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ACTUAL DESIGN MODEL DEVELOPMENT OF PROTECTIVE SCREEN OVER THE ACTIONS OF SUBWAY LINES

It is given calculation model development results of protective shield overexisting tunnels of subway in influence zone of transport interchange construction in the city of Minsk. The analysis of modeling problems of the system «construction - soil massif» is performed. It is proposed the approach to development of an adequate design model for complex engineering-geological conditions. An adequate calculation model of the transport interchange site was developed. The applying modern methods results of calculating the system «construction – soil massif» are given. The stress-strain state nature of the tunnel structures at all stages of the transport interchange construction is analyzed. The results of the calculation are compared with the data obtained during testing of the protective screen in full-scale conditions. The special practical significance of using such calculation methods at the design and construction stage of transport facilities is noted.

***Keywords:** transport facility, calculation model, soil, deformation, stresses.*

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РОЗРОБЛЕННЯ АКТУАЛЬНОЇ РОЗРАХУНКОВОЇ МОДЕЛІ ЗАХИСНОГО ЕКРАНА НАД ДІЮЧИМИ ЛІНІЯМИ МЕТРОПОЛІТЕНА

Подано результати розроблення розрахункової моделі захисного екрана над діючими тунелями метрополітену, які потрапляють у зону впливу будівництва транспортної розв'язки в м. Мінськ. Виконано аналіз проблеми моделювання системи «споруда – ґрунтовий масив». Запропоновано підхід до розроблення коректної розрахункової моделі споруд, що зводяться в складних інженерно-геологічних умовах. Наведено основні результати застосування сучасних методів розрахунку системи «споруда – ґрунтовий масив».. Проведено аналіз напружено-деформованого стану конструкцій тунелів на всіх етапах будівництва транспортної розв'язки. Виконано співставлення результатів розрахунку з даними, що отримані при випробуванні захисного екрану в натурних умовах. Відмічено особливу практичну цінність застосування таких методів розрахунку на стадіях проектування та будівництва транспортних споруд.

***Ключові слова:** транспортна споруда, розрахункова модель, ґрунт, деформація, напруження.*

Introduction. When calculating any structures, especially in complex engineering and geological conditions, it is necessary to consider the interaction of the structure and the foundation soils. For various reasons, designers pay great attention to modeling directly constructions of new structures, and their interaction with the ground is treated in a simplified manner.

To assess construction impact of transport facilities on existing structures, it is necessary to perform calculations using modern settlement systems. The use of general-purpose program complexes working on the finite element method for modeling soil work is the most common mistake. Typically, such programs use elastic models that are not capable to describe correctly soils work. As for the stress-strain state of the soil when applying the load, it cannot be adequately described in standard construction programs for calculation. Proper numerical simulation should be performed using specialized geotechnical software.

Knowing the reasons for the negative impact of new construction on existing structures, it can be minimized their possible deformations. This task solution is carried out by creating a computational model of new construction impact on the surrounding building, generalizing the experience of building analogues.

Use of a set of finite element analysis programs MIDAS and SOFiSTiK provides the possibility of joint calculation in one model of spatial systems «construction-base», including physically nonlinear properties, and including modules for solving static, dynamic, filtration and thermophysical problems.

The latest sources of research and publications analysis. At present, specialists in the field of tunnel and metro construction are no longer satisfied with traditional calculations [9]. Based on the results of the latest studies and publications analysis[1 — 6, 9, 11 – 17], it is possible to single out a group of designers who perform calculations in specialized programs. Basically, the obtained data are compared in different software complexes. The calculations are forecast, and the determination of the stress-strain state is not corrected in the course of the construction and installation works due to the lack of actual data. Often, the design team of accountants is not directly related to the organization performing the construction of the object and performing geodetic control. Studies to determine the actual state of objects in many cases are practically not carried out or are performed in insufficient volume [17].

Allocation of common problem unresolved parts. The problem of designers dealing with calculations in a three-dimensional setting is not even in the complexity of creating a computational model, but in the inadequacy of objective data. Such data include the engineering and geological conditions of the construction site, the absence of a specific decision on the mechanisms used at the stage of erection, their impacts on structures and the soil massif, the complete lack of information on the results obtained as the facility is erected and during its operation. Without solving these problems, it is impossible to construct an actual analytical model corresponding to the actual work of the structures and the surrounding array.

Formulation of the problem. For the construction of an adequate calculation model, its correction is necessary in accordance with the data obtained as the object is being built, and the testing of the structures by loading. Only according to the actual data obtained directly on the construction site before construction and during the production of works it is possible to adequately determine the work of structural elements, their stress-strain state and exact values for precipitation. According to these data, a public database should be formed and experimental data can be accumulated.

