Original Research Article

# Construction of Long-span Tensioned Membrane Structure in Zhijiang Feihu Sports Center

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***Abstract:*** Based on the author's experience in the past twenty years, this paper describes the construction process of membrane structure of space structure. The construction process of long-span tensioned membrane structure is mainly introduced.

***Keywords:*** Truss; Span; Membrane structure; Construction.

## 1. Project Overview

The stand project of Zhijiang Flying Tiger Sports Center is located in Zhijiang Dong Autonomous County, Huaihua City, Hunan Province. The main body is membrane structure and the structure form is skeleton type. PVC membrane body, membrane body area of about 12150 $m^2$ . The height of the grandstand roof is 30.900m, and the span of the main truss of the structure is 270m, which is the largest span in China. The overall atmosphere of the stand, with the membrane structure cover, complement each other.

Zhijiang Dong Autonomous County, the newly built Zhijiang Sports Center with a large span of tension-membrane structure sports stands, in China's minority areas is relatively rare, vigorously support the construction of spiritual civilization and economic development of minority areas, fully reflects the Party and the state's ethnic care policy.

## 2. Structural System

This project is the main body of steel truss, and the membrane structure of the roof. The characteristics and difficulties of this project are analyzed: (1) The main body is curved steel truss, which requires high precision of structure production and installation in order to meet the stress characteristics of the membrane; (2) Under the premise of full structural calculation and analysis, the curved steel truss has a greater force on the lower foundation. In view of the two difficulties of the project, combined with the characteristics of the project, the following countermeasures are made: (1) Arc steel pipe partial processing, production and installation, the use of factory processing, stretch bending, rust removal, the use of machine and manual matching blanking and welding technology, fully ensure the welding quality, and size accurate and safe; (2) In view of the larger reaction force of the curved steel pipe on the lower foundation, the designer has fully demonstrated and discussed the reinforcement and welding of the foundation embedded, and the construction scheme of two sets of columns is adopted to balance the force.

## 3. Technical Measures

The main steel components of this project are embedded steel columns, steel balls, main trusses, secondary trusses, arc rods and connection trusses (see Figure 1). The length of the steel column is long, and the materials are unloaded respectively according to the installation position after entering the field, and then lifted together with the main truss as a whole after docking and splicing. The main truss is considered to use 120 tons of crane

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partial assembly construction, and the secondary truss high-altitude scattered parts installation. The assembly of steel components is carried out in the area close to the installation operation point to reduce the secondary backhaul of components. That is, the steel column assembly is butt welded at the installation point of the stadium, and the main truss is assembled and welded in the stadium.

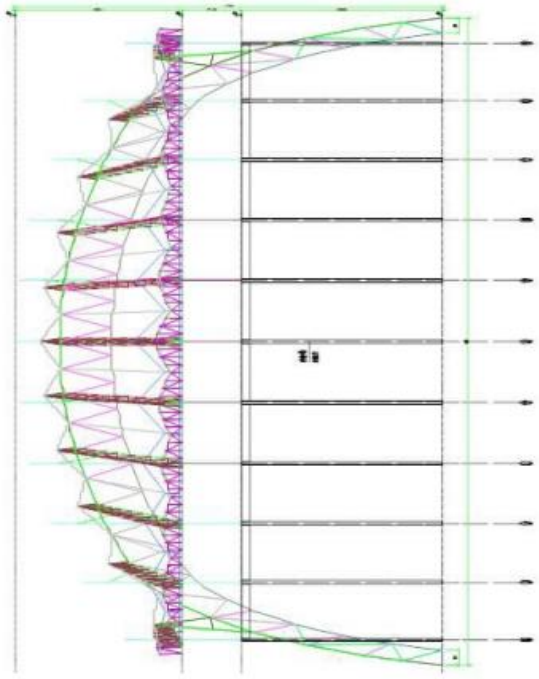

**Figure 1** Structural arrangement of elevation.

## 3.1 Lifting of Embedded Column

Install the embedded short column before installing the pipe truss. The short columns are integrated through steel joints with the main truss.

