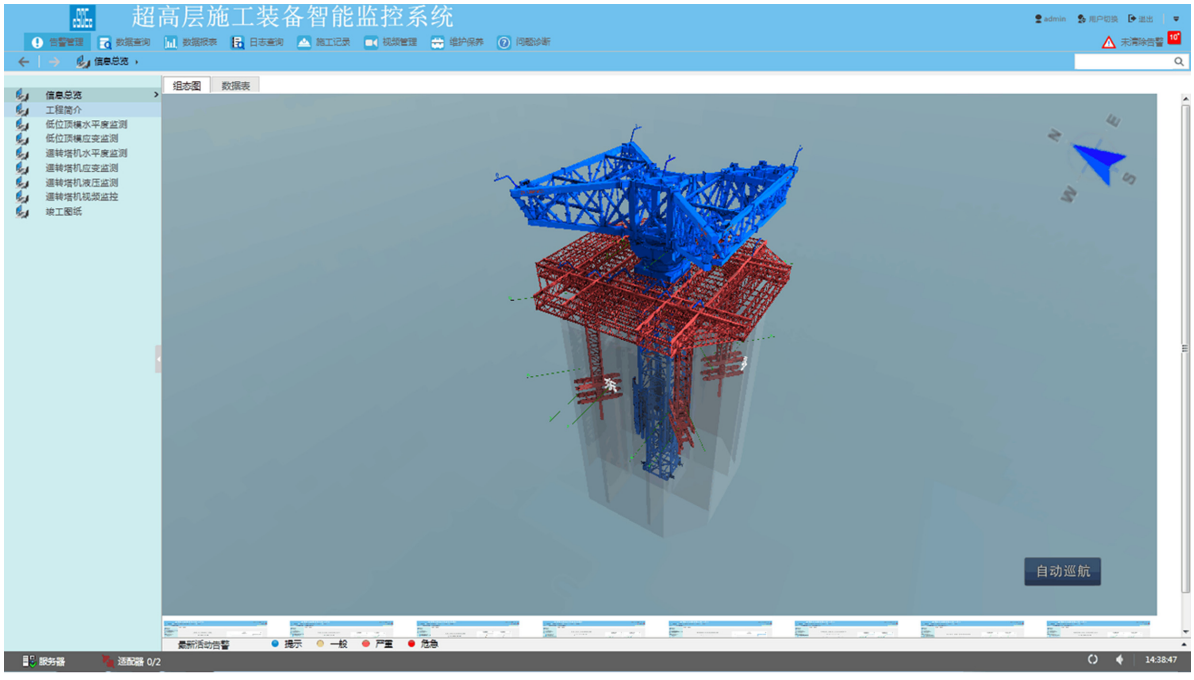


Figure 10. Interface of platform monitoring system.

2.3 Operating principle of the platform

The platform operating in 3 states. They are state of construction, state of lifting and state shutdown respectively.

In state of construction, all the loads and weights were transferred through upper supporting frame and lower supporting frame to the concrete wall of core tube. At the meanwhile, two layers of overturn-preventing units closed contact the concrete wall by self-locking cylinders. Vertical loads and horizontal loads were transferred to the concrete wall by supporting pillar and overturn-preventing units respectively. The platform is rotated by the hydraulic driving system to the operating angle, and cranes Implement lifting operations.

In state of lifting, several hydraulic lifting cylinders extending synchronously to lift the platform to upper floor. Before lifting, all the self-locking cylinders of overturn-preventing units draw back and the cylinders with scroll wheel extend to contact the wall. While lifting, the cylinders with scroll wheel resist overturn. After lifting, the upper supporting frames carry all the load of the platform and the lower supporting frames is elevated. All the cylinders with scroll wheel draw back and all the self-locking cylinders extend to contact the wall closely.

