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EVALUATION OF JET GROUTING EFFICIENCY AS A MEANS OF MINIMIZING THE HARMFUL IMPACT OF ESCALATOR TUNNEL

The article describes escalator tunnel construction using tunnel boring machines in Saint Petersburg. Rock mass jet grouting technology is used to reduce the harmful impact of underground construction on the earth surface in the mouth of the tunnel. Detailed analysis of the earth surface and rock strata subsidence data proved the effectiveness of the jet grouting technology. Subsidence of the surface and within the grouting area is almost zero.

The fact that the development of subsidence occurs mainly outside the zone of jet grouting soil is shown. A method for reducing subsidence by grouting additional unstable rocks in the massif, which will reduce the harmful impact of underground construction on the massif and the earth surface, is offered. To assess the efficiency of the proposed method, numerical modeling based on the finite element method was carried out. The modeling results showed that the proposed method reduces surface subsidence by 2-3 times.

Keywords: displacements and deformations, escalator tunnel, jet grouting, field survey data, modeling, finite element method.

Current projects related to the construction of underground escalator tunnels within the city limits face serious challenges due to engineering and geological conditions, the limited size of construction sites, and strict requirements for ensuring the safety of existing structures near the construction site. One of most effective solutions is to build escalator tunnels using power-driven tunnel boring machines (PTBM) with active face pressure support (Fig. 1).

The greatest impact on rock trough displacements on the Earth's surface is the physical and mechanical properties of rock mass and the displacement of the tunnel contour rock (convergence), determined by the boring process methods (weight pressure, level of grouting mortar outside construction zone). The construction of escalator tunnels using a PTBM in Saint Petersburg shows that strict adherence to process methods does not serve as a guarantee for preventing rock displacement across the tunnel contour. Currently, this technology is not capable of ensuring zero convergence, since rock subsidence in the arch crown outside the jet grouting zone is not less than 50–60 mm [1] in any conditions.

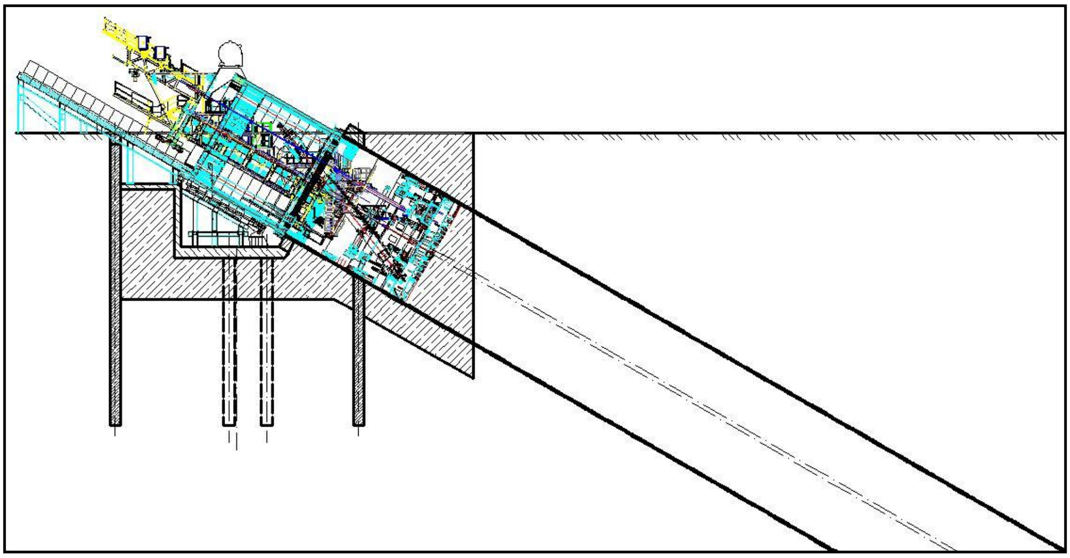

Fig. 1. Escalator tunnel boring with a PTBM

The main approach to reduce surface subsidence is to employ methods that help change the properties of geological material around the tunnel, for example, jet grouting around the tunnel mouth (Fig. 2). This strata consolidation technique is widely used due to its high process parameters and is described in various sources [2, 3]. As well as reducing surface subsidence level, this technology may result in major elevation of the grouting area (by 0.5–0.8 m), which places additional restrictions on this technology.

The field mining survey data obtained during the construction of Admiralteyskaya and Spasskaya underground stations prove the effectiveness of loose ground consolidation with jet grouting to reduce subsidence on the earth surface.

