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PRE-STRESSED STEEL STRUCTURES, DESIGN AND CONSTRUCTION

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Abstract: *The application of pre-stressed tendons and ropes has an essential influence on architectural expression, new structural concepts and economy of various types of steel structures. Especially advantageous re-distribution of the internal forces acting against those resulting from self weight and action of external loads is positive effect of the global pre-stressing of steel structures. Structures can be also simply pre-deformed in order to avoid or reduce deformations caused by self weight and other applied loadings. Examples of long span roofs, bridges and other pre-stressed structures are introduced in this paper. Methods of pre-stressing, force measurements and recommendations for design and construction are presented.*

Keywords: **Pre-stressed steel structure, Strain gauge, Hydraulic prestressing device, Prestressing procedure**

1. Introduction

We have designed and realized more than 40 globally pre-stressed steel and composite structures last 20 years. In addition to advantageous redistribution of internal forces and positive deflection of the structure, prestressing can also avoid the compressive forces and eliminate non linear character of slender tendons at any load configuration. Pre-stressed tendons can act as compressive members in the statical model in this case. Steel structures globally pre-stressed by tendons or ropes are mostly cost effective and favourable for environment thanks to reduction usually 25-30% of the self weight in comparison with standard solutions. Wide use of this type of structures is supported due to the improvement in CAD and FEM methods, the accessibility of tendon tension systems, the possibility of simple methods of the pre-stressing with hydraulic device on the turnbuckle and reliable strain-gauge measurements of the forces. Measurement of tendon's frequency spectrum by accelerometer is simple and cheap method for the future inspection of the structure.

2. Long – span roofs

2.1. Roof Structure of Sazka Arena (O2 Arena), Prague

In August 2001, the private Czech lottery company Sazka decided to fund the project and construction of a multipurpose Arena for 18,000 spectators within an extremely short deadline so that the Arena would be ready for the Ice Hockey World Championship held in Prague in April 2004.

The roof above the main arena is in the shape of a spherical cap spanning 135 m with the rise of 9 m. The spherical cap intersects with the oval shape of the Arena in a space curve. The roof structure of the main arena is formed by a prestressed spatial beam-string structure, consisting of 36 radial trusses with 36 tendons anchored in the central cylindrical truss. The roof is composed of nine types of trusses with tendons in four symmetrical sections. The space between the trusses and tendons was used for installation 3 circular bridges and movable trusses for installation of concerts technology. The circular tangential vertical truss bracings between the radial trusses stabilize the trusses against buckling, and ensure their common acting against the vertical loads. Thirty two trusses are supported by pinned columns, remaining four ones are supported by bearings allowing radial movement only, thus stabilizing the roof structure above the concrete part of the arena. The central cylinder was supported by falsework and then trusses were installed during erection. 36 tendons were prestressed in two steps by hydraulic devices.

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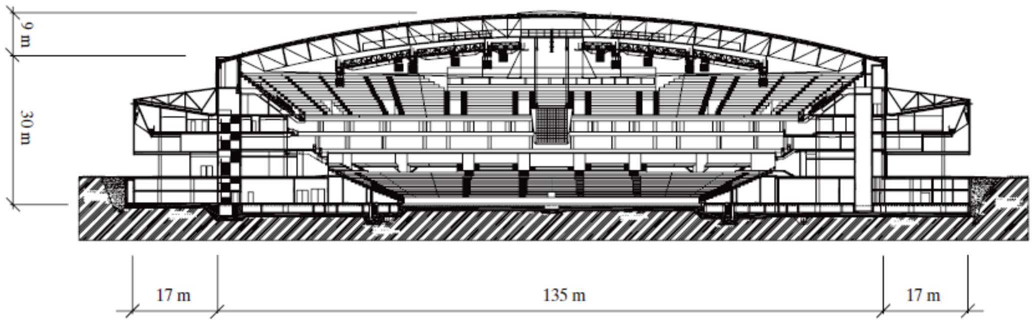

