New world's largest for northern Russia

Plans were recently announced to utilise the world's largest diameter TBM to bore a highway tunnel under the Rive Neva in St Petersburg, Russia, to alleviate seasonal road and river traffic problems. Mikhail Ryzhevskiy of the project concessionaire, LLC Nevskaya Concession Company, explains the background and plans for the project soon to commence

This article tackles the peculiarities of a unique construction project, taking place in the 'northern capital' of the Russian Federation, Saint Petersburg. Saint Petersburg is located in on the delta of the River Neva near by the Gulf of Finland, part of the Baltic Sea. It has well developed rail and road networks, an air communication system, access to the Volga-Baltic Waterway (VBW) and also access to various gas and oil pipelines.

In 2005 the city government made a decision to start construction of a road tunnel under the River Neva. The project was needed to tackle:

1. Traffic jams;
2. Absence of continuous communication between the left and right banks of Saint-Petersburg;
3. Shortage of ship navigation time.

To realise this idea a project concession agreement was created. Under the terms of the concession agreement the following project participants were brought together:

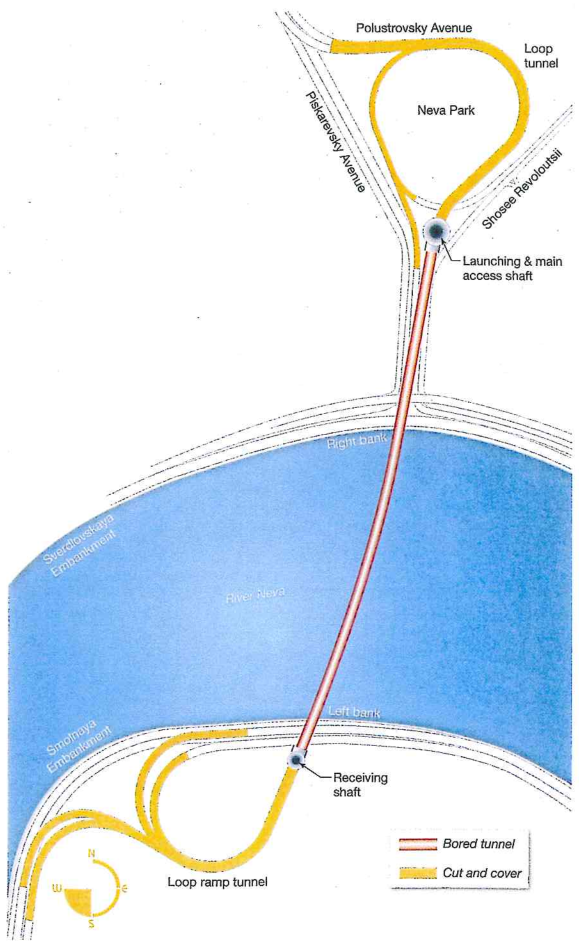
- The government of Saint Petersburg (responsible performer of the project);
- A private investor (concessionaire);
- Ministry of Regional Development of the Russian Federation (Chief controller of the federal budget);
- The State management company.

In April 2010 the concession owner selected LLC 'Nevskaya Concession Company' (NCC) as the private partner for the project, and is in charge of implementing the whole project. NCC engaged Stroyproject of Saint Petersburg as the main designer for performing tunnel design work. All directions concerning Orlovsky tunnel design come from NCC, and further checking of executed works are made by specialists from NCC. In addition, subcontractors were enlisted to carry out work on certain sections.

Tunnel description

Several options were examined while developing the concept of Orlovsky tunnel construction:

- Submersed tunnel: This is a relatively cheap solution. Implementation of this variant would require shipping restrictions on the River Neva, relocation of a municipal water intake, reconstruction of embankments, and with carrying over of utility systems. This method might incur high natural environment damage.
- Open cut method: This presupposes enclosure of the construction area with a restriction or with full closure of navigation on the River Neva. Realisation of this variant requires carrying over of utility facilities from Smolnaya and Sverdlovskaya banks, reconstruction of embankments, and entails high ecological risks. An inexpensive option.



