DEVELOPMENT TOP-DOWN METHOD OF UNDERGROUND CONSTRUCTION OR HI-TECH IN RUSSIAN

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PREHISTORY

Excavation for lift shafts and staircases at the A.S. Pushkin Museum's fund storage construction project carried out under the protection of only one ground level slab necessitated large openings filled with temporary steel support facilities, hence till bearing structures to be built at the ground/underground construction stage «zero» cycle was completed, it proved possible to erect aboveground structures for only two stores (Fig. 1). While developing design for this building's zero cycle, nobody thought of using bored columns to «suspend» the lift shafts and the staircases of the building's aboveground part, saying nothing of the fact that the simplified bored column erection techniques (which were adapted to the contractor's capabilities) left much to be desired. Without a reliable system of centering the reinforcement cages in their boring-holes, the erection techniques could not warrant that bored columns would not appear into the space of the lift shafts or the staircases.

Fig.1. Erecting lift shafts and staircases for the A.S. Pushkin Museum fund storage building in Moscow.

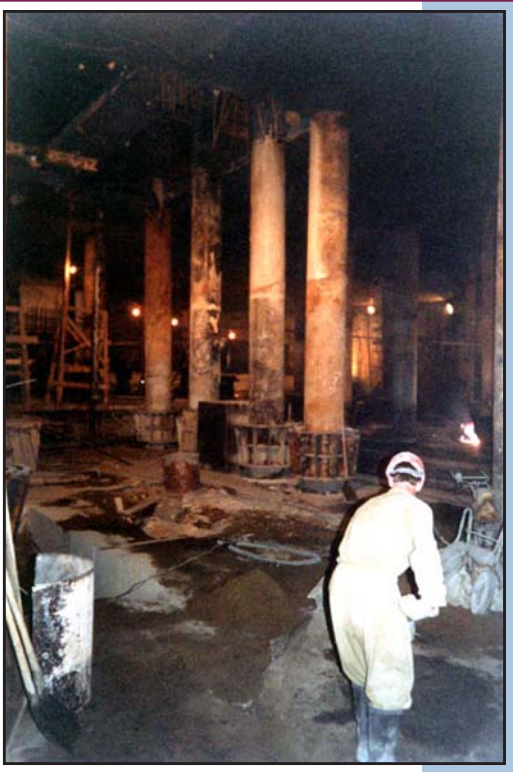

Fig. 2. «The Tsar's Garden» multifunctional complex in Moscow. «Suspended» on bored columns are lift and ventilation shafts of the Building 1 eight-storey aboveground part rigidity core.

While erecting Building 1 of «The Tsar's Garden» multifunctional complex, the building's aboveground part lift shafts and staircases making the building structure's rigidity core were for the first time «suspended» using bored columns making it possible to erect 8 aboveground stores before the foundation slab was completed. (Fig. 2).

Basically new bored column erection technology used a special centering system which secured that deviations of the bored column axes from the vertical were inferior to 1 in 500 making a new step in updating the whole top-down construction method possible. However, in the course of construction of Building 1, temporary openings still gaped in the underground floor-slabs at the sites of lift shafts and staircases as well as at those of access ramps, the openings being eliminated only at the final construction stage after completion of the foundation slab. Particularly challenging was large opening in the floor-slabs of underground stores at the place of the ramp, installation of a temporary steel support structure having proved to be required (Fig. 3).

Experience gained with «The Tsar's Garden» Building 1 construction project has demonstrated that rigidity of the underground store floor-slabs weakened with the openings is sufficient to provide for the top-down techniques to be safely used, still insufficient to minimize deformation of underground bearing structures and to eliminate their cracking. In spite of the fact that widths of the cracks did not surpass the allowable design values, this conclusion had to be driven from the nature and direction of the cracks and from the data of monitoring after deformations.

Fig. 3. «The Tsar's Garden» multifunctional complex in Moscow. Temporary steel support structure to fill openings in floor-slabs of the Building 1 underground part at the access ramp place.

Owing to «suspension» of the lift shafts and staircases in the aboveground part of the building, installing the internal partition and face walls, finishing the premises and fixing engineering systems were carried out simultaneously with erection of the bearing structures (Fig. 4).

Fig. 4. «The Tsar's Garden» multifunctional complex in Moscow. Erecting Building 1 face walls.

However, since bearing structures of the underground part of the building were not completed (lift shaft walls, staircases, ramp and foundation slab were not installed) and since the temporary steel support system could not be dismantled, it did not prove possible to start either finishing work or installation of engineering systems in the underground space.

While designing «The Tsar's Garden» Building 3, experience gained while erecting the Building 1 construction project was taken into account: it was stipulated that lift shafts and staircases would be erected under the «upwards» (in the aboveground part) and the «down-

wards» schemes (in the underground part) simultaneously (Fig. 5). At the place of the entry ramp, large temporary openings filled with steel support structures were still available. Given the adverse geological and hydro-geological site conditions of this construction project, we did not dare to erect the ramp under the «downwards» scheme and to completely dismantle the temporary steel support structures. Still, owing to the fact that at the construction stage, lift shaft and staircase walls were erected under the «downwards» scheme in the underground part of the building, higher three-dimensional rigidity of the system of underground stores was provided for resulting in essentially lower general deformations as well as decreased number and widths of cracks.