Structural and technological solutions/ In the zone construction influence of the overpass there were tunnels of the underground on the station Moscow – station East, the penetration of which was carried out in closed way, as well as the ventilation and ventilation chamber were made in the open way. The supporting structures of the tunnels are cast-iron and concrete lining, consisting of individual rings with a width of 1.0 m. The distillation tunnels are structurally separated from each other by a casing.

The reinforced concrete lining of both tunnels is made with the use of rings consisting of ribbed reinforced concrete blocks. At the top of each ring there are key liners (blocks). The rings of the lining are connected together by bolts in the longitudinal and transverse directions.

Bearing constructions of the vent block are prefabricated-monolithic bottom, monolithic reinforced concrete frames, prefabricated and monolithic walls. The covering consists of prefabricated reinforced concrete slabs and monolithic sections.

Over the subway tunnel, a city road overpass was designed (Figure 1). The scheme of the overpass – 24.0 + 21.0, width 37.5 m.

To stabilize the deformations of the ground above the tunnel, protective shield is provided, consisting of monolithic reinforced concrete slab on bored piles with a diameter of 0.63 m and 0.8 m. The protective screen is located above the tunnels, the thickness of the backfill between the arches of the tunnels and the bottom of the protective screen plate varies from 2 to 3 meters. The length of the bored piles of the protective screen is 14 m, in the case of the ventilation – 22 m. The slab thickness of the protective screen above the tunnels is 500 mm, above the vent block – 1000 mm [14].

Figure 1 – General view of the projected transport interchange at the intersection Independence Avenue from the Filimonova Street

Development of the calculation model. Calculations of modern projects of structures under construction in complex engineering-geological and constrained conditions are impossible without the use of modern software complexes that could consider real work of the soil. The process of establishing soil parameters for subsequent numerical modeling is the most important component of ensuring a qualitative assessment of the stress-strain state of the soil massif. Therefore, it is necessary to pay special attention to the choice of soil model and input parameters. It is also necessary to remember that it is necessary to conduct a series of preliminary research calculations on modeling the work of the system «construction – soil» [1].

The success of the design calculation depends to a large extent on how adequately the selected elements and models as a whole reflect the actual design.

In order to ensure the safe operation of existing metro lines, it becomes necessary to assess the negative impact of tunnel linings on the surface of construction work, which in the future will reduce the risk of bearing capacity loss and structure destruction. In the event based on the results of calculations, there are unacceptable deformations for normal operation, it is necessary to develop a set of protective measures to avoid the negative impact of new construction [7].

Simulation of the stress-strain state of the transport interchange and its changes during construction were carried out using the programs Midas GTS NX and SOFiSTiK (WinTube). These programs allow to determine the stress-strain state, both in soil massif and in structures interacting with the ground at any stage of structure erection. When modeling the «construction-ground» system, a spatial design scheme was used.

In the design scheme, the model was developed considering stage-by-stage development from the level of the existing surface in the zone of the operating subway lines, as well as assessing the possibility of raising excavation bottom and, correspondingly, the tunnel caused by elastic deformations during unloading of underlying subsoil.

When creating the design scheme, measures were taken to prevent dangerous uneven deformations of tunnels lining by stabilizing the surrounding soil mass to ensure uniformity in raising the entire circumference of the lining while maintaining the operational size and reducing the amount of raising the head of the rail.

The first and most important stage in the development of the calculating model for the transport interchange was geometric modeling. 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, i.e. the idealization was carried out-the transition from the initial physical system to the three-dimensional computational model. Next, the final parameters of the model were set considering the condition of the objects operation.

The transition from a design to a calculating model made up of basic models is most often done on an intuitive level, and the first motive behind this transition is geometric considerations («likeness» form) [10].

Step by step all the elements of the interchange site were created, namely: geological conditions, existing constructions of underground tunnels with vent block, as well as a protective screen with bored piles. All the elements of the model were as close as possible to the real ones.

The idealization of the computational model and the inability to make it absolutely adequate to the actual construction there was created a situation of some uncertainty, and it is precisely in this uncertainty that the design solutions [10].

One of the important aspects of creating transport structure computational model is that in difficult engineering-geological conditions there is the correct choice of the dimensions of the calculation area. It is known that it depends on the type of structures being calculated and can be adopted according to the following parameters, given in Figures 2 and 3 [10].

