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Mechanisms of Formation of Displacement Zones in Soil Mass During Construction of Urban Inclined Transport Tunnels

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The presented paper discusses the results of mathematical simulation of construction of a city's transport facility using the example of the inclined escalator tunnel of the Vasileostrovskaya subway station of the Saint Petersburg subway. The study focuses on the mechanisms of formation of zone of displacements caused by tunneling in soil mass, in particular, subsidence of earth surface (so-called subsidence trough), which can cause undesirable influence on a city's buildings and structures. The paper presents qualitative and quantitative evaluation of the simulation results.

Key words: Soil mass, city transport tunnels, sliding zone, deformation criteria of evaluation.

Nowadays, Saint Petersburg continues to undergo realization of the state program for the development of the city's transport network, including subway. The program comprises construction of new and reconstruction of previously build stations. One of the renovated stations is the Vasilieostrovskaya station, in which the second exit, the inclined escalator tunnel, is to be constructed.

The aim of the presented work is the prognosis and evaluation of displacements in soil mass and directly under earth surface in the zone of influence of mining works during the construction of the second hall and the inclined pass of the Vasilieostrovskaya station of the Saint Petersburg subway.

For prognosis and evaluation we used a mathematical simulation method based on the simulation of geomechanical processes on the basis of finite-element method and the data of full-scale studies of displacements and deformations of rocks. The presented results of prognosis and evaluation of displacements and deformations are applicable for the specific mining and geological conditions of mining works in the area of construction of the second exit of the Vasilieostrovskaya station.

Engineering and geology conditions of construction in Saint Petersburg are characterized by the thick layer of quaternary deposits of fine-dispersed inundated soils [1, 4, 5]. Preservation of excavated spaces with large volumes in those conditions is a complicated engineering problem.

Methodology

General information on technology and simulated stages of construction of the discussed object

The constructed object includes escalator tunnel and two pits: the starting pit for installation and start of operation of TBMS (tunnel boring mechanized system) and the pit for construction of the hall of the second exit of the Vasilieostrovskaya subway station.

Open excavation works were carried out using slurry wall technology. The method consists of construction of reinforced concrete wall along the perimeter of the planned pit by means of, for example, contiguous bored piles prior to excavation

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and further excavation under protection of the built walls. The parameters of wall are calculated in a way, which allows to partially or completely exclude undesired displacements in soil mass.

The important part of the technology of boring of escalator tunnels by means of TBMS is construction of auxiliary excavations, which allow to apply that kind of technology. The base excavation from the mentioned row is the starting pit, where TBMS is installed in and where it starts its operation. Large sizes of cylindrical pit of, approximately, 24 m diameter, which was constructed using slurry wall technology by means of contiguous bored piles, define conditions of appearance of deformation processes in the surrounding mass. Therefore, it is necessary to consider works related to the construction of those kinds of pits during evaluation of negative influence of mining works. Along with the starting pit of the Vasilieostrovskaya station construction of another pit for the underground hall, which also implements slurry wall technology, was designed.

Problems related to significant deformation of rocks during mining works in pits and tunneling of the upper part of the escalator tunnel led to the implementation of grouting technology for soil strengthening, which allows to significantly improve deformation characteristics (mainly, modulus of deformation) of grouted soil mass.

Construction of pits begins from construction of the protective slurry wall structure: contiguous bored piles of approximately 25.5 m length, which are placed around the circle of approximately 23.0 m diameter; effective thickness of the wall is approximately 1.0 m under the given conditions; then a forshaft is constructed, which plays role of a guide structure during excavation of parts between piles (which are called slabs). Soil in slabs is excavated under protection of bentonite slurry in zones adjacent to contiguous bore piles; width of slabs is 1.0 m. Then, in the course of alternated excavation of slabs reinforcement cages are placed inside them; after that concrete is cast using tremie method. After the time, when concrete achieves 70% of its nominal strength, concrete of the forshaft is dismantled and relocated to dumping place.

Under protection of the wall soil of the starting pit is excavated by means of the back digger, and structures designated for starting of TBMS are installed.

After that curtain grouting is carried out and additional load is created for mechanized tunneling of the inclined path and connection zone is carried by means of grouting of soil mass. The total volume of grouting works is as follows: total number of bores – 1911, total volume of grouted soil – 11.6 thousand m^3, total length of bores – 34.5 km.

