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# Influence of Soil Density and Moisture on Seismic Stability of Slope Structures

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**Abstract:**

This article discusses the results of the dynamic study conducted in the laboratory conditions to explore the effect of density and moisture of moistened loess soils on the dynamic stability of slope steepness. It is noted that the seismic stability of slope structures is determined by both internal factors, such as adhesion and friction forces, vertical stress components, soil density, base thickness, and external factors, such as the acceleration of oscillation and its components: amplitude, frequency, period. For static processing of the experimental results, a simplified method proposed for identifying the averaged value of soil indicators was used. The essence of this method is to plot a graph of the average values of a particular accumulated indicator, for example, the resistance of soil to shear under various dynamic loads. At the same time, the average indicator values are determined first from the data of two experiments, then three, four, etc. The experiments conducted on loess and sand slopes with different dynamic effects showed a direct dependence of slope steepness on soil density. There is a decrease in slope steepness with increasing clay particles in the soil composition, which indicates a greater dynamic stability of soils containing clay particles. Similar results were also shown by the experiments with fine dust particles (0.01-0.005 mm). The experimental studies on the influence of moisture on the stability of slope steepness showed that an increase in moisture always contributes to a change in soil strength. It is established that there is a significant change in this case in plastic soil cohesion, which makes it possible to conclude that soil strength in the slope composition is mainly determined by the amount of plastic cohesion depending on soil moisture. It is also established that any increase in soil moisture contributes to a decrease in plastic soil cohesion, which in turn increases the soil deformation capacity. Increasing the moisture content of loamy soil by 10-15% reduces plastic cohesion by almost two times within 1.5-2 hours. After 10-12 hours, there is a gradual increase in the value of cohesion, which apparently is due to the restoration of the destroyed soil cohesion with the course of time.

**Keywords** - Density, moisture, soil, seismic loads, slope steepness, oscillation, stress, base thickness, amplitude, frequency, periods.

## I. INTRODUCTION

The article deals with the results of the author's studies on the effect of soil density and moisture on slope steepness under conditions of various oscillations.

Refer to the formula for determining the seismic stability of slope structures [1]:

$$tg\alpha = \frac{(\sigma_{dyn} tg\varphi_{w+} c_v) tg\varphi_w}{0{,}64\, \gamma_w H k_c}$$

In accordance with this formula, the seismic stability of the $tg\alpha$ slope is determined by both internal factors, such as adhesion and friction ($c_v, \varphi_w$), vertical stress components ($\sigma_{dyn}$), soil density ($\gamma_w$), base thickness (*H*), and external factors, such as the acceleration of oscillation ($\alpha_c$) and its components: amplitudes (*A*), frequency (*f*), period (*T*).

When processing the research results and determining the averaged indicator values, the question arises about the required number of prototypes. For this purpose, there are numerous theoretical, more rigorous static methods for establishing the average indicator values. Among them, the most suitable for soils is the simplified method (method of mathematical statistics and establishment of the average value of resistance to shear of clay rocks) proposed by Z.V. Pilgunova [2], which was used in our study for processing the experimental results.

## II. RESULTS AND DISCUSSION

The essence of the method is as follows. With the accumulation of experimental data, in a normal or semi-logarithmic scale a graph is plotted for the average values of one or another indicator, for example, the resistance of soil to shear under a load of p=3 kg/cm2 , i.e. S_3. At the same time, the average indicator values are determined first from the data of two experiments, then three, four, etc.

