UNDERGROUND PARKING-GARAGE IN THE REVOLUTION SQUARE IN MOSCOW

FROM TECHNICAL PROPOSAL TO REALIZATION OF THE PROJECT

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Following the provisions of the Decree of the Moscow Government a four-level underground parking-garage was constructed in the Revolution Square. It was financed from the credit granted by the European Bank for Reconstruction and Development.

Participation of our company in designing of this project was due to shear coincidence. From spring 1996 another designing team was drawing up a design which implemented a distinctly different solution of structure and construction technology and this work was in full swing at that moment.

In September 1996 the building contractor – PJSC «Corporation Engeocom» invited our company to look through the design and give our considerations on it. As a result an alternative technical proposal has evolved which in the process of developing design documentation replaced initially developed design. Our proposal was supported by the customer and the general construction contractor. It took us only 10 days to develop a part of the new design and get approval of the state and independent expertise bodies.

Development of working documentation commenced at the end of November 1996 and continued concurrently with the construction of the project till April 1997. Design of principal parking structures including vault-shape lining, and elaboration of the design for organization of construction work were completed in January 1997.

To be fair, the beginning of major construction works in the conditions of severe incessant winter frosts, which caused multiple standstills of construction equipment, can hardly be considered encouraging. The adverse weather conditions added skepticism to most of the specialists as to the time framework set by the city authorities (principal construction and mounting works were to be completed by September 1, 1997 – on the eve of the 850th anniversary of Moscow).

It has been a new lining of the underground parking and the technology of its construction which allowed to cope with the set task.

Fig. 1.

CITY DESIGNING AND CONSTRUCTION SITUATION

The underground parking-garage in the Revolution Square is located near the Kremlin between the buildings of the «Moskva» hotel and that of the former Lenin Museum in the proximity of the Neglinka River collector (Fig. 1). Metro tunnels are running under the major part of the underground parking (left tunnel of the Pokrovskaya connecting branch runs at a depth of 5 m and right tunnel of the Arbatsko-Pokrovskaya line – at a depth of 10 m respectively below the foundation of the parking).

The arrangement and architectural planning of the underground parking-garage for 184 car spaces was developed by the General Designing Institute «Mosproekt-2». The structure incorporates a four-level parking-garage proper, an access ramp and a series of service premises and is connected by a pedestrian tunnel to the lower level of the constructed Trade and Recreation Complex in the Manege Square and by the access stair – to the upper level of the underground Archeological Museum (Fig. 2).

