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Assembly of the stand roofing steel structure for the football stadium in Gdansk

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Анотація. Розглядається технологія монтажу навісу над трибунами стадіону в Гданську, побудованого для Європейського футбольного чемпіонату Євро-2012. Силует, форма та колір фасаду стадіону нагадує усічений шматок бурштину. Металічна конструкція навісу над трибунами має квазі-еліптичну форму з максимальним діаметром 220,0 м та мінімальним діаметром 187,0 м, висоту 38,0 м, ферми навісу досягають 48,0 м. Конструкція навісу важить 7150,0 тон. Тривалість монтажу споруди – 226 днів.

Аннотация. Рассматривается технология монтажа навеса над трибунами стадиона в Гданске, построенного для Европейского футбольного чемпионата Евро-2012. Силуэт, форма и цвет фасада стадиона напоминает усеченный кусок янтаря. Металлическая конструкция навеса над трибунами имеет квази-елиптическую форму с максимальным диаметром 220,0 м и минимальным диаметром 187,0 м, высотой 38,0 м, фермы навеса достигают 48,0 м. Конструкция навеса весит 7150, 0 тон. Длительность монтажа сооружения - 226 дней.

Abstract. The technology of stand roofing assembling for the stadium built in Gdańsk for the European Football Championship – EURO 2012 was discussed. The stadium has a characteristic silhouette, its shape and colors of the façade resembling a cut block of amber. The steel structure of the roofing over the stand of quasi elliptical form, with the maximum diameter of 220,0 m and minimum diameter of 187,0 m, is 38,0 m height, the roof girders having a reach of 48,0 m. The roofing structure weight is 7150,0 ton. It was assembled in 226 days.

Key words: stadium in Gdańsk, roof girders, roof assembling.

Introduction. A consecutive European Football Championship tournament took place in June and the beginning of July 2012. Poland and Ukraine were entrusted by UEFA with organizing that event. Each of the hosts was obliged to build four modern stadiums meeting UEFA's standards. Warsaw, Gdańsk, Poznań and Wrocław in Poland and Kiev, Kharkiv, Donetsk and Lviv in Ukraine were the cities selected as the host venues.

The stadium in Gdańsk was designed for about 41 000 spectators. It was placed on a plot of 43 650 m^2 located between the Old Town and the New Port districts. A German architectural practice RKW Rhode, Kellermann, Wawrowsky GmbH from Düsseldorf won the competition for the stadium design and made the architectural design and building conception design. Building detail designs were worked out as follows:

- object erection – Prof. Dr. hab. Eng. Michał Topolnicki, the Gdansk University of Technology,
- concrete structures of foundations and stands - Autorska Pracownia Konstrukcyjna „Wojdak" Dr. Eng. Ryszard Wojdak, the design checked by Prof. Dr. hab. Eng. Tadeusz Godycki-Ćwirko,
- stand roofing steel structure - Konsultacyjne Biuro Projektów Żółtowski - Dr. hab. Eng. Krzysztof Żółtowski, professor, the Gdansk University of Technology.
- stand structure components, landscape architecture and coordination of the whole design work – Eilers & Vogel from Hannover.

The construction work was performed by a Hydrobudowa Polska / Alpine Polska Consortium.

The stand roofing steel structure was made and assembled by a consortium of:

- Energomontaż „Południe" S.A. from Katowice,
- PBG – Technologia from Wysogotowo near Poznań,
- Martifer Polska Sp. z o.o. from Gliwice,
- OCEKON ENGINEERING from Kosice (Slovakia).

Eng. Tomasz Osubniak, MSc, was the stadium stand roofing construction manager, while Eng. Tomasz Zyska, MSc, managed the final stage of the construction work and dismantling of the supporting lattice beams and mounting towers as well as lowering of the roof from the auxiliary structure.

General characteristics of the stadium roofing structure. Projective stadium has a near-ellipse-shape (Fig. 1) with the longest axis measurement 220,0 m and the shortest axis 187,0 m long. The stadium roofing is a welded steel structure composed by 82 sickle-shaped carrying girders (Fig. 2) as well as bracings and purlins. The carrying girders (distributed along the stand periphery with a spacing of about 8,0 m) have the form of spatial frameworks of a trapezoidal section.

