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THE NATURE OF THE CHANGE IN THE CONNECTIVITY OF MOISTENED LOESS SOILS DURING VIBRATION

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ABSTRACT

This scientific article presents the results of studies of the nature of changes in the connectivity of moist loess soils during vibration. Basically, the results of laboratory experimental experiments are presented to determine the weakening of the connectivity of moistened loess soil and its transition to a dynamically unstable (liquefied) state in the process of oscillation, which also significantly affect internal and external factors (the state of density-moisture content of the soil, the presence of colloidal minerals, particle size distribution, the value external load, nature, duration and intensity of dynamic impact, etc.) to reduce soil cohesion.

KEYWORDS

Loess soil, soil cohesion, moist soil, macroporous soil, fluctuation, soil density-moisture, colloidal minerals, granulometric composition, duration and intensity of dynamic impact, magnitude of external load.

INTRODUCTION

Macroporous loess soils occupy large areas on the globe (about 13 million km², which is approximately 10% of the land). Large areas occupied by loess soils are located in the CIS republics (former republics of the USSR), China, India, Iraq, Afghanistan, Australia, USA,

Canada, Argentina, Uruguay, Brazil, North Africa, Ruminia, Hungary, Bulgaria, Germany, Poland, France and many other parts of the world. Most large industrial and high-rise civil facilities, as well as many cities, are located in the development zone of loess

macroporous, subsiding soils, so the issues of accident-free construction on these soils will become particularly relevant. Some territories of the above states are located in seismically active zones of the globe, i.e. in these areas, earthquakes often occur with a magnitude of 6-9, and sometimes even 10 points on the International MSK-64 scale. The design and construction of buildings and structures on loess soils, in seismic regions, ensuring their strength, stability and reliable operation is one of the most difficult problems of modern construction. When designing and erecting buildings and structures on loess soils in seismically active areas, serious difficulties arise due to insufficient knowledge of the nature of the phenomena occurring in such soils during their fluctuations of various intensities [1-8]. The difficulty of using macroporous, subsiding moist loess soils as the foundations of buildings and structures in seismically active areas is mainly caused by the following conditions [4,5]:

- a) Loess subsidence soils in natural conditions, being in a moist state, are characterized by relatively low strength, which indicates a slight stability of their structure under dynamic influences;
- b) Buildings and structures erected on moist loess soils, even with low-intensity seismic effects, experience significant seismic precipitation due to structural disturbance and additional compaction of foundation soils.

The need to take into account these phenomena leads to the solution of a set of issues related to the identification of processes that cause dynamic structural disturbance and subsequent compaction of moist loess soils. Due to the lack of studies of the dynamic stability of moistened loess soils, as well as the developed calculation methods, designers are not able to correctly take into account soil conditions when designing buildings and structures. This often leads to

unreasonable solutions to the problems of designing the foundations of structures and to unjustified economic costs, and in some cases to severe consequences during strong earthquakes.

Quantitatively, the degree of compaction of moistened loess soils depends on many factors: bond strength, soil porosity, and the intensity and duration of oscillations. Consequently, the deformation of loess soils during vibrations is the result of very complex processes occurring in the thickness of the soil, which cannot be assessed by individual indicators, for example, by macroporosity or moisture content, etc. The deformation of the loess during shaking is associated with its unstable structure, which is characterized for loess soils by a weak connection of structural elements [9, 10].

Despite the long period of study of loess soils, the origin, as well as the mechanism of their deformation due to their internal connection, remain unclear. This is due to the diversity of genesis, properties and composition, as well as various natural moisture content of the rocks.

At present, experts have proposed various hypotheses about the structure of internal bonds of loess soils. However, in moistened loess soils, these bonds have a nature that is well described by modern electrokinetic theory. Additional water saturation of the rock is always accompanied by swelling of the soil associated with further thickening of the water shells of the particles. In this case, the soil particles move away from each other, leaving the zones of molecular extension, weakening the bonding forces between the particles. The force of attraction of water to a particle depends, in turn, on the thickness of the water shells, with an increase in which the force of molecular attraction decreases. This circumstance indicates a relatively

slight disruption of the structure of water-saturated loess soils when exposed to a dynamic load [6, 7].

An analysis of experimental data and cases of numerous damage to buildings and structures during earthquakes shows that the strength of moistened loess soils can decrease under certain dynamic conditions, and the soils themselves can go into a liquefied state. The strength of loess soils, as is known, is determined by their internal cohesion. This circumstance indicates the only possible option for reducing connectivity due to the transition of bound water in the water shells of soil particles into free water during the oscillation process.

