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Pregledni znanstveni članak

Global Monitoring of the Technical Condition for the "Donbass Arena" Stadium, Ukraine

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ABSTRACT. About 70% of the Ukrainian cities' territory has complicated geotechnical conditions and it requires reliable, constantly updated information about the changes in the Earth's surface and engineering structures. Contemporary trends of developing big cities and megalopolises show a total neglecting geotechnical processes occurring on the construction sites of modern, unique and complex structures. Adequate safety measures are often ignored while designing, constructing and, then, operating the above-mentioned objects which also include large sport facilities. Withal such facilities are included in the list of objects that have "… unique and very important economic and / or social value ..." as determined in Ukrainian national construction regulation, particularly National Building Code V.1.2-5:2007. They are subjected to mandatory scientific and technical support during the exploitation. One of the points of scientific and technical support is a requirement for monitoring the technical condition of framings. This paper describes the unique multipurpose monitoring system of the "Donbass Arena" stadium, which is located in extremely unfavorable geotechnical conditions.

Keywords: global monitoring, local monitoring, tectonic thrusts, measurements, sensors.

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1. Problem's description

Safe operation of large, complex and unique structures depends on the research, design and construction quality. The deformations of underground bases occur under the influence of various factors especially in complicated geological conditions, and it causes deformations, and sometimes collapse of the entire buildings and constructions. Therefore the specific requirements are placed on the stability of the foundations which demand increasing the bearing capacity of soils, a detailed study of the geological conditions not only during the research period, but also for the object's further operation. In the coal basins of Ukraine, where Donetsk is located, main complications of the buildings' and structures' exploitation are associated with repeatedly undermined territory (Gavrilenko 1995). Designing the protective measures that could withstand geotechnical risks to the most extent, and monitoring of the buildings' and structures' technical condition at the operational stage are the effective ways to reduce effects of geotechnical factors (Hoek and Palmieri 1998).

It is necessary to control the critical parameters of the structure framings during the monitoring, as well as to differentiate elements to be automatically controlled or measured by traditional monitoring. The very strong analysis of the object's design features and potential threats with applying mathematical modeling results, making engineering design of the emergences, development of hazards are the base elements for choosing constructions subjected to control.

2. Work's purpose

Ensuring the safe operation of building structures of the unique football stadium "Donbass Arena" (capacity – 50,000 people), located in complicated geological conditions, through the organization of a rational and efficient system of structural scrutiny (technical monitoring) of buildings and surrounding area.

3. Methodological issues of monitoring

In 2010 specialists of DE "Donetsk Promstroyniiproekt" had developed and put into maintenance an effective system of fracture-safe designing different structures – *global monitoring* (Malikov et al. 2010). In the process of creating a system of construction technical monitoring the object is considered as a unified system "sub-base – foundation – building frame – roof – environment".

In the general case *global monitoring* includes 7 types of *local monitorings*: geophysical, hydrogeological, geotechnical, geodetic, of reinforced concrete framings, of metal framings, automated system of monitoring – ASM (Fig. 1). *Global monitoring* enables to summarize in integral way the observation results, to diagnose possible deviations and damages and to take timely measures for preventing the development of unfavorable situations. Preferred applying area is the operational stage.

Local monitoring solves narrow problems of technical condition of the object and surrounding area. The *local monitoring* types are defined on the research and analysis of the structure's location conditions and design features. Table 1 presents a brief description for each kind of *local monitoring*. Monitorings №1-4 are produced by certified in corresponding areas engineers. Monitorings №5-6 are performed by certified civil engineers.

Control cyclic recurrence within *local monitoring* – from two to six months depending on the accumulation rate of deformations that are determined during the first year of observations (except ASM – carried out »on-line«). Four-cycle measurements should be realized in the first year.

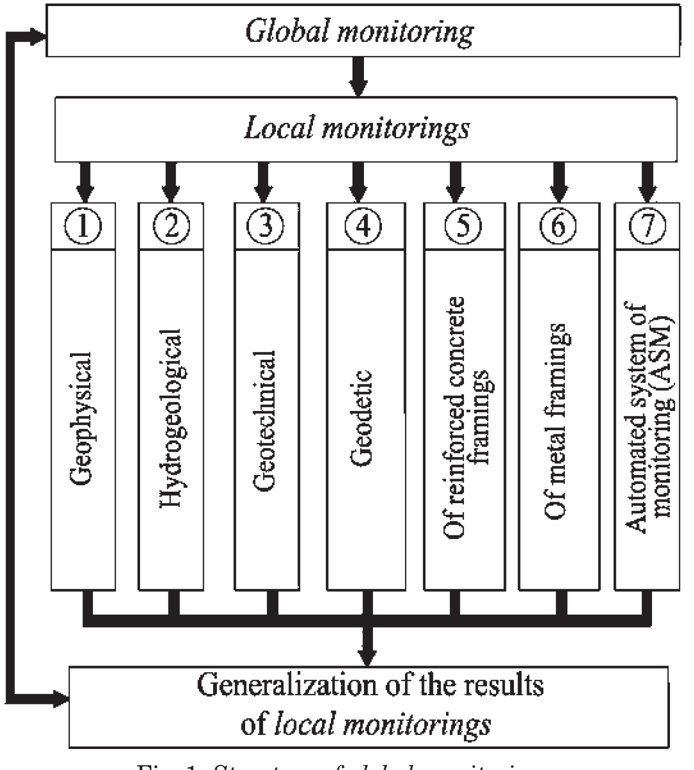

Fig. 1. *Structure of global monitoring*.

Local monitorings №№3-7 are being used for the »Donbass Arena« stadium. Implementing a monitoring system begins after the previous studies and calculations, gathering the information about hydrogeological, geophysical, geological and other conditions (Schneider 1998, Kleberger 1998).

4. Geological conditions analysis of the area and design features of the stadium

Among the adverse factors affecting the soil mass below the stadium area, the following should be noted:

- presence of the 3 flats of the French thrust fault plane with latitudinal strike and 2 flats of the Coke thrust fault plane directly underneath the stadium
- undermining the territory by the Kalinin coalmine
- contiguity of groundwater aquifers (depth ranges from 0.6 m to 5.3 m).

