RESEARCH ARTICLE

The research progress on lifting technique of 120 m span steel roof truss

Han-Shi Lu*, **Min-Ming Lu**
Nantong Second Construction Group Co., Ltd., Nantong, Jiangsu 226200, China

Abstract: Assembling and mounting of steel truss of super large span roof are analyzed. Steel truss factory prefabricated parts are used. An overall jig frame is sectionally assembled on site and lifted after being assembled in sections. Then, it is assembled in place in a mode that a temporary support jig frame is erected on site, so that large lifting and transportation equipment can be reduced. Thus, the cost is saved and the construction period is shortened.
Keywords: steel truss, assembling, sectional lifting, jig frame

*Correspondence to: Han-Shi Lu, Nantong Second Construction Group Co., Ltd., Nantong, Jiangsu 226200, China; Email: 594148920@qq.com

Received: July 2, 2017; **Accepted:** August 10, 2017; **Published Online:** September 30, 2017
Citation: Lu H S, Lu M M, 2017, The research progress on lifting technique of 120 m span steel roof truss. *Advances in Material Science*, vol.1(1): 14-21. http://doi.org/10.26789/AMS.2017.01.004

1 Project profile

The 189 mu experiment base in the west Jiangning campus of Hehai University is located in the Jiangning economic and technological development zone of Nanjing, the north side is adjacent to the Focheng road, the west side is the N-ingdan road, and the east side is the Yinlong rod. The steel structure comprises three parts, namely, the water flow experiment hall, the structure experiment hall and the water tower structure. The water flow experiment is of a large span steel roof structure supported by concrete columns and comprises three zones A, B and C. The roof of the zone A is a beam string structure truss and takes the overall planar shape of rectangle, which length is 300 m, width is 120 mm, cross section of the truss is an inverted triangle, main truss span can be 120 m, the highest elevation is 19.3 m, main truss has 21 trusses in all, diameter of the top chord is 377 mm, and diameter of the lower chord is 450 mm. The upper part of the truss consists of a win-dow frame and a C-shaped purline structure. The largest weight of the single truss is 67 t. Zone B is a common inverted triangle three-dimensional truss with planar length is 61 m, width is 47m and the largest span is 61 m. More-over, elevation of the highest point is 15.2 m, main truss comprises 4 trusses in all, the largest weight of a single truss is 32.5 t, and upper part of the truss is frame-shaped purline. Roof of the zone C is also a beam string structure truss, planar length is 90 m, width is 80 m, the largest span of the main truss is 80 m, there are 7 trusses in all, and the largest weight of the single truss is 34 t. Upper part of the truss consists of the window frame and the C-shaped purline structure. The main structure is made of steel Q345B.

2 Material and methods

The steel structure is large in work amount, short in construction period, large in space and much in association with construction field of civil engineering companies. Therefore, assembling field, piling place, movement of crane as well as transportation line of the truss shall be reasonably arranged, extra construction time shall be shortened, and the cost shall be reduced. Therefore, assembling of steel truss and material piling place shall be arranged inside the water flow hall. The truss of the water flow hall is large in span, namely, zone A is 120 m, zone B is 61 m and zone C is 80 m. The truss of zone B is lifted as a whole, the truss of zone A is divided into four sections, the truss of zone C is divided into three sections, and the sections of zones A and C are lifted separately. Besides that, jig frames as temporary support are arranged in the section positions of each truss.

3 Construction deploy

3.1 Assembling field arrangement

The field of the project is wide, the truss is large in span, and a great number of trusses shall be constructed. However, transportation of the truss which is assembled in different sections is highly required. Considering the factors such as crane movement, transportation cost and transportation line, the assembling field shall be arranged inside the mounting construction field, and thus the truss can be directly transported to the mounting site after the crawler crane is demolded. The truss of zone A is 120 m long and is assembled and mounted in four sections. The span of the truss of zone B is 61 m, and the truss is assembled as a whole. The span of the truss of zone C is 80 m, and the truss is assembled in three sections. The choice of truss assembling field. The transportation cost of the truss assembling field shall be taken into ac-count, and mounting convenience after assembling and demolding shall be also considered. Therefore, the assembling field shall be inside the truss mounting field or in an external area adjacent to the mounting field. The span of the main truss of zone A is 120 m, the main truss shall be assembled in four sections, each section is 30 m and is demolded, transported and lifted by using crawler crane. Two assembling fields are arranged between the RS axis and the NL axis, each field occupies space of 125 m × 19 m, and two sets of assembling jig frames are arranged in each field. The secondary truss assembling field can be ar-ranged inside the construction field.