Determining the change in the connectivity of loess soils under dynamic conditions is a known difficulty, and it becomes more complicated as the duration of the impact of the dynamic load on the soil decreases. Fixing at least a few points in experiments within tens of seconds, coinciding with the duration of the earthquake, requires very thorough experiments using the most accurate, continuously recording instruments and equipment. According to the analysis, to determine the change in soil cohesion in a few tens of seconds, a special research technique is needed.

MATERIALS AND METHODS

In our experiments, the nature of the change in loess connectivity was fixed by immersing a ball into the soil, installed on the surface of the sample. The ball stamp method proposed by Prof. N.A. Tsytovich, in order to determine the change in the magnitude of the adhesion forces of cohesive soils, very simply, conveniently and quickly (without unloading the sample from the vibrating platform) it is possible to establish the magnitude of soil cohesion before and

after vibration, which in the conditions of our experiments was not possible in other ways [11,12].

This makes it possible to determine the value of loess soil connectivity according to the formula (when the ratio of the stamp settlement l_s to its diameter d_s should be less than 0.1, i.e. $\frac{l_s}{d_s} \leq 0.1$):

$$C_w = 0.18 \frac{P_s}{\pi d_s l_s}$$

where, P_s – is the weight of the ball with the load; d_s – is the diameter of the ball; l_s – draft of the stamp; 0.18 – the coefficient was found theoretically on the basis of the established academician. A.Yu.Ishlinsky for plastic bodies of constancy of the ratio of hardness to yield strength.

Cohesion C_w , determined by the ball stamp method, should be considered as some complex characteristic that allows estimating not only cohesion (adhesion), but also internal friction for plastic soils to a certain extent, which can be used, for example, when calculating the ultimate load on clay soils according to the formulas of ideally coupled bodies (excluding friction, which is automatically taken into account by the value C_w).

The experiments were carried out according to the following methodology:

1. Two samples were taken from a single monolith. After preliminary compaction at a given load on one of them, the initial value of connectivity was determined.
2. The second sample was subjected to dynamic impact while maintaining the same static load. After the shaking ceased, a new connectivity value was determined (Table 1).

Table 1. Change in the connectivity of loess soils during vibration

Ground	Oscillation acceleration, mm/s ²	Connectivity, MPa	
		initial	ultimate
Loess loam	3000	0,05	0,0025
	2000	0,035	0,010
Loess-like sandy loam	3000	0,005	0,0003
	2000	0,01	0,001

RESULTS AND DISCUSSION

As a result of the experiments, two values of the connectivity values were obtained, corresponding to the initial $C_w(\eta)$ (before vibration) and the final $C_w(\kappa)$ (after vibration) states of the loess soil.

To elucidate the general nature of the change in the value of connectivity during vibrations, we relied on the indications of the deformation in time of the balls, which were widely used in our experiments. As noted, the immersion of the ball into the ground and its velocity during shaking testified to a decrease in the cohesiveness or viscosity of the soil under the conditions of the experiment.

All experiments were carried out in triplicate. The immersion of the ball into the soil and its speed during vibrations showed a decrease in the soil cohesion value under the experimental conditions.

However, it must be remembered that in all cases the loess shaking is associated with the transition of soil from one state to another (for example, from plastic to fluid, etc.), which after some time acquires a new state as a result of compaction under its own weight. This, in turn, slows down the progressive decrease in soil cohesion, and in the process of long-term shaking, we are already faced with the opposite picture, i.e. with a progressive increase in the value of $C_w(\kappa)$. Obviously, this is explained by the fact that, with prolonged shaking, the contacts between the

particles are restored again and free water turns into bound water, i.e. soil bonds are restored.

On the basis of these studies, it was possible to conclude that, unlike non-cohesive soils that can immediately compact after a structural breakdown, loose water-saturated loess soils with the compaction process undergo complex internal transformations as their cohesion is broken under vibration conditions. Obviously, this process in water-saturated loess soils is accompanied by a change in their connectivity, which was confirmed by experiments with a ball.

At the same time, special studies in laboratory conditions have established that the weakening of soil cohesion and its transition to a liquefied state depends on many internal and external factors, and we will briefly dwell on these factors.

Soil density-moisture state. When conducting an experiment with cohesive soils with preliminary compression of samples under a shear load, the total shear resistance under successively increasing loads increases not only due to internal friction, but also due to an increase in cohesive forces under conditions of increasing soil density and decreasing soil moisture. This circumstance gives reason to believe that the values of normal stresses (determining the initial density-moisture content of the soil) acting in the thickness of the soil can play a significant role as

indicators of the dynamic stability of the soil (due to an increase in cohesion).

