MULTIFUNCTION COMPLEX «THE TSAR'S GARDEN» IN MOSCOW

Combination of well-known and novel ideas in structures and technologies of underground construction is being successfully realized opposite to the Kremlin

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An ultra-modern business centre is under construction in extremely hard conditions in the very heart of Moscow. Jet-slab serving as a man-made confining bed, temporary diaphragm walls from lean concrete with reinforcing steel cages, bored columns of high bearing capacity and pinpoint accuracy of execution, concurrent erection of the underground and aboveground sections of buildings, waterproofing with a safety drainage layer – all these decisions were successfully employed here for the first time in Russia.

BRIEF DESCRIPTION OF THE OBJECT

It's hard to find any vacant place for a new construction in the centre of Moscow. No wonder that a site between the Moskva River and Vodootvodny high-water diversion channel which appeared along a Bolshoy Moskvoretzky Bridge after demolition of obsolete low-store houses having no architectural or historic significance became very attractive in spite of extremely hard conditions for construction.

It is clear that such a site on the island opposite to the Kremlin has an extraordinary value. However, due to restrictions in the height of newly constructed premises in this location, the new object required the development of the underground space.

At this location the Moscow based Company JSC FCC KEYSTONE started on the construction of one of the most ambitious complex projects having no equal in Russia.

«The Tsar's Garden» is an ultra modern business centre – the first in Russia «intelligent building» with a full automatic building management system.

It consists of three buildings independent in their infrastructure and forming a complex of an impressive size about 220 m long and 47 m wide. Aboveground sections of the buildings comprise 9 stores with a total area over 47500 m^2, and underground sections of 4 stores, over 36000 m^2. On the roof of the buildings at the level of the fourth floor will be placed an unheard garden over 1000 m^2 in size, which gave its name – «The Tsar's Garden» to the whole complex.

In the conditions of hard competition, we were lucky not only to win the contract for designing and supervision of the construction of the whole underground section of this complex, but also became ideologists of the construction of the entire complex.

LOCAL SITUATION OF THE AREA

The works are carried out in a space extremely constricted in all four directions where the area of the site exceeds the area occupied by the buildings of about 30%. Major problems are due to the fact that practically half of this difference, i.e. half of the «free» surface, is occupied by permanent underground and temporarily relocated aboveground engineering utilities.

In former times this area was a boggy place that explains the name of the nearest street and the square which preserved their ancient name Bolotnye (Boggy).

The geology of the site is extremely non-uniform. A layer of filled ground covers heterogeneous alluvial deposits represented by plastic and soft plastic sandy-clays, loam and clay, clayey sands of different size including quicksand.

Below lie eroded Perkhurovsky limestone, Neverovsky semisolid marly-clay and Ratmirovsky fissured limestone and dolomites with eroded roof. The geological exploration at the south end of the site has revealed erosive fluvial downcutting (river old bed). Perkhurovsky limestone and Neverovsky clay are completely washed out here and deep water table and water of the upper layer flow together forming a single water-bearing horizon at a depth of 3-4 meters from the surface.

The situation is dramatised by an emergency condition of the decayed top of wooden pile foundations of the majority neighbouring historic buildings.

CONSTRUCTION METHOD

The only viable solution for the construction of this complex in such severe conditions, was to adopt a combined method of building: i.e. to construct underground sections part by «top–down» technique simultaneously with the aboveground sections using the traditional «down–top» scheme (Fig. 1).