3. Crane slewing platform test

The crane slewing platform is applied based on Chengdu Greenland No. 8 super high-rise project for the first time. According to the actual hoisting requirements of the project, after using the crane slewing platform, the original 2 Zhongsheng ZSL1250 and 1 Zhongsheng ZSL380 are optimized into 1 Zhongsheng ZSL1250, 1 Favco M600D tower crane and 1 Zhongsheng ZSL380 tower crane. The total weight of the steel frame, the dead weight of the tower crane and the hoisting weight exceed 1,000t, and the overturning moment can reach 60,000 kN.m. For the first application of such major construction facilities, it is very necessary to conduct the experimental research. The test site is located at the china construction science and industry southwest base in the suburbs of Chengdu. According to the actual conditions of the site, a ZSL1150 which is slightly lighter than the ZSL1250 and a M600D are used for the test in the actual project construction, and a 90t counterweight is installed at the original installation position of the ZSL380 to simulate the tower crane. Combined with the finite element calculation results, the key monitoring is carried out on the rods with large stress to ensure the safety of the test process, and the collected results are quantitatively compared with the calculation results to verify the reliability of the design. At the same time, various functional tests such as no-load, on-load and rotation of the slewing platform are carried out to verify whether the indicators meet the design requirements. The real scene of the slewing platform test is shown in Figure 11.

3.1 Safety performance test

The test adopts two types of sensors: vibrating wire sensor and strain gauge. The vibrating wire sensor is used to collect the stress change of the main force-bearing components of the slewing platform during the installation process, and the strain gauge is used to test the stress and strain of the structure during the loading test.

The sensors are mainly arranged at upper, lower nodes and the stiffening plate of the slewing driving system, the bracket outside the central truss. The test is carried out in a graded loading method, according to the steps: no-load test operation → ZSL1150 tower crane load test operation → M600D tower crane load test operation → ZSL1150, M600D tower crane load test operation at the same time, and the test is divided into nine working conditions.

Overall, the trend of the experimental results and the calculation results are basically consistent. Among them, the stress on the underside of the lower chord bracket of the main truss on the side of the ZSL1150 tower crane under the hoisting condition is the largest, reaching 137MPa (about 124MPa under the no-load condition).



Figure 11. The real scene of the slewing platform test.

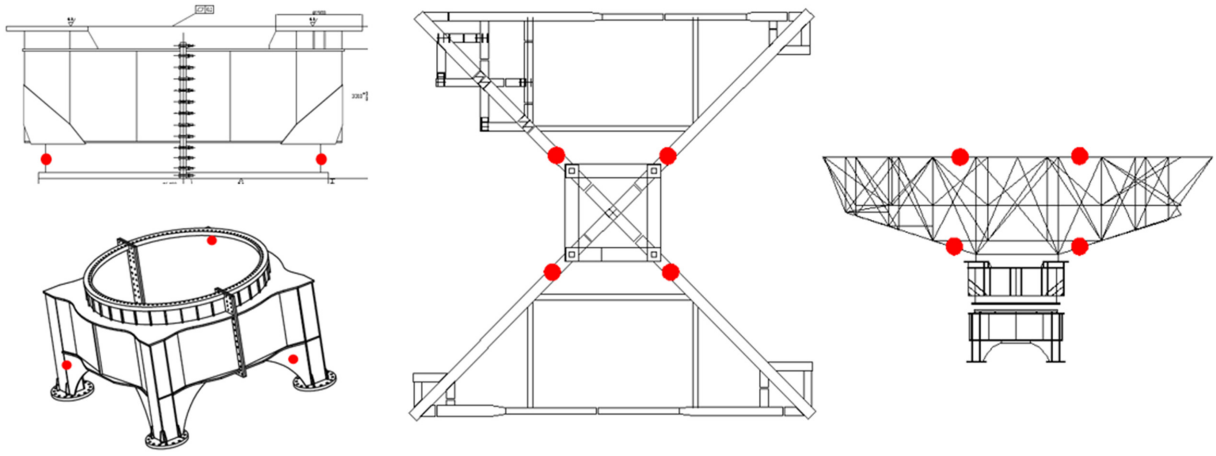


Figure 12. Arrangement of measuring points.

