CONSTRUCTION Process Analysis of Giant and Complex Steel Structures

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Abstract. The main structure of Xi’an Silk Road International Conference Centre is a giant steel braced frame structure. The façade of the structure is made up of huge suspended skirt-like suspended structure supported by cantilever roof trusses and steel suspensions, which adds up its complexity. In order to accurately control the installation precision and facilitate the installation of curtain wall glass in the later stage, the pre-chamber construction method is adopted in the roof truss installation to compensate the construction deformation of suspended structure. The static analysis is conducted by SAP2000 to propose a reasonable pre-camber value of the roof cantilever truss. The nonlinear simulation of the construction process is carried out. Through comparative analysis, the optimal sequence of the steel structure construction is obtained, which provides the theoretical basis for the construction of giant and complex steel structures.

1. Introduction

Xi’an Silk Road International Conference Centre has a plan size of 207m×207m and a height of 58.8m. It has one underground floor (with two partial floors) and three floors. The structure of underground is frame-core wall concrete structure, while the aboveground structure is giant steel frame. The façade of the building is a huge skirt-like suspended structure composed of roof cantilever trusses and crescent-shaped trusses hanging under the steel suspensions. The cantilever length of the roof truss has a maximum of 38m and a minimum of 25m. The length of the suspensions are ranging from 37.3m to 46.7m. The span of crescent truss is 207m with the maximum width of 43m. The weight of a single truss exceeds 3000t. The suspended skirt-like structure is connected to the main structure by sliding support, presenting a complex load-bearing system. In addition, the steel suspensions in the outer facade are also used for supporting the glass curtain wall, which requires precisely controlled installation technique.

2. Construction scheme

In order to control the absolute deformation of the main structure to be confined in the requirements of the architectural morphology, while compensate the relative deformation of the suspended structure, a vertical displacement controlling scheme is proposed. It is implemented by overhanging inverted chamber to control the absolute displacement and adjusting deviation to control the relative displacement. Two construction schemes are proposed based on the design documents and construction site conditions.
2.1. construction scheme I

Scheme I is an integral construction method, which is progressed from inside to outside according to the construction section. It starts at four sides at the same time (figure 1-a). Its initial state is the internal steel structure (figure 1-c). The specific construction process can be divided into four sections:

(1) integral structure installation at the middle span with 63m range

The upper crescent cantilever and the ring beam are firstly installed, then the first set of suspensions. The first set of secondary structure is established after the second set of similar truss and suspensions is completed. In this order, the first set to the fourth set of members within the range of 63m at the mid-span can be installed sequentially. Finally, the lower crescent cantilever in the area is installed. After all the installation completed, the supporting can be unloaded.

(2) integral structure installation at the core tube

The fifth set of upper crescent cantilever and ring beams are firstly installed, then the fifth set of suspensions. The first set of secondary structure is established after the sixth set of similar truss and suspensions is completed. In this order, the fifth set to the ninth set of members at the core tube can be installed sequentially. Finally, the lower crescent cantilever at the core tube is installed.

(3) integral structure installation in the corner

The primary and secondary trusses on the upper part of the corner are firstly installed, then the suspensions from 10th set to 12th set in order. The suspensions at the middle of the curtain wall can be erected afterwards. Finally, the lower crescent cantilever at the corner is installed.

(4) applying dead load step by step

The first step is to install the internal floor slab with the dead load of D1. The second step is to install the upper crescent cantilever and the metal roof, which together possessed the dead load of D2. The third is to install curtain wall glass with the dead load of D3. The fourth is to install the lower crescent roof, with the identical dead load of D2. Finally, the roof surface, the hanging weight as well as other superimposed loads are applied, which is denominated as D4.

![Scheme I sequence](image1)

a) Scheme I sequence

![Scheme II sequence](image2)

b) Scheme II sequence

![Initial State](image3)

c) Initial State

Figure 1. Construction sequence and initial state of construction

2.2. construction scheme II

Considering the impact of actual progress and construction conditions, it is assumed that the upper cantilever steel structure has been installed. Under this condition, the component separation installation method can be proceeded at four sides from outside to inside simultaneously (figure 1-b). The upper cantilever in the main structure can be completed first, then the suspensions. The specific construction process can also be divided into four sections:

(1) main cantilever truss installation

The installation of cantilever trusses is still from inside to outside

(2) installation of suspensions and secondary structure

The four sides are installed simultaneously from the outside to the inside, to complete the installation ranging from 1th set to 9th set of suspensions and secondary structure.

