Study the behavior of the boundary wall of deep foundation pit near the reconstructed building

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ABSTRACT

The article presents the geotechnical solutions for the renovation of a historic building - a monument of architecture, built in the 1907-1910 in Kazan. The reconstruction involves the construction of four-storey annex building near the existing historical building. In order to strengthen the base and the foundations of the existing building it is recommended to apply the brown-injection piles and high-pressure injection of grout into the ground base. Stability of enclosing structure from bored piles is provided by combined system of a ground berm and a multi-tiered system of strut.

Keywords: deep foundation pit; boundary wall; foundation; reinforcement of the base; soil; stability

1 INTRODUCTION

The building in question was built in 1907-1910 in Kazan, designed by architect K.S. Oleshkevich. The building layout has a symmetrical E-shape with one-story additional buildings, the walls are made of red clay brick. The Building reconstruction involves the construction of a 4-storey addition to the existing building in the underground version, while the former appearance of the building is preserved.

2 GEOTECHNICAL PROBLEMS DURING PROJECT IMPLEMENTATION

Geomorphologically, the territory of the building is located on the alluvial Middle Neo-Pleistocene fourth left-bank terrace of the Volga River (df^4Q_{II}). The territory in the survey area is complicated by erosional landforms (gully-beam system). According to the data of engineering geological surveys (Fig. 1), in the interaction between reconstructed and projected buildings and structures with the geological environment, quaternary alluvial-diluvial deposits (ad^4Q_{II}), covered by modern man-made soils (t_{IV}), are involved. The maximum thickness of the man-made layer is 2.2 m. Man-made soils are spread from the surface and are represented mainly by a chaotic mixture of loam, sandy loam, sand, soil, construction waste, woody and vegetation residues. Quaternary alluvial-diluvial loams and sands lie beneath the man-made soils. Loams vary in the number of plastic indexes (from light to heavy) and flow index (from hard to soft plastic), calcareous, iron-rich, with interlayers and lenses of sand and sandy loam. The sands are predominantly small, in the middle part of the section are of medium size, polymictic, less often are quartz with layers of loam and sandy loam. Within the study site, the presence of subsidence loamy soils (engineering-geological element (EGE) №3) with a thickness of 0,6-6,6 m is noted. Semi-solid and solid loams occur in the active zone of the soil deformation and have soaking uneven subsidence properties. Initial subsidence pressure ranges 0,103-0,205 MPa.

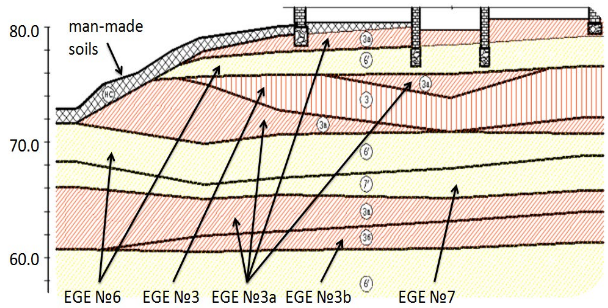

Fig. 1. Engineering geological section of the site.

During the implementation of the project, a number of problems arise, one of which is that during the examination of the historical building, the presence of significant defects and damages was found in the form of a vertical and inclined crack system, excessive deformations in the bearing brick walls and interfloor overlaps. The main reason for the formation and development these defects and damages is the presence of shear processes in the slope massif on which the building is located. The existing geotechnical situation is complicated by the presence of a subsidence layer within the compressed base thickness. The above stated required the reinforcement of the foundation base soils of the existing historical building and ensuring the stability of a slope as a whole.

The second, more difficult task is that the 4-storey underground addition to the existing building, designed in a 20-meter-deep pit, will be in close proximity to the foundation of the existing building wall (at a distance of 0.5 m). In connection with this fact, there is a need to ensure the sustainability of the foundations base and the historic building as a whole, both at the stage of underground structures construction and the existing building reconstruction, and at the stage of further operation.

In this connection, technical solutions were developed to strengthen the bases and foundations of the existing historic building, wall construction between the existing building and the newly erected underground additional structure in a deep pit, systems for ensuring stability of the enclosing wall and the building as a whole, which should be considered as a single set of measures designed to ensure the bearing capacity and stability of the bases, foundations and the historic building as a whole for the reconstruction period and further operation, as well as ensuring safe working conditions during an underground addition construction.

