Block Sliding Construction Technology of Large-span Prestressed Steel Truss Structure

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Abstract. This work, based on the construction process of large-span prestressed steel truss structure roof of Weifang Medical College as an example, used the load test calculation and construction process simulation analysis method to study the prestressed steel truss roof structure, ground single truss assembly, double machine lifting, string cable pretension, truss composition unit, unit block sliding, construction process force, deformation, and technologies. Under the constraints of the site, machinery, construction period and other conditions, the problem of large span and deep components was solved. It not only contributes to ensuring the quality and safety of the project structure but also makes all kinds of work operate simultaneously, which is conducive to shortening the construction period.

Keywords: Large-span steel truss, simulation analysis, prestressed pretension, unit block slip.

1. Project overview

The Cultural and Sports Center is located in the Fuyanshan Campus of Weifang Medical College, with a construction area of 25877.31 m^2 (one floor underground and three floors above ground). The main roof frame is a large-span tension-chord prestressed steel truss space structure as shown in Figure 1. The top elevation of the structure is +22.70 m, the support elevation is +13.80 m, and the truss height is 8.90 m. For the nine transverse main trusses with a span of 66 m, the span of the middle seven trusses is 66 m and the suspension cable is located at the bottom of the truss with a length of 43.60 m. Two trusses are at the end, with a span of 49.20 m, and a support elevation of +18.70 m. The rod adopts Q345B seamless steel pipe, and the string cable adopts a 5139 mm high strength galvanized steel wire. The amount of steel used for the truss is about 310 t.

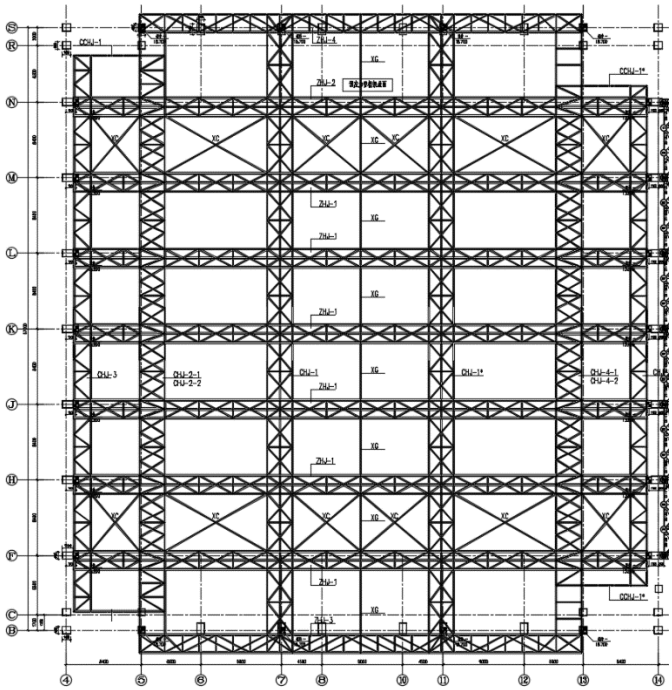


Figure 1. Steel truss plan

2. Key points and difficult points in truss installation

The whole truss is hoisted with a large-span, long-distance, high drop point and heavyweight. The lifting point is not a support point to change the stress state, and the stress and strain of the rod are easy to exceed the limit.

High truss, long span "π" type steel truss has large transverse displacement to avoid sliding lateral friction with difficulty.

The inverted triangle steel truss, how to form a sliding block to ensure safety and stability.

The roof has no operating platform, the main and secondary trusses are welded at high altitude, and the construction is difficult.

The two ends of the truss are located on the column side bracket. The slide rail has no longitudinal beam support, and a stable guide rail beam should be installed along the direction of the slide track.

The large-span steel truss has high altitude rail slide, and both ends are synchronous with no offset and no track stuck as the focus of control.

