

Steel Structure of Astana Stadium – Kazakhstan

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1. Introduction

Astana Olympic Stadium is planned to be one of the most outstanding architectural structures in the capital city Astana of Kazakhstan. The stadium is located on the highway that connects the city centre to the international airport. The stadium is open to multi-purpose activities with its 30.000 seat capacity. The stadium can host many events such as Olympic Games, concerts and various cultural activities besides football matches. Modern technologies that have been applied to the stadiums designed in recent years are also utilized in this stadium. The stadium roof and sidewalls of the seating areas are designed to be shielded completely to overcome the strong climate characteristics of Astana. The roof that covers the football field is retractable so that it can be opened or closed according to the activities held inside.

Astana stadium is a symbol structure for the city besides creating a modern look of the capital. The stadium provides a fascinating sight for both the local residents and the visitors of the city with its special lightening system and light shows.



Figure 1: Outside view of the stadium

2. Steel Structures

The stadium has a large and complex structural system of steel with considerable technical challenges. Reinforced concrete lower tribune structures of the stadium cover an area of 183 meters by 162 meters which is shaped nearly like an ellipse. The seating capacity of the lower tribune and upper tribune structures are 16.000 and 14.000 seats respectively. The roof has overall dimensions of 222 meters in length and 182 meters in width. Upper tribune and the roof are completely designed in steel. Also, a retractable roof is designed which is located directly above the middle of the football field.

Steel structures are examined under four headings:

- Fixed Roof
- Retractable Roof
- Upper Tribune Structure
- Sidewalls

2.1. Fixed Roof

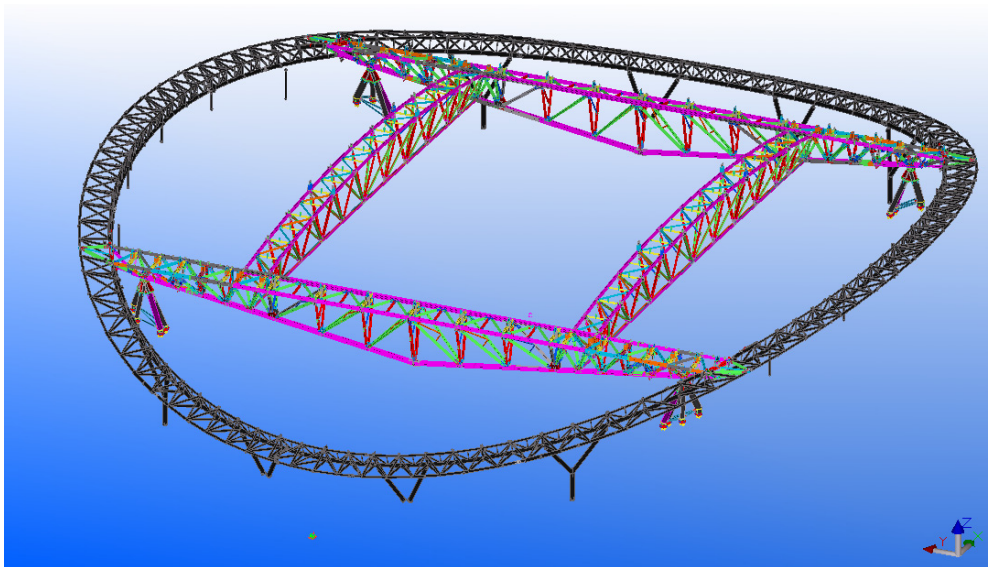


Figure 2: Main steel construction of the fixed roof

Figure 2, shows the main structural system of the fixed roof and Figure 3 shows the plan for the quarter of the main structure. 4 main trusses provide a frame in the fixed roof in order to allow the movement of the retractable roof which must be left open during the football matches according to FIFA regulations. Two of these trusses are named as main roof trusses. These main roof trusses which are parallel to the goal line have a span of 124.20 meters and they're supported by reinforced concrete cores named as "super columns" which are located inside the tribunes on both sides. Support points of the super columns are

marked in red in Figure 3. Some special movement control bearings are used for lateral movement purposes at the support points of steel to concrete.