- EPB or slurry TBM: This technology allows to tunnelling in complicated geological conditions without damaging hydrogeological processes under the River Neva. The current methods do not hurt the ecosystem of the construction area. Usage of a TBM is a more expensive solution compared with the first two variants.

After comparison and risk analysis it was decided that the TBM method is more appropriate from technological and safety points of view.

After this choice several design scenarios for the TBM method were reviewed.

First scenario: The tunnel has a twin-bore configuration, with an excavation diameter of 15.2m for each bore, designed for three lanes of traffic in each direction;

Second scenario: The tunnel had a single bore, approximately 15.9 to 16.1m in excavation diameter, configured internally to accommodate two lanes of traffic in each direction on two levels;

Third scenario: A single-bore tunnel with a unique external TBM shield with a diameter of 19.27m and capacity to accommodate three lanes of traffic in each direction on two levels.

After thorough examination of the options it was decided to implement scenario three, which corresponds to European standards. Moreover, the third variant is technically and economically the most feasible.

The planned depth of the tunnel is going to be from 20 to 33m, and the length of the tunnel under The River Neva will be 956m but the traversed length of the Orlovsky tunnel is planned at about 3km.

The Orlovsky Tunnel complex includes the following main structures:

- Bored tunnel, located under River Neva;
- Road interchange at the right bank, which includes loop-shaped ramps with exits to Piskarevsky Avenue, Shosse Revoloutsii and Sverdlovskaya Embankment;
- Traffic interchange at the left bank, which encloses loop-shaped ramps for switching between the Orlovsky Tunnel to the Smolnaya Embankment;
- Operational facilities.

Left: **Figure 1, Plan of Orlovsky Tunnel alignment and connecting road routes;** Right: **Figure 2, Geological profile along tunnel route**

Interchange design

The Orlovsky Tunnel is going to be constructed between the Liteyny and Bolsheokhtinsky bridges. To connect the tunnel to street and road network it is planned to set up road interchanges at both riverbanks.

The main factors that define the road interchanges are:

- Given design limits, approved by the Committee for Urban Development and Architecture,
- Capacity for a design speed of 80km/h at the main tunnel alignment and 50km/h on access roads,
- Provision of minimal longitudinal inclination,
- Implementation of a transport layout that will be convenient and provide road safety.

A traffic interchange will access to the roads: Piskarevsky Avenue, Shosse Revoloutsii and Smolnaya Embankment and also two slip-roads from Sverdlovskaya Embankment and Piskarevsky Avenue. The alignment of access roads to the tunnel itself will be realised via loop-shaped ramps on both riverbanks.

On the left riverbank the Orlovsky Tunnel will be connected to Smolnaya Embankment, which acts as a cross-distribution route.

The tunnel's connection to the historical centre of Saint Petersburg will be done through loop-shaped ramps.

The design for roadways on the right bank was developed within the assigned territory bounded by Piskarevsky Avenue, Shosse Revoloutsii and Polustrovsky Avenue.

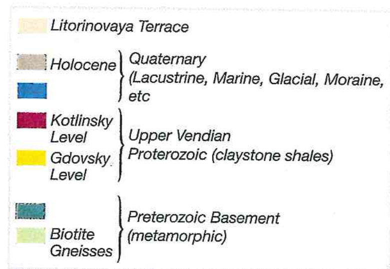
Due to the depth of the tunnel alignment under the River Neva some sections of the tunnel on the right bank construction site will be built by a top-down/slurry wall method and open-cut method located in the 'Neva garden' area. This solution has been accepted to make shorter sections for further transition of the higher part of the tunnel to the street and road network. Taking this into consideration, a shallow subway from the end of the bored tunnel zone will be built consisting of two-level, loop-shaped ramps.