3. Determining the truss installation scheme

The steel truss is located in the middle of the project roof with the basement under the venue, and the main ground and the audience stands along with the main structure of the project has been constructed. Considering the truss space location, structural characteristics, mechanical lifting capacity, site conditions, construction cost, and schedule, the whole outdoor assembly is used based on the computer simulation analysis and previous engineering examples. The construction scheme of the prestressed string cable is graded and pre-stretched, and the two main trusses are connected into a sliding unit. The sliding trusses are unloaded in place, and other trusses are installed in situ.

4. Track slip system

The sliding truss is supported on the +13.80 m with elevation 4-axis, 14-axis column on the bracket, without longitudinal beam, so two sliding rails should be installed on the two-axis column bracket.

4.1. Selection of the track beam type

The track beam is of HM588×300×12×20, connected with L75 corner steel for the concrete frame column. The beam span is 8.400 m, the calculated length outside the plane is 8.400 m, the width, and width ratio of the plate is S3, the allowable deflection limit [υ]-l/400 = 21mm, and the strength calculated net section coefficient is 1.000. Under the action of dead weight, the rail beam is a one-way vertical load.

4.2. Action and checking of the track beam

Section characteristics

$A = 1.8720 \times 10^{-2}$;

$X_c = 1.5000 \times 10^{-1}$, $Y_c = 2.9400 \times 10^{-1}$;

$I_x = 1.1400 \times 10^{-3}$, $I_y = 9.0100 \times 10^{-5}$;

$i_x = 2.4700 \times 10^{-1}$; $i_y = 6.9300 \times 10^{-2}$;

$W_{1x} = 3.8900 \times 10^{-3}$, $W_{2x} = 3.8900 \times 10^{-3}$;

$W_{1y} = 6.0100 \times 10^{-4}$, $W_{2y} = 6.0100 \times 10^{-4}$.

Track beam self-weight is shown in Table 1.

Rail beam dead weight $G = 1.4695 \times 10^{2}$ kG/m, converted to the beam average wiring load p=1.4401 kN/m.

Table 1. Support reaction under single working condition

Load type	Left support reverse force (kN)	Right support reverse force (kN)
Constant load standard value	R_{d1}=6.172	R_{d2}=6.172
Live load standard value	R_{l1}=120.000	R_{l2}=120.000

The internal force calculation of the beam section of load combination 1 (1.2 constant + 1.4 live) is shown in Table 2.

Table 2. Internal force of track beam section.

Section number	Bending moment (kN.m)	Shear force (kN)
1	-0.000	175.406
2	122.352	174.172
3	243.841	172.938
4	364.465	171.703
5	484.225	170.469
6	603.121	169.23
7	721.153	-168.000
8	603.121	-169.234
9	484.225	-170.469
10	364.465	-171.703
11	243.841	-172.938
12	122.353	-174.172
13	-0.000	-175.406

The combination 2 (1.35 constant + 0.71.4 live) track section internal force is shown in Table 3.

Table 3. Internal force of track beam section.

Section number	Bending moment (kN.m)	Shear force (kN)
1	-0.000	125.932
2	87.666	124.543
3	174.361	123.15
4	260.0835	121.76
5	344.833	120.37
6	428.612	118.989
7	511.418	-117.600
8	428.612	-118.989
9	344.833	-120.377
10	260.08	-121.766
11	174.361	-123.155
12	87.66	-124.543
13	-0.000	-125.932

For the maximum live bending moment of rail beam occurs in the load combination 1, the middle position is 721.153 kN·m, the maximum stress is 176.559 N/mm^2 < f=295.000 N/mm^2, implying that the bending strength of rail beam has been satisfied. For the maximum acting shear of the rail beam occurs in the load combination 1, the bearing position is 175.406 kN, and the maximum calculated shear stress is 27.877 N/mm^2 < f_v=175.000 N/mm^2, implying that the shear bearing capacity of the rail beam has been satisfied.

The local stability test calculation is shown in Table 4.

Table 4. Local stability checking.