The next stage is the construction of the second (external) slurry wall for the construction of the hall. The forshaft is constructed at the sides of the pit, at which borders of slabs are marked using paint. Each slab has a length of ~2.8 m and a depth of 19.0 m (the thickness of the slurry wall is 0.6 m). Excavation of soil is carried out by means of a flat grab under protection of bentonite slurry. In an excavated slab reinforcement cages (attached to the forshaft) and a limiter are placed; after that concrete is cast from down to top of slab using tremie method. After concrete achieves a strength of approximately 0.2...0.3 MPa, soil in the next slab is started to be excavated, and the whole cycle is repeated. After the time, when concrete achieves 70% of its nominal strength, concrete of the forshaft is dismantled and relocated to dumping place. Thus, the protective wall with dimensions in horizontal plane of 36.0 x 40.0 is consequently constructed.

Technological features of the construction

One of the features is the new for the mining and geological conditions of Saint Petersburg technology of construction of the escalator tunnel, which is based on implementation of TBMS with soil loading of a work face and high-precision prefabricated reinforced concrete modular lining. TBMS with soil (slurry) loading is widely used for sedimentary water-saturated not stable and low-stable soils. Implementation of TBMS of that class, aside from provision of high technological parameters of excavation and minimization of anthropogenic effect on geological conditions, is aimed for minimization of subsidence of earth surface due to application of active loading of working face and the system for filling of voids behind lining.

As the initial data for simulation of displacements and deformations we used performance characteristics of TBMS[13-14] lining. Prefabricated reinforced concrete lining of circular shape is constructed along with advancing of TBMS and installed under its protection. High precisions prefabricated water-tight lining comprises universal rings with internal diameter of 9.4 m and external diameter of 10.4 m and it consists of prefabricated reinforced concrete modules. The ring consists of 7 rectangular segment modules and 1 lock module. Nominal width of modules is 1.5 m, thickness is 0.5 m. Blocks are produced from concrete of B60 compressive strength class. Waterproofing of joints of lining is provided by means of installation of seals from special rubber elements along perimeter of modules. The ring has variable width with average width of 1.5 m, which makes it possible to install that lining at routes with bended stages. The lining has the following diameter: Do/Di=10.4/9.4 m. In total, the models include 15 aggregated stages of construction of inclined passage.

The last stage of the simulation simulates excavation of soil in the hall pit (in borders of the external slurry wall) for the depth of 4.0 m after construction of the inclined passage.

Simulation of construction of the facilities' complex

As the tool for evaluation of displacements and deformations we used mathematical simulation of geomechanical processes based on finite-element method (FEM), which was realized in ABAQUS software (also, part of calculations was carried out in PLAXIS software). FEM allowed to find displacements in three-dimensional and two-dimensional conditions with standard boundary conditions corresponding to the hypothesis of academician A.N.Dinnik [3] about absence of horizontal deformations of soils during historical loading of mass (absence of horizontal displacements at vertical boundaries of the model and displacements at the lower boundary of the model). In order to reduce the number of calculations and, thus, total time for simulation, we considered a half of calculated area along the vertical symmetry plane of the model (axial-symmetric problem)

Soil mass was simulated by tetrahedral elements with four nodes of "solid" type; structures of slurry wall, structures of the pit and lining of the tunnel were simulated by "shell" elements with three nodes. Total number of elements was 7,000,000 – for the second.

Dimensions of soil mass were as follows: length (along X axis) – 200 m, width (along Y axis) – 100 m, height (along vertical Z axis) – 80 m.

The main elements of the model were elements, which simulated soil layers, elements of frame of the pit (open excavation), protective structures and the inclined excavation:

1. Slurry wall made from contiguous bored piles, which are situated along the circle of ~23.0 m diameter, length of piles was ~25.0 m (effective thickness of the wall was ~1.0 m).
2. Slurry wall from prismatic sections of 0.6 m thickness and length from 2.3 to 4.2 m and depth of ~19.0 m. In horizontal plane the slurry wall is rectangular with dimensions 36.0 × 40.0 m.
3. The zone of grouting fills the internal volume of the circular slurry wall for the pit of ~15.0 m depth from the surface, and it protrudes from the wall along the axis of the inclined axis for 12.5 m reaching depth of ~24.0 m (width of the part of the grouting zone, which is protruding from the slurry wall is 18.4 m)
4. Lining of the inclined passage of ~10.0 m diameter with thickness of lining of 0.5 m and length along the axis of the tunnel of ~111.0 m (from the structures of the hall to the axis of the tightening chamber.
5. The load from the building of 44.0 kPa at the distance of 16.0 m from external slurry wall from the side of the tunnel (area of loading is 14.0 x 28.0 m).