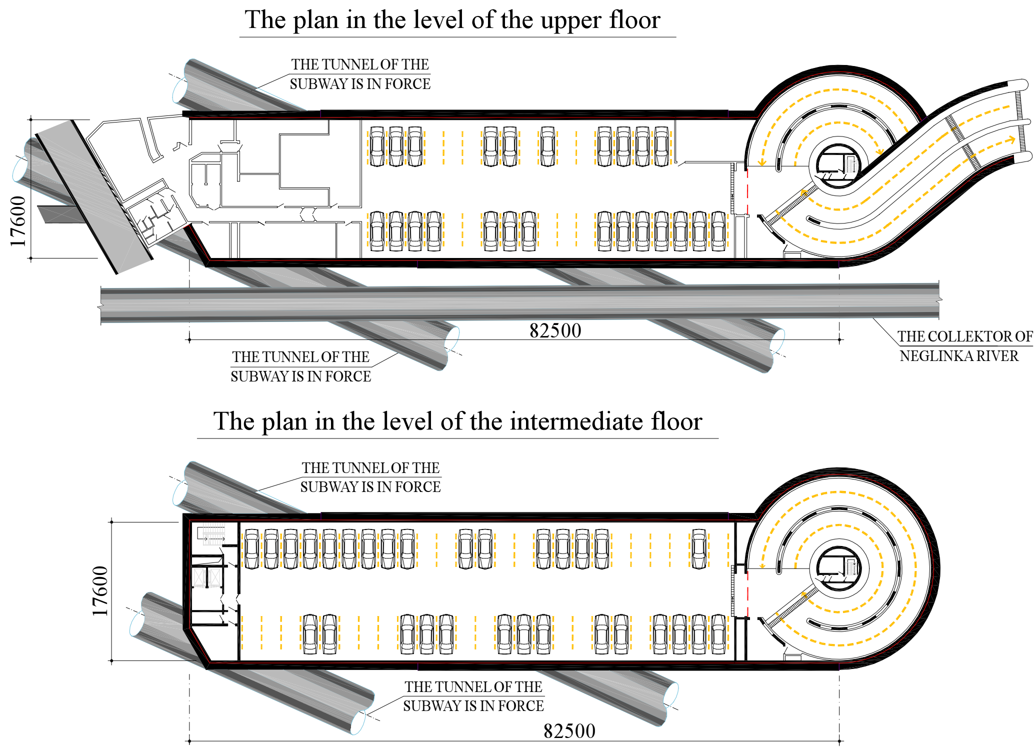

Fig. 2. Levels plans.

HIDROGEOLOGICAL CONDITIONS

Geological formation in the construction zone is composite and irregular and is represented by the following layers from top to bottom:

- fill (sand, construction debris, clay, clay loam with detritus) of 6-8 m thickness and remains of building foundations at a depth of 5-6 m;
- alluvial deposits of clay loam, sand lenses and sand loam of 4-6 m thickness;
- 3 to 5 m thick Izmailovskaya layer consisting of limestone crumbled to detritus, gravel and meal all filled with clay, blanket lenses of clay and underlying them large fractions of severely fissured limestone and dolomite;
- marl clay of 4 to 5 m thick Mescherskaya layer;
- 9 to 10 m thick fissured limestone of Perkhurovskaya layer;
- 6 to 8 m thick Neverovskaya layer of clay and marl.

Geological surveys revealed three water tables:

- upper water table overlying alluvial clay loam and clay;
- intermediate water table confined to Izmailovskaya level of limestone detritus overlying Mescherskaya layer of marl clay;
- lower water table confined to Perkhurovskaya layer of fissured limestone overlying Neverovskaya layer of clay and marl.

The parking-garage was constructed in the zone of the two upper non-artesian water tables which level according to the forecast wilt not exceed their seasonal rise after completion of construction.

Clays of Mescherskaya layer form foundation for bearing and retaining walls of the lining and limestone detritus do the same for the bed of the invert.

IN-SITU REINFORCED CONCRETE LINING OF UNDERGROUND PARKING-GARAGE

The idea to employ a four-level single vault in-situ reinforced concrete lining for the underground parking-garage in the Revolution Square was encouraged by the following key factors:

- evident operational advantages of the structures devoid of columns and wall partitions (both for increase of car space and possible replanning of the facility in the future);
- advantages of building single-vault lining which allowed to construct accomplished structure of each level in a single concreting operation;
- favorable arrangement, optimal cross-section size of the structure and allowable sloping of the parking-garage floor;
- ten-year experience in designing and operation of sloping-vault stations of the Minsk subway;
- years-old study of the construction and operation of the single-vault shallow subway stations in the cities of the former Soviet Union;
- carried out in 1995 assessments of material consumption, stress-strength condition and efficiency of utilizing subsurface space when constructing single-vault subway stations with «diaphragm wall» technology adapting it to different depths and employing various systems of single-vault structures;
- study of the relationship between hardening of concrete in sloping in-situ reinforced concrete vaults, its deformability and steel consumption which provide for set cracking resistance;
- creative approach of our experts to designing manifested by multi-variance and profundity in developing principal technical solutions.