3.2 Transportation lifting line

Zone A construction field is divided into three; south, north and middle areas by the huge jig frames. To ensure the water flow structure, six lines are arranged in the steel roof of the hall and are intersected with axes X-W, T-S, Q-R, L-K, N and D-E at five axes. Four internal crawler crane construction roads are arranged in zone A, and sectional trusses are mounted on each road. With respect to quality and progress, construction shall be carried out from the north and south directions to the middle construction seam simultaneously. According to the requirements and the limit on the on-situ construction field, 2 construction approach roads which are intersected with each other shall be arranged in zone A.

3.3 Road reinforcing treatment

As existing roads shall come across with excavated water corridors, which the crawler crane shall pass should be reinforced so as to ensure the constructed water corridors are not damaged by movement and lifting of the crawler crane.

4 Steel roof lifting scheme

4.1 Steel roof mounting in Zone A

4.1.1 General situation of structure

The roof of zone A of the water flow experiment all of the Hehai University is a beam string structure truss. The roof takes the planar shape of rectangle, length is 300 m and width is 120 m. The cross section of the truss is an inverted triangle, span of the main truss is 120 m, elevation of the highest part is 19.3 m, main truss comprises 21 trusses, diameter of the upper chord is 377 mm, diameter of the lower chord is 450 mm, the largest weight of single truss is 67 t, and main and secondary trusses are welded together. The upper part of the truss consists of a widow frame and a C-shaped purline structure. The roof is of a beam string structure. The plan is as shown in Figure 1.

4.1.2 Truss assembling

Because of large span, the main truss is manufactured in a sectional assembling manner on site, and to ensure the overall mounting precision, the main truss is assembled in sections in an overall factory pre-assembling mode. The main truss and the secondary truss are inverted triangular trusses which are assembled in an overall three-dimensional manner.

Manufacturing of assembling jig frame

Material: jig frames are erected by using steel tubes, profile steel and rectangular tube remains used in former projects. Main truss jig frames: vertical rods and inclined support rods are all welded steel tubes, and large H-shaped steel is adopted as bases. Support rods welded at two ends shall ensure stability of the jig frames, the vertical rods are weld-ed with the H-shaped steel at the bottom, an inclined sup-port rod is additionally arranged on the outer side, the vertical rods also have the function of limiting profiling, and the outer sides of chords are tightly adhered to the vertical rods when being assembled. To ensure that the jig frames have sufficient space to weld the web rods, the jig frames shall be mounted beyond the joints. The positions of the jig frames shall be determined ac-cording to the joint positions of the chords of the main truss, with the interval between jig frames shall not exceed 5 m. Four sets of jig frames shall be manufactured for each section of the main truss, and to ensure that the main truss is successfully assembled. Lifting equipment and jig frames shall be added according to practical construction progress [1]. Specific height of each jig frame shall be controlled by operators in the field according to the truss jig frame lay-out chart.

Jig frame assembling procedure and process

Draw the setting-out plan by technicians used computer, follow by mark the setting-out sizes, then set out the material and mark the assembling control points by operators by using marking pen. After that, place the jig frames according to the setting-out plan, then control the levelness of the jig frames by using gradienter and theodolite, continue with unify the elevation of the jig frames, then lift the chords in a pneumatic manner to place in corresponding positions in the jig frames. Moreover, measure the positions of web rod joints on the chords according to the setting-out plan on the ground, follow with assemble and weld the web rods, finally demold the assembled overall component. The main and secondary trusses are inverted triangular trusses, considering convenience in demolding and transporting the main truss backwards, overall horizontal assembling is adopted, and the assembled truss are transported to the lifting parts in sections. The beam string structure truss of zone A comprises four trusses, namely, ZHJ-1, ZHJ-2, ZHJ-3 and ZHJ-4, and ev-ery two beam string structure trusses are symmetric relative to the span axis. Due to the large span, sectional lifting method was adopted. Each beam string structure truss is divided into four sections, and each section was about 30 m long. The situation that mounting of web rods near the abutting position shall not be affected by upper support chords of the jig frames shall be also considered, so that through joints