Flange width to thickness ratio	B/T=6.55	Tolerable width and thickness ratio [B/T] =10.7	B/T < [B/T]
Plate height to thickness ratio	H_0/T_w=43.50	Tolerable height to thickness ratio $[H_0/T_w]$ =76.8	$H_0/T_w<[H_0/T_w]$

Overall stability test of track beam: The thin-length ratio of rail beam plane is λ_y: 121.212, overall stability coefficient φ_b is 0.637, the maximum positive bending moment occurs in the middle position of the load combination is 721.153kN·m, the maximum stress calculation value is 291.141 < f=295.000N/mm^{2,} implying that the overall stability of the track beam is satisfied.

The tracking beam deflection test calculation is shown in Table 5.

Table 5. Deflection checking calculation of track beam.

Section number	Bending moment (kN.m)	Shear force (kN)	Toughing value (mm)
1	-0.000	126.172	0.000
2	87.960	125.143	3.232
3	175.201	124.115	6.280
4	261.721	123.086	8.963
5	347.521	122.057	11.100
6	432.601	121.029	12.513
7	516.961	-120.000	13.023
8	432.601	-121.029	12.513
9	347.521	-122.05	11.100
10	261.721	-123.08	8.963
11	175.201	-124.11	6.280
12	87.960	-125.14	3.232
13	-0.000	-126.172	0.000

The standard load combination is 1.0 constant + 1.0 live, maximum deflection position is 4.200 m, maximum deflection is 13.023 mm < tolerable deflection 21 mm, so the track beam deflection test is satisfied. This concludes that the bending strength, shear bearing capacity, overall stability and deflection of the HM588×300×12×20 rail beam can be used to meet the construction requirements.

4.3. Sliding model and test calculation

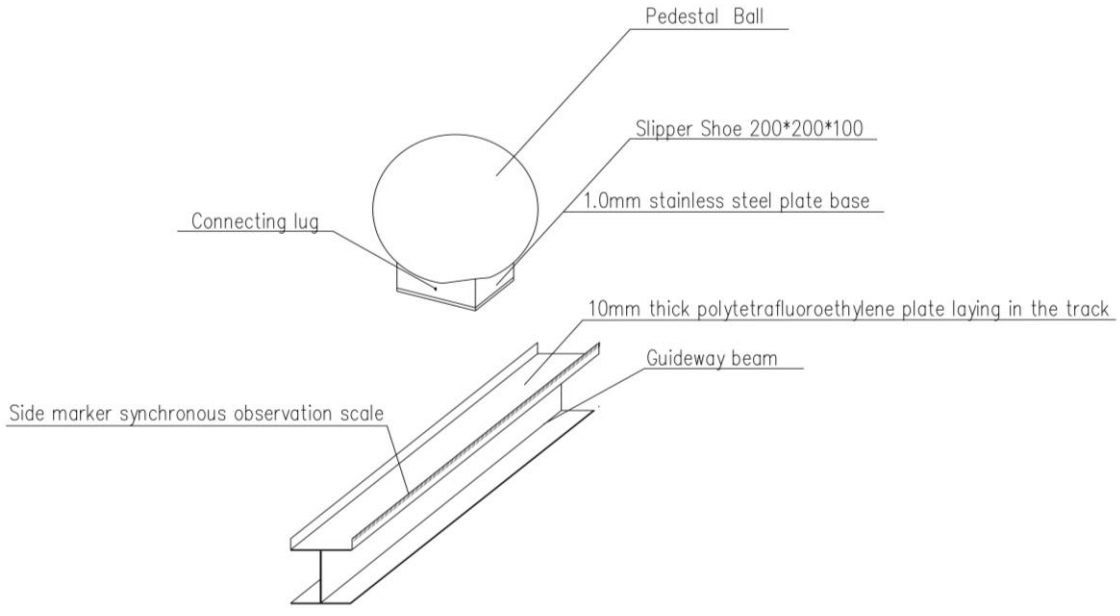


Figure 2. Schematic diagram of rail beam and slipper.