Lining of the structure incorporates (Fig. 3):

- enclosing (at the construction stage) and bearing (at operation stage) diaphragm walls;

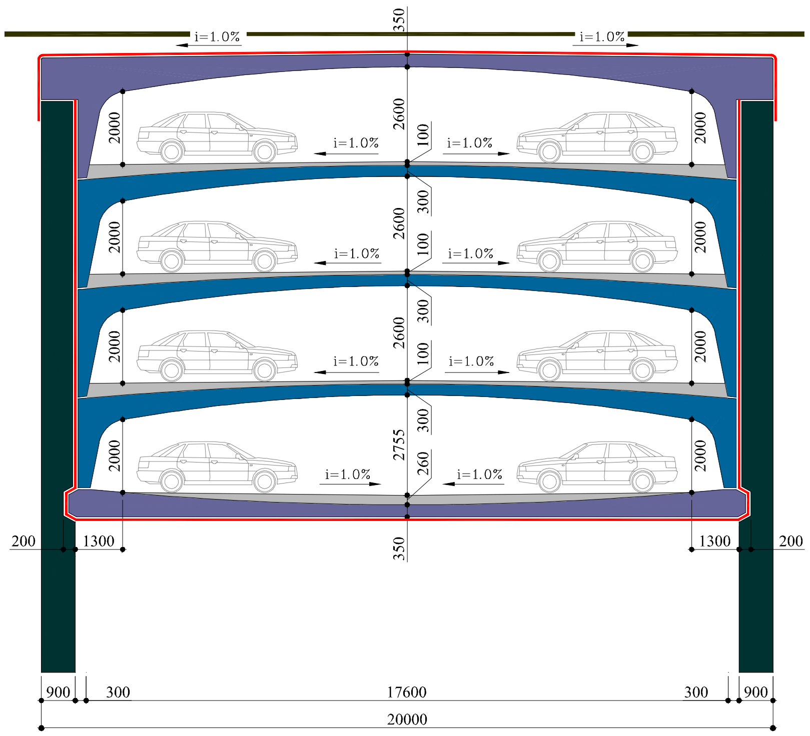

Fig. 3. Cross-section of the vaulted lining.

- sloping roof-vault rigidly connected by the upper sections of the abutments to diaphragm walls and flexibly bearing up against the walls with lower sections of the abutments via the layer of bound waterproofing material;
- sloping floor-vaults flexibly bearing by extended abutments against the walls via the layer of bound waterproofing material and having no rigid reinforcement ties between themselves, with the roof and the invert;
- invert in the form of a reverse sloping vault flexibly bearing against the walls and abutments of the lower roof-vault.

Adopted design of roof-vault, floor-vault and invert links to the walls and links of the vaults between themselves ensured high three-dimensional rigidity of the system and displacement compatibility of load bearing elements of lining which prevented damage to hydraulic seal during construction and operation of the project. It makes possible safe relocation and repair of adjacent utilities in the future during operation of the facility and allows to preclude soil water filtration through lining of the underground parking-garage. Though water filtration problem is very acute and appears now to be hard to solve for the underground complex in the Manege Square in spite of similar conditions and availability of soil drainage arranged under the invert.

Geometry of all the vaults was standardized to the inner radius to allow employment of single-type traveling form.

Diaphragm walls were constructed of grade B25 concrete, vaults and inverts – of B30 concrete. Regular bar reinforcement of A-I and A-III class was used for reinforcement of structures.

Prior to designing, single-vault lining was verified for its design fire resistance (not less than 2.5 hours) recommendations ensuring such resistance were formulated.

This work was performed by a specialized company «Intersignal».

High quality of diaphragm wall panel joints was achieved employing hydrocutters of Bauer company by cutting off concrete layer from butt edges of the leading panels when connecting sections of walls. Toothings in the diaphragm walls were constructed during assembly by filling requisite zones in reinforced three-dimensional cages with polystyrene foam blocks tied to effective reinforcement.

Waterproofing of walls and the invert was made of a single 4 mm-thick layer of «Izoplast P». This rolled bituminous material on a polyester base was pasted to the surface layer with traditional flashing off technique using propane burner. Pasting required the arrangement of high quality concrete surface under the invert as well as leveling off of diaphragm walls surface with sand-cement grout.

Joint points of the invert with diaphragm walls were supplementary strengthened with «Isolen» layer (made of reinforced light-resistant polyethylene), pasted to «Izoplast P» with «Neoplen» mastic.