The results show that the structural stress is mainly affected by the self-weight of the crane and the platform structure. The influence of the hoisting load considered in the test on the structural stress is relatively small, and the structure is in a safe state under the action of the self-weight and the hoisting weight.

In addition, by comparing the measured values and the calculation results of Midas Gen of the relative displacement of the steel frame deformation under no-load and working conditions 7, it can be seen that the calculated values of the other points under no-load and hoisting conditions are relatively consistent in the measured values except for the ZSL1150. At the position of the ZSL1150, although there is a certain difference between the measured value and the relative value, the deformation trend is consistent. The measured value changes from –2 mm under no-load state to -8mm under hoisting state, indicating that the relative displacement value generated by the hoisting weight is -6mm; the calculated value changes from –7 mm under no-load state to –14 mm under hoisting state, indicating that the relative displacement value generated by the hoisting weight is –7 mm. From the change of the relative displacement value generated by the hoisting weight, the deformation trend and value are consistent, which verifies the rationality of the calculation and analysis, and further illustrates the safety and reliability of the design.

3.2 Slewing performance test

According to the manual/automatic operation mode, the single and double motor drive modes, and the no-load and on-load conditions of the crane, the slewing performance test is divided into five working conditions, the slewing function and operating parameters of the slewing platform are verified respectively. According to the test results, the following conclusions are obtained:

1) The speed can both reach 15 min/r under manual mode and automatic mode, which is consistent with the design index.

2) After increasing the hoisting weight of 63t, the torque and the power of the platform do not increase significantly. The reason is that the total weight of the platform and the crane is about 1000t in the no-load state, and the increased load of 63t has little effect on the total vertical force of the platform.

3) The platform torque, the system pressure and hydraulic motor torque are all about 23% of the rated value at rated speed, because the high-altitude wind resistance moment considered by the design cannot be simulated in the test conditions on the ground and the load of the test condition is much smaller than the design condition. For example, the design vertical force load is 2000t, and the test vertical force load is only 1000t.

4) In the dual-motor drive mode, the load balance of the two sets of the slewing drives is good, and the load difference is within 10%.

4. Application of the crane slewing platform

4.1 Project introduction

Chengdu Greenland project has a structure height of 468 meters and 101 floors above the ground. The structure is a giant column frame-core tube structure. The outer frame is designed as a frame system composed of 16 rigid concrete columns and giant diagonal braces. The core tube and the outer frame are connected by three outrigger trusses. The architectural renderings and tower structure plan of Chengdu Greenland Project are shown in Figure 12.

4.2 Crane arrangement of crane slewing platform

According to the overall schedule of the project, the statistics of the number of professional hoisting components, and comprehensively considering various factors affecting the hoisting, three cranes can meet the schedule of the construction period.

Among the hoisting components, the largest hoisting component is the outer frame steel structure giant diagonal bracing node, weighing about 50t. The 30-50t components mainly include outer frame columns, outer frame diagonal

Table 1. Statistics of hoisting components weight

No	Weight(t)	Percentage	Component Type
1	30~50	1%	Mega column, bracing joint, truss joint
2	10~30	5%	Mega column, bracing, truss and wall steel plate
3	< 10		Other components

bracing nodes, outrigger truss nodes, etc., accounting for less than 1% of the total hoisting times. The 10-30t components mainly include outer frame steel columns, giant diagonal braces, outrigger trusses, steel plate walls and other components, accounting for about 5% of the total hoisting times. Other components are less than 10t. The statistics of hoisting components weight is shown in Table 1.