Bars of the upper belt have the spacing changing from 1205 mm at the bearings to 4280 mm in the girder axis curving zone, the spacing of the lower belt bars varies from 405 mm to 1200 mm, respectively. The largest girder height (in the curving zone) amounts to 5,8 m. S355J2 steel was used for the girders. For the belts (the upper and the lower one) ϕ355,6 pipes with wall thickness from 10 up to 16 mm were used –the pipes in the lower part of the girder have the largest wall thickness. All cross braces are made of ϕ219,1/8 pipes. The girders are joined together at each truss joint of the upper belt with horizontal tubular bars and cross braces of "X" type made of round bars (Fig. 3). Owing to those bracings as well as a ϕ500 x 20 mm linking ring, connecting together girder ends inside the stadium, the roofing structure forms a rigid quasi shell with a hole in the middle. Therefore, it may be independent of the reinforced concrete structure of the stand, resting only on it at 82 articulated joints on a carrying ring integrated in the floor at a height of about 7,0 m above the ground level (Fig. 4). Pivot bearing for the roofing steel girder has been achieved by welding bottom ends of the belt (the upper and the lower one) to a horizontal ϕ500 x 24 mm pipe and inserting the pipe in a cast steel bearing of the cradle type (Fig. 5). The pipe transferring reaction of the support to the bearing had the original diameter of 508 mm and wall thickness of 28 mm, but was machined on the outside in order to exactly fit the bearing. The pipe was filled next with expansive concrete of B28 class and closed with circular covers welded on the ends.

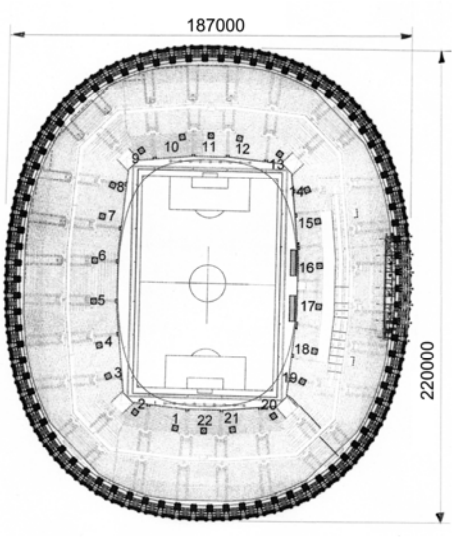


Fig. 1. Horizontal projection of the stadium (the numbered boxes show the layout of mounting towers supporting the roof carrying structure during assembly, the black squares along the stadium contour show locations of the bearings of 82 roof carrying girders – see Fig. 2)

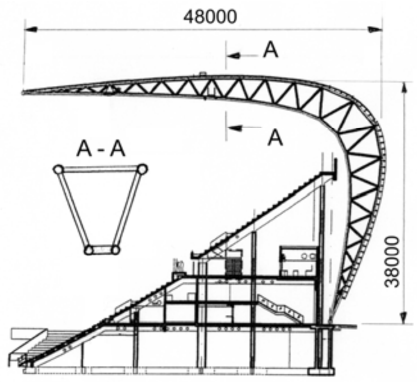


Fig. 2. Roof carrying steel girder – diagram and cross section not to scale (description - see the text)

The total mass of the stand roofing steel structure of the stadium in Gdańsk amounted to 7150,00 ton.

Fig. 3. Bracing between neighboring girders: ring-shaped (horizontal) made of pipes, cross braces made of circular bars

Fig. 4. Supporting of roof girders on the reinforced concrete ring in the floor at a height of about 7,0 m above ground

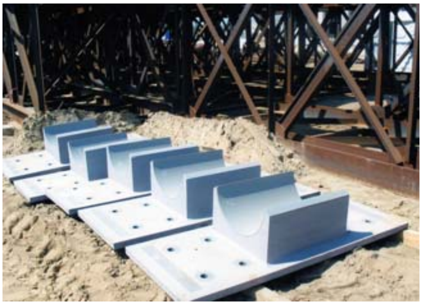


Fig. 5. Cast steel support bearings for the carrying girders and components of mounting towers (in the background) stored on the construction site