Table 1. *Short description of local monitoring.*

№	Type of local monitoring	Short description
1	Geophysical	Instrumental approach to determine the presence of caverns and other geological disturbances within the facility and surrounding area using geophysical tomographic measurement (seismic and electric exploration works) by translucence.
2	Hydrogeological	Determining the hydrotechnical conditions of a worksite using water monitoring wells.
3	Geotechnical	Analyzing existing geological conditions of the object. Constructing the system of ground and deep centrals on the surrounding area. Detecting the influence degree of complicated geological conditions on the structural integrity of the construction framings. Analyzing the earth's surface movements.
4	Geodetic	Constructing the system of bench marks, collimating staffs, targets on the building's territory and framings. Observing motions and displacements using modern surveying instruments.
5	Of reinforced concrete framings	Developing the system of observation and bench mark stations for tracking the behavior of movement joints and framings. Carrying out the measurements. Analysis of the stadium as a unified system "sub-base – foundation – building frame – roof – environment". Structural assessment of bearing elements.
6	Of metal framings	Inspecting metal structures, weld seams and bolted connections as well as heel joints. Measuring linear sizes and fixation of possible deviations. Instrumental measurements with detection of defects and damages.
7	Automated system of monitoring (ASM)	Developing the system of universal inductive sensors at the facility. Testing the system of fiber-optic sensors. Measuring the magnitudes and directions of structures' displacements. Frequency reading and processing the data of devices, operating in »online« mode, should not exceed one month.

The soil mass at the basement is structurally weakened; its mechanical properties are drastically reduced. Only 20% of the stadium territory consists of half-rocks or ledge rocks, the rest are clays, weatherworn argillites, siltstones, crumbling sandstones of highly low strength. Tectonic zones are by nature of complex geological structures broken by numerous fracture systems and have low power block structure. The stadium's territory is influenced by alternating vertical movements of the earth's crust. At the present time there is stable subsidence at the rate 0.5–3.0 mm/year. Compression of the soil mass occurs at the rate of 10–20 mm/year in the French thrust area (Serdiuk 2007).

As to the foundation as a whole, the extremely unfavorable conditions for the stadium because of the basement disturbance by two thrust fault planes that separate basement rocks for a number of blocks should be noted. These blocks are capable to move relative to each other under the failure of the old mining activity roof or due to minor seismic vibrations.

Structural protection measures from adverse geological conditions of the stadium are designed with allowance for following parameters:

- tectonic plate slopes: $i \leq \pm 3.0$ mm/m
- tectonic plate relative planimetric deformations: $\varepsilon \leq \pm 1.5$ mm/m
- tectonic plate curvature radius: $R \geq \pm 25$ km.

The main protective measures for the foundations under the effects of complicated geological conditions are:

- symmetric, relative to the North-South-East-West orientation, severing of the stadium by movement joins forming 14 flexural bays
- foundations are on a natural basis in each bay besides there is the reinforcement of low-modulus soil layers by rigid inserts of the precast concrete piles. Such measures lined probable settlements of the foundations between the bays around the perimeter of the stadium
- 3 types of foundations – slab; combined foundation that conjoins the plate with the adjacent system of crosswise strips; girder.

Constructively, the stadium presents a calotte with a three-storied terrace for spectators and with under grandstand premises, made in reinforced concrete structures, and a canopy top over most of the seats, made of metal structures. The characteristic asymmetric shape is represented in the geometry of the stadium calotte. The upper tier is cut so as to follow the contours of the roof, which in turn iterates the contours of the landscape. The calotte is reckoned like a contiguous solid-core terrace with the seats for sideliners which is divided into three tiers – the lower, middle and upper one.

Along the perimeter the stadium is divided: on the framework – by 14 movement joints with 80 mm gaps between the bays, on the roof – by 12 movement joints with 200 mm gap between the bays. Stability within the bay, as well as the horizontal load accommodation are provided by the reinforced concrete stiffening cores, where stairwells and elevators are placed (main twin stiffening cores and bearing supports of the roof are located on the foundations of 4 corner bays NA, NC, SA, SC – Fig. 2).

The main load-bearing elements of the stadium are: the radial multi-storey framework, which receives the loads from the sloping terraces; inserted floors and built-in under grandstand premises. Bearing elements of radial frames are: vertical and inclined columns; pronate joists that resist the load from the tiers; radial joists to provide radial stiffness; circular joists to connect the radial joists in the spatial system; inserted floors between the radial and circular joists.

The roof is based on the stiffening cores and integrated therein. Such a system has an important role in ensuring the dynamical stability of the whole building. The supporting truss is mounted on the bearing structure of the core line through the V-shaped verticals. The spatial constructional boarding is located between the supporting cantilever metal trusses and is formed by radial and circular elements of the upper and lower chords and diagonals.

5. Geotechnical monitoring

As part of the geotechnical monitoring, there was a decision to evaluate the effect of tectonic disturbances on the operational features of the stadium, as well as to define the criteria (subcritical and critical) of stress and strain state of supporting cantilever metal trusses, framework's stiffening cores and support pillars. These criteria are badly needed for justifying the accuracy of geodetic measurements, result analysis, as well as for passing a judgment on the implementation of preventive measures when obtaining the corresponding displacements (Duvansky et al. 2013).

The NA bay was chosen for study of changing the stadium's stress and strain state with possible developing tectonic processes. This bay is located in the worst geological conditions (see Fig. 2), specifically, in the intersection area of French and Coke thrusts where possible deformations of the soil mass because of undermining and structure's weight can be complemented with the movements in the tectonic disturbances area. A model for NA bay was developed with the simulation of the conditions of the basement deformations formation that are as close to real. In developing the analytical model the finite-element method was adopted as theoretical basis. The tectonic impact is set using the simulation modeling approach.

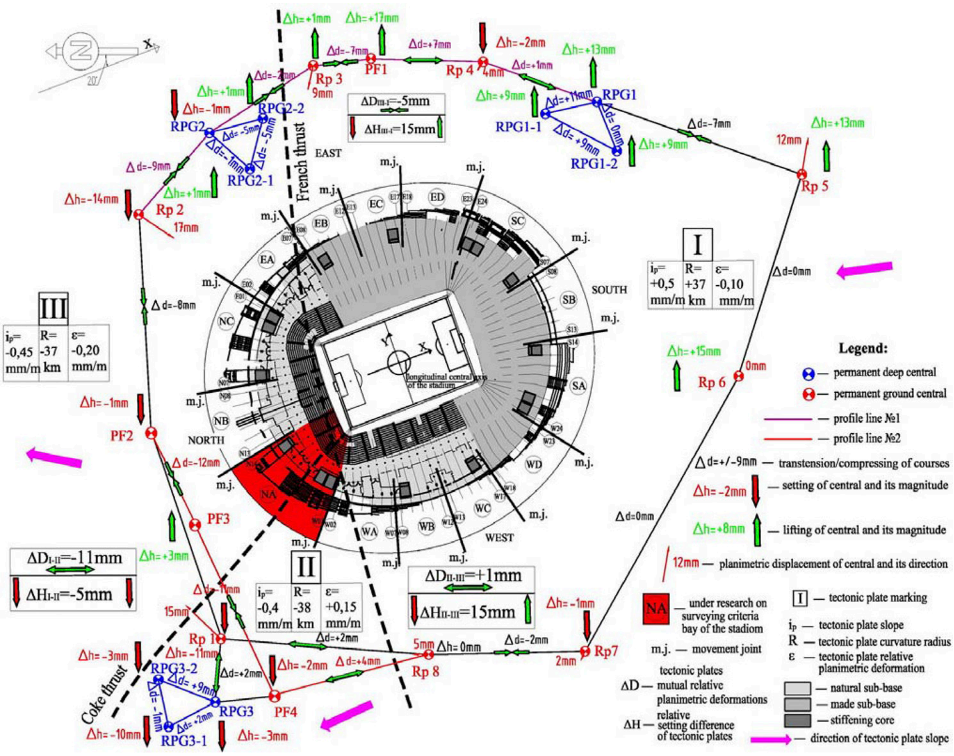

Fig. 2. *The »Donbass Arena« horizontal plan with displaying the main design features, geotechnical and geodetic control nets in the surrounding area, as well as the main parameters of geotechnical monitoring.*

