Soil Mechanics and Foundation Engineering, Vol. 47, No. 3, 2010

CONSTRUCTION ON PERMAFROST

EFFECT OF FREEZING-THAWING ON THE PHYSICO-MECHANICAL PROPERTIES OF A MORIANIC CLAYEY LOAM

UDC 624.139:624.131

L. T. Roman and Zhang Ze
Moscow State University, Moscow, Russia; and, Russian State Geologic-Prospecting University, Moscow, Russia.

Laboratory-derived dependencies of the change in grain-size distribution, water properties, density, and equivalent cohesion of frozen morainic clayey loam on the number of freeze-thaw cycles are presented.

Glacial deposits of the European portion of Russia undergo seasonal freezing-thawing, which considerably alters their physico-mechanical properties. Study of changes in the properties of soils during cyclical freezing-thawing assumes major significance, since they are used as beds for structures and raw materials for the production of construction materials, and may also be implicated in such natural phenomena as solifluction, frost heaving and weathering, collapse of banks, etc.

It is demonstrated in [1-3] that freezing-thawing gives rise to variation in the grain-size distribution, and to both a reduction in strength and hardening of the soils. The direction of the processes will depend on the variety of soils, their physico-mechanical characteristics, the freeze-thaw regime, and the number of freeze-thaw cycles [4, 5].

We investigated the influence exerted by freeze-thaw cycles on the physico-mechanical properties of a morainic clayey loam extracted from the Zagorsk proving ground maintained by the Russian Geologic-Prospecting University at depths of from 1.9 to 2.0 m, i.e., below the depth of seasonal frost. Quartz is the basic soil-forming mineral of the clayey loam. Albite, microcline, and hornblende are encountered among the primary silicates.

The physico-mechanical properties and grain-size distribution of the morainic clayey loam are presented in Table 1.

Variations in grain-size distribution, moisture indicators, density, and equivalent cohesion were investigated. Tests were conducted on two series of specimens 20 mm in height with a diameter d = 56.6 mm and undisturbed (I) and disturbed (II) structures.

A model ensuring similitude of physical-property formation during freezing-thawing under field and laboratory conditions was preliminarily developed. In Series I, the specimens were cut from monoliths. The Series II specimens were prepared from the disturbed soil. The soil was dried, pulverized, passed through a 2-mm sieve, wetted with distilled water, and then maintained for 24 hours to attain a uniform moisture distribution. The surface of the soil was covered with a film to ensure a constant moisture content for testing.

Translated from Osnovaniya, Fundamenty i Mekhanika Gruntov, No. 3, pp. 16-20, May-June, 2010.
0038-0741/10/4703-0096

TABLE 1

Physico-mechanical properties of morainic clayey loam (gII_{ms})	Grain-size distribution (%) of soil particles of size (mm)								
	5 - 2	2 - 1	1 - 0.5	0.5 - 0.25	0.25 - 0.1	0.1 - 0.05	0.05 - 0.01	0.01 - 0.005	< 0.005
Undisturbed structure (Series I): ρ = 2.18 g/cm^3; W_{tot} = 16%; W_L = 31%; W_P = 19%; I_P = 12%	0.4	2	3.6	7.9	11	28.8	25.9	8.9	11.5
Disturbed structure (Series II): ρ = 1.96 g/cm^3; W_{tot} = 24%; W_L = 32%; W_P = 19%; I_P = 13%	0	4.8	2.4	8.4	13.6	20.2	16.7	5.7	28.2

TABLE 2

Number of cycles n	Morainic sandy-clayey loam	
	Series I	Series II
0	Very slightly plastic	Highly fluid
3	Slightly hard	Very slightly plastic
6	Slightly semi-hard	Very slightly plastic
20	Slightly hard	Very softly plastic
40	Same	Same

The specimens were placed in an insulated mold for plane-parallel freezing-thawing. Both series of tests included 40 freeze-thaw cycles;. The specimens were frozen for 16 h in a refrigeration chamber at -7°C, and were then thawed and maintained for 8 h at +20°C. The specimens of each series were subjected to a different number of freeze-thaw cycles (3, 6, 20, 40). To assess the strength C_e of the frozen soil in the initial state at -7°C, one of the specimens was tested six times for 8 h by the impression of a spherical die with a diameter d = 22 mm under a constant load

$$C_t = \frac{0.18P}{\pi d S_t}, \tag{1}$$

where C_t is the cohesion relative to a unit of area, and S_t is the variable depth of impression.

Use of the spherical die to investigate the influence exerted by freeze-thaw cycles on the strength of the clayey loam in the frozen state is explained by the following. The equivalent cohesion C_e obtained in the tests is a strength characteristic of frozen soils, which rationally accounts for cementation of particles by ice, and internal friction. The procedure used for its determination was proposed by Tsytovich and Vyalov [6, 7], and is regulated by the GOST [8]. The value of C_e makes it possible to determine the resistance to normal pressure beneath the lower surface of a foundation [9].

