Determination of frost-susceptibility of soil

Détermination du potentiel du gel du sol

E.SLUNGA, Helsinki University of Technology, Finland
S.SAARELAINEN, Technical Research Centre of Finland, Finland

SYNOPSIS: The ISSMFE Technical Committee on Frost (TC 8) has treated the determination of frost-susceptibility of soils and given proposals for recommended methods and procedures. This presentation is a short summary of the work.

1 INTRODUCTION

The frost-susceptibility (FS) of soil has to be treated firstly as a soil property and secondly as the frost-susceptibility of a soil in situ. The first treatment is meant for comparing the properties describing frost-susceptibility of various soils with each other. The second one takes into account the influence of geological profile and boundary conditions in a soil layer e.g. the effects of the freezing index, depth to ground water level and stress state on the frost heave.

Frost action causes in a frost-susceptible soil frost heave, thaw-settlement and thaw-weakening. The frost heave is considered as an important design factor in many countries. A structure's technical design for frost action is first based on frost heave. After that the bearing capacity of the super structure during thawing also has to be controlled.

In conditions where the effects of thaw-settlement or thaw-weakening are more important than frost heave, other criteria have to be used e.g. the thaw CBR (Merkblatt 03/87) or the resilient modulus (Cole & al. 1986) but those criteria are not treated here.

2 FROST-SUSCEPTIBILITY OF A SOIL TYPE

It is recommended that the criteria for the determination of the frost-susceptibility of a soil be grouped on three (I-III) levels according to Fig. 1 as also proposed by Chamberlain (1981). The frost-susceptibility of a soil type may be evaluated on the basis of grain size distribution only (level I) if the structure in question tolerates frost heave to a certain extent and/or the work in question concerns big soil masses. In those cases the classification of soils into frost-susceptible or non-frost-susceptible materials is enough. The criterion proposed by the ISSMFE Technical Committee on Frost (1988) provides a good basis for that purpose (Fig. 2).

In borderline cases and generally in connection with more qualified structures the determination of frost-susceptibility has to be improved by other criteria based on the index properties and/or on the hydraulic properties of soils (level II).

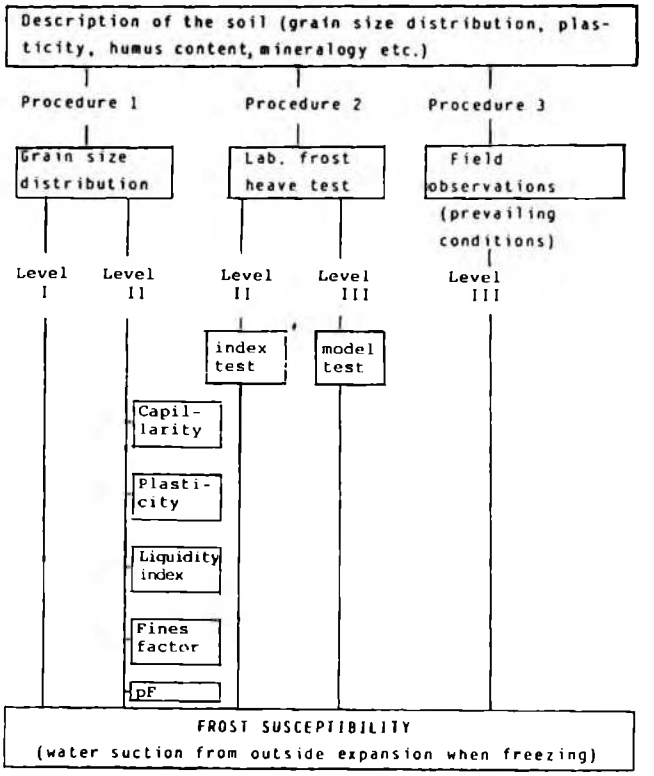

Figure 1. A scheme of reference methods for determining the frost-susceptibility of a soil.

Criteria for improving the frost-susceptibility-determination are shown in Table 1. The basic criteria are the segregation potential (Konrad 1980) and the rate of frost heave (Chamberlain 1981). It is proposed that these criteria be determined from the results of standardized frost heave tests (model tests). Using these parameters it is also possible to determine the degree of frost-susceptibility. The parameters are determined using in situ samples or samples, which have been compacted into a density corresponding to an in situ density of soil at a

Table 1. Determination of frost-susceptibility of a soil type (ISSMFE, TC8, 1988).