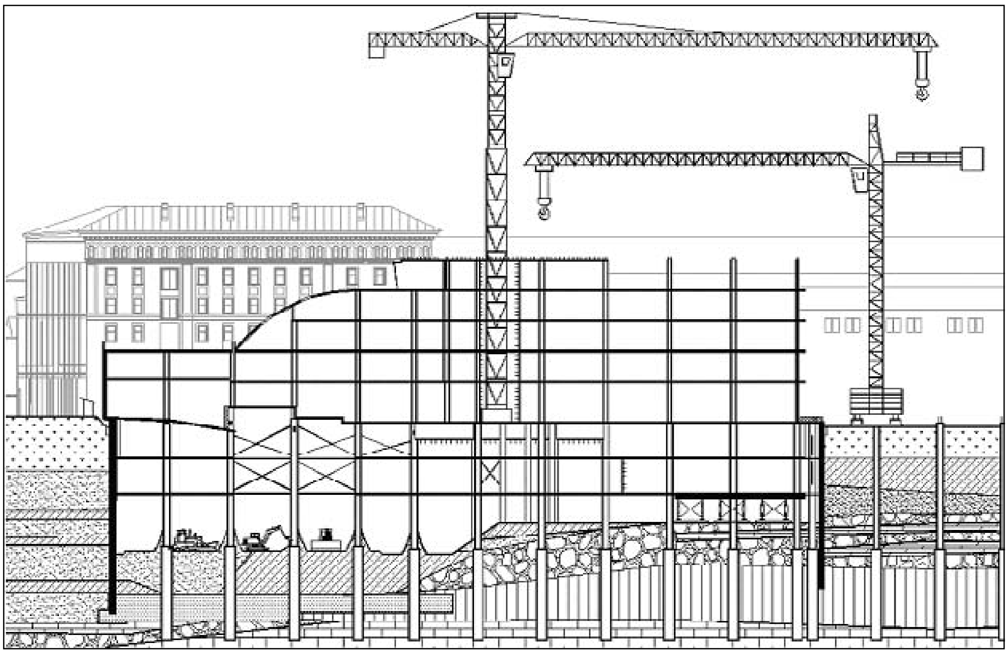

Fig. 1. Simultaneous construction of elevated and underground sections of Building 1

The perimetrical diaphragm walls and the bearing columns bored inside them support the structure during construction. They allow literally to «suspend» the above-surface sections of the buildings, including lift shafts and stair wells, above the deep excavation.

There are no limits to the construction speed of the external part of the buildings compared to the progress of realisation of the underground sections. Quite the contrary, the faster grow the upper floors of the buildings, the smaller is the value of settlement of the surrounding ground mass and of the existing buildings.

The complex is constructed in three stages and in a sequence in order to satisfy the priority of interests of investors and tenants: first, Building 1 on the side of Vodootvodnoy Channel, then Building 3 on the side of the Moskva River and at the final stage Building 2 between both constructed buildings.

For the construction of the underground section of Building 1 prior to excavation works inside diaphragm walls, a horizontal jet-grouted slab has been executed in the erosive fluvial layer as described in the following. The «top–down» technology has been used only for the construction of the bearing structures and of the protective walls of waterproofing lining of the 1st and 2nd underground stores. Each horizontal slab had in this case openings suitable for the further construction of lift shafts, stairs wells and access ramp to parking.

The experience accumulated during construction of Building 1 was employed in the construction of the underground section of Building 3. To speed up mounting of engineering utilities and finishing operations of 1st and 2nd underground stores, where most technologically services are located, also the outer walls of access ramp, stairwells, lift and ventilation shafts will be constructed on these levels in a «top–down» scheme. Thus, also this parts of building will be «suspended» to the bored bearing columns in addition to the corresponding parts of the aboveground section of the building.

The main difference between the construction of Building 2 and Buildings 1 and 3, is that Building 2 will be constructed after completion of Buildings 1 and 3 with a temporary access to the site at the opposite side through arches made in the neighbouring historical building, which will be fully renewed. The floor slab at ground level shall be partly used as site area for entry of concrete mixers, dump trucks, cranes and ground moving machinery.

Due to this combined construction method, the completion time of the eight-store Building 1 and its four-level underground section was merely 12 months. The same period of construction is scheduled for each of the Buildings 3 and 2.

All special geotechnical works for the construction of complex «The Tsar's Garden» were carried out by the Italian company – ELSE S.p.A. (Milan).

CONSOLIDATION OF FOUNDATIONS OF NEIGHBOURING HISTORIC BUILDINGS

Prior to the commencement of principal works for the construction of the Multifunction complex, the foundations of the 230 m-long adjacent historical building were consolidated by «jet-grouting» secant reinforced columns.

Totally 475 jet-columns, 80 cm in diameter were drilled, including short columns to add strength to the arch-shaped foundations. All jet-columns, with an average spacing of 65 cm, are reinforced with steel bars or pipes to reach the required bearing capacity.

CONSTRUCTION OF DIAPHRAGM WALLS

The perimetrical diaphragm walls 19 m-deep (22 m deep in erosive fluvial soil) were erected employing Italian technology of 2.5 m wide standard panels with keyed-joints and of up to 3.49 m wide non-standard closing panels.

With the exception of the zone with erosive fluvial soil, the diaphragm walls were brought down to a depth of 1.5 m into the layer of Neverovsky water-resistant marly-clay.