Within the framework of the working project, the following tasks were solved:

- a technical solution development to strengthen the bases and foundations of an existing historic building;
- a constructive solution development to the barrier structure of the pit;
- development of measures to ensure the stability of the barrier at the time of soil excavation in the pit and during further operation;
- development of a technological sequence of barrier installation and soil excavation in the pit.

Technical solutions to strengthen the foundations bases of the existing building - a monument of history and architecture allow tackling the following tasks in a comprehensive manner:

1. To transplant a part of the building in the axes "1-4" to the new foundation and thereby minimize the influence of technological processes on the installation of the deep pit in the close proximity of the wall foundation along axis 1 on the technical condition of the bearing and enclosing structures.

2. Reduce the wall movement in the pit, because the elements of strengthening the foundations bases play a gravity anchor role and limit the movement of the upper point of the wall in the pit during the excavation of the soil from the pit.

3. To reduce the lateral pressure a base soil of an existing building on a barrier structure of a deep pit to 25% due to changes in the stress-strain state of the soil within the collapse prism because of transferring some load to the reinforcing elements.

4. Unload the soil compressed thickness of the base of the existing building in case of a predictable soil soaking of the entire slope massif on which the construction site is located.

In order to optimize the cost of performing work on strengthening the bases and foundations, the existing building was conditionally divided into 2 parts, where different structural solutions were used to strengthen the bases and foundations (Fig. 2).

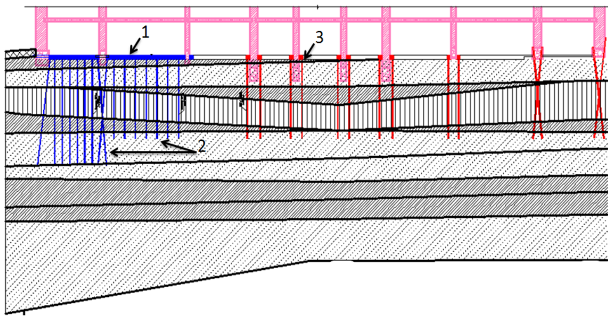

Fig. 2. Arrangement of elements for strengthening the soil foundation and existing foundation: 1 – new foundation (reinforced concrete raft); 2 – reinforcing elements in the soil; 3 – reinforcing elements of existing rubble foundations.

Thus, at the site in the axes "4-14", it was decided to reinforce the bases and foundations by partially transferring the load to vertical drill-injected piles Ø 150 mm 9 m length. The piles length is taken on a basis of a need for them to completely cut through the layer of subsiding soil (EGE № 3) and transfer the load to fine dense sands (EGE № 6). The piles are joined together by a reinforced concrete continuous grillage with a cross-section of 500 × 500 mm, and the transfer of loads on them from the walls of the building is carried out by means of through metal rolling beams concreted in foundations rubble masonry.

On the building part in the axes "1-4" it was decided to transplant the building existing foundations on a monolithic reinforced concrete raft 500 mm thick on a reinforced artificial base. To strengthen the soils, the technology of high-pressure injection of cement mortar into the soil was selected in the design amount through special injectors made of Ø 57 mm pipes, arranged with a certain step both under the entire newly constructed monolithic raft and under existing rubble foundations. Nonremovable pipe-injectors, adopted by a length of 9 m and 12 m, work as reinforcing elements. This soil reinforcement method allows creating a hard-reinforced array in the soil, which has low compressibility because a cement mortar after hardening becomes almost incompressible, and the soil around a injector in the injection process of the mortar under high pressure is also compacted. Besides, the presence of reinforcing elements in the soil will help to reduce the lateral pressure from the soil base of the existing building to the barrier structure. Based on previous studies (Mirsayapov and Koroleva 2011, 2014, 2015) the authors have developed a technique for calculating the gain of an existing building foundation base vertical reinforcement elements.

The main bearing elements of the pit barrier structure were bored piles Ø 1000 mm and a length about 33 m, joined along the top by the continuous grillage, which is connected across through reinforcing bars to the reinforcement raft foundation of the existing building. In this case, when calculating the barrier structure on the soil lateral pressure, the wall top can be considered fixed at the level of the reinforcement foundation raft.

As noted, the pit depth reaches 20 m, that dictates the necessity to installation multitiered bond of the supporting wall across the height. At this stage, there was chosen one of the two reviewed bond methods (strut, anchor), it is strut bond is the most reliable and amenable to a work quality control.

