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CONSTRUCTION PROPERTIES OF SUBSIDIBLE SOILS IN MONGOLIA UNDER CLIMATE CHANGE: PROBLEM AND SOLUTION

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Abstract: The main regional features of subsidence clay soils common in Mongolia are high porosity, low humidity and underfilling within the seasonal deep freezing due to their heaving and sublimation loosening. Using such soils as foundations for buildings and structures under conditions of increasing humidity is difficult at the design and construction stages, as well as during operation. This paper examines the results of analytical calculations to identify the dependence of a decrease in the physical and mechanical properties of subsidence soils on an increase in humidity and constructs the corresponding dependence graphs. Numerical modeling of the quantitative and qualitative assessment of the subsidence properties of sandy loam and loamy soils using the method of indirect signs and the probability of the formation of a subsidence process during soaking is also carried out.

Keywords: global warming, sublimation loosening, underfilling, atmospheric precipitation, sandy loam and loamy soils, deterioration of physical and mechanical properties

КОНСТРУКТИВНЫЕ СВОЙСТВА НЕУСТОЙЧИВЫХ ГРУНТОВ МОНГОЛИИ В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА: ПРОБЛЕММЫ И РЕШЕНИЯ

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Аннотация. Основными региональными особенностями просадочных глинистых грунтов, широко распространённых на территории Монголии, являются высокая пористость, низкая влажность и недоуплотнённость в условиях сезонного глубокого промерзания, обусловленные процессами морозного пучения и сублимационного разрыхления. Использование таких грунтов в качестве оснований зданий и сооружений при увеличении влажности представляет значительные трудности как на стадиях проектирования и строительства, так и в процессе эксплуатации. В настоящей работе рассмотрены результаты аналитических расчётов, направленных на выявление зависимости снижения физико-механических свойств просадочных грунтов от увеличения влажности, а также построены соответствующие графики зависимостей. Выполнено численное моделирование количественной и качественной оценки просадочных свойств супесчаных и суглинистых грунтов с применением метода косвенных признаков, а также оценена вероятность формирования просадочного процесса при замачивании.

Ключевые слова: глобальное потепление, сублимационное разрыхление, недоуплотнение, атмосферные осадки, супесчаные и суглинистые грунты, ухудшение физико-механических свойств.

INTRODUCTION

In recent years, the amount of precipitation has increased sharply due to changes in climatic conditions due to global warming almost all over the world, including Mongolia. As a result, the moisture content of the foundation soil increases to the point of water saturation, weakening and disintegration of the crystallization and cementation structural bonds of clay soils, and, as a rule, deterioration of their construction properties.

The problems of changing climatic conditions due to global warming are the subject of many researchers' works [1; 2; 3; 4; 5; 6; 7 and 8].

The territory of Mongolia is located at the altitude of the Central Asian plateau, the thickness of the vegetation layer and snow cover in winter is relatively small, the average annual temperature of the territory is about 0 °C, and the average number of days with negative temperature is more than 200. According to the norm of BNBD (SNiP) "Climatology of the territory of Mongolia", the depth of seasonal freezing of soils is 3.5 ... 5.0 m and sometimes in real conditions the depth of seasonal freezing of water-saturated coarse-grained soils with sandy loam and loamy filler reaches 6.0 meters, in rare cases permafrost is found under it [9; 10].

As a rule, wet clay soils to the depth of seasonal freezing are from weak to strong degree of heaving, in the thawed state have high porosity, relatively low humidity, undercompact.

Currently, in Mongolia there is an increase in the number of deformed buildings and engineering structures for the above-mentioned reasons. In this regard, the task of identifying the cause and developing a rational design solution are relevant for the construction industry of Mongolia.

Based on this, in order to clarify the pattern and dependence of the decrease in the construction properties of subsidence clay soils on the increase in humidity, regional features of this type of soil were identified.

METHODS AND MATERIALS

A.Regional feature. Based on the results of the studies, it was established that the main reason for the increase in porosity, loosening and decrease in the construction properties of soils is the sublimation process occurring in seasonally frozen clay soils [11]. The regularity of the flow and the nature of the origin of the sublimation process in frozen soils are reflected in the works of many scientists [12; 13; 14; 15; 16; 17; 18; 19; 20].