Waterproofing of the roof vault is made of bentomats using as the base geotextile material VOLTEX and sodium bentonite VOLCLAY.

STATIC BEHAVIOR OF LINING AND CALCULATIONS

Static behavior of lining of adopted design is similar to behavior of separate curved cages connected between themselves and with the walls and has nothing in common with the behavior of lining of cylindrical strutting vaults.

This conclusion can be easily verified. For this extended abutments of vaults in the structure of lining of underground parking-garage should be replaced with regular ones formed by external and internal central radii of the vault. In this case each section of the floor vault shall behave as curved extracentrally compressed beam resting on two dead-end articulations and its vertical deformation at the axis of symmetry will exceed 100 mm when the vault gets full design load.

Stage-wise graphic representation of bending moments and analysis of the value of horizontal pressure exerted on the soil by lining of underground parking-garage via diaphragm walls at extreme design load applied to all vault-floors and vault-roof including heavy transport loads serve to additionally prove quoted conclusion. Maximum horizontal design pressure exerted by the lining on the soil decrease from 0.01 MPa (top of abutment of the roof vault) to 0.06 MPa (bottom of abutment of the lower floor vault).

With practical absence of strutting efforts it is extended abutments that ensure three-dimensional rigidity and low deformability of sloping vaults.

Another specific feature of this lining is that each of the sloping vaults is capable of changing its form under its own weight (within controlled limits), reducing stress through design deformability when formwork is disassembled. In this case proper weight builds up a sort of prestress of the vault prior to application of operation load and increases its bearing capacity.

During acceptance and expertise of our proposal we had to prove many times these obvious and self-evident facts.

To defend technical solutions a large scope of various computer-based calculations of different models were performed. Within very short period of time with the assistance of the Ukrainian scientists we developed, adapted and employed new types of finite elements which enabled us to take into consideration such minor details of lining behavior which our opponents from the largest scientific and research institutes of Russia failed to model.

When developing working documentation all calculations were made anew and allowed for changes in stress-deformation of lining specifying the geometry at each particular stage of construction. Lining geometry was verified during adjustment of the layout of the underground parking-garage.

RAMP DESIGN

The ramp is designed in the form of a discontinuous (in plan) «bore» constructed of D=830 mm secant piles spaced at 650 mm. In-situ reinforced concrete helix-shape ramp access rests on a foundation slab with hold-down bore walls, pillars arranged along inner circle and walls of the cylindrical stairs shaft, which in their turn rest on a foundation slab.

Side pile wall facing the Manege Square is constructed of similar piles using «Casagrande» drilling rigs.

The same materials and structural principles as were employed for water proofing of the vault lining were used for waterproofing of the ramp.

TECHNIQUE OF CONSTRUCTING FOUR-LEVEL IN-SITU REINFORCED CONCRETE VAULT LINING

Construction of the underground parking-garage in the Revolution Square was carried out to cut-and-cover technique under protection of temporary piles. When preparing technical proposal semi-cut-and-cover technique of construction under protection of vaults built level-wise (from top to bottom) was also considered. This option, however, appeared to be more labor-consuming and due to brief construction time it was rejected.

Technological sequence of construction is represented by 6 principal stages shown in Fig. 4.

At the first stage (Fig. 4. 1) from the level of the guide beam diaphragm walls were constructed under slurry protection, and secant piles – under casing protection.

Blanket grouting of fissured limestone of Izmailovskaya layer was carried out prior to excavation above left subway tunnel. The pit was excavated under protection of 5 m spaced D=630 mm pipe struts resting on distribution chords of coupled steel beams №55B1.

Then the following operations were executed arrangement of concrete bed (Fig. 4. 2), waterproofing of invert and walls up to a level exceeding the top of the lower level abutment by min. 0.5 m. This work was followed by concreting of the concreting of the invert. Reinforcement of the invert of the vault lining was carried out employing 2.4 m-wide reinforcing space cage, which was manufactured at the site in advance in special guides. Frames were joined during assembly by overlap of the loop-shaped rod ends in cross section and of supplementary individual rods – in longitudinal section.