The sliding track system model is shown in Fig.2. The sliding track is welded with the groove steel 28 #a and the rail beam. The friction coefficient of PVC plate and stainless steel is 0.01, and the maximum total tonnage of the slide unit block is 74 t, namely, the friction force is F=N×f=74×10×0.01=7.4 kN. An inverted chain pull is F/2 =3.7 kN, and a 5t inverted chain gourd is selected. Select the 11 mm diameter wire rope according to the breaking tension to meet the use requirements.

5. Selection and layout of car crane

The truss slides from east to west, and the crane is placed at the component stacking site on the east side of the building. The single main truss is 34 t and the longest distance (M shaft) is 34 m. Two 300 t vehicle cranes are selected to meet the lifting requirements.

6. Truss lifting

6.1. Assembly of the truss unit

Build tire frame in the loose parts assembly area according to the requirements for hoisting preparation.

6.2. Simulation analysis of lifting working condition

The large-span whole truss lifting has great external impact, and the truss deformation and stress are not designed and controllable. ANSYS finite element simulation modeling analysis is used for truss lifting in advance to understand the changes of rods under each working condition and solve problems in advance. The hoisting of the main truss is divided into three working conditions: the tire frame (Fig. 3), 45-degree state (Fig. 4), and lifting process (Fig. 5).

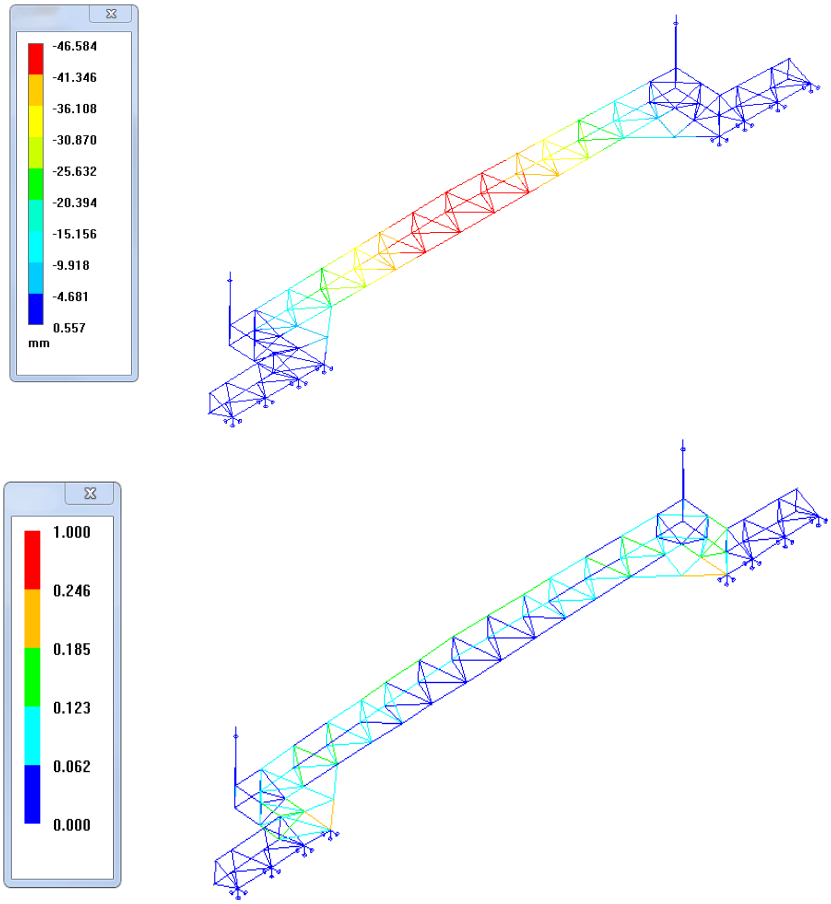


Figure 3. Force analysis diagram of off-platform state.

