CHANGES IN PLASTIC ZONES IN LESS BASES UNDER SEISMIC VIBRATIONS

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Abstract: This scientific article presents the author's hypothesis as the basis of his research. In accordance with this hypothesis, the central determining issue is the change in the strength characteristics of the soils around the foundation and the associated spread of plastic deformation in the sub-foundation zone of the foundation with all the ensuing consequences (soil uplift from under the base of the foundation).

Keywords: strength characteristics of soils, earthquakes, dynamic stability, bearing capacity, bulk soils, plastic deformation, connectivity, design load.

Introduction An analysis of cases of accidents in structures that suffered during strong earthquakes shows that soils lying in the zones bordering the foundation often cause a weakening of the bearing capacity of the foundation [1-7].

This is due to the fact that the pits opened for the construction of the foundations of structures are usually filled with the same soils (loose, bulk) without special observance of measures that increase their dynamic stability. Only in small cases, bulk soils around foundations are compacted with the help of rammers, which is often ineffective from the point of view of the task we are considering. As a result, the soils lying in the zones bordering the foundation are in many cases the most susceptible to dynamic impact. This ultimately leads to the unloading of the base of the foundations and the development of unacceptable plastic deformation of soils in the sub-foundation part of the base.

Let us give an example from the practice of operating a residential building 83 on the street Nakkoshlik in Tashkent (Uzbekistan). A four-story brick building with a technical basement of 2 m and a foundation depth of 2.4 m. Specific load from the weight of the structure is 0.14-0.15 MPa.

The soils lying at the base of the building are represented by loess-like loams, 20-22 m thick. Groundwater occurs at a depth of 17.0 m from the earth's surface. In the first years of the building's operation, the foundation soils turned out to be additionally moistened as a result of atmospheric water runoff (the slope of the relief towards the house), irrigation of adjacent areas, and failure of water supply facilities. At the same time, the moistened soil was characterized by the data in Table 1.

Table 1. The moistened soil

Index	Unit of measurement	Value
Soil particle density	t/m^3	2.68
Density of natural soil	t/m^3	1.79
Soil moisture	%	20.7
Porosity	%	44.6
Angle of internal friction	degrees	27^{0}25

Connectivity	MPa	0.0011

On December 11, 1980, an earthquake occurred in the western suburbs of Tashkent, the epicenter of which is located 17 km from the city center in close proximity to the village of Nazarbek, which gave the name to this earthquake. In the village, the earthquake was felt with a force of 7-8 points, in Tashkent 6-7 points on the MSK-64 scale (the magnitude of the main shock at the epicenter was 5.2 on the Richter scale), which caused deformation of the foundation soil of the house. Due to the seismic subsidence of moistened loess soils, cracks in the foundation and front wall with dimensions of 1-2 cm were formed. Cracks were also formed in bulk soils around the house. These cracks, varying in size (the largest 3-5 cm in the heavily moistened southern part) were accompanied by liquefaction and subsidence of soils. There was a bulging of the soil from under the base of the foundation as a result of a decrease in its bearing capacity.

Results. To study the cause of this phenomenon, soil samples were examined taken from depths of 2.6 and 4.5 m at the southern end of the house. The vibration of loess-like loam showed that the change in strength (cohesion) depends, to a greater extent, on the vibration frequency.

The experiments were carried out with vibration with acceleration α=600 мм/$с^2$. The change in the vibration mode in these experiments was achieved due to the oscillation frequency at a constant amplitude value. The recorded parameter in the case under consideration was the cohesion of the soil before and after the experiment. So, at a frequency f=2 Гц initial soil cohesion Cw(H)=0.004 MPa decreased to Cw(K)=0.0025 MPa; at f =6Гц respectively:C_w (H)=0.0045 МПа on the C_w (K) =0.0010 МПа; at f =10 Гц - C_w (H)=0.0050 МПа on the C_w (K)=0.0004 МПа at f=15 Гц - C_w (H)=0.0046 МПа on the C_w (K) = 0.

It is noted that at frequencies above 10 Hz (high-frequency earthquakes), the soil cohesion decreases to zero even with a 6-magnitude earthquake.

The above example quite clearly indicates a violation of the structure of the water-saturated soil and its subsequent compaction, and, at the same time, the transition to a liquefied state of the zones bordering the foundation is possible, causing unloading of the base and the development of plastic deformations (shear deformations) under the foundation of the building. The example also indicates the relevance of the task and its very important national economic significance.

In the light of the analysis of such cases from the practice of construction, the author set himself the task of studying the possible conditions for the violation of the structure and compaction of the water-saturated loess from the point of view of predicting changes in the bearing capacity of the foundation under these conditions. When solving the problem, it became necessary to develop some working hypothesis, which should be subjected to experimental verification and, in the future, theoretical justification using the experimental findings. As a result of the study, it was supposed to draw practical conclusions from them and give appropriate recommendations for the construction of structures on weak water-saturated loess soils related to the possible impact of seismic forces on them.