The cages of 204 panels of bearing diaphragm walls, 80 cm thick, were shaped in order to allow the easy formation of horizontal grooves for the connection of the floor slabs of two upper underground stores and of the foundation slab. Such zones were strengthened by additional reinforcing bars.

Two transversal temporary diaphragm walls 60 cm thick, comprising 33 lean concrete panels, separate the underground space of the three Buildings and can be easily demolished after completion of all buildings. The reinforcing cages, resembling to rigid space frames, are formed by longitudinal bars and cross-sectional external bars supplemented with standardised inner clamps tilted in two planes. They have been designed to increase crack resistance of concrete and to preclude plastic deformation of walls in case of any construction defects due to low workability of lean concrete.

The aggregates used for such concrete had 5-10 mm size. To increase water resistance of the temporary walls a 30 to 50 mm layer of shotcrete provided with reinforcing mesh has been applied to the surface of the walls during the excavation. This solution was successfully used for the first time in Russia.

CONSTRUCTION OF THE BEARING «BORED COLUMNS»

The successful realisation of such large-scale project according to schedule could not be feasible without using «bored columns» tailor-developed by our bureau for this unique object. We use the term «bored columns» to emphasise principal difference of this solution in comparison to the classic bored piles.

225 bored columns 26.5 m long were erected from the surface of the site with pinpoint accuracy of execution as a permanent bearing structure which does not need any subsequent reinforcement or completion beside painting or decorative facing (Fig. 2).

Manufacturing of steel columns with reinforcing cages required a special accuracy. The upper part of each reinforcing cage was encased in the proper steel column consisting of a pipe diam. 720 mm. The lower section (980 mm diameter) was the reinforcement of the pile-shaped foundation of the column with final diameter 1.2 m and was fitted out with a steel chamber at the bottom.

Every reinforcing cage contained one guide-pipe in order to allow the execution of a core boring under the column bottom for a subsequent accurate geological investigation to check the bearing capability of each single column. Two additional pipes were mounted inside the cage for final grouting in the steel chamber at column bottom.

The cage also contained two pipes for additional injection of cement grout into the foot. Imbedded pipes were brought into the bottom chamber.

To join bored columns and floor slabs of underground stores, new structurally unified assemblies were developed which proved simple and reliable at all stages of construction and which are fire-resistant in operation of the underground structures.

The execution of the columns took place in following phases:

1. Rotary boring 1.2 m diameter under bentonite slurry as deep as to the design level with bucket, chisel and rock drilling devices. Due to the definitive nature of the permanent steel columns and to the special features of the rigid connections of same with the reinforcing steel of the horizontal underground floors, the tolerance for deviation of columns axes from vertical line could not exceed 1:500 and for the level

Fig. 2. Building 1. Construction of foundation slab in the zone of lift shafts.

of columns heads ±100 mm.

2. Sinking of whole cage (steel column and entire cage in one single piece) into the borehole, resting on the bottom of the borehole.

3. Installation around the column, of the centring device equipped with a system of vertical and horizontal hydraulic jacks, resting on the guide pit.

4. Lifting of the column with vertical hydraulic jacks to a distance of 150-200 mm from the bottom of a borehole.

5. Centring the cage in plan using the horizontal hydraulic jacks and checking with an inclinometer the vertical position of the cage.

6. Sinking the cage to the bottom of the borehole with the vertical synchronously operating jacks.

7. Tremie concrete was poured inside the steel column by parallel filling of the annulus between steel column and borehole walls with crushed stone. Concrete Class B 30 having 16-20 cm slump was made up by gravel aggregates size 5 to 10 mm with addition of retardant.

The construction of the first ten bored columns proved the correctness of the designed method to obtain the required bearing capacity at the bottom of columns, under the existing geological conditions.

The individual core borings executed under the bottom of each column, performed through the pipes left in the cages for this purpose, showed that the actual geological composition of Ratmirovsky stratum very often significantly differed from the data obtained by the initial general geological exploration. The roof of decayed limestone and dolomites showed cave-ins (up to 4 m in depth) between large semi-rock boulders filled with marly-clay and mylonite.