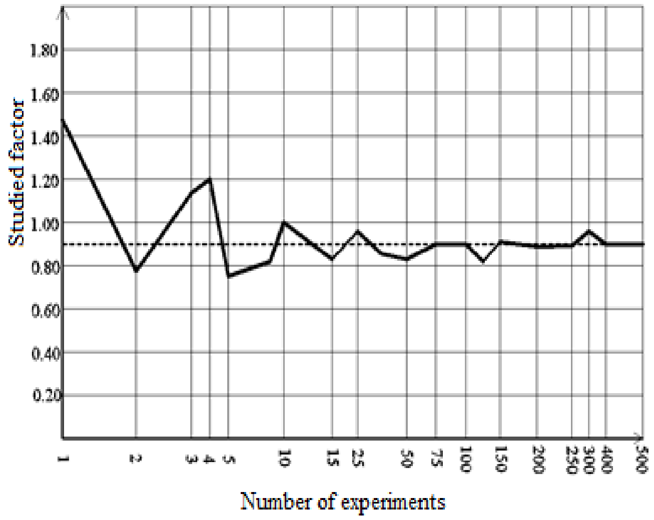


**Fig. 1**. Graph of the average values for determining the required number of test samples

As can be seen from Fig. 1, at the beginning with a small number of experiments, the spread of the average values of S_3 decreases sharply with increasing the number of experiments, and with 25 experiments and more, the change of the average values does not go beyond the limits of practical requirements. Obviously, in this case, we had every reason to limit ourselves to the testing of 25 samples during the experiments.

***Soil density***. The experiments conducted on loess and sand slopes with different dynamic effects showed a direct dependence of slope steepness on soil density.

Figure 2, which is based on the data from Table 1, shows the dependences of tg a = f (n) for the soils numbered 1, 3 and 6, on which the porosity characterizes the density state of a particular soil. It should be noted that the data in Fig. 2 could not be applied to other similar soils, because the porosity in this case refers only to the soil in question.

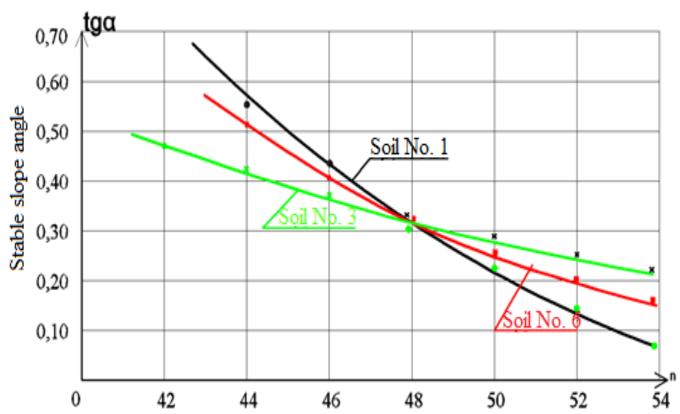


**Fig. 2.** Dependence of stable slope steepness on soil porosity

**Table 1** Generalized data on the dependence of stable slope steepness on soil density

| Soil | Soil porosity, % | | | | | | |
|---|---|---|---|---|---|---|---|
| | 42 | 44 | 46 | 48 | 50 | 52 | 54 |
| No. 1 | - | 0,56 | 0,44 | 0,32 | 0,20 | 0,13 | 0,08 |
| No. 3 | 0,48 | 0,44 | 0,38 | 0,34 | 0,33 | 0,22 | 0,21 |
| No. 6 | - | 0,52 | 0,40 | 0,32 | 0,25 | 0,20 | 0,17 |

In this respect, the data presented in Fig. 3, where soil density is expressed in relative terms, are the more general, which makes it possible to apply them to other similar soils.

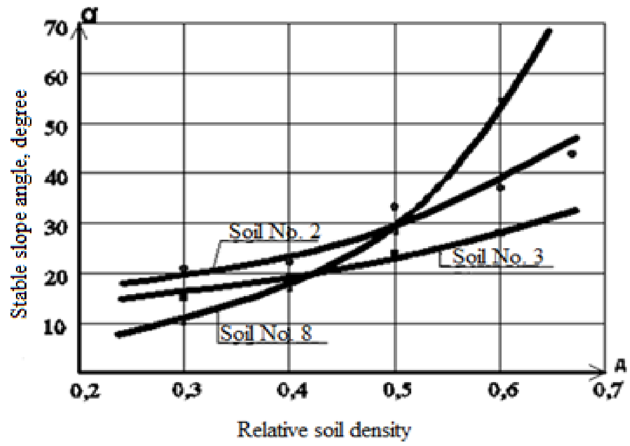


**Fig. 3.** Dependence of stable slope steepness on the relative density of loess soils

The relationship between soil density and its strength characteristics is widely discussed [3-5,7]. A significant effect of soil strength characteristics (the angle of internal friction *φ* and adhesion *c*) on the stability of slope steepness was also established in our studies (Fig. 4).