The magnitude of tensioning serves as the final and critical criterion for structures when the processes of steel rupture resistance or concrete deterioration under compression are observed. To define the criteria for the stress-strain state of the structures the work diagrams of the C345-grade steel (roof), A500C-grade reinforcing steel (framework, foundation), B40-grade concrete (framework, foundation) were used.

As a result of numerical studies, it is determined which building structure subjects for control; the locations of the geodetic reference points are defined. These locations (in NA bay) can be applicable for the whole stadium because of the structure similarity of the construction's bays (Table 2). The criteria, obtained for NA bay, are used for the other bays too inasmuch as the bay with the worst operating conditions was selected for numerical studies. The required accuracy of surveying, directly related to the operational admissible deviations, is determined using a reduction coefficient.

Also, as part of the geotechnical monitoring, the 3D model of the surface with the mapping of the geological structure of the stadium is developed (Fig. 3). The stadium's geotechnical network consists of: 3-bushes of deep centrals on each of the 3 tectonic plates, which are the basis for further development of the geodetic network and tracking the behavior of the thrusts wings (see Fig. 2); and 3 profile lines at the members of tectonic plates that are used for monitoring possible processes of compression/expansion of the soil mass.

Table 2. *Subcritical displacement of geodetic reference points obtained from numerical simulations.*

Criterion	**Stiffening core (the settlement difference between the edge points)**	**Columns of the third level (settlement)**	
	$\Delta h = \lvert h_2 - h_1 \rvert$, **mm**	h_3, **mm**	h_4, **mm**
Subcritical (without snow load)	19	–27	–25
Subcritical (including snow load)	29	–32	–29

Hereinafter it is provided to study in detail the geological profiles in the places of setting ground and deep centrals and to represent them in three-dimensional view.

The main results of the geotechnical monitoring during 2013 year include the following:

- tectonic plate relative planimetric deformation: ε = ±0.1…0.2 mm/m » $[\varepsilon_p]$ ≤ ±1.5 mm/m
- tectonic plate slope: i = ±0.4…0.45 mm/m » $[i_p]$ ≤ ±3.0 mm/m
- tectonic plate curvature radius: R = ±37…38 km > $[R_p]$ ≥ ±25 km
- relative setting difference of tectonic plates: ΔH = 5…15 mm
- tectonic plates mutual absolute planimetric deformations: ΔD = ±1…11 mm.

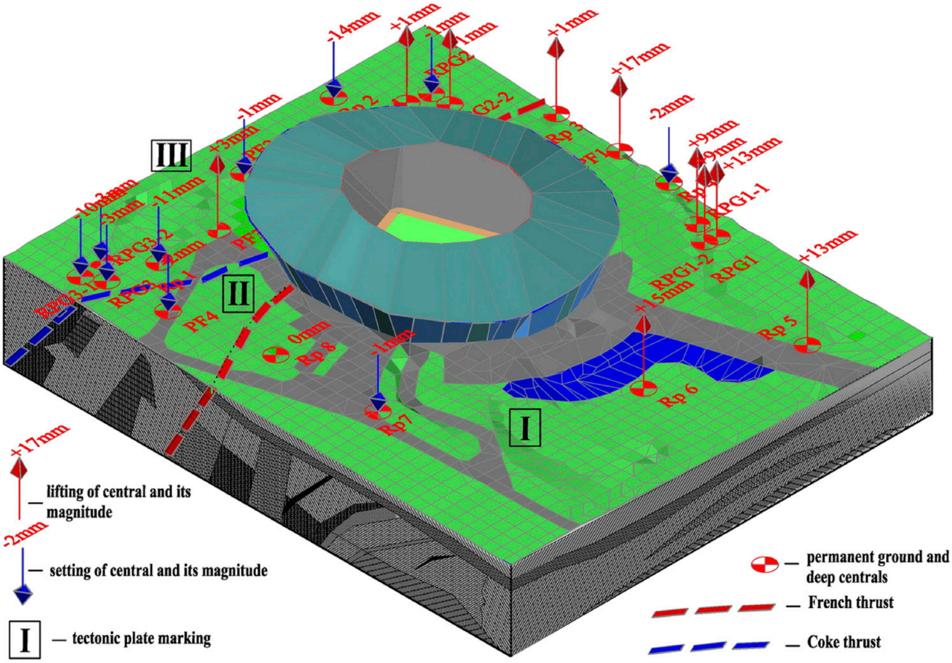

Fig. 3. *The 3D surface model of the "Donbass Arena" stadium and the adjacent territory in the zone of tectonic disturbances.*

6. Geodetic monitoring

Before starting geodetic monitoring the study for determining the most appropriate and efficient method of observing movements of the surrounding area and the stadium supporting structures was conducted. International experience concerning methods and tool support of geodetic monitoring for sport and unique structures was analyzed, the approaches and software for post processing of obtained results were studied (Eichhorn 2007, Kopacik et al. 2013, Georgopoulos 2011). The engineers' task was to develop such a system of geodetic monitoring which could meet all the official, financial, organizational requirements of the stadium's owner. The analysis of the most relevant for this object method was performed conventionally with measured distances up to 50 m. The classic method of monitoring (developing the geodetic network of ground reference marks and benchmarks, measuring movements by levels and tacheometers) is used as a basis. Other methods are compared with respect to classical approach (Fig. 4).

As can be seen, under the conditions of money economy, the traditional method ranks best in terms of accuracy and price, however, it has the highest hours of labor and time expenditures. The traditional method of geodetic monitoring was chosen taking into account the characteristics and conditions of the object as well as the object owner's preferences and requirements.