Calculation of foundations composed of weak water-saturated loess in seismic regions can be carried out using the well-known formulas of soil mechanics, subject to the obligatory observance of the condition $\boldsymbol{\alpha}_{кр} > \boldsymbol{\alpha}_{с}$ (где: $\boldsymbol{\alpha}_{с}$ - maximum seismic acceleration, acting on ground array**;** $\boldsymbol{\alpha}_{кр}$ - critical acceleration - threshold acceleration determined by the strength characteristics of the soil structure), if this condition is not met (i.e.при $\boldsymbol{\alpha_{\text{кр}}} < \boldsymbol{\alpha_c}$), then, when assessing the bearing capacity of the foundation, the decrease in the strength of the soil during vibration should be taken into account.

To determine the allowable pressure on the soil, there are various solutions based on the provisions of the theory of elasticity. Basically, these solutions differ from each other in the assumption, to one degree or another, of the zone of limit equilibrium (destruction) in the sub-foundation zone of the base.

These zones will obviously be extinguished by the pressure of the soil located in the edge zones of the structures above the base of the foundation H. Most of these developments are based on the well-known formula H.P. Puzyrevsky [13]:

$$Z = \frac{P_0}{\pi \rho_w}\left(\operatorname{ctg}\varphi + \varphi - \frac{\pi}{2}\right) - \left(H + \frac{C_w}{\rho_w \operatorname{tg}\ {}_w}\right) \quad (1)$$

where Z is the depth of the limit equilibrium zone;

Po - load acting on the base;

H - depth of foundation;

Cw - cohesion (plastic connectivity) of the soil;

φ_w- angle of internal friction of the soil;

ρ_w- average soil density at moisture W .

According to this expression, the limiting equilibrium (destruction) zone increases with increasing load Po.

However, in relation to the dynamic conditions of the soil, this provision is valid for the case when the condition αcr > αc is met. Otherwise (with αcr <αc) we are faced with the possibility of an increase in time of the destruction zone at a constant acting load (Po = const) in seismic conditions of the foundation. This increase is associated with a change (fall) in the strength characteristics of the foundation soils, due to the destruction of their structural connectivity when a seismic load is applied to the foundations of structures. In the cases under consideration, the stability of structures is determined, first of all, by the state of the soil in the zone bordering the structure.

Violation of the soil structure, which initially occurs in the marginal zones of the base of the foundation, gradually spreading into the depths, leads to unloading in the sub-foundation zone, which causes a decrease in the effect of deepening the foundation in seismic conditions. This is what characterizes the increase in the active zone, which passes into a dynamically disturbed state, depending on the intensity of the oscillation. Within this zone, as noted by many experts [1-7,10-12], there is a weakening of the strength of the soil due to the effect of counterpressure in cases of complete or partial water saturation.

As is known, the role of the deepening of a structure is reduced to providing an additional load in the marginal zone of the foundations at the level of their sole, which extinguishes the shear stresses acting here. With full weighing (liquefaction) of the soil layer in the zones bordering the foundation, the effect of deepening will be completely lost and the internal bonds of the soil under vibration conditions are gradually weakened. In this case, the effect of deepening will depend on the duration of the dynamic impact. Then the above formula becomes:

$$Z = \frac{P_0}{\pi \rho_w}\left(\operatorname{ctg}\varphi + \varphi - \frac{\pi}{2}\right) - \left(H_{c(t)} + \frac{C_{w(t)}}{\rho_w \operatorname{tg}\varphi_w}\right) \quad (2)$$

where, $H_{c(t)}$ - changing in time with fluctuations in the effect of deepening the foundation;

$C_{w(t)}$ - plastic cohesion of the soil at time t .

In expressions (2) $C_{w(t)}$, corresponds to the weakening of loess connectivity during oscillation and is determined by the formula:

$$C_{w\,(t)} = C_{w(k)} + [C_{w(\text{н})} - C_{w(k)}]e^{-\mu t} \ldots \quad (3)$$

where, $C_{w(\text{н})}$, $C_{w(k)}$ - respectively initial (before vibration) and final (after vibration) values of soil cohesion;

t - oscillation duration;

μ is a parameter determined experimentally.

In accordance with expression (3), the loess connectivity value at the initial moment of dynamic load application is determined by the dynamic parameter μ. Hence it follows that the dynamic parameter μ is a very important factor in our analysis, taking into account the possibility of soil transition to a dynamically disturbed state.

Thus, the value of the limiting equilibrium zone will increase due to a decrease in the loess connectivity in time and a drop in the deepening effect during oscillations (Fig. 1). Under these conditions, the tolerance of the fracture zone when determining the design load, as is done in the static calculation with dynamics, can lead to a violation of the overall stability of the foundation. Hence, in relation to the dynamic conditions of operation of foundations made of soils that can go into a disturbed state, Z=0 should be taken.