Fig. 5. «The Tsar's Garden» multifunctional complex in Moscow. «Suspended» on bore columns are lift and ventilation shafts of the Buil-ding 3 eight-storey aboveground part rigidity core.

September 2003, five-level underground parking-garage project of «The Alfa-Arbat-Center» multifunctional complex was successfully completed, design of the project having become most important stage of updating the top-down construction method on the basis of our own previous experience.

It is for the first time in Russia that on the basis of our «know-how» related to erection of multilevel underground parking-garage by top-down method, both lift shafts/staircas-es and access ramps with their serpentine parts were erected down-wards simultaneously with the floor-slabs. This innovation made it possible to use the ramp structure at all project construction stages both as permanent support system and for delivery of materials and small articles thereupon as well as to start finishing work and installation of engineering systems at the erected upper stores simultaneously with the soil excavation and with erection of the lower stores.

Although some solutions taken for the underground parking-garage project of «The Alfa-Arbat-Center» multifunctional complex may hardly be considered irreproachable since partially they were forced decisions, still the experience gained proved to be veritably priceless for the design of subsequent not less complex projects erected by top-down method.

EXPERIENCE GAINED WITH THE UNDERGROUND PARKING-GARAGE PROJECT OF «THE ALFA-ARBAT-CENTER» MULTIFUNCTIONAL COMPLEX

After completion of «The Tsar's Garden» Buildings 1 and 3 construction projects, it has become obvious for us that erection of ramps, lift shafts, staircases and pylons aunder the «downwards» scheme is both possible and highly profitable.

First of all, three-dimensional rigidity of the structures under protection of which soil excavation is carried out improves, their cracking is practically excluded, deformation of the erected structures is decreased as well as that of ambient soil masses and nearest buildings. Besides, there is no need to increase the thickness of floor-slabs, a solution common in case of the «top-down» method used in foreign countries.

Second, there is no any necessity more to use the laborious and much more yieldable temporary steel support structures for filling openings in floor-slabs at the place of ramps, staircases and

groups of lift shafts.

Third, it proves possible to erect absolutely all bearing structures of underground and above-ground stores simultaneously, hence, to build partition walls, to finish the premises and to install engineering systems and equipment under the «downward» or the «upward» scheme storey-by-storey simultaneously with the soil excavation on the bottom level, all these advantages resulting in essential cut in the total project construction time.

Forth, construction and finishing materials may be delivered to any floor over the ramps erected under the «downward» scheme using electric cars or small-size loaders.

Crucial for the design were the following factors:

- steel bearing framework of the main building of the «The Alfa-Arbat-Center» multifunctional complex was built in the first turn and barred the approach to the construction site lot from the North (Fig. 6);

- lease of the adjacent areas was stopped, since their owners who had noticed some project organizational mistakes used the associated problems to get additional profits and asked for an unreasonably high rental; this situation had made the site lot unapproachable from the South by the time we commenced the design;

- very close to the site, there were some protected buildings including the Ukrainian Cultural Center in Russia barring approach to the construction site lot from the West;

- thus, approach to the construction site was possible only from the East or from the Gogol Boulevard; edge of the pit as deep as 18.5 m was set practically right after the site fencing;

- trench walls for the four-level parking-garage were to be built according to previous design developed on the basis of the cut-and-cover techniques; besides, owing to discrepancy of the proposed and the actually revealed elevations of the top of the Perkhur disintegrated limestone not workable with the clamshell, depth of the trench was decreased;

- a 2-storey auxiliary block extension of the main building was to be anticipatory erected above the western part of the parking-garage; a superstructure could be built after some time above the eastern part of a multi-storey (up to 13 stores) office building at the third construction stage.

Fig. 6. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Erecting main building steel bearing framework after completion of underground parking-garage diaphragm walls.

Given the practically «dead end» situation, a combined top-down method had to be applied; resulting from this application, the tough nod of problems was quickly chopped up and the five-level underground parking-garage was built.

The adopted construction method was based on the anticipatory erection of:

- the eastern half of the roof slab (from the construction site entry gate) in the formworkless techniques, prior to the soil excavation in the pit under the -1st storey;

- complete floor-slabs above the -2nd and the -5th stores in the formworkless techniques, prior to the soil excavation in the pits under the -2nd and the -5th stores;

- both the ramps from the -1st to the -4th storey, prior to the soil excavation under them too including ramp pads in the formworkless techniques;

- western halves of the floor-slabs over the -3rd and the -4th stores with repeating formwork

based on soil grounds prepared beforehand, prior to the soil excavation in the pits under the -3rd and the -4th stores and under protection of the western ramp structures.

Slab above the -3rd storey was erected using repeating formwork based on soil grounds prepared beforehand after soil excavation of the pit under the -3rd floor.

Western part of the slab above the -2nd storey was erected following open soil excavation under the 1st storey anticipatory to and simultaneously with arranging the roof slab at this section, the formwork for the roof slab being based on the sections of the slab, which were cast without formwork right on the soil.

