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NOTICE

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SHEAR STRENGTH OF CLAYEY GROUND DURING THAWING
(ACCORDING TO LABORATORY AND FIELD STUDIES)

Materialy VIII Vsesoyuznogo Mezhduvedomstennogo Soveshchaniya po Geokriologii (Merzlotovedeniyu) (Materials of the 8th All-Union Interdepartmental Conference on Geocryology (Cryopedology)), USSR Academy of Sciences, Siberian Department, Cryopedology Institute, No 5, 1966, Pages 51-60

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At this time calculated soil charactertistics are established for their thawed state. However, the "critical" period for frozen foundations and earth road beds is the period of thawing of the soils. The weakening of clayey ground during thawing and failure to consider this fact when planning and designing the foundations of structures and earth road beds are frequently the cause of their deformation, especially in deep freezing regions.

In order to estimate the weakening of thawing clayey ground, the Novosibirsk branch of the All-Union Scientific Research Institute of Transportation Construction performed laboratory and field studies of the shear strength of these soils before freezing and after freezing and thawing. The characteristics of the investigated soils are presented in Table 1.

Considering that thawing soil packs quickly and increases its strength with time, the shear strength was determined by testing it in a stability meter by the procedure of unconsolidated undrained shear (the duration of each experiment was 5-6 minutes). Destruction of the samples was carried out under lateral pressures of 0.5, 1.0 and 2.0 kg/cm^2. In addition, the shear strength of the soil was also determined by the ball sample method of N. A. Tsytovich.

Samples of disturbed soil were obtained for testing by pressing the ground with defined moisture to a given density. The samples were frozen in a cold room at a temperature of -8°-10° C -- both without inflow of water from below and with inflow. Then the samples were thawed at room temperature after which they were tested in the stability meter or by the ball stamp.

Control samples of the same density and moisture but not subjected to freezing were tested simultaneously.

The degree of variation of the shear strength of the soil as a result of freezing and thawing was estimated by the dimensionless freezing sensitivity coefficient K_f:

$$K_f = \tau_{thawed}/\tau_{unfrozen},$$

where τ_{thawed} is the shear strength of the thawed soil, kg/cm^2;

$\tau_{unfrozen}$ is the shear strength of the unfrozen soil, kg/cm^2.

By thawed soil we mean the soil in which the ice inclusions have completely thawed out but the structural relations in it and its strength have not been restored.

By unfrozen soil we mean soil which has not been frozen or has thawed and fully recovered its strength. Studies with soil samples No 3 frozen without the inflow of water provided the following results.

Table 1

Soil sample No	Type of soil	Fraction content in %			Specific gravity, g/cm^3	Plasticity limits in %			Maximum molecular moisture,%
		Sandy, 2-0.05 mm	Silty 0.05-0.005 mm	Clay less than 0.005 mm		Yield point	Rolling limit	Plasticity No	
1	Loam, light, silty	37	46	17	2.70	28	18	10	--
2	Loam, heavy, silty	20	56	24	2.72	30	18	12	12
3	Loam, heavy, silty	17	48	35	2.72	38-33	20-22	16-17	15
4	Clay	38	24	38	2.75	46	22-24	22-24	20

The shear strength of both unfrozen and thawed soil decreases essentially with an increase in its moisture before freezing. The magnitude of the shear strength with identical moisture is 10-40 percent lower for thawed soil than for unfrozen soil (Figure 1a). The freezing sensitivity coefficient K_f increases with an increase in moisture, and it reaches a maximum for moisture near the rolling limit. It then decreases.

The variation of soil density with moisture near the rolling limit has no effect on the decrease in its shear strength after freezing and thawing (Figure 1,b). Increasing the initial density also increases the shear strength of both the unfrozen and thawed soil. The variation of τ_{thawed} and $\tau_{unfrozen}$ as a function of γ is found in practice to be directly proportional so that K_f remains constant with an increase in γ.

SEE PAGE 3A for Figure 1a, 1b.