The system of centrals and benchmarks on the stadium's territory and structures was established before starting of observing (placement locations were determined

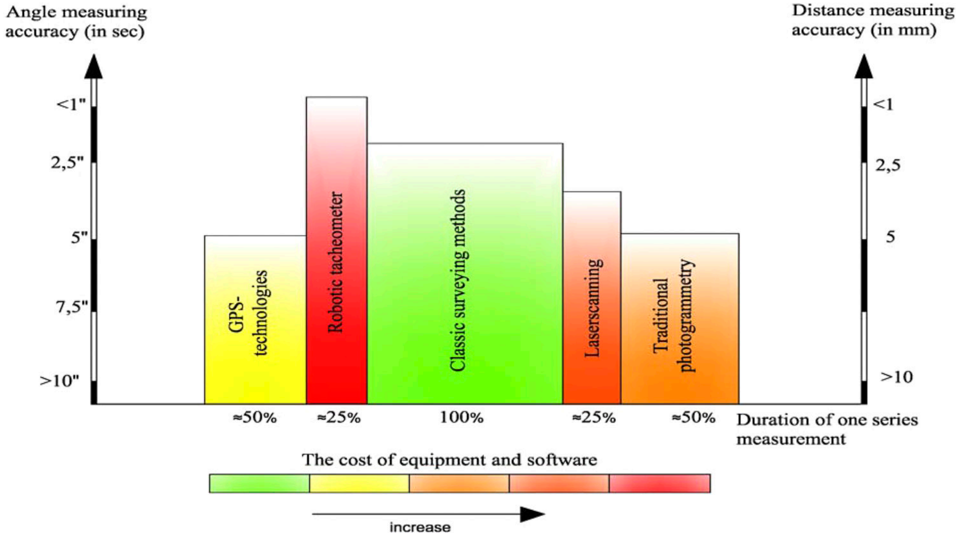

Fig 4. *Comparative analysis of the geodetic monitoring methods*.

in accordance with the geotechnical conclusions and subsequent algorithm of analysis of the results and judgments on the safe operation of the facility). An external traverse net was established on the basis of deep and ground centrals and profile lines of geotechnical monitoring. An internal geodetic network consists of: plane-table temporal stations; fixed in the corners of the football field points; benchmarks in the columns of the stadium's third level, which are rigidly braced to the foundation; reflective marks on the parapet wall and on the roof (Fig. 5). There are four connections between external and internal networks through respectively four entrances at the stadium. Every epoch of measurements the external geodetic network, that is the basis for the internal one, is aligned to the stable benchmarks of the Ukrainian national geodetic network; deep centrals are controlled using GPS.

From planimetric view the external geodetic network represents a closed traverse, where angular and linear measurements are conducted using Topcon tacheometers (2") by three tripod system with forced centering. Angles are measured in two faces, lines – in forward and reverse directions. Line measurement consists of 4 cycles in every direction, from which the average value is derived. Height measurements are carried out using electronic first-order level Sokkia with $\sigma = \pm 1$ mm/km. All instruments are subjected to checking and adjusting in the field before starting observations.

It is important to note, that the ideal situation would be creating the triangulation and trilateration network on the adjacent territory, however it turned out to be impossible because of a vast number of existing utility lines and the already completed park landscape. But settled polygonometry network shows rather high accuracy for such objects in view of the considerable amount of ground benchmarks, existence of deep centrals (see Figure 2) and multiple observations. The network adjustment is based on least squares principle. The results are used to perform variance estimation after an estimation process (Table 3).

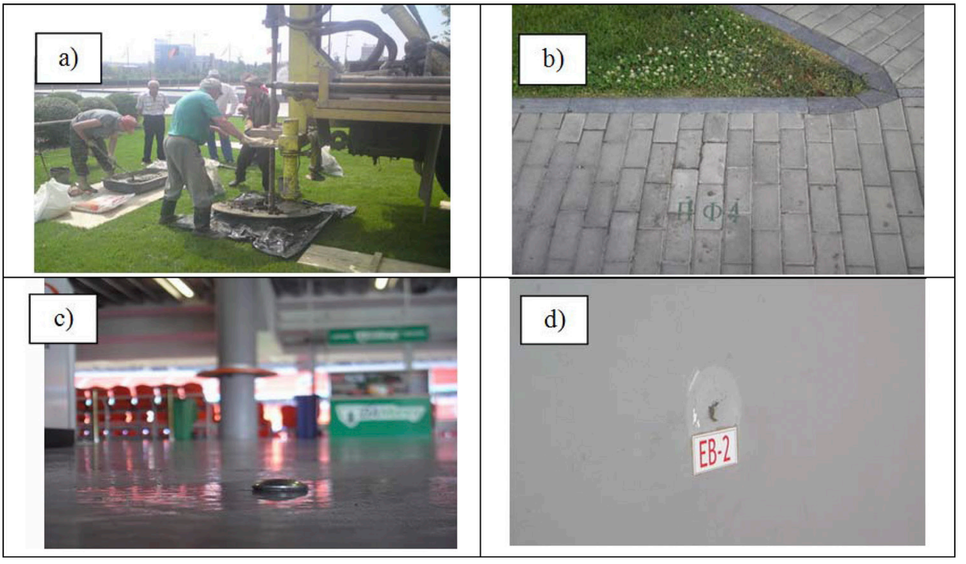

Fig. 5. *Constructing a system of benchmarks on the building's territory and framings;* a*), b) benchmarks on the adjacent territory; c), d) benchmarks on the structures.*

Table 3. *Mean-square errors of control points determined by the results of 2013.*

Measuring	**Mean-square errors**	
Distances	3.23 mm per km	Full mean-square error is combined of internal and external network errors: $m_L = \sqrt{m_{ext}^2 + m_{int}^2}$. Relative error of measuring ≤ 1/10 000
Angles	3.52”	
Coordinates	2.5 mm	
Height differences	3.5 mm	

As a result of the analysis it was proved that there was not any need in excessive accuracy using first-order geodetic instruments (0.5” angular measurements and ±0.2–0.5 mm of distance determinations), it wasn't economically justified.

The main basic parameters of framings to be measured are the linear and angular displacements in the most vulnerable and important places of construction (Lobov et al. 2012). Geodetic results serve as a base point for further calculations (the fragment is presented on Fig. 6) and modeling.