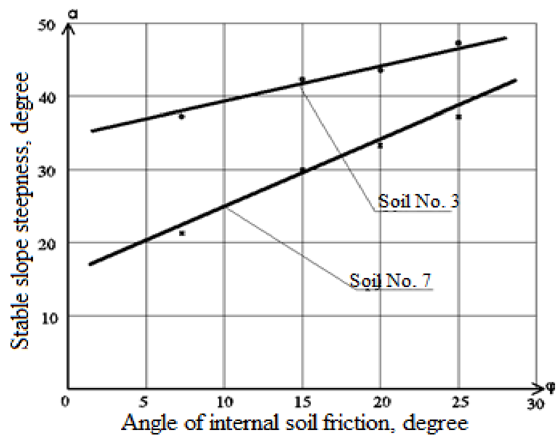


**Fig. 4.** Dependence of stable slope steepness on the angle of internal soil friction

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These experiments were carried out by shaking different soils. The soil density achieved with one cycle of the experiment served as the initial density for the subsequent cycle. It goes without saying that for the destruction of a slope consisting of soils with a density of the second cycle, a dynamic load should be higher than in the previous cycle. The cycles continued until the acceleration was 2,800-3,200 mm/s$^2$ (8 points). Each time before the next cycle, a sample was taken with a ring to determine the soil strength parameters.

When the question concerns the dependence of *tg a = f (n)*, one should pay attention to the following. In the experiments on loess with various genetic origins (aeolian, deluvial, proluvium), the value of *tga* was different despite the close initial soil density with the same shaking. At the same time, the value of *tga* decreased with increasing clay particles in the soil composition, which indicates a greater dynamic stability of soils containing clay particles. Obviously, this is due to the increase of soil cohesion with increasing clay particles and hence the increase in soil strength characteristics. A similar situation can be observed with small dusty particles (0.01-0.005 mm) (Fig. 5).

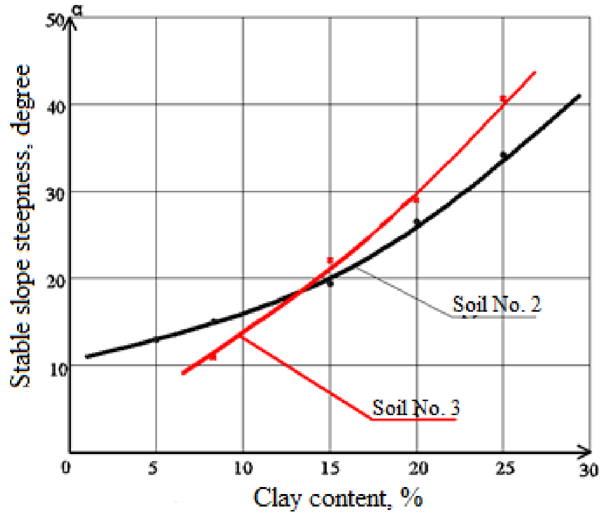


**Fig. 5.** Dependence of stable slope steepness on clay content in soil

***Soil moisture.*** The experimental results showed the dependence of slope steepness on soil moisture (Table 2).

**Table 2.** The change in slope steepness depending on soil moisture at $a_c$=2880 mm/s$^2$

| Soil | Soil moisture, % | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 10 | 15 | 20 | 25 | 30 | 35 |
| No. 2 | 0,63 | 0,41 | 0,25 | 0,17 | 0,13 | 0,12 | 0,72 |
| No. 8 | 0,54 | 0,49 | 0,35 | 0,34 | 0,37 | 0,34 | - |

The difference in the dynamic soil strength depending on its moisture was discussed by A.Kh. Sadykov and A. Zh. Zhusupbekov [6, 8]. In cohesive soils, any additional moistening reduces the plastic soil cohesion, and this in turn affects the slope steepness (Fig. 6).