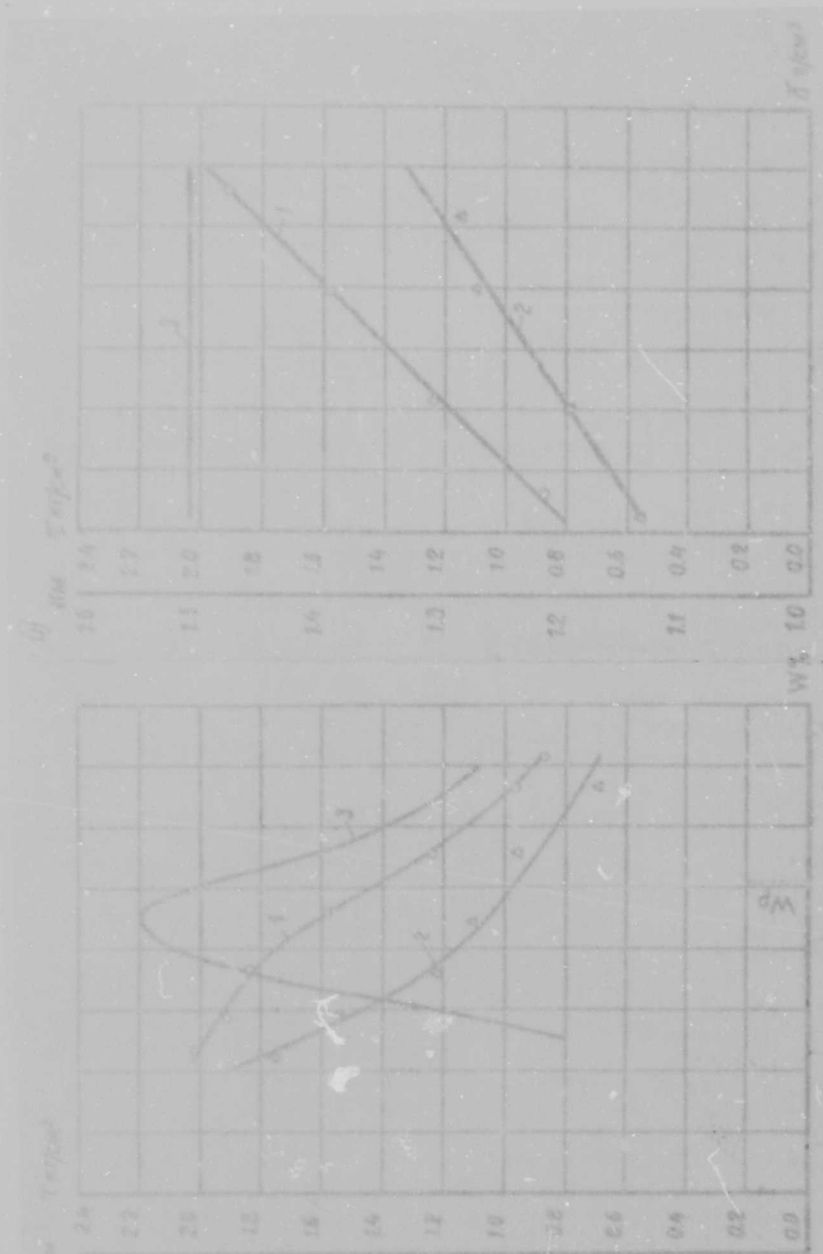
Figure 1a, b. Shear strength and coefficient K_f of soil sample No 3 as functions of moisture (a) and density (b). 1 -- shear strength of the unfrozen soil; 2 -- shear strength of the thawed soil; 3 -- variation of the coefficient K_f.

Key: A. τ, kg/cm^2 B. γ, g/cm^3

The number of freezing and thawing cycles also has no effect on the magnitude of the coefficient K_f. It was identical both for single and five freezing and thawing cycles.

It should be noted that in experiments with freezing of samples without inflow of water the moisture and density of the samples practically do not change during the freezing and thawing process.

It is highly characteristic that a decrease in shear strength of the soil with thawing arises from a decrease in the cohesion only; after thawing



its internal friction does not change or even increases somewhat. If we take the internal friction of the thawed and unfrozen ground as identical (which can only give a small error margin), then it is possible to judge the decrease in shear strength by the results of testing the soil with a ball stamp. This greatly facilitates the studies. The experiments demonstrated that the values of the coefficient K_f obtained by the results of testing the soil in a stability meter and by ball stamps differ from each other by no more than 5 percent. Therefore, the shear strength of soil samples No 1, No 2 and No 4 in the unfrozen and thawed states was studied only by means of the ball stamp. The earlier indicated results were repeated entirely in qualitative respects. In addition, it was established that the more clay particles the soil has in its composition, the more it lowers its strength as a result of freezing and thawing.