After the completion of the main truss assembly, the 120-ton crane lifts out the birthgear and puts it on the temporary support. The upper and lower ends of the short column are welded with temporary steel plate lifting points, and the embedded column is pulled to the node. The hemp rope at the lower end of the embedded column is used as a rope to prevent shaking and scratching other objects during the hoisting process. After the hoisting reaches the installation site, the positioning size between the truss and the concrete column should be adjusted first. After the adjustment of the axis position and elevation, the embedded part column should be installed. The embedded part column should move towards the support by pulling the ramping chain bolted on the supporting concrete column in advance, and the upper end of the short column should move towards the node through the bolted ramping chain to adjust the column direction. After the steel column is aligned with the embedded part, the measure steel plate is spot-welded on the support to fix the column body. After the position of the column is adjusted accurately, the welding can be implemented. After the welding is completed, the installation will be completed after passing the inspection.

## 3.2 Lifting of Embedded Column

The main truss is installed by the method of integrated lifting of the ground assembly, the secondary truss is installed by the method of integrated lifting of the support frame, and the truss and the roof beam pipe are installed by the method of high-altitude bulk. 5 sets of tire frames were arranged in the venue for assembly by 12-50t crane. After the assembly of 5 trusses was completed, the fetal gear was lifted out by 120t crane and placed on the temporary support for paint repair and wire rope adjustment. After the preparation work was completed, the hoisting was carried out by 120t automobile crane. In the process of truss hoisting, other trusses

are assembled, so that processing, assembly and hoisting work form flow construction.

### 3.2.1 Truss Assembly

Site requirements: truss assembly needs to be set up on a flat and solid ground, and the assembly is directly placed on the hard ground. Due to the roughness of the existing site, it is necessary to use a bulldozer for leveling, and backfill with road filler or residue, and then use a road roller for rolling. The assembly sequence of the truss is: upper and lower chord bar, lower chord belly bar, upper chord belly bar, upper and lower chord belly bar. (See Figure 2)

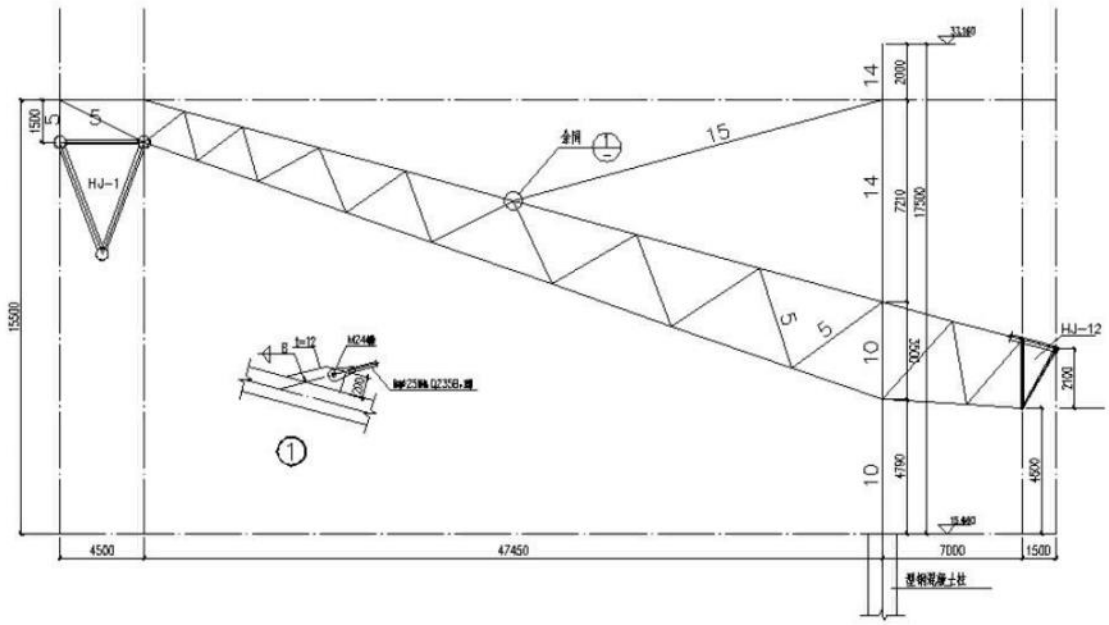


**Figure 2** Structural section.

In the process of bar assembly, according to the principle of first and second, that is, in the process of truss assembly, the main bearing bar should be assembled first, and then the secondary bearing bar should be assembled. If the secondary bearing bar occludes the weld of the main bearing bar during assembly, the weld of the main bearing bar should be welded first, and then the secondary bearing bar should be assembled. Since the weld at the joint is a intersecting line, if the installation position conflict occurs in the assembly process of the belly rod, it should be re-approved by the design institute. The belly rod can be cut in the middle position, and then wait for strong repair welding after the assembly is completed.