Fig. 1: Cross-section of the Arena

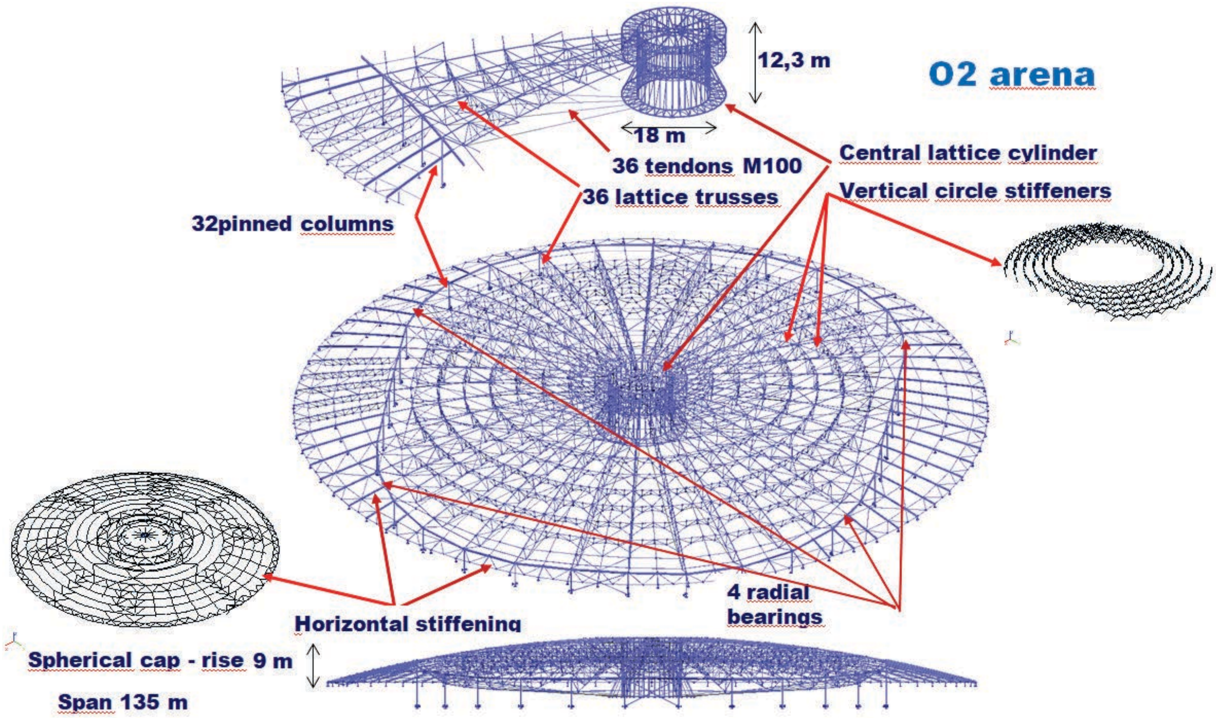

Fig. 2: Static model of the Arena

Fig. 3: Structure under erection – top view

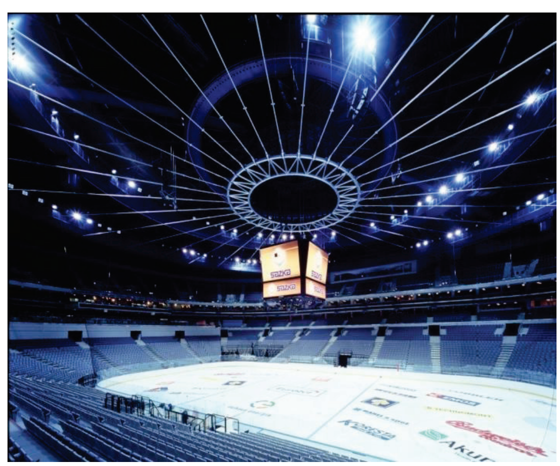

Fig. 4: Internal view

2.2. Roof Structure of Rock-net Arena, Chomutov

Based on the architect's ideas for the shape in relation to the surrounding undulating terrain of the foothills of the Ore Mountains (Krušné Hory), we selected an interesting structural system with the roof in a rounded shape with two curvatures suspended on the external arch on the longitudinal axis of the arena on prestressed tendons. The arch is made from a tube with a diameter of 1,000 mm, a span of 120 m and with the rise of 28 m. The arch is supported outside of the hall by two pairs of diagonal tendons, which are anchored to the foundation. Suspended on the diagonal tendons on the arch are tubular lattice trusses with a maximum span of 71 m with the rise of 3.5 m. With regard to the supporting tendons from the arch, the structural height of the trusses is 2 m only, which creates an impression of a very subtle structure when viewed from the interior to the roof vault.