Due to the fact that the pit does not have an opposite wall, there was no possibility of transferring a strut force to it, therefore, it was decided to use the reinforced concrete frame partially erected in the pit as a supporting structure. To ensure the barrier structure stability until the installation of the strut system, it is proposed to use the passive pressure of the loading soil berm along the wall by the axis “1” (Fig. 3).

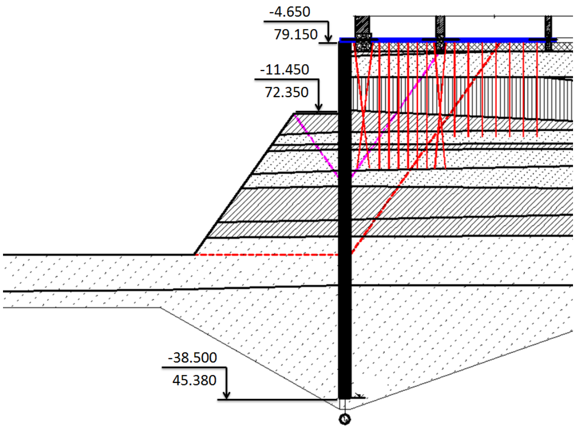

Fig. 3. Soil berm along the wall in the ground.

Therefore, in order to ensure the possibility of safely erecting the underground structure to the historic building, the work following technological sequence was proposed:

- barrier structure installation of bored piles Ø 1000 mm and the uniting grillage on the piles top, this grillage connects to the raft foundation for historic building reinforcement;
- the slope’s soil excavation until the foundation base level of the newly constructed building (the mark -24.900) leaving soil berms along the wall in the soil (Fig. 3);
- partly (within 4 spans) erection of a reinforced concrete framework of the underground additional building;
- tiered berms soil excavation in the pit and installation of the strut bond system of barrier wall with transferring load from struts to a slab of the framework at marks -10.750, -15.700, -19.750 (Fig. 4);
- making raft foundations for the monolithic frame of the underground additional building;
- the tiered dismantling of the strut system with the parallel concreting of floor slabs (Fig. 5).

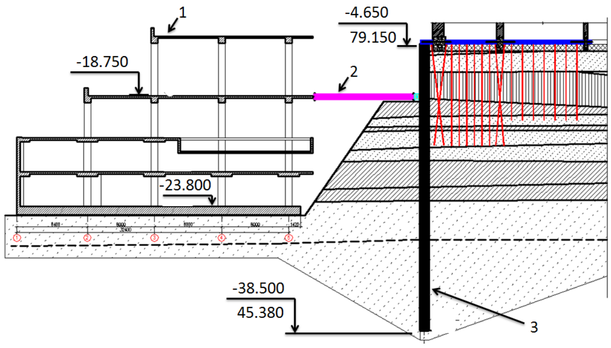

Fig. 4. Step-by-step development of berm soil and installation of a strut system for fixing the wall: 1 – new part of the building; 2 – a strut system; 3 – wall in the ground.

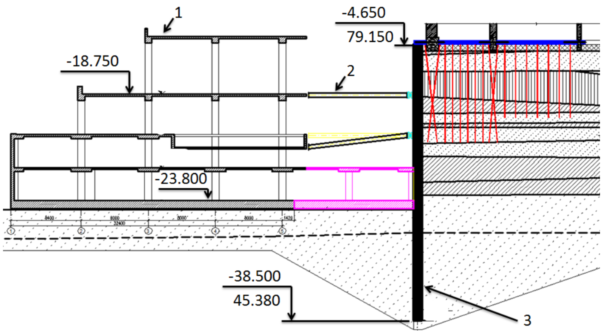

Fig. 5. Dismantling the strut system and concreting the remaining part of the monolithic frame: 1 – new part of the building; 2 – a strut system; 3 – wall in the ground.

The calculation of the bored piles pit barrier structure was made in the software package Lira 9.4 for the phased (in 4 stages) soil excavation from the pit.

Based on the designing experience such structures, the wall setting depth below the pit bottom is pre-accepted 13 m, while the total height of the designed barrier structure is 33 m.

