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The aluminium and polycarbonate covering of the canopy above the stadium in Gdansk

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Анотація. У роботі надаються відомості про елементи покриття навісу над стадіоном у Гданську, побудованим до Європейського футбольного чемпіонату у Польщі та Україні. У даній роботі розглянуті елементи полікарбонатного покриття, несуча конструкція та дренажна система. Також надана інформація щодо випробувань та досліджень, виконаних до здачі об`єкта, які визначають обрані конструктивні рішення, а також нинішній та майбутній технічний стан споруди.

Аннотация. В работе предоставляются сведения об элементах покрытия навеса над стадионом в Гданьске, построенным к Европейскому футбольному чемпионату в Польше и Украине. В данной работе рассмотрены элементы поликарбонатного покрытия, несущая конструкция и дренажная система. Также предоставлена информация о испытаний и исследований, выполненных до сдачи объекта, которые определяют выбранные конструктивные решения, а также нынешнее и будущее техническое состояние сооружения.

Abstract. The paper presents information about structural elements of covering of the canopy above the stadium in Gdansk as delivered due to the European football cup in Poland and Ukraine. The paper discusses elements of polycarbonate covering, bearing structure and drainage system. it also gives information about tests and research performed before delivery of the facility, which determined adopted solutions as well as its present and future technical condition.

Key words: covering, polycarbonate plate, roof purlins, canopy.

Introduction. Apart from its shape, the most distinguishing element of the Gdansk football stadium delivered for this year's European sports event, is the colour of its covering. It is this element of external enclosure in yellow and brown that reflects the architectural vision originating from amber, a fossil treasure of the Gdansk coast (Fig. 1). The pattern of an oval shape of amber is ideal for the functional system of the fan stands surrounding the football pitch. The delivered sports facility with its oval shape and measurements of 235,88 x 203,51 m became a reflection of the idea (Fig. 2).

Authors of the project submitted their all design activities to the above-mentioned architectural vision. The structure of canopy of the entire facility fully reflects the shape and colour of amber [6].

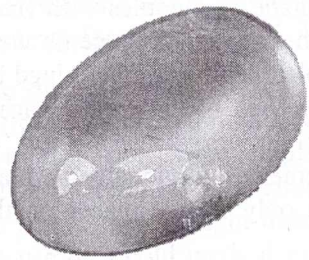

Fig. 1. An example of polished amber

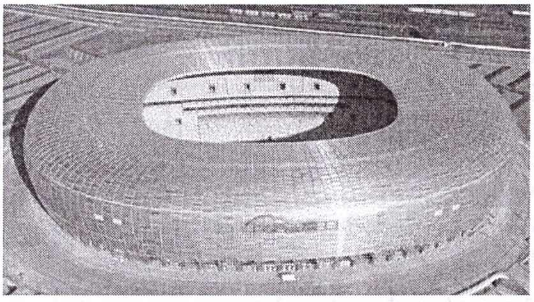

Fig. 2. The sports facility with its shape matching the concept of local richness

The general outline of the facility structure. The facility may be divided into two basic parts both as regards its material and functions. The first part is a wholly independent reinforced concrete bearing structure for fans, into which the permanent facility is embedded. This part of the facility is responsible for all functions connected with organisation of sports events and satisfying of fans' demands – stands with seats, catering facilities, social amenities and any transport routes. The technical core of the entire facility and its technical infrastructure is the above-mentioned permanent facility.

The reinforced concrete part is a base for support at an elevation of 6.82 from the football pitch level, which is the other and independent part of the steel bearing structure of the stadium canopy. This part functions both as a wall enclosure, i.e. façade covering the reinforced concrete part as well as a canopy over the reinforced concrete stands for fans.

The basic bearing structure of the stadium consists of 82 steel girders creating a ribbed structure of low-elevated dome with a hole in the middle. The size of this oval hole corresponds approximately to the size of a football pitch, i.e. 122,4 x 90 m. The lattice girders with a system of twenty circumferential pipes connecting the girders and the system of rod bracing are elements, which give the basic shape to the stadium body.

Thus constructed main body of the stadium and its covering reach the height of approx. 45.2 m above the football pitch level. The rod bearing structure of the canopy was clad with polycarbonate slabs on supporting elements in the form of aluminium beams.