Considering the factors such as the hoisting times of the components and the overall layout of the site, among the three crane configurations of the slewing platform, the Zhongsheng ZSL1250 (R = 55 m) tower crane is selected as the large crane, which is mainly used for the hoisting of large components such as giant steel columns, giant diagonal braces, and steel plate walls. A medium-sized crane is arranged at the opposite corner, and the Favco M600D tower crane is selected to mainly complete the hoisting of 10-30t medium-sized components, and can assist the ZSL1250 crane to complete the hoisting of some outer frame columns and outer frame diagonal braces. Zhongsheng ZSL380 tower crane is selected as the small crane, which is mainly responsible for the hoisting of light materials such as horizontal beams and steel bars.

According to the crane manual, the maximum hoisting weight of the ZSL1250 crane within a 19.4 m slewing radius is 64t. Using the slewing function of the slewing platform, the hoisting of 64t of components within a radius of 34.9 m from the center of the core tube can be used. Therefore, one such crane can satisfy the hoisting of the outer frame giant diagonal bracing nodes around the periphery of the core tube.

4.3. Overall layout of crane slewing platform

According to the structural characteristics of the core tube of Chengdu Greenland Project, the supporting jacking system of the pivoting platform is arranged in the middle tube of the core tube to expand the effective lifting area of the crane of the slewing platform. The crane layout plan of the slewing platform is shown in Figure 14.

The support and power system is designed with four sets of wall fulcrum points, which are located at the four corners of the inner tube of the core tube. Each group of the attached wall fulcrums is composed of two sets of micro convex fulcrums, “L”-shaped upper and lower support frames, which are perpendicular to each other at the corners of the core tube. The upper and lower support frames are respectively engaged with two slightly convex fulcrums at the corners of the core tube of the upper and lower structural layers. The actual installation of micro convex fulcrum and support frame of Chengdu Greenland Project is shown in Figure 15.

The upper support frame on the slewing platform is located on the third structural layer below the structural layer to be constructed, and the upper and lower support frame each spans one structural layer. The lower support column extends to three structural layers below the lower support frame, and two overturn-preventing systems are respectively arranged at the top of the transfer column and the bottom end of the lower column, with a distance

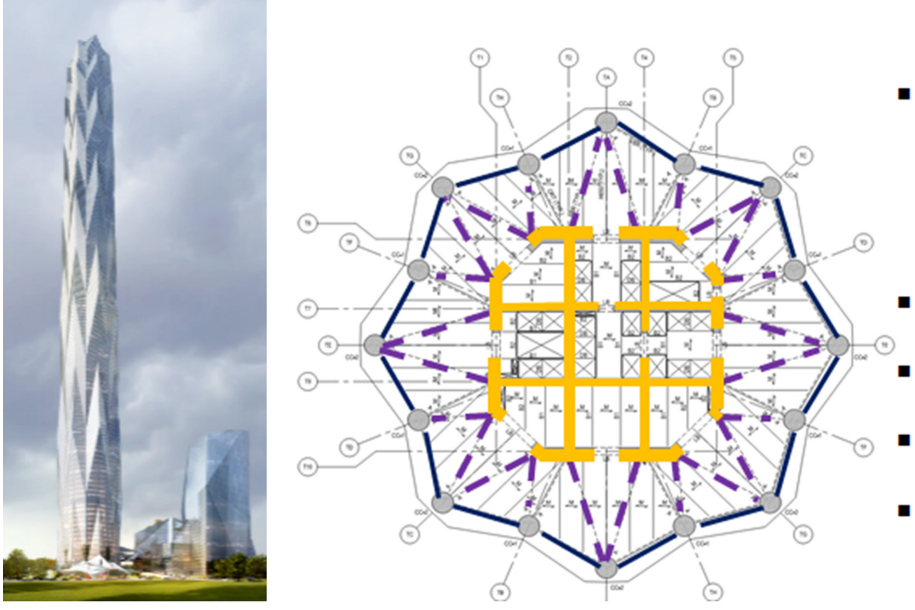


Figure 13. Architectural renderings and tower structure plan of Chengdu Greenland Project.