Secondary roof trusses are designed parallel to touch lines in order to cross the span between the main roof trusses which are placed 117 meters apart. The distance between the axes of the secondary roof trusses is 75.60 meters. The contours of the roof are defined with an elliptical edge truss with outside dimensions of 222.0 m. by 182.0 m. Plane trusses 10.8 m. apart are designed between the main and secondary trusses.

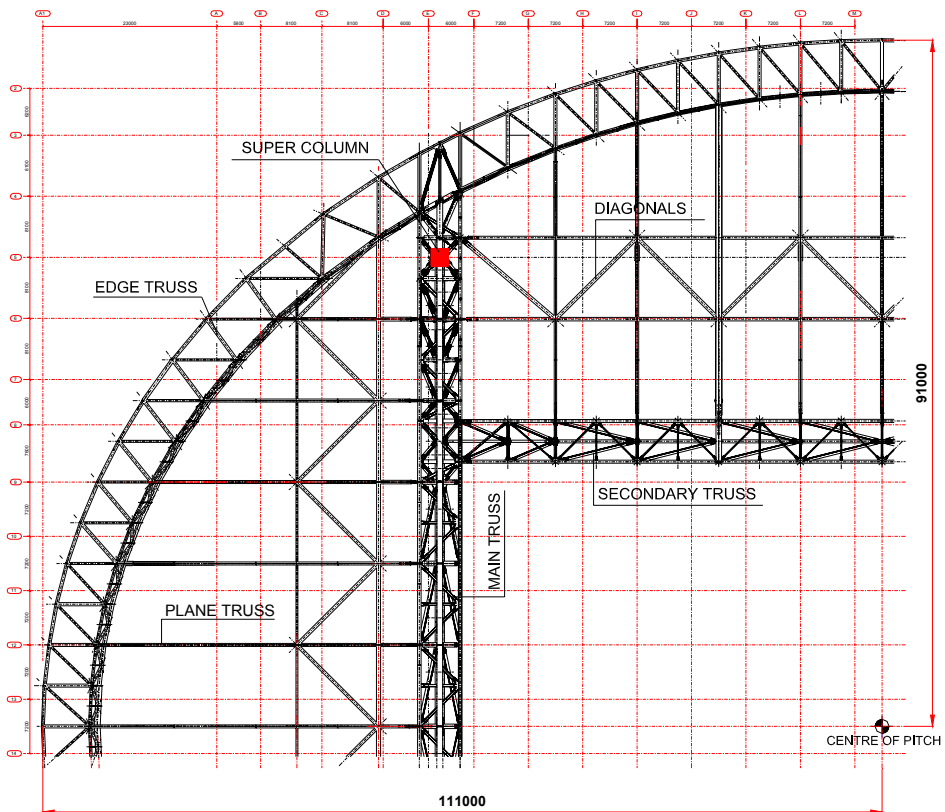


Figure 3: View of the quarter of the fixed roof

Above these trusses, purlins with 2.70 m spacings exist in order to carry the roof covering. Roof bracings are designed parallel to the main and secondary roof trusses in order to achieve lateral stability.

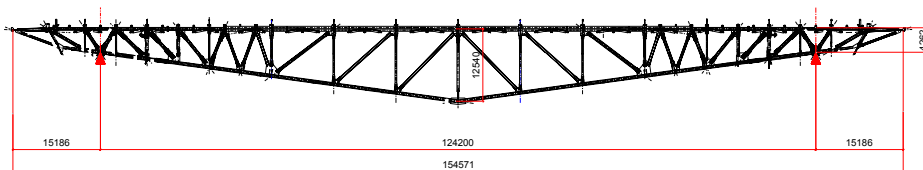


Figure 4: The main roof truss

Figure 4, is the side elevation view of the main roof truss which is the largest and the heaviest truss of the fixed roof. The main roof trusses have 5.40 m. width cross sections and they have a height of 12.0 m. at the middle of the span. The height decreases to 4.2 m. at the support points. These main roof trusses span 124.20 m. Their outside length is 154.57 meters and they are 950 tons each. HISTAR 460 type steel is used for the main and secondary trusses in order to overcome high stresses induced in truss elements. All other roof trusses are made of S355 ML quality steel with pipe cross sections. HEA type wide flanged I profiles are used for purlins.