To clarify the nature of the phenomena under study, the author carried out numerous experiments on undisturbed structures on samples of loess soils with varying degrees of moisture. At the same time, the initial and final values of connectivity were recorded, corresponding to a certain density-moisture content of the soil after shaking. The initial state of the density-moisture content of loess soils was created as they were moistened and subsequently compressed under various loads (0.01; 0.02; 0.04; 0.06; 0.08; 0.1 MPa) on pre-compaction devices.

It can be seen from Fig. 1 that the values of the connectivity of loess-like soil (loess-like sandy loam) at the same intensity of dynamic impact depend on its initial value, determined by the state of density-humidity equivalent to the acting pressure. Moreover, a more gentle change in connectivity under these conditions is characteristic of specimens preliminarily compressed by higher loads. Also, from Fig. 1, there is a change in the connectivity of compacted loess-like soil depending on various vibration accelerations, i.e. with an increase in the acceleration of vibrations, the soil cohesion decreases.

A similar pattern is also observed from the graph, which illustrates the change in soil cohesion as the pre-compaction pressure increases. The higher the moisture content of the soil and the lower its density (*ceteris paribus*), the more significantly the soil cohesion decreases. This circumstance is explained by a decrease in the forces of molecular attraction (with an increase in soil moisture), the magnitude of which depends mainly on the density-moisture state of the soil.

The case under consideration is characterized by a graph (Fig. 2) in the form of a function $C_w = f(w)$, compiled according to the results of the experiment on loess-like loam. During the experiment, the tested soil samples were given different humidity by artificial soaking. In all cases, pre-moistened soils were subjected to shaking with intensity $\alpha = 3000 \text{ mm/s}^2$ while maintaining the static load. With an increase in humidity up to 10%, even at vibration accelerations of 3000 mm/s^2 , which is equal to the value of seismic vibration accelerations at a 9-point seismic impact (according to the international scale MSK-64), no disturbance of the soil structure occurred, no decrease in soil cohesion was observed, and the soil did not experience any vertical deformations. When a moisture content of 14-15% (optimal humidity) was reached, a sharp decrease in soil cohesion occurred. This is due to a weakening of the cohesion of rocks with an increase in humidity. This decrease continues to the degree of humidity $S_r = 0,8$ and then the cohesion value tends to a constant value, which is clearly seen from the graph shown in Fig.2.

It follows that the decrease in the connectivity of the studied soils occurs most intensively in the range of moisture content from optimal to water saturation (up to the degree of moisture content $S_r = 0,8$).

The results of the experiments once again confirmed the previously noted conclusion about a sharp decrease in the cohesiveness of soils with an increase in their moisture content and a decrease in density.

Thus, the experiments showed a positive effect of density-moisture (due to the action of pressure P_0) on the value of the initial cohesion of the soil, in addition, a decrease in the magnitude of the seismic effect (α_{calc}), which can transfer the soil into a dynamically unstable state with an increase in the density-moisture of the soil. However, in this case, the processes



observed in the experiments are distorted, since the role of the change in the stress state during oscillation and the duration of the shaking is not taken into

account. This issue related to the nature of connectivity required a more detailed study.

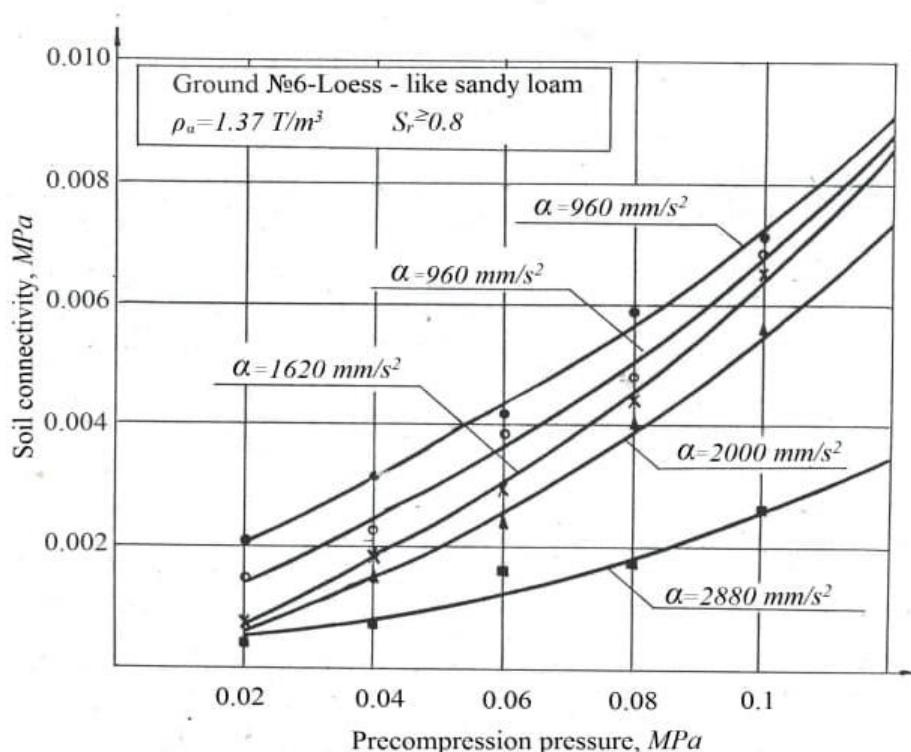


Figure 1. Change in cohesiveness of compacted loess soil depending on various vibration accelerations