The parts of the main truss need to be inspected and processed before they can be installed on the installation platform. After installation, welding should be carried out. During installation, attention should be paid to the order of assembly to avoid welding dead corners.

The high-efficiency plasma welding technology of carbon dioxide gas shielded welding is adopted for welding, which should be corrected after welding.

The performance and quality of the steel and welding materials used in this project shall comply with the provisions of the current industry norms and national standards, and have product quality certificates or inspection reports. Manual welding for general fillet welding and butt welding; $CO_2$ gas shielded welding is used for general fillet welding, V-shaped fillet welding and butt welding. Manual welders and carbon dioxide gas welding welders who participate in this work shall hold the welder examination certificate issued by the authoritative department before they can perform the corresponding welding work specified in the certificate. Before welding, the welding process technology should be disclosed to the welder so that the welder can understand and be familiar with the process requirements of structural welding.

Low hydrogen electrode and submerged arc automatic welding flux should be baked as required before use,

and then stored in the incubator for use. The low hydrogen electrode is baked at $350-400^{\circ}C$ for 1 hour, and the carbon dioxide wire does not need to be baked. Welding rod insulation tube use: When the low hydrogen electrode is used, the welder should be equipped with a welding rod insulation tube to prevent the welding rod from being damaged by moisture and pollution again.

Pre-welding preparation: Check the fitting accuracy of joints and bevels before welding, and the tightness of the backing pad. Repair the joints and bevels that do not meet the requirements. The selection of welding sequence should pay attention to: minimize welding deformation and shrinkage; Balance the heat added in the welding process; The parts with large shrinkage are welded first; After welding the parts with small shrinkage; Try to use symmetrical welding method.

Positioning welding: After the component assembly is completed, the positioning welding is generally 25mm long, for high-strength steel, the positioning welding length is 30mm, and the diameter of the electrode is $\phi 3.2mm$.

Assembly welding requirements: The production of steel structure components, its lofting, marking, cutting, correction, bending and edge processing, assembly, welding, hole making, friction surface processing, end processing, etc. should be strictly in accordance with the relevant requirements of the "Steel structure engineering construction quality Acceptance Code" (GB50205-2020). When there is a contradiction between the specifications, the higher requirements shall be implemented. The selection of welding sequence should pay attention to: minimize welding deformation and shrinkage; Balance the heat added in the welding process; The parts with large shrinkage are welded first; After welding the parts with small shrinkage; Try to use symmetrical welding method. When the difference in wall thickness is greater than 3mm for the joint splicing of round steel pipes with the same outer diameter and different wall thicknesses, the lining plate must be added for transition treatment. If the specifications of the coaxial rod on both sides of the node are not uniform, when assembling and welding, the splicing joint should be located on the side with a small cross-section area, and the length of the joint from the center of the node is greater than 500mm, so that the splicing joint leaves the end point of the branch pipe intersecting line for more than 100mm. The end of hollow components such as steel pipes is made of steel plate head and sealed with continuous welds to isolate the internal and external air and ensure that there is no water accumulation inside the components during assembly and installation. The welding seam of the steel pipe inserted into the joint plate must meet the following requirements: The welding seam should be continuously welded along the entire circumference and smoothly transitioned. The joint weld between the steel pipe and the joint plate is a stress weld, and the joint weld between the sealing plate and the joint plate and the steel pipe is a structural weld to ensure the sealing of the steel pipe. The selection of welding sequence should pay attention to: minimize welding deformation and shrinkage; Balance the heat added in the welding process; The parts with large shrinkage are welded first; After welding the parts with small shrinkage; Try to use symmetrical welding method.

The exposed butt weld should be polished after welding, and the surface of the weld should be polished and smooth, and the finish is the same as that of the base metal plate.

