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THE INFLUENCE OF CYCLIC FREEZING AND THAWING IN OPEN SYSTEM ON CONSISTENCY CHARACTERISTICS OF SOILS

Summary. The paper examines the effect of freezing thawing on the consistency characteristics and the specific surface area of five natural soils. All soil samples were subjected to alternate freezing and thawing up to 10 cycles. The open soil-water system was imposed, in which migration of free water was allowed during freezing. Such a system represents the situation with high soil water level what is particularly dangerous in natural conditions. Additionally, three durations of cycles, i.e. 12, 24 and 96 hours were applied. Significant changes in the plastic and liquid have been observed, although the overall trend is not evident. The results indicate a substantial effect of the duration of the cycle, although the ice crystallization occurred in every case.

WPŁYW CYKLICZNEGO ZAMARZANIA NA CHARAKTERYSTYKI KONSYSTENCJI GRUNTÓW SPOISTYCH W OTWARTYM SYSTEMIE GRUNTOWO-WODNYM

Streszczenie. W artykule przedstawiono badania nad wpływem cyklicznego zamrażania na charakterystyczne granice konsystencji i powierzchnię właściwą pięciu naturalnych gruntów spoistych. Próbki wszystkich gruntów poddane zostały zamrażaniu i odmarzaniu w 1, 2, 5 i 10 cyklach. Dodatkowym czynnikiem warunkującym proces zamarzania było kilka długości czasów zamarzania, tj. 12, 24 i 96 h. Założony, otwarty system gruntowo-wodny gwarantował migrację wody wewnątrz ośrodka w fazie zamarzania.

Po przeprowadzeniu kolejnych badań dla odpowiednich długości czasów trwania cykli zaobserwowano istotne modyfikacje w wartościach granic plastyczności i płynności. Jednakże ze względu na charakter i ilość zjawisk determinujących te parametry trudne może wydawać się wyjaśnienie jednoznacznego trendu zmian dla wszystkich rodzajów gruntów.

1. Introduction

The frost action in soils, in cold regions practically impossible to eliminate, and the complex structure of the soil medium determine a complicated character of the problem. Most related topics (the phase composition of frozen soil [4], [5], the depth of frost [3], frost heave

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phenomena [2], thaw settlement prediction [7]) were usually solved with reference to a long-lasting freezing or thawing process, without taking into account its cyclicity.

Therefore, the topic of the effect of a cyclic freezing-thawing on the properties of soil as a ground foundation arouses a lot of interest for some time [1], [9].

Unfortunately, investigations carried out in this field focused on a selected single aspect of cyclic freezing (e.g. on the mechanism of change in microstructure, [8]) and attempts to find its correlation with the change of geotechnical parameters were relatively uncommon [1], [6], [9]. Some laboratory tests previously carried out by the present writer on the effect of cyclic freezing-thawing on the value of plasticity index in the closed soil-water system confirmed the presumption that this parameter undergoes a significant modification as a result of successive cycles. They have also demonstrated that the nature of these changes was, to a significant extent, dependent on the number of cycles and the type of soil.

However, it is known that the intensity of the freezing process in natural conditions is additionally influenced by the migration of water towards the frost penetration zone [2], [7]. Thus a question arises if a similar mechanism of cyclic-freezing takes place in such conditions. Therefore the aim of the present research was an attempt to characterize the effect of the number of cycles in the open soil-water system and their length (duration) on the values of the soil consistency limits.

2. Materials and experimental procedure

For this study, five natural clayey soils not previously subjected to freezing were used in the experiment. The soils were obtained from Kielce, Poland, at about 3.0 – 5.0 m depth, well below the frost penetration depth in that region. Thus initial soil properties were established as reference. The properties are presented in Table 1.

Table 1

Soil initial properties

No of soil	Liquid limit w_L (%)	Plasticity limit w_P (%)	Specific surface area S (m^2/g)
1	28,9	14,8	57,1
2	48,8	10,2	157,9
3	42,3	17,1	63,8
4	32,6	14,2	60,85
5	26,4	10,75	40,8

All soil samples were then subjected to one dimensional freezing and thawing. Each sample was placed in a steel tube 60 mm in diameter and 140 mm in height. It was installed tightly in a hole cut in a thick impermeable styrofoam block, leaving the top susceptible to temperature change and the bottom equipped with drainage facility. Migration of free water was allowed from a container, the water temperature in which was kept at about +4°C.

