Khan Shatyr Entertainment Centre cable net supply, engineering and installation

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Summary. This paper addresses technical aspects of the Khan Shatyr Entertainment center, whose main feature is the 150-metre high mast with a tubular-steel tripod that supports a complex net of cables with a 200 x 195-metre elliptical base. The paper focuses mainly on all features related to steel cable net and cladding.

1 INTRODUCTION

The Khan Shatyr ("Tent of the Khan") Entertainment Centre is a multi-purpose retail and leisure facility located in Astana, the capital of Kazakhstan. One of the largest tensile structures in the world, the building provides the city with a focal point for people to congregate for civic, cultural and social events. Foster and Partners designed the structure, in line with local traditions, as a giant transparent tent that evokes the traditional nomadic building form.

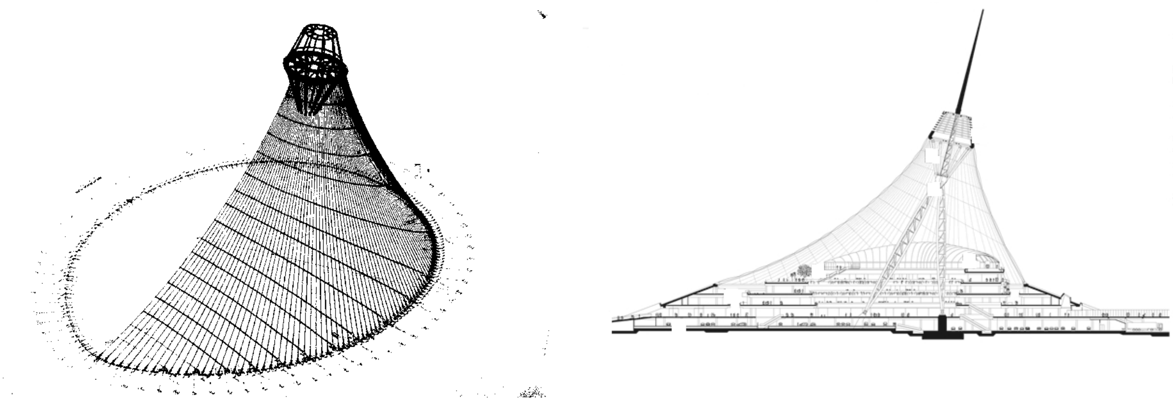

Figure 1: Khan Shatyr concept design

The tent covers an area of 100.000 square meters, sheltered from the city's drastically polar climate (temperature varies from -35°C in the winter to +35°C in the summer). The contribution of Redaelli and Montage Service to this giant structure embraces all aspects relating to cable net, from the production of the cables to the final on site installation.

2 STRUCTURE DETAILS

The single-masted cable net is the natural choice to provide such a giant, free-spanning enclosure with the minimum support: a single compression mast that lifts the cable net and creates a large volume underneath. The tensioned roof is made as a cable net, cables being extremely effective load-carrying structural elements due to the most efficient load transfer by pure tension.

Thus, the structure is designed as a tubular-steel tripod mast that rises from the 195x200-metre elliptical base and supports the cable net in a conical form. The whole mast, including its tip, is 160-metre high and it is made of about 2.500 ton of steel, the tripod consists of one 60-metre tall vertical back leg and two 70-metre long splayed front legs. Each tripod leg is a three-chord truss with a 1.000-millimetre diameter circular hollow section, which is made out of 40-millimetre thick tin. Mast's legs meet at a 7-metre high hub, constructed from a 150-millimetre thick steel plate; the hub centre line corresponds to the axis of the resultant axial force of cable net under prestress.

Figure 2: Details of the tripod mast.

Cables are connected 90-metre above the ground on a steel ring joined to the top of the tripod mast with 12 pinned struts and span to the sloped concrete perimeter that forms the base of the building. Concrete is the selected material for the structure's base due to its large thermal mass and consequent excellent insulation properties.

The top ring is articulated to allow for movements of the structure under asymmetric loads and thus reduce the peak forces in the cable net, as the entire roof is designed to move as wind and snow loads are applied. The cable net is made of 380 radial cables and 16 hoops, formed by groups of four and two cables. Radial cables are installed in pairs to provide the required strength and to facilitate the clamping between radial and circumferential cables. Hoop cables are arranged perpendicular to the ridgeline of the radials; they carry roof weight and permanent loads due to snow, restraining at the same time the roof under wind loads.

