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Installation Technology of Super Long Steel Hanger for Curtain Wall of Xi'an Silk Road International Convention and Exhibition Center

Yi Jiang, Zhiyan Che*, Xinyou Chen, Zhenghua Gong

China Construction Shenzhen Decoration Co Ltd, Shenzhen, China

Email address:

304736292@qq.com (Yi Jiang), 7959025@qq.com (Zhiyan Che), 646882671@qq.com (Xinyou Chen), 1754590132@qq.com (Zhenghua Gong)

*Corresponding author

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Abstract: There are 268 pieces of super long steel hangers on the façade of the curtain wall project of Xi'an Silk Road International Convention and Exhibition Center. A single piece of steel hanger is 26m~44m long and 7t~34t heavy. The difference between this project and the conventional construction method of curtain wall lies in that during the installation of steel hangers, the complex deformation of the main steel structure can make it difficult to accurately install steel hangers. The construction steps are simulated with SAP2000. The simulation defines 84 construction steps. After an accurate calculation of the deformation of the main steel structure that each piece of steel hanger must adapt to, the super long steel hangers are assembled on site. The overhanging end of the metal roof is about 5m~20m from the mounting axis of steel hangers, so the conventional process of installation from up to down cannot be applied. A 180T crawler crane is utilized for overall lifting and installation on the side. This is a new construction method of curtain wall that can control the installation accuracy within 5mm, ensure the flatness of the structural façade, improve the construction and installation efficiency, and guarantee the construction safety. It can provide a technical reference for similar large-scale curtain wall projects in the future.

Keywords: Curtain Wall, Super Long Steel Hanger, Deformation, Installation Technology

1. Project Introduction

Xi'an Silk Road International Convention and Exhibition Center is located at Shiyuan Block in the core area of Euro-Asia Economic Comprehensive Park of Chanba Ecological District in the northeast of Xi'an, with a total construction area of 207,112m^2. The reinforced concrete frame structure is underground, and the steel frame structure is above ground. The building height is 58.8m. The hanger of the curtain wall is a box column structure connected by pins at both ends and in the middle. Two steel hangers for curtain wall are connected by the box beam and dragged by tension bars (see *Figure 1.*). The maximum length of hangers for the curtain wall at the four corners of the building structure is 44.0m, and the minimum length is 26.0m in the middle of the building structure [2]. The plane is configured in arc shape, and the hanger material is 20mm, 30mm and 40mm-thick Q345B steel plates. There is a total of 268 pieces of hangers for the curtain wall.

Figure 1. *The architectural effect of external façade.*

2. Technical Characteristics of Project

1) The mullion adopts the steel plate welded box structure with the sectional heights from 300 to 700mm. A single piece of mullion is 26m-43m long and 7t-34t heavy, thus being very difficult for machining and lifting.

2) Different from the conventional curtain wall system [3], which installs keels after completion of the main structure, the main steel structure in some areas are still under construction when the steel hangers are being installed. The load in the entire construction process is varying and results in difficulties for controlling the structural deformation, accurate analysis of the deformation of every steel hanger, control of measurement accuracy, control of structural member fabrication and deformation and deformation control of field assembly. After the installation of steel hangers, both the bearing requirements of the main structure and the functional needs of the curtain wall structure must be satisfied.

The steel structure of the curtain wall has high requirements for installation accuracy. The planeness of structural façade, horizontal planes of structure, deformation of structural member fabrication and verticality of structural member installation should be controlled within 5mm as required by the design [4].

3. Simulation Analysis of Steel Hanger Construction Steps of Curtain Wall

According to the structural characteristics and possible difficulties in construction, the finite element method is employed for the construction simulation. In the simulation process, 84 construction steps are defined and the steel hangers for curtain wall are divided into twelve groups by their positions [5]. The structural operation software SAP2000 (Version V18.2.0, working condition number: 20180407SG) is applied for the simulation calculation of the simulated construction process. The construction steps are defined as follows:

Step 1: Install the internal steel structure; simulation calculation diagram (see *Figure 2*).