Assembly. Cutting of pipes for framework bars to be joined together at various angles and chamfering of edges for welding in various positions were performed at mechanical works in Kosice and partly also at works in Hungary cooperating with them. The pipes prepared in such a way were transported to the Martifer Metallic Constructions plant in Gliwice, where they were joined together into units having dimensions suitable for road transport to Gdańsk. Prior to shipping a trial assembly on special frames was performed at the Gliwice plant (Fig. 6), together with covering the units with a layer of anti-corrosion primer and the first coat of paint. After having been checked the girders were dismantled to be transported in parts to Gdańsk on multi axle trailers (Fig. 7).

Fig. 6. Trial assembly of a three-dimensional roof girder at the plant in Gliwice
(photograph courtesy of the Investor)

Fig. 7. Transportation of roof girder parts from the plant to the construction site
(photograph courtesy of the Investor)

After having arrived at the construction site parts of the roof girders were stored along assembly transoms, which were equipped with special tooling consisting of posts with brackets, platforms and grips to facilitate assembling and welding of the structures. In good weather welding was performed outside, while on rainy days or in strong winds it was executed inside the special protective tents. The tents, movable along tracks laid on both sides of the transoms, could be shifted over those zones where welding was being done (Fig. 8). A protection tent had the following dimensions: the spread of 13,0 m, height of 12,62 m, length of up to 35,09 m, depending on the number of modules 2,92 m long. The tent had a steel framework mounted on carriages, which allowed it to be moved along the track. The side walls and the roof were made of non-flammable PVC coated polyester fabric stretched across the steel framework. The end walls, made of the same material, were of folding type. These tents were also used for protection of assembled units during repairs of the anti-corrosion paint coat applied at the plant and damaged in the vicinity of welds made on site or mechanically damaged during transportation.

Fig. 8. Assembling of roof girders on site on two parallel assembly transoms (movable tents for protection of welding works on rainy or windy days can be seen in the background)

The lower sections of roof girders (the so called “façade” sections), bonded and checked thoroughly for correctness of joining, were transported directly to the reinforced concrete structure of the stand and mounted on the articulated bearings (Fig. 9). The respective roof girders had to be fastened to the reinforced concrete crown beam on the stand top until the entire stand roofing structure was assembled. That was done with the aid of segmented steel ring made of successively mounted double-tee bars. Bars of the roof girder lower belt were fastened to the ring using steel stirrup bolts (Fig. 10).

In order to set about assembling “roof” sections of the carrying girders it was necessary to erect inside the stadium 22 mounting towers for supporting lattice beams on which the end sections of the stand roofing carrying girders would be put. For the layout of mounting towers see Figure 1. The towers had the form of axially compressed steel framework pillars with square cross sections, each of them having the base tied to the reinforced concrete structure of the stand foundation and the head stabilized with four stays. Two of the stays were anchored at the bottom to the reinforced concrete stand structure (Fig. 11), while the remaining two were fastened to the ground anchors made under the stadium pitch (Fig. 12).

Fig. 9. The first assembled "façade" part of a roof girder (02.04.2010). The instant of temporary fastening of the girder to the segmented steel ring on the reinforced concrete stand crown beam

Fig. 10. Bars of a roof girder lower belt connected temporarily with stirrup bolts to the steel ring on the stadium stand reinforced concrete crown beam

Fig. 11. Anchorage of mounting tower stays to the reinforced concrete structure of the stadium stand (stays of two neighboring towers were fastened to one anchor)

Fig. 12. Anchorage of mounting tower stays within the stadium pitch – a ground anchor (note as for Fig. 11)

The "roof" sections of girders, bonded and checked thoroughly for correctness of joining, were transported to the assembling crane on special self-propelled multi axle platforms (Fig. 13). They were fitted there with scaffolds necessary for safe work at heights, and accessories to facilitate joining to the previously mounted "façade" sections of the girders.