The maximum values of the coefficients K_f of the investigated soils (with moisture near the rolling limit) are presented in Table 2.

Table 2

Soil sample No	Type of soil	Coefficient K_f
1	Loam, light, silty, $W_n = 10$	1.3
2	Loam, heavy, silty, $W_n = 12$	1.3-1.4
3	Loam, heavy, silty, $W_n = 16\text{-}17$	1.5-1.6
4	Clay, $W_n = 22\text{-}24$	1.7-1.8

The dynamics of variation of the shear strength with time were investigated using soil sample No 4 in its unfrozen and thawed states. It turned out that the shear strength of the thawed soil increases with time appreciably more rapidly than that of the unfrozen soil. Thus, the shear strength of soil sample No 4 increased during a time of about 17 days: in the unfrozen state it increased by 24 percent, and in the thawed state, by 89 percent. The shear strength of the thawed soil increases especially rapidly during the first hours and days after thawing. After approximately 3 days, the shear strength of the thawed soil increases to values which the soil had before freezing (without considering its hardening during this time). After 9 or 10 days the shear strength of the unfrozen and thawed soil becomes practically identical (Figure 2).

The coefficient K_f varies correspondingly: during the first hours after thawing it decreases quite sharply, and then the rate of decrease drops 9 or 10 days after thawing and becomes equal to one. V. P. Titov (1965) notes analogous dynamics of restoration of strength of thawed soils.

The basic cause of weakening of clayey soil as a result of freezing without inflow of water and subsequent thawing is considered to be breakdown

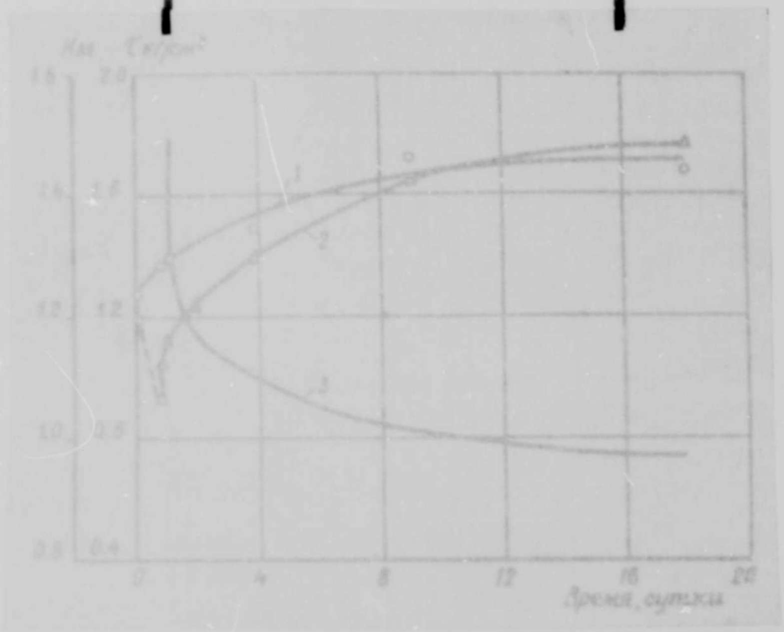


Figure 2. Dynamics of variation of the shear strength and the coefficient K_f. 1 -- shear strength of unfrozen soil; 2 -- shear strength of thawed soil; 3 -- coefficient K_f.

Key: a. K_f b. τ, kg/cm^2 c. time, days

of the structural bindings (Fedosov, 1940; Shusherina and Tsytovich, 1957; Titov, 1965, and so on). However, the greatest weakening is observed for moisture close to the rolling limit for which there is no visible breakdown of structure. At the same time, for high moistures the degree of disturbance of the soil increases, and the weakening of the thawed soil drops. These contradictions indicated there are other causes of weakening of thawed soils.

In our opinion, the relative increase in free water content in thawed soil (with identical moisture with the unfrozen soil) has great significance in this.

It is known that during freezing of soils, part of the bound water goes into ice. When the soils thaw the water is released and the soil aggregates only gradually bind it again. At the same time, the soil contains "excess" free water for a certain period of time, and this causes a reduction of cohesion of the soil. This principle has been confirmed by laboratory experiments performed with soil sample No 4.