The roof slab and the underground floor-slabs were divided into two halves along the deformation joint, which has been temporarily liquidated for the time of construction.

As noted above, in order to decline the use of the temporary steel support outward thrust structures, it is for the first time in Russia that both the ramps from the -1st to the -4th storey of the five-level underground parking-garage of «The Alfa-Arbat-Center» multifunctional complex were erected anticipatory with respect of the storey-by-storey soil excavation in the pits under them (Fig. 7).

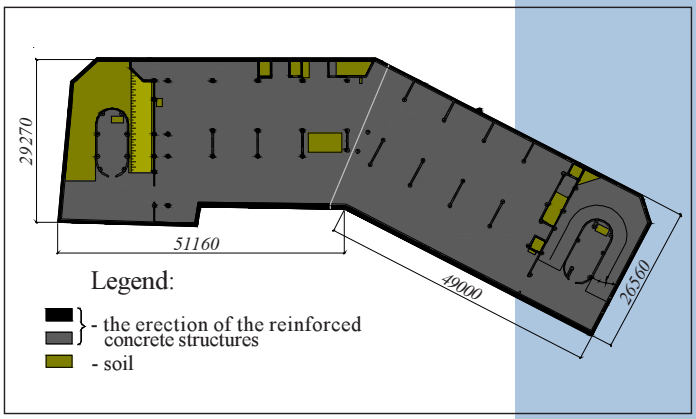

Fig. 7. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Location scheme of the underground parking-garage -2nd storey bearing structures and the ramp -3rd storey (serpentine part at the western half of the parking-garage is not conventionally shown) while excavating the 4rd storey pit under their protection.

In order to implement this idea for the ramps as well as for two lift shafts and one staircase, additional bored columns had to be provided under the ramp core central walls and under fire-protection walls separating the ramps from the parking area (Fig. 8). The additional columns made it possible to literally suspend ramp structures erected storey-by-storey under the «downwards» scheme over the pits excavated under them in the course of construction. The design of the «suspension» had to be developed for the fire-protection walls which served as supports for the serpentine ramp parts to be «suspended» on bored columns and three-dimensional calculations had to be made with due account of the strain-stress condition in the cast-in reinforced concrete structures of the ramps different at each construction stage (Fig. 9).

Fig. 8. «The Alfa-Arbat-Center» multifunctional complex in Moscow. View of the parking-garage western half -1st storey ramp after erection of the central core walls and external ramp fire-fighting walls before laying the roof-slab.

We took into consideration the experience gained from previous similar construction projects regarding situations when multiple through cracks formed in the walls «suspended» on the bored columns resulting from tensile stresses arising in the concrete of the walls and from the fact that contractors did not follow the requirement that before being loaded the concrete had to gain its 100 percent strength value.

Using specially designed structures and «suspended» wall reinforcing techniques, we could

both lift the requirement for the concrete to gain its 100-percent strength value thus expediting construction rates and completely excluded cracks to be formed in the walls.

To be objective, it should be noted that in spite of the struc-tural measures, singular hair-line cracks still formed in the lower fibres of the ramp serpentine parts under protection of which excavation was carried out, the cracks being directed to cores of the ramps. Since direction of the cracks coincided with that of the ramp part main work and since width of the cracks was insignificant, their appearance did not affect strength characteristics of the structure.

On the whole, this first experience of using ramp structures as permanent supports while excavating pits was more than successful making it possible both to improve construction safety standards and to considerably decrease construction time as well as to minimize settlement of foundations of protected buildings adjacent to the site (Fig. 10).

Data of monitoring after deformations carried out after com-pletion of the last 5th pit tier demonstrated that the increment of settlements of the above mentioned building foundations were inferior to 2-7 mm during the whole period of earthwork executed by the top-down method.

In no way can construction of the underground parking lot be called continuous, since in the course of con-

Fig. 9. «The Alfa-Arbat-Center» multifunctional complex in Moscow. View of the parking-garage western half -3rd storey ramp central core structures «suspended» on bore columns before erecting the -4th storey ramp.