As a result of the sublimation process of ice in seasonally frozen soils, the structure becomes loose, as a result of which the porosity n = (50...65)%, the porosity coefficient e = (0.70...0.84), the density of dry soil ρ_d = (1.35...1.60) tons/m^3 or undercompacted, the moisture content of sandy loam W = (0.04...0.06) and loam W = (0.05...0.08), and also as a result of repeated freezing and thawing, cracking and crushing of the solid part of the soil occurs, based on this, the content of dusty parts is 50…60%.

In such loose and highly porous soils, with an increase in humidity due to an increase in atmospheric precipitation, the process of changing mechanical properties actively occurs.

B. Method for determining the pattern of changes in mechanical properties from an increase in humidity. According to the method of Professor A.A. Mustafayev [21] carried out a calculation to determine the patterns of change in the mechanical properties of subsidence soils during moistening of loess-like sandy soil of the Darkhan-Selenga and Erdenet-Orkhon regions in the form of a dependence graph (Fig. 1...4).

A.A. Mustafayev defined wet loess-like sedimentary soil as a quasi-homogeneous and quasi-inhomogeneous continuous structure, and the equation of state of such a body has the form:

$$\sigma = \sigma^{п} + \sigma^{в} = \sigma^{у}; \; e = e^{у} + e^{п}; \quad e^{п} = e^{в}; (1)$$

where: U, V, P - index of the stress-strain state taken into account in the viscous state.
After certain transformations and substitutions in the above equation, the following equation is obtained, expressing the stress state of the soil massif.

$$\sigma = C - \rho_d(1+e)y + W(y,z) + \lambda\left(e_y + \frac{2}{3}\mu\right)(2-f)\frac{\partial e_y}{\partial t}; \quad (2)$$

In the state $W_{кр} \leq W \leq W_{sat}$, the pattern of change in strength and deformation can be expressed by the mathematical law of the second-order curve. For example: the mechanical parameters of wet soil change according to the following law:

$$C_W = C_H - C_H J_L(2W_{sat} + W_i); \quad (3)$$

$$\varphi_W = \varphi_H - \varphi_H J_L(W_{sat} + \frac{W}{2}); \quad (4)$$

$$E_W = E_H - E_H J_L(W_{sat} + 0.5W); \quad (5)$$

where: C_H - the adhesion force of soil with natural moisture content; φ_H - the angle of internal friction of soil with natural moisture content; E - the modulus of deformation of soil with natural moisture content; J_L, W_L, W_p, J_p are the values adopted from the results of engineering and geological studies; W_{sat} - the moisture content of water-saturated loess soil;

$$W_{sat} = \frac{e\,\rho\,W}{\rho_s}, \quad (6)$$

where: e is the porosity coefficient of loess soil;

$$e = \frac{\rho_s - \rho_d}{\rho_d}, \quad (7)$$

CALCULATION RESULTS

The results of calculations using method Mustafaev [21] are given in tables 1 and 2. Approximate indicators for calculating the loess-like sandy soil of the Darkhan-Selenge region:

ρ_s=1.62tonns/m3	$W_L = 0.18$	$e = 0.62$	$\varphi' = 24^\circ$
ρ_s=2.38tonns/m3	$W_p = 0.14$	$W_{sat} = 0.21$	$\varphi'' = 18^\circ$
ρ_s=1.47tonns/m3	$J_p = 0.11$	$C' = 27\ kPa$	$E' = 13\ MPa$
W=0.06	$J_L = \pm 0.00$	$C'' = 21\ kPa$	$E'' = 4.1\ MPa$

Table 1. Dependence of mechanical parameters (C, φ, E) on humidity (W_L) sandy loam soils of the Darkhan-Selengi region

№	W_i	J_L	C_w, kPa, according to the formula (3)	φ_w, grad, according to the formula (4)	E_w, MPa, according to the formula (5)
1	0.04	-0,523	14.18	24.27	11.89
2	0.06	-0,256	12.23	24.13	11.76
3	0.08	0,000	7.95	23.35	11.27
4	0.10	0,328	7.06	21.31	10.85
5	0.12	0,615	6.83	18.90	5.18
6	0.14	1,000	6.24	17.81	3.91
7	0.16	1,217	5.95	17.05	3.15
8	0.18	1,485	5.64	16.68	2.68

