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PREPARATORY STAGE FOR MONITORING THE LOAD-BEARING STRUCTURES OF THE OPERATED SUBWAY STATION

Modern technologies for the construction of a subway underground allow reconstruction of operated stations without stopping the movement of trains and subway disruptions. However, this problem is quite complicated, because at the device of transitive tunnels it is possible to violate the stress-strain state of the main load-bearing structures and ground of the station base, track upper-structure drawdown appearance that is impermissible for the safe operation of the subway. The article presents the results of the preparatory stage of theMinsk subway station main load-carrying structures state monitoring, as well as the results of spatial calculations based on design data, considering the stage of transition tunnel construction work from the first to the third branches.

***Keywords:** monitoring, subway station, transitional tunnel, reconstruction, design model, ground, deformation, stresses.*

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ПІДГОТОВЧИЙ ЕТАП ДЛЯ КОНТРОЛЮ НЕСУЧИХ КОНСТРУКЦІЙ СТАНЦІЇ МЕТРО, ЩО ЗНАХОДИТЬСЯ В ЕКСПЛУАТАЦІЇ

Проаналізовано сучасні технології будівництва підземного метрополітену, які дозволяють реконструювати експлуатовані станції без припинення руху поїздів та перебоїв метро. Досліджено досить складну проблему порушення напружено-деформованого стану основних несучих конструкцій та основ фундаментів станції та появи перенапружень надбудови над колією, яка необхідна для безпечної експлуатації метрополітену при влаштуванні транзитних тунелів. Наведено результати підготовчого етапу моніторингу стану основних несучих конструкцій станції метро м. Мінська, а також результати просторових розрахунків на основі конструктивних даних з урахуванням етапу роботи з будівництва перехідного тунелю з першої до третьої гілок.

***Ключові слова:** моніторинг, станція метро, перехідний тунель, реконструкція, проектна модель, земля, деформація, напруження.*

Introduction. In the Republic of Belarus, as in many other countries, there is a planned approach to the creation of metro lines. It allows to consider the current and future interests of the city and organizations involved in the construction and operation of subways. From the planned approach the principle of the metro design of the metro follows: the development of general scheme and the construction phase-out in conjunction with the master plan and integrated scheme for the development of city public transport all types.

Usually the general scheme of the subway is created before the development of the first-line project. The general scheme and the stages of construction constitute the strategic plan for underground development.

However, there often is situation when changes are made to the general plan of city development in connection with the current situation in the city economy and the country as a whole. It leads to the fact that the decisions made in the design and construction of the first stations may not be relevant at the time of new stations and tunnels construction.

A similar kind of problem arose during the design and construction of the interchange node from the first to the third branch of the Minsk Metro. The design the one of the intermediate stations of the first branch was carried out considering the long-term development of the master plan for the development of Minsk city. However, since the construction of the first branch, the general plan has been repeatedly changed, which led to the formation of a large transport hub in the place of the previously designed third branch. The modern city has a site on this site, which simultaneously crosses the railway station where trains run in four directions, a turning ring of tram routes, bus and trolleybus lines that have end points of the route in this part of the city, a metro line and intensive pedestrian traffic. When constructing the third branch of the station in an open location and constructing a transitional tunnel between the first and third lines, the construction would paralyze the traffic of the entire city. In this regard, it was decided to remove the third branch station beyond the transport hub. However, when designing a transition tunnel from the opposite side, it is necessary to make a breakthrough in the supporting wall, and also to make a penetration into the base of the station tray board, which can adversely affect the stress-strain state. During the construction of transitional tunnel, the project for the production of works does not provider stopping trains movement, which greatly complicates the construction task many times.