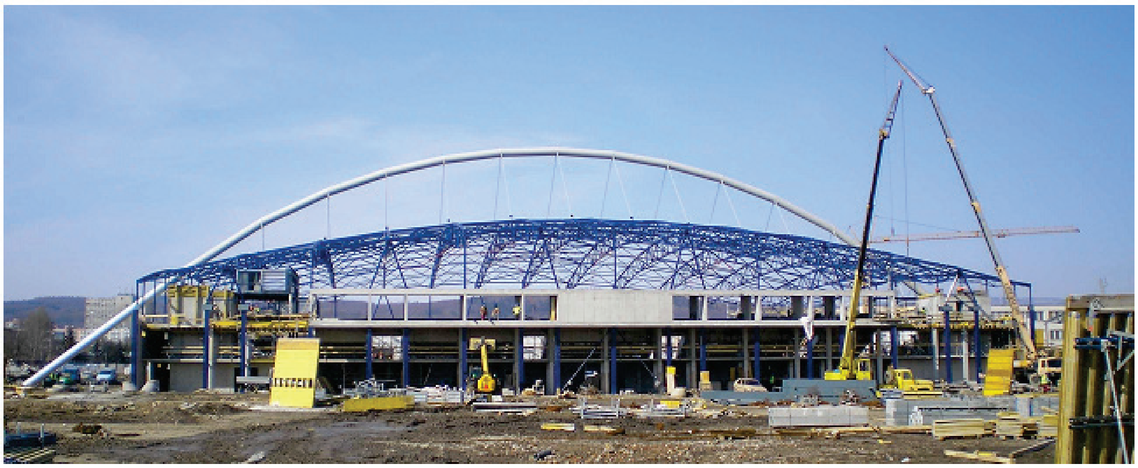

Fig. 5: Roof steel structure after assembly

The trusses are located from the centre with an equal distance of approximately 6,600 mm descending along the circumference so that the roof has a height of approximately 4.9 m with a span of 82.5 m along the longitudinal direction. The trusses are supported on two opposite longitudinal stands on slender steel columns. They are interconnected with vertical bracing, which ensures the stability of the lower chord of the truss while supporting the overall spatial interaction of the structure. The horizontal rigidity is ensured by two chord cross bracings from stiff tubular elements at the level of the top chords of the trusses crossing the longitudinal and transverse axes of the hall. In the longitudinal walls, the structure is stiffened with columns in the shape of an inverted V and by X bracing in the transverse walls.

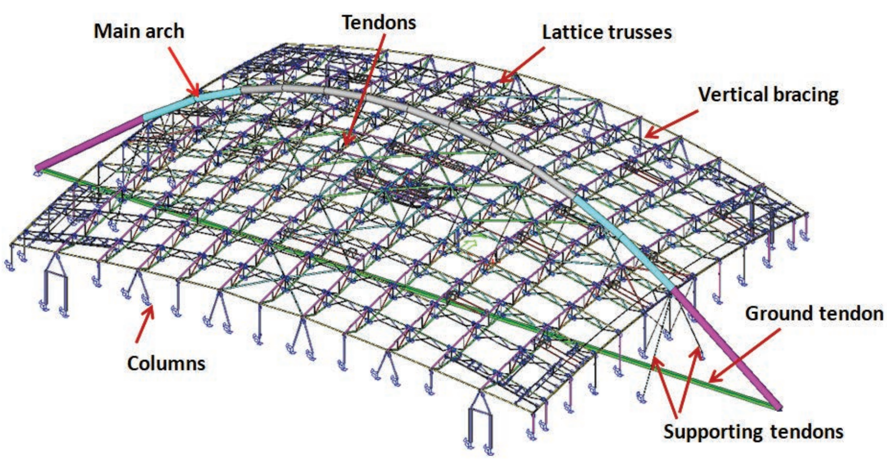

Fig. 6: Steel structure – static spatial model

Although the arena is cubature saving, the central clearance of the inner space is higher than with an ordinary structure, which creates space for alternative usage of the arena. The solution designed is also economical from the perspective of acquisition costs and with regard to minimisation of heated space; facade surfaces and thus contributes significantly to lowering future operating costs.