Mutual orientation of the both slurry wall structures, the lining of the escalator tunnel and the volume of soil mass, which is to be subjected to grouting, is presented in Figure 1; Figure 2 presents mutual orientation of elements of the reinforced concrete structures.

First, "circular" slurry wall is constructed, after that the soil mass subjected to grouting is starting to work together with construction of the second (external) slurry wall for the hall. After that soil is excavated for construction of the pit and structures themselves.

After that the inclined passage is tunneled, at that a part of structures of the pit is dismounted, as well as both slurry walls.

Tunneling of the inclined passage was

simulated at fifteen separate stages (for 5 rings of lining).

Soil layers are grouped by similar physical and mechanical properties due to the fact that in the discussed conditions there are a large number of those layers with various properties and thickness. In the model the soil mass is presented by six groups of layers.

In calculations soils are considered as elastic and plastic media, the strength of which is defined by the known criteria of Coulomb-Moor. Calculated physical and mechanical properties of

Table 1. Calculated physical and mechanical characteristics of groups of soil layers for the discussed conditions

No.	Name	Thickness of layer, m	γ, kg/m^3	E, MPa	ν	c, MPa	φ, °
1	Group No.1	5.0	2.00	21.0	0.33	0.005	32
2	Group No.2	20.5	1.94	7.6	0.39	0.005	12
3	Group No.3	2.0	2.06	13.1	0.34	0.015	23
4	Group No.4	5.3	2.10	14.0	0.35	0.032	24
5	Group No.5	8.7	2.20	80.0	0.35	0.038	20
6	Group No.6	38.5	2.27	150.0	0.35	0.080	22

Table 2. Numerical values of vertical displacements of earth surface during the construction of the object in the cross-section 1

Distance from the wall, m	Subsidence, m	Distance from the wall, m	Subsidence, m	Distance from the wall, m	Subsidence, m	Distance from the wall, m	Subsidence, M
0.00	-0.0084	23.26	-0.0144	61.13	-0.0026	101.15	-0.0008
1.61	-0.0079	27.26	-0.0158	65.11	-0.0019	105.16	-0.0008
3.22	-0.0074	30.76	-0.0159	69.08	-0.0015	109.17	-0.0008
4.82	-0.0070	34.26	-0.0147	73.06	-0.0012	113.18	-0.0009
6.43	-0.0067	37.76	-0.0128	77.07	-0.0010	117.20	-0.0009
8.04	-0.0065	41.26	-0.0107	81.08	-0.0009	121.21	-0.0009
9.65	-0.0064	45.23	-0.0084	85.10	-0.0008	125.22	-0.0009
11.26	-0.0064	49.21	-0.0063	89.11	-0.0008	129.23	-0.0009
15.26	-0.0082	53.18	-0.0047	93.12	-0.0008	133.25	-0.0009
19.26	-0.0112	57.16	-0.0034	97.13	-0.0008	137.26	-0.0009

Table 3. Numerical values of horizontal displacements of earth surface during the construction of the object in the cross-section 1

Distance from the wall, m	Subsidence, m	Distance from the wall, m	Subsidence, m	Distance from the wall, m	Subsidence, m	Distance from the wall, m	Subsidence, M
0.00	-0.0128	23.26	-0.0080	61.13	0.0013	101.15	0.0003
1.61	-0.0127	27.26	-0.0050	65.11	0.0011	105.16	0.0002
3.22	-0.0125	30.76	-0.0027	69.08	0.0009	109.17	0.0002
4.82	-0.0126	34.26	-0.0006	73.06	0.0007	113.18	0.0002
6.43	-0.0127	37.76	0.0006	77.07	0.0006	117.20	0.0002
8.04	-0.0129	41.26	0.0015	81.08	0.0005	121.21	0.0001
9.65	-0.0131	45.23	0.0019	85.10	0.0004	125.22	0.0001
11.26	-0.0132	49.21	0.0019	89.11	0.0004	129.23	0.0001
15.26	-0.0124	53.18	0.0018	93.12	0.0003	133.25	0.0000
19.26	-0.0106	57.16	0.0016	97.13	0.0003	137.26	0.0000