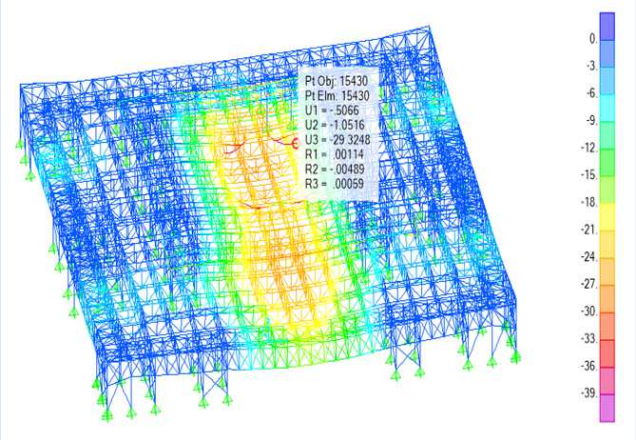

Figure 2. *Diagram on simulation calculation of static force.*

Step 2: Simultaneously install the first group of cantilevered trusses in the east, south, west and north, and erect the tire frame for supporting;

Step 3: Remove the tire frame support;

Step 4: Install the connecting truss between cantilevers;

Step 5: Install the hangers for the curtain wall at the end of cantilevers;

Step 6: Install the P600x14 round hangers;

Steps 7 to 11: Repeat the installation and removal of the second group [6];

Step 12: Install the first group of hangers for the middle curtain wall;

Steps 13 to 25: Repeat the installation of the third and fourth groups and the alternate construction of hangers for the middle curtain wall;

Step 26: Install the 63m lower crescent (configured with the tire frame) and the supplemental sections under the first, second, third and fourth groups of hangers;

Step 27: Remove the 63m lower crescent;

Steps 28 to 57: Repeat 2 to 6 for installing the fifth, sixth, seventh, eighth and ninth groups of cantilevered trusses and connecting trusses, removal of the tire frame and alternate construction;

Step 58: Install the lower crescent at a distance from the core tube (configured with the tire frame) and the supplemental sections under the fifth, sixth, seventh, eighth and ninth groups of hangers [7];

Step 59: Remove the lower crescent at a distance from the core tube;

Steps 60 to 61: Repeat the installation of the tenth, eleventh and twelfth groups of cantilevered trusses and connecting trusses, removal of the tire frame and alternate construction;

Step 78: Install the lower crescent at four angles (configured with the tire frame) and the supplemental sections under the tenth, eleventh and twelfth groups of hangers;

Step 79: Remove the third-section lower crescent at a distance from the angle end;

Step 80: Apply the permanent load on D1;

Step 81: Apply the permanent load on the metal roof of D2 upper crescent;

Step 82: Apply the permanent load on D3 curtain wall glass;

Step 83: Apply the permanent load on the metal panel of D2 lower crescent;

Step 84: Apply the permanent load on D4, and the hanging weight on roof surface and roof as well as other loads vary in different areas

Diagram of simulation calculation of static force (see *Figure 3*);

Through calculation, the vertical displacement lengths of all groups of hangers are obtained, and then the hanger lengths are adjusted on this basis. For example, the vertical displacement and lengths after adjustment of the first group of hangers (see Table 1).

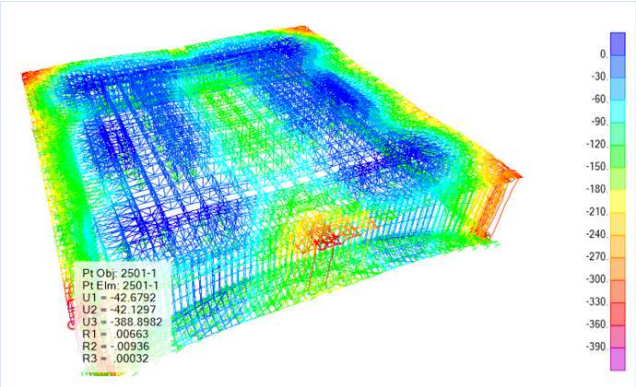

Figure 3. *84-step simulated calculation of static force.*

Table 1. *Length after adjustment of the first group of hangers (unit: mm).*

Direction	Position	Original length	Vertical displacement	Length after adjustment
South	Outer	1730	135	1595
	Middle	1530	108	1422
	Inner	550	88	462
West (East)	Outer	1730	40	1690
	Middle	1530	30	1500
	Inner	550	22	528
North	Outer	1730	53	1677
	Middle	1530	40	1490
	Inner	550	30	520

4. Machining of Steel Hanger for Curtain Wall

A refined design of every group of steel hangers is provided according to the data obtained from the simulation. If the refined design is conformable, it is reported to the competent authority for approval and sent to the processing plant for structural member fabrication. The steel hangers are too long to transport, so they are machined in sections and assembled on site. The key point for quality control lies in the control of deformation during the field assembly and welding.

4.1. Control of Lateral Deformation of the Steel Hangers for Curtain Wall

According to the working condition analysis, every hanger for curtain wall is assembled in a whole before lifting and installation. The hangers are set out and leveled on the cement ground by the length of their respective section. H section steel is fixed on the cement group by chemical anchors (see *Figure 4*). The anchors are configured at both ends of H section steel and the connection of two steel hangers.

