Geotechnical protection of engineering infrastructure objects in large cities under intense anthropogenic impact and long term operation

Sécurité géotechnique d'ouvrages du génie civil sous influence anthropogène intense et exploitation à long terme

Perminov N.A.
St. Peterburg University of Means of Communication, Russia
Zentsov V.N.
"Lengiproinzhproekt", Russia
Perminov A.N.
NIPIC Trasspecstroy, Russia

ABSTRACT: This article describes more than 30-year experience of scientific and technical support, design, construction and reconstruction of water supply and sewage facilities in St. Petersburg, Sochi, etc. It describes the specific defects of long-term operation of large-size pumping stations and deep-laid tunnels that cause risks and dangers of their use. It gives the results of geotechnical and design calculations, modeling of underground and tunnel constructions taking into account risk factors determined by defects that occur during construction and operation, and also taking into account external influences, including dynamic ones. The report gives a comparative analysis of calculated and industrial experiments, provides activity and implementation experience of geotechnical support of long-term operation of engineering infrastructure.

RÉSUMÉ : L'article décrit l'expérience de plus 30 ans d'assistance scientifique et technique, en conception, construction et restauration d'infrastructures de distribution d'eau et d'évacuation des eaux usées à Saint-Pétersbourg, Sotchi, etc. L'article détaille les défauts typiques des stations de pompage de grandes dimensions et des tunnels profonds, exploités sur le long terme et amenés à des niveaux de risque et de danger au cours de leur exploitation. On donne les résultats des calculs géotechniques et de conception, en simulant le fonctionnement des tunnels profonds, compte tenu des facteurs de risque induits par les défauts apparus aux étapes de la construction et de l'exploitation, ainsi que des influences extérieures, y compris les influences dynamiques. Le rapport présente l'analyse comparative des expériences théoriques et pratiques, et fournit les mesures à mettre en œuvre pour la sécurité géotechnique des ouvrages de génie civil exploités à long terme.

KEYWORDS: monitoring, geotechnical analysis, objects of water disposal, deeply lying constructions, tunnels, geoecological safety.

1. GENERAL INFORMATION ABOUT THE OBJECTS OF DEEP ENGINEERING INFRASTRUCTURE IN LARGE CITIES

With long-term operation and intensive development of engineering infrastructure of megalopolises increase the requirements to the ecology and efficient usage of land resources. During engineering development of underground spaces of such a megalopolis, design of integrated measures for protection of town-planning environment against negative anthropogenic impact is of special actuality. Thereupon there must be introduced special safety requirements for the sewage and water treatment facilities.

Sewage (transportation) of waste waters is done through the city sewerage system and tunnel collectors. In the general drainage system these facilities account for up to 60% in large cities and up to 70% in difficult hydrogeological conditions by construction volumes and costs.

Sewerage system objects data for the most typical Russian cities with the population over 1 million people is given in table 1.

Table 1. Length of sewerage networks and tunnel collectors in large cities of Russian Federation.

City	Sewerage networks length, km	Tunnel collectors length, km
Moscow	8354	550
St. Petersburg	8245	290
Volgograd	1054	52
Yekaterinburg	1220	230
Novosibirsk	1150	145
Samara	1200	215
Ufa	900	180

By now around 88% of all sewage collectors are made of ferroconcrete, around 7% - of metal (steel, cast iron), around 3% - of bricks, plastic, ceramics. Tunnel sewage collectors diameter is from 1.2 to 5.6 m, they are buried from 3 to 60 m underground. For example, in St. Petersburg all sewage network is divided into three basins that serve three main pumping plants up to 70 m deep and up to 66 m in diameter, with productivity of 1.5 mln m^3 of sewage per day. For such conditions the main constructive solution for the tunnels are the ferroconcrete tubings with inner ferroconcrete jackets.

Transportation volumes of waste waters in some sections of the tunnels reach 20 m^3 per sec, and in case of decrease of their operational reliability or failure will inevitably lead to a technospheric catastrophe.

"Lengiproinzhproekt" institute together with the St. Petersburg State Transportation University has been providing scientific and engineering maintenance, design, construction and rehabilitation of St. Petersburg sewerage system objects for more than 30 years: more than 70 pumping plants, including those with depth of 45 m, 59 m and 71 m, and with diameters of 47 m, 59 m and 66 m; more than 15 km of tunnel sewage collectors with diameters of 1.85, 2.5 and 3.4 m and with depth of 16 m, 24 and 37 m.

Table 2 shows the most typical defects of long-term operated pumping plants and deep tunnels.

Analysis of the materials of the investigations shows that at the moment 60% of gravity sewage tunnels and 80% of pressure sewage tunnels require repairs and sanitation. Instrumental probing (with geological radar) shows that 70-75% of inner surface of pumping plants wells and sewage tunnels have continuity violation and cracks which require strengthening of construct and renewal of waterproof shell.

