Results of testing the heaving properties of soils under conditions of seasonal freezing and thawing in the cryolithic zone

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Abstract. This paper presents the results of a study of the dependence of deformations and heaving forces of loam and sandy loam during freezing in a closed system. On the basis of experimental data, graphs of the dependence of heaving deformation and thawing sediment are obtained. The data obtained were analyzed, as a result of which some regularities were revealed between the degree of heaving and physical indicators of properties.

1 Introduction

Ensuring the stability of engineering structures on seasonally freezing soils is one of the most difficult tasks today. Much attention was paid to the study of heaving soils, but mainly it was about the vertical forces of frost heaving and deformation, introduced mainly to shallow foundations. During the construction and operation of design engineers and builders, it often becomes possible to detect severe frost heaving of soils and obtain uneven deformations.

In areas of distribution of seasonally freezing and permafrost rocks, one of the cryogenic processes is heaving. Determining the deformations of heaving forces is an important practical and theoretical task. Therefore, ensuring the frost resistance of the road structure is an important task to be solved in the design and construction of roads. One of the aspects of solving this problem is to determine the characteristics of frost heaving.

2 Description of the research

Laboratory studies of the content of artificially prepared samples of loam and sandy loam, affected from the main parts of Yakutia. Central Yakutia is located in the permanent permafrost zone. Accordingly, soils are subject to seasonal freezing and thawing.

The depth of seasonal thawing in rare areas of Central Yakutia can reach 2.6 m. In order to establish the laws of heaving during the present studies, the particle size distribution was determined.

The data obtained are shown in Table 1.

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Table 1. Granulometric composition and name of soils

N	Sample name	Grading, %, at particle size, mm							Name soil according to GOST 25100-95
		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	
1	Loam	1.80	3.13	20.20	22.04	13.21	13.21	26.41	Loam heavy
2	Sandy loam	4.00	15.80	36.80	18.04	3.70	10.04	11.62	Sandy loam

The stress-strain state of frozen soils is not stable, but undergoes continuous changes during freezing and a further decrease in temperature, tending to dynamic equilibrium.

The main cryogenic processes that form the stress-strain state are:

- phase transformation of water into ice, accompanied by an increase in its volume by ~ 9%;
- cryogenic migration of water to the freezing front in fine soils and dehydration of underlying horizons;
- pressure migration of water and soil mass, caused by squeezing out from locally freezing areas into less stressed thawed zones;
- temperature reduction of all components of the freezing soil.

The following tasks were set in the work:

- establish the influence of freezing conditions on deformations and heaving forces at different initial moisture content of sandy loam and loam;
- compare the values of heaving deformations and sediment during thawing;
- evaluate the redistribution of moisture and the formation of cryogenic textures under the specified freezing conditions.

The space between the clips was filled with sawdust to ensure plane-parallel freezing from the upper end of the samples.

The test temperature is minus 2°C.

Fig. 1. General view of the installation for determining heaving under conditions closed system.

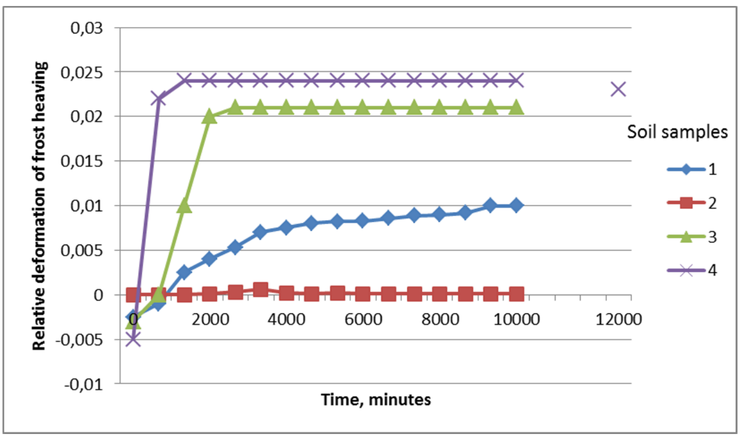
Samples of loam No. 1, 2, 3 were frozen at a temperature equal to -2 °C, and a sample of loam No. 4 was frozen at a temperature of -5 °C, at a given initial moisture content from 0.165

to 0.260 and density from 1.64 g/cm3 to 2.0 g/cm3. The physical properties of loam are shown in Table 2.

