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STUDY OF VULNERABILITY AND PROTECTION OF BUILDINGS AND STRUCTURES ON STRUCTURALLY UNSTABLE CLAY SOILS

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Abstract

The study provides a clear definition of the vulnerability of buildings and structures designed and operated on structurally unstable clay soils. The condition of critical external negative impact on structurally unstable clay soil was considered as a random variable. Distribution functions were given for various degrees of damage or destruction of objects on structurally unstable clay soils. The methodology for study and construction of engineering protection schemes for objects designed and operated on structurally unstable clay soils was presented. An example of the energy balance of the object engineering protection with optimal loading of the building was given schematically. A scheme for protection of an object on structurally unstable clay soils with their optimal loading and a scheme for protection of an object on subsiding soils using a screen and drainage were also provided. A formula was given for determining the degree of implementation of the objectives of protecting objects on structurally unstable clay soils

Keywords: vulnerability, structurally unstable soil, building, structure, engineering protection, scheme

I. Introduction

The threat of damage to structures due to uneven deformations of structurally unstable clay soils (subsiding, swelling, populated and water-saturated) depends on the relative position of the source of soil moisture or drying and the action of various loads (primarily the weight of the structure itself) acting on the structurally unstable soil.

A threat of negative impact on structurally unstable soil causes occurrence of damage if this negative impact (a sharp change in the moisture content of structurally unstable clay soils) leads to critical uneven deformations of buildings and structures. Then the structures are damaged or, in extreme cases, go into an emergency state (complete destruction), leading to significant discomfort (material and psychological) for the owners and people operating the facilities. The possibility of damage and destruction of buildings and structures due to the impact of adverse factors on structurally unstable clay soil depends on the vulnerability of the building (structure) - structurally unstable (clay) soil system. The issues related to the study of the vulnerability of technical systems and territories to various adverse impacts are discussed in the monographs by V.A. Akimov, N.N. Radayev, V.D. Novikov, V.V. Lesnykh [1, 2], V.V. Bolotin [3], A.A. Rogozin [4], V.A. Vladimirov, Yu.L. Vorobyev, N.A. Makhutov and et al. [5], V.T. Alymov and N.P. Tarasova [6], N.N. Chura [7] et al.Vulnerability, by definition, depends both on the properties of the object itself and its ability to withstand adverse impacts, as well as on the intensity of these impacts [4].

II. Theoretical definition of vulnerability of engineering structures on structurally unstable clay soils

Let $\Delta_{cr.}$ critical action (moisture, leaching, evaporation, transpiration, and the pressure of water extrusion from the soil) at which damage or failure of a building or structure doesn't occur. Critical action characterizes the geotechnical stability of a building or structure against external adverse impacts. Geotechnical stability is the property of a construction object (building, structure) to maintain its geotechnical parameters within construction norms and rules and perform its functions during and after external adverse impacts on structurally unstable soil. The property of a building or structure opposite to geotechnical stability is geotechnical vulnerability (it can be called conditional geotechnical vulnerability). The characteristic of conditional geotechnical vulnerability of a geotechnical object coincides with the characteristic of the geotechnical ultimate stability of the object (building or structure). This critical external action (or actions) is the threshold beyond which damage occurs, leading to a geotechnical emergency situation.

$$\Delta'_{cr} \equiv \Delta_{cr}\,, \tag{1}$$

In geotechnical calculations and related engineering assessments of the consequences of hazardous influences on structurally unstable clay soils due to the effects of individual unstable factors (duration of exposure, quantity of negative agents affecting the unstable soil, influence of adjacent soils), the critical action can be treated as a random variable *Jcr.* The complete probabilistic characteristic of conditional geotechnical vulnerability of buildings and structures is the distribution function of critical action:

$$F_{cr}(\Delta_{cr}) = P(J_{cr} < \Delta_{cr})\,, \tag{2}$$

Distribution function $F_{cr}(\Delta_{cr})$ for geotechnical objects of a specific type can be considered as the physical laws governing the damage or failure of buildings or structures under consideration of the detrimental effect.