Weld surface quality inspection: the weld slope is uniform, and there should be no defects such as cracks, non-fusion, arc pits, slag inclusions, welding bumps, pores and edge bites.

Non-destructive testing: The butt weld without special requirements should be a grade of quality, and the fillet weld should be a grade of quality (appearance grade two). The weld is the welding of the intersecting line, and the welding should be continuously welded along the whole circumference and smooth transition. The butt weld between the truss chord and the steel pipe of the belly bar, and the quality grade of the weld is first class; The quality grade of the all-permeable weld is two grades; Fillet welds and partially permeable welds are of grade 3 quality (appearance grade 2). According to the standard of "Code for Construction Quality Acceptance of Steel Structure Engineering" (GB50205-2020), the appearance quality defect inspection and internal defect ultrasonic inspection of welding seams in factories and sites are carried out. For welds with grade 2 quality, the

ultrasonic flaw detection ratio is 20%. The contents of the weld appearance inspection are: incomplete welding, root shrinkage, cracks, arc cracks, arc scratches, edge bites, spatter, poor joints, welding nodles, surface pores, surface slag inclusion, insufficient fillet weld thickness, and asymmetric fillet weld foot defects.

Corrosion removal spraying: rust removal and corrosion prevention of steel components: sandblasting, primer and intermediate paint are processed in the factory, and the sand blasting rust removal grade is not less than Sa2.5; Epoxy zinc-rich primer 80 microns; Epoxy cloud iron intermediate paint 180 microns; Polyurethane topcoat 60 microns; The color of the top paint shall be in accordance with the requirements of the building drawing (or specified by Party A). Paint should be sprayed before the trusses are removed, and damaged paint should be repaired before hoisting.

After the assembly, welding and painting of the truss is completed, the quality personnel should carefully inspect and accept the truss according to the procedures, process requirements and construction drawings and the provisions of the "Steel Structure Engineering construction Quality Acceptance Code" (GB50205-2020), and the hoisting construction can be carried out after passing the test.

### 3.2.2 Truss Lifting

Crane lifting foundation treatment: Due to the heavy weight of the 260-ton crawler crane, there are certain requirements on the bearing capacity of the foundation. According to the requirements of the crane manufacturer, the site of the crane walking area must be smooth and solid, so this area needs to be leveled by bulldozers and rolled by road rollers. During crane operation, in order to prevent accidents such as overturning of the crane, the crane manufacturer carries its own subgrade box to solve the bearing capacity problem of the foundation.

Trusses are introduced: After the truss assembly is completed, it is necessary to use a crane to lift the truss out of the gear. Since the truss is vertically assembled, the strings of the truss are placed on the beam of the gear, and there is no blocking rod in the vertical direction, and the truss is directly lifted out of the gear by the crane and placed on the temporary support, which is made of H200*100*6*8 and L70*6. Assemble support rods, V-shaped columns and other safety measures that need to be lifted together.

Order of trusses installation: Each stand is symmetrical from the middle to the sides.

The cantilever length of the truss is 37.52m~51.95m. After calculation, the deflection of the truss under its own weight is 8.6mm~33.3mm. Detailed statistics are shown in Table 1.

**Table 1** Deflection value of truss under its own weight.

| Number | Component Name | Total length (mm) | Overhang length (mm) | Distal deflection value(mm) |
|---|---|---|---|---|
| 1* | Main truss (13 axis) | 60450 | 51950 | 26.5 |
| 2* | Main truss (7.19 axis) | 61050 | 52550 | 33.3 |
| 3* | Main truss (10.16 axis) | 59273 | 50773 | 19.6 |
| 4* | Main truss (5.21 axis) | 56239 | 47739 | 15.7 |
| 5* | Main truss (3.23 axis) | 51866 | 46366 | 12.3 |
| 6* | Main truss (1.25 axis) | 46022 | 37522 | 8.6 |

In order to control the deflection of the far end of the truss during installation, the installation inclination of the 7.19-axis main truss is adjusted upward from the concrete support during installation, so that the installation elevation of the far end of the truss is 35mm higher than the design elevation, and the installation inclination of the 13-axis main truss is adjusted upward from the concrete support during installation, so that the installation elevation of the far end of the truss is 28mm higher than the design elevation. 10.16 axis main truss installation from the concrete support upward adjustment of the installation inclination, so that the truss far end installation elevation than the design elevation 22mm, 5.21 axis main truss far end installation elevation than the design elevation 18mm, 3.23 axis main truss far end installation elevation than the design elevation 15mm. 1.25 Shaft main truss distal installation elevation is 11mm higher than the design elevation.