When solving such problems, it is necessary to ensure strict control over the state of structures and the upper structure of operated subway line track, as well as for the state of the surrounding development that falls into zone of influence, without changing the operation mode of the station [1 – 5]. Using automated systems for monitoring the state of bearing structures allows to solve such problems: carrying out a complex of measures to monitor the state of the load-carrying structures of the station in the period before construction, during construction, and also during a certain period after construction. It allows comprehensive assessment of the technical condition of the structure main load-bearing and assigns appropriate criteria for the operation of the transport hub. The use of finite elements complex analysis programs provides the possibility of joint calculation in one model of spatial systems «soil – construction», including those with physically nonlinear properties [12, 13].

Recent sources of research and publications analysis. Analysis of the latest research and publications on this subject suggests that it is increasingly common in the practice of domestic and foreign metro construction to face the need to monitor existing structures of the underground during its reconstruction. This set of measures significantly facilitates the production of construction and installation works on the reconstruction of existing facilities of the underground, while ensuring its normal operation [1 – 5, 7, 8].

There is also a complex of tasks where monitoring is the most important component of the entire construction industry. These tasks arise as a rule in the reconstruction of underground structures located in the historical, business and cultural centers of the city, where the opening of the day surface of the ground has very negative effect on the state of the surrounding buildings falling into the zone underground structures construction and reconstruction influence [6, 9, 11 – 14].

The most important measure of the preparatory stage of monitoring is the creation of an adequate calculation model. The model must consider real work of all units and elements of the structure before the start of production. Only after a model is as close to real conditions as possible, it allows further to adjust it, basing on the data obtained during the monitoring. However, the design model is often not adjusted considering the changes occurring during the construction or reconstruction of underground structures [9, 14, 15].

Identification of general problem parts unsolved before. Modern technologies of construction of stations and tunnels of the underground allow to carry out construction and installation works practically under any engineering-geological and hydrological conditions, including in dense urban buildings. Realization of any ideas in difficult urban conditions is impossible without careful monitoring of the existing situation surrounding state in the city. It is necessary to determine only those specific tasks accurately and reliably, the solution of which will allow realizing any engineering ideas without significant damage to the environment [10].

The **goal** is to obtain the real values of changes in the stress-strain state, depending on the state where the transition occurs to a later date before the start of production, to know the initial stress-strain state of the structures during operation in the planned mode, considering the years of defects and structural damage operation. Only knowing the initial state of the structure it can be determined the criteria for changing the stress-strain state during the construction and operation of the structure. It should be noted that it is necessary to consider the results of monitoring when developing design solutions for the facility reconstruction.

Basic material and results. The station type is single-span with a vaulted overlap. The length of the station is 97.5 m.

The covering of the platform area is made in the form of a monolithic reinforced concrete vault, rigidly connected with the walls of the station (Fig. 1).

Figure 1 – General view of the platform site of the station before reconstruction

The outer walls of the platform area are monolithic reinforced concrete, using the «wall in the ground» method. To the inner surface of the walls there were fixed reinforced concrete blocks with a thickness of 200 mm with holes for the passage of engineering communications. Above these blocks, decorative granite slabs are made. On the bearing walls there are made consoles with service passages and lighting.

The tin plate is made of monolithic reinforced concrete on concrete preparation. The plate has a variable thickness in the form of an inverted arch. On the slab there is laid track concrete.

Overlaps are in the level of the platform - prefabricated reinforced concrete slabs and monolithic areas in the middle of the platform, as well as in the area of the removable overlap. The slabs are mounted in ribbed sizes 1.48x9.95 m with cantilever overhangs on both sides. The support plates are made on brick walls. Bearing walls of platform plates are made of bricks. Wall thickness is 380 mm.

Between the axis of the walls of the platform slab there are monolithic reinforced concrete walls separating the projected stairwell descents. The above-listed structures are designed and built considering the subsequent reconstruction of the station from the intermediate to the interchange.

Monitoring provides for continuous monitoring in full-scale conditions for deformations and forces in the bearing structures of the station, and verification of compliance with their design values ensuring accident-free operation of structures, and includes [13]:

– Visual monitoring;
– Geodesic-surveying above-ground monitoring;
– Geodesic-mine surveying underground monitoring of the state of structures;
– Instrumental monitoring of structures state;
– Electronic remote monitoring of structures state;
– Scientific support of monitoring work.