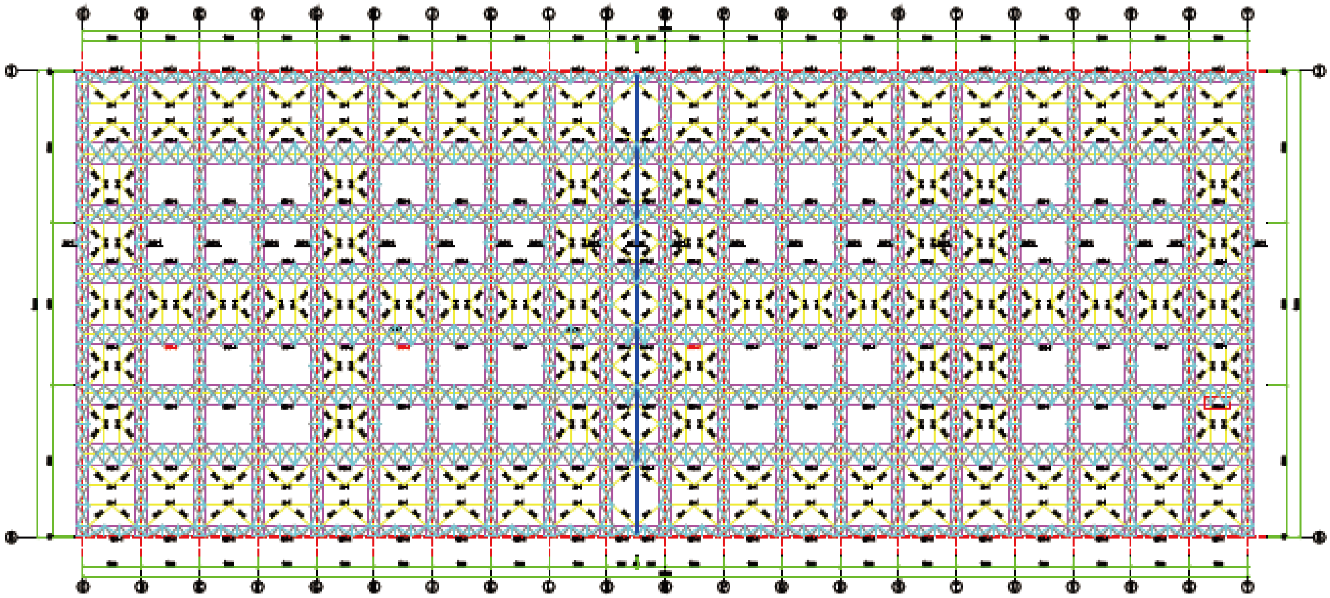

Figure 1. Plan layout chart of structure of zone A.

of the upper chord web rods shall be avoid-ed when the jig frames are arranged[2]. Division of lifting units of trusses is as shown in Figure 2.

4.2 Truss lifting

4.2.1 Lifting point and gravity center confirmation

Cross section of the truss of the roof takes the shape of inverted triangle, so that lifting points of the lifting unit are arranged on upper chord of the truss, steel wire ropes are connected with the joint of upper chord, and the units were lifted in a four-point manner. As the trusses are symmetric, left half section of the truss structure is taken as example. Left half section of each truss is divided into two lifting units, namely, left unit and middle unit. According to calculation, as cross sections of the trusses are symmetric, the gravity center is right above lower chord. On vertical plane, the gravity centers of different truss lifting units are as shown in Figure 3 (Figure 3.1 to 3.8).

4.2.2 Lifting point and gravity center confirmation

According to features of truss on site, the heaviest truss is adopted for internal lifting force analysis. ZHJ3 is adopted for analysis in zone A. Simple graph of four-section lifting is as shown in Figure 4 (Figure 4.1 to 4.4).

4.2.3 Statistics of sectional internal force of truss

Calculate the internal force of different rods according to models, and calculate other corresponding internal force values of the maximum and minimum internal forces of different sections. The maximum and minimum internal forces of the rods are as shown in Table 1.

Due to establishment and calculation of the calculation model of the rod truss, bearing strength, overall stability around axis, anti-shearing stress ratio and deformation of different trusses can be analyzed through software, and the internal force to the rods can meet the lifting requirements.

4.2.4 Lifting situation

According to structure features, the truss of zone A is divided into four sections, each section was lifted separately, and the maximum lifting weight is 18.5 t, so that the crawler crane of 100 t is adopted. Situation I: the working radius is 18 m, and one section of truss is 15 t in self weight. The lifting weight of the crawler crane of 100 t is 20.9 t, so that the lifting requirements can be met. After the main truss mounted, a truck-mounted crane of 25 t is adopted to mount the secondary truss and the window frame between two main trusses. Situation II: after the section I mounted, section II shall be mounted in the direction of axis 1. The working radius of the section II is 18 m, and the self-weight of the truss is 16 t. When the working radius of the crawler crane of 100 t is 18 m, the lifting weight is 20.9 t, so that the lifting requirements can be met. After the main truss mounted, the truck-mounted crane of 25 t is adopted to mount the secondary truss and the window frame between two main trusses. Situation III: after the section II mounted, section III shall be mounted in the direction of axis 1. The working radius of the section III is 18 m, and the self-weight of the truss is 17.5 t. When the working radius of the crawler crane of 100 t is 18 m, the lifting weight is 20.9 t, so that the lifting requirements can be met. After the main truss mounted, the truck-mounted crane of 25 t is adopted to mount the secondary truss and the window frame between two main trusses. Situation IV: the section IV finally mounted. The self-weight of the fourth section of truss is 18.5 t. When the