FROST CLASS	PLASTICITY CHART		CAPILLARY RISE /1/	LIQUIDITY INDEX/5/	FINES FACTOR/4, 6/	SEGREGATION POTENTIAL/7/	FROST HEAVE RATE /2/
	Soil type (USCS)	Plasticity index I_p/Liquid limit w_L, % /3/	m			$\frac{SP_o}{mm/h}$ / $\frac{K}{mm}$	mm/d
NEGLIGIBLE	GW, GP SW, SP	I_p < 1	< 1	≤ 0	< 2,5	< 0,5	< 0,5
LOW	CH	$I_p \geq 7; w_L > 50$	1,0-1,5	< 0,25	2,5-5	0,5-1,5	0,5-2
MEDIUM	CL Above A-line OH, MH Under A-line	$I_p \geq 7; w_L = 35-50$ $I_p \geq 7; w_L > 50$	1,5-2,0	0,25-0,50	5-10	1,5-3,0	2-4
STRONG	CL Above A-line ML Under A-line OL Under A-line	$I_p \geq 7; w_L < 35$ $I_p \leq 4; w_L < 50$ $I_p \geq 7; w_L = 35-50$	> 2,0	> 0,50	> 10	> 3,0	> 4

Soils above A-line with I_p between 4 and 7 are borderline cases requiring the use of several methods

/1/ Beskow (1949)
/2/ Chamberlain 1981)
/3/ Merkblatt fur die Vernutung von Frostschäden in Strassen. Entwurf 03/87
/4/ Rieke & al. (1983)
/5/ SNiP II-15-74
/6/ Vinson & al. (1987)
/7/ ISSMFE, TC8 (1988)

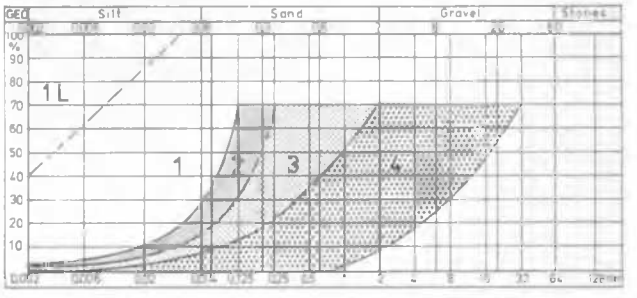

Figure 2. Determination of frost-susceptibility of a soil on the basis of grain size curve (ISSMFE, TC8, 1988).
1) If the grain size curve lies compleatly within region 1 the soil is always frost-susceptible (FS); in the region 1L the FS is low.
2) If the grain size curve falls compleatly inside regions 2, 3 or 4, the soil is non-FS.
3) If the lower part of the grain size curve permanently passes the boundary of the next region on the finer side, the soil is frost-susceptible.
4) Borderline cases have to be controlled with more exact methods.

depth of one meter. It is proposed that the specimen be consolidated by a load of 20 kPa. The recommended test-type is a constant-temperature test, during which the vertical load is very little, 3 kPa. The frost heave test may also be conducted with a constant rate of frost penetration.

The comparison of frost-susceptibility criteria based on index properties and on capillarity with the results from the laboratory frost heave tests in Table 1 is mainly done on the basis of literature and partly on the basis of a series of laboratory tests and field observations conducted in Finland 1986-87. The basic material is, however, limited and therefore a calibration in local conditions is necessary.

When checking the border between frost-susceptible and non-frost-susceptible soils on the side of coarse grained soils, suitable criteria are the height of the capillary rise and the fines factor. On the side of fine grained soils, suitable criteria for the same purpose are e.g. the plasticity and liquidity index.

The water content of soil corresponding to a certain pF-value (Jones & al. 1984) seems possibly also to provide a reliable frost-susceptibility-criterion for both of the above mentioned border areas, but a practical criterion on this basis is not yet established.

3 FROST-SUSCEPTIBILITY OF SOIL IN SITU

The frost-susceptibility of soil in situ may be determined by
- investigating
  - . if soil type is frost-susceptible assuming that all other requirements for frost heave exist (level I) or
  - . if there is available enough water for frost heaving in addition to all other requirements for frost heave (level II; e.g. the height of capillary rise, liquidity index and the depth to ground water level) or
- conducting
  - . frost heave tests for the determination of segregation potential or
  - . in situ observations of frost heave, frost depth, temperature and water content in soil.

Frost-susceptibility in situ should be determined on the basis of in situ observations or on basis of parameters from laboratory tests, taking into account the real soil con-

Table 2. Frost-susceptibility of homogeneous soil in situ for choosing structures (ISSMFE, TC8, 1988)

