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The construction of deep excavation ditch in weak soil in St. Petersburg

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ABSTRACT: The information about the engineering- geological conditions in the central part of St. Petersburg which are characterized by deep thickness of weak water saturated soil is given. Three buildings with large underground space constructed in St. Petersburg are considered as examples. The depth of each space exceeds 12 m and required the usage of modern and nonstandard construction and technological methods for protection of the ditch walls. The wall protection was done by sheet piles, by "Wall in ground" method, and "jet grouting". The soil excavation was carried out by traditional method or "Top–down" method. The basic constructive schemes and technological methods of ditch excavation, test results of deformation of the protection walls during excavation of the ditch and the settlements of the neighboring buildings are given.

1 INTRODUCTION

The development of the modern City is not possible without the development of underground space. But the construction conditions in St. Petersburg are much more complicated than in any other region of the country. Mainly this is explained by specific geological conditions—the central part of the City is located on weak, water saturated thixotropic soil, which change their properties depending on the effect of different forces—natural and technogenic. Most of the buildings which were constructed in 18–19 centuries or beginning and middle of 20-th century have cracks and damages of the bearing structures and require the reinforcement of their base and foundations (Mangushev, 2004).

Any additional settlement of such buildings during ditch excavation by traditional method (pile sheet wall, soil excavation, lowering of ground waters by open excavation and etc) may cause unpredictable result.

The construction in St. Petersburg require high professionalism starting with projecting work when you choose the method of supporting the wall of the ditch and the technology of the future work. The availability of the modern equipment for underground work and qualified personnel is of great importance. The examples of the construction of three modern buildings with large underground space in St. Petersburg are given in the present article.

2 FIVE LEVEL UNDERGROUND PARKING ON KOMENDANTSKAYA SQUARE

In 2006 the company "GEOIZOL" made the project and started construction of the circular 5 level underground parking on Komendantskaya Square. The depth reached 19,5 m and the diameter 78 m. The general cross section is shown in Figure 1.

The main problems which appeared during the construction were the absence of the experience in the construction of such types of buildings

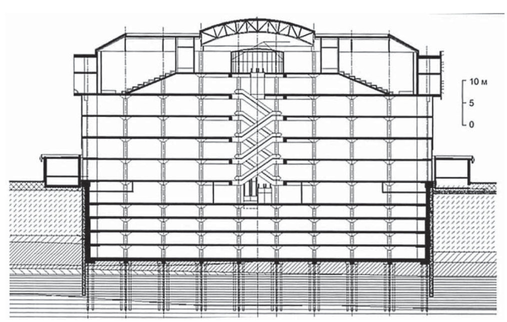

Figure 1. The general cross section of the building.

in St. Petersburg and complicated geological conditions (thixotropic soil in the upper part of the geological section, high level of ground waters and presence of big boulders).

Since the parking with such spacious underground room was constructed in newly developing region it was possible to dispose it at the distance of 100 m from the nearest buildings. This allowed to ignore the effect of the parking on neighboring buildings.

The technical solution of the erection of the underground part of the building suggested:

1. Initial trench made by “wall in ground” method 24 m deep and 0,8 m wide which was filled cement-clay solution (Fig. 2a) The ground was excavated by portions 3,3 m long each.
2. Immersion of the metal semicircular sheet pile into the trench and its subsequent concreting (Fig. 2b). Sheet pile served as a reinforcing element and additional seal.

Figure 2. Initial trench made by “Wall in ground” method (a) and sheet pile immersion (b).

3. Erection of monolith concrete beams which served as stiffening ribs and excavation of the ditch by portions while making monolith walls and parts of beam ceiling (Fig. 3).
4. The erection of 290 anchor borrow concrete piles 12 m long section 250 mm and concreting the reinforced concrete plate on the level—18 m (Fig. 4).

There were no influx of the water from outside of the wall since the “wall in the ground” reached the dense undisturbed Cambrian clay.

In order to avoid the floating up of the bottom of the structure under the pressure of hydrostatic force, the reinforcement of anchor borrow concrete piles was connected with the reinforcement of the lower plate. This allowed to make united anchor system.