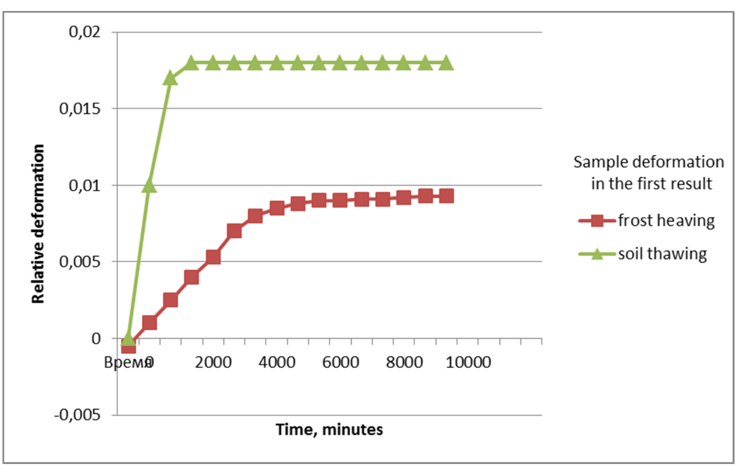
Table 2. Physical properties of the sample

Soil name	Sample number	Density ρ, g/sm^3	Soil moisture W_{tot}, %	Test temperature,°C
	1	1.74	22.7	
Loam	2	1.64	16.5	-2
	3	2.0	26.0	
	4	2.0	26.0	-5

The graphs of the dependence of heaving deformation and thawing sediment obtained on the basis of experimental data are shown in Figure 2.



(a)



(b)

Fig. 2. Dependency graphs of heaving deformation dependence (a) and comparison plots values of relative heaving deformation and defrosting precipitation versus time for sample N1(b).

Sample N2, having a moisture content of 0.165 and a density of 1.64 g/cm3, turned out to be practically non-porous with a monolithic cryogenic texture after freezing (Fig. 3). The fact that insignificant moisture during freezing of the soil led to the formation of ice only in the pores of the soil, without its swelling, forming a massive cryogenic texture (Fig. 3a).

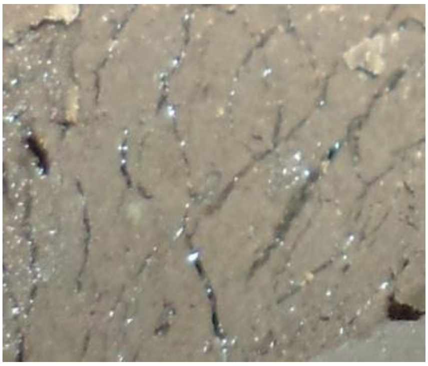
Sample No. 3 had a relative heaving deformation equal to 0.02, which is associated with high humidity close to full water saturation.

This led not only to filling the soil pores with ice, but also to heaving, due to an increase in the volume of water during freezing by 9% and the formation of a layered cryotexture (Fig. 3b). It should be noted that the cross-layered ice schlieren indicates the freezing of the samples not only from the upper end, but also in the direction of the side surface.

The heaving deformation of sample 4 exceeded that of sample 3, which is associated with a lower test temperature (minus 5 °C), which caused higher ice content due to the reduction of unfrozen water.

The relative settlement during thawing turned out to be approximately 2 times higher than the heaving deformation in samples 1 and 4, this is due to the compaction caused by moisture filtration and the compaction of the thawed soil aggregates under the action of its own weight.

a. Soil sample 2



b. Soil sample 3

Fig. 3. Texture of soil samples

In soil sample 2, which has a minimum moisture value equal to the rolling limit, a massive cryogenic texture was formed during freezing. In soil sample 4, which has a maximum moisture ness of the ice schlieren. content equal tfull water saturation, a schliere texture was formed during freezing. The width of the schlieren ranged from 0.1 to 0.5 mm, the distance between the schlieren was from 0.5 cm to 2 cm. According to the classification of B.I. Vtyurina (1970) – the type of cryogenic texture is reticulate, the subtype is obliquely vertically reticulated in the thickness of the ice schlieren.

Sandy loam samples 5, 6, 7 were tested in a closed system at a temperature of -2 °C. The physical properties of the samples are shown in Table 3.