Figure 4. *Fixation of H-section steel.*

The upper surface of H section steel tire frame is leveled and the long axis is plotted by the ink line.

Excess materials of the channel steel or H section steel are attached to the ink line and the "bracket" is welded [8] (see *Figure 5*).

Figure 5. *Fixation of the bracket.*

The sectioned rods of the steel hangers are put on the tire frame by the hoist and the crowbar is used to make it close to the "bracket" (see *Figure 6)*.

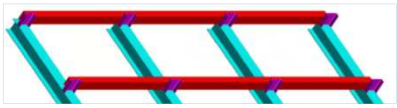

Figure 6. *Configuration of steel hangers.*

The theodolite is used to measure the overall flatness of assembled hangers and meanwhile, a 50m steel tape is utilized to check the overall length of the structural member. An adjustment should be made if there are any errors.

4.2. Height Control of the Horizontal Rods of Curtain Wall Steel Hangers

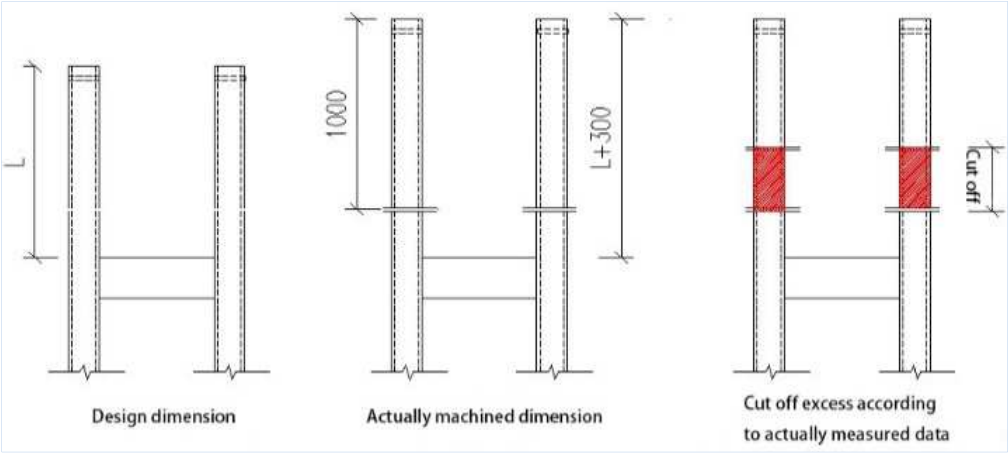

Figure 7. *Production and machining diagram.*

The upper end of steel hanger of the curtain wall is hanged on the lower end of the cantilevered truss and the lower end is located on the upper surface of the supporting truss. Due to the flexural deformation of the truss, in order to ensure the crossbar on the same plane, the steel hangers of the curtain wall are produced pursuant to the actually measured data. Given the construction schedule, the production procedure by actual measurement should be implemented on site as follows:

The upper end of steel hanger is prolonged by 300mm during factory production and cut at 1000mm from the upper end downwards [9] (that is, cut to be an independent unit of 1m length), and then the difference ΔL with the design data is calculated with the actually measured data. The lower opening of the 1m-long structural member is cut to the length of 1000-300±ΔL (when the truss is flexural upwards, +ΔL; when it is flexural downwards, -ΔL) [10]. It is rewelded after processing the cutting bevel (see *Figure 7*).

The lower end is prolonged by 100mm during factory production and cut at 1m from the bottom opening upwards. The other procedures are identical to those of the upper end.

5. Installation of Steel Hanger for Curtain Wall

5.1. Construction Sequence

Pursuant to the structural characteristics of this project and the division of working faces handed over by other entities, for the convenience of construction management, four construction areas are divided for the steel hangers of curtain wall, namely the first construction area (east), the second construction area (south), the third construction area (west), and the fourth construction area (north) (see *Figure 8*).

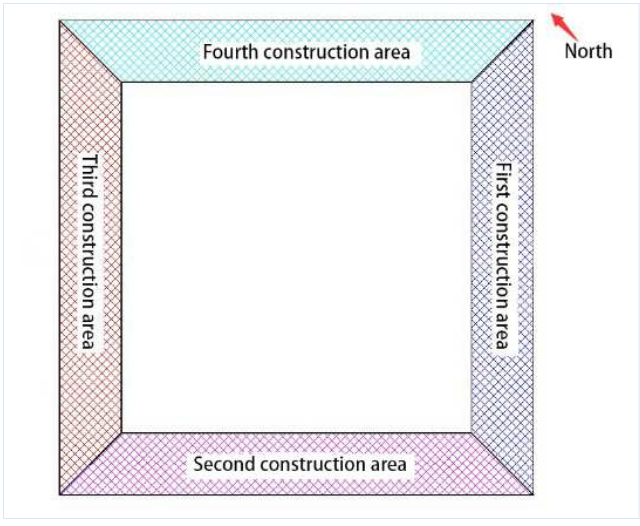

Figure 8. *Division of construction areas.*

In line with the construction sequence of the main structure, every façade is installed by prolongation from the middle to both sides. Two installation teams are configured for a façade, and the four facades are construction simultaneously [11].

