Designing and Constructing Foundations on a Landslide Slope

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Abstract: The article shows the experience of designing and installing foundations on a landslide slope in the difficult conditions of urban development of an individual residential housing located in Voronezh, 1 Sirenevaya st. Key words: construction on a landslide slope. MIDAS GTS NX, calculation and design of foundation slabs, micropiles, retaining walls, used reinforced concrete structures.

Introduction

The problems of designing and constructing on steep slopes become especially urgent in the face of the ever-increasing intensity of urban development in cities \cite{1, 2}. Calculations of the stability of the slopes rise to Charles Coulomb (1736-1806). To date, after two centuries, the assessment of the stability of slopes is still a difficult task in construction \cite{1, 3}. Difficulties in designing and building on slopes arise due to complex engineering and geological conditions and terrain differences \cite{4, 5}. Such conditions arose during designing and constructing on the site with a steepness of the slope more than 30\% in Voronezh, 1 Sirenevaya st. However, despite the additional costs connected to the anti-landslide measures, and especially to the establishing the foundation, this project is economically interesting \cite{6} for the following reasons: a beautiful view of the Voronezh Reservoir, the quiet center of the city of Voronezh (it is in 700 m from Lenin Square (Figure 1, Figure 2)), low cost of land.

Figure 1. – The view of the construction site on the aerospace map

Figure 2. – The construction site, the building space.
1. Engineering and geological conditions
The lithologic-stratigraphic section of the deposits of the building site was as follows:
EGE (engineering-geological element) 1: Filled-up ground: a mechanical mixture of chernozem with household rubbish. (datum 113.67-117.05 m). The exposed bed thickness is 5.0 m;
EGE 2: yellow sand, brownish-yellow, medium-sized, medium-dense, of low water saturation, with lenses of loam up to 10 cm. (datum 113.70-120.95 m). The exposed bed thickness is 5.0 m.
Groundwater was not detected.
The soils of EGE 2 (yellow sand, brownish-yellow, medium-sized, medium-dense, of low water saturation, with loam lenses up to 10 cm thick) are suitable for construction.
The difference in altitude between the site and the channel part of the Voronezh River is 40-50 m.
There are landslide phenomena of a different nature along the slope (Figure 2) [6]. The calculation on MIDAS GTS NX software also gave the result that the slope is unstable due to its own weight in the natural relief (Figure 3, Figure 4) [7-9].

2. Calculation and design.
When we calculated the soil settlement and the stability of the slope, it showed that unreinforced soils give ground blow from under the foundation base and that the slope is unstable (Fig. 5, Fig. 6) [2, 11, 12, 13]. When performing excavation works, the soil blow took place during the installation of reinforced concrete slabs on unreinforced bed soils, which confirms good convergence with the calculations (Figure 5) [2, 6, 14].
At the stage of working out the design decision, we adopted the following calculation scheme for calculating the building foundation (Figure 7). To reduce the soil blow from under the base, we designed an on-road edgestone in front of the building (Figure 7) [15, 16].
To reinforce the slope, we designed micropiles, which worked in combined action with the foundation slabs (Figure 7, Figure 10) [7, 12, 17, 18].

Complex engineering and geological conditions of the construction site required the use of new constructive solutions and the creation of an innovative technology for reinforcing slopes with the help of micropiles working in combined action with a thin-walled slab foundation [6, 10]. Evaluation of stability and soil settlement was performed using MIDAS GTS NX software [2, 7].
At the next stage, we calculated the settlement of the soil bed reinforced with the micropiles (Figure 8) [5, 14, 19, 20]. The calculation showed that strengthening the slope with the micropiles changed the settlement of the foundations, and they did not exceed the allowable value.

3. Foundation on a landslide slope.

The work on the landslide slope was carried out using a compact excavator EO112M.01, which worked as excavating equipment, produced ground-cement mixes. The excavator had different attachments that compacted the base soils and also arranged micropiles while performing high labor productivity (Figure 10) [16, 18]. To reduce the cost of the establishment of foundation slabs and retaining walls we applied used reinforced concrete ribbed roof slabs (Figure 12) [15]. In addition, we used vintage bricks, which remained after the demolition of the house under the threat of collapse (Figure 13) [16].
Further, we estimated the stability values of the slope of the foundation structure with reinforcement by slabs in combined action with the micropiles [15, 17]. The calculation was carried out using the MIDAS GTS NX software package by reducing the strength (reduction method), the result ($k_s = 1.4$) did not exceed the allowable values ($k_s = 1.2$) (Figure 9) [2, 5, 7].

Figure 8. The mosaic of the settlements with micropile reinforcement

Figure 9. The mosaic of the sliding surface with reinforcement by slabs working together with micropiles.

Figure 10. – The work of the excavator EO112M.01.

Figure 11. - Arrangement of panel thin-walled foundations of ribbed slabs.
4. Conclusion

1. MIDAS GTS NX program for assessing the stability of landslide slopes showed a good convergence of results with work performed on the construction site [6, 9].
2. Calculations showed that the combined action of micropiles with slabs allows one to strengthen landslide slopes [15, 17].
3. The application of used reinforced concrete ribbed slabs as slab foundations and retaining walls makes it possible to dramatically reduce the weight of the structures, which makes it possible to use automobile cranes, thereby speeding up the execution of works and reducing construction costs [5, 15, 16].
4. The excavator EO112M.01 solved the problem of manual labor during excavation on steep slopes and was used at the construction of micropiles, voluminous cement-mix grouting of the soils and consolidation of the soil base [3, 4].

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