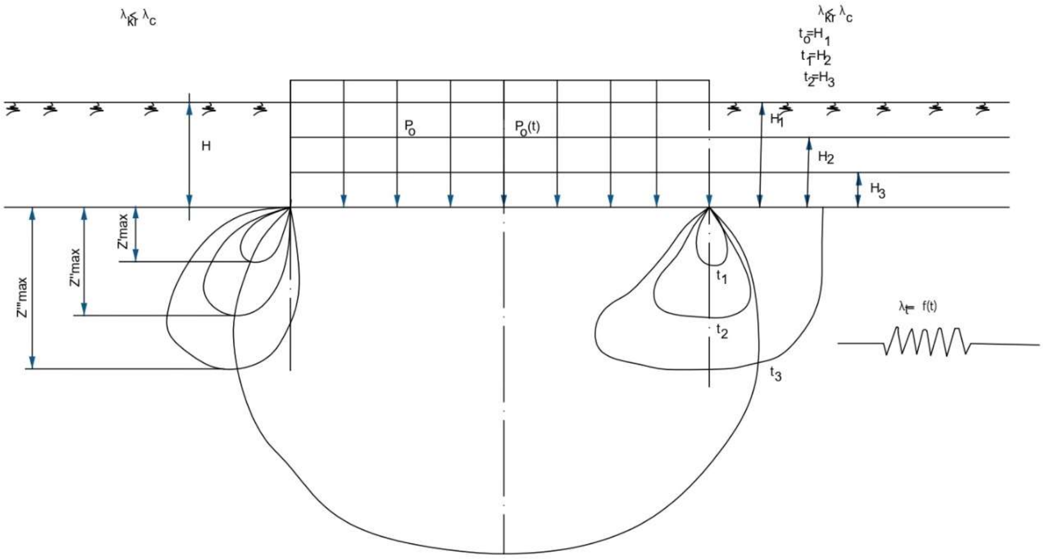

Fig.1 **Calculation scheme of the working hypothesis**

This hypothesis was put by the author in the basis of his research. In accordance with this hypothesis, the central determining issue is the change in the strength characteristics of the soils lying around the foundation and the associated spread of plastic deformation in the under-foundation zone of the base with all the ensuing consequences (soil uplift from under the base of the foundation).

Conclusions

1. The results of the analysis and generalization of macroseismic data on the consequences of strong earthquakes that occurred both in our country and abroad showed that most damage to structures during earthquakes was associated with soil conditions, their incorrect accounting, lack of research data and methods for assessing seismic stability cohesive soils, in particular loess soils, often led designers and builders to an insufficient solution to this problem.

2. The theoretical basis for the seismic disruption of the structure (liquefaction) of moist loess soils is the possibility of changing the shear resistance (soil strength) during various oscillatory movements. A change in soil shear resistance occurs in all cases of foundation soil vibrations, however, a violation of its structure (liquefaction) can occur if the seismic acceleration acting in this case exceeds the threshold (critical) acceleration due to the strength of the soil. The use of critical acceleration as a criterion for disturbing the structure of loess soils makes it possible to determine the dynamic shear resistance in the following criteria: when $\alpha cr > \alpha c$, the soil retains its structure and the change in shear resistance is determined taking into account only inertial forces caused by vibrations of foundation structures: when $\alpha cr < \alpha c$, the soil structure is destroyed and the shear resistance is determined taking into account the variable stress state of the medium and the soil strength parameters that change under these conditions.

3. The change in soil connectivity over time under oscillation conditions is calculated according to the above formula, according to which the change in soil connectivity is affected by the initial and final connectivity values, the duration of the oscillation and the dynamic parameter determined empirically. Numerous experimental studies have established a change in soil connectivity depending on the initial state of soil density-moisture, water-colloidal connectivity, granulometric composition, as well as on the intensity and nature (in amplitude and period) of the oscillation.

4. Loess soils, unlike non-cohesive ones, capable of rapid compaction when the structure is destroyed, being in a water-saturated state, cannot immediately compact, since the cohesion forces are violated only over time under vibration conditions. The cohesion of loess soils under conditions of intense vibration decreases gradually. The nature of the change in connectivity in time is established.

5. Loess soils are compacted as a result of a violation of the connectivity that determines their structural strength. Experiments carried out to study the coefficient of dynamic compaction found that the value of this coefficient is much less at the beginning of the destruction of the soil structure than in the further process of oscillation, which is explained by the influence of still undisturbed soil connectivity on the process of loess compaction.

6. The duration of the dynamic impact on the loess soil is of great importance in violating its stability. It affects the values of changes in soil cohesion, dynamic compaction coefficient.

7. Soils lying in the zones bordering the foundation are in many cases the most susceptible to dynamic influence and often cause a weakening of the bearing capacity of the foundation.

8. Violations of the soil structure that occur initially in the edge zones of the base of the foundation, gradually spreading into the depths, lead to unloading of the foundation in seismic

conditions

9. With full weighing (liquefaction) of the soil layer in the zones bordering the foundation, the effect of deepening will be completely lost and the internal bonds of the soil under vibration conditions are gradually weakened.

10. The size of the limiting equilibrium zone (plastic zone) will increase due to a decrease in the loess connectivity in time and a drop in the effect of deepening during vibrations.

11. In the seismic conditions of the foundation, the tolerance of the limiting equilibrium zone when determining the design load (as is done in the static calculation) can lead to a violation of the overall stability of the foundation.

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