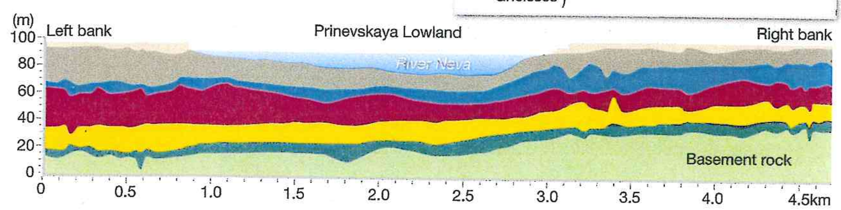
The number of carriageways on the ramps is identified by the rated traffic intensity in accordance with a traffic flow of 1,100 vehicles per hour.

Figure 1 (left) shows the roadway scheme and the tunnel alignment.

Geology

The city area includes a land mass area, numerous islands and peninsulas that are linked with each other by means of bridges and subway lines. There are about 100 rivers, streams, water-flows and approximately 20 canals within Saint-Petersburg. So there is a lot of water above and below St Peterburg as geological





surveys have proved. There is a presence of several aquifers within the zone of the Orlovsky Tunnel construction.

Saint Petersburg is temperate and humid with average annual temperature 4.3°C.

From a geomorphological point of view the construction area belongs to Litorinovaya Terrace of the Prinevskaya Lowland. The hydrographical network of the region refers to the Baltic Sea basin.

Geological investigations for the tunnel construction were held from August 2010 to December 2010.

The geology of Saint-Petersburg is presented by the following stratigraphy:

- Quaternary deposits;
- Sedimentary cover of rock basement (upper Vendian age - Proterozoic);
- Preterozoic basement.

The Quaternary sediments within a drilling depth of 101m are composed mainly of anthropogenic sediments of Holocene age (t IV), lacustrine and marine deposits (m, l IV), lacustrine-glacial (lg III), glacial deposits of the Luzhskaya glaciation phase (g III), intermoraine lacustrine-glacial deposits of the Moskovskiy horizon (lg II ms), and glacial sediments of the Moskovskaya glaciation phase (g II).

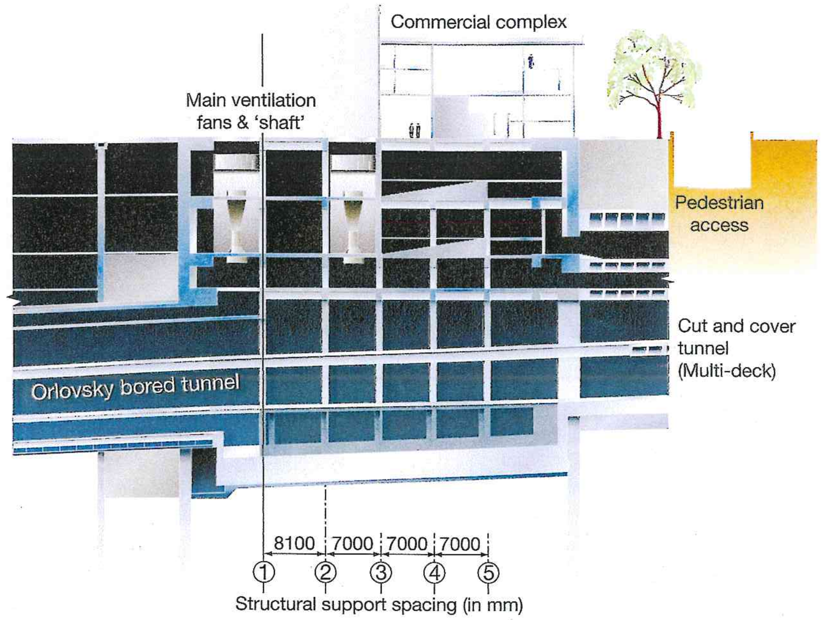
The sedimentary cover of the late Proterozoic age is composed mainly of claystone shales and are divided into the Kotlinsky level (Vk2) and the Gdovsky level. The upper part of the Kotlinsky level, that lies below the Quaternary sediments, is generally flat and is usually associated with constant thickness and lateral lithological uniformity.

The deep Proterozoic basement is mainly composed of biotite gneisses as a metamorphic basement.

The Orlovsky Tunnel is planned to be constructed in Quaternary sediments but the shafts will touch the Kotlinsky horizon.