The monitoring work is carried out in several stages. At present, the preparatory stage has been completed (before the reconstruction begins). The main work at this stage was work on the analysis of the initial information on the results of the survey. The results of geodetic (mine surveying) measurements for the two years period operation, preceding the start of the reconstruction works of the station, were subjected to careful analysis. Information on the technical condition of underground structures falling into the risk zone received from operating organizations was obtained. Measurements have been made to determine rolls, misalignments, deformations and uneven sediments of the bearing reinforced concrete track walls of the station. Geodetic marks were installed on the structures and the metro station with their binding to the city reference network. Beacons and detection sensors were installed on the cracks fixed in the station structures. Electronic sensors are installed on the reinforced concrete bearing wall, reinforced concrete tray plate. Full control over compliance with the technological regulations of works and scientific support of the preparatory phase was carried out.

The monitoring program provides for the emergence of data critical values obtained from an automated monitoring system (deformation of station structures, drawdowns and misalignment of running rails, where it is necessary to carry out measures to ensure the safety of train traffic), immediate coordination of decisions with the project organization, track service and tunnel structures of the operating organization and organization that provides scientific support for monitoring activities.

Visual monitoring prior to the beginning of the reconstruction included an inspection prior to the commencement of construction work and the installation of video surveillance in the planned development zone. The data from the CCTV cameras of the operating organization, obtained on request, are necessary to monitor the installed equipment and determine the VAT from the temporary operational load. The results of the work on visual monitoring will be provided in reports with photographs of the detected damages and their values, as well as recorded in the database - systematic results of observations suitable for processing and use with the help of specialized software packages.

Geodesic-surveying above-ground monitoring before the reconstruction included the construction of benchmarks for geodetic measurements and the performance of instrumental measurements in accordance with established benchmarks with reference to the city planned high-altitude network. Geodetic instrumental observations are conducted using optical digital and laser equipment in order to obtain high-precision results of changes in the planned altitude position of the installed brands and the speed of these changes. Based on the measurement results, the data will be entered in a single database.

Geodesic-surveying underground monitoring of the structures state included the installation of geodesic marks on the structures of the metro station and 3D scanning of the work site. Based on the measurement results, the data will be entered in a single database.

Instrumental monitoring of the state of structures prior to the beginning of reconstruction determined the width and depth of the crack opening, considering existing leaks in quantitative terms. The results of measurements are entered in a single database

Pre-commissioning of electronic remote monitoring of structures condition prior to the start of the reconstruction included the development of a scheme for the location of sensors at the station and the wiring diagram, the installation of electronic overhead strain gauge sensors on a reinforced concrete bearing wall and a tray plate, the installation of a wireless data transmission link via the Internet or cellular communications; installation of software on the automated workplaces of the construction organization and emergency technical assistance of the way service and tunnel facilities of the subway to control the stress-strain state of the station structures.

Electronic monitoring data has an internal record. Based on the measurement results, the data is stored in a single database.

Scientific support is provided at all stages of the station reconstruction. Prior to the commencement of monitoring activities, a database should be developed, where the recording of information must be strictly followed by all participants in the process. Periodic reports in the process of works production on the reconstruction of the station should contain the results of monitoring, information on the state of the facility, possible deviations and the forecast of changes in the state of engineering structures. It was made comparison of deformations and stresses in station structures, obtained from the results of calculations by design organizations with actual values and refinement, if necessary, of computational models. To specify the types and volumes of further work; there were developed recommendations for adjusting design decisions, the timing of repair or restoration work, proposals for further monitoring. The order and composition of the monitoring can be adjusted in the process of performing the work, depending on local conditions, opportunities and preliminary results.

To analyze the possible displacements in the structures of the platform area, a three-dimensional model of the monitoring object was developed. The model was created on the basis of design drawings.