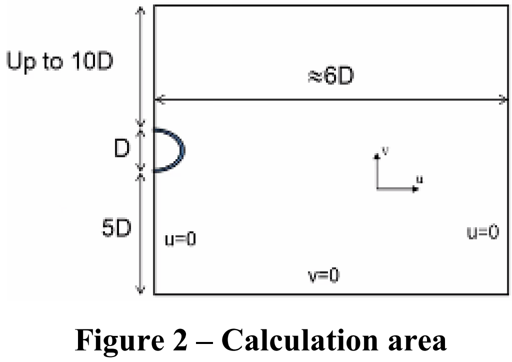

Figure 2 – Calculation area for shallow tunnels

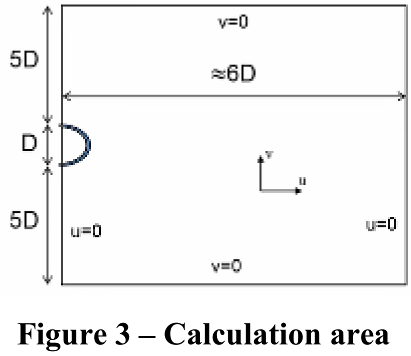

Figure 3 – Calculation area for deep tunnels

For this task, the design area was chosen for both shallow tunnels. However, in the course of the research calculations, it was corrected basing on the dimensions of the compressible earth stratum, within which deformations of the soil massif were considered..

The next stage in the development of the computational model is the idealization of structures materials and properties of soils. In most cases, the material is provided with the properties of ideally elastic, ductile or loose material. To select an adequate design model of the material, it is necessary to perform a series of experiments, rather than choosing more or less suitable geometric image [17]. As a rule, this stage is omitted, and known data on physical models of material work, previously obtained from experiments on absolutely other objects, are used in the calculation.

When calculating structures built in complex engineering and geological conditions, the adequacy of the model can be achieved only if a number of laboratory and virtual studies are carried out for the given object.

The geotechnical model was built on the basis of analysis and engineering materials generalization and geological surveys performed at the construction site at different times.

In the geological structure of the projected construction site are: sand with an admixture of sandy loam, sandy silts and loam. To simulate soil behavior, the following soil models were adopted: 1) the Mora-Coulomb model; 2) modified model of the Mora-Coulomb; 3) modified Mohr-Coulomb model with hardening. The type of the model was used in accordance with the properties of bedding.

To model reinforced concrete tunnel structures, Liner Elastic linear elastic model is used. In the design model, the characteristics of construction materials based on design drawings were laid.

To differentiate the results obtained between the elastic behavior of the protective screen plate and bored piles where small displacements occur and the surrounding soil massif where plastic behavior is possible, special interface element is used [10]. This is done to exclude the appearance of strains and stresses concentrations of that have no real physical meaning. The spatial rigidity of all structural elements of the structure was set in accordance with the design solutions.

It should be noted that prior to the beginning of the calculations, a survey of underground structures was conducted and their actual parameters were considered in the calculations.

The pre-geometric model was created in the AutoCad program and then imported directly into the Midas GTS NX calculation system. Each element of the model was given certain properties, in which the material, section or other properties were specified. The entire model is a database of 1D, 2D and 3D properties.

As a result, a calculation model was obtained, which is the volume of the soil (Figure 3) where existing underground structures are located (Figure 4).

After completing the construction of the geometric model, it was divided into a grid of finite elements. 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 (Figure 5) [10]. As for the boundary conditions and the weight of the structures themselves, they can be set automatically, which greatly facilitates the solution of the problem.

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 in two variants.

The performed calculations correspond to the technical codes of the established practice of TKP EN, as well as the national annexes to them for the design of bridges and pipes, identical to the design standards of the European Union.