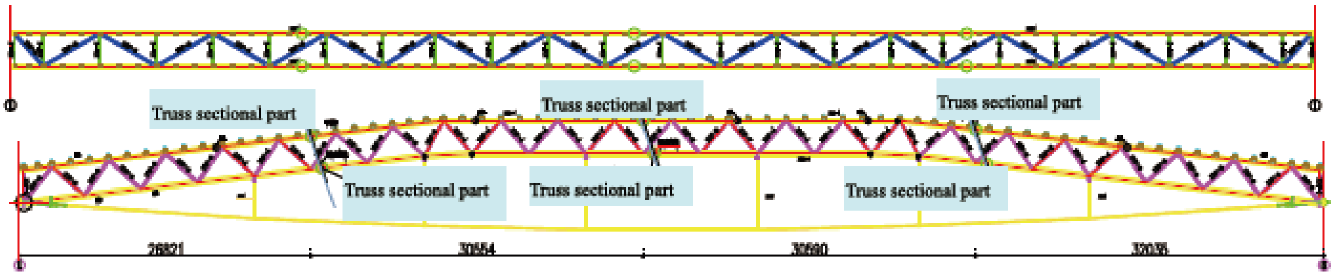

Figure 2. Lifting sectional point of main truss of zone A.

Table1.Unit internal force statistics of maximum and minimum internal forces of rods (unit: N, kN, kN, M)

Serial No.	Section No.	Maximum and minimum internal forces of rods	Position	Axial force N	Shearing force Q2	Shearing force Q3	Torque M	Bending moment M2	Bending moment M3
1	12	Maximum axial force N()	0.000	83.2	0.6	0.0	0.6	0.0	0.0
2		Minimum axial force N	5.250	-69.5	-9.0	-33.1	-2.2	-151.7	11.4
3		Maximum bending moment M3	0.000	-12.3	10.7	29.5	-3.7	-156	11.4
4		Minimum bending momentM3	3.294	-13.5	0.6	29.5	-3.7	-58.9	-7.1
5	23	Maximum axial force N	0.000	75.4	0.0	0.0	0.0	0.0	0.0
6		Minimum axial force N	0.875	-180.2	2.4	-0.1	-0.0	0.6	2.6
7		Maximum bending moment M3	5.250	-61.8	-5.7	-0.3	-0.1	-1.0	14.4
8		Minimum bending moment M3	0.000	32.8	-21.9	3.1	0.0	-1.7	-11.5
9	34	Maximum axial force N	0.000	86.0	0.0	0.0	0.0	0.0	0.0
10		Minimum axial force N	0.437	-154.6	2.6	-0.1	-0.0	0.1	4.2
11		Maximum bending moment M3	5.250	14.3	-8.2	-0.7	0.0	-2.0	14.6
12		Minimum bending moment M3	3.500	4.1	0.1	0.6	0.0	0.7	-2.8
13	45	Maximum axial force N	0.000	65.4	0.6	0.0	0.3	0.0	0.0
14		Minimum axial force N	0.000	-113.0	3.9	-0.9	-0.2	2.6	6.2
15		Maximum bending momentM3	5.250	-30.3	-4.7	0.1	-0.1	0.1	10.6
16		Minimum bending moment M3	3.294	-4.3	0.4	14.2	-1.8	-28.4	-7.7

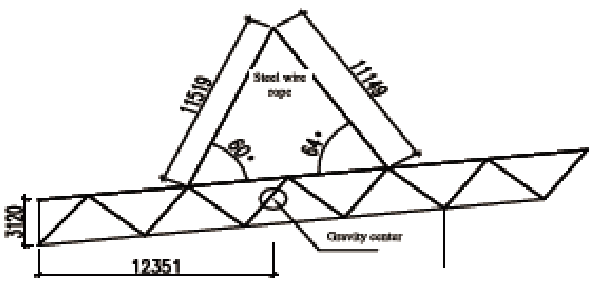

Figure 3.1. Relative gravity center position and lifting point position of left section ZHJ-1.