Freezing was induced by lowering the temperature to –25°C and subsequent thawing was activated at a room temperature of 20-22°C for 12, 24 or 96 hours in order to determine the effect of the cycle duration. The thermistor sensors were located in the soil vertically about 4 cm apart to monitor the temperature distribution in order to confirm the freezing process started within the soil sample. The tests were carried out for i = 1, 2, 5 and 10 cycles.

After a sample was subjected to the required number of freeze-thaw cycles, it was tested to determine any change in the initial properties.

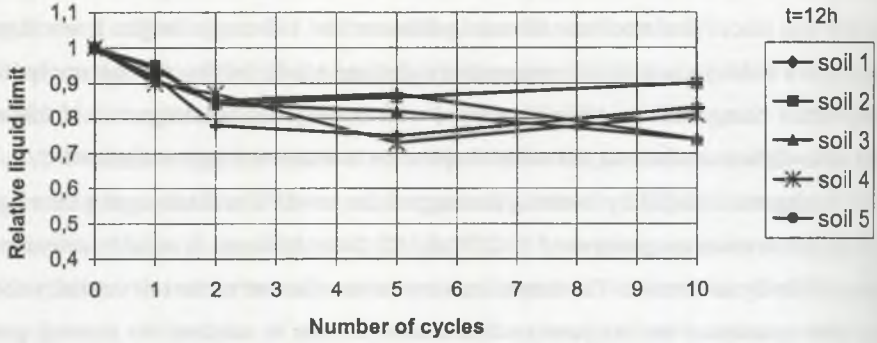
3. Discussion

The relative changes in the consistency limits (i.e. the proportions of the values after successive cycles to the initial values) are presented in Figures 1 to 6. It can be noticed that the values of all analyzed parameters underwent noticeable changes.

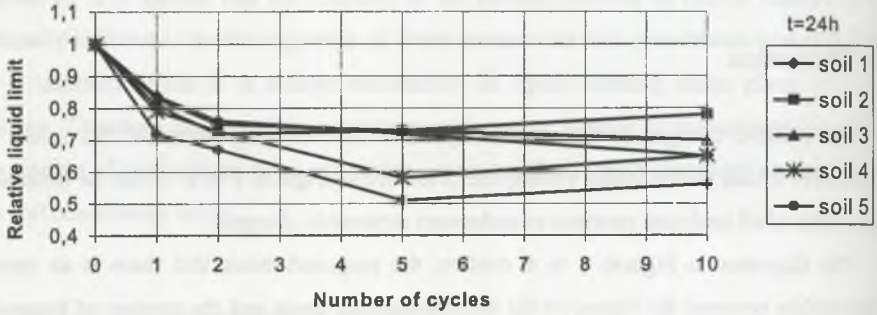
The diagrams in Figures 1 to 6 confirm the proposed thesis that there is an essential relationship between the values of the soil consistency limits and the number of freeze-thaw cycles. The impact of the first "freeze-thaw" cycle may appear particularly interesting, since it caused significantly more critical changes than the subsequent cycles.

The intensity of this process in the analyzed conditions is influenced, to a significant extent, by the migration of water over the frost penetration zone. Some results of tests on the frost transformation of the microstructure [6] speak in favor of such a thesis.

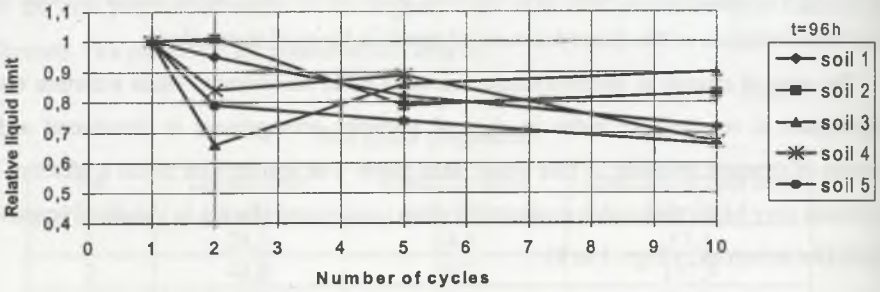
The zone of change in microstructure increases up to the moment when a certain state of equilibrium is reached, an order in mineral particles arrangement is introduced and the process of repeated bonding of free water takes place. The assumption of the a effect of such processes may be an reasonable explanation of an unexpected change in values of consistency limits (the extremes in Figs. 1 to 6).