The horizontal movement of the circular walls during the ditch excavation was checked with the help of inclinometers. Inclinometers were immersed into the earlier installed plastic tubes along the whole height of the “Wall in ground”.

Figure 3. The beams, parts of ceiling and excavation of the ditch level by level.

Figure 4. Anchor piles and monolith reinforced concrete bottom plate.

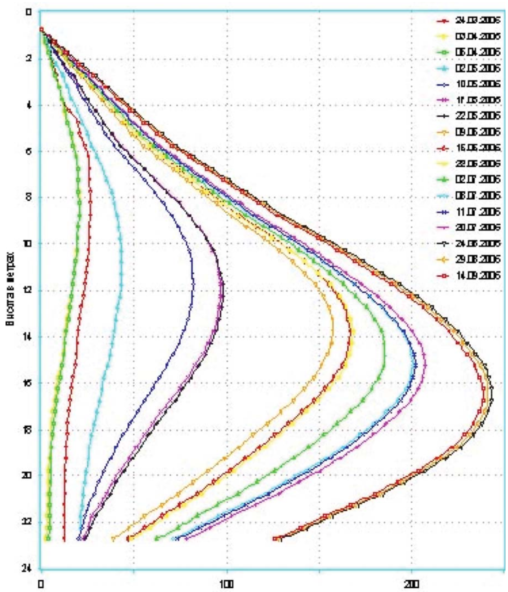

Figure 5. The horizontal movement of walls of underground structure within certain period of time.

Figure 6. General view of the building with 4 level parking.

The horizontal movement of walls of underground structure during excavation within certain period of time is shown in diagram (Fig. 5).

The maximal measured movement of the wall into the ditch was 250 mm and happened at the depth of 15 meters. A t the end of 2008 the building was put into operation (Fig. 6).

3 THE UNDERGROUND PART IN STOCKMANN TRADE CENTER

In 2007 the construction of the new Stockmann Trade Center was started in the center of the city on the corner of Nevskii Prospect. and Vosstania str. The building has 3–4 level underground space 15 meters deep in the form of trapezium (the base is 60 m the height of one of the sides 130 m) (Fig. 7).

On 2 sides of the construction site there were neighboring buildings. As a protective structure of the underground part the initial project suggested the metal sheet pile Larcen V 25 m long which was immersed by vibro immerser of high frequency.

The experience received in St. Petersburg showed that this method of immersing the sheet pile into unstable soil could result in the settlement of the neighboring buildings and exceed the allowed value. That is why foundations of the buildings along Nevskii Prospect were reinforced by piles "Titan" prior the excavation of the ditch. The piles were tested against 70 ton vertical loading.

Since the Client failed to agree with the owner of the building along Vosstania str. upon the foundation reinforcement of his building, it was necessary to make the protection wall along one of the sides of the ditch as "wall in ground" instead of pile sheet. Figure 8 (Smolenkov, 2009).

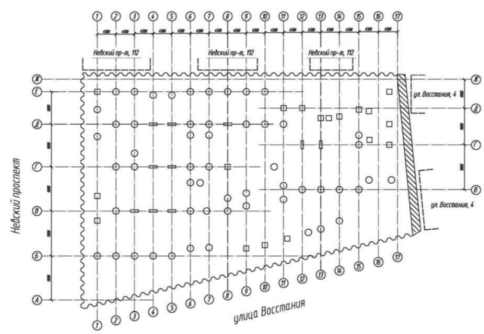

Figure 7. Scheme of the underground part of the Trade Center.

Figure 8. "Wall in ground" along one of the sides of the ditch.

Figure 9. Excavation of the soil under the ceiling.

Though the stiff sheet pile was used along three sides and "wall in ground" along the forth side, the stiffness of the structure was not sufficient due to the weak soil in the construction site. The deformation of the sheet pile below the bottom of the ditch could occur.

In order to avoid the damaging effect of the new building on the old neighboring buildings and metro station the engineers suggested to fix the lower part of the sheet pile at the depth 17–20 m by making the soil diaphragm by jet technology (Broid, 2004).