The main results of geodetic monitoring during 2013 are following:

- the displacements of stadium's benchmarks have a small trend to increase
- the direction of horizontal displacement – northern and north-eastern about 7–10 mm compared to the initial measurement; there is a building's subsidence up to 5 mm

№ column's axe	N13		N12		N11		N10		N09		N08
Distance m		5,7 m		5,5 m		5,5 m		5,6 m		5,6 m	
Settlement, mm											

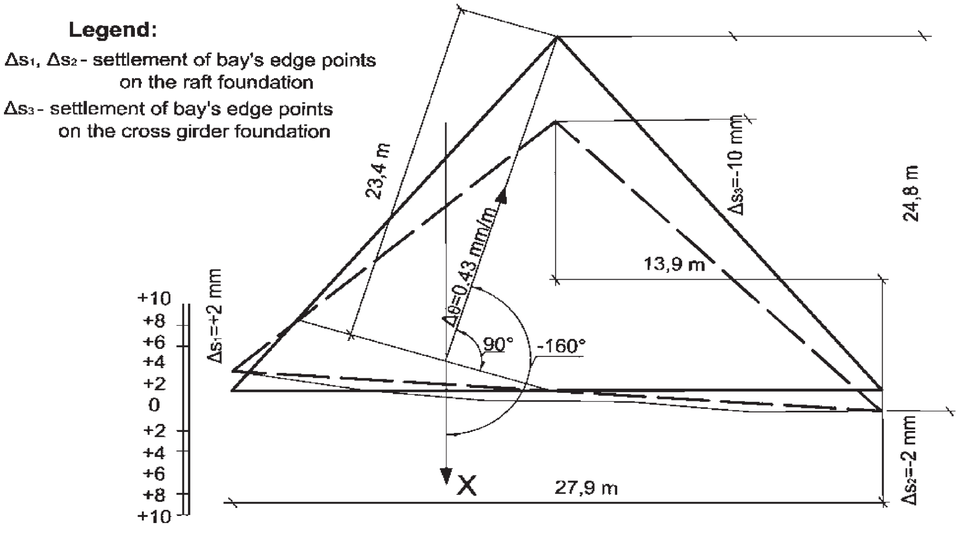

Fig. 6. *Processing results of geodetic monitoring – average settlement value and tilt of NB-bay.*

- tilts of the bays: in the zone with a natural base – $\Delta\theta$ = 0.25…0.57 mm/m; in the zone with an artificial base – $\Delta\theta$ = 0.25…0.45 mm/m
- settlement of the bays: in the zone with a natural base – Δh = +0.7…–5.35 mm; in the zone with an artificial base – Δh = –0.15…–8.5 mm.

NB-bay

- the whole length = 27.9 m
- average settlement: Δh = –5.35 mm
- average tilt: $\Delta\theta$ = 0.43 mm/m.

The results of geodetic monitoring can indirectly indicate possible dangers during operation of the facility, and are used to determine the design parameters, which are compared with the structural protection measures from adverse geological conditions and with the critical values of movements established earlier.

7. Monitoring of reinforced concrete framings

The selection of the most critical areas of construction, the definition of hazardous sections and reference points for placing the devices and benchmarks is implemented as part of this monitoring. The distribution of control points between different types of local monitoring, selection of commercially produced instruments and development of individual industrial gages, making and mounting on the facility are justified and conducted. Instrumental and visual observations, voltage and microclimate measurements are conducted, as well as actual displacements, stresses and strains in controlled structures are determined during the monitoring (Fig. 7). Structural and integrity level assessment, analysis of the construction behavior scenario as a whole are carried out.

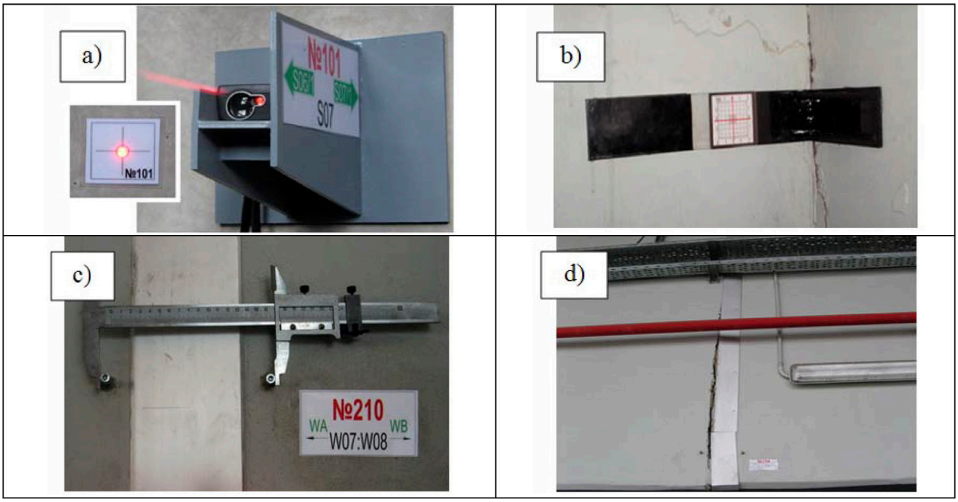

Fig. 7. *Monitoring elements of reinforced concrete framings;* a*) fixes control point for distance-measuring device when observing horizontal displacements; b) observing stations in the individual "problem" areas of the framework; c) observation of the movement joints behavior; d) characteristic framework deteriorations during stadium operation*.

Among other things, the following is being operated:

- inspection of foundations
- determining the presence of cracks, spalls, destructions
- inspection of protective coatings
- identifying the degree and corrosion depth of concrete and reinforcement
- observation of the movement joints' behavior (Fig. 8).

As the main results of monitoring during 2013 we can emphasize:

- fixed maximum displacement of movement joint compiles 25.4% of compensation capability (a = 80 mm)
- characteristic traces of movement joints' work are the local damages, these don't impede the normal operation and don't decrease the load-bearing ability
- the main trend for movement joints is closure (compressing)
- emerging and disclosure of cracks up to 0.5 mm in dividing slag stone walls is noticed
- there is a quantitative difference between settlements of bays on natural and on artificial bases
- deformations of reinforced concrete stiffening cores (angle from vertical) amount to: $\Delta\varphi = 0.001 \ldots 0.017$ rad.