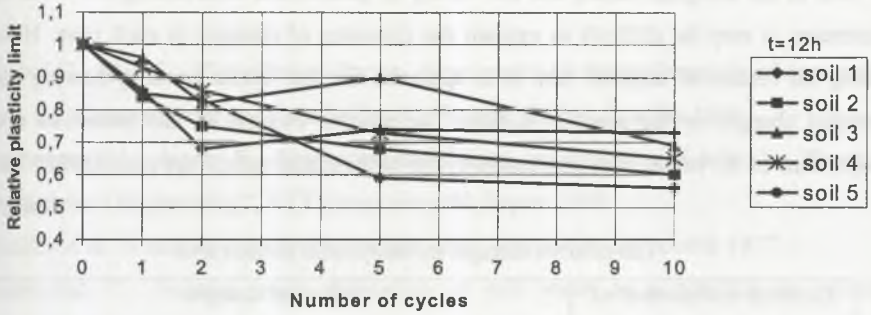
Rys. 1. Względne zmiany granicy płynności dla czasu trwania cyklu t=12 h
Fig. 1. The relative changes in the liquid limit for t=12 h



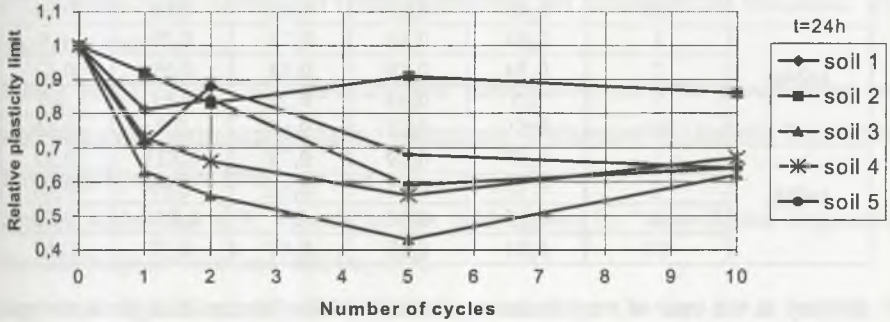
Rys. 2. Względne zmiany granicy płynności dla czasu trwania cyklu t=24 h
Fig. 2. The relative changes in the liquid limit for t=24 h



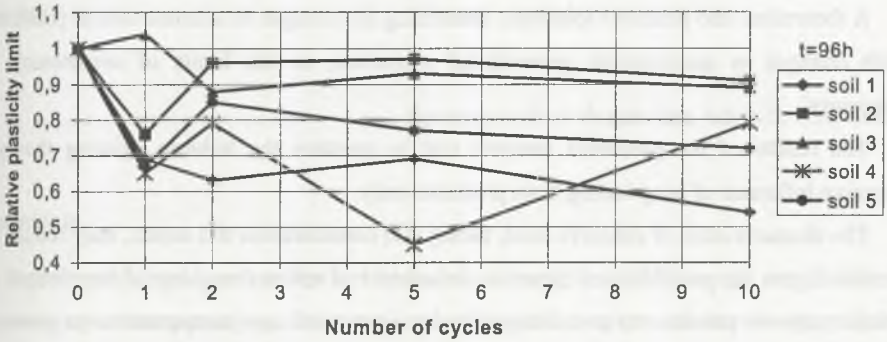
Rys. 3. Względne zmiany granicy płynności dla czasu trwania cyklu t=96 h
Fig. 3. The relative changes in the liquid limit for t=96 h



Rys. 4. Względne zmiany granicy plastyczności dla czasu trwania cyklu t=12 h
Fig. 4. The relative changes in the plasticity limit for t=12 h



Rys. 5. Względne zmiany granicy plastyczności dla czasu trwania cyklu t=24 h
Fig. 5. The relative changes in the plasticity limit for t=24 h



Rys. 6. Względne zmiany granicy plastyczności dla czasu trwania cyklu t=96 h
Fig. 6. The relative changes in the plasticity limit for t=96 h

Due to the complex nature and the variety of phenomena determining the value of this parameter, it may be difficult to explain the character of changes in each case. However, basing on results of sorption test, it is apparent that the cyclic freezing-thawing induces essential changes in the specific surface. The relative changes in this parameter (i.e. the proportions of the values after successive cycles to the initial values) are presented in Table 2.