Figure 5: Erection of main roof trusses

The photograph in Figure 5 is taken during the erection of the main roof trusses at night. The photo shows the main roof truss in front and the secondary truss on the right side.

2.2. Retractable Roof

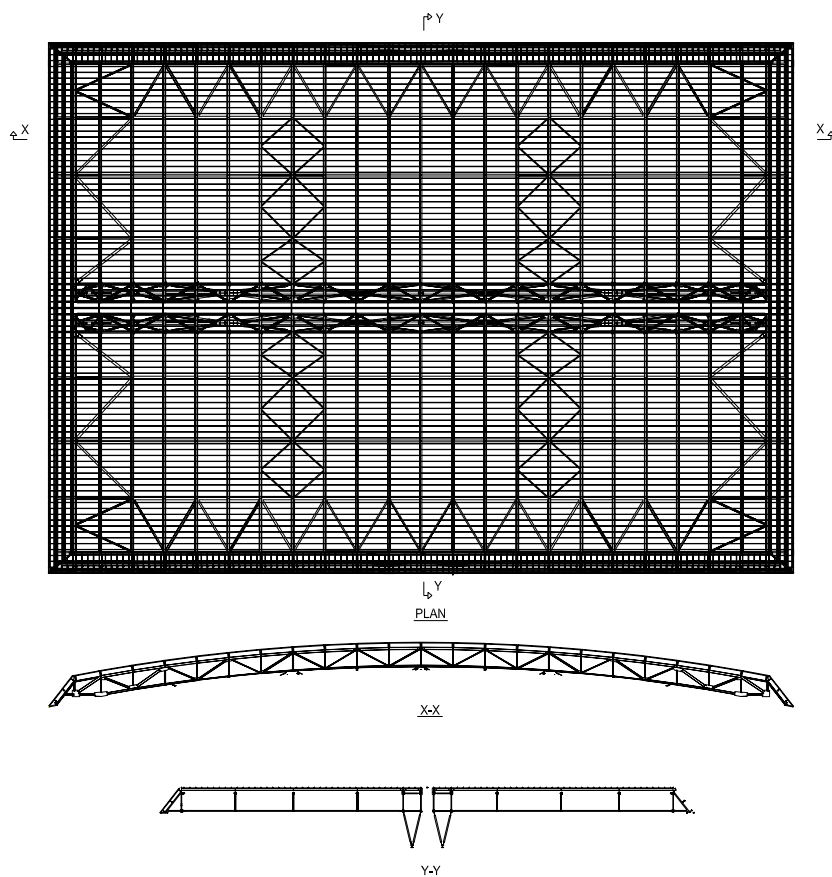


Figure 6: The Plan and cross sections of the retractable roof

The area over the field is covered by a retractable roof as shown in Figure 6. The retractable roof is composed of two separate panel wings moving towards sides. Each of the retractable panels is supported by the fixed roof by means of six points marked in red in Figure 7. The roof can be opened or closed by the movement of the two panels on the wheel groups formed on those support points. The panels of the retractable roof cross 117 meters space. Truss frame arches that have square hollow section bracings on the field sides are designed in order to cross that span.

All other roof trusses which have smaller spans (secondary roof trusses, outer and inner roof trusses) are designed as truss frames. When the roof is closed, the moving panels are covered with transparent polycarbonate layers in order to utilize daylight for the field.

