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Experience of Russian-Chinese industrial cooperation on the construction of the Moscow metro

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ABSTRACT The commissioning of the Big Circle Line in Moscow, some sections of which were laid jointly with Chinese underground builders, provided the first experience of interaction with foreign construction contractors on the Moscow Metro. The paper investigates this experience which is of value for the development of such works in the future. The analysis was carried out on the basis of scientific and technical documentation on certain facilities, the progress and results of construction and installation works, and information on other events. The paper describes the facilities where construction and installation works were carried out by joint efforts and shows the peculiarities of interaction between Russian and foreign (Chinese) metro builders on a number of sections of the Big Circle Line of the Moscow Metro. The achieved results are demonstrated by the example of individual underground stations. The study reveals the peculiarities of material and technical support of works on the sections constructed by Chinese construction contractors. The mutual exchange of experience, technologies, and work management practices along with the application of various tunnel boring machines from both countries (Russia and the PRC) has yielded fruitful results, demonstrated the possibility and efficiency of the direct engagement of foreign tunnel builders at Russian sites in close cooperation with their Russian counterparts, and revealed a scheme for rational division of labour, work management, and logistical support of works.

KEYWORDS: Big Circle Line; Chinese metro builders; metro construction; Moscow Metro; Russian metro builders; tunnel boring machine

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Научная статья

Опыт российско-китайского производственного сотрудничества на строительстве Московского метрополитена

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АННОТАЦИЯ В связи с вводом в Москве в эксплуатацию Большой кольцевой линии, проложенной на отдельных участках совместно с китайскими метростроителями, получен первый опыт взаимодействия с зарубежными подрядно-строительными организациями на Московском метрополитене, исследованный в статье и представляющий ценность для развития таких работ в перспективе.

Анализ проведен на основе научно-технической документации по отдельным объектам, хода и результатов строительно-монтажных работ, информации о других событиях.

Охарактеризованы объекты совместного производства строительно-монтажных работ, показаны особенности взаимодействия отечественных и зарубежных (из КНР) метростроителей на ряде участков Большой кольцевой линии Московского метрополитена, на примере отдельных подземных станций продемонстрированы достигнутые результаты. Выявлены особенности материально-технического обеспечения работ на участках, сооружаемых китайскими подрядными строительными организациями.

Взаимный обмен опытом, технологиями, организацией работ, применения разнообразных тоннелепроходческих механизированных комплексов обеих стран (России и КНР) дал плодотворные результаты, продемонстрировал возможность и эффективность участия зарубежных тоннелестроителей непосредственно на российских объектах в тесном взаимодействии, выявил схему рационального разделения труда, организации и материально-технического обеспечения работ.

КЛЮЧЕВЫЕ СЛОВА: Большая кольцевая линия; китайские метростроители; метростроение; Московский метрополитен; российские метростроители; тоннелепроходческий механизированный комплекс

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INTRODUCTION

Cooperation between Moscow metro builders and their foreign counterparts has a long history and is characterised by great diversity. There were periods when Russian metro builders were directly involved in design and construction works in foreign countries (the Prague Metro [1], the Budapest Metro [2], and the Calcutta Metro [3, 4]); provided advisory assistance to their foreign colleagues (the Beijing Metro [4], the Bucharest Metro [5], and the Belgrade Metro [5]); and trained specialists. For long periods in recent times, cooperation has been limited to the exchange of experience and technology transfer, including within the framework of and as part of events held by the International Tunnelling Association, to the purchase of imported tunnel boring equipment, and so on.

In recent years, the scale and pace of metro construction in the capital of the Russian Federation have increased to an unprecedented extent. The programme for the development of urban transport adopted by the Moscow Government provides for the intensive expansion of its underground component — the underground, the first line of which was put into operation in May 1935 [6, 7]. The Moscow Metro is among the leading underground railway systems in the world in terms of construction rates and a number of operational indicators. Over the past 12 years, the expansion of the capital's underground is characterised by the unprecedented scope and timing with the maximum involvement of scientific, technical, material and labour resources along with the intensive application of achievements of the world's metro construction industry.

As a result, the length of the Moscow Metro has grown 1.5 times. More than 200 kilometres of new tracks, 109 stations and 11 motor-car depots have been put into operation. The works are carried out in the shortest possible time and with high quality. A large-scale pool of research, design, construction, installation and auxiliary organisations is involved. According to the plans of the Moscow City Government, 25 more stations and 58 kilometres of interstation sections are to be put into operation in the near future (by 2027).

In the current context and as part of the strengthening and expanding of cooperation with friendly countries, a decision was made to involve foreign contractors in metro construction works. Chinese metro builders pioneered the initiative, which is natural given the achievements of China in this field along with the long-standing professional ties between Russian and Chinese metro builders who have been cooperating since the very beginning of the emergence of the metro in China [4].

