THE ROLE OF THE ZONE OF CONTACT OF FROZEN SOILS WITH FOUNDATION MATERIALS IN THE FORMATION OF ADFREEZING STRENGTH

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Abstract

The influence of the structure and properties of the contact zone between frozen soils and foundation materials on the character of its failure under shear, and on adfreezing strength, is considered for a wide range of negative temperatures. Data obtained show that the character of failure in the contact zone varies and that there is a complicated temperature dependence of adfreezing strength at different ranges of temperature. A reversal of the pattern of values of the adfreezing strength of sandy soil and clayey soil is also observed. Analysis of experimental data shows that marked trends are affected by changes in the structure, properties and unfrozen water content of the contact zone with changes of negative temperatures.

Introduction

Adfreezing strength of soils is conditioned in many respects by the structure of the contact zone of frozen soil with the foundation material. Many investigators (e.g., Votyakov, 1958; Sadovsky, 1967; Vorobiov, 1973; Prazdnikova, 1982; Shusherina et al., 1982) have noted the presence of an intermediate ice layer at this contact, the formation of which depends on adfreezing conditions. If the ice layer is thin enough, it is characterized by higher strength. In this case, adfreezing strength is conditioned by the difference of strength at the contacts between the frozen soil and the ice layer and between the ice layer and the foundation material and it corresponds to a looser contact. The author has assumed that failure of frozen soils under shear must have a distinct character at different sub-zero temperatures. This should be reflected in the temperature dependence of adfreezing strength. These questions are investigated in this paper.

Methods

Investigations were conducted with specimens of remolded Gjel clay and Yakutsk sandy loam. These soils were placed into metallic rings which were adfrozen with steel discs. The values of gravimetric water content of the frozen clay and sandy loam were 31-32% and 26-27%, respectively; the values of density were 1.88-1.89 g/cm³. The direct shear tests were conducted using a single-plane shear apparatus PRS constructed by Sadovsky and Gorodetsky (Sadovsky, 1967) at a loading rate of 0.1 MPa/s. The experimental temperatures were -1, -2, -3, -4, -5, -6, -7, -9 and -12°C. At each temperature, 6-10 tests were carried out. As a result, average values of adfreezing strength were determined for each temperature. Surfaces of tested specimens adjoining to foundation material were investigated and photographed by means of an optical microscope.

Character of frozen soil failure

The presence of intermediate ice layers at the contacts between frozen clay and sandy loam and steel was observed in all cases of adfreezing. The thickness of these layers reached 0.6 mm for the clay and 0.05 mm for the sandy loam. Lower temperatures led to a decrease in ice layer thickness.

The test results show that in the temperature range of 0 to -3°C, failure takes place along the boundary of the contact ice and foundation material both for clay and for sandy loam (Figures 1a and 2a). The character of failure changes at lower temperatures. At temperatures from -3 to -5°C, a failure of clay occurs partially along the boundary between the contact ice and foundation material and partially along the boundary of the frozen soil and contact ice. Part of the ice layer remains attached to the foundation (Figure 1b) and the lower the temperature, the greater the area of this part. Failure of clay specimens at temperatures below -5°C occurs entirely along the boundary of the contact between the frozen soil and ice or within the frozen soil (Figure 1c). Failure within the boundary of the soil - contact ice was observed for sandy loam at temperatures lower than -3.5 - -4 °C (Figure 2b).
Similar results were obtained by Saveliev (1974) for sand, loam, kaolin and ascangel and by Shusherina et al. (1980) for sand and loam. According to Saveliev (1974), this phenomenon can be explained by the condition of the contact zone at different temperature ranges. At negative temperatures near the freezing point of the soil, failure of the soil specimens is responsible for the presence of a diffusion film of unfrozen water (in the terminology of Saveliev (1978)) at the boundary of the contact ice - foundation material, which decreases the adhesion forces. Moreover, a contact of ice and foundation material is usually not complete because of incomplete desorption of gases from surface micro-roughnesses of the material. So, the contact of the ice layer - material is stronger. At lower temperatures a diffusion film of unfrozen water in the boundary of contact ice - material freezes and only the firmly bonded layer of unfrozen water remains. So, failure occurs along the less strong contact of ice layer - frozen soil, due to the decreasing influence of unfrozen water in the frozen soil.
Temperature dependence of adfreezing strength

Temperature is known to be an important influence on adfreezing strength. Numerous investigations (e.g., Vyalov, 1959; Tsytovich, 1973; Shusherina et al., 1982) have shown that the adfreezing strength increases with decreasing temperature by a non-linear relationship, which is reflected geometrically by a smooth curve. But the literature also contains other data (e.g., Tsytovich and Sumgin, 1937; Peve and Peidj, 1974).