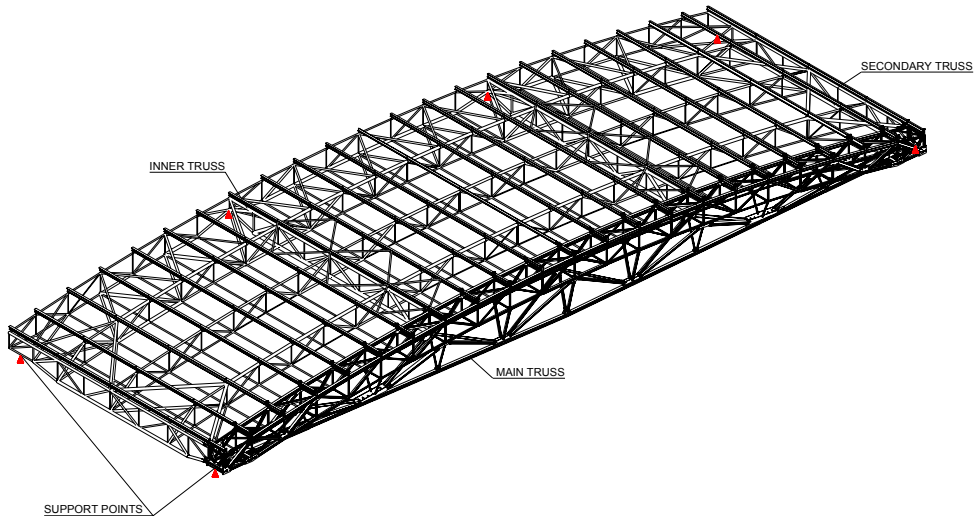


Figure 7: Axonometric view of the retractable roof.

2.3. Upper Tribune Structure

Upper tribune structures have a complex geometry. Steel structures are chosen in order to overcome the problems of formwork and pouring of concrete for this part.

Tribune steps are designed as prefabricated reinforced concrete. These steps are carried by 7.20 meters apart rectangular hollow section steel beams. The steel beams are made of 50 mm. thick plates welded to each other forming a cross section height of 800 mm. with a width of 400 mm. Tribune beams are connected to steel columns made up of pipes which are then supported by the reinforced concrete construction below as seen in Figure 9.

Rear ends of the tribune beams are connected with steel arches crossing a span of 113m. in order to transfer the reactions to the super columns. These arches have square hollow sections of 600 mm by 600 mm. made up of 50 mm. thick plates. They also carry the columns supporting the roof edge trusses.