(3) installation the supper structure at the corner

The primary and secondary trusses at the upper part of the corner are installed firstly, then the suspensions from 10th set to 12th set, and finally, the suspensions at the middle of the curtain wall in order.
(4) full range of lower crescent installation
The full range of lower crescents are installed, and then unload in steps from inside to outside.
(5) applying dead load step by step
The installation sequence is the same as construction scheme I with the identical symbols varying from D1 to D4.

3. The simulation of construction process

3.1. calculation model
Taking the structural characteristics and modelling conditions into consideration, the finite element software SAP2000 was used to conduct a complete modelling of the steel structure on the top of the main body and the suspended facade structure[1]. The beams and columns are simulated by beam element, and the floor is simulated by membrane element. Section and material of the members are assigned strictly according to actual conditions. The overall model of the suspended steel structure of the project is shown in the figure 2.

Figure 2. Profile of steel structure modelling in xi 'an convention centre
In order to ensure the ordinary conditions of the suspended part of the curtain wall and reduce the unexpected stress of the structure, it is particularly important to connect the suspended part with the main structure to resist the horizontal wind load while preventing the vertical deformation. The technique adopted in this project is to permit vertical limited sliding, namely to control the radial and tangential direction non-movable[2-4].

3.2. calculation results

3.2.1. calculation results of inverted camber
Considering all the superimposed dead load and the load of whole structure are loaded simultaneously, the pre-adjustment value of the inverted camber can be calculated by single iteration. The linear vertical deformation of the crescent cantilever member on the suspended system is shown in the figure 3.
Figure 3. Deflection results of inverted camber

The inverted chamber values at the lifting points of suspensions are shown in Table 1. The point is numbered according to the direction shown in figure 3. Each side is numbered from 1 to 24, as shown in Table 1.

Table 1. Deformation of the curtain wall suspensions.

| Number | Inverted Chamber-South (mm) | Inverted Chamber-West (mm) | Inverted Chamber-East (mm) | Inverted Chamber-North (mm) |
|--------|-----------------------------|----------------------------|---------------------------|-----------------------------|
| 1      | 203.15                      | 212.03                     | 205.87                    | 212.39                      |
| 2      | 178.04                      | 186.82                     | 180.30                    | 185.67                      |
| 3      | 118.14                      | 126.56                     | 123.34                    | 124.42                      |
| 4      | 71.64                       | 77.70                      | 77.82                     | 74.25                       |
| 5      | 45.78                       | 50.27                      | 53.44                     | 46.36                       |
| 6      | 32.34                       | 42.50                      | 47.59                     | 34.04                       |
| 7      | 29.49                       | 53.79                      | 56.39                     | 30.11                       |
| 8      | 28.79                       | 66.08                      | 65.15                     | 26.34                       |
| 9      | 39.43                       | 66.04                      | 62.00                     | 24.97                       |
| 10     | 72.60                       | 56.01                      | 52.70                     | 26.62                       |
| 11     | 101.06                      | 46.68                      | 44.53                     | 29.09                       |
| 12     | 116.91                      | 42.17                      | 41.08                     | 35.23                       |
| 13     | 117.17                      | 41.62                      | 41.50                     | 34.76                       |
| 14     | 102.07                      | 44.25                      | 44.68                     | 27.82                       |
| 15     | 74.85                       | 52.07                      | 51.53                     | 24.98                       |
| 16     | 40.38                       | 60.33                      | 59.10                     | 24.06                       |
| 17     | 29.39                       | 61.95                      | 59.95                     | 25.72                       |
| 18     | 30.47                       | 51.36                      | 50.25                     | 29.79                       |
| 19     | 33.40                       | 41.48                      | 43.67                     | 33.80                       |
| 20     | 46.57                       | 49.20                      | 50.55                     | 45.92                       |
| 21     | 72.16                       | 74.64                      | 78.06                     | 73.64                       |
| 22     | 118.74                      | 120.14                     | 126.40                    | 123.93                      |
| 23     | 178.91                      | 178.80                     | 186.45                    | 186.07                      |
| 24     | 205.87                      | 203.15                     | 212.39                    | 212.03                      |