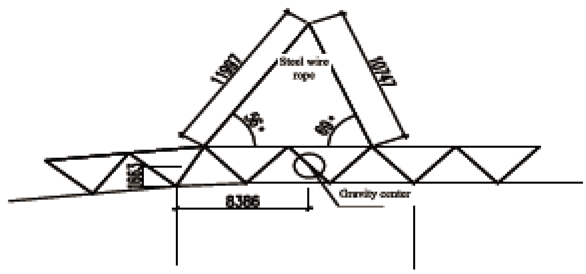

Figure 3.2. Relative gravity center position and lifting point position of left section ZHJ-1.

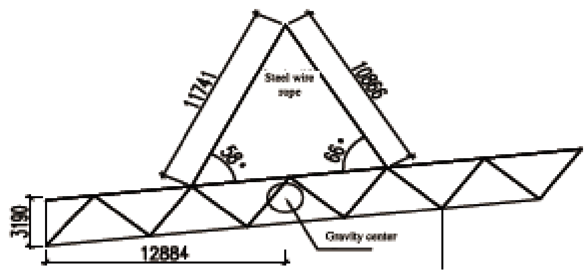

Figure 3.3. Relative gravity center position and lifting point position of left section ZHJ-2.

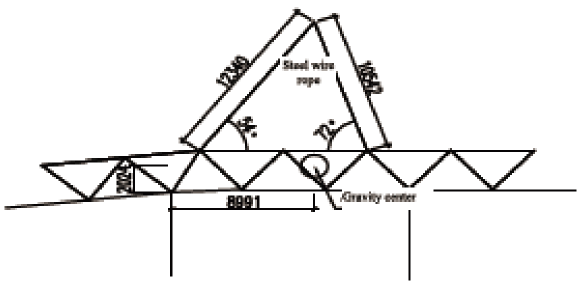

Figure 3.4. Relative gravity center position and lifting point position of middle section ZHJ-2.

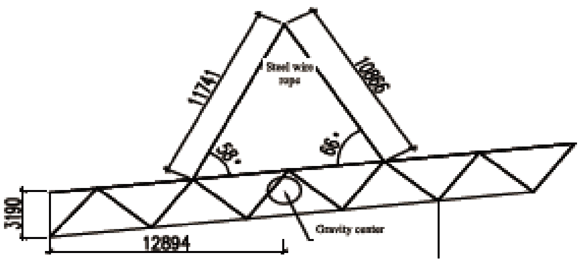

Figure 3.5. Relative gravity center position and lifting point position of left section ZHJ-3.

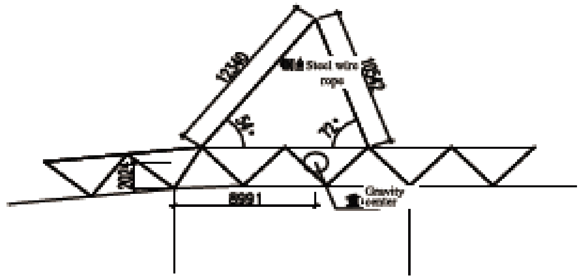

Figure 3.6. Relative gravity center position and lifting point position of left section ZHJ-3.

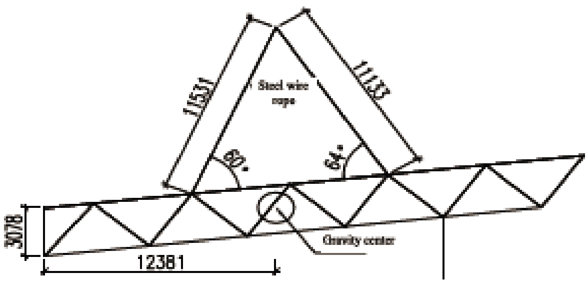

Figure 3.7. Relative gravity center position and lifting point position of left section ZHJ-4.

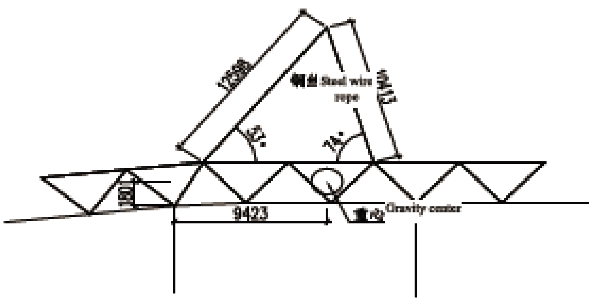

Figure 3.8. Relative gravity center position and lifting point position of left section ZHJ-4.