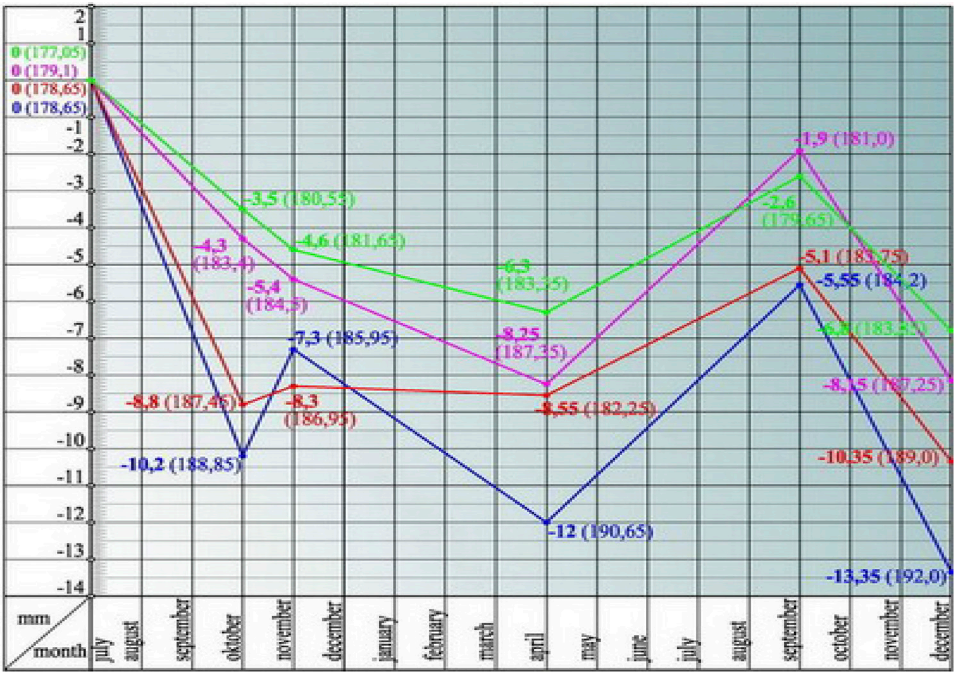

Fig. 8. *Diagrams for analyzing the behavior of movement joints*.

8. Monitoring of the roof metal framings

Inspection of metal structures, weld seams and bolted connections, as well as heel joints with measurement of linear magnitudes and fixing probable deviations are carried out here (Fig. 9). The tilts, tension, horizontal displacement magnitudes are determined. The results and readings of geodetic monitoring and ASM sensors are analyzed. The compressions and distensions are observed, inspection of the protective coatings is carried out. Special attention is paid to the inspection of the roof in winter with the snow and ice loads, etc.

We obtained several results during the monitoring in 2013:

- increments of displacements for moving heel joints in load-bearing roof trusses: –9…+11 mm
- maximum displacement: –49 mm. Trend of the displacement is disclosure
- fixed maximum displacements amount to 30.6…38.9% of allowed design values
- the main damages (fixed during visual examination) are local exfoliations of paint coatings
- deformations of cantilevering parts of trusses (angle from vertical): $\Delta\varphi$ = 0.001…0.008 rad
- deformations of the roof are characterized, in most cases, by changes in temperature.

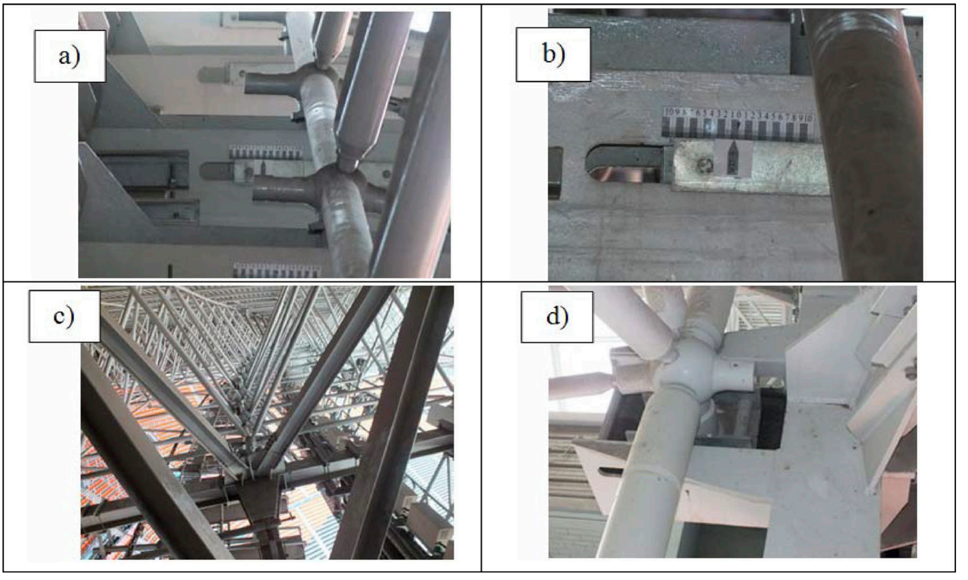

Fig. 9. *Carrying out the monitoring of the roof metal framings;* a*), b) instrumental measurements of running blocks of the roof; c), d) visual inspection of the stadium roofing*.

Fig. 10 represents the moving diagrams of truss heel joints.

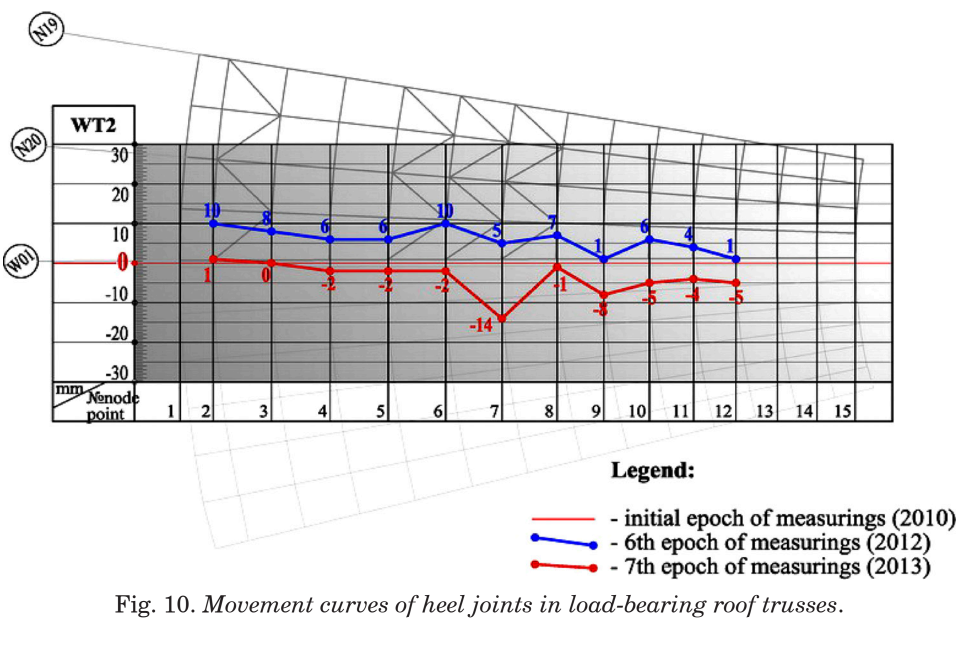

Fig. 10. *Movement curves of heel joints in load-bearing roof trusses*.

9. Automated system of monitoring (ASM)

ASM is aimed at remote recording, processing, transmitting information in »on-line« mode and consists of a system of universal inclinometers (pendulum sensors), data collector and interconnection links. The observation of tilts, horizontal displacements magnitudes and directions of the framework structures and roofing are observed using this system. The sensors' scanning is realized by permanently placed at the stadium data collection and processing equipment in automatic mode with programmable time interval. This system is connected with the emergency services of the stadium also in automated regime.