Field mining survey data related to soil subsidence levels, obtained using traditional geodetic methods (survey of subsidence level on wall check points, monitoring marks on building facades) and hole monitoring with extensometers were analyzed.

The method is based on the following approach: vertical holes with extensometers installed at various depths (spacing is approximately 10 m) are drilled along and perpendicular to the tunnel axis. These devices help obtain information about the displacement of the installation point with respect to the hole mouth. It should be noted that levelling hole heads is also very important to obtain information on point displacement in rock strata. The main distinctive feature of hole monitoring is the possibility to automatically collect continuous data which makes it possible to monitor occurrence and determine general mechanism for subsidence distribution in rock strata.

During construction of the escalator tunnel at the Admiralteyskaya underground station, hole E1 with extensometer was within the soil consolidation area (Fig. 3). The survey showed that point displacement in the consolidated area on the surface and in rock strata was practically zero. It can, therefore, be concluded that the jet grouting area fully prevented soil subsidence [4].

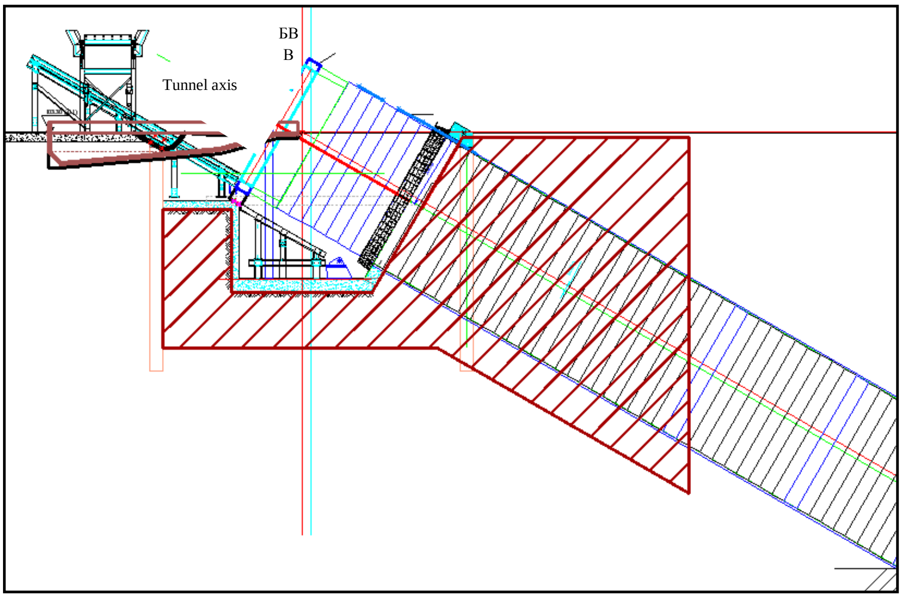

Fig. 2. Jet grouting of soils during construction of the escalator tunnel at the Spasskaya underground station – Cross-section along the tunnel axis

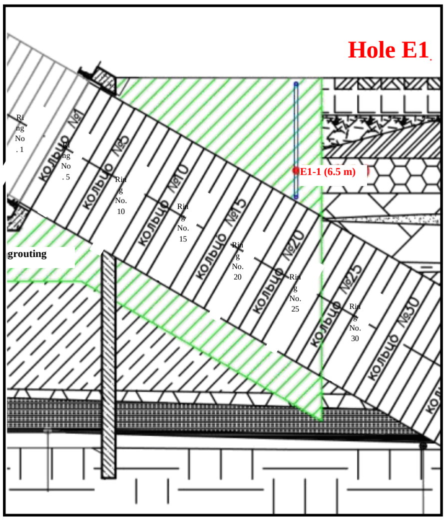

Fig. 3. Hole E1 with subsurface check mark (extensometer) at jet grouting section

Using hole check points to monitor soil subsidence shows that the most intensive geomechanical processes are being developed in the first part of the strata – along the tunnel length outside the jet grouting area. In this area, the subsidence level varies in depth, the maximum values in the tunnel arch are more than 100 mm, and the level reduces as it gets closer to the surface. During construction of the escalator tunnel at the Spasskaya underground station, the maximum earth surface subsidence (44 mm) was in the mouth of hole E1 located 7.4 m from the soil consolidation area.

The displacement and deformation mechanisms determined as a part of field survey activities allow us to provisionally separate the strata tunnel route into three sections subject to the subsidence intensity level (Fig. 4):

1. Minimum subsidence area – PTBM bores the construction site mouth jet grouting area. The subsidence level data obtained during mining survey activities lie within the limits of the measurement accuracy.