Changes in the grain-size distribution of the morainic clayey loam indicated that both dispersion and coagulation of soil particles take place during freezing-thawing in both series. The variation in the grain-size distribution, and, accordingly, the classification of the soil as a function of the number n of freeze-thaw cycles is presented in Table 2.

As the studies indicate, the 0.05-0.005-mm fraction in the undisturbed clayey loam (Series I) undergoes dispersion, and a reduction in their percent content is noted (Fig. 1, a). The fine, 0.01-0.005-mm silt particles aggregate, and go over into the neighboring 0.05-0.01-mm fraction, while the 0.05-

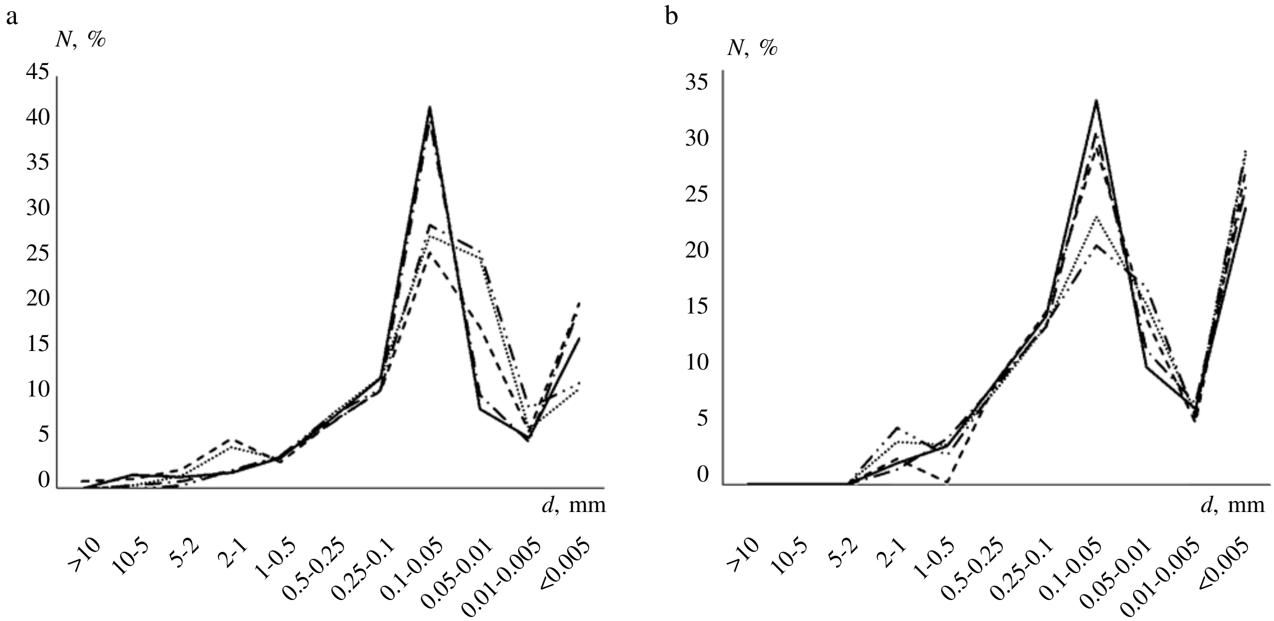

Fig. 1. Variation in grain-size distribution N of morainic clayey loam as function of n: a) undisturbed; b) disturbed. n: —··— 0; ··········3; -------6; —·—·—20; ———40.

0.01-mm size transitions into the 0.01-0.05-mm fraction, the content of which is increased from 28.8 to 41.7%.

Similar processes also occur in the disturbed clayey loam (Fig. 1, b). An increase in the content of the finely disperse 0.1-0.05-mm fraction is characteristic; this is dictated by breakdown of the largest microaggregates. On the whole, transformation of the dispersivity of the clayey loam under investigation as a result of freezing-thawing results in both cryogenic aggregation, and also dispersion of silty-clayey and colloidal particles in both series.

The experimental studies demonstrated that variation in the dispersivity of the soils is attenuating in nature. We evaluated the rate of change in dispersivity as a function of n on the basis of determination of the coefficient K_{var} [2], which makes it possible to characterize the variability of the entire spectrum of dispersivity and the dynamics of the process

$$K_{var} = \frac{1}{n} \Sigma |a_i - b_i|, \tag{2}$$

where a and b are the contents of a fraction prior to and after the cryogenic effect, respectively, and i is the number of the fraction.

Figure 2 shows the dynamics of K_{var} as a function of n.