Fig. 13. A "roof" section of a roofing carrying girder (about 48 m long) transported on a self-propelled multi axle platform from the paint shop tent to the mounting crane

A LIEBHERR 1350 crawler crane was used for mounting the girder „roof" sections. The crane, with the boom and jib of 42 m length each, the working radius of 34 m and the total mass of ballasts (main and auxiliary) amounting to 163,0 ton had a lifting capacity of 38,0 ton (Fig. 14). The mass of roof girder to be mounted was equal to 31,0 ton. Mounting of the first roof girder is shown in Figure 15.

Assembly joints of girder belt pipes had been designed as butt joints welded on one side. To facilitate joining of the pipes guides made of four crossing metal sheets were welded inside the pipes of the section to be assembled. Protruding portions of the sheets narrowed toward the ends, thus forming truncated cones which centered the pipes being joined (Fig. 16).

To make possible adjustment of the weld groove between the pipes to be joined thrust pieces were welded near the edges of both pipes (Fig. 17). These pieces were linked together with bolts provided with nuts below and above the thrust plate. By turning the nuts one could adjust the pipe edge spacing so as to ensure a thorough penetration of the weld made on site.

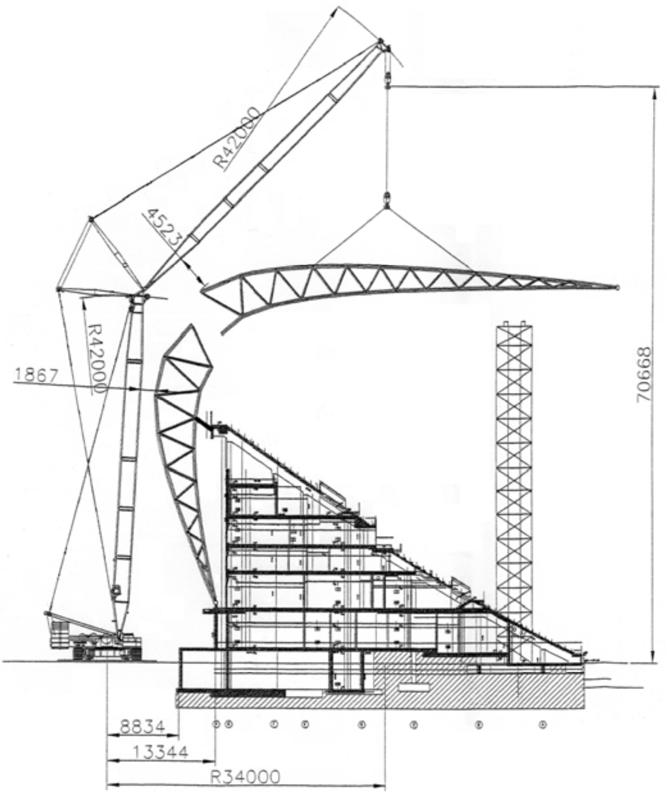


Fig. 14. Diagram of carrying girder “roof” section mounting

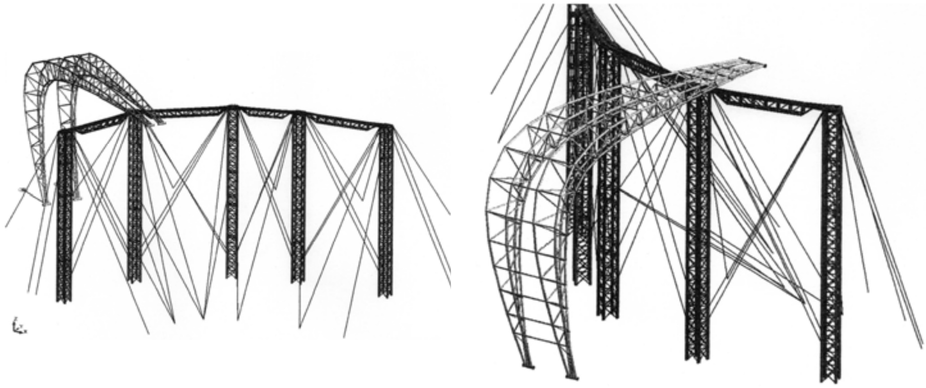
Fig. 15. The first assembled “roof” section of a roof carrying girder(13.05.2010)

Fig. 16. Ends of the upper belt bars of a girder “roof” section fitted with fixtures to facilitate assembling

Fig. 17. Accessories for adjustment of the weld groove width of the girder upper belt pipe joint

Each carrying girder, beginning from the second one with assembled “roof” section, was linked to the preceding girder by means of circumferential bars. The purpose was to make a rigid structure – compare Figures 18a and 18b.