The pace of metro construction in the PRC [8–10] shocks the global specialist community. The first metro in Beijing began to be built three decades later than in Moscow, in 1965. And if in 2006 the capital of the PRC had 114 kilometres of metro, in 2012 there were 442 kilometres, and by 2015 the metro length reached 708 kilometres. By 2020, the task was set to bring the length of the metro in Beijing to 1,050 kilometres, and this is only in one city. The length of the metro network in China exceeds 8.7 thousand kilometres. The underground operates in 47 cities of the country. This is the result of the Chinese Government's programme to build a metro system in every regional centre with a population of more than 1.5 million people. China Railway Construction Corporation Limited (CRCC)[1] plays an important role in the implementation of the programme. CRCC has a 75-year history and is a major construction corporation supervised by the State-owned Assets Supervision and Administration Committee of the State Council of the People's Republic of China (SASAC). This mega-scale construction company is one of the most powerful and largest general construction groups in the world, operating not only within the PRC, but also in more than 130 countries and regions around the world, engaging in contracting, planning and design consultancy, among others. CRCC Corporation has a complete production chain including research, planning, survey, design, construction, supervision, operation, maintenance, investment and financing, and plays a leading role in the design and construction of tunnels and urban railway transport in particular. It employs 267,000 professionals, operates four corporate design institutes, and has accumulated vast experience both at home and abroad which was recognised by many international professional awards and distinctions. CRCC Corporation has extensive experience with information modelling technologies. The company has developed high-quality and modern software for these purposes.

What is of interest is the nature and management of joint works between Russian and Chinese metro builders in the complex urban transport conditions of the Russian metropolis, in the close proximity of the operating underground network and in difficult engineering and geological conditions.

MATERIALS AND METHODS

Within the framework of the Agreement between the Government of the Russian Federation and the Government of the People's Republic of China on the Encouragement and Mutual Protection of Capital Investments, CRCC's subsidiary in the Russian Federation, CRCC Rus LLC, participates in the construction of the Moscow Metro. To date, 11 tunnels of the south-western and eastern sections of the Big Circle Line (BCL) have been built in Moscow under the existing stations Michurinsky Prospekt and Prospekt Vernadskogo, under the motorways Michurinsky Avenue, Leninsky Avenue, and Vernadskogo Avenue, under the railway tracks of the Kaluga direction of the Moscow railways, the Nagatinsky Backwater of the Moscow River, and the Kolomenskoye Museum Reserve; six tunnels of the Kommunarskaya metro line, including under underground utility mains and city motorways — the Moscow Ring Road and Kaluga Highway. The Chinese company built five metro stations in excavations of up to 30 metres deep in dense urban areas.

[1] URL: https://english.crcc.cn/

A special place is occupied by the participation of CRCC Rus LLC in the construction of the largest project of Moscow metro builders, the Big Circle Line. The competition was open, everyone could take part in it. The Chinese firm won. In January 2017, a contract was signed between Mosinzhproekt JSC and CRCC Rus LLC, under which Chinese specialists (mainly employees of CRCC's 16th Department) built three stations of the BCL in Moscow. The Chinese specialists were involved in the construction of Aminievskaya station (including interstation tunnels with tunnelling structures and dead ends behind the station), Michurinsky Prospekt and Prospekt Vernadskogo stations: a double-track tunnel from Nagatinsky Zaton station to Klenovy Bulvar station and further to the transition chamber, and single-track tunnels towards Kashirskaya station. CRCC Rus LLC performed the main construction (tunnelling) works, while finishing work, installation of equipment, installation and testing of traffic control systems and other precise transport systems were carried out by Russian contractors.

To meet these needs, CRCC Rus LLC has set up in-house production of high-precision tunnel lining in Russia. For this purpose, 12 sets of tooling moulds for 6.0/5.4 metre diameter lining and four sets of tooling moulds for 10.5/9.6 metre diameter lining were used. More than 14,000 tunnel lining rings with a diameter of 6.0/5.4 metres and 1,500 tunnel lining rings with a diameter of 10.5/9.6 metres were manufactured and installed.

For the purposes of construction of metro facilities in Moscow, CRCC Rus LLC manufactured in the PRC in accordance with the customer's specifications and delivered to Russia six tunnel boring machines (TBMs): five units with a diameter of 6.25 metres and one unit with a diameter of 10.8 metres. Technical characteristics of the machines are as follows (data for a 10.8 metre diameter TBM are given in parentheses): rotor diameter, m: 6.28 (10.8); diameter of tunnel boring machine shell, m: 6.25 (10.84); length of tunnel boring machine head part, m: 9.5 (11.4); total length of tunnel boring machine, m: 87 (68); total weight, tonnes: 460 (1,700); power, kW: 1,750 (6,000).