The structure of roofing cover. The roofing cover of the stadium was made of stripes of flat plate polycarbonate elements. Particular stripes of the covering are separated from one another with radial roof gutters. The gutters are embedded in the covering and in the roofing part of the canopy they are used for drainage of rainwater. In the façade part the gutters, at the considerable part of their length, constitute a spacing element between particular stripes of the covering made of colourful plates. The covering plates are made of modules with fixed width of 800 mm. In this axial spacing, aluminium supporting elements were mounted. At the circumference of the facility, the plate length is determined by a division imposed by the geometrical system of the belt of the upper bearing girder and variable distance between particular girders. This method of coverage made it necessary to built each of its elements individually. A plate with specific geometrical format may be mounted only in two places on the stadium covering.

The polycarbonate plates are mounted on two longitudinal edges – on aluminium bearing purlins equipped with a set of seals. At shorter edges located at radial gutters, the plates are based only on special elements, i.e. so-called "parapets" equipped with seals in the plate support zones. The method of fixing and sealing of the covering plate was developed following additional tests made in the Institute of Building Technology in Warsaw [4, 5]. The fixing and sealing deviates from standards solutions commonly used in the types of building elements (Fig. 3). The above-mentioned tests confirmed correctness of use of the double set of seals due to ensuring of the covering tightness, thermal operation of the plates and ensuring of appropriate tolerance of delivery and assembly of bearing and covering elements (Fig. 4).

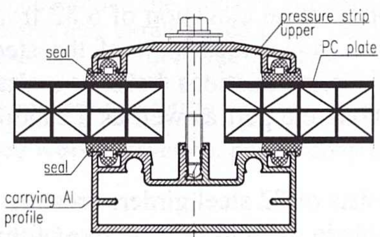

Fig. 3. Standard method of fixing and sealing of polycarbonate plates

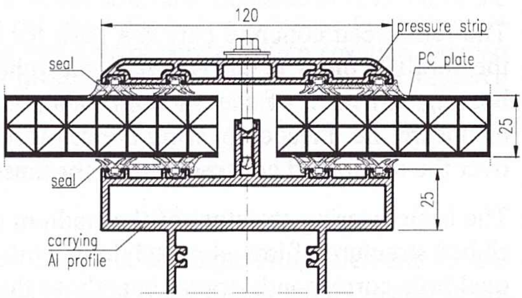

Fig. 4. The fixing and sealing made in the covering of the Gdansk stadium

The supporting structure of the covering. Bearing purlins of the polycarbonate covering were made individually of designed aluminium sections with closed cross-sections and various heights (Fig. 5) ranging from the mini9mum height of 25 mm to the height of 225 mm [7]. The possibility of individual production of the sections made it possible for optimum selection of heights of the sections due to needs resulting from the span between support points on the girders and distribution of loads. The bearing sections were made of aluminium type acc. to EN AW-6060 (EN AW - AlMgSi) and PN EN 573-3:2009 and the delivery condition of T64 acc. to PN-EN 515:1996. The sections were made with the use of a squeezing method. This technology of production of elements made it possible to deliver bearing sections together with support elements for the plates and elements used for fixing of seals.

The small slope on the roof part of the covering made it necessary for bearing purlin sections used in this part to be made with bending enabling water to drain away from polycarbonate plates and directly to the radial gutter. At the section between circumferential gutter No. 1 and 2, the bending radius was R=50 m. On the façade part, straight-lined elements were used. the elements were bent with the use of a cold method in a prefabrication plant with the use of appropriate roller bending machines.