The role of water-colloidal connectivity. Colloidal minerals that are part of soils affect the degree of damage to their structure during shaking.

The process of hydration is accompanied by a thickening of the water shells on the particles, which leads to an increase in the distance between them, and as a result, to a weakening of the manifestation of intermolecular forces and the very cohesion of the

soil. The properties of soils containing clay particles are also largely determined by the group of colloids.

The relationship between the composition of colloidal-dispersed soil minerals and the violation of their structure was studied by prof. B.M. Gumensky, determining the effect of vibration on the properties of montmorillonite, kaolinite and hydromicaceous clays at a vibration frequency of 4000

rpm and an amplitude of 1 mm. Based on these experiments, B.M. Gumensky made the following conclusions [9]:

1. The degree of compaction of clay soils during vibration does not depend on their initial physical state, but is determined only by the duration of the shaking. This is explained by the fact that shaking causes a redistribution of particles in clays and causes their denser packing due to the appearance

of free water due to the transformation of physically bound water during vibration. The transformation, in turn, depends on the duration of the shaking. Vibration creates, as it were, lubrication and the possibility of easier movement of particles relative to each other. In this case, bound water, which is in the cells of the framework and is released during its destruction, also plays a certain role.

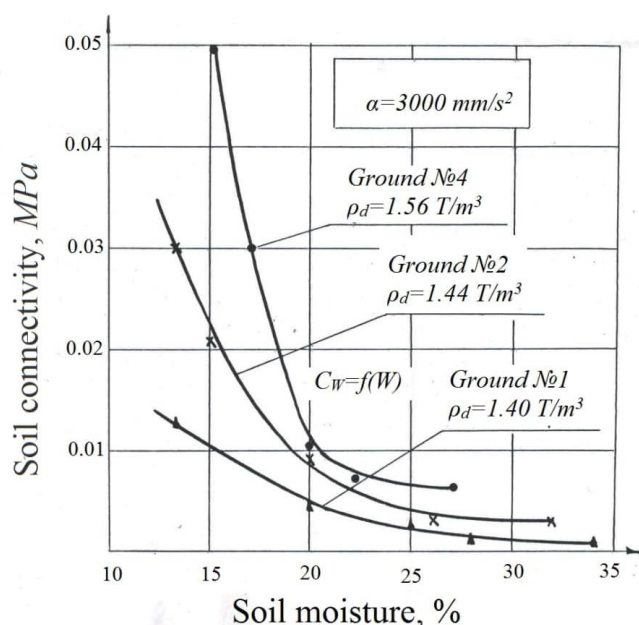


Figure 2. Reducing the cohesion of loess-like soils with an increase in their moisture content

2. Vibration has the following effect on the strength of the structure of clays of different mineralogical composition. With the initial moisture content of clays vibrating for 15 minutes, the highest structure strength was noted for hydromicaceous clay (compaction 12.5%), the lowest for kaolinite (14.6%), and the lowest for montmorillonite clay (35.4%).

The large compaction of montmorillonite clay is explained by the content of a large amount of diffuse water in it, compared with hydromicaceous and kaolinite clays.

Consequently, in minerals from the montmorillonite group, the ability to transition into a dynamically unstable state is more pronounced than in minerals

from the hydromica or kaolinite groups. This suggests that the violation of the soil structure depends on the structure of crystal lattices and colloidal minerals. The latter indicates an increase in the ability of the transition to a dynamically unstable state of soils, in the colloidal shells of which there are montmorillonite minerals.

The role of the granulometric composition of the soil. When considering issues related to the violation of the structure of the soil during vibration, a certain importance is attached to the size of its particles.

Researchers who have studied the thixotropic transformation of clay soils set the maximum particle size limit for the transition of soils to a dynamically unstable state of 0.005 mm. Views of this kind were expressed by Winkler. In his opinion, all substances having a particle size of less than 0.005 mm, if they are sufficiently friable, can be liquefied in water.