For the purposes of transportation from the PRC to Russia, the panel systems were disaggregated into 14 and 40 elements for the TBMs of 6.25 metres and 10.8 metres in diameter and of 2 to 130 tonnes and 5 to 180 tonnes in weight, respectively.

In addition, CRCC delivered to the Russian Federation five Zoomlion T8030-25U full-swing tower cranes[2] of increased lifting capacity: with the maximum lifting capacity of up to 25 tonnes, maximum boom length of 50 metres, and maximum crane height of 45 metres, and two grapple rigs for the construction of enclosing structures using the "wall-in-soil" technology.

For tunnelling of the south-western section of the Big Circle Line, CRCC Rus LLC used five TBMs (ZTE6250 DZ397 "Maria"; ZTE6250 DZ398 "Daria"; ZTE6250 DZ399 "Evgenia"; ZTE6250 DZ400 "Galina"; and ZTE6250 DZ401 "Polina"). Three-kilometre tunnelling work on the BCL section between Nagatinsky Zaton and Klenovy Bulvar stations was performed by a 10-metre long TBM ("Pobeda" (Victory) as a symbol of the long-standing friendship between Russia and China based on mutual support and trust, and as a reflection of the countries' contribution to the victory in the Second World War). The TBM was designed by Chinese colleagues according to the technical specifications developed by Mosinzhproekt in accordance with the hydrogeological conditions at the construction site and taking into account the accumulated experience of using 10-metre shields in Moscow. This method of tunnelling allows for avoiding the construction of tunnelling structures and ventilation shafts and thus does not require additional construction sites to be cleared, which is important considering that this section of the line passes near the Kolomenskoye Museum Reserve.

Interaction between Chinese and Russian specialists in metro construction was not limited only to solving production problems. The exchange of scientific and technical experience is of great value, too. On November 15–18, 2019, the 1st International Conference on Exploration and Utilization of Underground Space (EUUS2019)[3] organised by the Institute of Rock and Soil Mechanics of the Chinese Academy of Sciences (IRSM-CAS) and the State Laboratory of Geomechanics and Geotechnics (SKLGME) with the participation of 30 research institutes and enterprises was held in Wuhan, China. The Russian delegation represented by Mosinzhproekt took part in the conference and made a presentation on the analysis of parameters determining the value of the excess excavation ratio in mechanised tunnelling [11]. Based on the analysis of engineering, geological and technological factors, Mosinzhproekt specialists have developed recommendations for determining the excess excavation ratio depending on the type of soil and diameter of a TBM [12, 13].

Let's take a closer look at the works performed at the BCL facilities.

The section from Prospekt Vernadskogo station to Aminievskaya station (including Michurinsky Prospekt

[2] Crane market. URL: https://cranemarket.com/specs/tower-cranes/zoomlion/t8030-25u

[3] First International Conference On The Exploitation And Utilization Of Underground Space (EUUS2019) In Wuhan, China. *EarthScienceMatters*. URL: https://www.earthsciencematters.com/first-international-conference-on-the-exploitation-and-utilization-of-underground-space-euus2019-in-wuhan-china/

station) of the BCL is 4.63 kilometres long. Engineering and geological conditions of the construction site are classified as Category III (complex): geological processes are widespread and have a determining influence on the choice of design solutions, construction and operation of facilities.

All three mentioned stations are shallow-buried and were built in an excavation for single-track tunnels.

The shallow-buried Aminievskaya station is located within the south-western section of the BCL. Its depth is 15 metres. It is designed as a three-bay structure with two rows of columns and an island platform 163 metres long and 12 metres wide (*Fig. 1*). The axis of the station is orientated parallel to the nearby Aminievskoye Highway. The station is designed to provide pedestrian connections with the railway platform and, via an underground passage, with the opposite side of Aminievskoye Highway.

The length of the section between Aminievskaya station and Michurinsky Prospekt station is about 1,473 metres. The tunnel route passes under the railway tracks, the Ochakovka River and Michurinsky Prospekt station of the Kalininsko-Solntsevskaya line of the Moscow Metro. The depth of the section ranges between 19.5 and 34.3 metres.

Prospekt Vernadskogo station (*Fig. 2*) has a depth of 17.3 metres. The engineering and geological conditions of the project construction site are classified as Category III of complexity (complex). It is designed as a three-bay structure with two rows of columns on a 12-metre-wide island platform. There are four underground levels. In the central part of the platform, there are stairs for transfers.