Inverts of service rooms and the ramp were reinforced with individual rods wire-tied in their cross-shape connection. Concrete mix was fed with «Schwing» self-propelled concrete pump and buckets.

At the second stage, after concrete of the invert gained 50% strength (Fig. 4. 3), resting on it prefabricated steel modular moving form with veneer boarding was assembled. This work was preceded by disassembly of temporary piles at lower level.

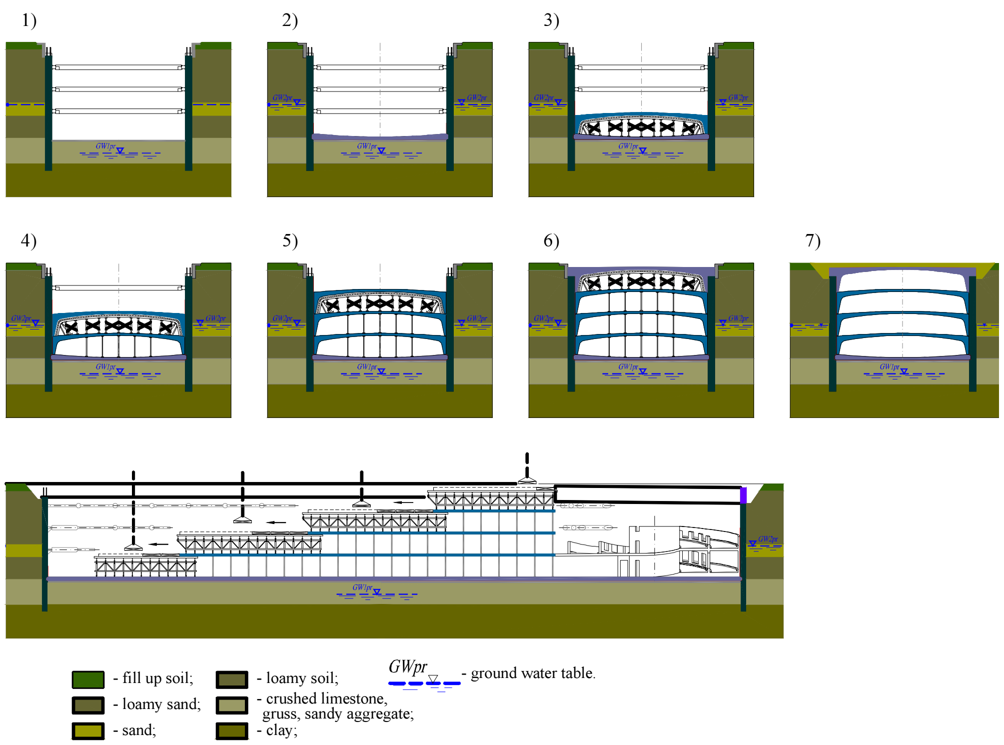

Fig. 4. The vaulted lining erection technology.

Each of 17.5 m wide sections of this and of subsequently constructed vaults were reinforced with the same type 2.4 m-wide reinforcing space cages.

Stage three (Fig. 4. 4): After concrete of the lowest floor gained 60% strength resting on it second set of form was assembled to concrete the intermediate vault. As form sections were removed from under the lower vault (in the opposite to the ramp direction) they were replaced with temporary support posts. Disassembly of temporary posts of the intermediate level was preceded with waterproofing of walls.

The intermediate vault was also concreted in 17.5 m-wide sections.

Stage four (Fig. 4. 5): After concrete of the lower intermediate vault gained 60% strength form sections were moved out and replaced by similar support posts and temporary posts of the upper level were dismantled. This work was followed by waterproofing of walls, assembly of the third set of modular form and concreting of the next intermediate vault.

Stage fife (Fig. 4. 6): After concrete of each section of the successive intermediate vault gained 60% strength parts of the form were moved out and replaced by new support posts, the fort set of form was assembled and roof vault was concreted.