Table 2. The list of defects typical for the long-term operated (more than 30-45 years) deep pumping plants and tunnel collectors.

Location of the defect	Description and photo of the defect		
Sunk wells walls	Up to -25÷30m marks. On some sections of sunk well walls there's leakage through knots. In the knots area there's leakage of concrete corrosion. Defects are of repetitive nature.	-30 to -40÷45m marks. On the surface of the wall there're marks of intense leakage through the cracks. Defects are of mass nature. In the knots area there's leakage of concrete corrosion.	More than -45m marks. On the surface of the wall there're marks of intense leakage through the cracks. In the knots area there's leakage of concrete corrosion. Defects are of mass nature.
Sewage tunnels lining	Tubing lining shows leakage. Underground waters go to the collector through cracks and knots in solid ferroconcrete inside lining. There's leakage of concrete corrosion and salts.	There's a water-filled space in the form of a thin gap between the tubing lining and the jacket of collector. Defects are hidden, can be found geological radar probing of collector facilities.	Solid ferroconcrete inner lining (jacket) is destroyed, there's intense leakage in welded seams.

2. ANALYSIS OF FACTORS INFLUENCING THE SAFETY OF DEEP ENGINEERING STRUCTURES AND MEASURES FOR THEIR ELIMINATION

2.1 Analysis of monitoring data for the construction of sunk large pumping plants and of the inspection results after long term operation

The slotted soil column for construction of sunk wells for main pumping plants in the conditions of St. Petersburg is characterized as follows: top part is presented by quaternary beddings to the depth of 14.0-25.0 meters (middle-density water-saturated dust sand E=11 MPa, C=0 MPa, φ=30°; laminar silt sandy loam E=4 MPa, C=0.01 MPa, φ=15°; laminar silt loam, very soft E=9 MPa, C=0.025 MPa, φ=16; semisolid silt loam with gravel, pebbles E=14 MPa, C=0.028 MPa, φ=28°), lower part is represented by top of positioned Proterozoic bluestone (E=19 MPa, C=0.04÷0.06 MPa, φ=18-21°).

Figure 1 shows the monitoring results for the construction of a large sunk well using the method of PSTU (Perminov N.A., Lombas S.V., 2004).

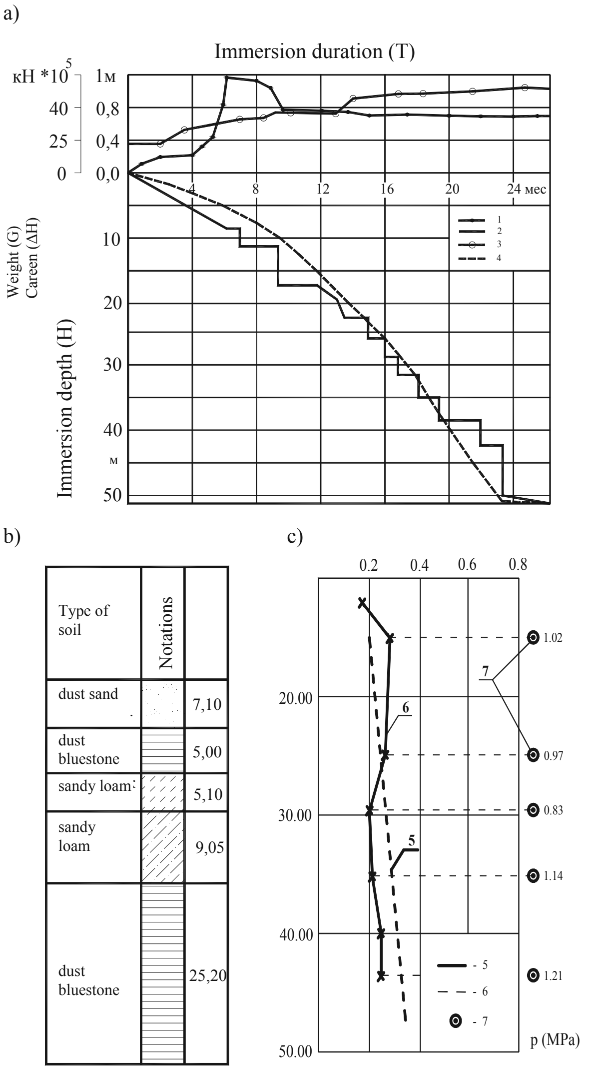

Figure 1. The monitoring results for the immersion of a large sunk well:
a) motiongramm of immersion; b) engineering and geological conditions; c) monitoring data
1 – diagram of vertical misalignment (careen); 2 – diagram of immersion; 3 – weigh of the well shell; 4 –ditch bottom; 5,6,7 – correspondingly, calculated, averaged and peak values of lateral soil pressure.