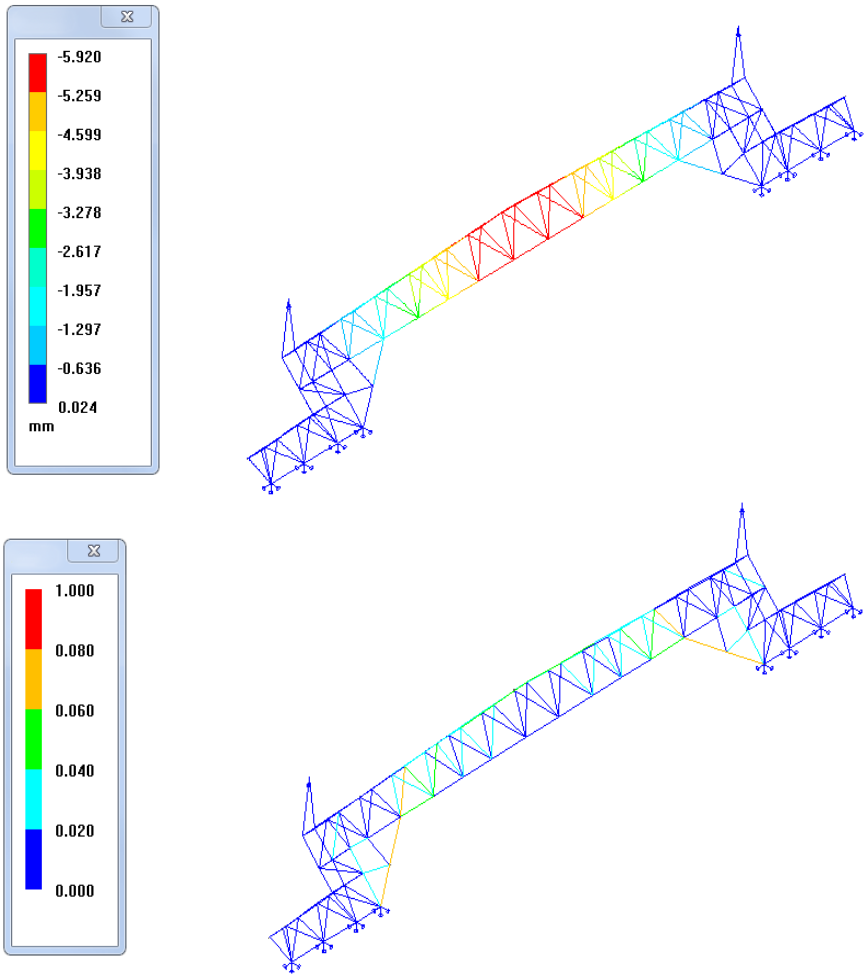
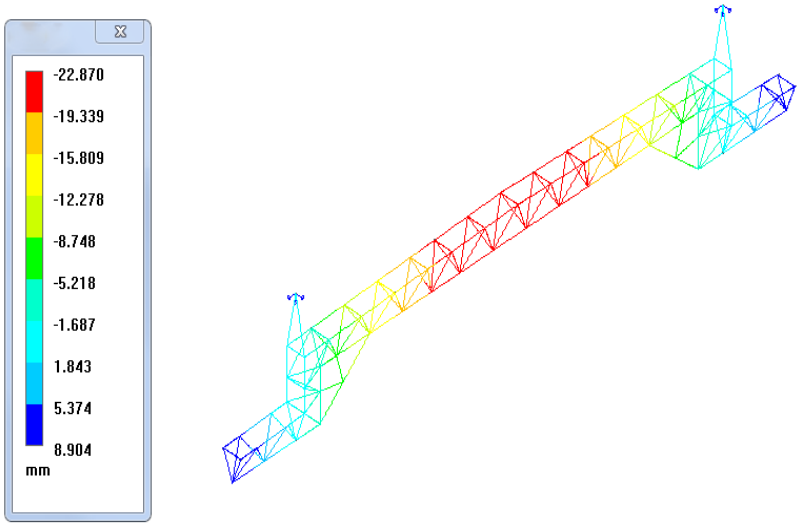


Figure 4. The 45 degree stress analysis diagram.