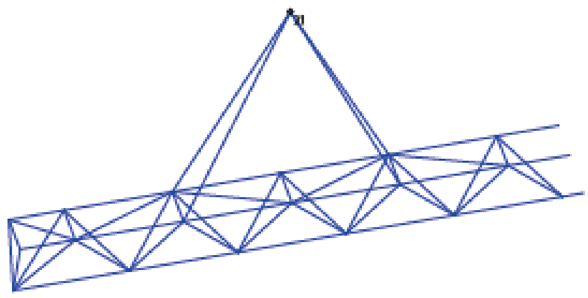

Figure 4.1. Section 12 of zone A.

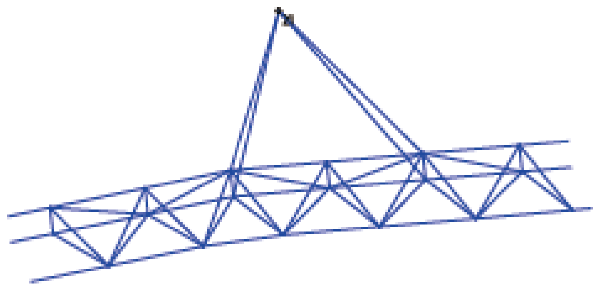

Figure 4.2. Section 23 of zone A.

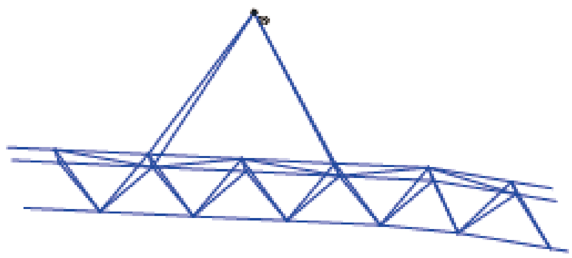

Figure 4.3. Section 34 of zone A.

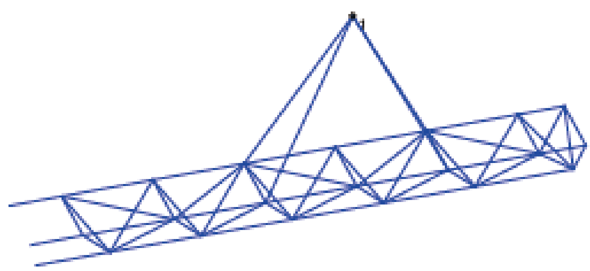

Figure 4.4. Section 45 of zone A.

Table2. Component lifting mode table.

No. of component	Total length (m)	Section length (m)	Weight (t)	Lifting height (m)	Lifting point selection	Crane selection	Lifting rope selection
Main truss of zone A	120	28 – 32	15 – 18.5	20	Four-point tying Two-point lifting	100 t crawler crane	6 * 19 + 1 Steel wire rope with diameter of φ34

working radius of the crawler crane of 100 t is 18 m, the lifting weight is 20.9 t, so that the lifting requirements can be met. After the main truss mounted, the truck-mounted crane of 25 t is adopted to mount the secondary truss and the window frame between two main trusses.

4.2.5 Checking calculation of lifting steel wire rope

Lifting modes and lifting point arrangement of lifting components are as shown in Table 2. The pull force to the steel wire rope is calculated according to:

$$T = G/(4 * sin\alpha)$$

Where Tpull force to steel wire rope (N); Gweight of component, weight of maximum steel truss after sectioning: 18.5 t; included angle of steel wire rope and com-ponent; Minimum α = 53 degrees. Then:

$$T = 18.5 * 9.8/(4 * sin53) = 56.8kN$$

Safety coefficient of steel wire rope (safety coefficient of tying lifting rope is 810):

$$\sigma = \frac{3FL}{2bh^2}$$

According to the technical parameter table of the steel wire rope, the breaking pull force of the steel wire rope with the diameter of φ 34, 6 * 19 + 1 is 606 kN under the condition that the anti-pull strength is met, and the steel wire rope can meet the lifting requirements.

4.2.6 Support jig frame setup

Support arrangement Main truss of the beam string structure truss of zone A is mounted in four sections. When being mounted, the jig frames are erected in the combination positions and are used for supporting and fixing two upper chord steel tubes of the truss[3]. As shown in Figure 5, ϕ114 and ϕ60 steel tubes are made into standard sections of 6 m 2 m by us-ing in workshop in advance, and are transported to the field to assemble the jig frames. The standard sections are connected by using M20 high-strength bolts and thus can be conveniently disassembled to recycle repeatedly, and the mounting time can be shortened[4]. As shown in Figure 6.

The base box is 0.2 m thick, 8.6 m long and 1.6 m wide, and two bases are arranged below each support. Connected parts of the base boxes and the jig frames are fixed by using clamping plates of 20 mm thick, and clamping plates are welded with the base boxes. As shown in Figure 7.