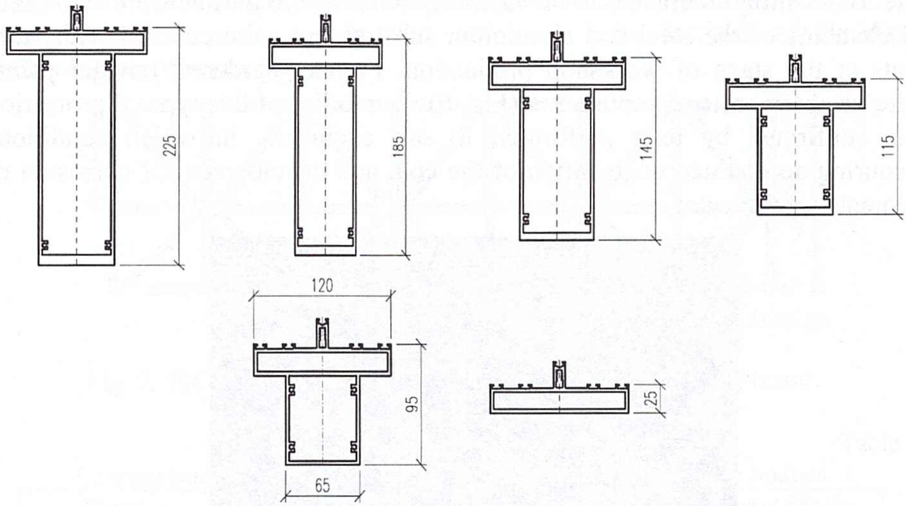

Fig. 5. Aluminium sections of roof purlins

Bearing elements of the gutters were made of aluminium sheets in sections with the modular length of 800 mm. the metal gutter is merely a support element, which gives a basic shape to the eater drainage elements, which were made of reinforced roof film made of modified PVC.

Elements of the aluminium substructure of the external covering are fixed on the steel bearing structure with the use of support elements enabling adjustment of their location with respect to one another. The adjustment made it possible to mount bearing elements of the covering in compliance with the fixed assembly spacing regardless of tolerances for the delivered steel bearing structure. The connection consists of two parts:

a) fixed part – made in the form of steel support tables, which were connected with the main bearing structure by way of welding. The elements were used for profiling of the support surface for the covering. The support plate of the table was equipped with oval holes for adjustment of location of subsequent elements;

b) adjusted part:

— made in the form of steel angle bars with uneven angles for assembly of bearing purlins joined with screws and equipped with oval holes at the contact with the fixed surface of the table,

— made of aluminium angle bars for bearing gutters, which were fixed with the use of self-tapping screws at appropriate levels.

Due to assembly tolerances, oval assembly holes in the purlins were also used. all elements of the steel and aluminium substructure were covered with paint coats at the stage of workshop production. Furnace-hardened powder paints were used for protection purposes (Fig. 6). Durability of this type of protection was confirmed by tests performed in salt chambers, in which conditions favouring accelerated degradation of the coat and development of corrosion of elements were created.

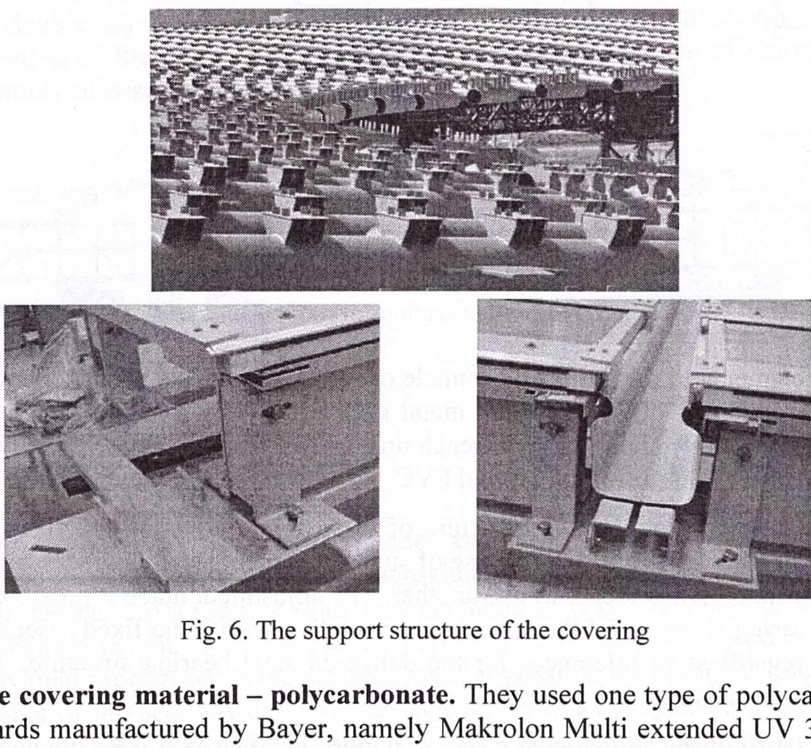

Fig. 6. The support structure of the covering

The covering material – polycarbonate. They used one type of polycarbonate boards manufactured by Bayer, namely Makrolon Multi extended UV 3x25-25 ES. It is a board with the thickness of 25 mm and chamber structure presented in Fig. 7. As seen in the transverse cross-section, the board has a lattice structure, which determines its high bearing capacities and rigidity. For the purposes of the Gdansk design, the geometrical structure of the board cross-section was modified by the manufacturer by way of additional thickening of all walls creating the element (tab. 1). The board used is characterised by greater unit weight – 5 kg/m^2 [2] as compared to boards manufactured as standard and according to the manufacturer's approval. [1] – 3,5 kg/m^2. Owing to this operation, it was possible to obtain greater bearing capacities of the board as well as rigidity, durability and resistance to impacts from large soft bodies with the weight of 50 kg and small bodies being equivalents of hale.