The random variable of critical action on known types of structurally unstable soils, interacting with typical buildings or structures, is typically distributed according to the normal law:

$$J_{cr} \in N(\mu_{cr}, \sigma^2_{cr})\,, \tag{3}$$

where μ_{cr} is the mean of the critical action on structurally unstable clay soils, and $\sigma^2_{\Delta_{cr}}$ - variance of the mean expectation Δ_{cr}.

Accordingly, the complete probabilistic stability of geotechnical objects under critical external actions is characterized by the function:

$$R_{cr}(\Delta_{cr}) = P(J_{cr} \geq \Delta_{cr}) = 1 \cdot F_{cr}(\Delta_{cr}) \tag{4}$$

representing the dependence of the probability of geotechnical objects stability on the considered structurally unstable clay soils on the level of adverse external impact.

Different distribution functions are distinguished

$$F_{cr}(\Delta_{cr} \geq |d) = P(J_{cr.d} < \Delta_{cr}) \tag{5}$$

for different degrees *d* of damage or destruction of objects on structurally unstable clay soils, or for degrees of damage or destruction not less than a specified D:

$$F_{cr}(\Delta_{cr}|D) = \sum_{d=1}^{D} F_{cr}(\Delta_{cr}|d)\,. \tag{6}$$

These functions for each object situated on structurally unstable clay soils can be established on the basis of existing experience gained from analyzing the consequences of past damages and failures of buildings and structures on structurally unstable clay soils. This can also be derived from assessments of the resilience of buildings and structures under uneven deformations of structurally unstable clay soils. Critical external factors for specific geotechnical objects can be evaluated through the following methods:

- field-experimental methods: using data on the degree of damage and destruction of buildings or structures of similar construction on corresponding types of structurally unstable clay soils due to previous adverse external factors;
- computational-experimental methods: based on the results of studies on the response of buildings or structures to trial external impacts on structurally unstable clay soils with which these buildings or structures come into contact;
- computational-modeling methods: employing theoretical models and computer programs considering the structural features of buildings or structures to resist damages and emergencies both in normal conditions and with engineering protection against various adverse external impacts on structurally unstable clay soils.

$F_{cr}\left(\Delta_{cr}|d\right)$ for a fixed critical adverse external impact on structurally unstable clay soils, Δ_{cr} can be called "physical vulnerability" of buildings or structures interacting with structurally unstable soils referring to the proportion

$$\alpha_d\left(\Delta_{cr}\right) = N_d\left(\Delta_{cr}\right)/N \tag{7}$$

of damaged (destroyed) buildings or structures in the case of a specified intensity of Δ_{cr} . В (7) $N_d\left(\Delta_{cr}\right)$ of external negative impact *d*, representing the number of buildings (structures) that incurred damage (destruction) from the total number *N* of buildings (structures) interacting with structurally unstable clay soils in the area affected by the specific intensity of external negative impact Δ_{cr} . As is evident, mathematically, they coincide:

$$\alpha_d\left(\Delta_{cr}\right) \equiv F_{cr}\left(\Delta_{cr}|d\right). \tag{8}$$

III. Methodology for the study of the schemes for engineering protection and objects on structurally unstable clay soils

The stability of the considered geotechnical objects is established on the basis of everyday experience and experimental construction and operation of buildings or structures on structurally unstable clay soils. This stability is then codified in building codes, regulations, and guidelines at a level where the prevented damage from failures and accidents still outweighs the additional costs of engineering protective measures enhancing the stability of these objects constructed and operated on structurally unstable clay soils.

According to the modern standards, engineering protective measures against external negative impacts and the uneven deformations caused by them increase the cost of buildings and structures by 20-40%. Without these protective measures, repair costs for buildings and structures, depending on the type of unstable soils, range from at least 20-50% up to the complete demolition of the emergency structure, resulting in 100% loss of the object, plus costs for demolition and site remediation of the affected area.

