Structural and technological solutions for engineering and geological surveys, design and operation of buildings and structures on clay soils

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Abstract. The paper offers design and technological solutions and recommendations for engineering and geological surveys, as well as the design and operation of buildings and structures on clay soils in Stavropol. The existing experience of construction in engineering and geological conditions of specific soils and associated hazardous engineering and geological processes that influence the choice of engineering protection methods for new construction and reconstruction of existing buildings and structures has been studied. Clay soils in the city are characterized by swelling and shrinkage due to seasonal fluctuations in humidity in the upper part of the aeration zone, including in the flat areas of the city, and landslide processes on the slopes. When designing foundations for areas with swelling soils, it is crucial to consider the soil's ability to expand in volume as the humidity increases, known as swelling. In swelling soils, when the humidity decreases, the soil undergoes shrinkage. The paper also provides recommendations for water protection measures during the preparation of foundations for new construction. These measures primarily focus on addressing soil swelling rather than shrinkage. Structural and technological measures are presented to increase the rigidity and strength of buildings by dividing them into separate compartments with sedimentary seams, and introducing reinforced concrete continuous belts at several levels of the building.

1 Introduction

The uniqueness of the engineering and geological conditions of the territory of Stavropol is that 95% of its area is occupied by very specific structurally unstable soils, which are associated with dangerous geological processes [1-3] . These soils include swelling and shrinking clays, as well as landslide clays, loose silty collapsible sands, loess collapsible loams, and various technogenic accumulations [4-6].

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All of them are sensitive to technogenic impacts, which are inevitable during the economic development and reconstruction of urban areas [7-9].

Swelling soils are characterized by:

- distribution and conditions of occurrence of swelling soils, their thickness, mineral and lithological composition, structure (presence of pockets, lenses and layers of dusty and sandy material) ;
- structural and textural features, conditions of occurrence of covering and underlying soils;
- the magnitude of the opening, the depth and direction of propagation of shrinkage cracks, the thickness of the cracking zone [10-11];
- relative swelling (free and under load);
- soil moisture after swelling; swelling pressure;
- linear and volumetric shrinkage of soil;
- humidity at the shrinkage limit;
- changes in the properties of swelling soils during the construction and operation of facilities.

When designing foundations for areas with swelling soils, it is crucial to consider the soil's ability to expand in volume as the humidity increases, known as swelling.

When building on swelling and shrinking soils in the city of Stavropol, the following anti-deformation measures can be recommended - the installation of layered screens in the backfill of the pit sinuses.

2 Methods and materials

After building foundations, builders almost always leave uncompacted soil in the backfill of pits, through which water easily penetrates under the foundations of buildings. In most cases, the requirements for backfilling soils are underestimated, and two options for backfilling are recommended:

1) backfilling with sandy material with the installation of annular wall drainage around the perimeter of the outer walls;

2) filling the cavities with clay soil with its layer-by-layer compaction to the value of the compaction coefficient $K_{com} = 0.95$.

The second option seems more complicated, since the space between the foundation and the wall of the pit is often narrow, and it is difficult or impossible to ensure high-quality compaction of the soil to the required density.

Current regulatory documents for such narrow spaces recommend backfilling with low-compressible soils (crushed stone, sand-gravel mixture, etc.).

The swelling soil is replaced with local non-swelling soil compacted to a specified density.

It is allowed to use swelling soils for backfilling cavities and trenches, provided that the amount of soil rise does not lead to a deterioration in operating conditions.

Constructive solutions come down to stabilizing the moisture content of the clay soil surrounding the foundations, stabilizing its structural connections, and converting the shrinking and swelling soil into an inert material.

In this case, the scope of work is reduced to the volume of backfill or the active zone under the base of the foundations.

The first method is to install backfills that do not respond to seasonal changes in humidity.

It is allowed to use swelling soils for backfilling cavities and trenches, provided that the amount of soil rise does not lead to a deterioration in operating conditions.

The magnitude of the soil rise, as well as its subsidence, cannot be determined in design practice. The material in the backfill must satisfy two incompatible requirements: not allow water to pass through and not react to soaking.

To meet these requirements, the backfill should consist of local materials such as sand and clay. The backfill should primarily be composed of sand, with thin and frequent layers of clay interspersed throughout.

Sand, the pores of which are completely or partially filled with water, will serve as a buffer system to maintain stable moisture in clay layers and ensure mechanical stability of the entire volume of soil.

In addition, the presence of thin (1-3 cm) clay layers within the sand, which are supplied with water from it, prevents the formation of shrinkage cracks. The implementation of this method to protect residential buildings is straightforward both structurally and technically.

Layered screens can be made both in the backfills of pit cavities and in the swelling foundations of buildings under construction (Fig. 1).