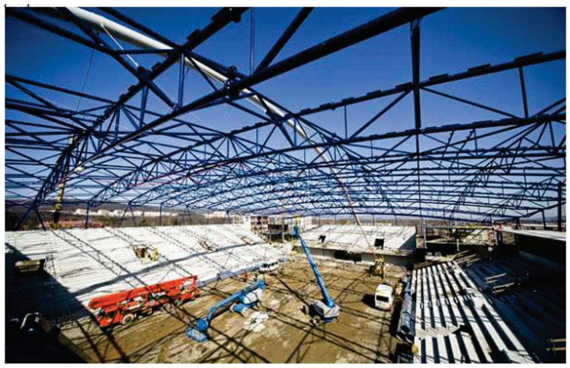

Fig. 7: Structure under erection

Fig. 8: Internal view

2.3. Hangar Mošnov

The hangar in the Mošnov airport is situated southwards near the Ostrava town. It serves for medium maintenance of various types of aircrafts from January of 2008.

The roof of the main hangar structure consists of 7 bowstring lattice trusses, spanning 143,5m with the rise of arch 12m, pinned on 14 lattice columns of the rectangular cross section, fixed to the foundation. The distance between the trusses is 12m. The tubes of diameter 610mm with the wall thickness of 18mm create the top arched chords of the lattice trusses. Web members are also made of tubes. The pair of the prestressed tendons with rolled threads of diameter 105mm and material S520 are used as the bottom chords of the lattice trusses. There are two systems of horizontal bracing in the roof structure. The upper bracing in the plane of top arched chords is created from tubes, and lower bracing in the level of the bottom chord of the main trusses, consisting of prestressed tendons M48, which carries wind load resulting from the upper hangar door's rail. The stability of the structure is hereafter ensured by bending rigidity of fixed columns in the lengthwise direction of the truss and by X-shaped bracing with prestressed tendons as diagonals located between the main columns in the transverse direction. There are no purlins in the structure. The roof cladding panels are fixed directly to the upper chords of the lattice trusses and span thus 12m with adjacent 6m cantilevers at both extremities. The structure of the hangar is statically independent on the adjacent service building, nevertheless the building serve as the back wall of the structure. Therefore three-directional dilatation detail between the hangar and adjacent building allowing the deflection of hangar roof due to the wind and snow load had to be developed.

