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Strength Parameters of Sagged Loess Soils during the Soaking

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Abstract. It should be noted that the change in the strength parameters of loess soils when they are saturated with water differs from the conventional soils not only in quantity, but also in quality. The article contains the results of a study of the effect of soaking time on the strength of loess loam.

1. Introduction
Loess is a soil in the form of a cover the depth of which may vary from several meters to 50-100 meters. Their distinctive feature is subsidence, which is a sharp violation of the soil structure. When construction takes place on the undermining areas and subsidence soils, their strength characteristics are of particular importance.

Loess soils are widely spread in the South and the South-East of Ukraine, the Northern Caucasus and the Central Black Earth Region of Russia. Despite their long-term study, the loess soils as the bases of constructions have not been fully investigated.

As is known due to the unstable structure the loess soils dramatically change their physical and mechanical properties under the influence of moisture.

Strength properties of sagged loess soils are characterized, as noted by a number of researchers [2, 3, 6, 7, 8, etc.] by two indicators: the angle of internal friction *"φ"* and the adhesion capacity *"C"*. With the increase in the humidity of the subsiding soil until its complete saturation with water and taking into account the dynamic loads, the adhesion capacity is reduced by 3 to 10 times and the angle of the internal friction is reduced 1.1-1.4 times. With the increase in the degree of density, the adhesion and the angle of internal friction increase.

Based on numerous laboratory studies, it has been found that soaking plays an essential role in changing clay soil strength properties. In ordinary clay soils the reduction of strength is insignificant. When the sagged loess soils are wet, there is a sharp decrease in the adhesion values and not significant decrease in the angles of the internal friction due to the wedge effect of water molecules in thin films and softening of cementation bonds between the soil particles.

It is known that the subsidence, as a rule, lasts longer compared to the settlement at natural humidity. For example, subsidence deformations of the stamp base usually last for tens of days. While the settlement of the load stages stabilizes within few hours, the foundation subsidence of a construction lasts for several months; however, the settlement of soils is a faster process. Thus, the loess subsidence takes quite a long time and it can be regarded as a rheological process with a gradually decreasing speed.

Basing on the processing and generalization of information the authors analyzed the features of the formation of sagged loess soils. The results of hundreds of experiments using consolidometers to determine the relative subsidence of loess soils were used in this paper.

2. Material and methods
In order to solve the problem, the authors carried out experimental studies of water saturated subsiding soils.

As is known, there are various methods for determining the indices of soil strength, tests on uniaxial crushing using triaxial compression devices (stabilometers), penetration using box shear apparatus, etc. The most widely used method is the determination of shearing resistance.

Strength indices of sagged loess soils depend on many factors, including methods of preparation of samples for testing, duration of soaking, shear rate, etc.

For loess soils that have subsidence properties during the soaking the value of the compressing vertical pressure, which is connected with the initial pressure or the subsidence threshold is of great interest.

3. Main part
Large-scale field studies on soaking large strata of subsiding soils in the presence of the experimental foundations performed in various ground conditions have made it possible to establish the general nature of the development of subsidence in subsurface depths and to reveal particular cases of their manifestation.

There are three identified zones (Figure 1):

I – deformable zone, within which there is a subsidence of the soil under the joint action of the load from the foundation and the own weight of the soil. It extends from the base of the foundation to the depth at which the vertical stresses from the foundation load σ_Z and the soil's own weight $\sigma_{\square Z}$ are equal to the initial subsidence pressure P_{np}, i.e. $\sigma_Z + \sigma_{\square Z} = P_{np}$.

II - passive zone with almost no deformations of soil in the process of soaking, since the total stresses due to the own weight of soil $\sigma_{\square Z}$ and the foundation load σ_Z in it are smaller compared to the initial subsidence pressure P_{np}.