Of interest are the statements of Prof. M.N. Gersevanova that the necessary condition for soil liquefaction is colloidal fractions no larger than 0.001 mm. At the same time, there should not be fractions larger than 0.01 mm in the soil, since they quickly settle. However, studies by B.M. Gumensky revealed a greater role for the mineralogical composition of colloidal particles, rather than grain size [14,13].

To clarify the significance of the particle size in the possibility of violating their stability, we conducted a series of experiments with various soils. The soils taken for testing were characterized by different physical properties (in terms of density, granulometric composition, etc.). The main parameter to be measured in these experiments was the fixation of the beginning of the immersion of the ball installed on the surface of the test sample. As already noted, during the

vibration process, the ball sinks into the ground due to the weakening of its connectivity.

The results of the experiments made it possible to draw the following conclusions. The transition of cohesive soils to a dynamically unstable (liquefied) state does not depend on the particle size and mineralogical composition, but is determined by the porosity of the soil, the intensity and duration of the shaking.

P.L. Ivanov made a similar conclusion for sandy soils. With appropriate shaking, it was possible to break the structures of soils having particles of any size. At the same time, the duration of stay in a liquefied state depends, under all other conditions, on the particle size and the amount of heavy minerals in the composition of the soil. With an increase in the particle size, the duration of the presence of particles in a disturbed state is reduced. The role of heavy minerals in the composition of the soil during the acceleration or deceleration of the process of breaking its structure is quite obvious and does not require further explanation [15, 16].

Intensity and nature of oscillation. As is known, at present, in the field of dynamics of non-cohesive soils, the question of the violation of the static stability of any non-cohesive soils under the corresponding dynamic conditions is indisputable, only the magnitude (intensity) of the applied dynamic load is unknown. This generally applies to loess soils. However, along with the intensity, the oscillation duration will also play a certain role in the violation of dynamic stability.

The results of numerous experiments made it possible to establish a directly proportional dependence of the immersion of the ball into the ground on the intensity of the oscillation. This confirmed the influence of the

shaking intensity on the violation (weakening) of the soil strength.

The main task of our research is to establish the decrease in the cohesion of loess soils depending on the intensity of the oscillation. For this purpose, experiments were carried out with various types of loess soils (sandy loam, loam). The sample was subjected to dynamic impacts of various intensity.

It can be seen from Fig. 3 that the values of the connectivity of loess soils, other things being equal, depend on the intensity of the dynamic impact, i.e. decrease with increasing intensity, measured by acceleration.

The decrease in the connectivity of loess soils with increasing accelerations is unconditional. However, it is necessary to single out the most significant influence on the decrease in the cohesion of soils of the

oscillation frequency. As the practice of construction and analysis of the consequences of earthquakes shows, for the foundations of structures, the most dangerous (in terms of violation of dynamic stability) are high-frequency earthquakes (Gazli, Uzbekistan, 1976, frequency 16 Hz; Tashkent, Uzbekistan, 1966, frequency 10 Hz, etc.).

The author conducted experiments to determine the role of vibration frequency in reducing the cohesion of moist loess soil. The experiments were carried out with vibration with an acceleration of $\alpha=600\text{mm/s}^2$. The change in the vibration mode in these experiments was achieved due to the oscillation frequency at a constant amplitude value. Soil cohesion was determined before and after vibration. The experiments were carried out at vibration frequencies from 2 to 12 Hz. The frequency changed stepwise with three-minute intervals (Table 2).

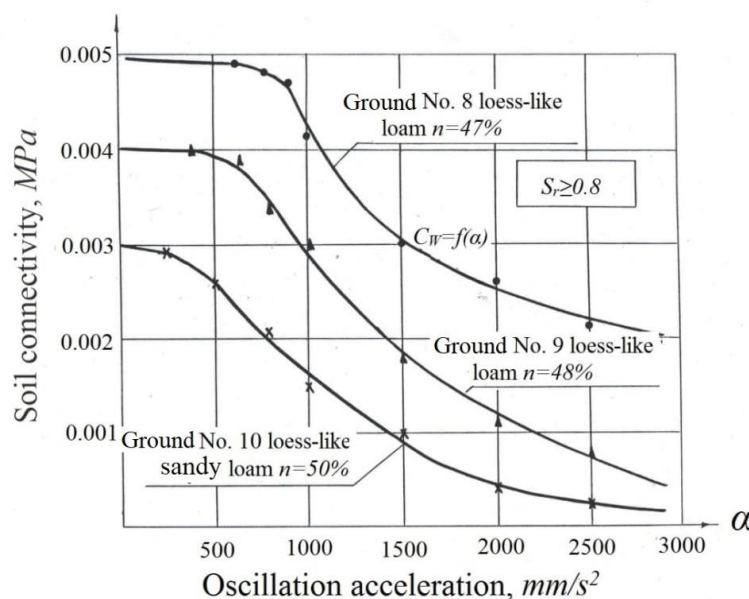


Figure 3. Change in the connectivity of loess-like soils from the acceleration of vibrations