The curves of temperature dependence of the adfreezing strength of clay and sandy loam with steel obtained by the author are presented in Figure 3. It is seen that these curves contain points of inflection in which the relationship with temperature changes. At temperatures of less than -4.5°C for clay and -3.5°C for sandy loam, the adfreezing strengths after smoothly increasing increase more intensively (marked at 1 in the figures). At lower temperatures, another inflection point is present in which the intensity of increasing adfreezing strength reduces. This inflection point corresponds to -7°C for clay and -4.5 °C for sandy loam (marked at 2 in the figures). These data are in agreement with data obtained by Tsytovich (1937) for clay, silt and sandy loam adfrozen with wood.

As discussed above, in the temperature range from 0 to -3°C, failure of the specimens of clay and sandy loam occurs along the boundary of contact ice layer with the foundation material, while at temperatures colder than -5°C for clay and -3.5 °C for sandy loam, failure occurs along the boundary of the contact ice layer - frozen soil or within the frozen soil. According to Goldshtein (1948), Sadovsky (1973), Shusherina et al. (1980) and others, the shear strength of frozen soils is greater than the adfreezing strength. Moreover, at decreasing temperatures the rate of increase of the former is higher than that of the latter. This obviously explains the appearance of the first inflection point in the curves presented in Figure 3.

To explain the appearance of the second inflection point in these curves it is necessary to redraw the curves of the unfrozen water contents in clay and sandy loam against temperature in logarithmic co-ordinates (Figure 4). The represented graphs are broken lines with break points at -7.3°C for clay and -4.2°C for sandy loam. At temperatures below these values, the unfrozen water contents decrease less rapidly with decreasing temperature. It can be seen that the break point in the

Figure 3. Adfreezing strength ($\tau_{ad}$) of clay (a) and sandy loam (b) with steel as a function of temperature ($|\theta|$), 1, 2 - points of inflection.

Figure 4. Unfrozen water content ($w_u$) in clay (1) and sandy loam (2) as a function of temperature ($|\theta|$) (in logarithmic co-ordinates).
lines in Figure 4 corresponds to the second inflection point in the curves of of adfreezing strength versus temperature (Figure 3). Thus, the decreasing rate of increase of adfreezing strength of clay and sandy loam at second inflection point in Figure 3 appears to be the result of the declining intensity of decrease in the unfrozen water content in these soils. It is interesting to note that Zhu and Carbee (1987) marked break points corresponding to identical values of temperature at graphs of tensile peak strength against temperature, and graphs of unfrozen water content against temperature, plotted for silt in logarithmic co-ordinates.

Dependence of adfreezing strength on soil type

Analysis of the values of clayey and sandy soil adfreezing strength (Figure 3) shows an inverse relationship at different temperature ranges. In the range from 0 to -3.5°C, the adfreezing strength of clay is more than that of sandy loam. At temperatures from -3.5 to -7°C, this pattern is reversed. At still lower temperatures, the adfreezing strength of clay becomes more than that of sandy loam again. These data are in agreement with results obtained by Tsytovich (1937), Vyalov (1959) and Saveliev (1974).

Analysis of the conditions of the frozen soils and foundation material contact zone and the character of its failure at different temperatures can explain these findings. According to Shusherina (1982), the contact ice layer equalizes the influence of the composition and properties of frozen soils on the adfreezing strength. This is true at high negative temperatures, when failure occurs along the boundary of the contact ice - material and the influence of soil on adfreezing strength is minimal. Consequently, at these temperatures, the adfreezing strength of clayey soils can be equal to or more than that of sandy soils. At lower temperatures, when failure occurs along the boundary of contact ice - frozen soil or in the frozen soil, the adfreezing strength is conditioned in many respects by the frozen soil strength. On the other hand, the strength of frozen soils depends greatly on the unfrozen water content. So, the adfreezing strength of sandy loam becomes greater than that of clay. The second reversal of the adfreezing strength relationship at low temperatures, occurs after an intensive phase transition of soil moisture, and appears to be due to compensation of the difference in unfrozen water contents by the greater specific area of clayey soil particles.

Conclusions

This investigation leads to the following conclusions:

1. The adfreezing strength of soils with foundation materials depends on the structure of their contact zone.
2. Different types of contact zone failure are observed at different ranges of temperature.
3. A complicated dependence of adfreezing strength of soils on temperature is shown.
4. The relative adfreezing strengths of clayey and sandy soil reverse at different temperatures.

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