Properties of the entire covering set consisting of the polycarbonate board and aluminium support structure have been confirmed in tests on elements with real measurements as performed in test stations in the Institute of Building Technology in Warsaw [4].

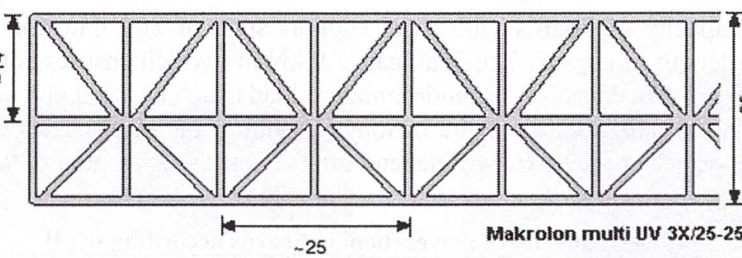

Fig. 7. The transverse cross-section through the polycarbonate board

Table 1

Comparison of thicknesses of constituents of polycarbonate boards

Board constituent	Standard thicknesses according to the Technical Approval [1]	Thicknesses delivered for the purposes of the stadium in Gdansk [4]
	[mm]	*[mm]*
upper wall	$0{,}7^{\pm 0{,}20}$	$1{,}32^{-0{,}12}$
lower wall	$0{,}7^{\pm 0{,}15}$	$1{,}30^{-0{,}11}$
rib wall	$0{,}45^{\pm 0{,}15}$	$0{,}43^{-0{,}03}$ upper part $0{,}63^{-0{,}09}$ lower part
slanted wall	$0{,}12^{\pm 0{,}04}$	$0{,}15^{-0{,}02}$ upper part $0{,}11^{-0{,}02}$ upper part

The increase of thickness of the element also improved fire resistance parameters, which made it possible to classify the boards according to EN 13501-1:2007 as classes with the following properties [3]:

— B – as regards response to fire – non-flammable product, no flashover,
— s_2 – as regards smoke emission – average smoke emission,
— d_0 – as regards occurrence of burning drops/particles – no burning particles.

In order to increase protection against destructive power of ultraviolet, during production the board material was coated with a special 100 mm coextruded layer, which was melted homogenously into the material. The manufacturer ensures that this solution will increase life of the material by at least three times [2]. This will mean over 40 years of use of polycarbonate elements in the facility.

However, the modification of the material connected with thickening of walls creating the board structure had a negative impact upon a light transmission index, which decreased by about 10 % and continued to be the value at the intended level of 60 % for colourless boards. This value is particularly significant for issues connected with vegetation of grass on the football pitch. Therefore, considerable part of the canopy was clad with colourless boards with greater light transmittance.

Bearing capacity of boards with axial support span of 800 mm and greatest assembly length of approx. 7 m is at least 7.9 kN/m^2, which ensures appropriate reserve of bearing capacity for environmental loads such as wind and snow and treading of technical staff on the canopy. It should be emphasized here that bearing capacity of the board will depend on its length as presented in table 2.

Table 2

Bearing capacity of polycarbonate boards according to [4]

Support conditions	Board length [m]	Characteristic bearing capacity [kN/m^2]
free support on two longitudinal edges with axial support span of 800 mm, free rotation on the support	1	>10
	2	>10
	3	9,2
	4	8,4
	5	8,2
	6	7,9
	7	7,9

However, it should be pointed that, during use, the material is subject to degradation and decrease of its strength as connected with the degradation. Pursuant to the information received from the manufacturer, the initial strength of the level of approx. 60 MPa will decrease with time to approx. 50 MPa. This decrease of strength may occur within 20 years of use.

Boards in five amber colours laid in a composition specified in the design were used for covering of the stadium. The polycarbonate boards were cut in workshops at appropriate lengths and equipped with channel closing elements. At the end of each board they installed sealing tapes protecting against penetration of water into the channels as well as metal protective fixtures. At the contact point with the board the metal protective elements were additionally sealed with silicon compound (Fig. 8).