The simulation was carried out in specialized geotechnical software. The stress-strain state of the «soil – structure» system was calculated by the finite element method in the conditions of the three-dimensional problem. The information model is a collection of volumetric elements and is designed in such a way that all the stages of the stress-strain state of the structures can be considered in the calculation. All the elements of the model were as close as possible to the real ones.

At the first stage of the model creation, the study of theoretical foundations and the collection of information about the object were carried out, causal relationships between the variables describing the object were revealed, namely, the interaction of the system «engineering structure – soil massive», its main components were studied.

The ground was set by the Mora-Coulomb model. In general, the material model is a system of mathematical equations describing the relationship between stresses and strains. The Mora-Coulomb model is based on the relationship between the effective stresses change rate σ 'and the strain rate ε'.

When creating this model, the traditional parameters of materials were used: the modulus of elasticity, the intrinsic weight, the specific cohesion, the angle of internal friction and the Poisson's ratio, etc.

In the design model, the characteristics of construction materials based on design drawings were laid. The characteristics of the soils were determined on the engineering and geological survey results basis.

An important question in the simulation was the adequate specification of the geometric and rigidity parameters of the structure.

At this stage, the input and output data were determined, simplifying assumptions were made about the determining ratios, the boundary and initial conditions of the object, the stage of production and the history of stresses, i.e. the idealization was carried out-the transition from the original physical system to the three-dimensional model. Next, the final parameters of the model were set considering the condition of the object operation.

In the design scheme, the model was developed considering the technology for the reconstruction of the platform section of the station.

After completing the construction of the geometric model, a finite element grid can be constructed. The process of building a grid is based on the stable principle of triangulation, where the optimal sizes of triangles are found, and an unstructured grid is constructed.

Calculations were carried out considering the sequence of production work developed by the project organization.

1. Construction of an abutment excavation pit to a station platform site and the device of its fastening.

2. Arrangement of vertical soil-cement piles reinforcement of the "wall in the ground" of the station.

3. Development of a pit with a fastening device to the bottom of the tray. Strengthening existing station structures.

4. Development of excavation soil with a protective screen device made of pipes under the tin plate.

5. Fixing the ground under the tin plate. Development of soil to the design mark.

6. Arrangement of technological apertures 800×2300 mm in existing structures of «wall in the ground» of the station.

7. Development of soil.

8. Installation of monolithic areas after each entry.

9. Opening of openings in the station existing «wall in the ground» at full cross-section.

After completing the construction of the geometric model, it was divided into a grid of finite elements. During the process of constructing, the grid is based on the stable principle of triangulation where the optimal sizes are found, and an unstructured grid is constructed with condensation in the most critical places (Fig. 4). With regard to the boundary conditions and the weight of the structures themselves, they can be set automatically, which greatly facilitates the solution of the problem.