Quaternary sediments are represented by sandy loam, sand, loamy sand, silt loam and silty clay loam (according to USDA classification). Based on field and laboratory results, specialists from NCC found out that most of the soils that will be involved in the Orlovsky Tunnel construction are soft, very soft, unconsolidated and water saturated. Moreover, some soils have thixotropic behaviour (Figure 2, page 13, shows the geological profile of the tunnel). Laboratory research was performed according Russian State Standards and British Standards.

There are several water driver aquifers within the construction area that cause difficulties as well. Observation wells will be installed for monitoring water levels within



construction site.

All these peculiarities and complicated geological structure are considered in design solutions for Orlovsky tunnel

The tunnel can be divided into three parts: launch and dismantling shafts and the tunnel itself under groundwater.

Right bank shaft

All the accepted design concepts are based on checked geomechanical and static calculations.

The TBM launch shaft on the right bank has cylindrical form with a diameter of about 52m. The maximum and minimum depths of this shaft are around 44 and 46m (see Figure 3, above). The shaft is divided into several sections by height, namely: lower and upper transport modules, apparatus floor and ventilation sections. An emergency exit is located near the ramps.

The structural design is represented by reinforced construction of cylindrical forms, a base plate, floor slab, concrete kentledge and spacing plates. Construction is top-down with support of different levels by means of concrete slabs with vertical supporting structural elements, a flight of stairs and staircase landings. Steel columns with barrette foundation are planned to be used as additional supporting structural elements during. All structures are made of reinforced cast concrete.

Left bank shaft

The design of the shaft on the left bank for dismantling the TBM is similar to the launch shaft in most respects. It has a cylindrical form with a diameter 33m. Maximum and minimum depths of this shaft are about 42 and 43m. The construction is also divided into several floors by height criteria as: lower and upper transport modules, apparatus floor and ventilation sections. The emergency exit is again located near by the ramps.

The structural design of the construction area is presented by walling, base plate, concrete kentledge, vertical supporting structure elements, reinforcement frames and more over flight of stairs and staircase landings. Steel columns with barrette foundation are planned to be used as additional supporting structural elements at construction period by analogy with launch shaft. All structures are made of cast reinforced concrete.

Under water

Tunnel construction under the River Neva is executed with a slurry TBM.

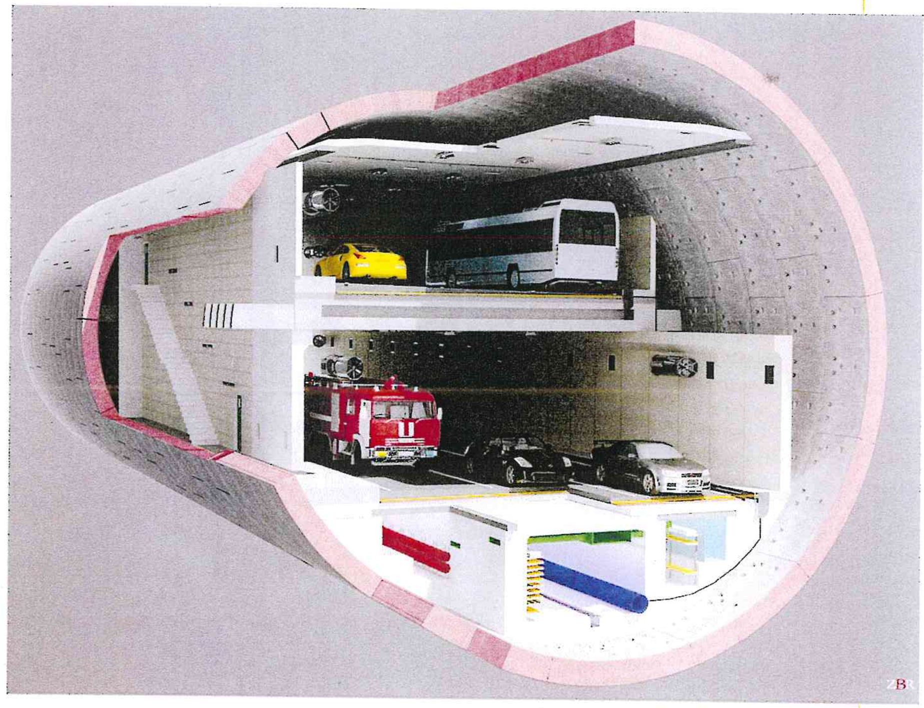
Accepted technologies

The Orlovsky Tunnel, especially the solution of one tunnel bore with a diameter of 19m is a technically challenging project as this tunnel dimension hasn't been executed anywhere in the world before.