The sensors are placed in such way that their damage, third-party movement are not possible. The sensors are located on reinforced concrete stiffening cores, cantilever-arms of supporting thrusts and at mid-span of the structural blocks of the metal roof (Fig. 11). The ASM allows at an early stage to detect the direction (range – 360°) and tilt values with an accuracy of 1 arcsecond (horizontal displacement of 0.001 mm). The relative settings during observation of the object are being calculated using obtained data.

ASM sensors are placed on structures on the assumption of their minimum amount and necessity to monitor for further analysis (that was earlier defined). By analogy with geodetic monitoring, the sub-critical and critical criteria of stress and strain state of the reinforced concrete stiffening cores of the framework and the cantilever-arms of supporting thrusts of the roof were developed for the control of impending hazards in »on-line« mode. Table 4 shows the calculated figures for one of the reinforced concrete stiffening cores (one of tested bays), where the ASM sensor is placed.

The sensor system is connected with the emergency services and in the case of achieving subcritical displacements these services can take precautionary protective measures. During sport events if critical criteria is achieved the system provides a signal for people evacuation, and the signal is sent to the emergency services about such achievement. The corresponding diagrams of the materials' work are laid down in the basis of determining the criteria. To achieve the limit stress-

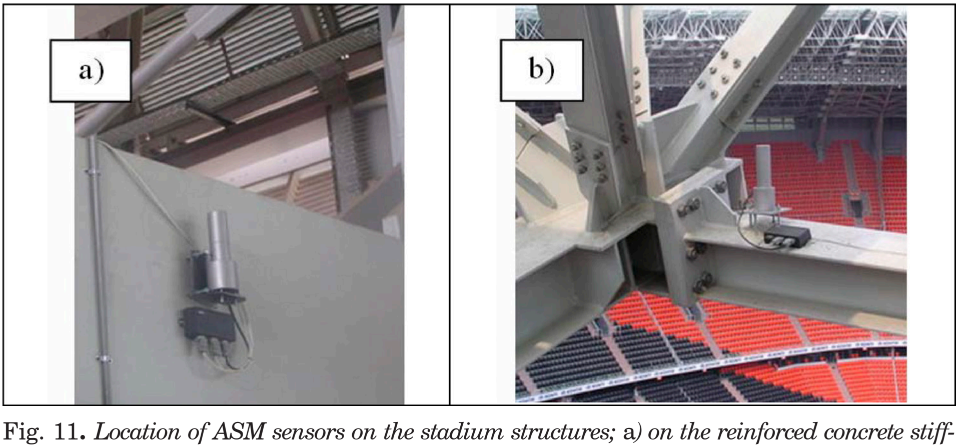

Fig. 11. *Location of ASM sensors on the stadium structures;* a*) on the reinforced concrete stiffening cores of the framework; b) on the cantilever-arms of supporting thrusts of the roof.*

es in the materials the emergency load combination with increased overload factors was used for simulating extraordinary situations.

The main results after monitoring in 2013 are:

- tilts of reinforced concrete stiffening core (relative to the central axis of the stadium): i^c = 15.6435x10^{-5}…4.061x10^{-5} rad
- tilts of cantilevering parts of load-bearing roof trusses (relative to the central axis of the stadium): i^t = 21.0426x10^{-5}…6.4434x10^{-5} rad.

These values do not exceed determined subcritical criteria.

Fig. 12 shows the scheme where displacements of ASM sensors are presented in mm (for roof elements). Typical schemes are used for other types of local monitorings to show the displacements' directions and values of different stadium's constructions.

Table 4. *Calculation results for stiffening cores' tilts of NC bay in N06, N07 axes.*

Load combinations	**Estimated indicators of structures (stiffening core)**					
	Set fair average tilt, measured during monitoring, i^y_m, rad	**Calculation tilt i^y_r, rad**	**Summary tilt $i^y = i^y_m + i^y_r$, rad**	**Calculation tension in concrete σ_b, MPa**	**Calculation tension in reinfor-ce-ment σ_s, MPa**	**Criterion magnitude, MPa**
Design criterion, fyd	5.9 · 10^{-4}	8.8 · 10^{-4}	14.70 · 10^{-4}	15.06	414.8	415.0
Sub-critical criterion, fyk		9.8 · 10^{-4}	15.70 · 10^{-4}	18.07	498.5	500.0
Critical criterion, ftk		11.0 · 10^{-4}	16.90 · 10^{-4}	21.68	599.1	600.0

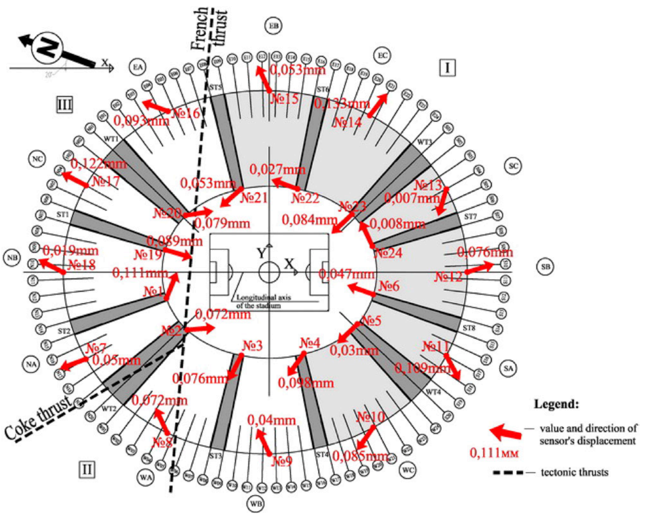

Fig. 12. *Displacements of ASM sensors on roof elements (typical scheme).*

10. Generalization of the results of local monitorings

A selected set of monitoring types and the corresponding approaches provide the ability to carry out the overall adjustment of the local monitorings' results and to systematically diagnose possible damages and deviations.

To ensure the safe operation of the stadium there was a decision to implement a system of estimating the residual operation time of framings as follows:

- development of the spatial calculation (design) models of the system "sub-base – foundation – building frame – roof – environment" for each of the bays where the devices and benchmarks (for registration the displacements) are placed (Fig. 13)
- the calculation model is subjected to the abnormal load combinations and to the measured displacements (see Fig. 13)
- the tension in framings is determined subsequent to the results. Then they are compared with the design resistances
- the residual operation time of the respective framings' lifting properties is defined further.

The results of the generalization are necessary for optimum managerial decision-making in the case of emergence of whatever hazardous situations. Using the results of generalization allows estimating reliably the possibility of further safe operation of the stadium structures.