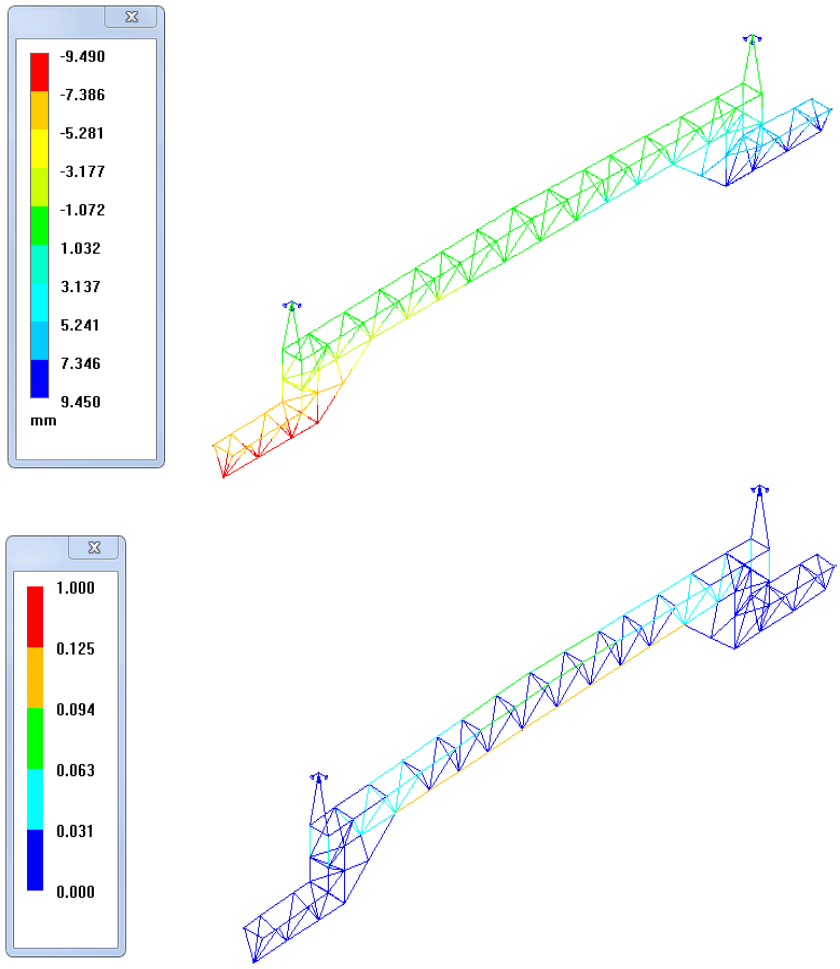


Figure 5. The mechanical analysis diagram of hoisting process.

The force analysis results of the model show that the maximum displacement and maximum stress ratio of the hoisting process occur during the truss separation, and the maximum displacement is Z to 46.58 mm, less than 1/400. The maximum stress ratio is 0.246 (less than 1), which meets the deflection requirements.

7. Slide-shifting technology of truss construction

7.1. Hoisting of truss and pre-tension of string cable

The main truss of axis F and axis H is assembled on the ground, with binding wire rope and lifted at uniform speed. In the lifting process, the center of mass is in center, both ends of the truss are flat to observe the state of the lifting components at any time to ensure the stability in the air. When sliding, it needs to observe the side mark scale of the slide and manually fine tune the slide boots to ensure the accurate fall into the specified position of the slide. Subsequently, the cable wind rope is temporarily fixed to prevent overturning. The prestressed string cable is determined according to the principle of span displacement and minimum span deflection under the action of the dead weight of the truss, and the initial tension value of the string cable is 550 kN. The string cable realizes the first-stage tension, and the medium deflection is 3mm upward to ensure that the truss deflection and support displacement are controlled within the allowable limit.

7.2. Assembly of the first set of sliding units

Welding secondary trusses between the F axis and H axis main trusses form an independent stable sliding unit on the sliding track.