For the barrier structure calculation there were represented diagrams of active σ_a and additional σ_q pressures on the pit barrier determined by the formulas taking into account the features of the soil massif deformation reinforced by vertical elements, reflecting the active pressure decrease and the passive pressure increase on the barrier:

$$\sigma_a = \gamma \cdot z \cdot \lambda_a - \frac{c}{tan\,\varphi}(1 - \lambda_a) \tag{1}$$

$$\sigma_q = q \cdot \lambda_a \tag{2}$$

Where λ_a is the soils active pressure coefficient, determined by the formula:

$$\lambda_a = \left(\frac{cos\varphi}{1+\sqrt{sin(\varphi+\delta)\cdot sin\varphi\cdot cos^{-1}\delta}} \right)^2 \quad (3)$$

Where φ is conditional values of the reinforced soil base internal friction angle; *c* is conditional values of reinforced soil base specific adhesion; δ is the friction angle of the soil on the contact with the wall.

The additional pressure on the soil, transmitted from the existing building foundations, located in close proximity, was taken as a continuous uniformly distributed load at a depth of 12 m (at the bottom of the injectors of the reinforcement for the existing building) with intensity q = 108 kPa.

At every stage of soil excavation, the pit barrier structure lower part was simulated as a beam on an elastic base, using the appropriate coefficient of subgrade reaction depending on the soil type and the layer depth.

Struts from steel pipes transfer the load to the monolithic frame of final stiffness, therefore, in the design scheme, the supports are made supple, the characteristics of which are taken on the basis of the reinforced concrete frame flexibility to the horizontal load.

As a calculations result, internal forces epures in the pit barrier structures sections were obtained, and forces in struts at all stages of the soil excavation were determined.

As the calculations illustrated, the qualitative and quantitative picture of bending moments and forces in struts changes at each stage.

Thus, within the soil excavation, the efforts in upper struts are decreasing from 3 to 8 times. Moreover, the greatest effort concentration is always observed in the lowest tier for any stage of the soil excavation.

The bending moments, in turn, when installing the struts next tier change their sign, the stretched and compressed zones of concrete turn out to be from one or the other side of the pit barrier structure. However, the absolute values of the bending moments do not drastically change, the moments maximum values at each stage differ within 1.5-2 times.

The required reinforcement of the bored piles barrier structure and cross-section of the steel pipes struts are selected by the internal forces maximum values. For the maximum bending moment value obtained by calculation results on 1 linear meter of the barrier for the fourth stage of the soil excavation M_{max} = 885.7 kN m required the installation of 20 rods Ø 28 mm reinforcement class A 400. Struts are designed in 3 tiers with a step of two upper tiers 3 m, for a lower tier 2 m with a diameter of steel pipes 530 mm.

In the field of transmission strut efforts on slabs in the technological seam concreting rafts line installation of embedded elements in the form of two steel plates is provided connected by rolling U-section № 22 for ease mounting struts and exceptions concrete floor slabs collapsing from concentrated strut forces.

The wall maximum displacement from the barrier deflection, the struts compression and the monolithic frame deformation and the soil deformation in the embedded zone was 19 mm according to the calculations results, which does not exceed the allowable value.

The adequacy of the pre-adopted embedment of the barrier structure below the pit bottom was checked by calculating the soil massif stability loaded with a building weight by a deep shear, for which a circular-cylindrical sliding surfaces method was used. The stability coefficient of the soil massif was 1.9 with the minimum allowable value of 1.3.

3 CONCLUSION

Based on a comprehensive analysis of the available data, a work technological sequence has been developed in order to ensure the possibility of safely constructing an underground addition to an existing building.

The calculations of the bearing capacity and the pit barrier structure stability at the all stages of soil excavation. The pit barrier movements and the required reinforcement values were established, and the bored piles reinforced frame design was developed.

A check was made of a soil massif bounded by a bored piles wall and loaded by a closely located existing building for loss of stability along with a circular-cylindrical sliding surface.

To monitor the behavior of a newly constructed and existing building, defects timely detection, existing deviations prevention and elimination, as well as assessing a correctness of the adopted calculation methods and design decisions, it is necessary to establish geotechnical monitoring of the constructed and existing buildings.

REFERENCES

Mirsayapov I.T., Koroleva I.V. (2011). Prediction of deformations of foundation beds with a consideration of long-term nonlinear soil deformation. Soil Mechanics and Foundation Engineering. V. 48. I. 4. 148-157.

Mirsayapov I.T., Koroleva I.V. (2014). Bearing capacity and deformation of the base of deep foundations' ground bases. Proc., Geotechnical Aspects of Underground Construction in Soft Ground, Seoul, 401-404.

Mirsayapov I.T., Koroleva I.V. (2015). Computational model of the carrying capacity of a reinforced foundation with cyclic loading. Soil Mechanics and Foundation Engineering. V. 52. I. 4. 198-205.