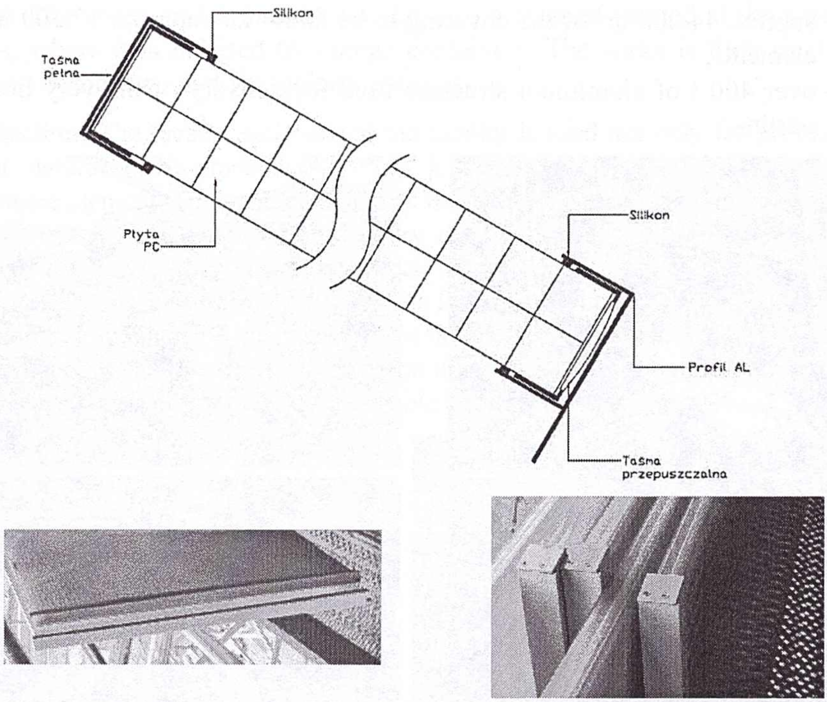

Fig. 8. Sealing of the polycarbonate board channels

Assembly. The assembly of the covering support structure elements and the very polycarbonate covering will be made with the use of a single element method. The façade was assembled with the use of scaffolding placed on the ground level and the roof was assembled with the use of scaffolding suspended on steel bearing girders. The strong point of aluminium and polycarbonate, i.e., their little weight, proved extremely useful during the assembly, as the entire process was realised only with the use of human hands. [Fig. 9]. Cranes and freight lifts were used only for transportation of material boxes. All connections within the covering are delivered as screw connections with the use of ordinary and self-tapping screws. The polycarbonate boards were fixed to the structure with the use of tightening strips connected with self-tapping screws.

The assembly of support structure under the roof covering started in June 2010 before completion of assembly of the steel bearing structure – following the period of approx. 3 months from placing of the first steel element. The first elements of the covering made of boards were mounted at the end of November 2010 and the assembly completed at the turn of April and May 2011. In this period the assembly works had to be interrupted due to severe weather conditions during the winter period. Some figures such as the below-mentioned prove the large number of works performed in connection with the covering:

— approx. 44.000 m^2 of the covering to be laid – i.e., approx. 17.500 board elements,

— over 400 t of aluminium structure used for delivery of the very bearing purlins.