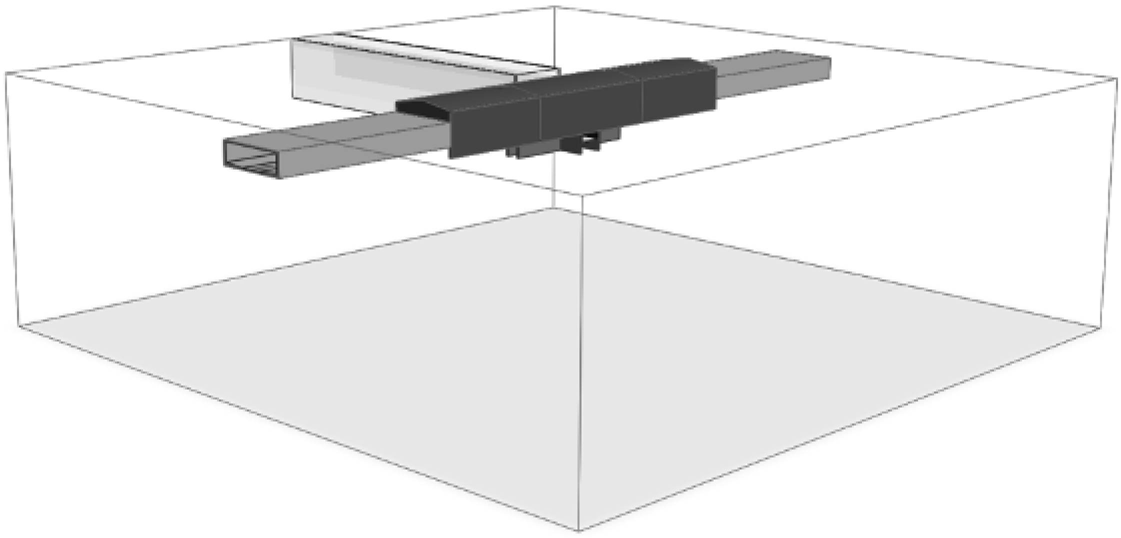

Figure 2 – General view of the geometric model of the construction site

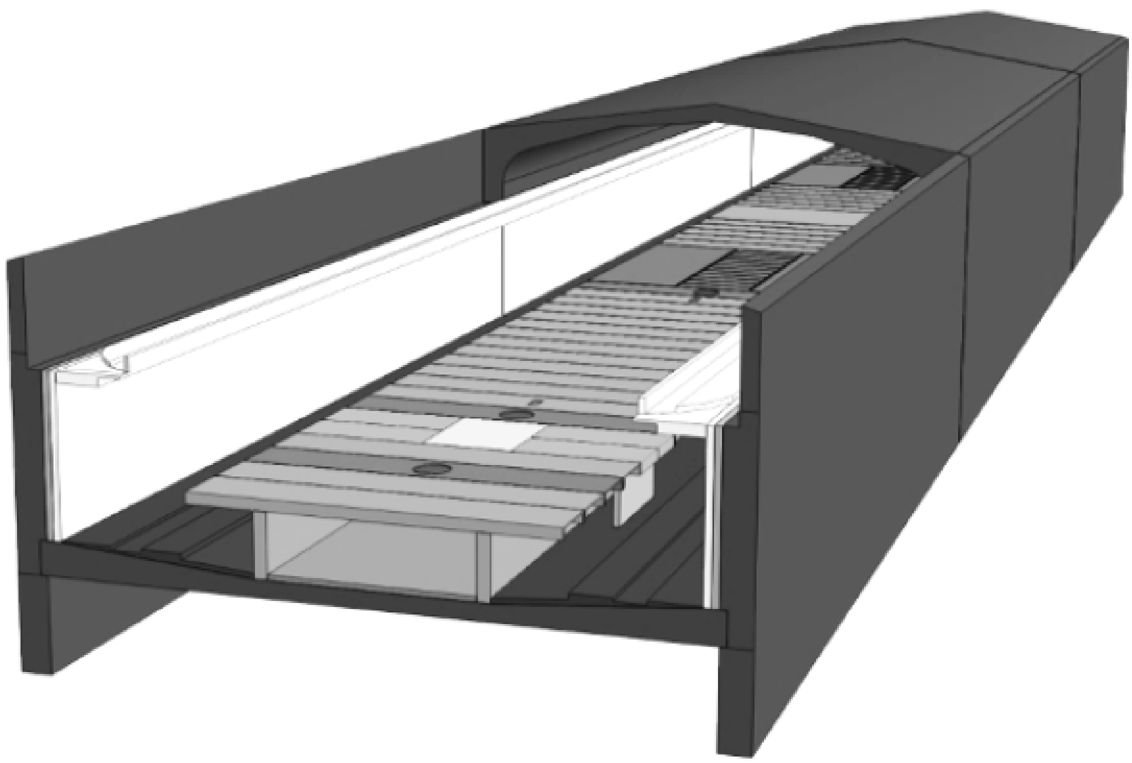

Figure 3 – General view of underground structures that fall into the zone of influence during reconstruction

Before the calculation was started, all the necessary stages of design calculation were considered including production technology. The calculation was carried out according to the stages of erection.