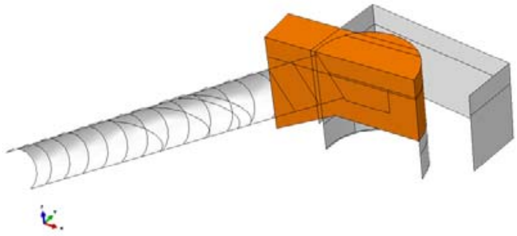

Fig. 1. Mutual orientation of the grouting zone, slurry wall and the tunnel lining

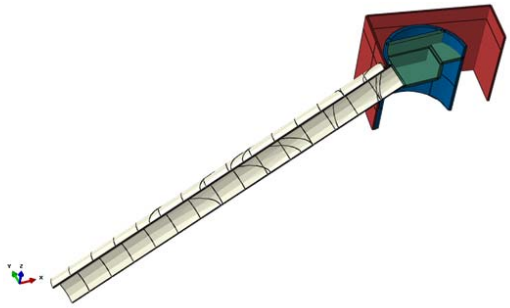

Fig. 2. Mutual orientation of elements of the reinforced concrete structures

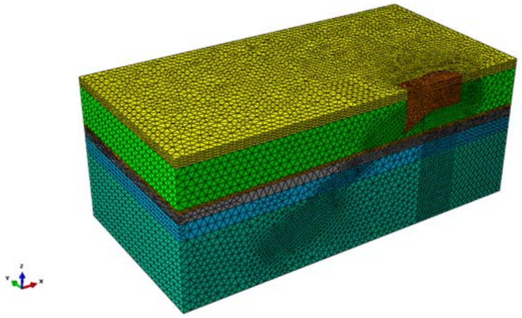

Fig. 3. Overview of the finite-element model of soil mass, which is containing the discussed object

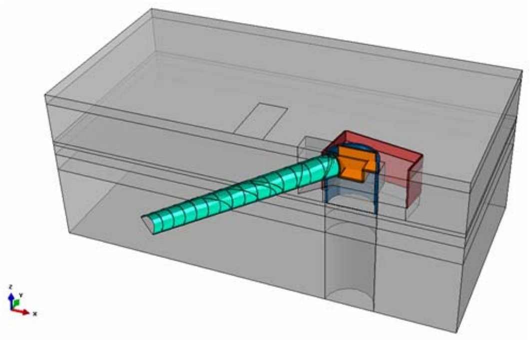

Fig. 4. Overview of slabs and elements of the protective structure in the containing mass

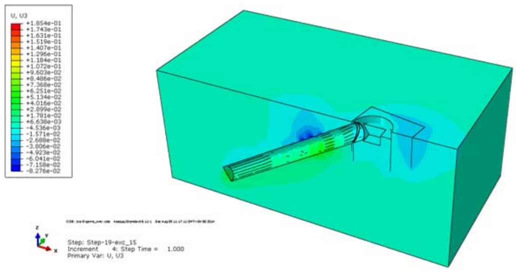

Fig. 5. Diagram of resulting vertical displacements (with specified characteristic cross-sections 1, 2 and 3)

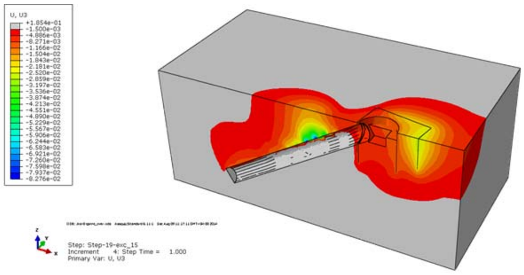

Fig. 6. Zone of intensive vertical displacements (up to 0.0010...0.0015 m) (with specified characteristic cross-sections 1, 2 and 3).

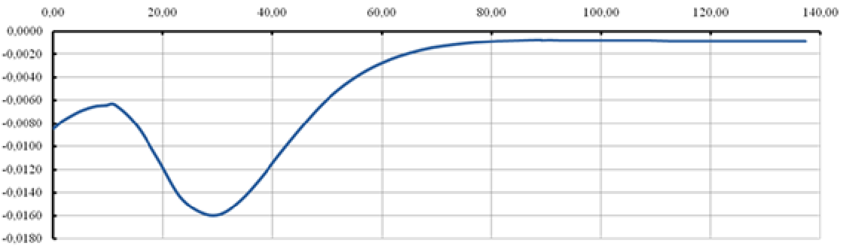

Figure 7. Distribution diagram of horizontal displacements along the first cross-section (Vertical axis represents values of displacements, horizontal axis – distance from the external wall of the pit)

soils in the area of construction are presented in Table 1.