The curves of the variation in the grain-size distribution in both series indicate asymptotic attenuation of the processes. Two segments are isolated. The effect of the initial cycles corresponds to the first segment. It has a higher rate of change, and is characterized by the largest number of irreversible processes involving transformation of the grain-size distribution – by the breakdown of coarse silty particles, and coagulation of the finer ones. In conformity with the classification outlined in [2], this segment applies to high rates of change in the grain-size distribution ($K_{var} > 1$). For the clayey loam under

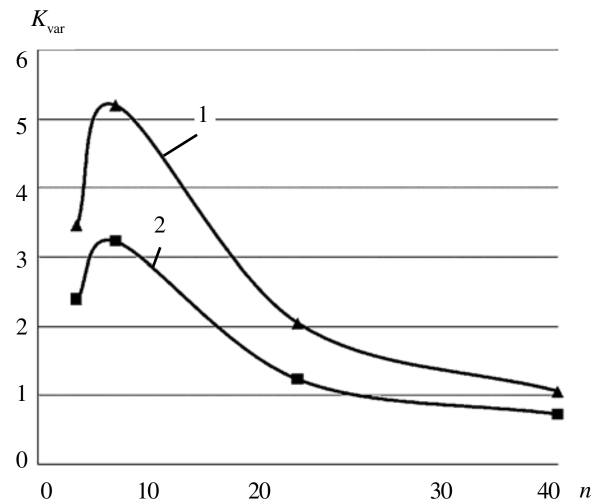

Fig. 2. Dependence of K_{var} on *n*: 1) Series I; 2) Series II.

investigation, it encompasses six cycles; this is comparable to the rate of change of the grain-size distribution for the freezing-thawing of kaolinite clays.

For the second segment, essentially only reversible processes involving transformation of the grain-size distribution take place during freezing and subsequent thawing. With continued freezing-thawing, the grain-size distribution approaches as closely as possible to an equilibrium state.

Analysis of the variation in the grain-size distribution of the undisturbed soil (Series I) indicates a lower rate of change, since the passage of soil through the 2-mm sieve dictated greater uniformity. In this series, there is virtually no dispersion of sand grains, but aggregation of silty and clayey particles is manifested with the formation of a fine-grain fraction.

Analysis of the variation in the basic physical properties owing to repeated freezing-thawing indicated that the in-situ moisture content of the soils remains virtually unchanged, since all specimens are frozen in a closed system, and the indicators have a poorly expressed tendency to diminish, because the upper and lower plasticity limits W_P and W_L decrease negligibly with increasing n; this is associated with the accumulation of the finely disperse fraction.

The density is also reduced after cyclical freezing-thawing in connection with an increase in porosity. The effects obtained are observed through six freeze-thaw cycles.

The tendencies of physical-property indicators to vary are in agreement with theoretical notions concerning the effect of the grain-size distribution that is formed during freezing-thawing.

Investigations of C_e indicated the following. The influence exerted by n on the strength of the frozen morainic clayey loam is closely associated with the formation of dispersivity, density, and the water properties. The equivalent cohesion of the undisturbed and disturbed clayey loam decrease with increasing *n*. The following laws are considered despite the significant scatter of experimental data.

In the undisturbed clayey loams (Series I), cohesion diminishes significantly after six cycles owing to an increase in porosity and the amount of water that had not frozen [10] (Fig. 3, a).

In the disturbed specimens (Series II), the freeze-thaw cycles caused a reduction in strength as a result of all cycles (Fig. 3, b). As is apparent, the strength of the disturbed specimens (Series II) is lower than that of the undisturbed specimens (Series I); this may be explained by breakage of initial structural bonds.