III - subsidence zone of soil from its own weight within which there is a subsidence of the soil from its own weight. It begins at the depth where the vertical stresses of the soil's own weight are equal to the initial subsidence pressure ($\sigma_{v,Z} = P_{np}$) and it ends at the lower boundary of the subsidence strata.
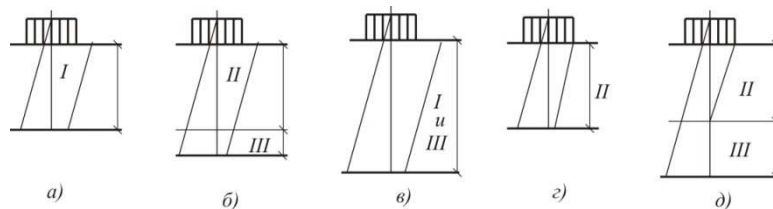

Figure 1. Typical zones

Depending on the foundations size, the load, the thickness of the subsiding soil and other factors five special cases can be distinguished from the general case:

a) when the thickness of a layer of subsiding soils is not significant, zones II and III may be absent and the subsidence of foundations will occur only in the deformable zone caused by the foundation load and the soil's own weight;

b) when the sizes of foundations are rather small and a layer thickness of the soil is not very significant, zone III may be absent and the subsidence occurs only in the deformable zone;

c) when the load from the foundation is relatively low or it is absent and a layer thickness of the soil is not very significant, zones I and II are absent and the subsidence of soil during its soaking is not

observed;

d) when the foundations and the loads are significant, zones I and II merge, as a result of which the soil subsidence occurs from the soil's own weight within the entire zone;

e) when the load from the foundation is relatively low or when there is no foundation, zone I is absent and the soil subsidence occurs only from the soil's own weight.

In the process of bases preparation by compacting the subsiding soils with heavy tamping, installation of soil bedding, as well as ramming the pits, reducing the pressure on the ground to the size of the subsidence pressure, fixing the upper soil layer, the general case of deformation of soils is transferred into special cases of d and e. Similarly, when the loess soils are preliminary soaked, the general nature of deformation of the subsiding soil is transferred into special cases of a, b and d when the possibility of subsidence on the soil's own weight is completely excluded in zone III.

Soil conditions for subsidence are divided into two types:

Type I is the type of a layer of subsiding soil with no soil subsidence caused by the soil's own weight or when the subsidence does not exceed 5 cm. The subsidence is mainly observed in the deformable zone (cases a, b, d).

Type II is the type of layers of subsidence soils with the soil subsidence caused by the soil's own weight occurring directly in the lower part of the subsidence stratum with its value amounting to > 5 cm. In the presence of an external load the subsidence within the deformable zone is also possible.

To determine C and φ, the compaction loads were initially less than the initial subsidence pressure for a series of samples taken from the depth of 2.0 m. The soil characteristics were as follows: $\gamma_0 = 1.60$ g/cm^3; $\varepsilon = 0.939$; $W_p = 0.17$; $W_l = 0.30$; the relative subsidence at $P = 1.2$ and 3 kp/cm^2 was 0.014, respectively; 0.037 and 0.052.

Part of the water saturated soil samples (series 1) was pre-compacted at the following pressures: $P = 0.2$; 0.4; 0.6 kp/cm^2 and the shear tests were carried out at the same pressures.

For some water saturated soil samples (series 2) the samples were pre-compacted at the pressure of $P = 0.6$ kp/cm^2 and then shifted at the pressure of $P = 0.2$; 0.4 and 0.6 kp/cm^2. The third group of soil samples (series 3) of natural moisture and in the water saturated condition were compacted and cut at the pressure of $P = 1.0$; 2.0; 3.0 kp/cm^2. A number of samples (series 4) with the same moisture values were pre-compacted at the pressure of $P = 3.0$ kp/cm^2 and cut at the pressure of $P = 1.0$; 2.0, 3.0 kp/cm2 (Table 1).