3.2.2. calculation results of vertical deformation

(1) construction scheme I

According to the construction process, a total of 76 steps are designed in the nonlinear stages. The vertical deformation results of crucial construction steps are shown as follows:
Figure 4. Vertical deformation of construction stages for scheme I

(2) construction scheme II

According to the construction process, a total of 57 steps are designed in the nonlinear stages. The vertical deformation results of crucial construction steps are shown as follows:
4. Comparison of simulation results from different construction schemes

In order to further understand the influence of the different construction processes to the deformation of the suspended system, key lifting points are selected for in-depth comparative analysis of the changes of the construction path[5].

1) south mid-span lifting points

Tracking the vertical deformation of the lifting point at the south mid-span curtain wall of two different construction schemes, the results are in figure 6.

As the figures indicate, due to the differences of the installations, the final results diverse significantly. In scheme I, the vertical displacement at the lifting point of the mid-span curtain wall reaches 120mm after the 27th step (unloading of the lower crescent part of the mid-span). At this time, only 8 sets have been installed on the upper structure of each side. The final vertical displacement is 158mm. The vertical displacement of scheme II is only 90mm after the 53th step (all the crescent part has been unloaded). At this time, 24 sets of the upper structure on each side have been installed. The final vertical displacement is 136mm.
Therefore, it can be obtained that, due to the great influence of the stiffness differences of the upper steel structure, the installation sequence of the cantilever structure and the unloading sequence of the lower crescent part have a great influence on the deformation of the southern mid-span truss. The pre-installation of the upper structure in 63m span the unloading of the lower crescent part will result in large deformation at the mid-span.

(2) west truss lifting points

Tracking the vertical deformation of the lifting point at the west truss (5th set in the west) of two different construction schemes, the results are in figure 7.

It can be seen from the figures above that the vertical deformation of curtain wall lifting point in the west core tube in step 59th of scheme I (unloading the second lower crescent part) is 39mm, and 45mm after unloading. the vertical deformation of the curtain wall in the west core tube in step 51th of scheme II (unloading the second section of the crescent part) is 37mm, and 44mm after unloading. The results are much the same.

Therefore, it can be concluded that, although the installation sequence of the suspended structure in the steel frame (the integral type of scheme I and the separated type of scheme II) leads to different deformation trends of the lifting point on the west side, the structural deformation of the lower crescent part in this area is basically the same before and after unloading. The installation sequence of the steel structure in this area has little influence.

(3) corner curtain wall lifting points

The vertical deformation of the lifting point of the curtain wall at the southwest corner are tracked in the two different construction schemes. Due to the differences in pre-order construction steps, the step 60th of scheme I is to install cantilever in the corner, while that in step 38 of plan B is different. The final results are in figure 8.

It can be seen from the figures above that the curve trends are basically the same because the subsequent installation order of the corners is similar. The main cause of the final differences is the starting point and the slope. At the beginning of scheme I, there is initial 42mm vertical displacement due to the cantilever deflection of the corner end. The final displacement is 213mm with a small slope. Scheme II has a vertical displacement of initial 45mm due to the cantilever deflection. The final displacement is 226mm with a relatively high slope. The reason is that the unloading of the lower
crescent part has been completed in the core tube of scheme I, forming a complete structure with increased stiffness. It can provide stronger constraints for subsequent structural installation.

5. Conclusion
In view of the construction of complex giant steel structures, the pre-camber method of roof cantilever truss to compensate the construction deformation of suspended structures is analysed based on the experience of similar projects. By carrying out static analysis with SAP2000, the reasonable pre-camber values of the roof cantilever trusses are obtained. The construction process is nonlinearly simulated for the different construction sequences of the two structures. Through comparative analysis, the optimal construction sequence of the steel structure is proposed, which provides the theoretical basis for the installation accuracy control of the complex giant steel structures.

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