General sequence of the simulation

Overview of the model is presented in Figure 3, and Figure 4 presents overview of elements of courses and elements of the protective structure in the containing mass.

The resulting mode of deformation of the soil mass containing the system of courses is formed stage-by-stage, at that, calculation of all stages was carried out as follows:

1. Geostatic calculation of the specific weight of the soil mass containing the discussed system;
2. Construction of the slurry wall, the shape of which is circular in the horizontal plane, in the soil mass, in order to protect the pit;
3. Construction of the slurry wall, the shape of which is rectangular in the horizontal plane, in the soil mass for construction of the station's hall and grouting of the designed volume of the soil near the pit;
4. Excavation of soil in the pit;
5. Mounting of the reinforced concrete

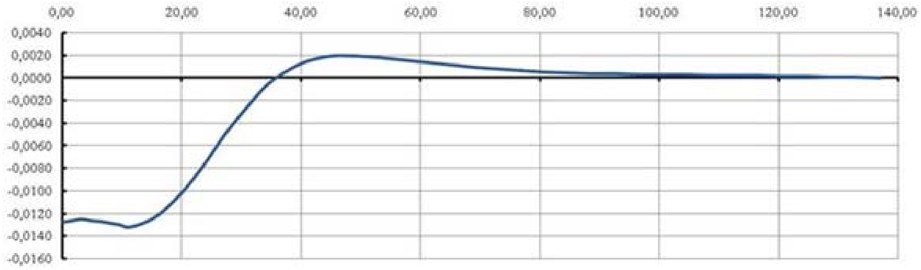

Figure 8. Distribution diagram of vertical displacements along the first cross-section (Vertical axis represents values of displacements, horizontal axis – distance from the external wall of the pit).

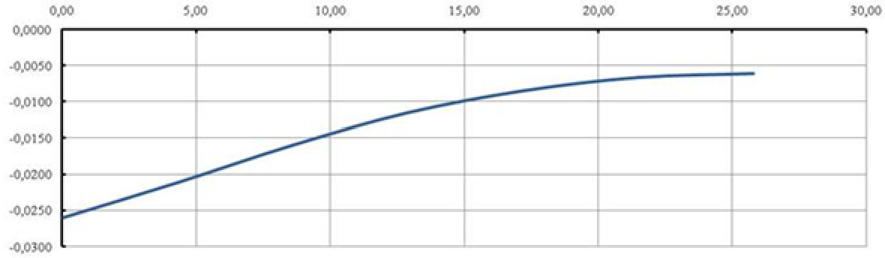

Fig. 9. Distribution diagram of horizontal displacements along the second cross-section (Vertical axis represents values of displacements, horizontal axis – distance from the external wall of the pit)

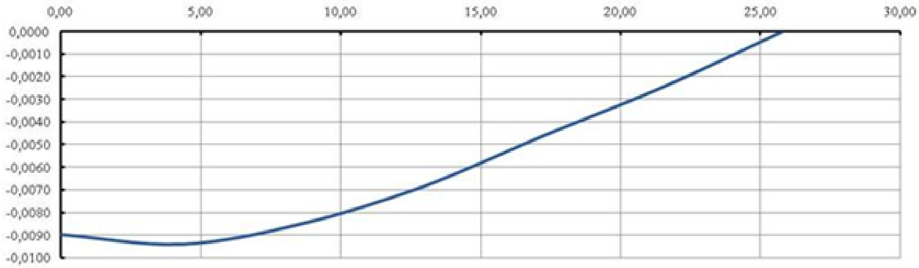

Fig. 10. Distribution diagram of vertical displacements along the second cross-section (Vertical axis represents values of displacements, horizontal axis – distance from the external wall of the pit)

structures in the pit;

6. Excavation of soil in the first aggregated slab in the inclined passage with partial dismounting of the pit's structures and the slurry wall; installation of the tunnel lining;
7. Excavation of the soil of the second aggregated slab in the inclined passage and installation of the tunnel lining;
8. After that the stage No.7 is repeated for the whole length of the tunnel (in a whole, 15 aggregated slabs).