The stresses in the reinforcement and concrete were measured using primary device string type PSAS and PLDS. To determine the soil pressure membrane load cells with a range of 0 to 12MPa and measurement error of 5-7% were used. The measurement was done both in the discrete and continuous mode using the local electronic switches (LEC), and data storages (END).

Analysis of monitoring data of large sunk wells with diameters from 50 to 66m and a depth of immersion of 55 to 71m shows (see Figure 1) that in the process of immersion in the soils with different strengths and asymmetric structures deviation from the vertical axis (careen) is observed, with a shift of the center up to 1.5-1.8 m. In this case, according to an automated continuous monitoring, as a result of abrupt landings (breakdowns) stresses in the reinforcement, concrete and soil pressure may exceed the calculated and the average values (according to the discrete measurements) 12-15 times.

To estimate the stress-strain state of the well shell with a sharp landing (breakdown) numerical modeling was conducted. In the calculations the finite element method (FEM) and the software package Robot Professional 2010 were used. The calculation is carried out for spatial shell with diameter of 66m and a height of 71m (with the number of three-dimensional finite elements equal 50828), falling under its own weight at an angle of 15 ° from a height of 140 cm on the compliant soil (average coefficient of elasticity for multilayer soil is taken K = 16500kN/m3). In the model because of the inclination angle the friction forces on the lateral side of the well were applied in the upper part of the shell on one side and in the bottom part on the opposite side.

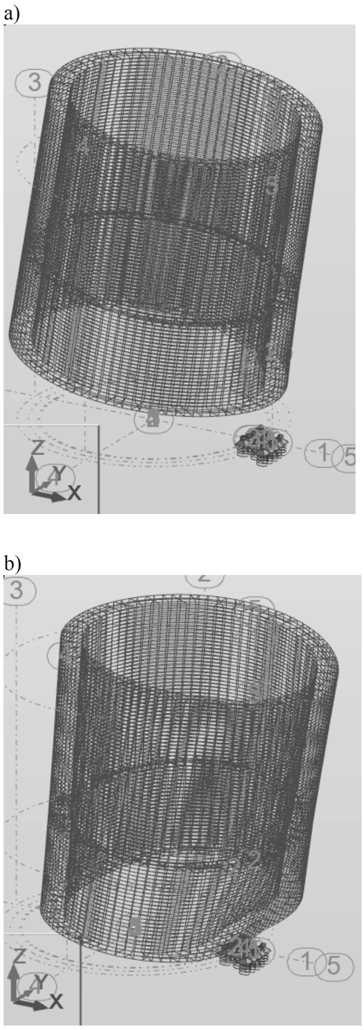

Figure 2. The results of numerical modeling of a sunk well with diameter of 66 m and a height of 71 m for the conditions of a abrupt landing (breakdown): a) the original position, and b) position after a fall from a height of 1.4 m at an angle of 15 °.

The results of numerical modeling have shown (see Fig. 2) that in case of a dynamic blow (if the well is dropped from a height of 140 cm) equivalent von Mises stresses in the construct equal Sdin = 256MPa at the top of the shell and Sdin = 1538MPa in the area of the bottom rest, which respectively exceeds the limiting strength of concrete class B30 [Spred] to 14 or more times, and the changes in the geometry of the shell are observed.

Thus, already in the process of the well immersion the construction of the well is damaged and the concrete is disintegrated due to breakdowns. Later during operation micro cracks lead to leakage, seepage and corrosion of concrete. To further ensure the safety of operation of facilities of this type it is necessary to strengthen and waterproof the construct by high-pressure injection of polymer resins.

2.2 Geotechnical analysis of technical condition of the sewage tunnels under intensive anthropogenic impact and long term operation

Geotechnical analysis of the sewage tunnel was carried out for the most typical section located in a zone of intense dynamic impact of transport and the impact of new construction.

Figure 3 shows the diagram of the tunnel compressions for more than 35 years of service life.

