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It will host soccer matches for the two Adana teams. The 33,000 seat capacity stadium roof has a surface area of 24,000m². The roof is covered by a lightweight PVC membrane, supported by the compression ring, secondary arches and the upper cable tension ring in the radial direction, and the radial cables in the transversal direction.

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Cable Erection of Adana Stadium Suspended Roof – Turkey

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Abstract
This paper describes Redaelli contribution to the construction of the New Adana Stadium roof in Turkey. It will host soccer matches for the two Adana teams. The 33,000 seat capacity stadium roof has a surface area of 24,000m². The roof is covered by a lightweight PVC membrane, supported by the compression ring, secondary arches and the upper cable tension ring in the radial direction, and the radial cables in the transversal direction.

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Keywords: Stadium, Cable Net Roof, Tension Ring, Radial Cables, Steel Cables, Suspended Roof

1. Introduction
Adana Stadium cable net roof design is based on the bicycle wheel principle using cable “spokes” or radial cables connected to two cable tension rings (one upper & one lower) and one outer steel compression ring. Due to the convex shape of the radial cables, the interconnecting elements between the upper and lower radials are steel strut elements, also known as flying masts.

The radial cables run along 40 axes from the compression ring to the cable tension rings. All the cables which make up the upper and lower cable tension rings are connected by couplers, thus creating a circular ring of cables. Redaelli’s scope for the project was providing the cable net roof design, the cable supply, the cable installation and the big lift synchronized tensioning of the 184 steel cables. The total cable length was 8080m resulting in a total cable net mass of approx. 250 tonnes, including the cable sockets.

The final shape of the radial cables has been designed to reduce the horizontal force on the compression ring, to protect spectator sightlines and to achieve an efficient structural behaviour under live loads, avoiding significant deformations. The stiffness of the roof is provided by prestressing the cables after lifting completion.

The compression ring is placed on top of the existing steel columns, which support the outer façade, and it is duly reinforced to withstand the new roof and supported by spherical bearings. The radial cable spans are between 44m in the long side and 52m in the shorter side and are connected by vertical flying masts and diagonal steel struts, thus forming radial cable trusses.

2. Redaelli design
The roof was designed by Maffeis Engineering, who were responsible for the as engineering services, both for roof design (compression ring, cable net and fabric) and for cable net erection. The Adana Stadium Roof consists in a typical spoked-wheel structure, having an outer compression ring and two inner tension rings. In this type of structure, the shape of the compression ring is one of the key parameters and the Designer often investigates different curvature profiles, in order to reduce the bending stresses and optimize the design. Unfortunately, for the Adana Stadium, the compression ring oval shape was already fixed by the concrete bowl geometry and by the presence of a façade structure, standing on the perimeter of the stadium. Hence, the “flat” shape of the compression ring on the long sides of the stands represented the most critical item to be taken into consideration and all the design choices were made in order to avoid over stressing of these weak parts.
The shape of the tension rings was designed in order to achieve an affine geometry with the compression ring ones. “Affine geometry” means that the angle variation of the compression ring and of the tension rings was set to be equal. Studies were carried out in order to perform the best geometry and at the end it was obtained a geometry were the angle changes are exactly the same as it can be seen from the plot below:

Figure 1. Affine geometry of the roof.

Once the geometry of the rings was achieved, the second step was to determine an appropriate curvature for the radial cables connecting the compression ring to the tension rings. It was found that the more curvature the radial cables have, the less load is introduced in the compression ring, because the force is inversely proportional to the sag \[H = \frac{pl^2}{8f}\]. For the Adana stadium, it was set a low curvature for the radial cables located in the corners (where the compression ring has a strong curvature and therefore it is stiff) and a big curvature on the long sides (where the compression ring is “flat” and it is weak):

Figure 2. Typical section of the roof.
The third design parameter was the orientation of the radial cables. In order to drag the load on the corners of the compression ring, the radial cables were inclined as much as possible (avoiding excessive deviation forces on the tension ring, which would have led to big ring connectors, and always ensuring to have a regular spacing for the membrane design):

Horizontal bracings are included in the design in order to reduce the bending moment of the compression ring (mainly on the long sides) and to reduce its displacements.

Diagonal bracings are contemplated between the lower and upper radial cables to reduce the deformations in the central part of the roof under snow and wind loads.

