

Tunnel boring works with the use of information modelling technology in Moscow metro design

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Abstract: Designing and construction of new transport infrastructure objects in large megacities is caused by dense urban development, dense network of engineering communications and operating underground facilities. The location of stations and tunnelling of underground tunnels in such conditions is associated with an increase in the cost of construction and installation works. Special methods as well as the use of information modelling technology serve as tools to optimize the costs arising in the course of project implementation within a tight schedule. This is illustrated in the example of the construction of distancing tunnels from the station 'Klenovy Boulevard' to the station 'Kuryanovo' of the projected Biryulevskaya line of the Moscow Metro crossing the station 'Klenovy Boulevard' of the existing Big Circle Line. As part of the design, two options for the crossing were analysed: under the Klenovy Boulevard station of the Big Circle Line and, respectively, above the existing tunnel of the station complex. Thanks to the application of information modelling technology, the second option was chosen, where the route was modelled with coordinated information models reflecting the already implemented design solutions for Klenovy Boulevard on Big Circle Line station, as well as a fragment of the projected crossing between Klenovy Boulevard and Kuryanovo stations, passing over the technical inspection station. At the same time, the distance between the existing and under construction structures in the cross-section according to the adopted structural solutions will be no more than 1,7 m. It is therefore necessary to increase the bearing capacity of the soils and prevent possible deformations. To preserve the strength and stability of the soil mass, a part of the excavation is to be filled with expanded clay concrete in the tunnelling zone of the tunnel boring mechanized complex. The described experience reflects the practical significance of information modelling technology implementation in the construction of structures within the framework of dense urban development and creates an economic effect.

Keywords: construction; information modelling technology; metro; tunnel; tunnelling

1. Introduction

The design and construction of new transport infrastructure facilities in large metropolitan areas is due to dense urban development, a dense network of utilities and existing metro facilities (Agafonov et al., 2024). The placement of stations and the passage of subway tunnels within the specified conditions leads to an increase in the cost of construction and installation work. Considering major construction projects in the city of Moscow, it is impossible not to mention the construction of the Big Circle line (BCL) of the Moscow metro (Fig. 1). This is the largest metro construction project in Russia and one of the largest in the world – the length of the line is 70 km, 31 stations and 2 electric depots. And 20% of the stations were already built with the support of the information model (Viazovoi et al., 2024; Kivlyuk et al., 2024).

In recent years, information modelling technologies have become the basis for improving the efficiency and reducing the risks inherent in underground construction projects (Arayici, et al., 2011; Azhar, 2011; Liu, et al., 2017). The use of special methods, as well as the use of information modelling technology (BIM), are tools for optimizing costs incurred during the implementation of a project in a short time frame. This technology promotes closer collaboration, accuracy, and efficiency in the design process,

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shifting the industry paradigm towards an approach focused on timely and operational data exchange between participants in the construction process (Charehzehi, and Ahankoob, 2012; Paskaleva, Beronneau, and Bednar, 2024; Zhaofeng, 2024). The article (Nadot, at al., 2024) notes that the creation of information models within the framework of the BCL project of the Moscow Metro allowed:

- to detect and prevent conflict situations in the design process in advance;
- identify priorities in a timely manner and focus resources on the most important areas of work;
- use the BIM database when conducting copyright supervision;
- to implement 4D planning, which integrates a 3D model with the construction schedule, which allowed for a dynamic analysis of the planned and actual progress of work;
- to implement spatial coordination of the premises used in the cramped conditions of underground construction.



Fig. 1. Diagram of the Moscow Metro's Big Circle line.

Additionally, it should be noted that Guinness World Records has recorded a world record on the Big Circle line for the number of tunnel-boring mechanized complexes (TBM) used in the construction of the subway: 23 billboards did not work simultaneously on one project in any megacity in the world.

This article discusses the construction of transfer tunnels from Klenoviy Bulvar station to Kuryanovo station of the projected Biryulevskaya line of the Moscow Metro with the intersection of the existing BCL, which is a complex of underground and aboveground structures providing not only transportation of people, but also the functioning of the BCL as a whole.

2. Methodology

As part of the design, two intersection options were analysed: under the Klenoviy Bulvar BCL station (option 1) and, accordingly, between the current tunnel of the station complex and the above-ground metro lobby (option 2, shown in Fig. 2).

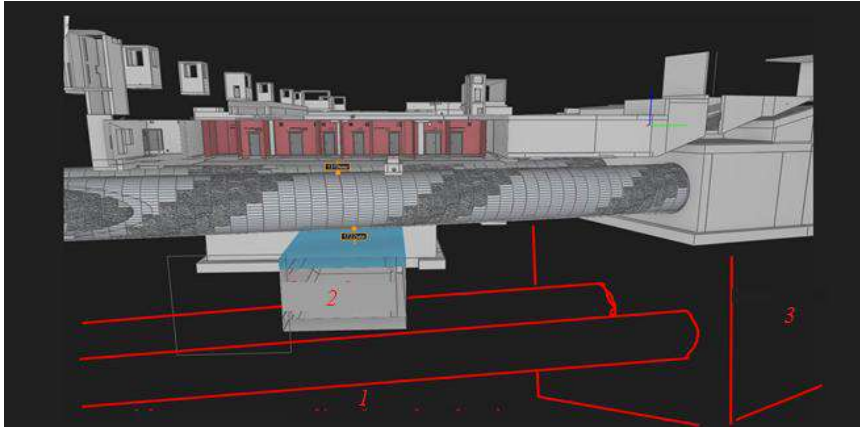


Fig. 2. Options for the route of the Biryulevskaya metro line tunnels: 1 – option 1 for the tunnel route (under the existing line); 2 – double-track tunnel for the Biryulevskaya metro line; 3 – additional wall volume in the ground.