Figure 8: Tribune steel structure erection

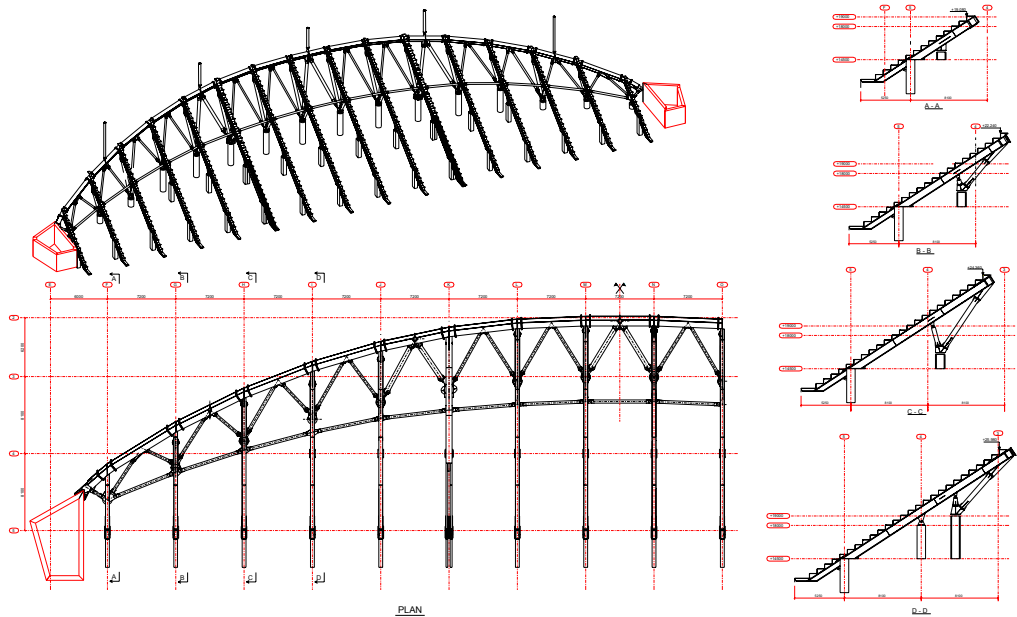


Figure 9: Upper tribune steel structure construction

2.3. Side Walls

The tribunes are completely shielded by means of a side wall structure which is 223 meters by 182,60 meters in plan. Figure 10, shows the axonometric view of the side wall. Truss frame columns with 8,27 meters spacings are designed in order to resist the wind loads and carry the covering. The height of these columns vary between 30,47 meters to 9,00 meters. Columns are connected to each other by means of horizontal truss frames placed 4.00 m. apart. Columns are pin connected to the reinforced concrete construction below.

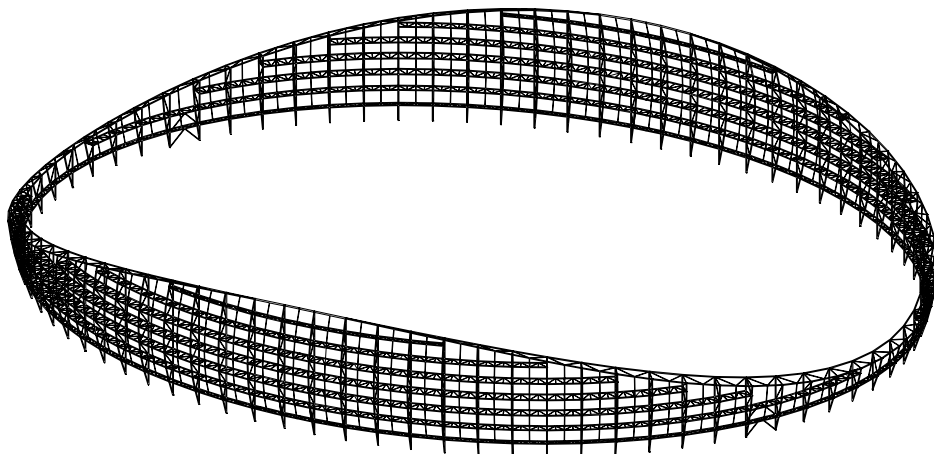


Figure 10: The axonometric view of the side walls



Figure 11: Side Wall Erection

3. Critical Design & Erection Decisions

Some critical issues encountered during the design and erection of the project are also discussed in this paper such as: Wind loading and snow loading values to be used in calculations, importance of thermal expansion factor in strong climates and importance of calculating and taking precaution in erection phases.

3.1. Roof Loading

Self weight, covering, wind loading, snow loading and temperature change are the most common values considered in statical calculations of a roof. Among those, self weight and covering are the most accurate ones. Wind and snow loading on the other hand are bound to meteorological factors and vary in each structure according to topographical, and geographical positions as well as the shape of the structure. For that reason, extra care should be given while taking the loading values from standard codes for important structures.

3.1.1. Wind Loading

The wind loading value is given as 38 kg/m^2 in the code (SNIP 2.01.07-85) for Astana. However, from meteorological data a value of 50 kg/m^2 is derived. Furthermore, a wind tunnel test is conducted that revealed a wind loading value of 165 kg/m^2 for this structure which is more than 4 times higher than the code value.

3.1.2. Snow Loading

The snow loading value is given as 100 kg/m^2 in the code (SNIP 2.01.07-85) for Astana. However, there were some incidents in close regions at those days namely collapsing of several roofs because of excessive snow. Therefore, regional authorities were called regarding this matter. It was agreed by all parts that a snow load of 126 kg/m^2 should be taken in calculations for this structures and further adjustments are to be made in the national codes.