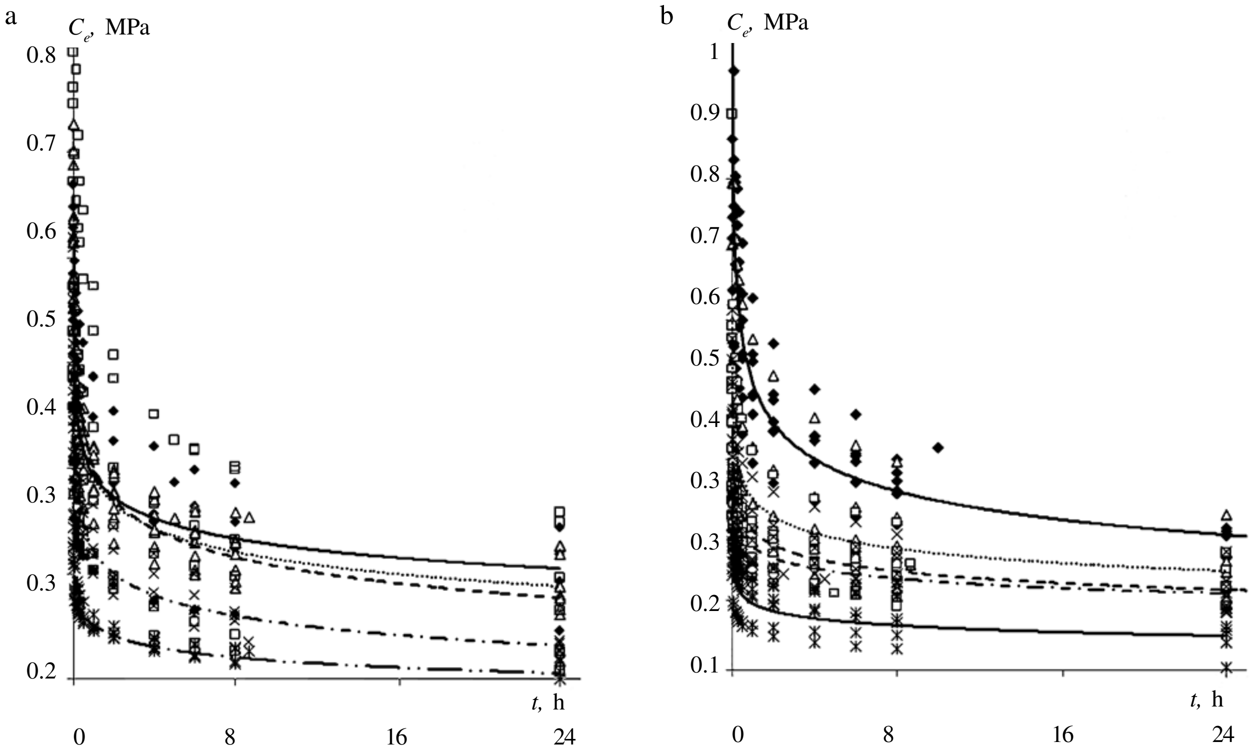

Fig. 3. Dependence of C_e on t for 0-40 freeze-thaw cycles: a) undisturbed; b) disturbed: ◆) —— 0; Δ) ········ 3; ■) ------- 6) ×) –·– 20; ✱) –··– 40 cycles.

Conclusions

1. Accumulation of the fine-sand fraction (0.1-0.05 mm) occurs during alternating freezing and thawing of a morainic clayey loam.

2. Rate of change in grain-size distribution and all physical properties diminishes after six cycles.

3. Alternate freezing and thawing of a frozen morainic clayey loam leads to a reduction in its strength.

The study was conducted with financial support in the form of grants from the Russian Fund for Fundamental Research/GFEN (Russian-Chinese joint projects 08-05-92220a and 08-05-92213a), the Russian Fund for Fundamental Research (Project 09-05-00551a) and Grant NSh-0478.2008.5 from the President of the Russian Federation.

REFERENCES

1. V. N. Konishchev, *Formation of Disperse-Rock Composition in the Cryolithosphere* [in Russian], Nauka, Novosibirsk (1981).
2. *Fundamentals of Geocryology. Part 1. Physico-chemical Bases of Geocryology* [in Russian], edited by E. D. Ershov, Izdatel'stvo Moskovskii Gosudarstvennyi Universitet, Moscow (1995).
3. I. A. Tyutyunov, New notions concerning the nature of the strength of frozen soils, *Proceedings of the Second International Conference on Permafrostology* [in Russian], No. 4, Yakutsk (1973), pp. 142-148.
4. E. D. Ershov, *Cryolithogenesis* [in Russian], Nedra, Moscow (1982).
5. I. A. Tyutyunov, M. V. Averochkina, and V. P. Titov, Effect of freezing and thawing on the structure,

composition, and properties of cohesive soils, *Proceedings of the Second International Conference on Permafrostology* [in Russian], No. 4, Yakutsk (1973), pp. 98-104.
6. S. S. Vyalov and N. A. Tsytovich, "Estimation of the bearing capacity of cohesive soils from the impression of a spherical die," *Dokl. Akad. Nauk SSSR*, **3**, No. 6, 1193-1196 (1956).
7. N. A. Tsytovich, *Determination of Cohesive Forces of Frozen Soils by the Spherical-Probe Method* [in Russian], Fondy Instituta Merzoltovedeniya, Akad. Nauk SSSR, Moscow (1947).
8. *GOST 12248-96. Soils. Methods of Laboratory Determination of Strength and Deformability Characteristics* [in Russian].
9. *Construction Rule and Regulation 2.02.04-88. Beds and Foundations on Permafrost* [in Russian].
10. E. D. Ershov, *Phase Composition of Moisture in Frozen Soils* [in Russian], Izdatel'stvo Moskovskii Gosudarstvennyi Universitet, Moscow (1979).