7.3. The first set of unit slides

During removing the cable wind rope, one brake and two machines start the inverted chain gourd on both sides at the same time. The sliding unit slides along the sliding track to the corresponding axis position of the F axis and H axis under the action of traction force, as shown in Fig. 6

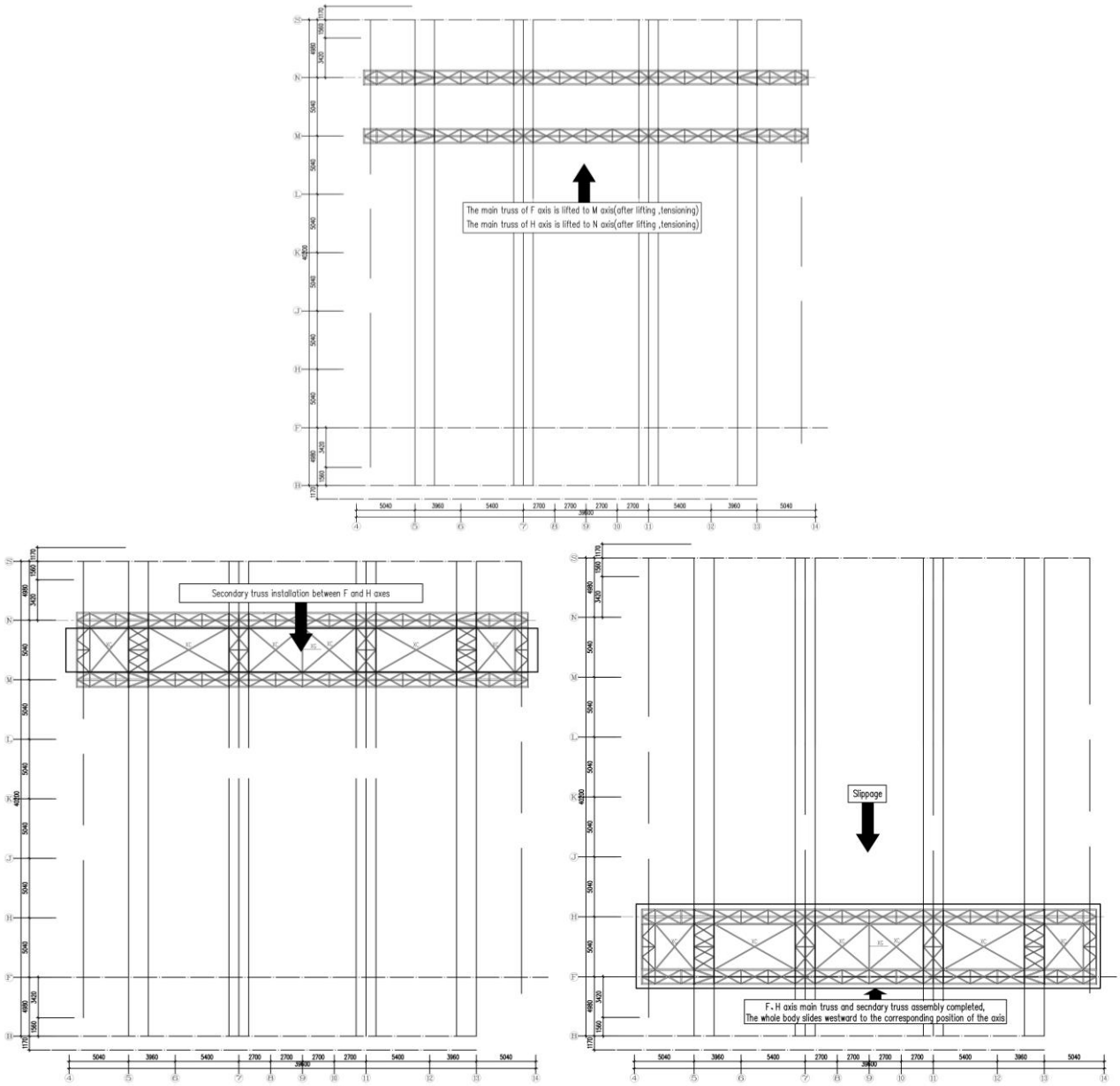


Figure 6. Group 1 unit block slip process.

