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LES PRESSIONS DE SOULEVEMENT DUES AU GEL DANS LES MATERIAUX PARTICULAIRES

SOMMAIRE

Les mesures de la pression de soulèvement d'équilibre des lentilles de glace dans des ensembles très serrés de grains de verre de grosseur uniforme relativement à la dimension des grains sont en accord avec la théorie d'Everett et Haynes. On a établi des mesures semblables de la pression de soulèvement pour des fractions de particules fragmentaires de la grosseur du silt et du sable fin. L'auteur montre que les particules plus petites à l'intérieur d'une grosseur donnée exercent une influence prédominante sur les pressions de soulèvement d'équilibre des lentilles de glace engendrées. Il en conclut que les critères actuels qui se fondent sur la grosseur des grains -- avec des limites quant au montant de grains fins permis -- est une façon acceptable de définir la sensibilité au gel des matériaux de terre aux fins de la technique des ouvrages en terre.

FROST HEAVING PRESSURES IN PARTICULATE MATERIALS

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ABSTRACT

Measurements of equilibrium ice lens heaving pressures in close-pack arrays of uniform size glass beads (Penner, 1966) in relation to bead size are in agreement with the theory of Everett and Haynes (1965). Similar heaving pressure measurements were determined on fractions of fragmental particles in the silt and fine sand range (Penner, 1967 and 1968). It is demonstrated that the smaller particles within a given range have a predominant influence on the equilibrium ice lens heaving pressures generated. From this it is concluded that the present criteria based on particles size -- with limits on the amount of fines permitted -- is an acceptable approach to defining the frost susceptibility of earth materials for soil engineering purposes.

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The smallest particles in a particulate porous system play an important role in determining the magnitude of ice lens heaving pressures generated. The supporting theory lends credence to using particle size as a valid frost-susceptibility criterion for naturally occurring materials. This note reviews in brief the theory of ice lens growth, the nature of frost action problems in earth structures, the importance of accurately predicting the frost susceptibility of earth materials, the experimental measurements of ice lens heaving pressures in simple systems to test the theory, and the measured relationship between the ice lens heaving pressure and the size of fragmental particles in more complex porous systems.

THEORY AND PRACTICE; PAST AND PRESENT

Following the development of the theory on ice lens growth under idealized conditions in porous media (Everett, 1961), a more comprehensive and generalized treatment applying to real porous systems was published for pore geometries of greater complexity (Everett and Haynes, 1965). These widely-quoted theoretical papers have greatly stimulated frost action research in recent years, largely by providing a sound and convincing theoretical basis. The theory, however, was not a completely new concept, nor was this claimed by the authors (Everett, 1961; Everett and Haynes, 1965). Aspects of the thermodynamics of freezing porous systems had been dealt with in some detail earlier by Edlefson and Anderson (1943), Winterkorn (1955), Jumikis (1956), Penner (1957), and Gold (1957).

Extensive laboratory testing of soils for frost susceptibility had been carried out much earlier by Beskow (1935), Taber (1929), Casagrande (1932), and later by the U.S. Corps of Engineers. This last study, described by Linell and Kaplar (1959), provided workable empirical relationships between the grain-size composition of soils and frost susceptibility that could be applied directly to soil engineering problems.

THE NEED FOR IMPROVED FROST ACTION PREDICTIONS

Despite changes in design approaches, e.g., the use of thermal barriers, the need for further improvements in the assessment of frost susceptibility for earth structures has become even more critical in recent years. The demand for higher quality highways, railways and airport runways is a result of the increased train and vehicle speeds and the higher take-off and landing speeds of aircraft. Roads and airports must now have a year-round capability to support larger loads and large unheated structures such as parking garages and warehouses require stable foundations. On the other hand, readily available sources of good quality earth materials, such as sands and gravels, are being rapidly depleted in many regions. Engineering failures that result from frost action are not only expensive to repair, but cause much inconvenience when the temporary loss in the use of the structure is also involved. It is imperative, therefore, that where freezing is permitted, the performance of earth materials that are borderline with respect to frost susceptibility are properly assessed so that good materials will not be excluded and poor quality materials will be recognized and processed or rejected to avoid costly mistakes.

BASIS FOR FROST-SUSCEPTIBILITY CRITERIA

A commonly used approach is to determine frost susceptibility experimentally, or to estimate it on the basis of heave rate. Acceptance or rejection is based on the amount of heave, over a winter period, that can be tolerated without detrimental effects. Changes in the riding quality resulting from differential heave that is permitted and possibly the loss of strength on thawing, would be the limiting performance factors for highways, streets and airport runways. The amount of differential heave that can be safely accommodated without damage to the foundation and superstructure would be the determining factor for unheated structures.

Heaving pressures that are generated during the freezing of earth materials due to the ice-water phase change can also be used to assess frost susceptibility. This criterion has not found acceptance in practice although it is directly applicable to heaving problems involving foundations of buildings.

The measurement of heaving pressures resulting from ice lensing, however, has been most useful to test the validity of frost heave theories mainly because the heaving pressure is one of the variables in thermodynamic equations that can be measured experimentally.