Figure 3: Cable net layout.

The cable net is clad with a three-layer envelope, which allows sunlight through and at the same time maintains an ambient microclimate all year round in a location that experiences extreme temperature variations. The cable supported fabric roof material is Ethylene Tetrafluoroethylene (ETFE), a fluorine-based plastic transluscent film which combines high corrosion resistance and strength over a wide temperature range with excellent chemical, electrical and high-energy radiation resistance properties.

ETFE cladding is installed as 3.5x30-meter cushion panels tapered towards the cone and connected to the cables using a system of aluminium clamps, which are able to tolerate movements of the cables under wind and snow loads. The cushions can change shape as the cables move closer, adapting from an eye-shaped cross section to an almost cylindrical shape. In such an extreme climate, the challenge is to prevent ice forming on the inside of the cushions during winter. This is achieved by a combination of temperature control and directing warm air currents up the 19.000-square meter inner envelope surface.

3 CABLE SUPPLY

All radial and hoop cables are Open Spiral Strand (OSS), manufactured using helically wound hot-dip galvanized high strength steel round wires, spun in opposite directions around a central core. Redaelli supplied the entire cable system for the Khan Shatyr Entertainment Centre, the following table summarizes the entire supply, in terms of cable type, diameter, number of elements and socket types. The total length of cables supplied is about 40.000 meters.

Table 1: Details of cable supply

ITEM	Cable Type	Diameter (mm)	Element number	Socket 1	Socket 2
Circumferential Cables	OSS	38	16	CYL	CYL
	OSS	38	44	TBF	TBF
Radial Cables	OSS	38	332	CYR	TTF
	OSS	38	48	TTF	TBF

Fork (TTF and TBF) sockets are made of high strength cast steel, whereas cylindrical sockets (CYL and CYR), turnbuckles, threaded bars and pins are produced using machined high strength alloy steel. Cables are connected to the sockets with Polyester resin. Either the circumferential cables are fitted with cylindrical sockets in a closed arrangement or they have adjustable fork sockets to connect them to anchoring V-trusses. Hereafter some pictures illustrate the main items of cables supply.

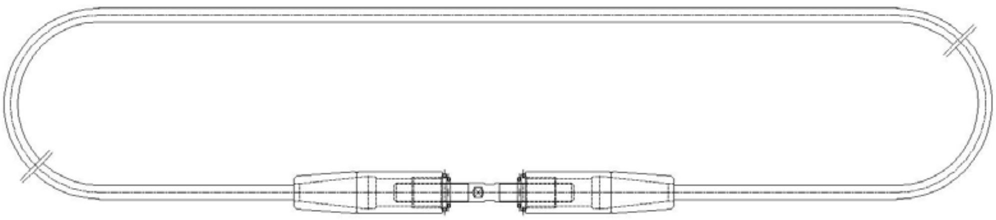

Figure 4: OSS hoop cable arrangement with CYL sockets.

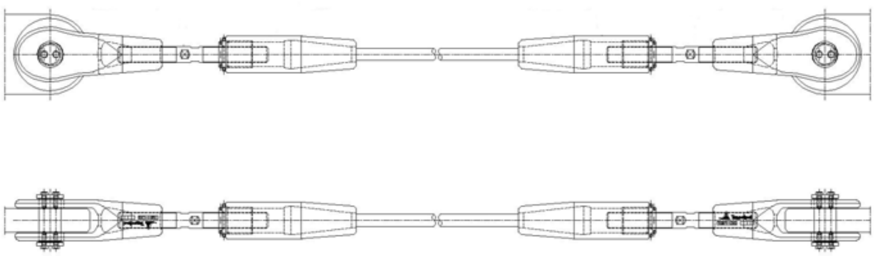

Figure 5: OSS cable arrangement with TBF sockets.