ρ=1.64tonns/m³	W_L=0.27	e=0.53	φ'=21°
ρ_s=2.51tonns/m³	Wp=0.18	C'=27кПа	φ''=16°
ρ_d=1.48tonns/m³	Wsat=0.31	C''=19кПа	E'=14.2 MPa
W=0.11	Jp=0.13		E''=4.6 MPa

Approximate indicators for calculating the loamy soil of the Erdenet-Orkhon region:

Table 2. Dependences of mechanical indicators (C,φ,E) on moisture content (W_i) of loamy soils of the Erdenet-Orkhon region

№	Wi	J_L	C_w, kPa according to the formula (3)	φ_w grad, according to the formula (4)	E_w, MPa, according to the formula (5)
1	0.06	-	47.21	22.31	12.92
2	0.08	-0,623	46.83	22.10	12.34
3	0.10	-0,381	43.55	21.60	11.98
4	0.12	0,000	27.91	20.32	9.12
5	0.14	0,431	17.83	18.61	4.87
6	0.16	0,762	14.67	17.72	4.05
7	0.18	1.243	13.05	17.30	3.29
8	0.20	1,520	11.81	16.82	2.76
9	0.22	1,836	10.71	16.47	2.68

Based on the calculation results given in Tables 1 and 2, a graph of the dependence for determining the value of mechanical indicators was constructed (Figures 1; 2; 3 and 4).

a. Graph of the dependence for determining the value of the flow index J_L

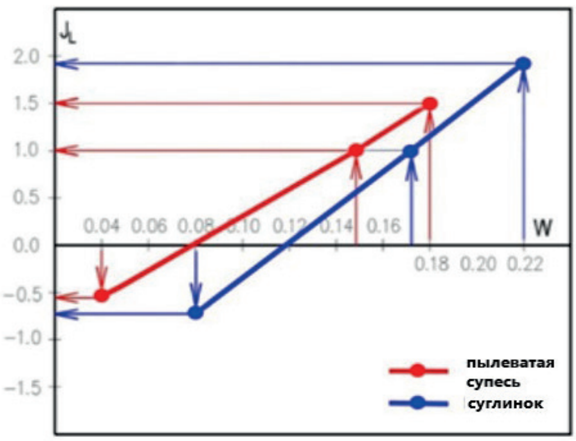


Figure 1. Graphics for determining the value of the fluidity index depending on the increase in soil moisture $J_l=f(Wi)$(Nyamdorj. 2021)

Based on the analysis of the $J_L = f(W_i)$ dependence graph, the following was established:
- for sandy loam: with an increase in soil moisture W = 0.04...0.08, the fluidity index changes J_L = – 60…0.00, with a further increase in moisture W = 0.08…0.18, the index J_L = – 0.00…1.50, i.e. it increases linearly proportionally;
- for loam: with an increase in soil moisture W = 0.08…0.12, the fluidity index changes J_L = – 0.75…0.00, with a further increase in moisture W = 0.12…0.22, the fluidity index J_L = 0.00…1.80, i.e. it increases linearly proportionally.

b. Dependency graph for determining the value of the adhesion force C_w

Based on the analysis of the graph of the dependence $C_w = f(W_i)$, the following was established:
- for sandy loam: with an increase in soil moisture W = 0.04 ... 0.08, the adhesion force changes C_w = 14.18 ... 7.95, with a further increase in moisture W = 0.08 ... 0.18, the indicator C_w = 7.95 ... 5.64 decreases according to a non-linear dependence;
- for loam: with an increase in soil moisture W = 0.06 ... 0.14, the adhesion force decreases in the range C_w = 47.21 ... 17.38, with a further increase in moisture W = 0.14 ... 0.22, adhesion C_w = 17.38 ... 10.71 decreases according to a non-linear dependence.

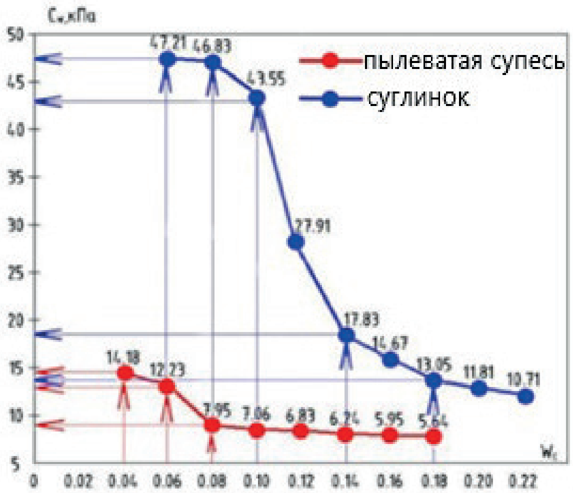


Figure 2. Graphics for determining the value of the angle of internal friction $C_w=f(Wi)$ depending on the increase in moisture content of clay soils (Nyamdorj. 2021)

c. Graph of the dependence for determining the value of the angle of internal friction φ_w