2. Large subsidence area starts where the boring machine exits from the grouted area to loose quaternary deposits and extends up to Proterozoic clay boundary. This area features major subsidence in the arch crown as well as large vertical on-surface displacements.

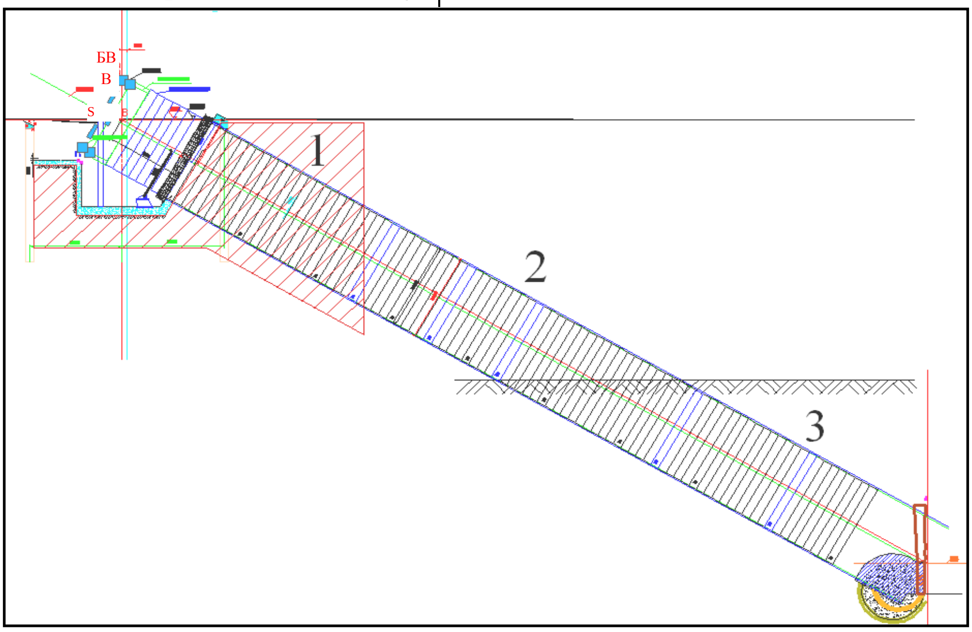

Fig. 4. Provisional sectioning of the massif during construction of the escalator tunnel at the Spasskaya underground station (in accordance with subsidence rate).

3. The subsidence decay area, where the PTBM enters solid clays with high deformation and strength characteristics (the total modulus of deformation exceeds the respective values for quaternary deposits by tens of times).

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Despite relative deepening, section 2 has largest surface subsidence level. To reduce hazardous strata movement processes in this section, additional consolidation by jet grouting was proposed for the tunnel mouth (section 1) and in the strata depth up to the consolidated clays (section 2); it was also proposed to consolidate the soils without disturbing the sub-surface area (Fig. 5).

This approach would improve the mechanical properties of the massif near the tunnel and minimize the impact of jet grouting on the earth surface. "Protective" sub-surface mass makes it possible to reduce surface "swelling" which can occur when performing these works.

In order to analyze the effectiveness of the proposed method, 3D geomechanical modelling with Plaxis 3D software tool was proposed. This tool is an optimum solution for geo-engineering calculations; it is widely used around the world.

The created model (see Fig. 5) included the current mass consolidation method (section 1), mass section proposed for consolidation, tunnel lining constructed in a step-by-step manner. The total modulus of deformation for these sections is determined in accordance with test field data and taking into account actual physical and mechanical characteristics of the geologic material mass inside the tunnel. The total modulus of deformation values were checked on a previously created model for boring the Admiralteyskaya underground station escalator tunnel; on different models, these values reside in the interval of 200–500 MPa.

Analysis of the calculation results proves the effectiveness of additional soil consolidation of section 2. Fig. 6, *a* shows that major subsidence occurs within the section described above. As expected, the subsidence level is reduced in the additional consolidation area; the subsidence residual part is located in section 3. The calculation results show that the subsidence level can be reduced by 2-3 times compared to initial boring conditions (Fig.6, b).

In addition to the changed subsidence level we also should note the changes in distribution of vertical surface movements.