Based on the results of spatial calculations, the predicted displacements of the bearing structures of the platform area in the work area amounted to 7 – 8 mm. The predicted changes in the stresses in the bearing structures of the station are 5 – 11 MPa.

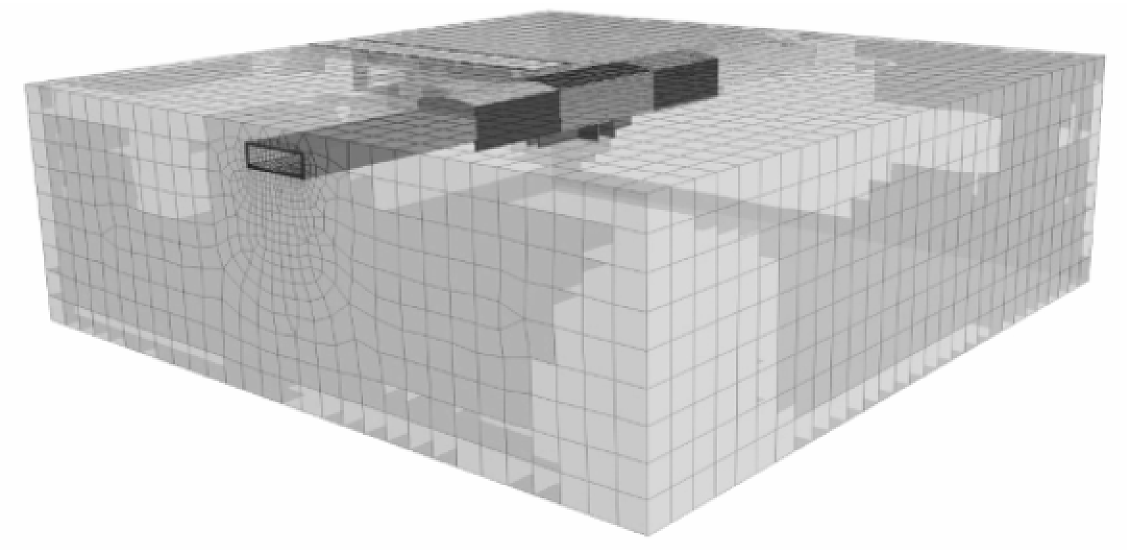

Figure 4 – The volume finite-element calculation model

On the basis of the performed calculations analysis, the maximum stresses occur in the wall in the zone of technological openings device and amount to 6 MPa. It was recommended to make metal or reinforces concrete clip of a wall part between adjacent apertures.

The maximum displacement of the supporting wall and the trough plate with track concrete occurs during the construction of the excavation pit. It is due to the removal of the active pressure on the wall. In addition to creating an active lateral pressure on the existing wall of the station, the surrounding rock massif of the station perceived part of the rasp from the vaulted cover of the station.

Removal of soil from the excavation in the zone of construction and installation works production on the junction of the transition tunnel will result in the horizontal component of the reference reaction of station vault being perceived only by the rigidity of the wall and the junction of the wall with the vault, which will lead to a significant change in the stress-strain state of the wall in the ground, as well as to possible cracking. To reduce the negative impact of the horizontal reaction of the vaulted cover on the wall, the project provided construction of so-called buttresses, which partially compensate for the removal of lateral pressure.

Metro facilities belong to highly responsible facilities with an increased risk of exploitation, thus it is necessary to monitor the movements and deformations of the existing structures of the platform site during the works.