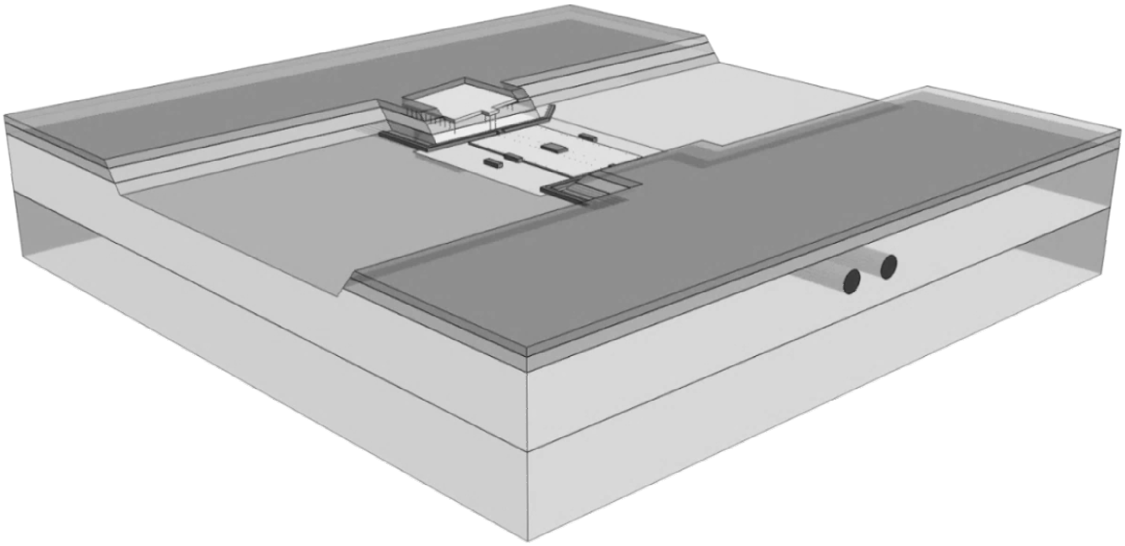

Figure 4 – General view of the geometric model of the transport interchange area

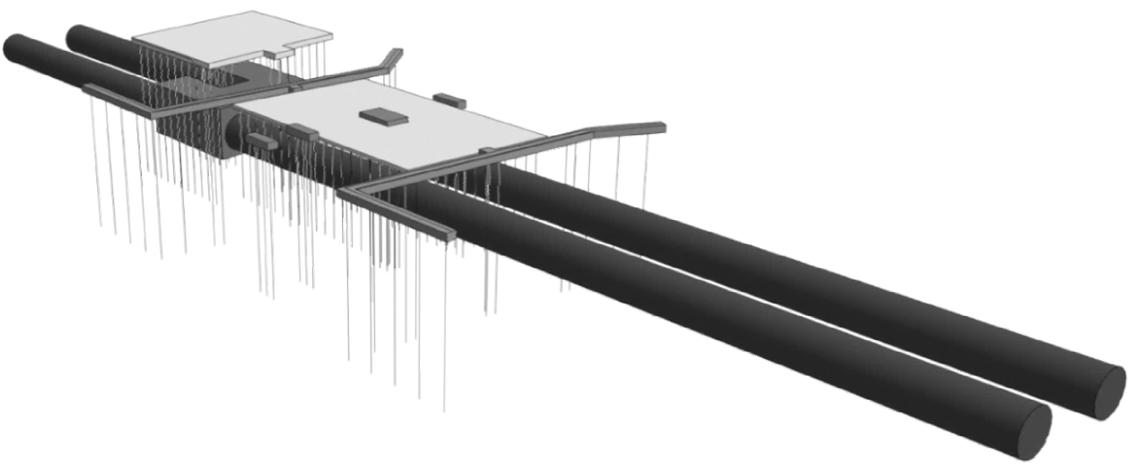

Figure 5 – General view of underground structures falling into the zone influence of construction

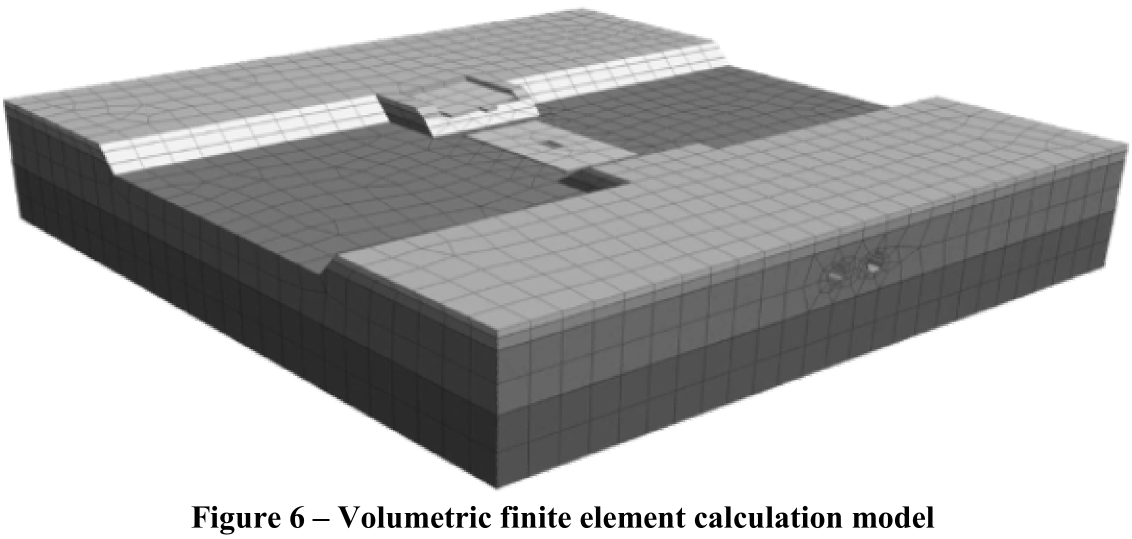

Figure 6 – Volumetric finite element calculation model of the transport interchange

Calculation results.