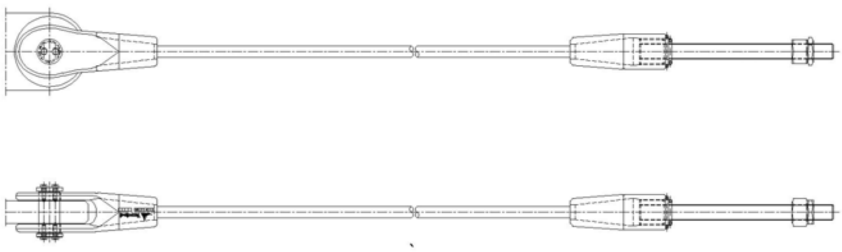

Figure 6: OSS cable arrangement with TTF and CYR sockets.

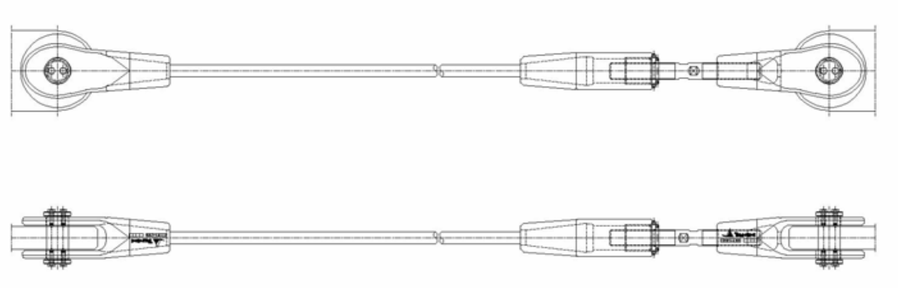

Figure 7: OSS cable arrangement with TTF and TBF sockets.

In order to eliminate initial inelastic strains, cables are prestretched pulling the cable to 50% of its minimum breaking force, with minimum five cycles. The desired cable cutting lengths and intermediate clamp positions are precisely marked under specific loads and controlled temperature. Closed hoop cables are up to 182-metre long with 189 intermediate markings corresponding to the crossing points with radial cables, resulting in a total of 5750 clapms positions which are individually measured and marked to the millimeter.

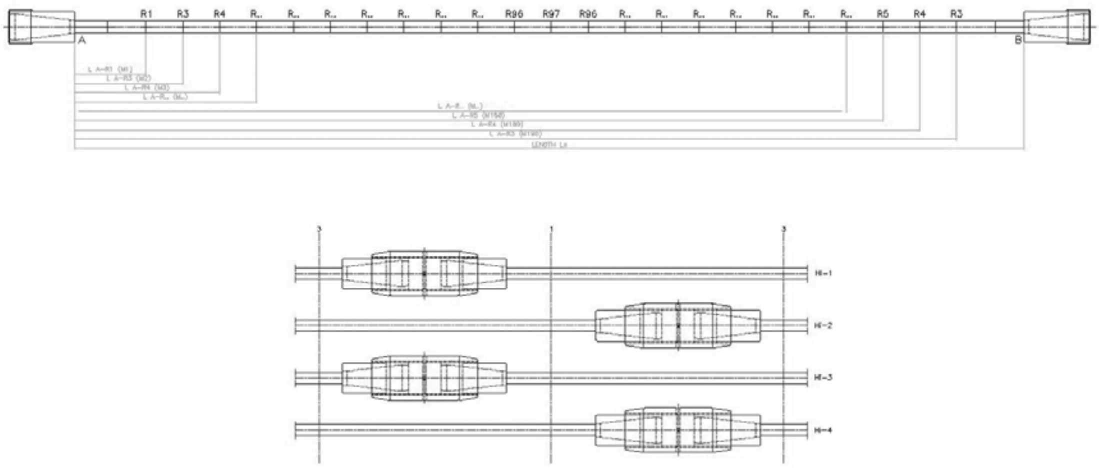

Figure 8: Marking of hoop cables.

Tests are executed to verify cable modulus of elasticity and minimum breaking force and to evaluate actual clamps sliding force through a campaign of tests where actual clamps are forced to slide on a cable sample and the corresponding force is recorded. In addition to clamp slippage tests and cable tensile test, long term test is performed in order to define the actual creep coefficient and long term behaviour of the cable system.

3 CABLE NET INSTALLATION

Installation of such a complex cable net structure and its massive dimensions is a great challenge. Montage Service studied the engineering of cable installation and performed all related site activities, as well as the installation of ETFE cladding.

