Vibration creep of loess soils

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Abstract. Taking into account the rheological properties (creep) of clay soils when solving problems of soil mechanics is important, because many inaccuracies in forecasts related to soils arise from an under-accounting of these properties, which are characteristic of clay soils. The report deals with the issues of vibration creep of moisten loess soils, related to the precipitation of structures and the permissible load on the soil. The method of experimental research and the results of experiments on the dependence of the coefficient of soil vibration creep on the acceleration of vibrations are presented. The factors influencing the vibration creeping deformations of the forest, including the role of soil adhesion and the duration of shaking, are established. Research results are of great importance in the practice of constructing unique engineering structures in seismic areas.

1. Introduction
The accumulation of volume deformations over time is characteristic for compaction of loess soils under vibration effects [1-5]. This is due to the gradual accumulation of mutual displacements of particles from each individual oscillation period. As the frequency of concussion increases, the mutual displacements of the particles are superimposed and the process of their continuous displacement occurs [6-9].
The vibration creep soil is called accumulation of deformations over time at constant acceleration of vibrations and stresses [6].
The influence of vibration creep is especially clearly manifested in water-saturated loess soil that is subjected to intense shaking. As experiments show, in this state of loess, the internal friction forces between particles under the action of vibration can be completely destroyed, and the soil acquires the mechanical properties of a viscous liquid [10-14]. In such a forest, bodies with a density greater than its density sink at a certain rate, and at a lower rate, they float up.

2. Methods
The creeping property of the soil, which is manifested in the conditions of concussion, can be characterized by the coefficient of vibration creep [6]. The coefficient of vibration creep of the loess and the factors influencing this indicator are determined with almost sufficient accuracy using the method of «ball test» by N. A. Tsytovich. This method is based on the Stokes formula, which establishes the dependence of the speed \( v \) of movement of the ball in a viscous medium on the force \( N \) acting on it, the radius of the ball \( r \) and the coefficient of vibration creep \( \eta \) (1):

\[
N = \frac{4}{3} \pi r^3 \eta v
\]
Studies on the manifestation of vibration creep and the process of this phenomenon have shown that vibration creep depends on many factors, the main ones are: the state of density-humidity of the soil, its mineralogical and granulometric compositions, strength characteristics (the angle of friction and cohesion), the external load acting on the soil, the force and nature of the vibration effect (acceleration, frequency, amplitude, period and duration of vibrations), etc. [15-18].

The method of conducting experiments to study the dependence of the coefficient of soil vibration creep on the acceleration of vibrations was as follows.

The soil with a certain density and humidity was placed in a test vessel of the vibration unit. Then, at a constant value of the acceleration of the vibrations, the ball was recorded as sinking under various static loads acting on it. After completing the experiments with a certain value of vibration acceleration under a given static load, the acceleration value was changed, the dive study was performed again at the following load values, and so on.

### 3. Results and Discussions

In As a result of this type of experiments, graphs of the dependence of the ball's immersion on time for different load values are compiled, while the value of the oscillation acceleration remains unchanged. The results of research showed a variable rate of immersion of the ball in the soil at the beginning of the experiment, and then a decrease in this speed as the depth increases. However, as the ball sinks, the acceleration of the dive tends to zero, and the speed becomes more or less constant. This circumstance depends on the magnitude of the load applied to the ball and the value of the acceleration of the oscillatory movement.

The relationship between the steady rate of immersion of the ball and the load acting on it is linear. The coefficient of proportionality between the load applied to the ball and the steady speed of its immersion (the coefficient of vibration creep), as seen in Figure 1 depends significantly on the acceleration of the oscillation.