Here, the maximum subsidence levels areconcentrated near vertical projections of the

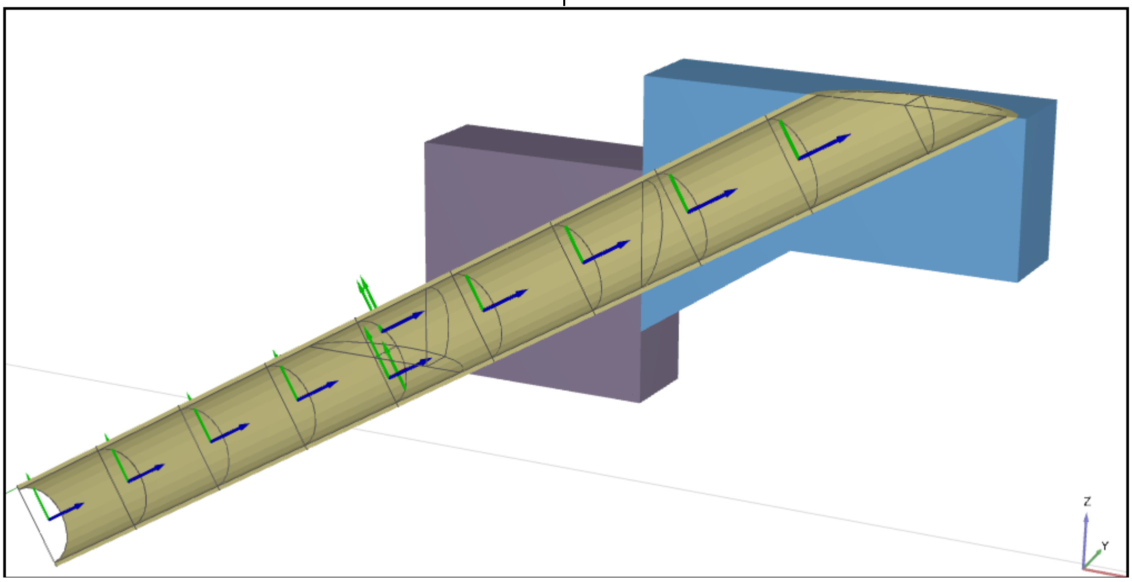
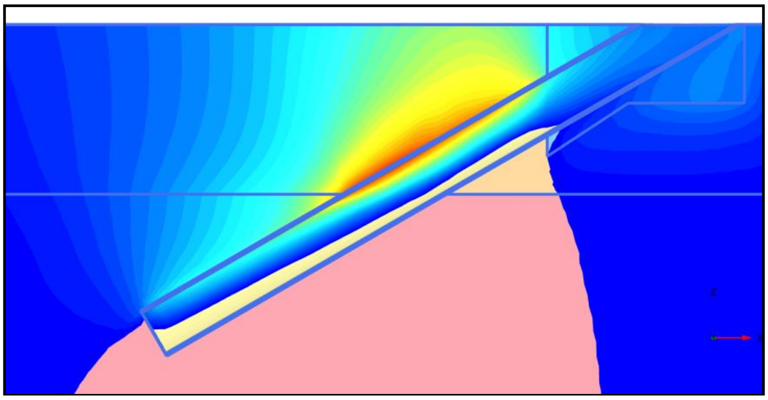
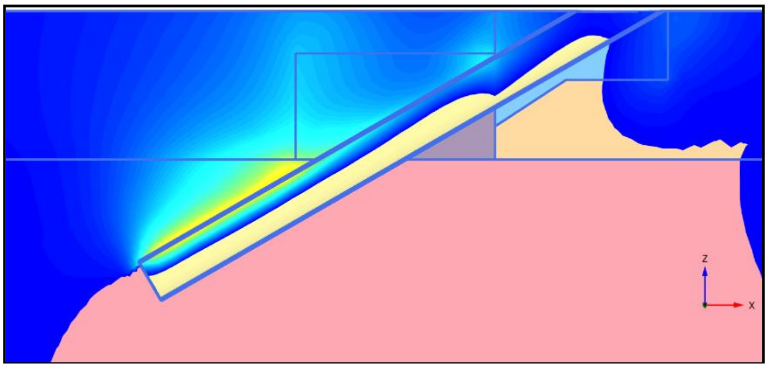


Fig. 5. Spasskaya underground station escalator tunnel model with consolidation of middle mass section.