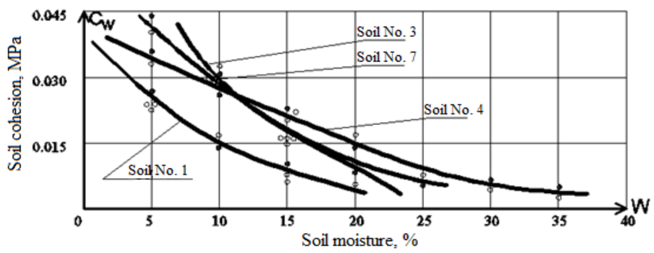


**Fig. 6**. Dependence of the form Cw=f(w) for the studied soils

The experimental studies conducted to explore the influence of moisture on the stability of slope steepness showed that an increase in moisture always contributes to a change in soil strength. Plastic cohesion in this case undergoes a significant change, which makes it possible to conclude that soil strength in the slope composition is mainly determined by the amount of plastic cohesion $(c_w)$, depending on soil moisture.

The generalized dependence of the stable slope steepness on different moistures of loess soils is given in Table 3, which shows a significant effect of soil moisture on slope steepness. In general, the stability of slope steepness also depends on other factors, besides soil density and moisture. Among them, an important role belongs to soil cohesion.

**Table 3.** The effect of moisture on slope steepness

| Soil | External load, MPa | Oscillation acceleration, mm/s$^2$ | Soil moisture, % | Stable slope angle, tga |
|---|---|---|---|---|
| 2 | 0.03 | 3000 | 11,5 | 0,38 |
| 2 | 0.03 | -«- | 16.0 | 0,26 |
| 2 | 0.03 | -“- | 24.2 | 0,18 |
| 8 | 0.03 | 3400 | 14.9 | 0,42 |
| 8 | 0.03 | -“- | 20.0 | 0,37 |
| 8 | 0.03 | -“- | 28.5 | 0,23 |

Numerous experiments conducted by N.N. Maslov, N.A. Tsitovich and Kh.Z. Rasulov [5] and others showed that plastic cohesion in loess may vary depending on soil moisture, which is shown in Figure 7 as a dependency. As seen from the graph, any increase in soil moisture contributes to a decrease in, which in turn increases the soil deformation capacity.

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 8 (2019), pp. 1259-1262


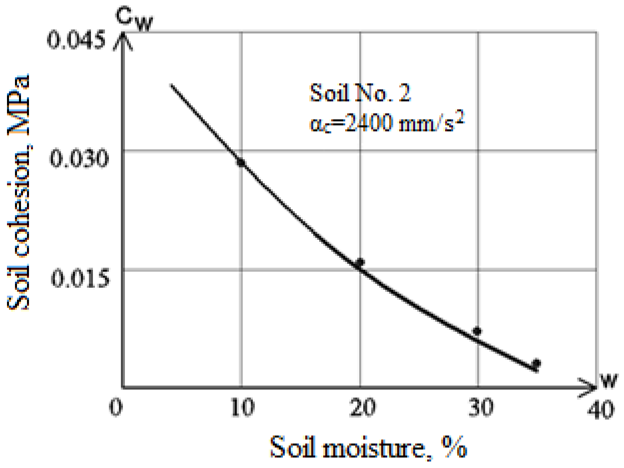


**Figure 7**. Dependence of the form $C_w$=(w) for loess soil No. 4

It is known that an increase in moisture is always associated with the transition of soil from one state to another (for example, from plastic to fluid) [8]. This, in turn, contributes to the weakening of soil cohesion up to a certain point, and then there is a gradual growth due to an increase in soil density (Figure 8).