Further development of the underground space was done by Top-Down method. Some new technical solutions were applied: borrow piles-columns reinforced by steel tube and special metal profile and also borrow piles of standard diameter and with expansion in the lower part up to 1300 mm which supported the ceiling. The length of the piles was 40,8 m.

The ceilings which were put on the ground and under which the soil was later excavated through technological apertures, served as strut elements for protecting the structure. (Fig. 9).

After finishing the ceiling on the ground level the construction of the overground elements—columns, walls, ceilings of the upper floors—was started.

All the works on the ground level and further construction of the over ground level did not cause any serious additional settlements of the neighboring buildings, their foundations were earlier reinforced by piles "Titan". But the building which was not reinforced in its foundation, received deformation of the bearing structures and required the restoration.

4 THE ERECTION OF THE UNDERGROUND PART IN THE TRADE CENTER IN LIGOVSKII PROSPECT

In 2006 the territory which earlier was intended for the construction of the railway station was bought by another Company. The plans were changed and it was decided to construct there a trade Center with underground 3 level parking. The third level must have independent entrance from Ligovskii prospect which was not possible due to several reasons and as a result it was decided to have 2 levels.

The ground characteristics in the construction site are typical for the central part of St. Petersburg—glacial moren deposits, laid below weak water saturated sea, lake and lake glacial-deposite. are located on the depth 25 m.

Since the destination of the building changed, the construction scheme was changed. It became necessary to evaluate the bearing capacity of the existing piles which were erected earlier. For this purpose the ditch was excavated and piles were tested under the loading 3000 kN.

785 piles with diameter 550 mm were added to the existing piles using DDS method and 6 of them were tested under static loading (Mangushev et al., 2010).

The test results showed the growth of the bearing capacity of the piles erected earlier—the settlement of the pile was less than 30 mm under the loading 3000 kN.

When the work started again at the construction site at the end of 2006 there was already sheet pile along the perimeter of the construction site immersed to the depth of 11 m. The preliminary calculations showed that the stability of the pile sheet protection was not provided after the excavation newly projected ditch 8,5 m deep.

Different variants were checked and finally semicircular pile sheet 21 m long was chosen.

The calculations made by different experts showed that the stability of the pile sheet can be provided on condition of certain sequence of work done while excavation of the ditch.

According to the calculations made in the computer programmer "Steel Wall", during the last period of ditch excavation the deformation of the sheet pile when 2 levels of struts were made, should be equal to 34 mm and maximal value of the bending moment 303,0 kN, coefficient of the stability 1,94 (Fig. 10).

The technology of ditch excavation included the excavation of its central part and making slopes of the pile sheet wall on the projected mark and the erection of the monolith reinforce concrete plate in the center, followed by erection of strut in the form of metal beams between reinforce concrete plate and sheet pile protection. (Fig. 11).

It was suggested to make ditch excavation part by part in the area of location of metal beams and after that to make final concreting of monolith plate and walls of the underground part, after that the struts were dissembled. All the work was done

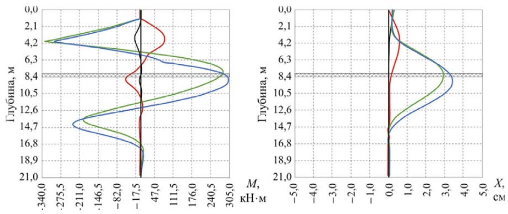

Figure 10. Calculated value of the moment M and movement X at different stages of the ditch excavations.

Figure 11. View of struts in the ditch.

Figure 12. The construction of the underground part of the Trade Center at Ligovskii prospect.

very close to the existing rail way and the building of the railway station.

The further construction of the underground part of the building was done by open technology under the protection of the sheet pile and walls in the underground part (Fig. 12). At present time the construction of the building is successfully finished.

5 CONCLUSIONS

The considered examples of these civil buildings in St. Petersburg with large underground space showed that it was possible to make the deep large ditches in soft soil on the condition of proper selection of the rigidity of the protection structure. The choice of these structures is determined by calculations and organizing the test sites.

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