Frontal vertical bracings are contemplated between lower and upper tension ring to increase the stiffness under unbalanced load cases, without the need of increasing the prestress level of the system.
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Regarding the cladding, a double curvature membrane in PVC was designed which is supported by steel arches. The prestress of the membrane was set to a precise unit value in warp (≈4kN/m) and in weft (≈2kN/m) direction as a compromise between the installation and the required stiffness against downwards and upwards loads.

![Figure 4. Quarter isometric view of the roof.](image)

**Figure 4. Quarter isometric view of the roof.**

![Figure 5. FEM for fabric design.](image)

**Figure 5. FEM for fabric design.**

### Table 1. Summary of Redaelli Supply.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>CABLE TYPE</th>
<th>DIAMETER</th>
<th>SOCKET A TYPE</th>
<th>SOCKET B TYPE</th>
<th>M.B.L. (kN)</th>
<th>Qty (no.)</th>
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All Redaelli cables are made by hot-dip galvanized high strength steel round wires, spun largely in opposite directions around a central core. Full lock coil cables (FLC) have external layers of interlocking Z-shaped wires which provide self-locking of the cable section.
3. Redaelli supply

Redaelli supplied the cable system for the Adana Stadium Roof. The following table summarizes the scope of supply, in terms of cable type, diameter, number of elements and socket types.

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Figure 6. Full Lock Coil Cables.

In order to eliminate initial anelastic strains, the master length of cables were pre-stretched with minimum five cycles. The individual cable lengths and intermediate clamp positions were
precisely marked under specific loads and controlled temperature, a total of 40 marking positions on each ring cable and 4 marking positions on each radial cable was executed.

Fork sockets and connectors were made of high strength cast steel, whereas the cylindrical sockets, turnbuckles, pins and clamps were produced using machined high strength alloy steel. Adana Roof cables were connected to the sockets with Polyester resin.

Hereafter some pictures illustrate the main items of Redaelli’s supply.

Figure 7. Full Lock Coil Cable (FLC) with CYC Coupler Cylindrical Sockets (Tension Ring Cables).

Figure 8. Full Lock Coil Cable (FLC) with TTF/TTF Sockets (Radial Cables).

Figure 9. Full Lock Coil Cable (FLC) with TTF/TBF Sockets (Bracings).
The overall quality of the supply was assured by a wide campaign of tests on every component. In addition to destructive and not destructive controls on forged sockets, full scale tensile tests were executed on one cable sample for each size, the samples were fitted with sockets equal to permanent ones. Furthermore, 200-hour long term tests helped to verify the creep on the cables, as well as slipping force tests were used to establish the sliding force of radial clamps and ring cable connectors. Control activities were carefully inspected and examined, also by means of external supervisors, and each step of the production process was accurately tracked and overseen.

4. Site activities

All activities related to cables installation and tensioning were agreed with the Main Contractor so that Redaelli presence on site was organized and synchronized with other site works. Cable installation and tensioning followed the procedure defined by the Designer. Site activities performed by Redaelli are grouped and described in the following paragraphs.

4.1. Site preparation and lay down of the cables

Site preparation was carefully planned considering the necessary storage areas for such a large supply and required assembly areas at proper location according to the site activities schedule.

All cables were supplied in coils and were unwound using uncoilers with the required capacity.

The first step of cable installation was to uncoil every cable and to lay it down. Cables were uncoiled lifting the top socket with a crane and placing each cable lying at the corresponding position, so that cable system layout was generated on the ground level. For each axis of radial cables, reinforced wooden strips were previously placed on stadium stands and wooden saddles were provided to let the cable sliding over the parapet.
Similarly, timber platforms were built at the location of ring connector castings to protect their surface and the concrete below. The exact position of each timber platform was theoretically calculated according to the cable system layout. These platforms had an internal opening to allow for the sliding of ring connectors during tensioning operations.

Figure 12 Cables Lay Down

5. Clamps installation and spreader beams

Once radial cables were laid down, radial cable clamps were located at the corresponding marking positions and they were installed and tightened to connect the struts to radial cables, thus forming cable trusses along radial axis. The upper ring cable connectors have been laid down before the lay down of upper ring cables upon the corresponding platforms, while the lower ring cable connectors afterwards.