Table 1. Overall results of shear tests of loess loam

Tests	Initial pressure at compaction P, kp/cm^2	Shear P, kp/cm^2	Moisture of soil			
			natural		water saturated	
			C, kp/cm^2	φ, degrees	C, kp/cm^2	φ, degrees
1	0.2; 0.4; 0.6	0,2; 0,4; 0,6	-	-	0.05	16
2	0.6	0.6; 0.4; 0.2	-	-	0.07	16
3	1.0; 2.0; 3.0	1.0; 2.0; 3.0	0.30	21	0.11	20
4	3.0	3.0; 2.0; 1.0	0.5	20	0.13	19

It can be seen from the table that the samples of soils of series 1 and 3 have lower values of the specific adhesion C and slightly higher φ as compared to the results obtained using the preliminary soil compaction method (series 2 and 4). To a certain extent this is explained by the fact that the density of too compacted samples at final vertical pressures $P = 0.6$ and 3.0 kg/cm^2 will be greater than at the compaction pressures $P = 0.2$; 0.4; 1.0 and 2.0 kp/cm^2 at which the cut is carried out in the experiments of series 1 and 3.

When assessing the strength of loess, depending on the duration of soaking, there is a different resistance to shear. In the course of the manifestation of subsidence deformation the soil strength decreases sharply, since at the beginning of soaking the softening of the cementation bonds occurs

most intensively. After the manifestation of a subsidence deformation accompanied by compaction of the soil, as well as the manifestation of additional contacts between the particles and the formation of a new structure its strength somehow increases.

For example, the strength parameters of water saturated loam at the moment of soaking were as follows: $C_1 = 0.13$ kp/cm^2 and $\varphi_1 = 18°$; 24 hours after soaking $C_2 = 0, 16$ kp/cm$_2$ and $\varphi_2 = 20°$, and after 48 hours $C_3 = 0.20$ kp/cm^2 and φ3 = 20°40´.

This change of strength indices of loess soils is very important and should be taken into account when assessing the bearing capacity and, especially, the stability of slopes and back slopes.

To clarify what was said, special experiments were carried out. In this experiments the loess loam were used. The shear tests were carried out with soaking under the load of $P = 1.0$; 2.0, 3.0 kp/cm^2. The soaking time varied from 5 minutes to 24 hours (Table 2).

Table 2. Influence of soaking time on strength indices of loess loam

Soaking time t, hour	Strength indices of soil	
	C, kp/cm^2	φ, degrees
1/12	0.05	17
1/2	0.07	18
1	0.08	18.5
6	0.09	19
12	0.10	19.5
24	0.125	20

As it can be seen from Table. 2, when soaked for 5 minutes, i.e. at the initial moment of manifestation of the subsidence deformation, the minimum values of strength parameters $C = 0.05$ kp/cm^2 and $\varphi = 17°$ were obtained. After 24 hours of soaking $C = 0.125$ kp/cm^2 and $\varphi = 20°$, the shrinkage deformations increase 5 ... 10 min after soaking. Subsequently, the increase rate in the manifestation of subsidence deformations changes sharply. Strength parameters are also affected by the shear duration (fast is t = 15, 30 and 60 s, accelerated shift is t = 5 min and a slow one).

With a rapid shift the value of the specific adhesion and the angle of the internal friction are reduced. To a certain extent this is due to the fact that during the shift there is a violation of both primary and secondary strengthening adhesion. With a rapid shear due to the process speed of experiment (t = 15 ... 60 s) the contact between the particles of the soil changes all the time and the adhesion of the hardening does not have time to for its manifestation. In the Research Center of Construction it was also stated that in case of a rapid shift, there is a change in the strength of parameters compared to a slow one.

4. Conclusion

In contrast to conventional clay and non-subsiding soils the loess soils require a special approach when assessing their strength. The values of the strength parameters of loess soils are affected by the methods of preparing soil samples for testing, the duration of their soaking, the shear rate and other factors. Therefore, the evaluation of the strength of soils must be carried out according to the method that corresponds to the real conditions of the soil base of the construction. This is a common task for geological engineers, as well as for design engineers.

Using the recommendations on the proposed values of C_w and φ_W it becomes possible to carry out more accurate assessment of the bearing capacity of the base under the conditions of high seismicity and dynamic impact. Besides, the design of bases becomes more reliable and the economic efficiency increases. The accumulated experience in this area can be useful both for engineers and designers in the field of foundation engineering as it is aimed at improving the safety of construction, improving the quality of buildings, and shortening the design time.

5. Acknowledgments

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