# 4. Membrane Structure Installation Programme

## 4.1 Construction Site Layout

According to the work needs, the 200 $m^2$ site is designated as the on-site storage yard during the membrane construction. The construction unit sets up a temporary warehouse on the site as a warehouse for goods when membrane structure hardware and membrane surface installation tools are transported to the construction site.

Considering the needs of smooth construction road and civilized construction, the film surface transported to the construction site is directly unloaded into the storage yard, and the outer packaging of the film surface is not damaged after unloading, so as to avoid damage to the film cloth. In order to prevent the erosion and pollution of rainwater, the color strip cloth is used to cover the film surface packaging. During construction, the film cloth is directly removed from the packaging and used in turn according to the construction area (see Figure 3).

**Figure 3** On-site membrane material yard.

Before the installation of the film surface, the film cloth should be removed from the packaging box by the crane, placed on the transport vehicle, and then transported to the installation site by barge. Therefore, the construction road of the original steel structure is used as the road of the crane and the transport vehicle during the construction of the membrane structure.

## 4.2 Main Construction Techniques and Construction Methods

This project selects an 80T truck crane as the main machine for vertical transportation of membrane structure, and selects a 5-ton truck as the mechanical equipment for membrane surface transportation in the field.

After the installation and construction team enters the field, the operation platform shall be set up and the safety handrails shall be fixed. After the construction preparation work is completed, the construction of membrane surface shall be carried out. During the installation of the first membrane surface, the construction quality shall be paid attention to and the construction personnel shall be trained to master the installation and construction technology of membrane surface of the project, and the speed of construction progress shall not be pursued. Install the remaining film surface in turn. After the installation of the main film surface is completed, the work of making up the shortage and sweeping up the tail is carried out.

Membrane surface construction process: preparation before construction → installation of rope mesh → film surface in place → film surface expansion → film surface tensioned peripheral fixation → hanging cloth on the back of outer film fixed.

On the premise that the installation of steel structure meets the installation conditions of film, 10 brown ropes are first drawn on the surface of the secondary steel structure system as special film supporting. It is required to develop the film according to the bale instructions of the film material (see Figure 4). And the outer end of the packaging material is fixed with a special splint and a side rope. After the film material is unrolled, it is necessary to use a number of wind rope to temporarily press the film according to the weather conditions at that time to prevent it from being damaged by the wind.

**Figure 4** Schematic diagram of membrane spreading.

The film is immediately stretched on the four periphery, and 10 anti-rope nets are drawn on the outer surface of the film to prevent the film from being blown back and forth by strong winds and damaging the film material. On the basis of the initial radial tension of the membrane in place, the rope net supporting the membrane can be removed. After removing the rope net, the permanent fixation of both sides of the warp film requires initial fixation from the central position of the film to both sides. After the completion of the warp fixation, the zonal fixation principle is also required to be fixed from the center of the film to both sides (see Figure 5). After permanent fixation on all four sides, fixation on the back of the membrane is performed. The other installation methods are basically the same.

**Figure 5** Tensioned Membrane Schematic.

## 4.3 Membrane Surfacing

Prerequisites for membrane surface installation: (1) The structure must be installed, the membrane structure support and other preliminary works must be installed, and should meet the design requirements and pass the acceptance. (2) The overall structure is stable and safe. (3) The painting of components should be completed; The preparatory work for construction in the relevant area has been completed. (4) The processed film material is installed as soon as possible after being bundled (not more than 30 days), and the overall arrangement is made. Avoid affecting the technical performance parameters of the film. (5) The person in charge of the technical guidance for the installation of the membrane surface considers that the construction can be carried out after a comprehensive inspection of the site. (6) Completed the construction organization design and received the commencement order approved by the supervision engineer.