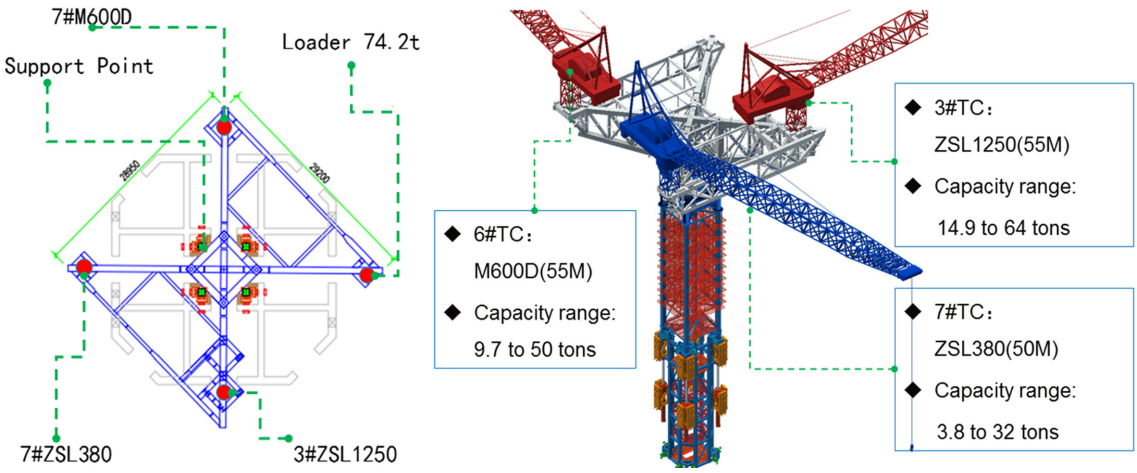


Figure 14. Arrangement of cranes on slewing platform.

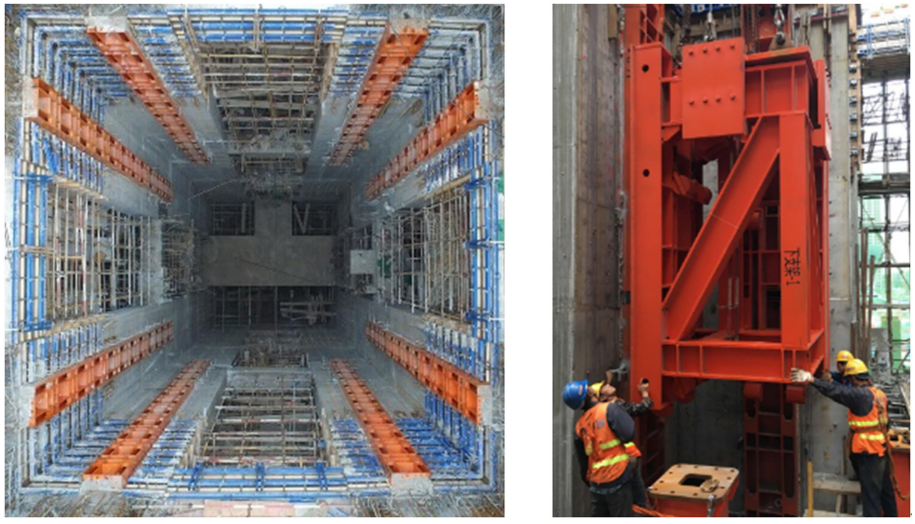


Figure 15. Real view of micro convex fulcrum and support frame installation of Chengdu Greenland Project.

of about 22 m. The steel frame is located on the core tube construction formwork, with a clearance of about 10.2 m from the top to meet the operating space requirements of construction facilities such as concrete placing machines and construction elevators. The vertical layout of the slewing platform is shown in Figure 16.

The steel frame is about 28.5 m long and 28.3 m wide. The ZSL1250 and the M600D tower cranes with similar deadweight are placed symmetrically, and the ZSL380 tower crane is set with counterweights diagonally to balance the overturning bending moment caused by its deadweight. The center of the crane base is 15.5-18.5 m away from the center of the core tube, which is located between the core tube and the outer frame steel frame. The actual plane view of the slewing platform is shown in Figure 17.