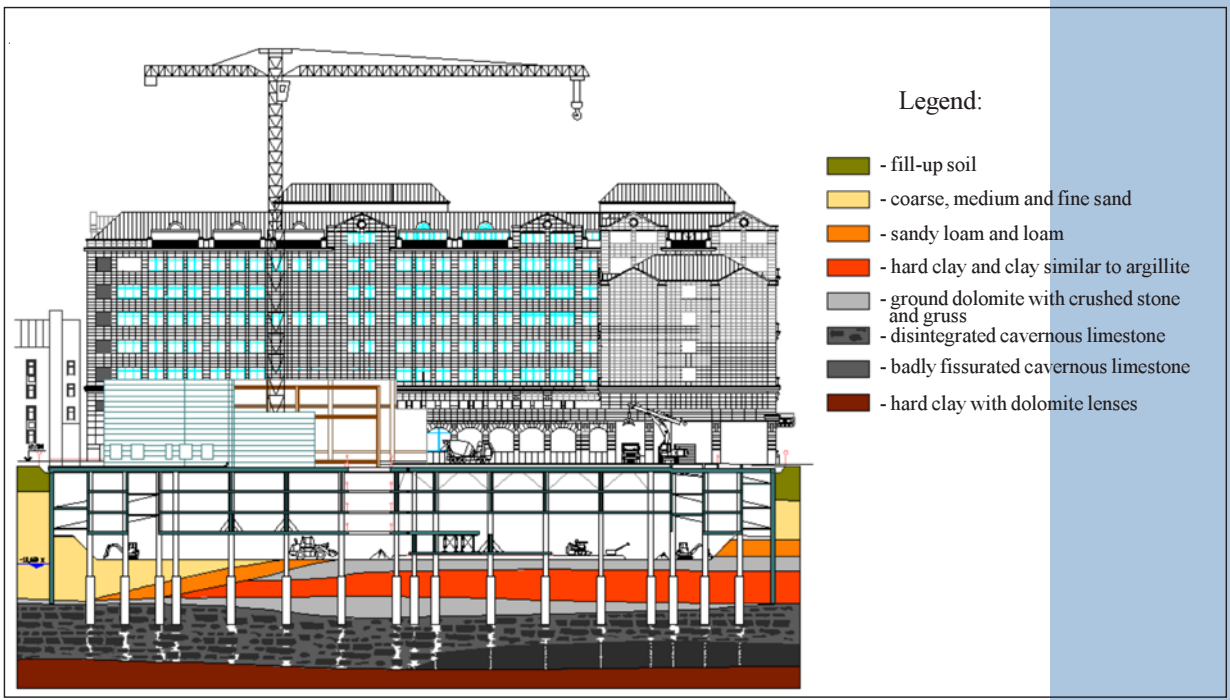

Fig. 10. «The Alfa-Arbat-Center» multifunctio-nal complex in Moscow. Erecting floor-slabs over the parking-garage wes-tern half -4th and -5th stores as well as the western half -3rd storey internal bearing structures. Excavation in the pit 4th tier under protection of the -3rd storey ramp structures at both parts of the parking-garage. Proceeding with erection of the extension.

struction of «The Alfa-Arbat-Center» multifunctional complex, the client and the general contractor changed their priorities several times.

In spite of such hampering conditions, it proved possible to carry out the whole package of work needed to build the five-level underground parking-garage, that is earthwork, erection of cast-in reinforced concrete structures and waterproofing, for 12 months only including one month lost to grout the karst-prone Perhur limestone in the base of the diaphragm walls. Average rate of excavation performed under protection of the underground floor-slabs made 500 m^3 per day reaching 800 m^3 per day in case of the 3rd and the 4th tiers (Figs. 11, 12, 13, 14, 15).

Fig. 11. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Hitachi EX300-5 clumshell excavator working through temporary erection opening and bringing muck to the surface to be loaded into dump trucks while excavating 2nd tier of the pit.

Fig. 12. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Hitachi W130 motor loader transporting muck to temporary erection opening while excavating the 2nd tier of the pit. Muck is brought to the surface using Hitachi EX300-5 clumshell excavator and loaded into dump trucks.

It is for the first time in Russia that one could witness finishing work and installation of engineering systems at the stores from the -1st to the -4th being carried out, construction materials, equipment and articles being delivered using the ramps and a new aboveground

Fig. 13. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Excavation in the 3rd tier of the pit under the parking-garage western half -2nd storey ramp.

Fig. 14. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Hitachi W130 motor loader transporting muck to temporary erection opening while excavating the 3rd tier of the pit under the parking-garage western half -2nd storey rump.

Fig. 15. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Excavation in the 4th tier of the pit in the parking-garage eastern half ramp area.

Fig. 16. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Facing materials transported over the ramp to the -3rd storey with small-size loaders while excavating the 5th tier of the pit.

Fig. 17. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Installing ventilation and fire-fighting permanent systems at the -2nd storey while excavating the 5th tier of the pit.

Fig. 18. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Completing construction of the extension to the main building. Erecting structures of the third stage construction package over the underground parking-garage eastern half while excavating the 5th tier of the pit.

building block being built simultaneously with excavation in the 5th tier (Figs. 16, 17, 18, 19). Why not «Hi-Tech in russian»?

No wonder, that in the course of construction, there were so many technical excursions to the project with participation of representatives and employees of both Russian and foreign construction companies.

Fig. 19. «The Alfa-Arbat-Center» multifunctional complex in Moscow. Completing excavation of the 5th tier of the pit near the erection opening.

FURTHER UPDATING TOP-DOWN CONSTRUCTION METHOD

It is well known that professionalism in the design of construction projects is first of all manifested itself in the individual approach to each new project. Since any project built by the top-down method is usually unique, it becomes inevita-

ble for us to adapt the previously used technical solutions and principles to each new project and to update them, the updating proceeding in two main interrelated directions related to solutions crucial for construction technologies and construc-tion structures.