Table 2. Influence of oscillation frequency on the change in the connectivity of moistened loess soil

Ground	Oscillation acceleration, mm/s ²	Vibration frequency, Hz	Connectivity to vibration, MPa	Connectivity after vibration, MPa
Loess loam	600	2	0,0041	0,0025
Loess loam	600	6	0,0045	0,0010
Loess loam	600	10	0,0050	0,0004
Loess loam	600	12	0,0046	0

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

As follows from the performed experiments, the decrease in the connectivity of moistened loess soil also depends on the oscillation frequency. The influence of dynamic action on the decrease in soil cohesion is more effective if, all other things being equal, this action is characterized by a high frequency.

With an increase in the acceleration of the oscillatory movement, as studies have shown, the degree of change in the strength characteristics of the soil increases accordingly. However, in many experiments with a ball, its gradual immersion into the ground was noted at constant values of the shaking acceleration. This shows that, along with the magnitude of the calculated acceleration, the duration of the impact is of great importance. Depending on it, the degree of violation of the structure (connectivity) of the soil increases.

Oscillation duration. Back in the fifties of the last century, Prof. N.N.Maslov and Yu.Ya.Velli, in experiments with water-saturated clays, drew attention to the great importance of the duration of

ground shaking in the process of violation of its stability. In particular, Yu.Ya.Velli noted that the value of critical acceleration for cohesive soils should be determined taking into account the duration of the expected shaking. In studies with loess soils, we came across some of their specific features:

- Compaction of moistened loess during shaking manifested itself after a certain period of time;
- The compaction intensity at the initial moment was characterized by relatively low values.

This indicated the need to take into account the duration of the shaking along with its intensity when assessing the seismic resistance of cohesive soils, which made it possible to make the amount of time required for the destruction of the soil structure and the manifestation of its corresponding deformation primarily dependent on the strength of the bonds. The instability of the structure of loess soils is explained by the characteristic weak connectivity of their structural elements. The bond strength depends on the composition and water resistance of the aggregate. The ability of softening and dissolution in water of a natural cementing substance, which creates a connection between loess particles, determines completely or to a large extent the nature of the connections. The nature of the connectivity of loess

soils is expressed by the physicochemical nature of the bonds, their water resistance and mechanical strength.

Let us assume that the soil has a loose structure and has cohesive forces. The loss of stability of the structure (liquefaction) of such a soil is possible in case of violation of the cohesion forces between its individual particles under the action of pressure on the contact particles in the process of shaking.

The analysis of studies shows that the following basic conditions are necessary for the violation of the structure of loess soils:

- 1) Loose composition of soil particles, in which the porosity of the soil n_n before the start of the shaking, causing a violation of its structure, would be greater than the porosity of the soil n_k after the impact of the specified factor, i.e. $n_n > n_k$;
- 2) The intensity of the shaking, expressed as acceleration, must be able to break the forces of connection between its particles;
- 3) The duration of the shaking should be the time required for the transition of bound water into free water.

An analysis of these conditions shows that if the cohesive forces between the soil particles are not disturbed by the current vibration, the soil does not deform. Soil deformation does not occur even when the duration of the oscillation is measured in only a few seconds (for example, the duration of an explosive effect).

In nature, there may be cases when, in different zones of the soil mass, the cohesion forces between particles are due to cements of different strength. Obviously, during vibration, the deformation of the particles will be different in different places, the soil structure will be

preserved where the cohesive forces are the strongest and are due to more rigid cements. Figure 4 shows the effect of shaking duration when changing the connectivity of moist loess-like soils. As follows from the graphs, the magnitude of the decrease in soil cohesion within 60-120 sec. when fluctuating with intensity $\alpha = 2500 \text{ mm/s}^2$ is about 5-15 times or more. With further shaking, the cohesiveness of the soil begins to gradually increase. The beginning of intensive deformation of moistened loess soils in the process of oscillation corresponds to 5-30 sec. and more from the moment of applying the dynamic load on the ground. This is explained by the fact that during the shaking of the loess soil, which has some connection between particles, the dynamic load is perceived primarily by these connections, for the complete destruction of which a certain time is required. The nature of the change in connectivity over time obviously depends on the physical and chemical phenomena in the soil that occur during the oscillation process.