4.4 The installation of crane slewing platform

After the binding of the first floor rebar is completed, the installation of bearing component shall be started. After the construction of the three-layer bearing components are completed, the supporting frame, supporting column and other supporting jacking systems shall be installed in turn; then install the rotary drive system and the top steel frame.

Only one ZSL1250 tower crane is arranged in the core tube for installing the crane slewing platform. After the installation of the slewing drive system, the steel frame is installed by using the slewing function of platform without jig frame.

Firstly, the central truss shall be installed, and the single chip truss shall be horizontally assembled on site. After the installation of the central truss is completed, the sheet truss is installed by rotating the central truss so that the lifting and installation position of the single chip truss is within the lifting capacity of the crane.

Before the installation of single chip truss, the hoisting analysis shall be carried out first, and the installation sequence, rotation angle and direction shall be planned

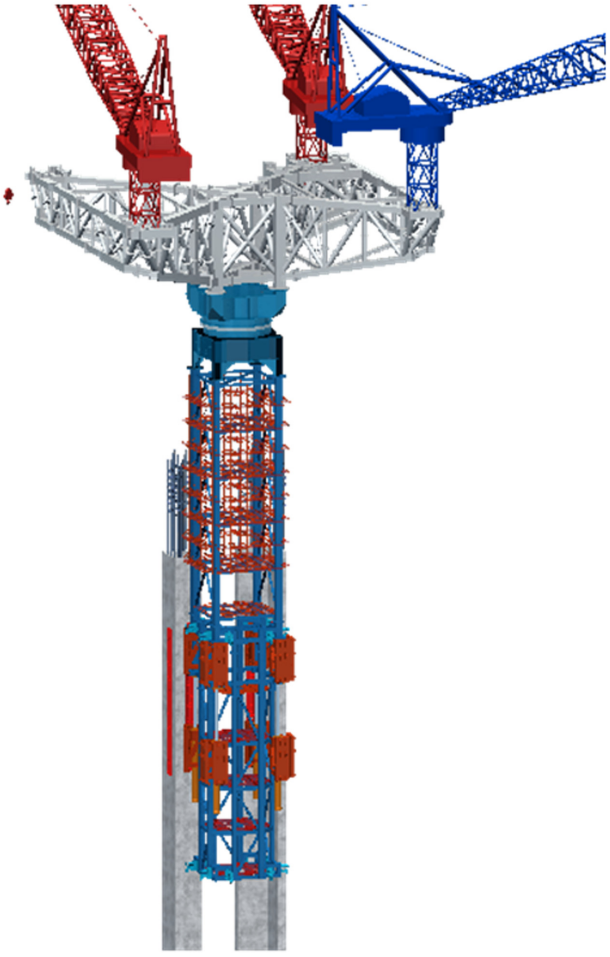


Figure 16. Vertical layout of the slewing platform.

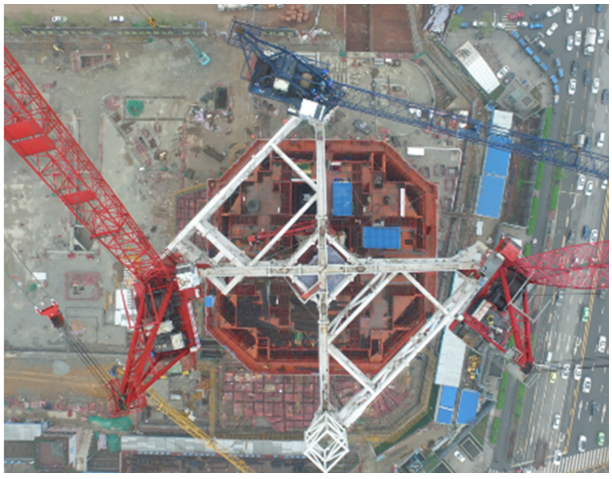


Figure 17. Actual plane view of the slewing platform.

according to the installation sequence of main truss first, then secondary truss, and finally the connecting members, until the whole platform structure is completely installed. The installation of the steel frame without jig frame is shown in Figure 18.