Taking into account that the tunnel will go under the River Neva where soil conditions are extremely difficult (mainly unconsolidated, soft, or very soft with inclusions of pebbles and boulders, and with some aquifers in the construction area) an active face support, and pressurised TBM is required to avoid water ingress,

Left: **Figure 3, Section through the launch shaft on the right bank**

Right: **Figure 4, Cutaway perspective of the designed interior of the bored tunnel**



large settlements or collapses. It was decided to use a single shield TBM. In this case precast segments will be installed in the tail of the TBM. Brushes sealing in the tail skin, and rubber gaskets between the segments in the longitudinal and radial directions assure a watertight system during construction. The investigation conducted showed that only a Mixshield (a slurry shield with an air cushion and stone crusher) fulfils the requirements.

Herrenknecht was chosen as a manufacturer for making innovation TBM shield with inner diameter 19m. A schematic drawing of the TBM and back-up is presented in Figure 5 (below, right).

Diaphragm walls

Monolithic reinforced concrete diaphragm walls (DWs) act as enclosing, antifiltration, supporting walls of the designed structure around launch and dismantling shafts.

DWs are planned to be built with the help of hydraulic grab equipment following technology, which presupposes flushing-up, the panel's line by using synthetic joint waterproofing tape 'Waterstop'. Grapple tongs with boom lengths of 2.8 to 4m will perform trenching.

T-shape and G-shape grapple tongs will be used for quality formation of the diaphragm walls. A high quality of panel connections will be guaranteed by using 'Stopsol' removable end stops. The task sequence for construction of diaphragm walls is:

- Diversion (carrying over) of engineering subsurface services from the work area.
- Walling of the monolithic reinforced concrete foreshaft.
- Assembly of clay slurry plant.
- Fabrication of reinforcement cage panels for insertion in walls.
- Grapple excavation of development area under bentonite slurry protection .
- Replacement of bentonite slurry in excavation areas with freshly made or recycled mix.
- Setting of panel reinforcement cages in wall area using grapple tongs.
- Panel concreting.

After DW concreting the upper level of concrete (depth 400 to 600mm) with debris inclusions should be cut off.

Jet grouting

To ensure safe initial cutting and exiting of the TBM at the start of tunnelling, installation of a vertical groundwater cut-off is planned beyond the launch shaft. As soils within the construction area are mainly unconsolidated, weak reinforcement of the ground is essential.

Jet grouting will perform soil solidification between the groundwater cut-off and launch shaft.

Jet grouting involves erosion of soil by high pressure jets of grout (air-enshrouded grout and water) and the simultaneous injection of cement suspension grout into the disturbed soil by means of a jet monitor. This high-pressure jet is used for local ground break-up and mixing the soil to form 'soilcrete' with better characteristics. The created 'soilcrete' formation consists of the grout just jetted and existing soil particles as fine and coarse aggregates.

The task sequence for jet grouting operation is:

- Preparatory work,
- Drilling of pilot borehole with washout at planned depth,
- Local soil break-up and mixing with a high-pressure jet of grout.

Conclusion

In the summer of 2011 Nevskaya Concession Company (NCC) received a positive decision from the Russian State Enterprise for the Orlovsky Tunnel construction giving the go-ahead.

The independent engineer COWI finalised checking of project documentation and approved the chosen construction and engineering methods.

The Orlovsky Tunnel shall be opened for operations and traffic in December 2015.

Below: **Figure 5, Longitudinal section, cross-sections and cutterhead view of the world's largest Herrenknecht Mixshield TBM and back-up systems**