Upper parts of the jig frames are solidified by using 4 ϕ 12 steel wire ropes, and two ϕ 189 steel tubes are arranged on two adjacent main rods of the jig frames below the rope support by using two ϕ 20 high-strength bolts. Internal force analysis on self-weight of jig frame bearing truss. The beam string structure truss of zone A is lifted in four sections, and jig frames shall be arranged at three points[5]. Support jig frames for longitudinal and transverse sup-port and window frame of the roof of the beam string structure are subjected to maximum force of 185 kN. Live load in the mounting process shall be taken into account, the axial force is 240 kN, and eccentric distance is 0.5 m. The maximum height of the support jig frame is 19.52 m, and 20 m is adopted in calculation; structural column cross section is a rectangular cross section of 2000 mm * 2000 mm primarily, and Q235 steel is adopted. Maximum horizontal displacement and vertical and transverse displacement are combined, and according to analysis on calculation model, the maximum deformation displacement position of the jig frame is at the uppermost end of the jig frame (those of the 10th and 130th jig frames are respectively on the outer side and inner side angles of the top parts of the jig frames), the maximum vertical displacement is 2.5 mm, the assembling precision requirements of the steel truss are not affected, and to control lateral displacement of the steel truss, cable ropes are added at the upper part of the jig frame so as to reduce lateral de-formation of the jig frame. For the maximum displacement of the rod while the jig frame is in the mounting bearing state, the total displacement at the #10 point is 5.1 mm, the maximum displacement in the X-direction is 2.9 mm, the maximum displacement in the Y-direction is 3.9 mm, and the maximum displacement in the Z-direction is 1.4 mm (compression); the total displacement of the #130 point is 5.0 mm, the maximum displacement in the X-direction is 2.5 mm, the maximum displacement in the Y-direction is 3.6 mm and the maximum displacement in the Z-direction is 2.5 mm (compression).

Conflicts of interest

These authors have no conflicts of interest to declare.

Authors contributions

These authors contributed equally to this work.

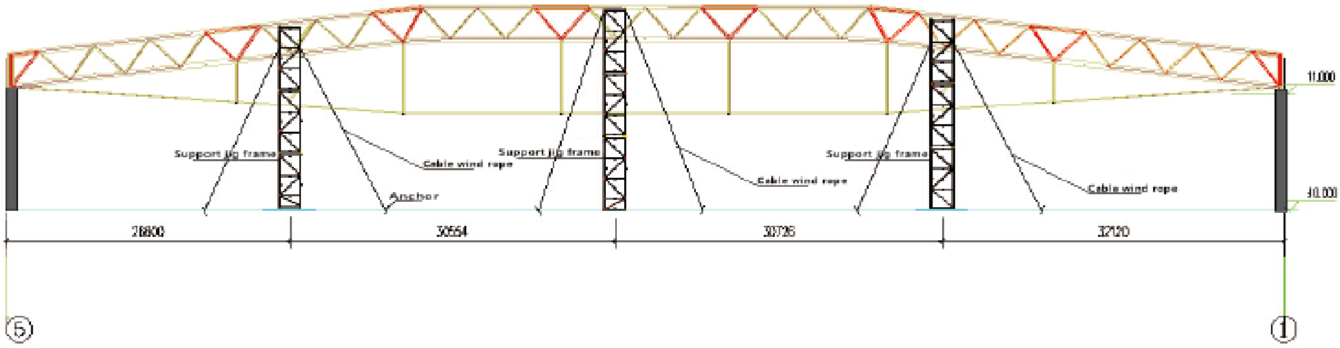

Figure 5. Layout chart of support jig frames.