A fragment of the resulting analysis where the reserves of constructions' bearing capacity are shown is presented in Table 5. Together with timely detection of displacements and dangerous faulting this table is the main purpose of the work.

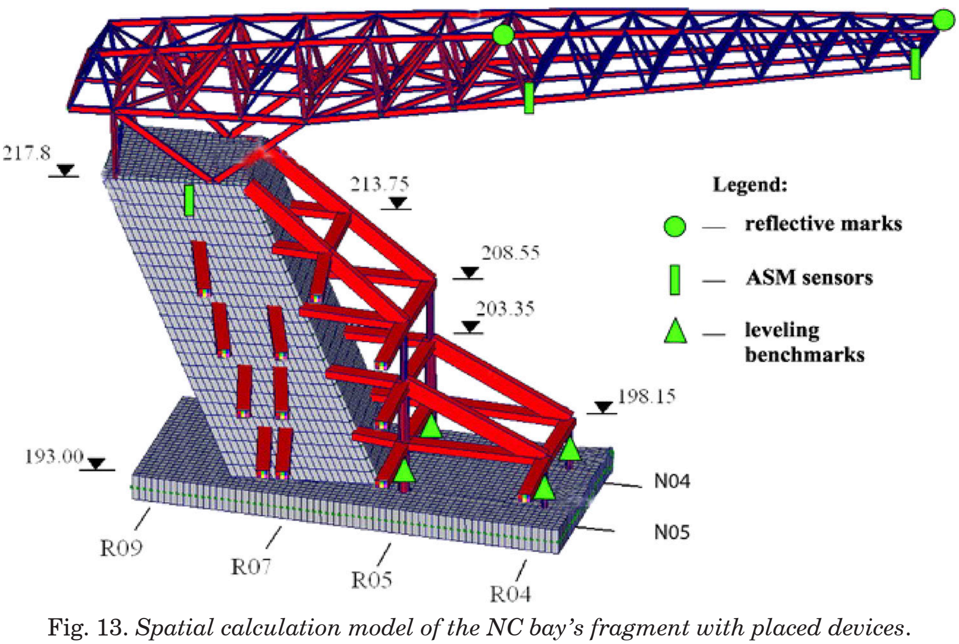

Fig. 13. *Spatial calculation model of the NC bay's fragment with placed devices*.

We can understand how much of the residual load capacity of any construction in any place is left and what element needs to be strengthened or unloaded. Results are presented with percents. These figures indicate how much the construction can be additionally loaded to its design full load capacity.

Table 5. *Fragment of resulting analysis*.

Column types	**Column section, diameter, mm**	**Working reinforcement square A500C, cm^2**	**Bearing capacity [M], kNm**	**Actual efforts $(N \cdot e_0)_I$, kNm**	**$[M]-(N \cdot e_0)_I = \Delta M$, kNm**	**Reserve of bearing capacity** $\frac{\Delta M}{[M]}$ **x 100%**
1	550	12Ø16 A_s = 24.03	248.6	147.0	101.6	41
2	550	12Ø16 A_s = 24.03	270.3	179.0	91.3	34
3	800	16Ø20 A_s = 50.27	902.0	713.0	189.0	21
4	800	16Ø20 A_s = 50.27	738.0	590.0	148.0	20

The implemented monitoring scheme and obtained results allow judging that the stadium is fully equipped with all necessary devices and benchmarks for regular observing the technical condition of constructions and surrounding area. Visual and instrumental observations are provided with corresponding programs and techniques of effectuating monitoring works.

Geodetic monitoring plays significant and main role in the whole system of global monitoring. It is a core (“heart”) of this system because geodetic methods of measurements and analyzing the results are used in every local monitoring as well as data obtained during geodetic monitoring are applied for spatial calculations on residual load-bearing capacity of all stadium’s constructions. Geodetic monitoring is closely connected with geotechnical one, they are based on similar given data and held inseparably. Only this can give the complete understanding of ongoing processes (Zalesky et al. 2002, di Mauro and van Cranenbroeck 2012, Chmelina and Kahmen 2003).

11. Conclusions

1. Institute DE “Donetsk Promstroyniiproekt” with the participation of leading scientific and technical organizations of Donbass: UkrNIMI, DonNACEA, ZD NE NIISK, and in collaboration with OOO (Ltd.) “Donbass Arena” has developed a novel system for global monitoring of building object.

2. This overall system is implemented and provides the safe operation of the unique five-star stadium “Donbass Arena” located in difficult geological conditions.

3. The monitoring system is constantly being improved and upgraded, updated with new devices, benchmarks and reference points allowing to carry out different researches and to rationalize the existing system.

4. Periodical or continuous monitoring of structures or processes can only be defined, designed and realized in an interdisciplinary approach. Monitoring is executed in close cooperation with experts from other academic fields (Wunderlich 2006).

5. The global monitoring system meets the requirements of normative and legislative acts concerning the issues of scientific and technical support of construction projects (DBN 2007) and the special acts relating to each local monitoring as well as all UEFA requirements imposed for such stadiums (Guide 2008).

6. With respect to geotechnical conditions the stadium's site is predominantly characterized by compression processes that correspond to previous results of geophysical studies.

7. According to the results of global monitoring in 2013 no critical value of displacements has been reached. The stadium's safe exploitation is guaranteed.

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Globalni monitoring tehničkih uvjeta za stadion "Donbass Arena", Ukrajina

SAŽETAK. Oko 70% teritorija ukrajinskih gradova ima složene geotehničke uvjete što zahtijeva pouzdane i stalno ažurirane podatke o promjenama na zemljinoj površini i građevinskim objektima. Suvremeni trendovi razvoja velikih gradova i megapolisa pokazuju potpuno zanemarivanje geotehničkih procesa koji se pojavljuju na gradilištima modernih, jedinstvenih i složenih građevina. Odgovarajuće mjere sigurnost se često ignoriraju prilikom dizajniranja, gradnje i funkcioniranja gore spomenutih objekata što također uključuje velike sportske objekte. Osim toga, takvi objekti su uključeni u popis objekata koji imaju „…jedinstvenu i vrlo važnu gospodarsku i/ili društvenu vrijednost…" kao što je definirano u Ukrajinskom nacionalnom zakonu o graditeljstvu, posebno u Nacionalnom pravilniku o gradnji V.1.2-5:2007. Oni podliježu obaveznoj znanstvenoj i tehničkoj podršci tijekom eksploatacije. Jedan od točaka znanstvene i tehničke podrške je i potreba monitoringa tehničkih uvjeta. Ovaj rad opisuje jedinstveni višenamjenski sustav monitoringa stadiona "Donbass Arena" koji je smješten u izrazito nepovoljnim geotehničkim uvjetima.

Ključne riječi: *globalni monitoring, lokalni monitoring, tektonski pomaci, mjerenja, senzori.*

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