Were the experience gained with such a difficult project as «The Tsar's Garden» multifunctional complex at Sofiyskaya Embankment in Moscow not available, a couple of years ago it would have been impossible even to imagine that temporary steel support structures can be completely abandoned and that ramp structures of the underground five-storey parking-garage of «The Alfa-Arbat-Center» multifunctional complex could be erected under the «downwards» scheme. Moreover, erection of ramps under the «downwards» scheme opens the way to such a highly effective construction management when simultaneously with excavation, engineering systems and equipment can be installed, underground premises can be finished and soil excavated in the course of excavation can be removed to the surface using the erected ramps to be loaded into dump-trucks.

There's much more to come. Clients and investors have repeatedly shown their interest to reduce the amount of their investment by finding ways for buildings to be put into operation with unfinished underground stores, the stores being finished on account of profit gained from operation of the building. Indeed, it may be reasonable under certain circumstances to put a building into operation with finished aboveground structures and limited number of finished underground stores minimally needed for the first period of operation, so that the whole project could be completed without barring operation of these stores. This is particularly vital for underground parking-garages, storage premices and garages. This is no secret that in densely built-up urban areas, the cost of underground construction projects essentially exceeds that of those aboveground; however, owing to rise of the cost of land and to the overall urbanization, underground construction gets more and more demanded.

The top-down method in civil construction have made such an obvious progress that the second-turn construction of underground stores does not seem to be fantastic so far. On demand of the client, we are at present ready to give our proposals for any future project.

Under market economy, a demand is always answered with a proposal. Given the fact that the baret system of erecting support structures so traditional for western countries has from the very beginning been orientated exclusively to the classic top-down construction method, there is no wonder that the demand for our technology which allows to simultaneously proceed with the construction both upwards and downwards from the ground level raised so much.

It is well known that the baret system uses temporary-steel beam columns whose carrying capacity is limited because of their flexibility and which are to be cast in concrete after completion of the foundation slab before erection of aboveground stores. Since the steel beam columns are not necessarily erected strictly vertical and since their carrying capacity is limited, contractors hardly dare to erect 2 or 3 aboveground stores before the underground part of the project is completed.

Owing to an essential cut in the overall project construction time, the use of bored columns characteristic with high rigidity and carrying capacity gained very soon after the erection brings the top-down method of underground construction to a new quality level. It is at least unethical to compare the cut-and-cover and the top-down method on the basis of the cost of the project underground part only and on the basis of the classic «top-down» scheme.

Under particularly adverse site geological conditions and in densely built-up urban areas, the most safe and at the same time combined top-down method does not practically have any competition, since in case of the cut-and-cover techniques, direct construction cost of the underground part of the new building should be added with costs associated with the consolidation of foundations and structures of neighboring protected buildings.

Given the combined top-down construction method implementation urgency and experience gained last years, we have considerably updated the bored columns erection technology, simplified

the structure of their reinforcement cage and that of their interfloor and foundation slab junction nods, improved construction reliability, «foolproofness» and safety.

These innovations would have been impossible without reaching a new design quality level (Figs. 20a , 20b), providing for the designer's supervision after implementation of the proposed solutions and taking into account minor drawbacks revealed in the course of construction. Considerable aid results from examination of data obtained in the course of monitoring after deformation of bearing structures of underground works built by the top-down method according to our designs.

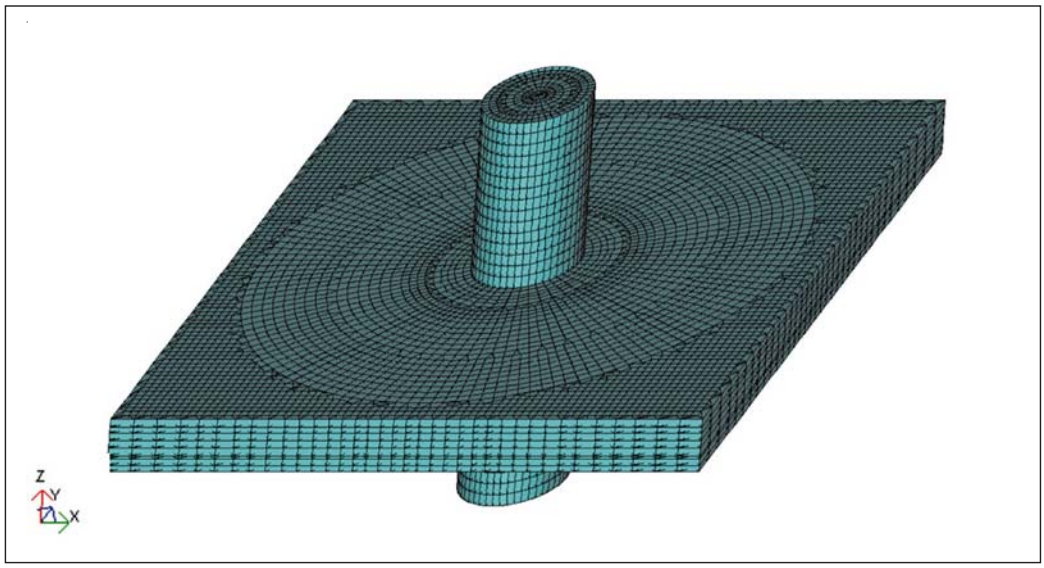

Fig. 20a. «The Alfa-Arbat-Center» multifunctional complex in Moscow:
Fragment of the bore column to floor-slab junction nod three-dimensional model.