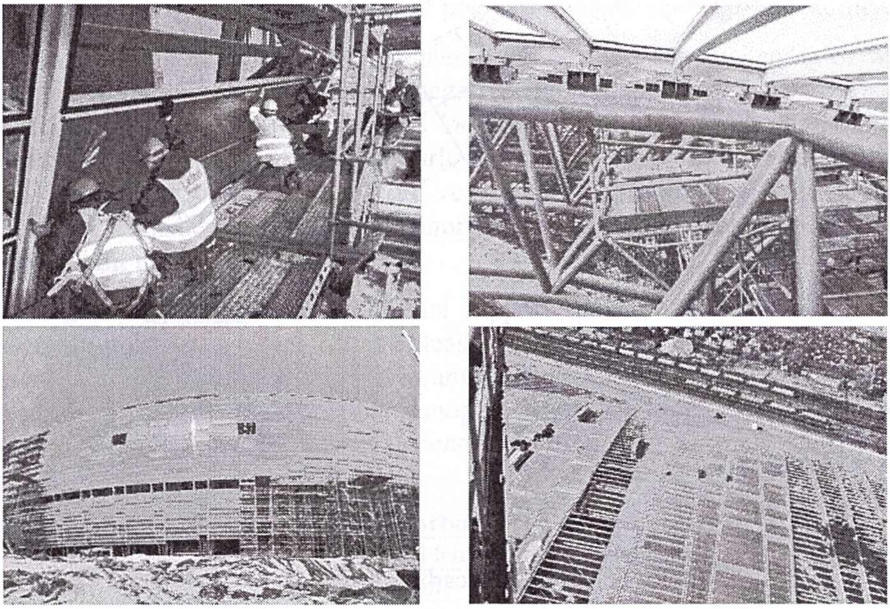

Fig. 9. Assembly of the covering made of polycarbonate boards

Drainage of the canopy. Drainage of the entire covering was embedded in the roof covering structure. The open drainage system includes a system of 144 radial gutters and three circumferential gutters. Both gutter systems were placed both on the roof part and façade part. The radial gutters were mounted above each tubular section of the upper belt of the main steel girder. The circumferential gutters constituting the main drainage system for the canopy were located in the following places:

— internal edge of the canopy, above a bearing pipe fastening the canopy,

— at the breaking of the facade and roof part,

— at the half height of the facade part.

The method of assembly and fastening of polycarbonate boards with the use of tightening strips forced delivery of the roof part and the already mentioned bent bearing purlins. The bending enables gravitational drainage of rainfall water from the board surface and directly into the radial gutters adjacent on both sides. Water from the radial gutters is drained into circumferential gutters, where drainage inlets were located. Next, the water flows through ducts fastened to girders. The water drains through the ducts to a channel located at the base of girders, where it is directed to storage containers. The water is then used for watering of the lawn and for sanitary purposes.

Illumination. The facade enclosure of the facility is used not only for protection against natural environment effect, but it also constitutes a decorative and informative element. Transmittance of light through polycarbonate boards was used by designers for the purposes of delivery of illumination of the entire facility. Lighting installation of the decorative back lighting of the façade were placed on three levels on the reinforced structure of the facility. The backlit facade emphasizes accurately the shape of bearing structure of the facility roof and covering as visible in the presented photographs (Fig. 10). The upper line of back lighting reflects the variable shape of stands, which is also visible on the facility facade.

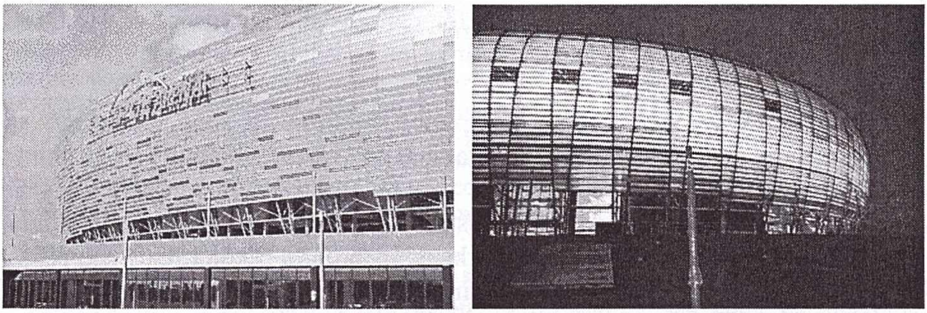

Fig. 10. The wall enclosure in daytime and at night

Additional elements. Apart from the above described basic elements of the covering, the following technical equipment was delivered in the subject part as embedded and sealed:

- — a two-row circumferential set of snow guards protecting against sudden sliding of a thick layer of snow from the arced part of the covering,
- — a drive system used for operational use of the covering,
- — a system of protection against fall from height for technical staff performing any works on the covering,
- — manholes for the covering and technical manholes,
- — a system of weather monitoring.

Evaluation of the covering. Following one year of use after commissioning of the facility, no cases of damage to boards or worsening of properties connected with tightness of the entire covering were found on the covering of the stadium roof. The experience gathered from stadiums delivered worldwide and the Gdansk stadium allow us to assume that such type of solutions will become common in our landscape on a greater scale both as regards public and housing facilities.

It is expected that within next approx. 15-20 years of use, the polycarbonate covering and its support structure will not require any major renovations, which will certainly contribute to lowering of costs of use of the facility.

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