Table 3. Physical properties of the sample

Soil name	Sample number	Density ρ, g/sm^3	Soil moisture W_{tot}, %	Test temperature,℃
Sandy loam	5	1.91	15.0	-2
	6	1.80	11.1	
	7	1.81	20.4	

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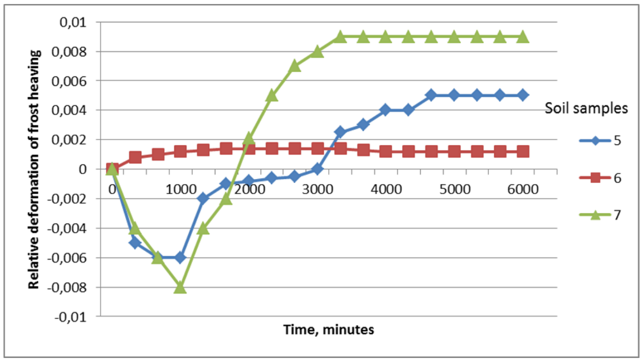
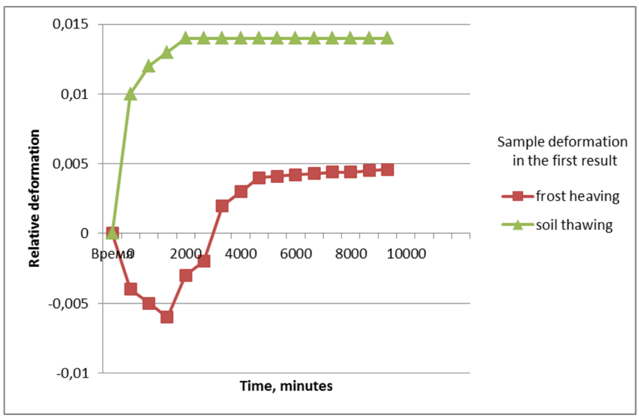


(a)



(b)

Fig. 4. Dependency graphs of heaving deformation dependence (a) and comparison plots values of relative heaving deformation and defrosting precipitation versus time for sample N5 (b).

The obtained dependences of the development of the relative heaving deformation in time and the dependence of the sediment during thawing are given in Fig.4. Where you can see the nature of development, both heaving deformations and thawing sediment, sandy loam and loam are identical. However, the quantitative values of sandy loam heaving are 2 times less than those of loam, which is due to a higher content of large particles and lower initial moisture values (tables 2 and 3).

For sample 7, which has a humidity close to full water saturation. The ratio of thaw shrinkage to heaving deformation for sample 7 turned out to be 0.04.

a. Soil sample 6

b. Soil sample 7

Fig. 5. Texture of soil samples

Comparing the cryotextures of loam (Fig. 3b) and sandy loam (Fig. 5b), one can see that the ice content of loam is higher, which is associated with higher humidity.

The obtained values of heaving deformation in a closed system made it possible to determine the degree of heaving of the studied soils in accordance with GOST 28622-2012, by the value of the relative heaving deformation (Table 4). Heaving soils are classified from almost non-heaving to excessively heaving.

Table 4. Determination of the degree of heaving according to GOST 28622-2012

The degree of soil heaving	Relative deformation of frost heaving of the sample, ε_{fh}
Non-porous	ε_{fh} <0.01
Slightly heaving	$0.01 \leq \varepsilon_{fh} < 0.04$
Medium-heavy	$0.04 \leq \varepsilon_{fh} < 0.07$
Strongly pebbled	$0.07 \leq \varepsilon_{fh} < 0.10$
Excessively heaving	$0.10 \leq \varepsilon_{fh}$

Table 5. The results of determining the degree of heaving

Test conditions and type of installation	Soil name	Soils sample numbers	Degree of heaving
Close system	loam	1	Non-porous
		2	Non-porous
		3	Slightly heaving
		4	Slightly heaving
	Sandy loam	5	Non-porous
		6	Non-porous
		7	Non-porous

The degree of heaving of both loam and sandy loam depends on freezing conditions and initial moisture. Under test conditions in a closed system, only at an initial moisture content close to full water saturation, the soils are classified as weakly heaving, and at a moisture content less than full water saturation, the soils are classified as non-heaving.

3 Conclusions

The performed studies of the formation of deformations and heaving forces of loam and sandy loam during freezing in a closed system confirm the patterns previously established by many researchers:

During freezing, especially under conditions of high (close to the freezing front) level of groundwater, intense migration processes occur.

1) At low initial humidity, ground moisture is fixed in the form of evenly distributed ice-cement, a massive cryogenic texture is formed, there is no heaving;
2) When the humidity is close to full water saturation, freezing leads to bulk swelling;
3) Heaving deformations are less than thawing sediment.

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