Figure 19 shows tips of the first two assembled roof girders; the tips end with segments of the linking ring. On completion of all girders assembly and welding of the missing sections of this ring it became the main linking ring playing the essential function in the roofing behavior.



a) b)

Fig. 18. Diagram showing a "roof" girder resting on the supporting lattice beams, the girder immediately after assembling, two adjacent girders linked with circumferential bars prior to the mounting of the next girder

Fig. 19. Tips of two adjacent girders resting on the supporting beam. Components of the main linking ring measuring ϕ 500 x 20 mm can be seen on the girder tips

Figure 20 shows a further stage of the construction work – assembling of twelve carrying girders.

Dismantling of the supporting beams and mounting towers was an essential and technically difficult stage of the works. Dismantling was only possible after having welded together and checked the whole main linking ring connecting all the roof carrying girders. When that was done one had to set about disconnecting the roof carrying structure from its temporary links to the reinforced concrete crown beam on the stand top. The roof carrying structure had to become independent of the reinforced concrete structure. Cutting of the stirrup bolts joining the steel girders with the reinforced concrete structure (see Fig. 10) stirred up a lot of emotions, as that could not be done for all of 82 girders simultaneously. One was afraid that successive releasing of the girders from those temporary joints could result in local unstressing of the steel structure and hence its deformation. However, no such effect took place.

Fig. 20. Assembled 12 "roof" segments of the stand roofing carrying structure

Heads of the mounting towers, and specifically the middle parts of these heads, could be shifted vertically within the range of several tens of centimeters with use of appropriate hydraulic lifts. Such design of the heads made it possible to dismantle the supporting beams and afterwards the mounting towers themselves. The procedure adopted can be outlined as follows:

- two hydraulic lifts, controllable from a central station, were installed on each tower,
- those lifts were used for lifting the whole steel roof by about 30,0 mm,
- backing pads and supports on which the beams rested were removed,
- the supporting beams were lowered by 650,0 mm using hydraulic lifts. That was broken down into stages of about 200 mm each. The state of the roof carrying structure was checked after each stage,
- geodesic measurements made on completion of the final stage showed that the respective carrying girders settled at the ends by 260,0 mm to 370,0 mm. Those results differed from calculated ones by 5 ÷ 12%. This was acknowledged as acceptable, having in mind unavoidable differences in manufacturing of the respective girders,

— the difference of levels between the bent roof girders and the supporting beam tops was in the range of 390,0 mm to 280,0 mm, which was a distance sufficient for supporting beams dismantling.

Operations of lifting and lowering of the roof carrying structure was carried out by a specialized Polish company SLING.

The mounting towers consisted of three segments bolted together, therefore they could be dismantled by separating the segments after successively unbolting them.

The completely assembled roof carrying structure is shown in Fig. 21; Fig. 22 shows Prof. A.V. Shimanovskij and Eng. I.B. Shumovskaya visiting the construction site.

Fig. 21. Completely assembled roof carrying steel structure of the stadium (31.08.2010 – photograph courtesy of the Investor)

Covering of the object with polycarbonate plates on aluminum purlins was done by another contractor and will be the subject of another paper, written for this conference by Dr. Eng. Dariusz Kowalski.

Assembling of the stand roofing steel structure of the stadium in Gdańsk lasted from April 2 to November 14, 2010. Despite the fact that most of the work was done at substantial height, no serious accident occurred.

The stadium, commissioned on completion of all works, is shown in Fig. 23.

Fig. 22. Professor Aleksandr V. Shimanovskij and Eng. Irina B. Shumovskaya visiting the Gdańsk stadium construction site. During the visit in Gdańsk an agreement on scientific cooperation with the Gdansk University of Technology was signed (10.05.2011)

Fig. 23. The stadium in Gdańsk after commissioning (19.07.2011 – photo by A. Jemiołkowski)

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