Before climbing the crane slewing platform, first adjust the direction and elevation angle of the crane boom to balance the crane slewing platform. The mechanical self-locking oil cylinder of the two overturn-preventing devices is separated from the wall, and the lateral wheel set mechanism extends close to the wall. Then start the jacking cylinder and the climbing of the slewing platform.

During the climbing process, a specially person should be assigned to ensure that there are no obstacles on the



Figure 18. Real view of no jig frame installation of steel frame.



Figure 19. hydraulic system monitoring interface of crane slewing platform.

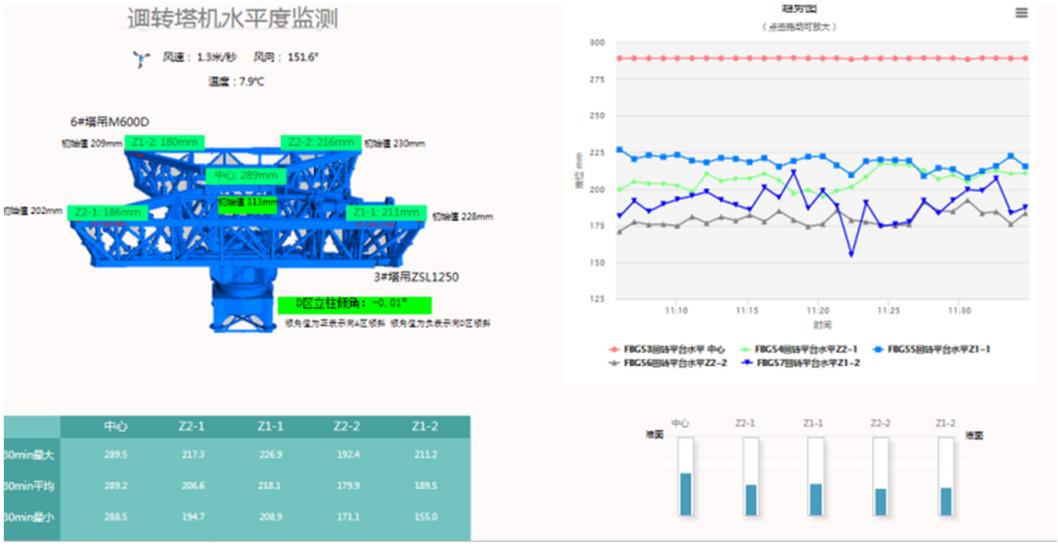


Figure 20. levelness and verticality monitoring interface of crane slewing platform.

climbing path and there is sufficient safety distance. At the same time, the distance between the wall and the roller of the overturn-preventing device should be observed, stop jacking immediately in case of any change, continue jacking when the cause has been found out and treated.

To judge whether the mechanical action of the support system is correct, whether the steel frame is horizontal and whether the force of the jacking oil cylinder is balanced during the climbing process, the apparent monitoring, levelness monitoring and verticality monitoring of the crane slewing platform shall be strengthened. When the monitoring value exceeds the design allowable value, the pump should be stopped quickly, and the overturn-preventing self-locking oil cylinder should be extended to the wall. After completing the above emergency treatment, troubleshooting shall be carried out, and jacking shall be continued after treatment. The hydraulic system monitoring interface, levelness and verticality monitoring interface are shown in Figure 19 and Figure 20 respectively:

After the climbing is completed, the upper and lower overturn-preventing devices should be extended out to the wall through the process of symmetrical and graded loading.