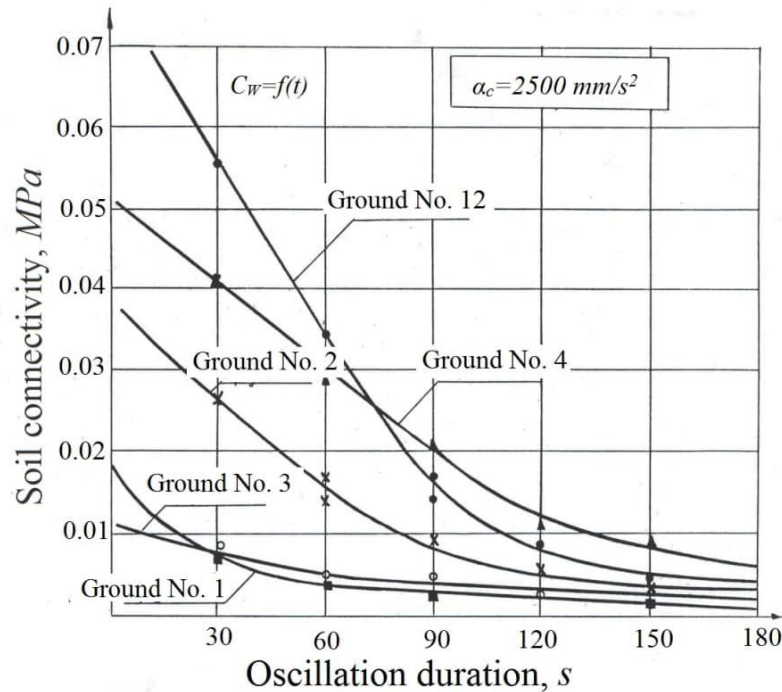


Figure 4. The nature of the change in the connectivity of loess-like soils in time during fluctuations. The experiments were carried out at the degree of soil moisture

From these experiments, it was also possible to trace the fact that short-term dynamic loads applied to the soil violated only the weakest structural bonds of the soil, and subsequent, relatively long-term vibrations violated these bonds more effectively. Therefore, we can conclude that the decisive role in the seismic disruption of the connectivity of moist loess soils belongs to the oscillation time. To substantiate this conclusion, experiments were carried out with soils with the same physical and mechanical properties and vibration intensity. The duration of the shaking served as a variable parameter. It should be noted that the soil compacted by 5 mm at an acceleration of shaking of 1000 mm/s² for 3 minutes did not deform at an

acceleration of 1600 mm/s² for 40 seconds. So the dynamic

The stability of loess soils is maintained by the strength of structural bonds, and along with other factors, the duration of oscillation plays a certain role in their disruption.

The greater or lesser resistance of soils to the applied dynamic load depends on their strength indicators - the angle of friction and cohesion. The value of the angle of friction and cohesion in loess soils depends primarily on moisture and decreases with increasing moisture content.

The strength of highly moistened (water-saturated) loess soils in the plastic state is due only to the cohesion forces C_w , which have a water-colloidal character. In plastic loess, both internal friction forces (φ) and brittle bonds (C_c) are practically reduced to zero. According to studies, these types of soils are capable of moving into a dynamically disturbed state at the smallest values of seismic acceleration α_c , since they are characterized by small values of critical acceleration α_{cr} [where: α_c is the maximum seismic acceleration acting on the soil mass; α_{cr} - critical acceleration-threshold acceleration, determined by the strength characteristics of the soil structure. Calculation of foundations composed of weak water-saturated loesses in seismic regions can be made using well-known formulas of soil mechanics with the obligatory observance of the condition decrease in the strength (cohesion) of the soil during vibration should be taken into account].

Low-moistened loess soils are characterized by the presence of internal friction (φ) and cohesion (C_w) in their strength, and sometimes in a very weak form, brittle adhesion C_c . To break the stability of such soils, slightly more acceleration and duration are required due to their increased strength. However, in this case, the decisive factor is the state of moisture (on which φ and C_c depend) and the value of the connectivity of these soils. As has been repeatedly noted, an increase in the moisture content of wetted loesses reduces their connectivity and, accordingly, the magnitude of the critical acceleration α_{cr} . The above facts allow us to assume the relative invariability in time of the factors of internal friction (φ) and structural cohesion (C_c) under conditions of shaking of loess soils. It is believed that the connectivity C_w retains its original state within the current seismic acceleration up to the critical value, and subject to the conditional $\alpha_c > \alpha_{cr}$, it decreases in time under certain conditions to zero.

Thus, the influence of the duration of oscillations in the weakening of the dynamic strength of soils is characteristic only of loess soils that are in moistened and water-saturated states. This was repeatedly observed in our experiments, partially described.

In conclusion, it should be noted that in the considered plan, the task of the study is reduced to establishing the cohesion of the soil, the strength of which under all conditions determines the necessary duration of the shaking. For this reason, many clay soils can be earthquake resistant if they have the strongest cohesive forces. The duration of one or more phases of the earthquake in these cases will be insufficient to break these links.