Stage six (Fig. 4. 7): Four-level cast-in-situ reinforced lining was completed. Temporary support posts were disassembled level-wise from top to bottom. Floors were constructed at each level followed by waterproofing and back fill of the roof vault and reinstatement and improvement of the site.

The most critical and interesting stage of constructing the vaults commenced from the day (April 4, 1997) when concrete was laid in the first section of the lowest floor vault. This stage showed the advantages of the design and construction technology of the new type of lining, among which were:

- possibility to lay concrete in the vaults at several levels concurrently using;
- prefabricated steel modular moving form with veneer boarding;
- interchangeability of all sets of standardized form;
- continuous manufacture on the site of reinforcing space cages of only two basic types both for floor vaults and roof vault;

- total abandonment of welding of reinforcement during assembly;
- possibility to mechanize laying of big volumes of concrete mix.

As a result average rate gained at constructing the vaults was 90 through 100 m/month. It is not, however, top rate for such type of lining. Construction of vaults of the underground parking in the Revolution Square was restrained by standstill in the work caused by the fact that shield used for construction of the underground pedestrian passage between future parking and trade complex in the Manege Square was removed from the tunnel and laid in the pit of the constructed parking-garage.

Separate problem of construction was to control sagging of sloping unconventional vault. Our design provided for two configurations of each vault. Initial configuration (configuration of form) allowed for 50 mm construction rise in the crown. This design value incorporated the following settlements:

- under gravity load of the vault after removal of form;
- caused by vault creep when waterproofing material is trampled down with abutments;
- from permanent working load (floor, engineering facilities) and live log duration working load (cars);
- from partial transfer of live duration load (form and laid concrete weight) when concreting the above lying vault.

Vaults acquired derived configuration after stabilization of settlement under the action of all design loads. Thus internal vault radius made up ~45 mm, and external vault-floor radius ~100 m.

Underground parking-garage after completion

After removal of form from the vault sections concreted first measurements of actual combined settlements under gravity load of the vault and vault creep during trampling down of waterproofing material showed ~20-30 mm that corresponded to forecast settlement. Further settlement of ~10 mm was caused by deformation of form after laying of concrete mix. This value could not be taken into consideration as designing of lining and of the form was carried out concurrently. As a result, form for concreting new sections of the vault was assembled with 10 mm construction rise.

Proper installation of temporary supports which prop up lying below vaults when concreting above lying vaults caused problems at the initial stage. Supports of design carrying capacity were required to preclude transfer to the vaults of loads which exceeded design operating loads. Installation of bendable low carrying capacity supports led to excess of these loads and 40-50 mm summary increase of construction settlements in several concreting sections.

At a later stage when individual design of construction works was urgently elaborated no more bendable supports were used and thus the problem solved.

Of course first introduction of such an unusual solution brought about a number of minor problems which the constructors and designers resolved without mutual reproaches and unnecessary fuss.

It is worthy noting that to compensate for experimental nature of construction when selecting strong and crack-resisting reinforcement of the lining we employed besides standard safety factors also supplementary 1.5 coefficient which can be reduced if this solution is employed again.

CONCLUSION

Pace of constructing underground parking-garage in the Revolution Square in complex city designing and construction and geological conditions was unprecedented for such type of structures in Russia. Major construction and mounting works started December 5, 1996 and were completed – July 15, 1997.

17.6 m span clearance of employed configuration of the sloping vault has no analog.

Four-level vault lining of the underground parking-garage in the Revolution Square has the following characteristics:

- consumption of concrete for lining 86.5 m^3/m;
- consumption of rein-forcing-bar steel for lining 11.1 t/m;
- consumption of concrete per vault-floor 11 m^3/m;
- consumption of reinforcing-bar steel per vault-floor 156 kg/m^3;
- consumption of concrete per vault-roof 15.7 m^3/m;
- consumption of reinforcing-bar steel per vault-roof 169 kg/m^3.

Middle speed of the vaults concreting – 90-100 m/month.