The damage (destruction) possibility to considered geotechnical structures and the occurrence of emergency situations significantly depends on the protection of buildings or structures on structurally unstable clay soils, ensured through the implementation of preliminary protective engineering measures included in the construction project of buildings and structures on territories occupied by structurally unstable clay soils.

Methodological principles for engineering protection of buildings and structures operated on structurally unstable clay soils are proposed against various hazardous negative externalities on the basis of alteration of energy potentials.

The following components are identified for solving the problem of engineering protection of objects designed and operated on structurally unstable clay soils: the source of negative externality (Δ), the source of constant load (q) from the building or structure, the source of probabilistic shortterm external (seismic) impact (S), the receiver (structurally unstable soil) of external impact (T), and the engineering protection which shields or reduces the intensity level of negative externality on structurally unstable clay soils to permissible values for safe construction and operation of objects (Z).

Let's consider from the total flow of negative energy E directed towards the receiver T and entering the engineering protection Z (Fig. 1), part E is reflected (shielded), part E_2 is absorbed by the receiver (soil) T, and part E_3 is dissipated into zones outside the receiver T. Thus, Z can be characterized by the following energetic coefficients:

- reflection coefficient $\xi = E_1 / E$,
- absorption coefficient $\beta = E_2 / E$,
- dissipation coefficient $\rho = E_3 / E$.

The overall equilibrium state of geotechnical object is represented as follows:

$$\xi + p + s = 1. \tag{9}$$

Sum

$$\beta + \rho = 1 - \xi - h\ , \tag{10}$$

where

$$h = E_h / E\ , \tag{11}$$

characterizing the unreflected energy flow E_h passed into the engineering protection Z.

If $\beta = 1$, then Z reflects all the energy of negative externality on the structurally unstable clay soil.

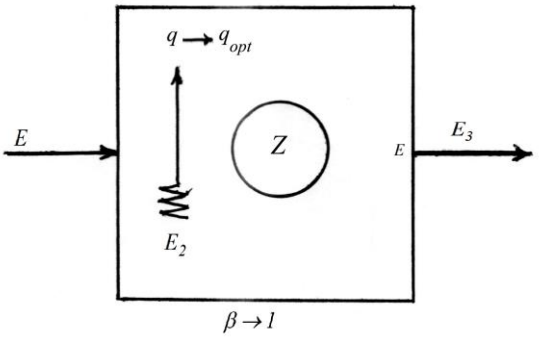

Figure 1: *Example of the energy balance of engineering protection for an object on structurally unstable clay soil (q_{opt} - optimal load)*

If $\rho = 1$, then Z reflects all negative energy from external impacts on the object associated with structurally unstable clay soil.

In practice, protective measures are often used in a combined form, for example $\xi + \rho = 1$. This means employing protective anti-filtration screens and draining water away from the protected area beyond its boundaries using specialized drainage systems.

The study [8] represents the examples of absorbing negative externalitys (soaking) on structurally unstable subsidence and swelling clay soils, with a protective measure involving maximizing water absorption by the soil. In these examples, techniques for optimizing the load from buildings or structures on the foundation soil were employed, specifically $q \rightarrow q_{opt}$. .

In the first example, the base area of the building foundation was maximally expanded (replacing strip foundation with a raft foundation). This approach achieved a specific pressure on the subsiding soil that was lower than the initial settling pressure. In the second case, the width of the strip foundation of a building on swelling clay soil was reduced to ensure that the specific pressure from the foundation on the soil base was less than the active pressure due to swelling of the clay soil [9]. The energy protection balance scheme for engineering protection of objects on structurally unstable soils during $\beta \rightarrow 1$ is shown in Fig. 1.

For the aforementioned examples, the protective engineering measure Z ensured achieving optimal loading of structurally unstable clay soils (subsiding and swelling) by buildings constructed on them, denoted as q_{opt} . This approach made structurally unstable soils fully transparent to negative externalities (soaking).