![Graph](image)

**Figure 1.** Graph of the dependence of the speed of the ball sinking into the soil on the intensity of the oscillation

\[ N = 6 \cdot \pi \cdot \eta \cdot \nu \cdot r \]
Figure 2 illustrates the graph of the dependence of the value of the coefficient of vibration creep on the acceleration of vibrations. As can be seen from this graph that at acceleration of vibrations, smaller vibrations of the forest practically does not affect the value of the coefficient of vibration creep of the soil. Only when $\eta > 1.5$ g the vibration creep coefficient begins to decrease. The relationship between the coefficient of vibration creep and the acceleration of vibrations can be approximately represented as:

$$\eta = \beta \times (\alpha - \alpha_0),$$

where $\alpha_0$ - the threshold vibration creep of a soil.

The dependence of the cohesion forces in connected soils on their state of humidity suggests that the coefficient of vibration creep will also depend on the humidity of the loess. In this direction, research has also been carried out on a vibration installation, the method of which is similar to experiments to determine the dependence of the coefficient of vibration creep on the acceleration of oscillatory motion. Experiments were conducted with the same ball and in the same loess soils of different humidity, however, the acceleration of vibrations, as well as the static load applied to the ball remained unchanged in all studies.

Figure 3 illustrates the graph of the dependence of the value of vibration creep of forests on soil humidity.

The figure shows that the coefficient of soil vibration creep is not constant over time and depends on the loess cohesion forces. However, the cohesion forces, as the viscosity coefficient of clay soils, can increase or decrease depending on the degree of moisture. Reducing the cohesion force in additionally water-saturated soils reduces the value of the coefficient of vibration creep. If we assume that the amount of cohesion forces in soils depends on the moisture content in them, then we can assume that the coefficient of vibration creep will also depend on the soil humidity. In our experiments, any increase in soil moisture (for example, up to 12-13%) this led to an increase in the value of the coefficient of vibration creep (8 or more times). Further increase in humidity causes a gradual decrease in its value.
Figure 3. Character of changes in the cohesive and viscosity of the soil when moisten

The results of experiments on the dependence of the coefficient of vibration creep on soil moisture suggest that, all other things being equal, the ball will be immersed by vibration (hence the increase in the coefficient of vibration creep) at the highest speed in the case when the soil is in a fully water-saturated state.

In studies with loess soils we encountered some specific features:
- the dampened loess compaction during oscillation was shown some time after the load was applied;
- the intensity of compaction at the initial moment was characterized by relatively low values and gradually increased to a certain value until it reached a stable state;
- the duration of being in a stable state of deformation depended on the soil humidity.

This indicated the need to take into account the duration of the oscillation along with its intensity when assessing the vibratory creep of the soil, which made it possible to make the amount of time necessary for the manifestation of creeping deformation of the soil dependent primarily on the strength of the loess cohesions.

It is known that the instability of the structure of loess soils is due to the characteristic weak connectivity of their structural elements. The bond strength depends on the composition and water resistance of the aggregating substance. The ability to soften and dissolve in water a natural cementing substance that creates connectivity between loess particles determines the nature of the bonds in full or to a large extent.

The nature of connectivity of loess soils is expressed by the physical and chemical nature of the bonds, their water resistance and mechanical strength. Let’s assume that the soil has a loose addition and has cohesion forces. Loss of stability of the structure of such a soil is possible when the cohesion forces between its individual particles are violated under the influence of pressure on the contact particles during oscillation.

4. Conclusions

The Analysis of the research results in the light of the above assumption shows that the following conditions are necessary for the violation of the structure of connected soils and the transition to a creeping state:
- loose addition of soil particles in which the porosity of the soil before oscillations of $n_{o}$, which causes the violation of its structure, would be more of porosity of the soil $n_{k}$ after exposure to the given factor, i.e. $n_{o} > n_{k}$.
- the intensity of the vibrations as acceleration, must be able to break the forces of cohesion between particles of soil;
- the duration of the oscillation should be the time required for the occurrence of a stable creeping state of the soil;
- if the cohesion forces between the soil particles are not disturbed by the active vibrations, the soil is not deformed. The vibration creeping state of the soil is also not apparent when the duration of the vibration is measured only in a few seconds (for example, the duration of the explosive effect).

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