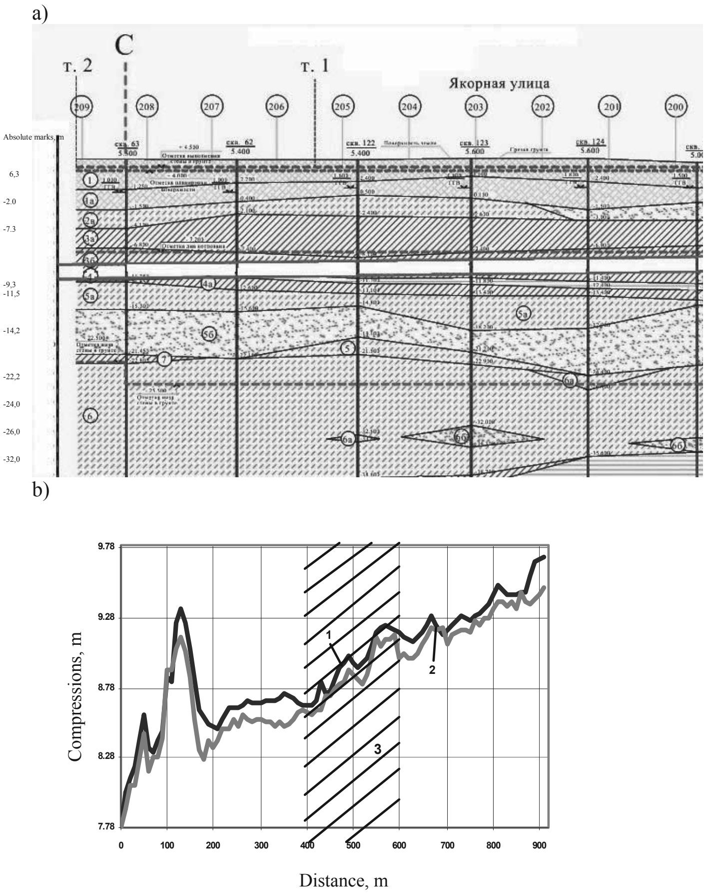

Figure 3. The diagram of comparison of the compressions on the arch axis of the collector: a) engineering and geological section, typical for laying-out sewage tunnels in St. Petersburg, b) the diagram of compressions: 1 - survey results of 2010, 2 - executive survey data of 1975, 3-area of the collector, protected from the influence of the construction be a screen of low modular material.

Uneven tunnel compressions, modified on the arch axis range from 5 to 276 mm. Comparative analysis of engineering and geological section on the tunnel route and its placement on the plan relative to the traffic junction showed that the greatest compressions up to 276 mm are located in the area of the tunnel under intense dynamic effects of the traffic, passing the layer of thixotropic quaternary deposits.

Evaluation of the dynamic impact of the transport was carried out by the study of the oscillatory process with a set of manifold gauges CM TSP installed in the arch and blocks of the recording equipment (Perminov N.A, 2011)

The frequency of the oscillations of the collector during various traffic loads from 15 to 35 Hz, and the vibration amplitude to 35-70 microns was recorded. According to the research (Goldshtein M.N., Lapidus L.S., Reznikov O.M., Storozhenko V.I., Sinaevsky N.I, 1973) for this type of ground deposits and the appropriate level of the dynamic effects the decrease of strength characteristics C and φ is up to 35% and 17%, respectively. To ensure the operational reliability of tunnels vibration protection measures, such as the use of spiral-wound technology for internal lining the tunnel are suggested.

For this section of the collector the numerical modeling was carried out to determine the maximum allowable axis displacement of tunnel lining. The criterion for the safety of the construct is the maximum allowable tensile stress of the concrete in the typical points of lining. Maximum allowable deformation and displacement values are presented in Figure 4.

a)

b)

3. SUMMARY (CONCLUSION)

Data received from long-term field observations for continuous operated embedded constructions being a part of megapolis water discharge system as well as the results of calculation and modeling allowed to conduct geotechnical analysis of the residual bearing capacity and to develop measures to ensure the safe operation of facilities of such type under the conditions of intensive external influences.

As experience shows, the presence of geotechnical tracking of environmentally hazardous facilities of such type for the entire period of their life cycle, including design, construction and long-term operation (even under intensive man-induced impact) provides the safety of the stable functioning of the megapolis utility infrastructure.

4. REFERENCES

Perminov N.A., Lombas S.V. 2004. Complete geo-technical and monitoring services for the construction of the underground structures in a megapolis. Geotechnikal problems on cons-truction of large – scale and unique projects. Proceedings Of International Geotechnical Conference dedicated to the Year of Russia in Kazakhstan 23-25 September 2004, Almaty, Kazakhstan. ISBN 9965-25-409-5 Edited by academic of NAN RK, Dr.Sc., Professor Sh.M. Aitalyev and Dr.Sc.,Professor A. Zhusupbekov.

Perminov N.A, 2011. Geotechics jf Had Soils-Weak Rocks. Experience of tunnel collectors monitoring at engineering development of underground face of megapolis. Part 3. 1705-1712.

Goldshtein M.N., Lapidus L.S., Reznikov O.M., Storozhenko V.I., Sinaevsky N.I. Particularities of dynamic properties of soils with pulsating load on the surface. The proceedings of an international congress on mechanics of soils and foundation engineering. – Moscow, Stroyizdat, 1973, p.329-331.