At the stage of soil development without performing protective measures, as it was expected, the bottom of the excavation and, correspondingly, the tunnels, caused by elastic deformations occurred when unloading the underlying soils. Raising the level of the railhead and the lining was 10…11 mm (Figure 7).

When creating a calculation model, measures were taken to prevent dangerous uneven deformations of the tunnels lining by stabilizing the surrounding soil mass to ensure uniformity in raising the entire circumference of the lining while maintaining the operational size and reducing the amount of rail head raising [14].

Considering carrying out of protective measures along the sides of tunnels in the form of rows from bored piles with a diameter of 630 mm in increments of 1650 mm, considering the stage of ground development to the design level, with the device of a monolithic reinforced concrete plate with a thickness of 500 mm, the stresses in the soil massif stabilize and the tunnels are raised evenly by 6 – 8 mm (Figure 8) [14]. This ensures the preservation of the geometric shape of cast-iron lining tunnels.

With the subsequent construction of pavement on a monolithic slab over the cast-iron lining of the tunnel, the weight of the cargo will increase and the overall rise will decrease.

Figure 7 – Deformations arising in the lining of tunnels, without performing protective measures

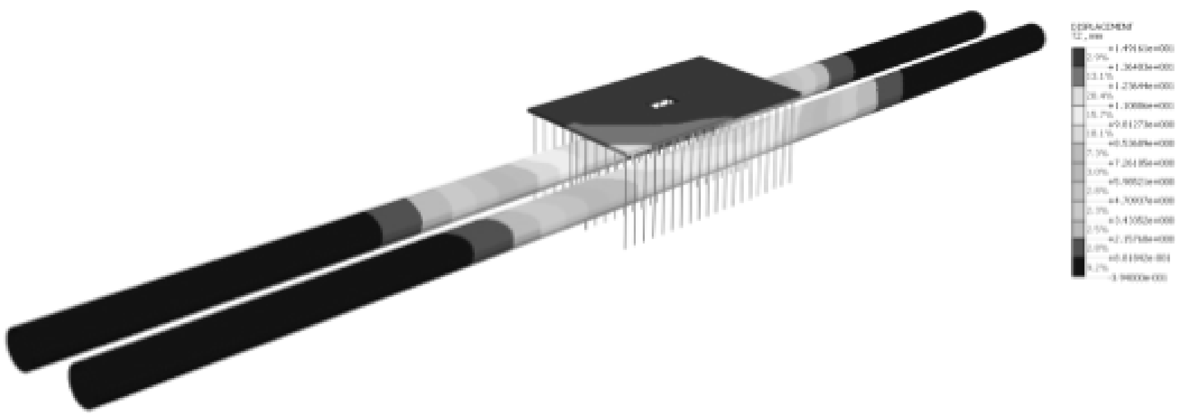

Figure 8 – Deformations arising in the lining of tunnels, with the implementation of protective measures

To study the operation of the protective screen plate in full-scale conditions and to verify compliance with the calculated assumptions, static backfilling tests were performed on the erected protective shield, thereby stabilizing the long deformations of tunnel rise. The results of the test correlate with the calculation and confirm the adequacy of the developed model.

It should be noted that an adequate calculation model it is not only the correctly chosen models of structures and materials, but also timely correction considering change in the actual state of structures and soils during construction, also considered when performing calculations.

Based on the performed calculations, minimizing the impact on the operating tunnels of the subway during the construction and subsequent operation of the traffic intersection, the necessary protective measures were assigned and strictly carried out.

Conclusions. Timely and objective assessment of new construction impact on the existing underground facilities of the subway allows developing design solutions that hinder the negative impact of construction, affecting the existing metro facilities operational reliability.

Modeling and calculations in a three-dimensional setting open access to the creation of full-fledged complex models with complex geometry, geology, boundary conditions and loads. However, the methodological support for such models development is at the very beginning of formation and must be compared with real data.

Such methods introduction in the design of various transport facilities would help in creating a database of experimental field studies, and avoid a huge number of emergency situations.

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