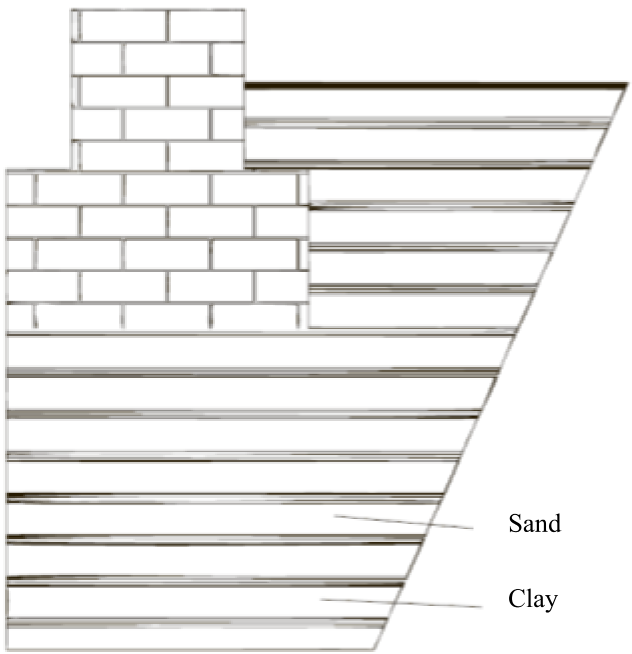

Fig. 1 Layered screens in building foundations and backfills

2nd method. By direct rotation of the auger, clay soil is extracted from the backfill, and by reverse rotation, sandy soil is fed into the bosom of the pit. Replacing swelling clay with inert sand (bored sand pile) performs two functions: it creates a rigid reinforcing element in the volume of swelling soil and a moisture buffer-stabilizer for the surrounding shrinking and swelling clay.

3rd method. It is proposed to make concrete bored, reinforced and unreinforced piles, made by auger method or using pneumatic hole punches. The technology makes it possible to make piles in any cramped conditions, including in the basements of emergency buildings. It has been comprehensively tested in various cities of the North Caucasus.

4th method – Lime piles. Holes with a diameter of 32-50 cm pass through the soil and are filled with quicklime. In unstable soils, wells are drilled with casing. Lime reacts with groundwater, is quenched with a large release of heat, and the lime pile increases in diameter to 60-80%.

The technology can be improved by using a screw method for filling lime.

This will make it possible to abandon casing pipes in quicksand unstable soils, to abandon rammers that are lowered into casing pipes to batch compact lime, and will make it possible to use serial survey drilling rigs for work on emergency sites that are sensitive to dynamic impacts.

3 Results

The main task of engineering and geological surveys on clayey landslide slopes is to establish the degree of the slope stability and its prediction.

A correct solution for this specific problem with clay soils in Stavropol has yet to be found. In many cases, including when calculating landslides, the stability coefficient turned out to be more than 1.0.

The discrepancy between the calculation schemes and the actual development of landslides can be explained by:

1. The layering of clay deposits and the presence of thin sandy layers, which made it difficult to representatively select samples for laboratory shear tests. Soil monoliths were better selected and preserved from stronger layers of clayey strata.

2. Short-term laboratory shear tests could not fully take into account the long-term processes of relaxation and creep of clayey soils in the massif.

3. The presence of fine sand layers in the clayey stratum inevitably contributes to the development of suffusion processes, which are also not modeled in laboratory conditions.

These processes could sharply reduce the stability of the landslide layer, since they are accompanied not only by the removal of water-soluble salts, but also by destructuring and softening of the soil due to the destruction of its structural bonds.

The processes associated with weathering and the formation of deep (up to 5-7 m) shrinkage cracks in the summer, especially on southern-facing slopes, remain unexplored.

Despite these problems, standard research on landslide slopes currently carried out by local survey organizations should not be abandoned.

These studies need to be supplemented with the following:

- monitoring of landslide slopes according to special programs drawn up with the participation of scientific organizations;
- conduct a more in-depth study of the structure, composition and properties of specific clay soils on the territory of Stavropol;
- evaluate the effectiveness of existing landslide prevention measures and begin testing new methods of strengthening landslide soils.

The reliability of landslide prevention measures and structures is primarily ensured by a qualified assessment of the engineering and geological conditions of the territories presented in km^2 in Figure 2.

To ensure the success of new and underdeveloped methods, it is crucial to have author's supervision and scientific support from specialized organizations.

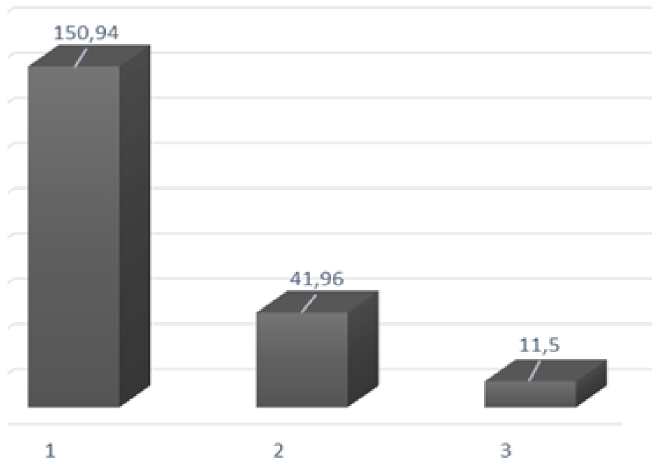

Fig. 2 Distribution of lands in Stavropol according to the conditions for the development of landslide processes (districts – 1, 2, 3)

All technologies, including regulatory ones, must undergo pilot production testing of their effectiveness before the start of construction work, followed by possible adjustments to the project.

4 Discussion

Pile foundations are considered the most effective method of construction on swelling and shrinking soils. In this case, preference is often given to bored concrete piles, since driven piles require preliminary drilling of leader wells.

Swelling clays greatly reduce their load-bearing capacity when soaked and swollen. They must be tested under natural conditions with soaking of near-pile soil.

During the soaking process, due to a decrease in the strength characteristics of clay soils, pile failure may occur, which is no different from the subsidence of piles in loess soils.

To calculate the bearing capacity of piles, it is impossible to use static sounding data, which, as in subsidence soils, creates the illusion of reliability of structurally unstable soil.

5 Conclusions

The bedrock clays of Stavropol are often saline and aggressive towards the concrete of underground structures. The use of piles in the seismic conditions of Stavropol, even with their support on reliable soils, requires additional and special justification.

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