FROST CLASS	CAPILLARITY RISE /1/ m	LIQUIDITY INDEX /5/ $\frac{w - w_p}{w_L - w_p} = I_L$	
NEGLIGIBLE	< 1	$I_L \leq 0$	z > 0,5m; fine sand z > 1,0 m; silty sand z > 1,5 m; silt z > 2,5 m; clayey silt z > 3,0 m; clay
LOW	1,0-1,5	$0<I_L<0,25$	z ≤ 0,5 m; fine sand 0,5 m > z ≤ 1 m; silty sand 1 m < z ≤ 1,5 m; silt 1,5 m < z ≤ 2,5 m; clayey silt 2 m < z ≤ 3 m; clay
MEDIUM	1,5-2 z ≥ 1 m; moraines z ≥ 1,5 m; sediments	$0,25<I_L 0,50$	z ≤ 0,5 m ; silty sand 0,5 m < z ≤ 1 m ; silt 1 m < z ≤ 1,5 m ; clayey silt 1,5 m < z ≤ 2 m ; clay
STRONG	> 2 z < 1 m; moraines z < 1,5 m; sediments	$I_L > 0,50$	z < 0,5 m ; silt z < 1 m ; clayey silt z ≤ 1,5 m ; clay
z = Distance from the design freezing depth to ground water level			

/1/ Beskow (1949)
/5/ SNiP II-15-74

ditions and the relationship between the measured or calculated frost heave and the tolerable frost heave. The classification of soil in situ into different classes on the basis of the degree of frost-susceptibility is possible only for certain types of structures e.g. roads or parking areas etc. The classifying criteria is then the tolerable frost heave assuming that the bearing capacity during thawing is satisfied. The frost heave has to be calculated according to accepted design conditions.

3.1 Approximate design

Approximate design is often used e.g. in connection to unpaved low-class roads or traffic areas when choosing the class of design and the type of pavement for the structure. The frost-susceptibility of the soil in situ may be evaluated indirectly with the aid of Table 2. The determination of frost heave is based on the soil type, the height of the capillary rise, the liquidity index and on the depth to the ground water level. In principle, the relationship between the degree of frost-susceptibility and the frost heave is the same as in Table 1, but more approximate.

3.2 Design based on frost heave tests and in situ observations

If the frost-susceptibility of soil plays an important role in the function of structures in question, one should conduct laboratory frost heave tests and/or in situ-observations. With the aid of these measures it is possible to carry out detailed design taking into account the special requirements of the structures (level III) and to calibrate the FS-criteria of lower levels. The parameters used in frost heave calculations have to be determined in conditions which correspond to the in situ conditions as closely as possible. Those frost heave tests which are conducted for the determination of the frost-susceptibility of a soil type shall be done according to the instructions discussed in chapter 2 (model test).

Table 3. An example of recommended design values for the freezing index (F) and tolerable frost heave in connection with some different structures.

STRUCTURE	TOLERABLE FROST HEAVE mm	DESIGN FREEZING INDEX	MAX CHANGE IN GRADIENT o/oo	LEVEL OF FS-CRITERION
Buildings	0	F_{50}	0	III
Ice hockey rink	...10	F	...2	III
Railways	0	F_{20}	...4	III
Main roads	...60	F_{10}	4...6	III
Regional roads	...90	F_{10}	4...11	II-III
Parking places	...120	F_5	15...	I-II

The calculation of frost heave in order to determine the frost-susceptibility of foundation soil should correspond to accepted design-values concerning the freezing index, external load and ground water level. The design values have to be selected according to the local conditions and practice for the structures in question. An example of recommendations for that purpose is given in Table 3.

If the calculated frost heave corresponds to a freezing index (F) occuring more often than the recommended value: once in 5, 10, 20 or 50 years, the tolerable value has to be checked

separately. A frost heave greater than the tolerable value has to be reduced to an accepted level by using effective insulation, drainage or other preventive measures.

4 SUMMARY

The frost action in a frost-susceptible soil occurs as: frost heave, thaw-settlement and thaw-weakening. Which of these processes is the determining factor for design depends on the local climate and soil conditions as well as on the sensitivity of the structures in question to the effects of frost action. The concept of frost-susceptibility (FS) is usually based on frost heave. In conditions where the effects of thaw-settlement or thaw-weakening are more important, criteria other than frost heave have to be used.

The frost-susceptibility of a soil type may be determined by several laboratory methods (e.g. grain size distribution, consistency, capillarity, fines factor and laboratory frost heave test) or by in situ observations. It is reasonable to group the methods on various levels depending on their accuracy.

When determining the frost-susceptibility of soil in situ also the local climate, loading and ground water conditions have to be considered in addition to the soil characteristics. The local conditions may be very different in various parts of the world.

The most important criterion in a frost-susceptibility classification is to separate the FS-soils and the non-FS soils from each other. For the FS-soils it is also important to determine the degree of the frost-susceptibility. A successful international FS-classification would provide a unanimous base for the determination of the FS of a soil type. Because of the different local conditions the choosing of structures corresponding to different FS-classes has to be done separately in different regions according to the local practice. The ISSMFE Technical Committee on Frost (TC 8) has produced a recommendation to improve uninification in the determination of the FS of soils.

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