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On determining frost susceptibility of soils

Abstract. Freezing and thawing of soils are common in cold regions. They may even be considered as limit states from the thermo-hydro-mechanical point of view. Thus, to characterize the behavior of freezing and thawing soils, some basic principles should be considered. Design to prevent frost damage should be based on theories that have been shown to apply to field conditions. The laboratory procedures used in the design should imitate the expected freezing behavior, and the tested specimen should be prepared to simulate the soil conditions in the field. The parameters from the test should be applicable to the design model. If these principles are not applied, then the frost susceptibility can be considered as a limit classification property describing the risk of damage in freezing and thawing.
Keywords: frost susceptibility, frost damage risk, laboratory testing, modelling.

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Introduction

Freezing and thawing are characteristic ground processes in cold regions, which cover about 70% of the dryland on the Globe (Tsytovich 1975). In the Arctic, the ground is perennially frozen and is called "permafrost", as to in more southern regions, the freezing only occurs seasonally, with intermediate thaw periods.

The most common implications of cold climate and freezing are frost heaving and thaw weakening of soils. To limit frost heaving, specific measures are needed to limit heaving so that the risk of damage is reasonable.

Thaw weakening is mobilized, when frost-susceptible ground, containing excess ice, thaws, and releases water, causing loss of strength, and bearing capacity, which may lead to excessive shear deformations and rutting of road surface. This may in bad conditions lead to total failure of the road and stop of trafficking.

In hydraulic liners that are constructed using frost-susceptible materials, freezing and ice segregation may cause the formation of shrinkage cracks in the soil and/or irreversible compression of soil matrix which may increase hydraulic conductivity thus degrading the function of the liner.

Artificial ground freezing is applied as a temporary strengthening for excavations, cavities and tunnels. It may also occur at cooled structures like cold storages, ice rinks etc.

To control the long-term behavior of a structure exposed to cold, some principles should be applied during design. Some effects are resulting as complete failure, jeopardizing the usability of the structure, like slope stability, watertightness of hydraulic liners or extreme thaw-weakening on roads, or frost heaving of foundations. In less severe cases, these effects cause considerable maintenance needs and related costs.

Impacts of freezing and thawing in soils

Freezing causes moisture redistribution in partially saturated soils. it does not, usually, cause volumetric expansion. When saturated soils freeze, ice segregation results from moisture flow driven by pore water suction related to freezing point lowering at the freezing front. The freezing point decrease is characteristic of fine- grained soils such as silts and clays. In relatively slow frost penetration, ice is segregated in ice layers and lenses in the freezing soil. The frost heave ratio (frost heave divided by the thickness of the actual frozen layer) can vary from 0% to 20%. The suction (negative pore pressure) generated in freezing soils can cause an increase of consolidation pressure in cohesive soils. (This may be the origin of dry- crust phenomenon in natural clays and silts.) When clayey soils are frozen for the first time, which often happens in artificial ground freezing, the suction generated may cause excess compression and later settlements during thaw. In addition, the freeze-thaw induced compression may result in the formation of cracks in the thawed soil. The resulting increase in hydraulic conductivity can cause the failure of the liner.

As a frozen road structure, or a pavement on a frost-susceptible subgrade starts to thaw, the road is softened, and its mechanical response degrades compared to that before freezing. When the thaw front proceeds to the frozen, ice-rich subgrade, water saturates the pavement and subgrade, and its load response (bearing capacity) is lowered. This results in increased total and irreversible deflections, seen as increased surface settlements and rutting. Excess transport may cause “spring breakdown” and interrupt the flow of traffic in the worst cases.

Thaw impacts are often treated as an indirect observational problem. The problem has been less studied from soil-mechanics framework. The thaw deformation of roads might be handled as an accumulated cyclic shear problem, considering effective stresses during thaw. In practice, the trafficability can be estimated when knowing the actual frost penetration, actual thaw penetration, and measured pavement response during thaw.

Definition

A frost-susceptible soil is defined in terms of frost-heaving and/or thaw weakening behavior (eg. Andersland & Ladanyi (1994), Chamberlain (1980), ISSMFE/TC08 (1989)).

Besides natural ground and natural soils, we may have the need of investigating frost-susceptibility of constructed fills (eg. road layers) or artificially frozen ground. Moreover, the durability of construction materials is also affected byfreeze-thaw and thus should be tested.

Validity

Frost heaving has been always seen on the roads and has been subjected to research to explain it (Taber (1930), Beskow (1935), Casagrande (1938), andothers). Criteria of frost-susceptibility have been collected and presented by Chamberlain (1980) and ISSMFE/TC8 (1989) among others. Indirect criteria are also applied, because they give easy and quick answer to the problem, but their reliability is not known.

The criteria for assessing FS (frost susceptibility) have been stated, but not generalized, due to lacking theory. Thermodynamically based theories are, e.g., therigid ice theory (Miller 1977, 1980 and Sheng et al. 2013) and the segregation potential theory (Morgenstern& Konrad 1980, 1981, 1982 and Saarelainen 1992). Currently, most design guides and frost related literature define criteria that are not consistent with the theories and the experimental testing practice is variable.

Criteria for classifying frost-susceptible soils or freezing expansion should becommonly agreed by the Geotechnical Community.

Discussion of the development of a common freezing test procedure is still atan initial phase. What we need is a theory for ice segregation in freezing soil, and the parameters needed to predict frost heaving. To ensure the validity of the theory and the frost heave test, the comparison between site and laboratory behavior should be carried out. An example, such a comparison for frost heaving has been presented in Saarelainen (1992). Henry (2005) compared three frost heave models’abilities to predict frost heave of laboratory specimens frozen under realistic field conditions. Similar research utilizing field sites and conditions would be of great benefit to frost heave prevention design. However, the work should also beexpanded so that theory and criteria should also be made available for strength lossand weakening in thawing soils, as well as for the change in hydraulic conductivity.