Figure 13. Ring Cables Connector.
The spreader beams are temporary steel structures used to connect the radial cables to the pulling strands. The beams are two piece components which clamp around the radial cables and transfer the tensioning force of the strands to the cables. A stabilization nose is necessary to prevent the spreader beam from rotating; it is also important that the alignments of the fork sockets are correct to facilitate the insertion of the pins in the final configuration. The spreader beams were assembled on wooden platforms at the top end of radial cables.

![Spreader beam](image)

Figure 14. Spreader beam.

6. Big Lift

The cable net of the Adana Stadium consists of 8 tension ring cables, 80 radial cables and 80 X-cross bracing cables. Once the tension rings were laid down on the ground, the relevant radial cables were attached to the tension ring connectors and disposed along corresponding axis for final pin connection. A single strand jack for each axis, was installed on the compression ring and upper radial cables were pulled by temporary strands connected to the temporary clamps, lifting the entire cable net. The upper tension ring was lifted pulling each upper radial cable with one strand jack. On the other hand, a double climbing strand jack system was installed on the top of the tribune and lower radial cables were lifted off by spreader beams, connected to the compression ring. The lower tension ring was lifted off pulling each lower radial cable with two strand jacks. It is plain to understand that such a challenging operation requires the greatest care and accuracy at each stage.

6.1. Preliminary activities

It was essential that all equipment was carefully overhauled and inspected prior to transportation on site, equipment testing being documented in detail. Likewise, it was crucial to verify the strands resistance and their safety coefficient with respect to the expected loads.
6.2. Installation of Big Lift equipment

Working on such a large-scale structure, accessibility had to be taken into proper and careful consideration. Particularly, it was necessary to be able to operate promptly and smoothly on socket pins during the final connection, the so called “cable pinning”, so two steel platforms have been installed for each axis, at both side of the radial cable anchorages. For the first lifting of the upper radial cables, a single jack each axis has been located on the top of the compression ring, supported by a steel frame bolted in correspondence with two compression ring segments. A sliding steel saddle positioned at the exit of the strand bundle has been fixed to follow the strand geometry during the entire lifting, especially for the first stage, where the angle is higher.

![Figure 15. Single jack on compression ring and steel platforms.](image)

For the second lifting of the lower radial cables, a double climbing jacks each axis have been located on the top of the tribune, connected to the spreader beam. As a consequence, a strand bundle connects the spreader beam to the anchor point positioned on the compression ring, close to the final point.

![Figure 16. Pinning of the lower radial cable.](image)

Every jacking system was connected with a control cable to the Lifting Control Centre, which was located in a control room, from where a full and good overview of site operations was guaranteed.
6.3. Cables lifting
Cables were lifted at 40 points strictly following the designer procedure. Some strand jacks had a nominal pulling capacity of 40-70 tonnes, while others had a nominal pulling capacity of 120 tonnes. Hydraulic pumps were used, to achieve an equal pulling speed on radial cables. The main target during lifting operation was to succeed in lifting the entire cable net from its supports minimizing the sliding. At each step of cables lifting, topographic survey of the structure was executed to compare actual positions and theoretical values supplied by the Designer, as geometrical and tensional status of the roof had to be continuously monitored.

6.4. Pinning of cables
The cable net was lifted until external sockets of upper or lower radial cables could be pinned on their final anchor plates. At that point, lifting operation was interrupted and the pinning of upper or lower radial cables was carried out. The cables were adjusted manually towards the anchoring plate. As fork socket was in position, the pin was put in and the tensioning operation was completed. After pinning of upper radial cables, the flying struts were connected to the relevant clamps. While the bottom connection of the struts has been performed during the second lifting, once the cable net geometry and the level were right. Both the upper and the lower pinning have been carried out following the design sequence, to minimize the possible overstress in the cables.

7. Conclusions and remarks.
The overall production process succeeded in delivery the supply within the required time schedule and quality target. Throughout the supply, the characteristics of each component were monitored and evaluated in order to guarantee the final output to be satisfactory. Site activities planning and logistics proved to be accurate and efficient, all site activities were performed successfully. Despite the complexity of such a large building site and the challenge of several concurring site activities, the greatest control of each step related to the installation and tensioning of cable system was upheld. It was also guaranteed the necessary accessibility and broad outlook on working areas, so that any possible difficulty could be promptly detected and solved. The following pictures show the roof after completion.