4.6 Monitoring system of crane slewing platform

During the operation of the crane slewing platform, the intelligent monitoring system is adopted to monitor the whole process. By collecting the stress, strain, verticality, levelness, wind speed and other relevant data during the

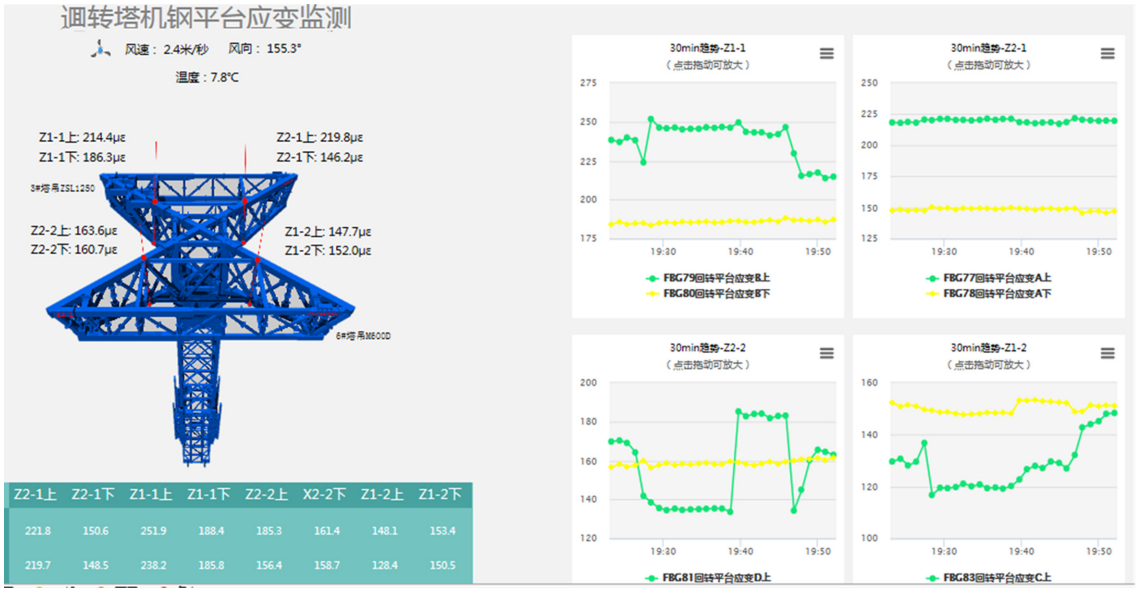


Figure 21. Stress-strain monitoring interface of crane slewing platform.

operation of the equipment, it provides a reference basis for the research and judgment of the operation state and the treatment of emergencies, so as to improve the overall safety of the equipment. The platform has experienced the test of strong winds, hoisting of heavy steel member and especially the Jiuzhaigou M7.0 earthquake on August 8, 2017. The monitoring data show that all mechanical indexes are in the elastic range when the earthquake occurs, and the overall safety is controllable. The stress-strain monitoring interface is shown in Figure 21.

5. Conclusion

The crane slewing platform is a globally innovation in vertical transport of high rise building construction. After detailed designing and sufficient testing, the slewing platform was successfully applied in the construction of Chengdu Greenland Center super high rise building project. By using the slewing platform, the configuration of cranes was optimized, from configuration of 2 cranes of ZSL1250 type and 1 crane of ZSL380 type to configuration of 1 crane of ZSL1250 type, 1 crane of M600D type and 1 crane of ZSL380 type, which totally saved 3 million of RMB Yuan. Several cranes sharing the base platform, and occupying only one core tube grid, thus the layout conflicts of cranes are avoided. By using the slewing platform, the lifting range of each crane is greatly expanded. In further, each crane's position can be replaced by other cranes as backups.

Totally 98 times of lifting operations are completed in Chengdu Greenland Center super high rise building project construction. Every lifting operation cost 6 hours, saving 2 months of construction period in total.

Since being put into use, the slewing platform had experienced heavy component lifting, extreme wind weather, and Jiuzhaigou 7.0 earthquake on August 8, 2017. Monitoring data shows that all performance indicators are in the normal range, the safety is guaranteed.

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