Michurinsky Prospekt station (*Fig. 3*) has a unique layout due to the complex topography of the site and an elevated transfer link to the newly built Michurinsky Prospekt station of the Kalininsko-Solntsevskaya line. It is one of the deepest among shallow stations (with a depth of 19.4 metres and seven underground levels). It is designed as a three-bay structure with two rows of columns on a 14-metre-wide island platform. The architectural solution is dedicated to the Russian-Chinese friendship.

Lifts were installed at all of the three stations — no station complex in Moscow is now built without them.

In addition to the described station complexes of the Moscow Metro, CRCC Rus LLC successfully completed the excavation of 9 tunnels with a diameter of 6.25 metres on the south-western section of the BCL, including the application of unique measures to ensure safe completion of excavation works in the area of the existing structures.

Works were carried out along the Kaluga Highway in the Greater Moscow area (Kommunarka district) from Ulitsa Novatorov station to Stolbovo station in the section from Ulitsa Novatorov station to Kommunarka

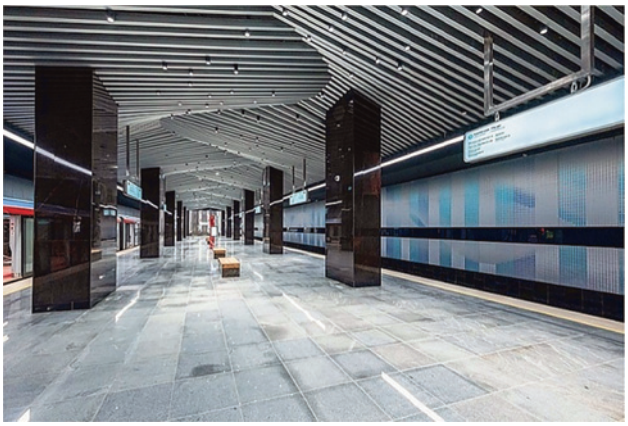

Fig. 1. Interior of the station platform at Aminievskaya station of the BCL (photo by Mosinzhproekt JSC)

Fig. 2. Prospekt Vernadskogo station of the BCL (photo by Mosinzhproekt JSC)

Fig. 3. Michurinsky Prospekt station of the BCL (photo by Mosinzhproekt JSC)

the tunnelling period, geotechnical monitoring [15] and scientific and technical support of construction were carried out [12, 16, 17].

The tunnels between Aminievskaya station and Michurinsky Prospekt station were built with the help of six-metre-long TBMs “Evgenia” and “Daria”. The tunnel from Aminievskaya station to Site No. 6 in front of Davydkovo station was built by a similar TBM, “Maria”. The same-type TBMs, “Galina” (ZTE6250DZ400) and

"Polina", were used for tunnelling between Prospekt Vernadskogo and Ulitsa Novatorov stations.

All the above-mentioned shields ensured tunnelling by a subsidence-free method in difficult subsurface and hydrogeological conditions in a dense urban setting of Moscow, including the use of unique measures to ensure safe completion of tunnelling works.

Since 2017, CRCC Rus LLC has in total completed the following scope of work in Moscow: tunnelling of interstation tunnels with the use of 6.25 metre diameter TBMs: 15 tunnels with a total length of 19,800 metres, the same operations with the use of 10.8 metre diameter TBMs: 2 tunnels (2,700 m); construction of the main structures of station complexes at 5 stations (225,000 m^3). In addition, CRCC Rus LLC carried out design works for the south-western section from Prospekt Vernadskogo station to Kuntsevskaya station of the BCL.

RESULTS

The experience of the joint efforts of Russian and Chinese metro builders in building new lines and constructing underground stations of the Moscow Metro has demonstrated the efficiency and effectiveness of such cooperation. A rational distribution of design and construction works was practiced taking into account the capabilities and experience of the parties, as well as different regulations in force in the cooperating countries (the Russian rules SP 120.13330.2022 "Underground Railway Systems" and the Chinese norms [18]), customary design and technological solutions, and peculiarities of machinery and equipment. This opens up great prospects for further industrial cooperation.

Large social and economic effects in Moscow have also been achieved. For example, the launch of the new stations Aminievskaya, Michurinsky Prospekt and Prospekt Vernadskogo of the Big Circle Line will save local residents up to 40 % of their daily travelling time in the city; the burden on the existing metro stations will be significantly relieved: by 25 % at Prospekt Vernadskogo station of the Sokolnicheskaya line and by 35 % at Michurinsky Prospekt station of the Kalininsko-Solntsevskaya line.

CONCLUSION

The mutual exchange of experience, technologies, and work management practices along with the application of various tunnel boring machines from both Russia and China has yielded fruitful results, demonstrated the possibility and efficiency of the engagement of foreign tunnel builders directly at Russian sites in close cooperation with their Russian counterparts, and revealed a scheme for rational division of labour and work management.

Cooperation between Russian and Chinese metro builders has great prospects.

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