a

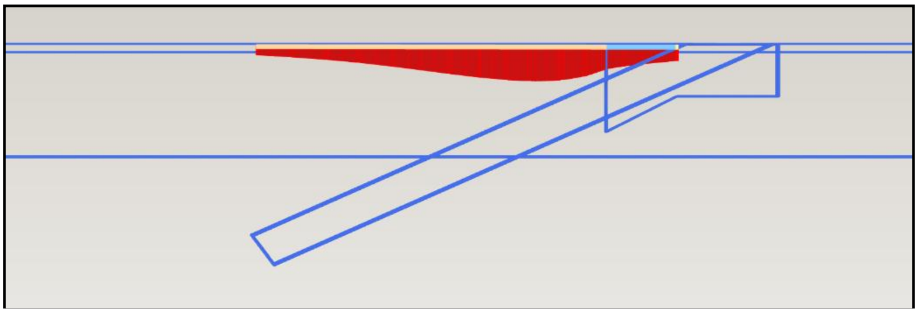


b

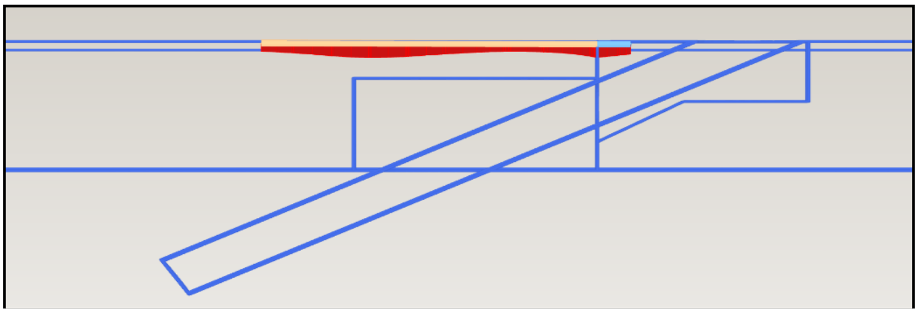
Fig. 6. Distribution of vertical movements (subsidence) during construction of Spasskaya underground station escalator tunnel:

a – without additional solid consolidation

b – with additional quaternary deposits consolidation.



a



b

Fig. 7. Trough movement during construction of Spasskaya underground station escalator tunnel:

a – without additional solid consolidation

b – with additional quaternary deposits consolidation.

consolidation area boundaries; this is due to relatively active movements within these boundaries (Fig. 7).

The performed studies allowed a number of conclusions to be formulated.

Escalator tunnel PTBM boring with active face pressure support makes it possible to significantly decrease the harmful impact on buildings and structures during mining operations.

As experience has shown, despite a range of modern PTBM methods, it is impossible to fully prevent occurrence and movement of rock mass in strata and on the surface.

Major surface movement occurs above the escalator tunnel top section where the depth of the inclined working is not too great while the bearing strata are water-logged and unstable. In the bottom part of the tunnel, at the entrance to the bed rock, the deformation processes are practically zero.

Soil consolidation by jet grouting at the escalator tunnel mouth area ensures a significant decrease in the movement and deformation rate on the surface and during the construction process. This is proved by the field survey data and displacement mathematical modelling. The surface subsidence levels do not exceed several millimeters in the grouted area.

The positive effect of jet grouting (notable improvement of soil deformation and strength characteristics) which helps decrease deformations during boring may come to nothing due to major soil surface swelling during high pressure grouting.

This work proposes additional soil consolidation in the deep tunnel section, up to the bed rock. However, these works should be performed only in the deep tunnel section, without grouting the upper strata. The model calculation results show that such consolidation can dramatically decrease the main subsidence above the tunnel and minimize the harmful impact of jet grouting.

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Title:	**Evaluation of jet grouting efficiency as a means of minimizing the harmful impact of escalator tunnel construction**
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Abstract:	The article describes the escalator tunnel construction using tunnel boring machines in St. Petersburg. To reduce the harmful effects of underground construction on the Earth's surface in the mouth of the tunnel technology is used jet grouting rock mass. Based on the analysis of field data of the earth surface subsidence and rock strata proved the effectiveness of the jet grouting technology. Subsidence of the surface and within the grouting area, are approximately null. The fact that the development of subsidence occurs mainly outside the zone of jet grouting soil is shown. A method of reducing subsidence by grouting additional unstable rocks in the massif, which will reduce the harmful effects of underground construction for an massif and the earth's surface, is offered. To assess the efficiency of the proposed method, a numerical modeling based on the finite element method is carried out. According to the modeling results it is revealed that the proposed method will reduce the subsidence at the surface by 2-3 times.
Keywords:	displacements and deformations, escalator tunnel, jet grouting, the data of field observations, modeling, finite element method.
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