RESULTS

Examples of numerical values of vertical and horizontal displacements of earth surface in the characteristic cross-section 1 are presented in Tables 2 and 3. Orientation of the characteristic cross-sections (1, 2 and 3) is presented in Figures 5 and 6 along with diagram of the resulting vertical displacements and zone of intensive vertical displacements (up to 0.0010...0.0015 m). Mechanisms of formation of vertical and horizontal displacements of earth surface along three characteristic cross-sections are graphically represented in Figures 7...12.

The discussed objects have a significant influence on the soil mass. Maximal subsidence from each of the pits exceeds 10-15 mm, and from the escalator tunnel it exceeds 40 mm.

The zone of displacements, after construction of slurry walls and excavation of soil in the pits outside the zone with grouted soil, spreads from walls of the pits for more then 15-20 m, at that, maximum subsidence is reached at first meters from the wall. At distance of 10 m displacements becomes comparable with accuracy of on-site measurements of displacements.

In the zone with the most unfavorable conditions (from the point of view of possible development of deformations) near point of joining of all three excavations displacements of soils are restricted by grouting of soils, which carries out its function of restriction of deformations. Subsidence and horizontal displacements in that zones didn't exceed several millimeters.

The zone of the most serious deformations from the construction of the escalator

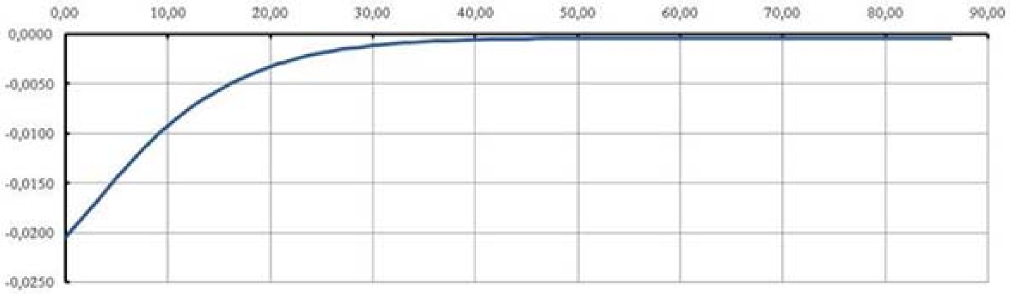

Fig. 11. Distribution diagram of horizontal displacements along the third cross-section (Vertical axis represents values of displacements, horizontal axis – distance from the external wall of the pit)

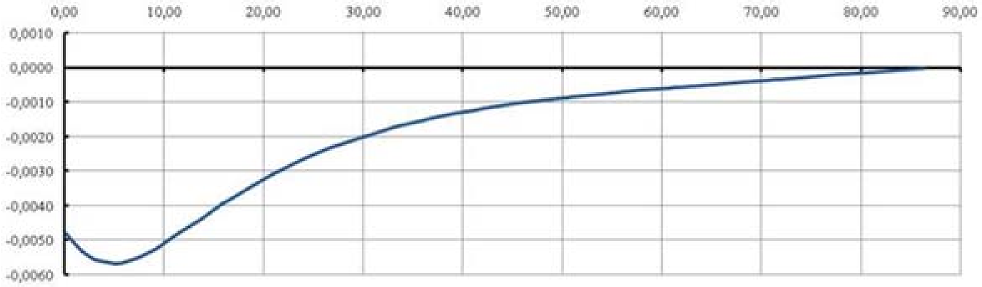

Fig. 12. Distribution diagram of vertical displacements along the third cross-section (Vertical axis represents values of displacements, horizontal axis – distance from the external wall of the pit)

tunnel is located beyond borders of the zone of grouting in the end of the first third of the tunnel and is related with layers of the weakest soils. The zone of the maximum subsidence on surface is situated 20-25 m away from the pits. In that zone subsidence reaches 40-45 mm.

Analysis of overlaps of displacements from different excavations shows that zones of maximum displacements from the pits and the escalator tunnels are not overlapping, mainly, due to effect of grouting. Zone of overlapping of displacements on surface, where mutual influence of the excavations is the clearest, is located, approximately, near border of the zone of grouting from the side of the escalator tunnel.