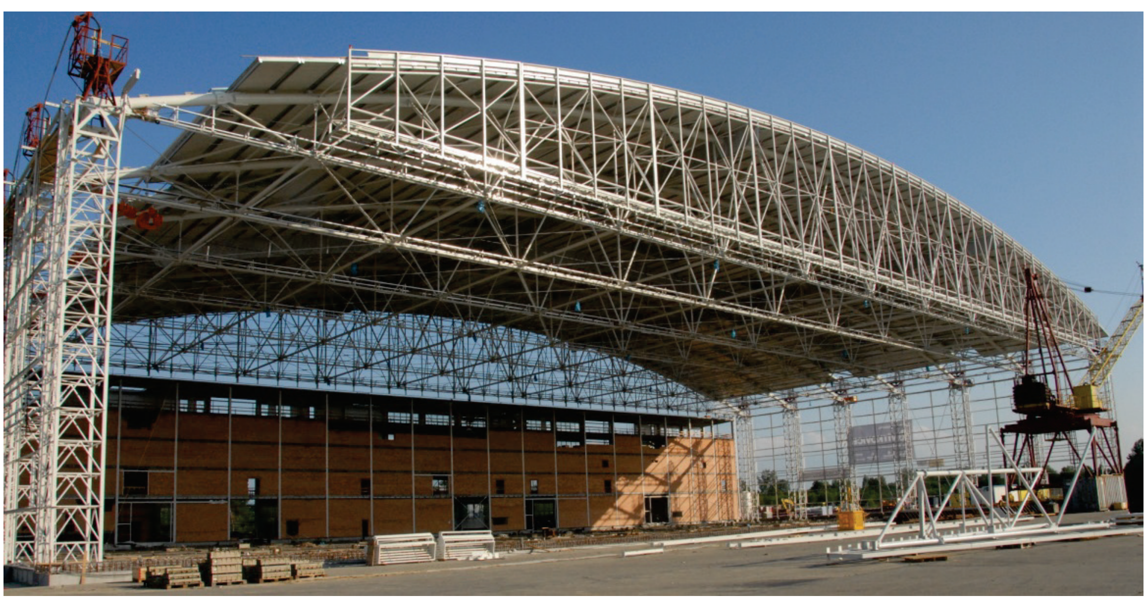

Fig. 9: Hangar Mošnov after lifting of the roof structure

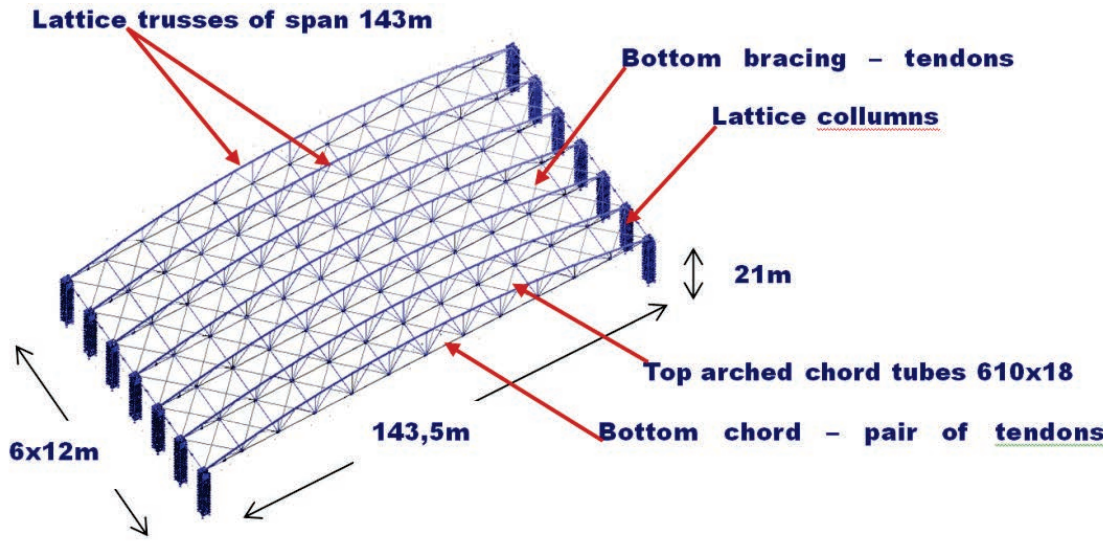

Fig. 10: Steel structure – static spatial model

The whole structure of main arch trusses was completed commonly and finally upper and lower bracings were installed. When pre-erection on the ground was completed the roof was temporarily supported each 12m in both directions. The roof structure was pre-erected in pre-deformed shape to eliminate further deformation resulting from vertical load as self-weight, roof cladding and technology. The main trusses had to be manufactured in reduced lengths with regard to prolongation caused by loading. Lifting of the ends of the trusses by hydraulic jacks, until the structure was raised from the temporary supports activated the structure and prestressed tendons by self weight in main bottom chord and horizontal bracing of the roof. Then roof cladding and complete technological equipment was installed to the roof structure on the ground. The structure was lifted by 14 lifting units, of bearing capacity 125t each, situated at the top of the columns, to the final position onto the column top. Prestressing of the wall's bracing was carried out by the hydraulic device technotensioner applied on turnbuckles in two steps.