5.2. Selection of Lifting Equipment

The statistics of the parameters are collected for every group of steel hangers of the curtain wall. The crane specification is selected through the stability analysis [12]. There is an overhanging eave beyond the structural face on the upper part of the curtain wall hangers, so the two conditions (lifting weight and lifting height) must be considered at the same while the crane is being selected. The lifting distance and weight should be analyzed in accordance with the actual situations. The changes in the lifting distance and the lifting height of steel hanger at every face should be checked. Aiming at the large arm length requirement of crawler crane, it is finalized that the 180t crawler crane fixing the boom at 52m, the theoretical lifting weight has an assurance coefficient of about 20~30% [13].

5.3. Installation of Steel Hanger for Curtain Wall

The overhanging eave made of steel structure (in a half-moon shape) is located at the upper cornice of hangers and protrudes the mounting axis of hanger outwards by 5m~20m. It cannot be installed by the conventional up-down method but lifted by a 180t crawler crane for installation on the side.

Locating of lifting lug: Since the hanger is installed by the inclined plug-in, the lifting lug must be unbalanced while guaranteeing safety, and ensure that the rear hanger height is higher than the height of crane top after lifting up. There must be a horizontal included angle of 60-70 degrees in the air after lifting up the structural member, and the included angle of any two steel wire ropes must be ≤60°. Analyzed by the constructed length, the lifting lug position is:

When L≤35000, the lifting lug must locate at 6000mm from both sides of the center of gravity of structural member;

When L>35000, the lifting lug must locate at 8000mm from both sides of the center of gravity of structural member.

Due to the limitation of transportation, the lifting lug must be welded and installed on site [14].

According to the locating line upon measurement, a locating plate is welded at the bottom end of the hanger, and the stiffened lug plate on another side is installed. Close attachment of the steel hanger to the locating plate means that it has been properly installed in the front and rear directions, and the left and right directions may be adjusted through manual hoists. In this process, two sets of theodolites are used to measure and control the perpendicularity of steel hanger. After being located and adjusted, the steel hanger is fixed by spot welding. Then, the actual length from the pinhole to the bottom face is measured. The lug plate is set out and cut in line with the measured data, and then welded after the pin is put through (see *Figure 9*).

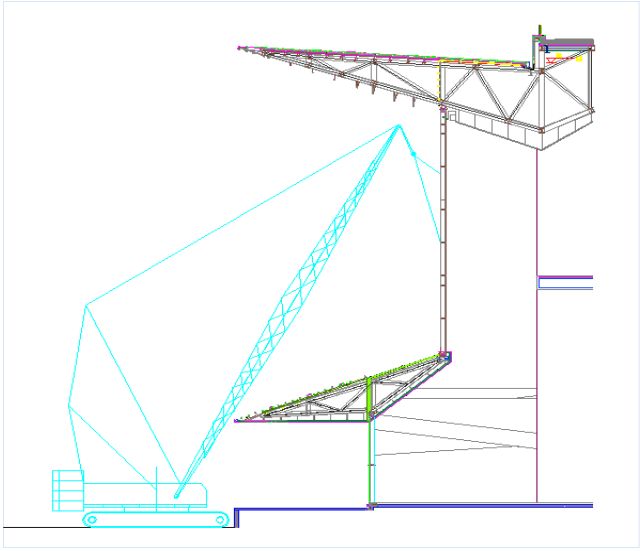

Figure 9. *Schematic of structural member installation and locating.*

6. Conclusions

When the load of the steel hanger of curtain wall for Xi'an Silk Road International Convention and Exhibition Center varies, the deformation of steel hanger changes either. Finally, the structural analysis software SAP2000 is utilized to simulate the construction steps, calculate the settlement of main structure at every piece of steel hanger, and then formulate the machining scheme for steel hangers with consideration to the settlement. Finally, the technical difficulty of the uncontrollable deformation of steel hangers is solved by integrating with the field construction and installation process. In case of restriction over construction conditions, the crawler crane and hanging basket are used to successfully complete the installation of steel hangers, and the overall structural deformation is still within the permissible range of settlement deformation during design. Meanwhile, it greatly reduces labor force and waste of materials, and hence may be used as a reference for similar projects [15].

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