Giant dimensions of the structure, difficult accessibility to Kazakhstan's capital and small window of opportunity for site operations due to extreme climate are the main aspects that influences engineering and planning of the installation. The difficult access to site requires a careful study of transports, as all prefabricated materials are outsourced and site equipment is sent from Germany. Steel sections of tripod are prefabricated in Turkey and transported to site on trucks, ETFE cushions are made in China, numbered and labelled to be transported to site by train.

The erection of the tripod is done as a dramatic single lift process, where the mast is pivoted around pins at the base of the two front legs. In order to lift the tripod mast, a 80-meter high temporary tower is built and anchored to the structure concrete perimeter. Strand jacks running from the towers pull the tripod into position, with hub, struts and top ring already installed. As the front legs are erected, the top of the back leg is lifted on a temporary connection under the hub and its base slides on a bogie running on a rail truck. The mast top structure has a weight of 400 ton and it is supported with temporary bracing during the lift of the structure. This temporary bracing remains in position until all cable net is installed and correctly prestressed.

Figure 9: Big Lift of the tripod mast.

With the mast in its final position, cable net installation can start. Site operations are scheduled to avoid the worst of high winds that may occur during the winter. The installation sequence envisages at first radial cables lifted individually and pinned at the top anchorages. Cables are left in a slack condition, cable clamps are installed, and hoop cables are placed on top of the radials. This operation performed at height is especially difficult as two pairs of cable in orthogonal directions are involved (see Figure 10). Once all hoop cables are in place, radial cables are tensioned form the bottom adjustable socket to bring the net into shape and providing the required prestress.

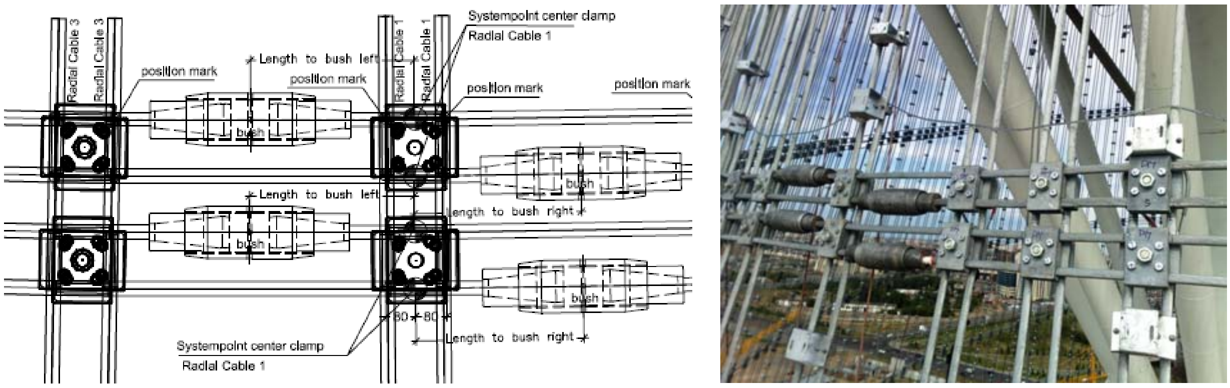

Figure 10: Crossing of radials and hoop cables.

The ETFE cushions are installed sliding into their extrusion from the base and pulled through the top. Since cushion frames are more rigid than the panels themselves , the cushions are arranged in properly studied staggered arrangement, so that the hoope frame of one panel can squeeze in on the mid point of the adjacent panel and benefit from its flexibility.

Figure 11: ETFE panels during and after installation.

4 CONCLUSIONS

The Khan Shatyr Entertainment Centre spectacular design leads to numerous challenges for engineering and installation of the steel structure. All efforts put in place to succeed with these tasks results in an accurate production of cable with exact intermediate markings, careful planning of logistic to purchase the materials and deliver them on site, meticulous study of site operations to allow for all activities to be successfully completed within a time frame dictated by the extreme environment of the area.

The outstanding result is a land marking structure in one of the world most severe region, where people can significantly benefit from the comfortable microclimate created by this imaginative structural solution.

Figure 12: Khan Shatyr Entertainment Centre after completion.