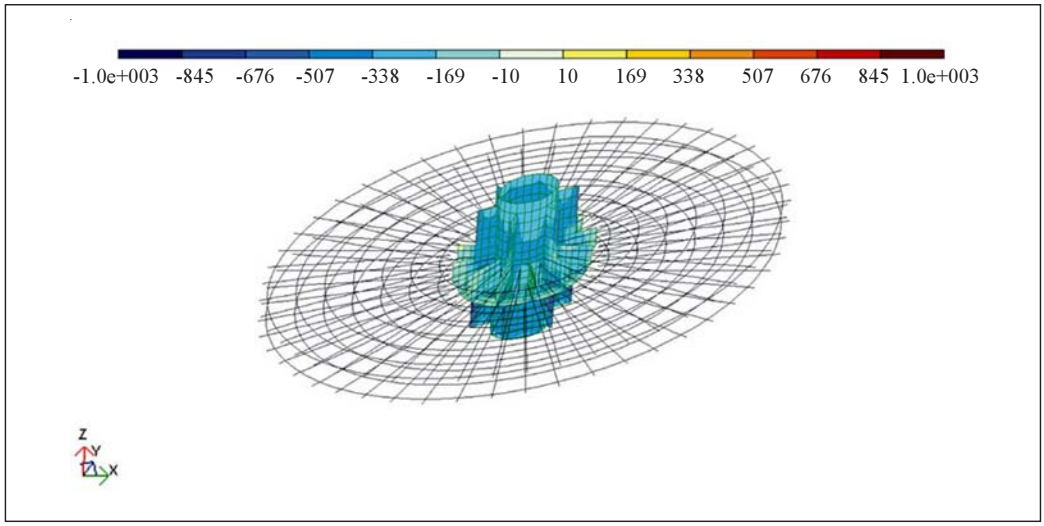

Fig. 20b. N3 (kg/cm^2) main stress isometric field in steel structures of the bore column to floor-slab junction nod.

Innovations and achievements in the field of the top-down construction method management are currently used by us to design the zero cycle of the Hilton 5* hotel building construction project recently commenced in Moscow on the order of INGEOKOM CJSC in Tverskaya Street at site of the former Intourist hotel removed in accordance with decision of the Government of Moscow. 11 aboveground and 5 underground stores will be erected without filling the existing pit depth up to 8 m remained after the removal. (Fig. 21). Area of each of the five underground stores will make about 5000 m^2. Taking into account that the load upon bored columns located close to edge of the

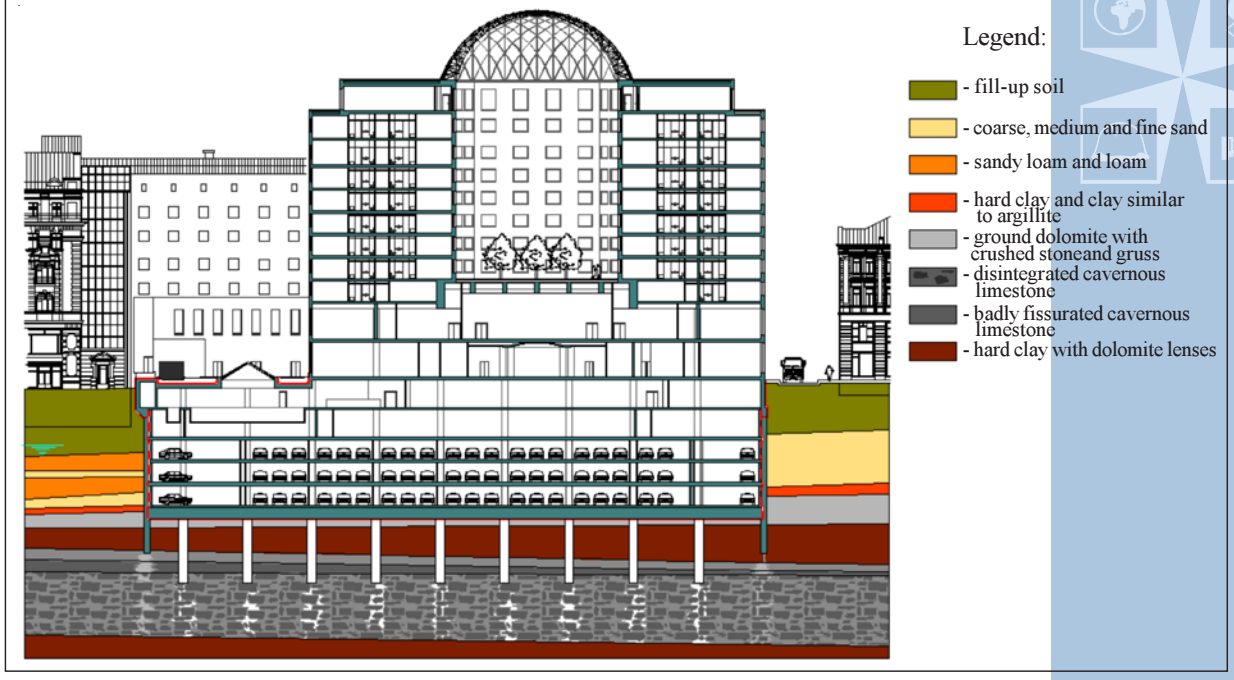

Fig. 21. Hilton five-star international hotel building, address Bid. 1, 3-5 Tverskaya Street, Moscow. The project is under implementation.

atrium will reach 3000 t in the ground level slab (elevation 0.00 m), special bored column structure and reinforcement technology were developed for this project making it possible to use steel pipe-formwork as a rigid reinforcement formwork casings at the operation stage.