3.2. Temperature Effects

Apart from taking adequate thermal expansion factors during statical calculations which might cause stresses in some members in such strong climates where the temperature change is around $\pm 30^\circ \text{ C}$, care should also be taken during erection phases. For example, during the erection process of the main truss which weighted 950 tons, the truss had to be split into 3 pieces. 2 parts at the support points were erected and the middle part was to be lifted by means of a VSL heavy lift equipment into place. Many site measurements of the connections were taken. Each revealed a different result. At the end, it was realized that the different measurements were due to 15° C temperature change during the day. It was concluded to finish the erection process at night in order to fit the pieces together. Therefore, temperature change is also an important parameter in such big projects where climates are severe and erection should be completed in similar temperatures to avoid connection problems.

3.3. Erection Phases

Important erection phases are also calculated in this project in order to check the structure under the new load distributions introduced during erection. This is fundamental because some operations may result in buckling or insufficiency in members due to eccentricity or extra loading.

Figure 12, shows the statical model prepared for the lifting scenerio of the secondary trusses. The total weight of the truss to be erected is 250 tons. Platforms for VSL equipments are built on the main trusses for this operation. Due to the eccentricity of the platforms buckling deformations are introduced on some members of the main truss. In order to avoid it, temporary columns are placed under the platforms.

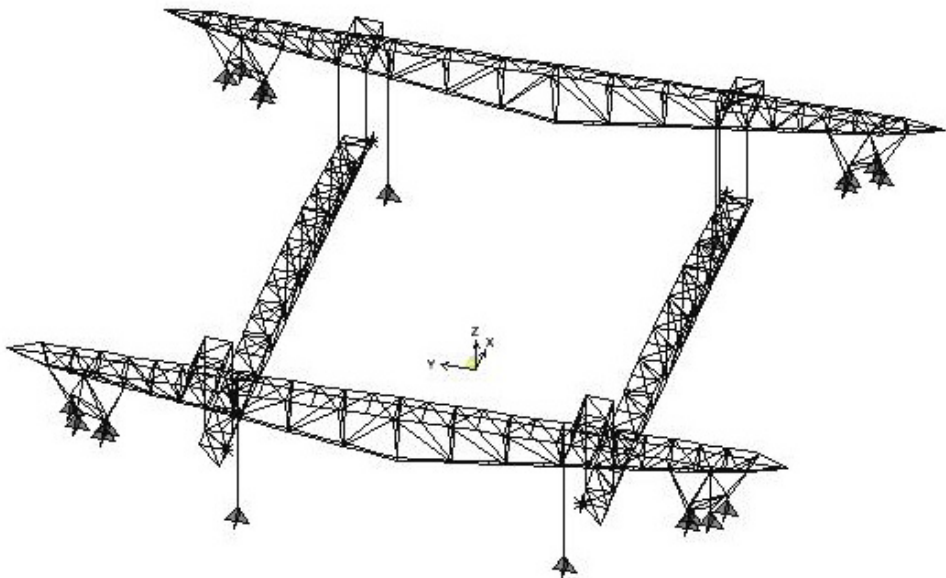


Figure 12: Statical model for erection of secondary trusses

After, the succesful lifting operation temporary columns had to be discarded. However, the columns would be removed one by one which altered the symmetry in the structure. After, examining this process, it was seen that this operation would cause inadequacy in some members of the main truss.(Figure 13)