Table 2

The relative changes in the specific surface area

Duration and number of cycles		Values of changes				
		soil 1	soil 2	soil 3	soil 4	soil 5
t=12h	1	0,77	0,88	0,84	0,9	0,89
	2	0,7	0,813	0,69	0,81	0,82
	5	0,57	0,84	0,89	0,72	0,75
	10	0,49	0,89	0,62	0,66	0,64
t=24h	1	0,64	0,86	0,78	0,79	0,9
	2	0,54	0,79	0,83	0,69	0,87
	5	0,5	0,81	0,59	0,61	0,8
	10	0,51	0,75	0,67	0,7	0,65
t=96h	1	0,87	0,89	0,79	0,823	0,95
	2	0,72	0,81	0,62	0,69	0,86
	5	0,55	0,85	0,9	0,817	0,79
	10	0,81	0,69	0,67	0,72	0,57

Similary to the case of the consistency limits, the most intense changes in the specific surface occur after the first two cycles, independently on the cycle duration.

Therefore, in fact, not only a fenomenological establishing changes but also the determination of the degree of internal structure modification is of critical importance.

A theoretical and practical solutions, combining the changes in microstructural parameters with changes in macroscopic geotechnical properties, as the limits of consistency, are necessary.

The results of the presented research call in question the hitherto existing theory of negative influence of long-lasting frost processes only.

The characteristics of cohesive soils, taking into consideration this aspect, may reduce to a certain degree the possibility of incorrect assessment of soil at designing of foundations and would make it possible to avoid the negative impact of low temperatures on pavement structures in cold regions.

REFERENCES

1. Baykal G., Türe E.: The effect of freeze - thaw cycles on the performance of compacted clay. In: "Contaminated and Derelict Land", Thomas Telford, London 1998.
2. Jessberger H.L., Jagow R.: Determination of frost susceptibility of soils. In: "Frost in Geotechnical Engineering", VTT Symposium 94, Espoo 1989.
3. Jumikis A.R.: Thermal Geotechnic, Rutgers Univ. Press, New Brunswick 1977.
4. Kozłowski T.: Freezing point depression of soil water as a function of mineral composition and physical properties, Archives of Hydro-engineering and Environmental Mechanics. Vol. XLI, 3-4, 1994.
5. Kozłowski T.: Influence of the total water content on the unfrozen water content below 0°C in model soils, Archives of Hydro-engineering and Environmental Mechanics. Vol. XLII, 3-4, 1995.
6. Kumor M.K.: Zmiana mikrostruktury iłów monomineralnych i iłu plioceńskiego pod wpływem cyklicznego przemrażania i odmrażania, Wydawnictwo Akademii Techniczno-Rolniczej, Bydgoszcz 1989.
7. Phukan, Andersland A.B.: Foundations for cold regions. In: "Geotechnical Engineering for Cold Regions". McGraw-Hill Inc, 1978.
8. Stępkowska E.T., Skarżyńska K.M.: Microstructural changes in clays due to freezing. In: "Frost in Geotechnical Engineering", VTT Symposium 94, Espoo 1985.
9. Yong R.N., Boonsinsuk P.: Alteration of soil behaviour after cyclic freezing and thawing. In: "Ground Freezing. Fourth International Symposium on Ground Freezing", Sapporo 1985.

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Omówienie

W pracy przedstawione zostały wyniki badań nad wpływem cyklicznego zamarzania na charakterystyki konsystencji gruntów spoistych. Oryginalny wpływ analizowanego projektu wynikał z przeprowadzania badań w otwartym systemie gruntowo – wodnym, gdzie oprócz działania niskiej temperatury w specjalnej komorze laboratoryjnej zagwarantowano migrację wody ku strefie przemarzania próbek gruntów.

Dla wszystkich gruntów wartości analizowanych parametrów uległy wyraźnym zmianom. Szczególnie interesujący może okazać się wpływ pierwszego cyklu „zamrażanie, odmrażanie". Powodował on bowiem znacznie bardziej krytyczne zmiany niż pięć czy dziesięć cykli. Biorąc pod uwagę wyniki badań przy 24- i 96-godzinnych cyklach, można wnioskować, że dłużej trwające cykle zamarzania powodują analogiczne zmiany parametrów, jednak że efekt ich działania jest znacznie większy.

Charakterystyka gruntów spoistych z uwzględnieniem tego aspektu może ograniczyć w pewnym stopniu możliwość przyjęcia złej oceny podłoża przy projektowaniu różnego rodzaju obiektów budowlanych i negatywnego wpływu niskich temperatur na podłoża nawierzchni.