7.4. The second set of sliding units slide

In the same way, K axis, J axis truss lifting, string cable tension, connecting the secondary truss slide to the corresponding axis position of K and J axis.

7.5. Truss slip to a certain place

Secondary truss connection between the main trusses of shaft J and shaft H. Then, the third group of M-axis and L-axis truss units are assembled. By connecting the secondary truss between L and K axes, the three group trusses are installed in place.

7.6. Slide-shift truss unloading

After the truss slides are in place, install four jacks on each truss boot site. Lift the overall truss evenly according to the requirements, remove the slide and sliding boots, and then drop the whole to the corresponding truss support to complete the truss unloading.

7.7. In-situ hoisting of other trusses

The main truss of N axis, S axis, and B axis is directly hoisted to the corresponding position of its axis support to connect the secondary truss and complete the installation.

7.8. Pulling the string cable according to the roof load condition

After the installation of the truss, the installation shall be completed in stages according to the roof steel beam purlin, roof panel and roof works. According to the graded tensioning value, graded tensioning ensures that the truss rod has uniform force, controllable deflection, and safe structure during construction.

8. Process monitoring

In the process of truss lifting and sliding, the truss deflection, support displacement and sliding synchronization should be controlled.

8.1. Arrangement of monitoring points

Under the truss string (sliding direction side), it puts the reflectors on the welded hollow ball of the middle and quarter span and support while recording the coordinate values of the truss slide, as shown in Fig. 7.

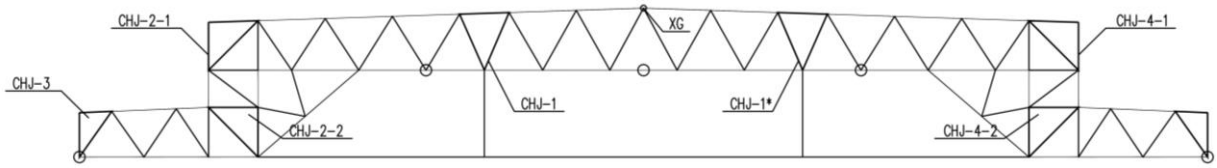


Figure 7. The layout of monitoring points.

8.2. Monitoring of deflection and displacement

During the sliding process of the truss, it needs to constantly inspect the sliding state, and special personnel shall observe and record the deflection and displacement of the truss. If an abnormality is found, it needs to stop immediately to find out the cause, troubleshoot and slide again. During the process of truss installation, the maximum deflection occurs in the K axis main truss span, the lower deflection is 8 mm, and the maximum change of support transduction displacement occurs in the total M shaft truss with 13 mm. Within two months of roof completion, the maximum deflection of the span is 48 mm (tolerable value 109 mm).In conclusion, during the construction period, the maximum deflection of the truss, the support displacement remain stable and controllable. The measured value does not exceed the design allowable value, and the structure is safe.

8.3. Synchronous slide monitoring

The main factors that affect the truss slide are the offset of the slide unit and the traction force. For the sliding process, the patrol and control personnel should correct the side scale in time to ensure that the two slides are synchronized. The reverse chain gourd model is consistent, start and stop one brake and two machines, to ensure the synchronous operation of the gourd at the same time with consistent traction.

9. Conclusion

In the large-span steel structure installation project, there are many uncontrollable factors in the construction process, which can cause potential safety risks. Thus, the engineering analysis software shall be used in advance to simulate the stress state, and strengthening measures shall be taken according to the actual situation. For the construction of prestressed steel truss, it is necessary to scientifically calculate the graded tension of string cable and adopt the graded tension process to ensure the truss deflection, controllable stress, and structural safety in the sliding process. Large-span steel truss adopts the unit block sliding construction technology, which can ensure the consistent volume and type of the sliding unit. Also, The traction force can balance, and the sliding process offset, rail stuck, and synchronization can be easy to control. The successful operation case of truss sliding construction provides a reference for similar engineering construction in the future.

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