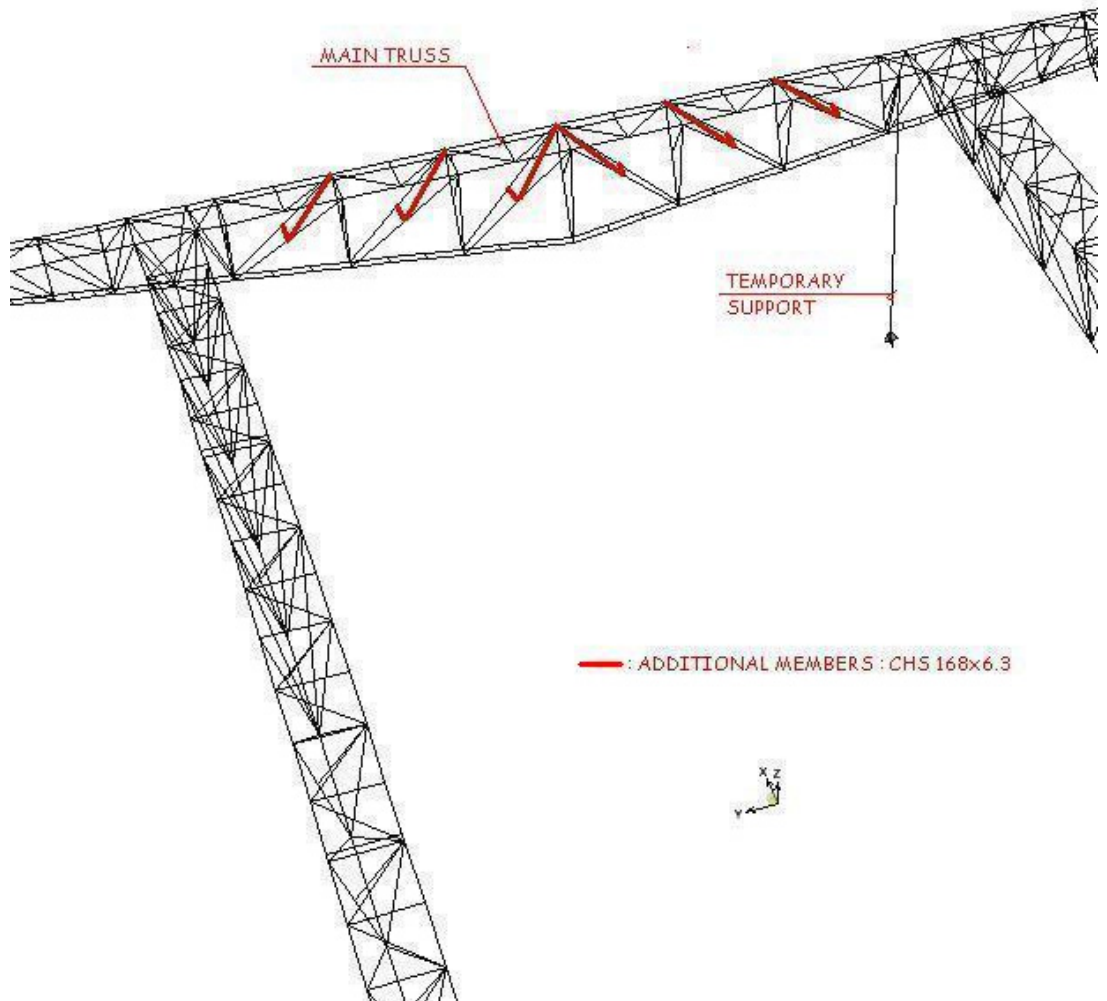


Figure 13: Strengthening of the truss

Additional members were welded for those insufficient diagonals and the dismantling operation was performed safely afterwards.

4. Conclusion

This project resulted in a total of 9555 tons of steel construction with 1673 tons of HISTAR 460 NK type high strength steel which is divided as follows:

	<u>TONS</u>
SUPER COLUMN	216
FIXED ROOF	5298
RAIL BEAMS	320
RETR. ROOF	1618
TRIBUNES	1245
SIDE WALLS	756
ANCHORAGES	32
BOLTS	<u>70</u>
TOTAL	9555

Table 1: Tonnage

This project, of which each and every single stage required great responsibility, qualified engineering and extreme effort, has been completed and the opening ceremony hosted the presidents of 10 countries worldwide in July 6, 2008.