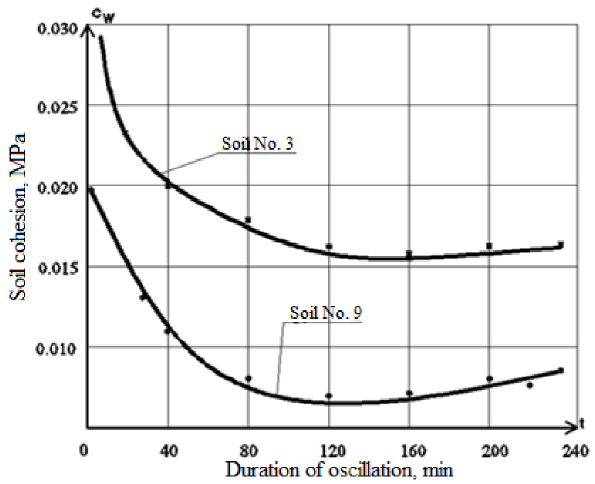


**Fig. 8.** The nature of changes in soil cohesion in time during the oscillation process with the acceleration $\lambda_c$=2000mm/s$^2$

In accordance with Figure 8, as the moisture content of the loamy soil increases by 10–15%, there is an almost two-fold decrease in plastic cohesion during 1.5–2 hours. After 10-12 hours, a gradual increase in $(c_w)$ is observed. This circumstance, apparently, is connected with the restoration of the destroyed soil cohesion with the course of time.

## III. CONCLUSIONS

The experiments have shown a decrease in slope steepness with decreasing soil density and increasing soil moisture. At the same time, any decrease in slope steepness is associated with an increase in the volume of construction work.

## REFERENCES


[1] D.J. Artykbaev, and K.S. Baibolov, Earthquake resistance of slopes, Bulletin of Kazakh Academy of Transport and Communications named after M. Tynyshbaev, 106 (3), 2018, 17-21.

[2] Z.V. Pilgunova, Method of mathematical statistics and establishment of the average value of resistance to shear of clay rocks, Proceedings of the Laboratory of Hydrogeological Problems of the Academy of Sciences, 14, 1958, 12-21.

[3] Proceeding of the 3rd Central Asian International Geotechnical Symposium “Geotechnical Problems of Construction on Collapsible Soils in Seismic Areas”, Dushanbe, 1, 2005, 237.

[4] Kh.Z. Rasulov, The applied method of seismic resistant base. Proceedings of the Conference "Scientific and Applied Foundations for Solving the Actual Problems of Seismology". Tashkent, 2006, 202-204.

[5] Kh.Z. Rasulov, and A.U. Tashkhodzhaev, Conditions for the formation of landslide processes during earthquakes. Proceedings of the International Conference "Problems of Assessing Seismic hazards and Reducing the Effects of Earthquakes." Tashkent, 2008, 5, 240-242.

[6] A.Kh. Sadykov, Experimental studies on factors affecting the critical acceleration of slope loess soils. Problems of Architecture and Construction, 1, 2010, 37-39.

[7] F.F. Zekhniev, and D.D. Akhmedov, Geotechnical construction problems in complex engineering and geological conditions of Tajikistan and their solutions. Proceedings of the 3rd Central Asian International Geotechnical Symposium. Dushanbe, 2005, 174-179.

[8] A.Zh. Zhusupbekov, Influence of pore pressure on the stability of alluvial dam slopes. Proceedings of the 1st Central Asian Geotechnical Symposium. Astana, 2000, 1, 176-187.

[9] G.Zh. Zholtayev, Tectonics and sedimentation conditions in the east of the Pre-Caspian syneclise in the early Permian era. Geology and Exploration of Kazakhstan’s Resources, 1998, 15-20.

[10] G.Zh. Zholtayev, and B.M. Kuandykov, Geodynamic structural model of the south of Eurasia. Oil and Gas, 2, 1999, 62-74.