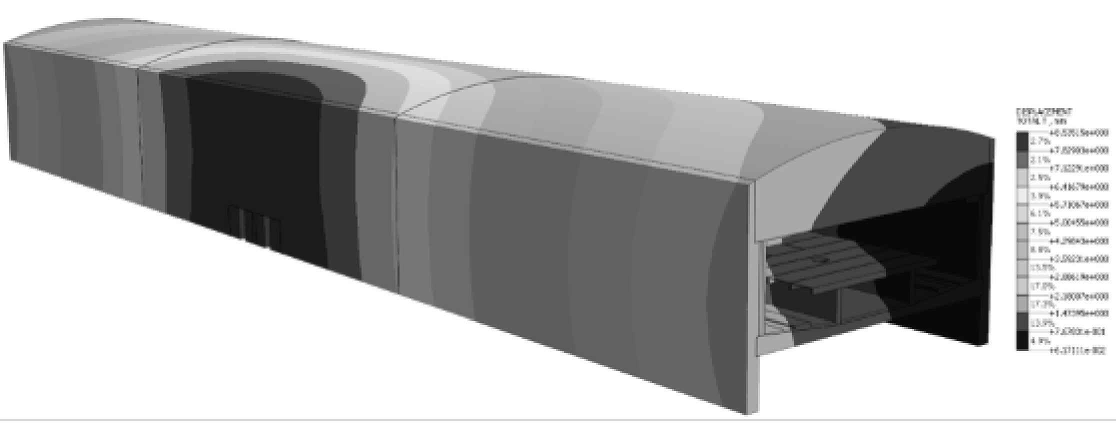

Figure 5 – Deformations occurring in the wall and vault of the station, at the time of tunneling

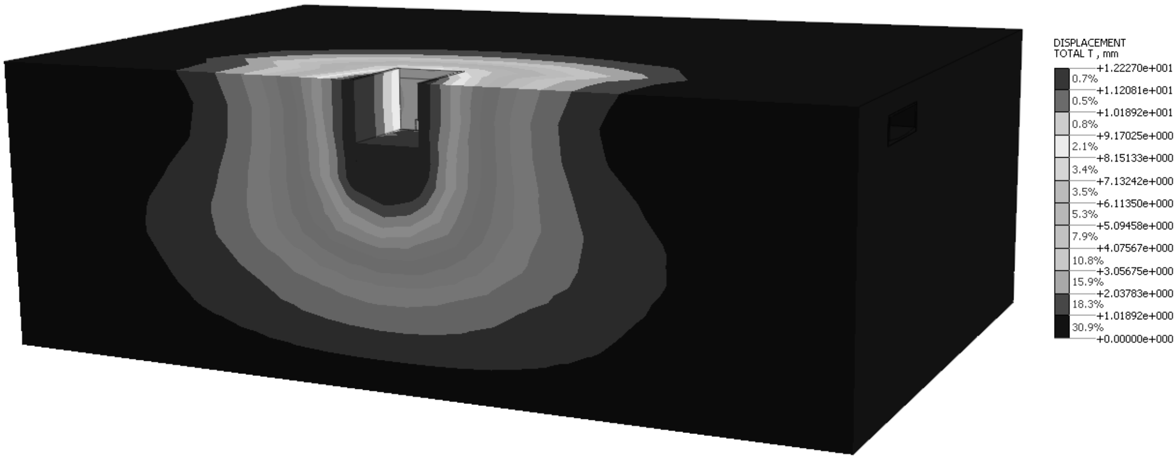

Figure 6 – Deformations of the soil massif after opening of the excavation

Conclusions. The preparatory stage of monitoring the construction and installation works for the reconstruction of the metro station in operation plays one of the key roles of the entire work course. It allows to consider the possible risks associated with the impact on the current strained-deformed state of the «soil – construction» system in a dense urban environment. This will significantly save labor costs and the cost of all construction in general. But mainly it will allow to prevent possible emergency situations related to the safe operation of the underground in the period of production. Preliminary calculations carried out with the help of modeling in a three-dimensional formulation enable the creation of full-fledged complex models considering the joint work of «soil – construction».

It should be noted that the computer simulation of the structure behavior under various loads can in no way replace the carrying out of field studies and testing of materials samples. It is necessary to improve the methods for calculating complex spatial problems associated with the operation of underground structures.

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