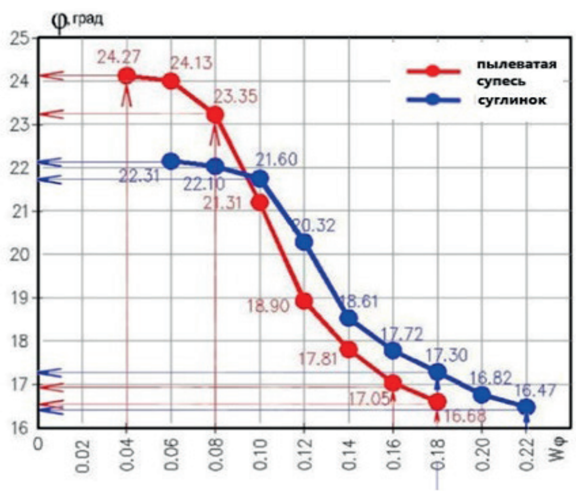


Figure 3. Graph for determining the value of the angle of internal friction $\varphi_w = f(W_i)$ depending on the increase in moisture content of clay soils (Nyamdorj. 2021)

Based on the analysis of the graph of the dependence $\varphi_w = f(W_i)$, the following was established:

- for sandy loam: with an increase in soil moisture W = 0.04…0.18, the angle of internal friction φ_w = 24.27…16.68 decreases according to a nonlinear dependence;
- for loam: with an increase in soil moisture W = W = 0.06…0.22, the angle of internal friction φ_w = 22.31…16.47 decreases according to a nonlinear dependence.

g. Graph of the dependence for determining the value of the deformation modulus E_w

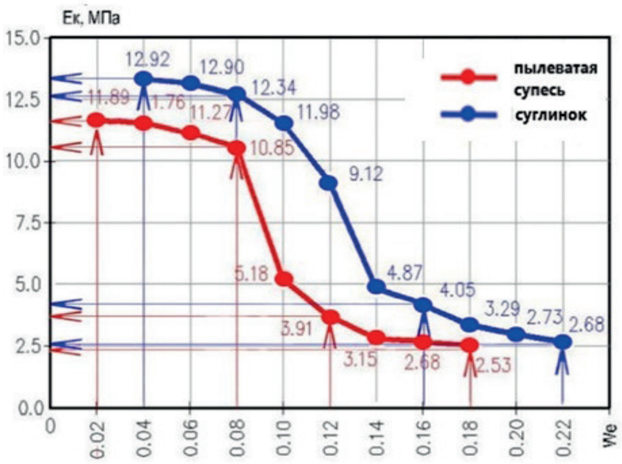


Figure 4. Graphics for determining the value of the deformation modulus $E_w = f(W_i)$ depending on the increase in moisture content of clay soils (Nyamdorj. 2021)

Based on the analysis of the graph of the dependence $E_w = f(W_i)$, the following was established:

- for sandy loam: with an increase in soil moisture W = 0.02…0.18, the value of the deformation modulus E_w = 11.89…2.53 MPa decreases according to a nonlinear dependence;
- for loam: with an increase in soil moisture W = 0.04…0.10, the value of the deformation modulus E_w = 12.92…2.68 MPa decreases according to a nonlinear dependence.

Based on the results of the analysis of the numerical values on the graphs $J_L = f(W_i)$, $C_w = f(W_i)$, $\varphi_w = f(W_i)$, $E_w = f(W_i)$ depending on the properties of the subsidence soil and the moisture state of the given site, the possibility of application is established taking into account the probability of change within ±5.0% and the compatibility of the numerical values determined by the graph's with the classification characteristics established by the standard, have an error of 3.0-9.0%.