CONCLUSIONS AND RECOMMENDATIONS

As we said above, loess soils (loesses, loess-like soils) are among the most structurally unstable soils in the group of cohesive soils. In their natural occurrence, they are low-moisture, macroporous, subsiding, and generally have a loose structure. Under the influence of external forces and humidity, their structure is sharply disturbed, strength (cohesion) decreases, and the soil is deformed, i.e. are compacted, and buildings and structures built on them without special measures to prevent deformation are damaged and can even lead to destruction. In particular, this moment is more aggravated in difficult ground conditions, especially in seismic regions. Therefore, special attention should be paid to the construction of buildings and structures on moist loess soils.

Studies of the nature of the change in the connectivity of moist loess soils during vibration showed:

1. Reduction of the strength characteristics of moistened loess soil, the angle of internal friction

and cohesion (adhesion) during vibrations with acceleration exceeding the critical value unconditionally. But at the same time, a change in the strength of connectivity is especially noted, which is intense in the process of oscillations.

2. The decrease in the connectivity of moistened loess soils in the process of shaking is explained by the transition of part (under certain conditions completely) of bound water into free water, increasing the volume of free water in the soil. The results of the studies showed less than about 50% of the amount of bound water in pre-vibrated samples compared to samples investigated without vibration, which indicates the transition of bound water into free water in the process of ground vibration. The dependence of the transformation of bound water into free water on the value of soil cohesion, the duration of the vibration affecting the soil, etc. is established.
3. The weakening of the connectivity of moistened loess soils and its transition to a liquefied state depends on the initial density-humidity corresponding to the current stress state of the soil, water-colloidal minerals, granulometric composition, on the intensity, nature (in frequency and amplitude) and duration of the oscillatory movement. At the same time, in montmorillonite minerals, the ability to transition into a dynamically disturbed state is more pronounced than in minerals from the hydromicas and kaolinite groups, which is explained by the content of a large amount of diffuse water in montmorillonite minerals than in others. The transition of loess soils to a liquefied state does not depend on the particle size, but is determined by the intensity and duration of the shaking. With an increase in particle size, the time spent in a liquefied state is correspondingly reduced. The role of actively acting acceleration and duration of shaking in the

disturbance of the loess soil structure is very significant.

4. With an increase in the active acceleration on the ground, the degree of destruction of the structure (connectivity) of the moistened loess soil increases.
5. Analysis of the research results showed that if the cohesion (adhesion forces) between the particles of the soil are not violated by the current vibration, the soil is not deformed. Soil deformation also does not occur when the duration of the shaking is measured in just a few seconds. Despite the fact that the studied soils were characterized by almost the same physical and mechanical parameters, the effect of deformation as a result of shaking of different duration is not the same.
6. The compaction of moist loess soils and the associated liquefaction occurs as the connectivity that determines their structural strength is broken.
7. Reducing the connectivity (seismic resistance) of moist loess soils with an increase in vibration accelerations is unconditional. However, it is necessary to single out the most significant influence on the seismic resistance of soils of vibration frequency. As the practice of construction and analysis of the consequences of earthquakes shows, for the foundations of structures the most dangerous (in terms of violation of dynamic stability) are high-frequency earthquakes (Gazli, Uzbekistan, 1976, frequency 16 Hz; Tashkent, Uzbekistan, 1966, frequency 10 Hz, etc.).

As follows from the performed experiments, the decrease in cohesion (deformability) of the soil subjected to research depends on the vibration frequency. The influence of dynamic action on the decrease in the cohesion (deformability) of the soil is

more effective if, all other things being equal, this action is characterized by a higher frequency.

8. Vibration methods of soil compaction give good results in seismic areas. Our experiments have shown that under high-frequency dynamic impacts, the soil structure is easily disturbed and the soil is effectively compacted. Our studies also showed an intensive increase in time of the strength characteristics (especially due to cohesion) of pre-vibrated moist loess soils. A particularly great effect is achieved under such conditions when exposed to high-frequency vibrations on the ground. Also, in order to achieve a given soil density, it is necessary to take into account its certain moisture content, i.e. soils must be compacted with optimal moisture. This is necessary to ensure its proper strength, deformability within certain limits and workability, in relation to the sealing mechanisms available to the construction site. With vibrocompaction, the soil of the bases perceives the dynamic impact on itself beforehand, before the construction of buildings, which has a positive effect on the seismic resistance of the foundations of structures in seismic areas. Among the soil compaction methods that ensure the complete elimination of the subsidence properties of the loess layer, the method of soil compaction using vibratory machines (vibratory rollers) is reliable and economical.

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