Fig. 11:Structure assembled on the ground

Fig. 12:Lifting of the roof

This project was elaborated as an alternative to original design with standard solution without prestressed tendons. Thanks to the original structural and erection solution, 400 tons (25%) were saved comparing to original design and average weight of the roof structure 65 kg/m2 has been achieved. Thanks to the assembly of the steel, structure of the roof, roof cladding and technology equipment on the ground before lifting up the construction time has been significantly shortened and commonly with steel amount reduction significantly reduced the cost of steelwork for investor.

Fig. 13:Troja bridge in Prague

3. Bridges and footbridges

3.1. Troja Bridge in Prague

The bridge with the main span 200,4m with the rise 20m is a simply supported bowstring-arch type bridge with two longitudinal prestressed steel-concrete chords and two twins of inclined network type webs created by 200 prestressed hangers connected to the arch and to the longitudinal steel part of the chords through connection plates. The main reason of hangers prestressing during the installation was to ensure their linear behaviour during releasing the deck from the erection supports in the river. Prestressing of the hangers near the ends of the arch are higher, to ensure favourable redistribution of internal forces in the arch acting against ones originated from releasing the arch from the supports. Installation and prestressing of the hangers were carried out in six phases according to in advance elaborated prestressing procedure in order to minimize adjustment of previously finished phases.

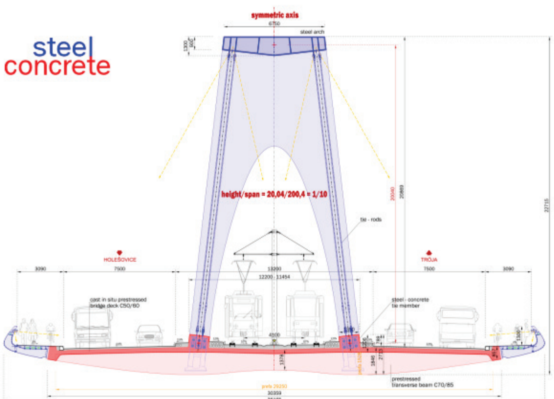

Fig. 14:Cross-section

3.1. Footbridge in Jaroměř

Comenius Bridge in Jaroměř for pedestrians and cyclists of length 61m and width 4,5m connects historical centre of the town with the right bank of the river. . It was built instead of the original bridge from the year 1886 destroyed by flood in 2013. Sufficient height of level of deck of the bridge above the flood level enabled to realize unusual subtle triangular prestressed beam-string structure with central compressed beam. The bridge acts as a simple beam on refurbished historical abutments. Three corner tendons are prestressed to ensure favourable redistribution of internal forces in the structure and to deform the structure opposite to the deflection from vertical loading. The structure is hot-dip galvanized without any additional painting.

Fig. 15:Footbridge in Jaroměř

Fig. 16:Structural details of the bridge

4. Composite steel – concrete structure of the building Trimaran in Prague

The commercial and business centre Trimaran is situated in district of Prague, Pankrac, Czech Republic. The trio of three truss girders, which are supported on central part of seven storey reinforced concrete building as simple beams, carry on the overhanging ends the suspended four storey building above the ceiling of the conference room on one side and, as counterweight, the three storey building hanging above existing building on the other side. The steel superstructure consists of 582 tons of steelwork and 257 pre-stressed tendons Macalloy (122 tons).

Fig. 17:Suspended concrete structure of Trimaran

Fig. 18:The trio of three truss girders

Fig. 19: Trimaran

References

Janata, V. "Sazka Arena, Prague, Czech Republic", *Structural Engineering International Vol 15, Number 1 pp. 40-43*.

Janata, V., Lukeš, M., Gregor, D., and Jermoljev, D. (2007) Application of tendons in the structure of large span hangar in Mošnov, Czech Republic", *Proc. IASS Venetia.*

Janata, V. and Beran, J. (2011) Roof structure of the Chomutov arena suspended on prestressed tendons, In. *Proc. IASS London.*

Janata, V., Gregor, D., Šašek, L., Nehasil, P., and Koukolík, P. (2014) Troja Bridge in Prague - Steel structure and prestressed network of tendons. In *Proc. IASS Brasilia.*

Janata, V., Beran, J., Lukeš, M., Lahodný, J., and Nehasil, P. (2016) Comenius Bridge in Jaroměř, Czech Republic. In: *Proc. IASS Tokyo.*