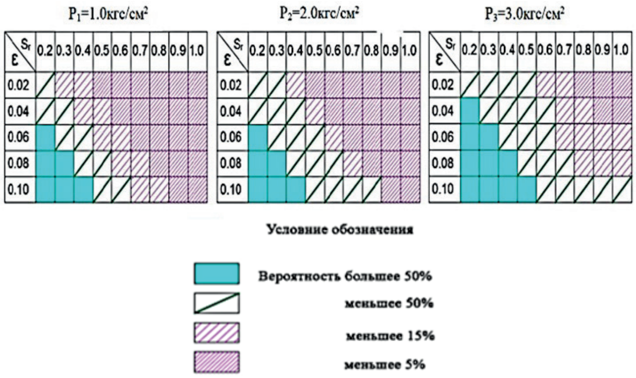
B. Evaluation of subsidence properties by the method of indirect signs. Loess-like clay soils, common in some areas of Mongolia, do not belong to the category of subsidence soils according to the standards of soil classification in other countries, including Russia, but at different pressure values and an increase in humidity, a significant subsidence is observed, therefore, there is a need for classification by indirect signs. The problems of the need to classify subsidence soils by indirect signs are devoted to the works of many researchers [22; 23; 24; 25; 26; 27; 28].

Based on the results of 231 laboratory tests to determine the mechanical properties of loess-like subsidence soils common in Mongolia, a comparison was carried out in order to identify the pattern of subsidence formation and calculate the amount of subsidence under the effects of various pressures and soaking, and the results obtained are presented in Table 2.5 [11].

Based on the analysis of the research results, it is established that with the porosity coefficient value within the range of (0.300 - 0.409) ... 0.910, under the action of pressure of 0.1; 0.2; 0.3 MPa, the probability of occurrence of subsidence deformation increases. Based on the results of the numerical analysis performed using the R-Plus calculation program, the following regression equations and a diagram were compiled to assess the probability of subsidence formation (Figure 5).

$$lg\delta_1 = -1.744S_r + 0.886e_0 - 2.153;\ n=69;$$
$$S^2_{oct}(lg\delta_2) = 0.2116;$$
$$lg\delta_2 = -1.806S_r + 0.855e_0 - 2.093;\ n=121;$$
$$S^2_{oct}(lg\delta_2) = 0.2115;$$

$$l_g\delta 3=-1.641S_r+0.922e_0-1.9972;\ n=147;\quad S^3_{oct}(l_g\delta_3)=0, \tag{8}$$



<u>Figure 5.</u> Diagram for assessing the probability of subsidence

RESULTS AND DISCUSSION

Currently, climate conditions are changing dramatically around the world due to global warming, as a result of which the construction properties of clayey, especially subsidence soils are deteriorating sharply, and there is a high probability of further activation of these processes. We observe that the number of deformed buildings and infrastructure structures for various reasons under the influence of increased humidity of clayey soils of foundations is noticeably increasing from year to year.

In such situations, how reliable is the calculation of a subsidence foundation and, perhaps, foundations made of other types of clayey soils for I and II limit states according to the provisions of current standards and regulatory literature? Maybe something needs to be changed and supplemented? If necessary, in what direction? Or is there nothing special, all these situations are taken into account in the calculation models, only reasonable use is necessary? The solution and discussion of this problem are important not only for Mongolia, but also in other countries where there are subsidence and non-subsidence clayey soils of different origins.

CONCLUSION

1. Analysis of numerical values on the graphs of the dependence $J_L = f(W_i)$, $C_w = f(W_i)$, $\varphi_w = f(W_i)$, $E_w = f(W_i)$ shows the possibility of application taking into account the probability of change within ±7.0% and the compatibility of numerical values determined by the graphs with the classification characteristics established by the standard with an error with a convergence of 3.0...9.0%.
2. Based on the results of solving the regression equations, the probability of occurrence of subsidence of loess-like soil is determined by indirect signs for the purpose of preliminary assessment. At the same time, it is possible to determine the probability of occurrence of subsidence with sufficient accuracy by nomogram (Figure 5).
3. Taking into account the established regional characteristics and the regularity of changes in mechanical indicators, a theoretical and methodological justification has been developed for the innovative use of scientific methods, such as pile foundations, foundations in a rammed pit, and artificial improvement of subsidence soil foundations, including compaction with heavy ramming, a soil cushion with geosynthetic reinforcement, chemical fixation by cementation and silicification methods, taking into account the soaking of the subsidence base of buildings and structures.

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