On the order of Codest International SRL Italian company acting on behalf of Hines American company, we started designing the zero cycle of an office building, address Bid. 6, Gashek Street (Dukat-3). The building of 14-aboveground and 3 underground stores and 20640 m^2 total area will be erected after our technology and on the basis of our «know-how» (Fig. 22).

Current year, on the order of Tuks-6 Ltd., it is proposed to commence construction of the Neglinnaya-Plaza multifunctional complex to be built within an area between Neglinnaya Street, Rozhdestvenka Street, N. Kiselny Lane and Trubnaya Square. Project construction conditions related to underground part of the complex, area of the lowest storey making 10000 m^2, is referred to as dangerous in terms of possible development of landslide phenomena and danger to safety of nearest buildings and structures. It is with this end in view that we proposed that the zero cycle to be built by the top-down method; the proposal was approved by the state expert commission and taken by the client and the investo-

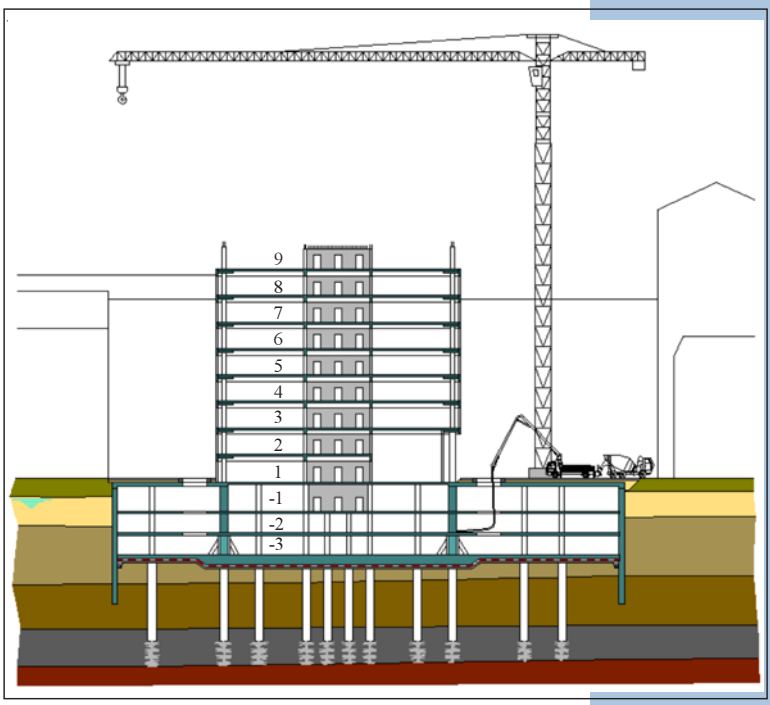

Fig. 22. Erecting the «Dukat-3» office building, address 6 Gashek Street, Moscow. Design proposal.