DISCUSSION

In the mass vertical displacements are distributed unevenly. Characteristic zones of slides are localized according to geological layers. The value of displacements is, generally, defined by physical and mechanical characteristics of soils. Thus, layers of loamy sands and clay loams (layers No. 2 and No. 3), which have lower deformation characteristics (modulus of deformation is 9.2 MPa and 7.6 MPa, respectively) show the maximum displacements. Surrounding soils have restricting effect on propagation of vertical displacements. Upper layer adjacent to surface (filled soils and sands) show almost uniform subsidence, which is demonstrated by almost vertical isolines of vertical displacements.

The zones of the highest vertical displacements in the mass are situated under the middle part of the tunnel. The maximum values of total vertical displacements (subsidence) are, approximately, 75-80 mm. Attenuation of subsidence in the soil mass occurs closer to the end of the tunnel, where, according to geological feature, there are layers of Proterozoic clays of high strength. Not smooth shape of isolines of displacements at transition between one layer to another is related with nonunifromity of physical and mechanical properties of soils, which constitute the soil mass.

Near to the end of the tunnel, subsidence of the mass above arch are decreasing, however, because thickness of soil above it is small, subsidence at surface appear in almost unchanged form, as opposite to the situation in the buried part of the tunnel. Moreover, soils near earth surface have higher deformation characteristics and don’t create conditions for intensive attenuation of displacements above the first third part of the tunnel’s length. Maximum subsidence at earth surface reaches 40-45 mm. Point of maximum subsidence is situated in the first third part of the tunnel (by length)

Vertical deformations in the mass are distributed unevenly in relation to the outline of the tunnel. Vertical deformations of tensions above and under the tunnel reach maximum values in layers of clay loams (layers No. 2 and No. 4) and vary from 0.004 to 0.006.

Horizontal displacements are distributed in the mass quite evenly in relation to the center of the tunnel. At that the largest values appeared in one geological layer (layer of clay loams No. 2). Maximum value of horizontal displacements in that area reaches 36-40 mm. The specified zone of increased horizontal displacements affects formation of the zone of subsidence at earth surface: it increases size of trough in transversal direction in the first third part (by length) of the escalator tunnel and values of subsidence in that zone.

According to the results of the simulation, transversal horizontal deformation (deformations of tensions) at side of the tunnel at the level of its axis are distributed almost uniformly along length of the tunnel, except the zone in the layer of clay loams described above.

Transversal horizontal deformation (perpendicular to horizontal projection of the tunnel’s axis) in the mass above and under the tunnel (compression deformations) is relatively small at whole length of the tunnel. The zone of the largest deformation, which, approximately, by two times exceeds average values for the whole length of the tunnel, is situated in the layer of clay loams mentioned above.

Accumulated experience in simulation[2, 7, 9, 10, 12] and analysis of full-scale test data allows to make conclusion about certain mechanisms of development of subsidence trough at the surface. Trough of displacements in horizontal plane has a roughly elliptical shape, which is becoming wider under the buried part of the tunnel.

That shape is related to the fact that during movement of the working face of the excavation in depth of the soil mass the zone of subsidence under the working face is constantly increasing, at that, values of vertical displacements are decreasing. Thus, features of geometry of lay-line of the escalator tunnel define shape of trough, which is formed on earth surface (increase of trough's width with decrease of subsidence). Shape of trough, in turn, defines degree of influence of mining works on earth surface and surrounding buildings and structures. Due to dissymmetry of shape of subsidence trough in horizontal plane, we decided to use several characteristic cross-sections of it for analysis displacements (subsidence) and deformations.

For evaluation of degree of influence of mining works it is necessary to consider not only analysis of displacements (subsidence), but also analysis of deformations, as first derivatives from displacements, because, in particular, those parameters define level of influence on undermined objects. All troughs of displacements obtained for surface have smooth transition of subsidence. Considerable peaks in profile of troughs appear only in zones at the ends of troughs, where subsidence has minor values comparable with accuracy of calculations by means of finite-element method. That zones were not considered in the analysis.

CONCLUSION

Distributions of vertical displacements (subsidence) in trough were analyzed together with distributions of deformations of inclinations (as first derivative by vertical displacements), deformations of curvature (as second derivative by vertical displacements) and horizontal deformations (as first derivative by horizontal displacements).