Application in design

Effects of freeze-thaw should be described so that they can be applied in design and planning, not only as classification but also in quantitative manner. Figure 1 is an example of frost heave design using the Segregation Potential.

Conclusion

1. The main effects of soil freezing are frost heaving, thaw weakening, freeze- compression, and cracking that increases the hydraulic conductivity of soils after thaw.
2. To get applicable parameters for design, the test procedures should imitate natural freezing or thawing, and the parameters should fit to the design model.

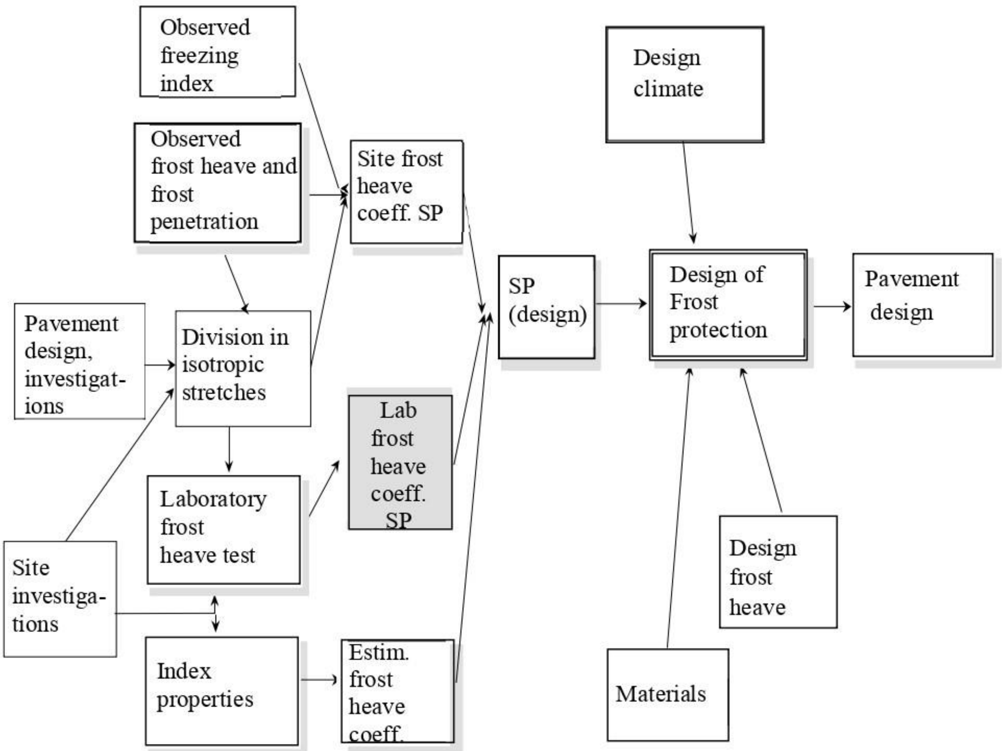

Figure 1. Pavement design considering frost heave utilizing the Segregation Potential (SP)

3. The frost susceptibility may be considered as a soil property that can also be indirectly estimated using classification properties or coarsely estimated withunverified laboratory freezing tests.

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Топырақтың аязға бейімділігін анықтау туралы

Аңдатпа. Топырақтың мұздатуы және еруі суық аймақтарда жиі кездеседі. Оларды термо-гидро-механикалық тұрғыдан алғанда шекті күй деп қарастыруға болады. Осылайша, топырақтардың мұздату және еріту кезінде жағдайын сипаттау үшін кейбір негізгі принциптерді ескеру қажет. Аяздың зақымдануын болдырмайтын дизайн далалық жағдайларға сәйкес келетін теорияларға негізделуі керек. Жобалау кезінде қолданылатын зертханалық процедуралар мұздатудың күтілетін жағдайына сәйкестендіру, ал сыналған үлгіні даладағы топырақ жағдайларын модельдеуге дайындау керек. Сынақтан алынған параметрлер дизайн үлгісіне сәйкес келуі керек. Егер бұл принциптер қолданылмаса, онда аязға сезімталдықты мұздату және еріту кезінде зақымдану қаупін сипаттайтын шекті жіктеу қасиеті ретінде қарастыруға болады.

Түйін сөздер: Аязға сезімталдық, аяздан зақымдану қауіпі, зертханалық тексеру, модельдеу.

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Об определении морозостойкости почв

Аннотация. В холодных регионах обычны промерзание и оттаивание почв. Их можно даже рассматривать как предельные состояния с термогидромеханической точки зрения. Таким образом, чтобы охарактеризовать поведение промерзающих и оттаивающих грунтов, необходимо учитывать некоторые основные принципы. Дизайн, предотвращающий повреждение от мороза, должен основываться на теориях, применимых к полевым условиям.

Лабораторные процедуры, используемые при проектировании, должны имитировать ожидаемое поведение при замерзании, а испытанный образец должен быть подготовлен для моделирования условий почвы в поле. Параметры испытания должны быть применимы к расчетной модели. Если эти принципы не применяются, то восприимчивость к заморозкам можно рассматривать как предельное классификационное свойство, описывающее риск повреждения при замерзании и оттаивании.

Ключевые слова: морозостойкость, риск повреждения от мороза, лабораторные испытания, моделирование.

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