According to the needs of on-site installation of the membrane structure, a high-strength steel wire rope is set up every 2m or so for temporary support during the installation of the membrane material. The processed film is unrolled on the temporary supported steel wire mesh and placed in the design position, and the film is stretched to the design position with the tension tool. After the tension stress is applied to the film surface during the design, it is fixed with the pressing film plate.

### 4.4 On-site Laying of Formed Membrane Surfaces in Position

After the film material processed from the factory is transported to the construction site, it should be placed neatly in the order of construction, and it is necessary to confirm that the film number indicated on the package is consistent with the number on the installation drawing.

### 4.5 On-site Unfolding of Membranes

The necessary conditions for membrane surface development: (1) According to Article 8.2.6 of the technical specification for membrane structure, it is not appropriate to install the membrane unit when the wind force is greater than level 3 or the temperature is lower than $4^{\circ}C$; And not heavy rain days; (2) The drawing of the rope net meets the requirements of the application group; (3) All safety assurance measures for the installation of the membrane structure should be arranged in place; (4) Installation guide at the site inspector. The site installation personnel carefully check the number of the film material again, and the film material can be unrolled only after it is correct. In the process of film material development should avoid sharp scratches film material.

After the membrane material is developed at the construction site, it should be carefully checked whether the membrane surface is damaged during transportation and development. In the process of development should be first developed from one direction, one direction after the completion of development, in one side of the film with a temporary fixture fixed, you can expand the film in the other direction. The spacing of the temporary fixture is 2m, and the temporary fixture is a device that temporarily fixes the film material. The connection between the temporary fixture and the boundary of the membrane structure can be fixed by a thin wire rope or by a long U-bolt. The expansion of the film material should be completed piece by piece, and a temporary fixed piece of expansion. When the adjacent film is temporarily fixed, pay attention to the position relationship between each other. When installing the temporary fixture after the film is unrolled, attention should be paid to the use of tools to avoid the installation tools scratching the film.

After the film material is developed and fixed on the spot, the quality of the film material should be carefully checked by full-time inspectors, and there is no damage or pollution during the development of the inspection. No quality problems before entering a process. If there are problems, they should be dealt with in time.

### 4.6 Installation of Counter Rope Mesh

When the membrane pulling work is finished, in order to prevent the damage of wax material caused by sudden wind on the construction site, the reverse rope net should be installed in time. The diameter of the net can be not less than 10mm hemp rope, the net should be set vertically and horizontally, and the interval in each direction should not be greater than 5m and half the distance of the material.

### 4.7 Perimeter Fixing of Membrane

The structural form of this project is a hard boundary skeleton membrane structure, which means that the structure of the fixed membrane material is a hard boundary, and the membrane surface is directly fixed on the membrane structure bracket. The membrane material boundary is prestressed by temporary fixing equipment. When the prestress is applied to the design value, the membrane material completed by tension is fixed by installing the boundary pressing membrane plate.

When the membrane surface is pulled and tensioned by the tensioning device to the design position, the buried rope at the membrane boundary will exceed the bottom plate of the hard boundary of the steel structure

by 10mm, the tension of the tensioner will be stopped, and a white transparent rubber gasket 50mm wide and 5mm thick will be laid on the upper part of the membrane material. After the rubber gasket is laid, an 8mm thick compressed film junction plate will be installed on the upper part. The film binding plate is fixed by the stainless steel bolts with a distance of 200mmM12 and the border bottom.

The bolt spacing on the membrane structure support is matched with the eye hole on the membrane cloth, and the membrane surface can be fixed on the bolt when the membrane bra reaches its installation position. When the film surface is fixed, the eye holes in some places may be inconsistent with the positions of bolts on the support. Therefore, on-site holes are required. When opening the hole, use a utility knife or punch. Do not use a hammer to directly knock the film cloth to open the hole. When the membrane surface is fixed all around, remove all clamps.

When the membrane cloth is installed, the operator's gloves must be clean and oil-free; Shoes must be soft soled rubber shoes; The installation tool must be placed smoothly, and it must be safe and controllable when used; Gadgets must be placed inside the kit. After the installation of the film surface, ensure that the film cloth is not damaged and the surface is not dirty. The total amount of steel used in this project is 200t and the film material is 12150m (Figure 6).

**Figure 6** As-built drawings.

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