Fig. 2 illustrates the transparency scheme of structurally unstable clay soils to external negative moisture (W) under optimal loading conditions of structurally unstable soils (T).

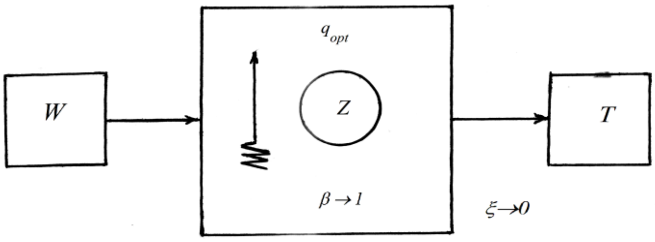

Figure 2: *Scheme of protection for geotechnical object on structurally unstable clay soils at their optimal loading*

Consider the case, when the building is located on subsidiary soil of a type II along the subsidence. In its natural state, the building retains its stability due to the structural strength of subsidiary soil. The building will go into a state of emergency under a negative externality (uneven soaking) due to uneven subsidence of the substrate. For the purpose of preventing an accident, a comprehensive protective film screen and drainage are provided.

Fig. 3 shows the scheme of reflection (screen) and removal (drainage) of negative externality (soaking) on subsidiary soil, loaded with the weight of the building, exceeding its structural strength in the moistened state.

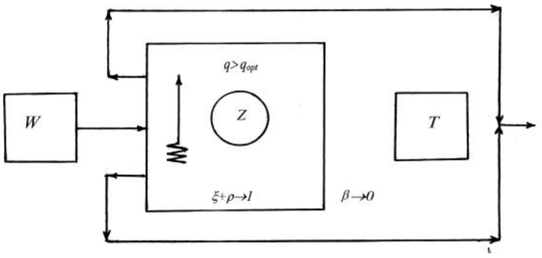

Figure 3: *Scheme of protection of an object on subsidiary soil in the case of using reflective anti-filtration screen and discharge drainage*

Realization degree of the objectives of protection of buildings or facilities (objects), erected and operated on structurally unstable clay soils can be expressed by:

$$K_s = \frac{M_z}{M_w} \tag{12}$$

where K is the protection coefficient of the object on structurally unstable clay soils; M_z – the cost of protective engineering measures; M_w – the cost of repairing a geotechnical object damaged or affected by the negative externality W (uneven soaking).

If $K_s \leq 0{,}3$ this is considered acceptable for the design and practical implementation of protective engineering measures. If $0.31 \geq K_s \geq 0.50$ this is considered a necessary condition for the design and practical implementation of protective engineering measures when there is no choice of construction site for critical buildings and structures. If $K_s > 0.50$, this is considered an unacceptable condition for the design and implementation of protective measures for geotechnical objects on structurally unstable clay soils.

IV. Conclusion

A threat of negative impact on structurally unstable soil causes occurrence of damage if this negative impact leads to critical uneven deformations of buildings and structures.

In geotechnical calculations and related engineering assessments of the consequences of hazardous influences on structurally unstable clay soils due to the effects of individual unstable factors, the critical action can be treated as a random variable.

The random variable of critical action on known types of structurally unstable soils, interacting with typical buildings or structures, is typically distributed according to the normal law. Critical external factors for specific geotechnical objects can be evaluated through the following methods: field-experimental methods; computational-experimental methods; computational-modeling methods.

Methodological principles for engineering protection of buildings and structures operated on structurally unstable clay soils are proposed against various hazardous negative externalities on the basis of alteration of energy potentials. The schemes are given of protection for geotechnical object on structurally unstable clay soils at their optimal loading and of an object on subsidiary soil in the case of using reflective anti-filtration screen and discharge drainage.

It is proposed to define realization degree of the objectives of protection of buildings or facilities (objects), erected and operated on structurally unstable clay soils through the object's protection factor.

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