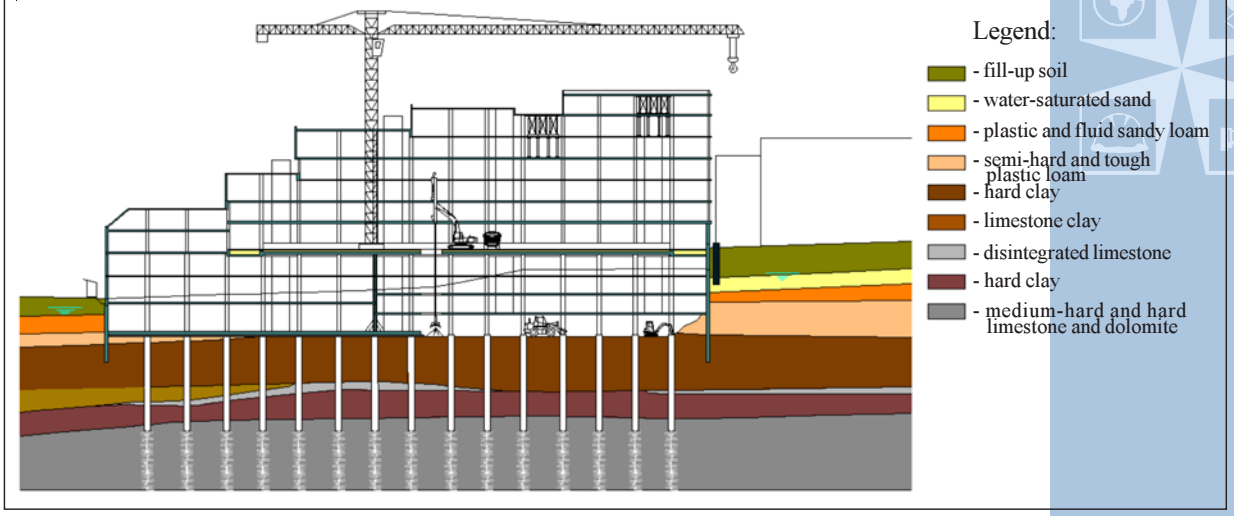

Fig. 23. Neglinnaya-Plaza multifunctional complex in Moscow (integrated reconstruction including new components and restoration of the following houses: Bldgs. 1 to 5, 20/2 Neglinnaya Street; Bldgs. 1 and 2, 31/6 Pozhdestvenka Street, Bldgs. 1, 2 and 5, 4 Trubnaya Square). Basic construction technology solutions.

for implementation (Fig. 23).

Proposal is prepared for KPT group of companies on basic techniques to be used to build a hotel and recreation complex in the eastern part of Block 359 in Moscow.(Fig. 24). Area of each of the underground stores exceed 16500 m^2. The proposed top-down method adapted to the zero cycle designe are characteristic with some particular features provided to withstand difficult geological and hydro-geological site conditions.

Yet while building «The Tsar's Garden» multifunctional complex, it was proved by monitoring after deformation of the zero cycle structures that for the bearing structures there is no any settlement problem, but there is a problem of bulging. For «The Tsar's Garden» Building 1 and Building 3 projects, in case bore columns are embedded in the soil to the depth of about 10 m below the foundation slab, eight aboveground stores proved to be sufficient load to reduce bulging at the

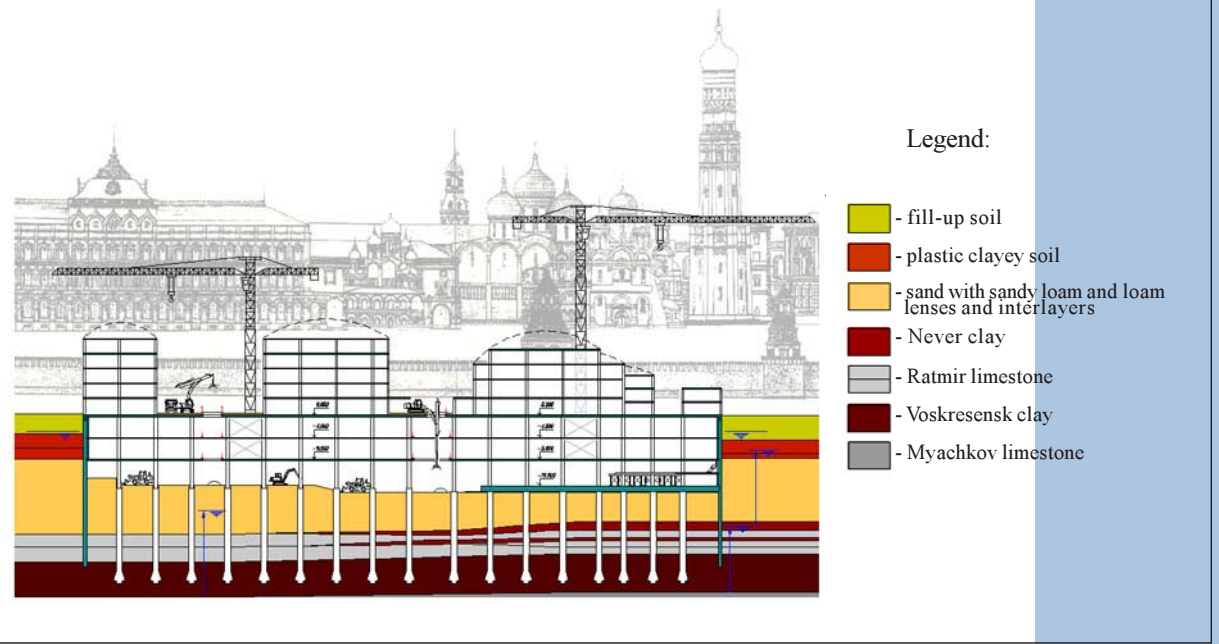

Fig. 24. Hotel and recreation complex in the eastern part of Block 359 in Moscow. Design proposal.

final excavation stage to 10-12 mm.

Given the fact that depth of the pit exceeded 17 m and there were only 6 aboveground stores, bore columns in this complex were to be furnished with anchors to resist both bulging at the construction stage and floating at the operation stage, soil mass below the pit bottom being drawn to counterweigh the bulging (floating) forces. Specially for such cases, we designed modified foot-widened bored columns capable of resisting compressive stresses up to 1100 t without any reinforcement in its upper part at the level of the foundation slab and tension stresses up to 1200 t in its lower part under the foundation slab.

The above described solutions related to construction techniques based on a new bore column structure and erection method protected with patents in the Russian Federation and abroad form intellectual property of Yurkevich Engineering Bureau Ltd. and can not be used without consent on the part of the authors.

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