After the first core borings at column bottoms, was taken the decision to enlarge the foot of each column with a jet-grouting treatment. The operation was done by flushing out the sediments of bentonite mud and the soft ground and the fine soil between boulders with 40 MPa jet of water followed by jet-grouting at a pressure not exceeding 20 MPa. Such pressure lower than normal for jet-grouting treatment, was employed to preclude mixing of clayey ground with cement grout, what would inevitably lead to a loss of grout strength and increasing the hardening time. After completion of jet-grouting operations, an additional injection at 1 to 1.5 MPa to the freshly cemented bottom was executed using supplementary injection pipes.

EXECUTION OF THE HORIZONTAL JET-GROUTING CURTAIN

Under the southern part of the Building 1, the ground consists of an erosive fluvial zone where there is no layer of Neverovsky water resistant marly-clay and the artesian water of the underlying horizon flows together with the overlying non-artesian water horizon. To significantly reduce water inflow into excavation during construction of this Building, it was necessary to execute a horizontal curtain of jet-grouting 3 m thick. Such «jet-slab» was formed by 1198 secant jet-columns at a depth of 20 m, on a surface of over 1500 m^2. This solution was the first in Russia and one of the most deep in Europe.

This jet-grouting curtain allowed to complete the «zero-cycle» of Building 1 only with a perimetrical drainage ditch. The water inflow from all jet-slab area did not exceed 40 m^3/h including water leaking through the joints of the diaphragm walls panels.

EXCAVATION WORKS AND WATER DRAINAGE

The excavation works inside diaphragm walls is made by back-hoe hydraulic excavators before concreting of the slab at zero level and by small bulldozers and loaders for the lower levels to the max. depth of 15 m. The height of each excavation layer is 3 to 4 m. Soil along diaphragm walls and bored columns is excavated with small-size Bobcat excavators. The boulders of Perkhurovsky limestone are crushed with hydraulic hammers mounted on miniexcavators.

A perimetrical drainage ditch is dug at each excavation level to collect residual water in sumps with exhausting pumps operating at intervals when required (Fig. 3).

Fig. 3. Building 3. Excavation of the first layer viewed from the roof of Building 1.

Starting from the second underground floor, the excavation and the construction of the underground structures are done in two stages: first in one half of the surface leaving a berm in the second half. Such sequence has been chosen in order to minimise the deformations of the surrounding ground mass and reduce negative effects on the neighbouring buildings and on the nearby bridge.

During construction of Building 2 excavation accept in the same manner but in one stage from second to fourth layer.

EXECUTION OF THE REINFORCED CONCRETE UNDERGROUND STRUCTURES

Great attention has been paid to the construction of the underground reinforced concrete structures in order to avoid settlements during concreting. Upon it a crushed stone draining and bearing layer 15 cm-thick has been laid to support the formwork for the overhanging reinforced concrete slab, resting on wooden joists.

The horizontal slabs of the underground space of the first building have been executed with this «top–down» method.

Such technology of concreting of floor slabs was employed for the first time in Russia with excellent results.

The lean concrete laid on the bottom of the excavation, supports the waterproofing membrane package and the reinforced concrete foundation slab.

After achievement of every excavation level, the exposed surface of diaphragm walls is prepared for receiving the waterproofing membrane package. The reinforced concrete protecting wall is concreted after completion of each underground floor slab.

WATERPROOFING OF THE UNDERGROUND SPACE

The design of the waterproofing system with safety drainage layer has been developed with the aim to ensure high reliability in a continuous «aquarium» scheme.

In case of local undetected failures of waterproofing layer, the safety internal drainage layer allows to collect and to discharge water (filtered through the external geotextile filter) into the drainage sumps of the indoor fire-fighting system of the underground parking, which are fitted out with pumps.

The structure of waterproofing system consists of following layers:

- geotextile with density of 800 g/m^2, as external filter-bed;
- geomembrane 2 mm thick from very flexible and light-stabilised polyethylene (VFPE), the strips of which are butt-welded with contact hot-air- or extrusion-method. All weldings are 100% tested for continuity;
- «Tensar» geonet 6.3 mm thick from polyethylene, forming a safety internal drainage layer;
- geotextile with density of 550 g/m^2, as protective layer and internal filter-bed ;
- polyethylene film 0.16 mm thick that prevents penetration of safety drainage layer and internal filter-bed by cement milk during execution of cast-in-place reinforced concrete protective walls, designed to bear full-scale hydrostatic pressure.

Experience of construction of Building 1 is a full scale test of high efficiency and reliability of this waterproofing system which has no analogues in Russia.