The amount of bound water was determined by continuous drying of the soil -- by the break points on the kinetic drying curves (Gumenskiy, 1955).

In the unfrozen state the soil contained 26 percent bound water. If the soil was first subjected to freezing and then continuous drying, the amount of bound water in it depended on the initial moisture of the soil (Table 3).

Table 3

Initial soil moisture, %	Amount of bound water before freezing, %	Amount of bound water in the soil after freezing and thawing,%	Percentage bound water converted to free water
21	21	15	6
23	23	17	6
26	26	19	7
30	26	22	4
41	26	25	1

Increasing the initial soil moisture to 26 percent caused increased conversion of bound water to free water during thawing. Further increase in the initial moisture caused damping of this process. This is explained by faster return binding of the water by soil particles in the case of high moisture.

The largest amount of bound water is converted to free water for an initial soil moisture before freezing equal to the amount of bound water in the soil (26 percent). It is characteristic that the greatest relative drop in strength of the thawed soil is observed approximately with the same initial moisture (24-25 percent).

As the return binding of the water and restoration of structural relations between the aggregates and soil particles takes place the shear strength increases. This process takes place more rapidly during the first days, and then the rate of increase in shear strength decreases. Later, a slow increase in strength takes place as a result of restoration and reinforcement of the structural bindings.

The effect of freezing with inflow of water from below on weakening of the soil during thawing was studied by the ball stamp using soil sample No 3. The initial moisture of the samples was about 17 percent, and the density was 1.55 g/cm^3. After single freezing the samples expanded, their density decreased to 1.40 g/cm^3, and the moisture increased to 27-28 percent. The shear strength of the soil decreased by 10-15 times during thawing. After five freezing and thawing cycles, the density decreased still more, and the moisture increased to the yield point. The shear strength dropped almost to zero. The basic cause of this weakening of the soil was in this case loosening and overwetting as a result of inflow of water from below and disturbance of the structural bindings.

In the spring and summer of 1965, we performed field tests on thawed soils. The rotating cutting device of the All-Union Scientific Research Institute of Transportation Construction and the ball stamp were used for this purpose. A vane wheel 10 cm high was used. Thawed and unfrozen soils from

SEE PAGE 7A for Figure 3.

Figure 3. Shear strength and coefficient K_f of soil used for making fills in the winter as a function of the soil density. 1 -- shear strength at the time of thawing of the soil; 2 -- shear strength one to three months after thawing of the soil; 3 -- variation of the coefficient K_f.

Key: a. K_f
b. τ, kg/cm^2
c. γ, g/cm^3

the foundation site of two excavations and two fills (soil sample No 4) were subjected to testing. In addition, the soil used in a winter fill 7 meters high and completely frozen during the construction process (soil sample No 3) was also tested.

The shear strength of the thawed soil was determined in the layer directly adjacent to the soil still frozen. The shear strength of the unfrozen soil was determined at a depth exceeding the depth of seasonal freezing by 0.5 meters. In the winter fill the shear strength of the unfrozen soil was determined, on the contrary, in the upper layers where it had been in the