Option 1 required significant deepening of the foundation pit of the future Klenovy Boulevard station, which would lead to a multiple increase in the cost and duration of construction and installation work, as well as additional costs for appropriate measures for buildings and structures that were in the increased zone of influence of construction.

Thanks to the use of BIM, option 2 was chosen, where the route was modelled taking into account coordinated information models reflecting already implemented design solutions for the Klenovy Bulvar BCL station, as well as a fragment of the projected stretch between Klenovy Bulvar station and Kuryanovo station, passing over the technical inspection point. This solution leads to optimization of the construction process and reduction of the project budget (Fig. 3).

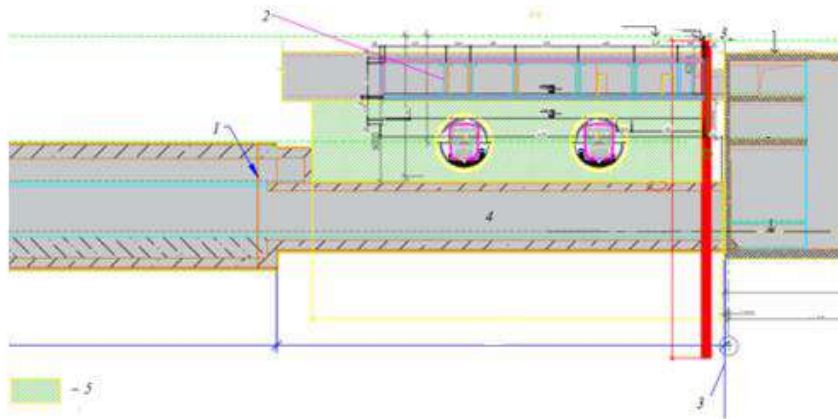


Fig. 3. Longitudinal section for option 2 at the intersection of the Biryulevskaya metro line tunnels with the existing Klenovy Boulevard station: 1 – expansion joint; 2 – pedestrian crossing; 3 – beginning of the station complex; 4 – railhead level; 5 – backfill work area at the intersection of lines.

At the same time, the distance between existing and under construction structures in cross-section according to the adopted design solutions will be no more than 1.7 m. Therefore, it is necessary to increase the bearing capacity of soils to prevent possible deformations (Konyukhov, 2021; Kulikova et al., 2023). To preserve the strength and stability of the soil mass during the construction of the BKL, a part of the excavation was filled with expanded clay concrete in the TPMK sinking area.

The expanded clay concrete installation is provided in two stages:

1. laying expanded clay concrete up to the 109.45 mark (1 m below the axis of the 3rd tier of fastening). After gaining strength with expanded clay concrete of at least 75 %, the 3rd tier of fastening is dismantled;
2. laying expanded clay concrete and backfilling to the bottom of the preparation for permanent structures of the pedestrian crossing (Fig. 4).

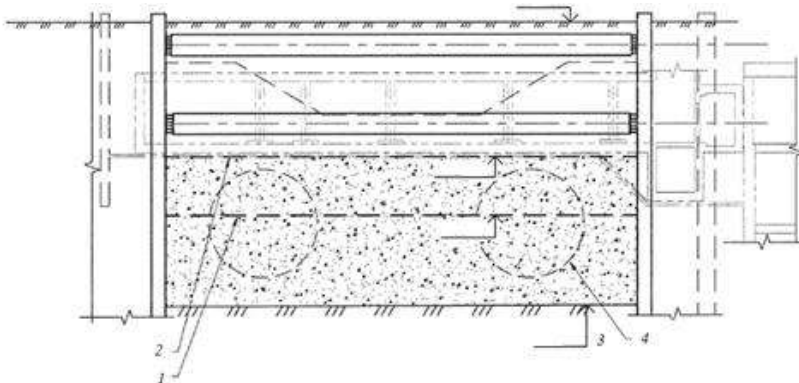


Fig. 4. Diagram of expanded clay concrete laying and backfilling: 1 – first stage of expanded clay concrete laying; 2 – second stage of expanded clay concrete laying; 3 – excavation depth mark; 4 – TBM rotor dimensions.

The TPMK ‘Herrenknecht’ tunnelling complex with a 6.25 m diameter hydraulic face loader has been selected for the passage of the Biryulevskaya line of the metro, which has successfully completed the passage of 13 tunnels in the city of Moscow, which is more than 16 thousand running meters.