Due to the fact that program implementation of FEM didn't allow to calculate inclinations, values of subsidence together with horizontal coordinate by angles of mesh were exported into the external system, where inclinations were calculated using the known approximate formula:

$$i_m = \frac{\eta_{j+1} - \eta_j}{l_{j,j+1}} \quad ...(1)$$

where η_j and η_{j+1} are vertical displacements(subsidence), $l_{j,j+1}$ is length of interval between nodes j and j+1.

Deformations of curvature were calculated using the known approximate formula:

$$k_n = \frac{i_{j+1} - i_j}{l_{av}} \quad ...(2)$$

where i_j and i_{j+1} are inclinations of two adjacent intervals, l_{av} is average length of both intervals.

Due to the absence of accepted standards and low sensitivity of subsidence, calculated using finite-element models, to boundary values in ending zones of trough, we used the value of deformations of inclination and horizontal deformations i_h = å$_h$ = 0.0002 as the main boundary criterion [21]. Sizes of half-troughs in transversal direction didn't exceed 42 m for a case of application of the given boundary criterion.

Horizontal deformations were calculated during standard calculation procedures for all software realizations of FEM.

In longitudinal cross-section maximum subsidence in trough were reaching 40-45 mm. The largest deformations of inclinations were reaching 0.004. Values of horizontal deformation of tensions were reaching 0.0002, compression deformations – 0.0006-0.0008. Deformations of curvature may reach 0.0002-0.0003 1/m.

The biggest inclinations in transversal cross-section were reaching values of 0.0020-0.0022. Deformations of curvature may reach 0.0003-0.0004 1/m, horizontal deformations of tensions – 0.0005-0.0007, compression deformations – 0.0019-0.0021.

Inclinations along the cross-section of foundations of buildings of 10th line of Vasilievsky island reach 0.002-0.003, values of deformations of curvature are 0.0003-0.0004 1/m, horizontal deformations of tension – 0.0005-0.0007, compression deformations 0.0019-0.0021.

If half-troughs, which are formed on earth surface has the biggest sizes (first tens of meters), then for description of shapes of that kind of troughs and for analysis of distribution of deformations in them it is reasonable to use intervals of 6-8 m long. Troughs discussed in the paper have exactly that length of intervals. Data analysis for length of intervals, which are bigger then discussed ones, shows that the discussed values (inclinations) can significantly change. In the discussed case the increase of length of intervals leads to the decrease of inclinations and subsidence trough becomes smoother.

Values of maximum deformation of inclinations for length of intervals of 15-20 m are decreasing to level of 0.0012-0.0015. The zone of appearance of that kind of deformations is not big and it is situated around the zone with maximum deformations.

Analysis of the total influence of construction of the pit and escalator tunnel was carried out on the basis of complex models and geometrical summation of displacements and deformations, which were obtained by means of simulation for independent structures.

Overlapping of deformations from two main excavations creates conditions for decreasing of values of deformations of inclination above the upper part of the escalator tunnel. Due to small sizes of trough from construction of the pit total deformations of the major part of the undermined area are almost the same with those obtained during simulation of the escalator tunnel.

Application of overinjection in zones behind lining of the tunnel (space between lining and soil line of the tunnel) for decrease of subsidence on surface. Provision of overinjection in 20% (by volume), which was tested during excavation of horizontal stage tunnel at Frunze line of subway [18-20], potentially allows to exclude subsidence on surface and even lead to nonuniform swelling (rising) of surface with maximum values in the vicinity of projection of the tunnel's axis. At that in the zones values of swelling can reach 6-8 mm. That kind of nonuniform swelling can negatively influence load-bearing structures of buildings [6, 15], because maximum vertical deformations of inclinations at that can reach 0.0004-0.0006, deformations of curvature – 0.00005-0.00007 1/m, horizontal deformations of tensions 0.0004-0.0006, compression deformations – 0.00005-0.00010. Decrease of parameters of overinjection to, approximately, 10% level can potentially create conditions for minimal displacements at the surface. However, deformation parameters near the tunnel, which was excavated with that parameters, will become more complicated, and predictability of behavior of soils, especially in out-of-limit conditions will significantly decrease.

Even without considering technological complications, which appear in a case of excavation with that kind of parameters for an inclined escalator tunnel, justification of that kind of method of excavation, without a doubt, will require more detailed studies of mechanisms of development of deformation processes using full-scale testing data from the similar objects, where it is necessary to test the aforementioned parameters with overinjection without undermining of city's buildings and structures.

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