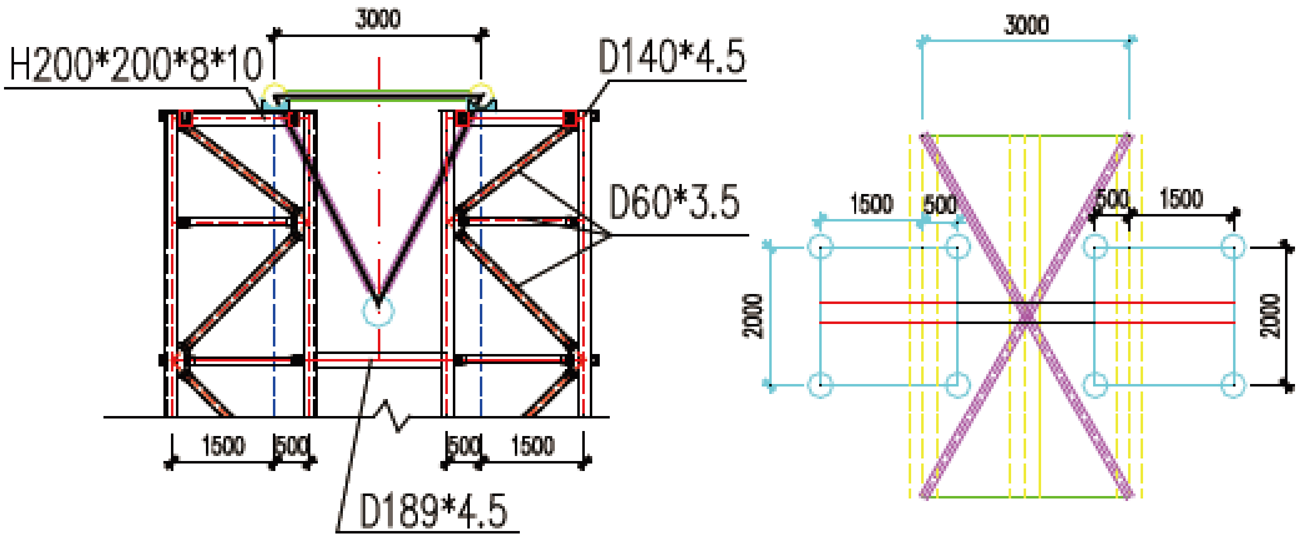

Figure 6. Details of joints of jig frames of zone A.

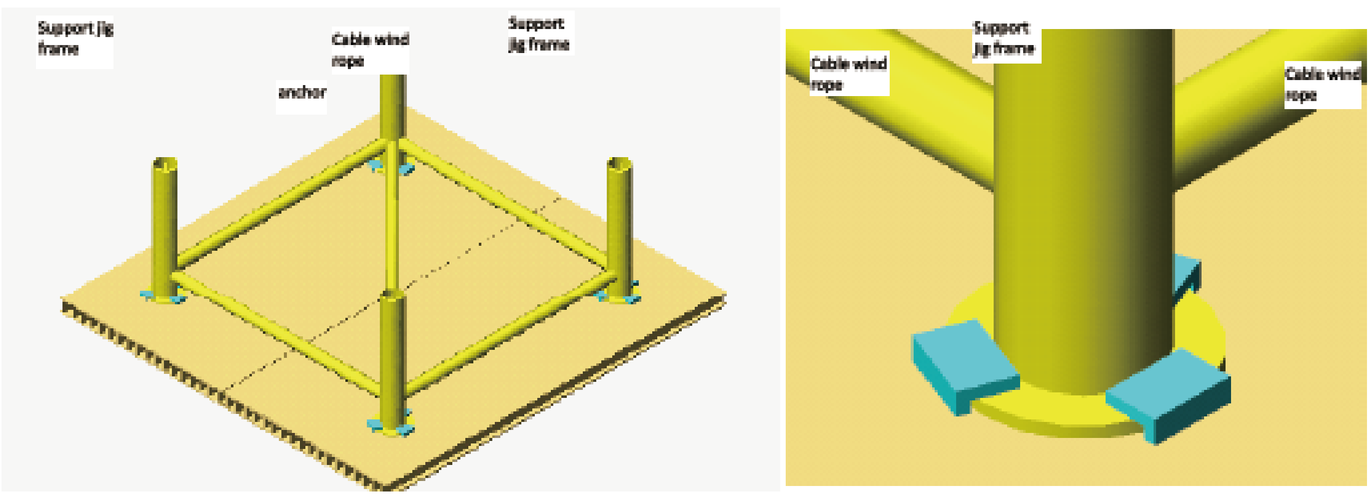

Figure 7. Schematic diagram of bottom joint of support jig frame.

References

[1] Central Research Institute of Building and Construction Ministry of Metallurgical Industry, 2002, *Code for acceptance of construction quality of steel structures*,China Planning Press, China.

[2] Liu W, 2001, Design and study on steel tube arch of Nanjing international exhibition center. *Building Structure*, vol.08: 31-33, 42.

[3] Li J Q, Chen Y F and Liu X F, 2006, Construction and mounting technique of large span steel tube truss. *Inner Mongolia Science Technology Economy*, vol.9.

[4] Zhang R S and Song H Z, 2009, Mounting technique of large-span truss steel roof of Tianjing airport terminal. *Tianjin Construction Science and Technology*, vol.02.

[5] Deng Y S, 2012, Mounting and construction technique of s-tadium tube truss structure. *Fujin Construction*, vol.08.