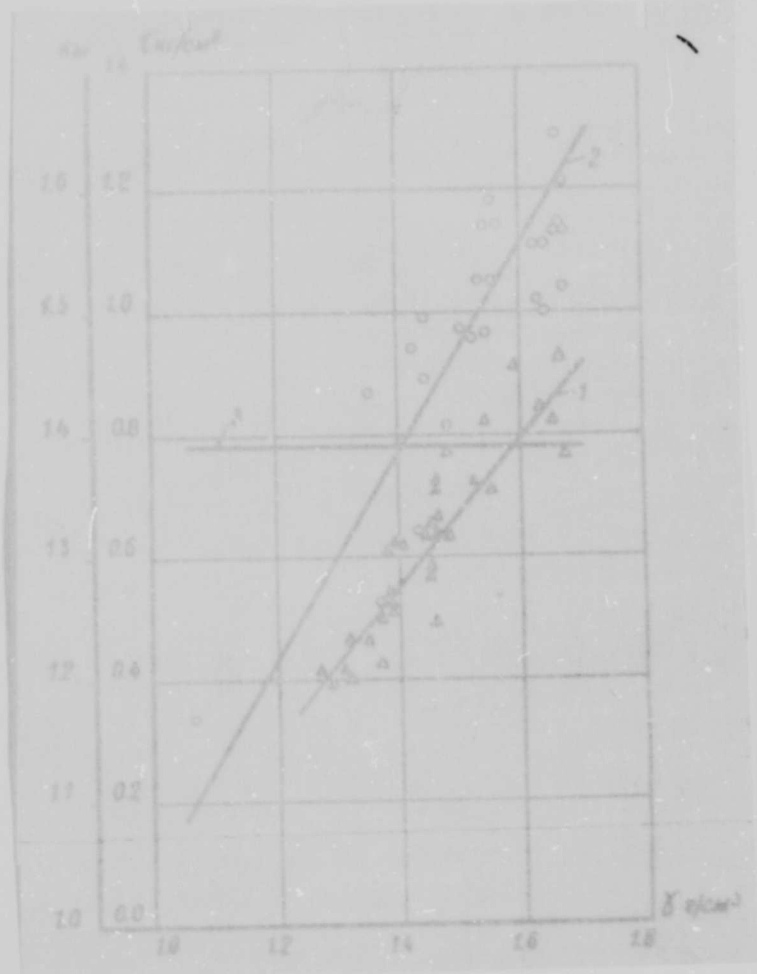


Figure 3.

Table 4

Results of testing thawed soils of a dirt railroad bed by the rotary cutting device

Item No	Form of earth road bed	Soil No	Depth of freez-ing, m	Depth of thaw-ing,m	No of days from time of thawing	Depth of test-ing, m	Dens-ity g/cm3	Mois-ture, %	Shear strength, kg/cm3	Coeffi-cient of freezing sensitiv-ity K_f
1	Excavation	4	1.60	0.80	3-5	0.75	1.45	32.9	0.406	2.51
		4	1.60	0.80	--	1.95	1.49	30.4	1.02	
2	Excavation	4	1.70	0.70	5-7	0.55	1.49	31	0.46	2.17
		4	1.70	0.70	--	2.10	1.47	31.6	1.04	
3	Excavation	4	1.50	0.70	3	30.68	1.53	28.2	0.665	2.11
		4	1.50	0.70	--	1.85	1.56	27.6	1.40	
4	Fill	4	1.90	1.06	7-10	0.70	1.57	22.2	0.795	1.31
		4	1.90	1.06	--	2.50	1.53	28.4	1.04	
5	Fill	3	7.0	2.3	80	0.45	1.55	19.6	2.52	1.63
		3	7.0	2.3	5	2.25	1.45	20.5	1.53	

thawed state no less than a month at the time it was tested. When determining the shear strength of the soil by a ball stamp soil samples were taken from the same depths by a core lifter and subjected to slow testing. Freezing of the soil in the fills took place without excess ice separation (that is, in practice without inflow of water from below). The freezing of the soil in the excavations took place with high excess ice separation, that is, with inflow of water from below.

By means of the ball stamp testing of soil sample No 3, the coefficient K_f and the shear strength of the unfrozen and thawed and soils were found as functions of the soil density. These results confirmed the laboratory tests (Figure 3).

Tests using the rotary cutting device demonstrated that the layer of thawed soil at the interface with frozen soil is always in a weak state. If the freezing of the soil took place without excess ice separation, the shear strength of the thawed soil at the interface with the frozen soil was 1.3-1.6 times less than that of unfrozen soil. When freezing the soil with excess ice separation, the shear strength of the thawed soil was 2-2.5 times less than that of the unfrozen soil (Table 4). Here, it is necessary to consider that the thawed soil was tested in a 10 cm layer. In a thinner layer it weakens to a still greater extent during thawing.

Basic Conclusions

1. The largest relative reduction of strength of thawed soils frozen without inflow of water from below is observed for soil moisture near the rolling limit.

2. The initial density of the soil does not affect the degree of weakening of it during thawing if the soil froze without inflow of water.

3. The shear strength of the soil after thawing increases rapidly. This must be considered when determining the strength characteristics of thawing soils.

4. One of the causes of reducing the strength of thawing soil is increased content of free water in it (with identical moisture with the unfrozen soil).

5. When calculating the foundations of structures and dirt road beds it is necessary to consider significant weakening of thawed clayey ground even in the case of low soil moisture. The calculated characteristics of such soils can be discovered by using a ball stamp.

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