A tunnelling complex with a bottom-hole hydraulic loader, compared with a shield with a ground loader, allows for more accurate control of the physical properties of the slurry and pulp, as well as maintaining a set pressure in the bottom-hole chamber (Jarast et al., 2023; Konyukhov, 2023; Mahdi et L., 2019).

The chisel head performs the function of a means of penetration, while the fastening of the bottom hole space is carried out by counterpressure of a special solution, in particular, bentonite or clay-water (mud) suspension (Mazein et al., 2019).

The slurry is pumped into the hydraulic loading chamber, from where it enters the bottom hole space, and then seeps into the ground, forming a filtration crust, either a waterproof partition (fine-grained soil), or a fully impregnated zone (coarse-grained) to provide back pressure in the head of the shield.

The clastic material developed by the working tools of the rotary chisel head consists partly of soil, and partly of bentonite or a clay (mud) mixture. This mixture is pumped (hydraulic excavation) from the hydraulic loading chamber into a separation unit on the surface, which processes it for subsequent use..

3. Results

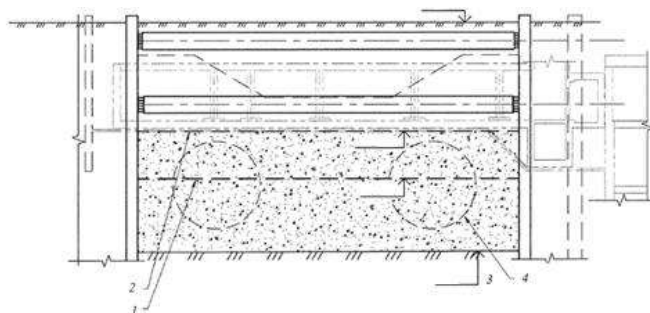
These measures were taken into account when assessing the impact of tunnelling on the operating station, taking into account the recommendations (Lebedev, 2018); the calculation model was performed in the PLAXIS software package. The calculations were performed in a 3D formulation using the Hardening Soil model. The physical and mechanical characteristics of the soils were determined based on the results of laboratory studies and optimized using mathematical modelling in the PLAXIS SOIL TEST virtual laboratory. The results of model studies of the effect of the passage of distillation tunnels on the operating station are shown in Tables 1 and 2 and in Fig. 5.

Table 1. Predicted maximum additional vertical total displacements of tracks falling within the calculated zone of influence of construction.

Track number at 'Klenovy Boulevard' station of BCL	Total vertical displacement of tracks (taking into account previous stages) [mm]		Settlement [mm]	Deviation in level [mm]	Skew [mm]	Track widening (narrowing) [mm]
	Calculation stage					
	Tunnelling of the first tunnel	Drilling of the second tunnel				
1st	0,18	0,67		Less than 1		
2nd	0,15	0,74		Less than 1		

Table 2. Predicted maximum additional vertical and horizontal displacements of metro structures falling within the calculated zone of influence from TBM tunnelling ('Klenovy Boulevard' station on the BCL).

Structure	Tunnelling stage	Maximum additional displacements, mm		Technical condition category	Maximum permissible additional settlement, mm, according to SP 474.1325900.2019
		vertical	horizontal		
Underground vestibule and staircase	First	12,1	1,4	II	30
	Second	16,2	2,8		

**Fig. 5.** Additional vertical movements of the Klenovy Bulvar BCL station at the stage of tunnelling the 2nd tunnel.

According to the results of mathematical modelling, the maximum additional total vertical movements and the relative difference in precipitation of buildings, structures, and utilities do not exceed the maximum permissible values established by regulatory documents of the Russian Federation. The integrity and operability of the building structures of the BCL, structures, and engineering communications are ensured, additional safety measures are not required.

The use of numerical modelling of the impact of the passage of the Biryulevskaya Line tunnels on the operating Klenovy Bulvar station of the BCL made it possible to clarify the relative location of structures in the BIM model of the line under construction. However, monitoring of existing metro facilities and the surrounding buildings is provided for the entire period of tunnel driving.

4. Conclusion

The methods used in the design of the considered section of the Biryulevskaya metro line will make it possible to implement complex capital construction projects. The described experience reflects the

practical significance of the introduction of BIM in the construction of structures in dense urban areas and shows the economic effect (Table 3).

In the near future, information modelling technology may become the main tool for implementing complex capital construction projects, which undoubtedly include the metro. The introduction of information modelling technologies creates an opportunity to improve the detection of collisions, prioritize work, optimize planning accuracy and cost control, which will increase the efficiency and profitability of the construction process.

Table 3. Predicted maximum additional vertical and horizontal displacements of metro structures falling within

No	Parameters under consideration	Option 1	Option 2
1	Volume of excavated soil, m ³	203.970,0	97.278,0
2	Volume of trench 'wall in the ground', m ³	24.613,9	12.252,2
3	Volume of excavation pit support, t	5.275,2	2.515,9
4	Construction period of the pit, months	17,9	12,0
5	Cost of construction and installation works, thousand rubles	5.084.442,7	2.489.097,7

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