THEORY OF ICE LENS GROWTH TESTED WITH UNIFORM GLASS BEADS

The equation by Everett and Haynes (1965) relating the equilibrium ice lens heaving pressure to the radius of uniform glass spheres in a close-pack array was tested (Penner, 1966). The equation that applies to this particular geometry is as follows:

$$\Delta p = \frac{2\sigma_{iw} \cos\theta (1 + B')}{r}$$

where Δp is the heaving pressure, r is the radius of the sphere, B' is a constant equal to 5.6, θ is the contact angle and σ_{iw} is the in-water interfacial energy term (35 ergs cm^{-2}) (Hesstevedt, 1964). The agreement that was shown to exist between this equation and the measurements carried out by the author for two sizes of beads, 19.4 and 12 microns diameter, is believed to verify experimentally the equation.

HEAVING PRESSURES IN FRAGMENTAL MATERIALS

The laboratory equipment developed for the earlier studies on glass beads was also used to determine the heaving pressure in sized fractions of fragmental particles. Two studies have been published on this aspect by the author (Penner, 1967; Penner, 1968). Elutriation techniques were used in both cases -- potter's flint and PFRA silt -- to separate the particles into narrow size ranges. The particle sizes for all fractions was determined by preparing smears of the separates on glass slides and measuring the particle sizes on enlarged microphotographs. The size assigned to each particle was the average of the largest and the smallest particle diameter; in this way the complete size distribution was established by measuring some 500 particles from each sample.

The author's studies referred to were for size fractions larger than clay size because the size of particles in the clay range could not be determined readily with the same accuracy. Sedimentation analyses were not considered to be sufficiently precise to establish the particle sizes for these studies. The solid line in Fig. 1 is the plot of the Everett and Haynes (1965) equation. The ice lens pressure-diameter values for the uniform-size glass beads are shown as open squares. The solid circle symbols are the results for the various fractions of PFRA silt. The open circles are for the fractions of potters flint. In each case the measured ice lens heaving pressure is plotted against the measured diameter of the smallest size particle in each fraction. The range in particle size for each fraction is given on the Figure near the plotted point.

The values fall both above and below the theoretical line but it is believed that the measure of agreement achieved draws attention to the predominant influence of the smallest particles in establishing the heaving pressures. Deviations in the measurements from the theory are thought to be attributable to the fragmental nature of the particles, variations in sample density, local non-homogeneity, and errors in pressure measurements. It is believed that at equilibrium (state of non-propagation of ice) the ice/water boundary positions itself over the minimum sized pores and to achieve this the boundary must have an undulating configuration.

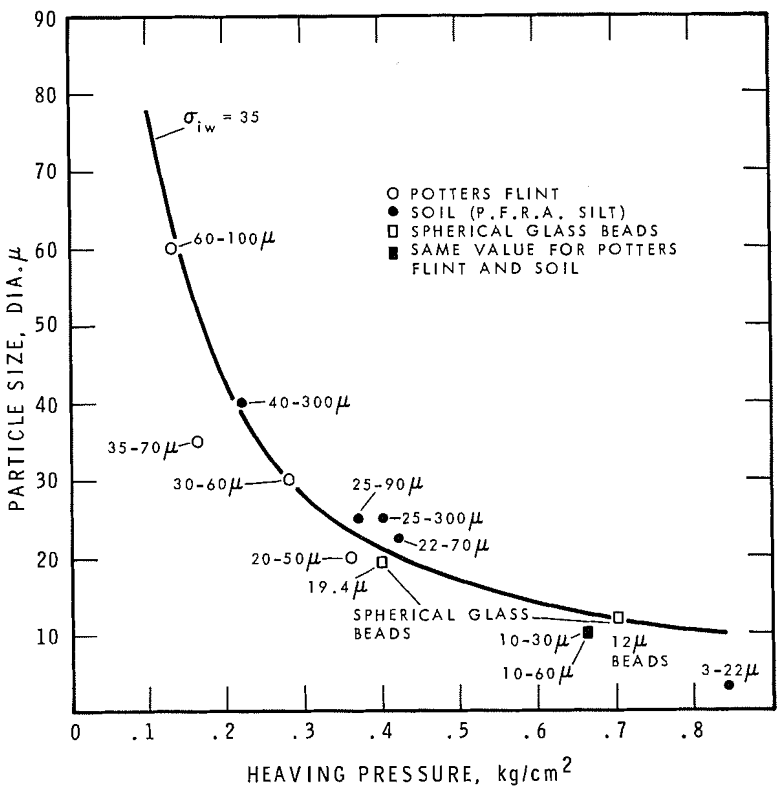

FIGURE 1 Relation Between Heaving Pressure And Smallest Particle in Fraction

CONCLUSIONS

The results given in this note support the use of particle size as a valid property for establishing frost susceptibility. The importance of the smaller particles in a soil system is based on a theory that has been supported by laboratory measurements and to which the heaving pressures due to ice lenses in real porous systems conform.

The research studies indicate that criteria used based on grain size could be improved by increasing the allowable minimum size of the smallest particles with further limitations on the permissible amount of fines.

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