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Heaving behaviour of soils in the step freezing mode

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Results are presented over a wide range of soil textures supporting the linear relation between the logarithm of frost heave rate and the cold-side temperature – overburden pressure ratio proposed by Penner and Ueda. The relation is simple to determine experimentally, permits heave predictions at various other temperature and pressure conditions for engineering purposes, and allows soil frost susceptibility comparisons to be made with the results determined by other laboratories.

Des résultats sont présentés pour un large éventail de textures de sols, qui confirment la relation linéaire entre le logarithme du taux de soulèvement par le gel et le rapport entre la température au front froid et la pression des terres, proposée par Penner et Ueda. La relation est simple à déterminer expérimentalement; elle permet des prédictions de soulèvement sous des conditions pratiques variées de température et de pression et elle autorise des comparaisons entre les mesures de susceptibilité au gel de sols obtenues par des laboratoires différents.

[Traduit par la revue]

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Introduction

Penner and Ueda (1978) proposed that the heave rate established at the beginning of the test using the step freezing mode can be expressed as an exponential function of the ratio of overburden pressure to cold-side temperature. More test results are available now for a greater textural range. The purpose of this note is to present additional information in support of that proposal. The simple rate equation used was

$$[1] \quad \frac{\mathrm{d}h}{\mathrm{d}t} = a \exp\left(bP/T\right)$$

where $\mathrm{d}h/\mathrm{d}t$ = initial heave rate (mm/min), h = heave, t = time, P = overburden pressure[1] (kPa),

[1]The overburden pressure term also includes the cell–soil friction component during heaving.

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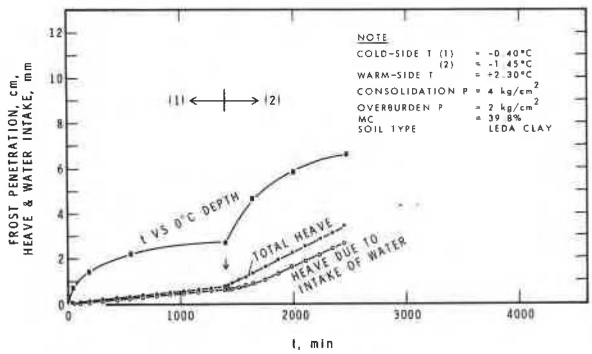

FIG. 1. The influence of lowering the cold-side temperature.

T = cold-side temperature (°C), and a, b = constants dependent on soil type.

This approach to frost heave testing has the advantage of predicting heave rate at various P/T ratios, provided that frost susceptibility based on heave rate is an acceptable criterion[2]. It also permits a comparison of frost heave results of soils between different organizations that are not using the same test freezing temperatures and pressures. The constants a and b may be obtained either from two separate tests at different P/T ratios or by introducing a second drop in the cold-end freezing temperature after the heave rate becomes constant at the initial temperature (Fig. 1). The results using both approaches are shown in Fig. 2.

Sample preparation, the freezing procedure, and the apparatus have been described earlier (Penner and Ueda 1977, 1978; Penner and Walton 1979). Figure 3 gives the mechanical analyses of the soils studied recently. The overburden pressure and freezing temperature range, soil symbols, and the statistical correlation coefficient between heave rate and P/T are presented in Table 1. The results for Leda clay (Ottawa); Fairbanks (Alaska) soils; and Beaver Creek and White River (Yukon Territory) were all determined using the *one-step* freezing procedure at various cold-side temperatures and pressures. The results for the Mackenzie Valley (Northwest Territories) soil were obtained by both *one- and two-step* freezing runs. The heave results of the second freezing step imposed are shown in Fig. 1. The cold-side temperatures used in the second step were in the same range as the points plotted with the closed circle ●, where a low cold-side temperature was imposed as the initial freezing step. Yet all these results fall on the same line (correlation coefficient 0.95). It should be noted especially that total heave rates used in this paper include both freezing of *in situ* water and water transmitted to the freezing front.

The importance of the step freezing method is predicated on the supposition that the important soil frost susceptibility criterion required is the heave rate, more specifically the initial total heave rate. Attention has been directed elsewhere (Penner and Walton 1979) to the matter concerning the decrease in heave rate as the test progresses but it has also been shown that a good estimate of the heave drop-off with time is possible. When making comparisons of frost susceptibility of soils the initial heave rate is an acceptable criterion; where heave rate is required for design purposes over a long period, however, the drop-off with time is important and must be con-

[2]Other criteria in use are maximum heave pressure generated, ice segregation ratio, etc.

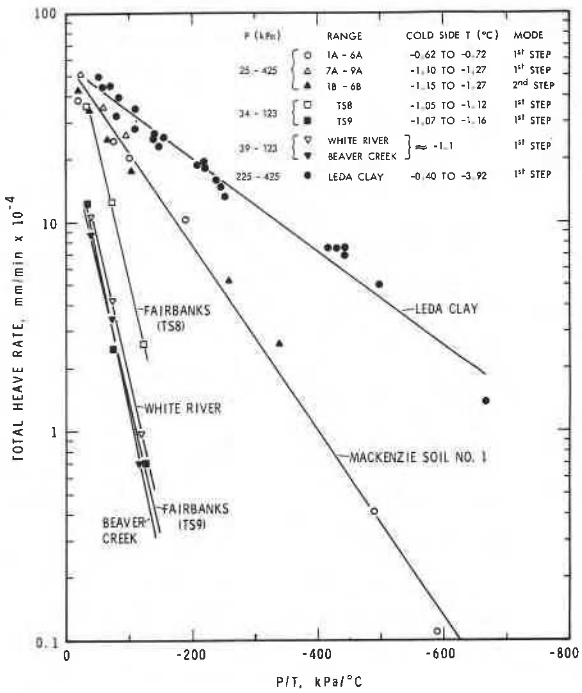

FIG. 2. Total heave rate vs. P/T ratio.

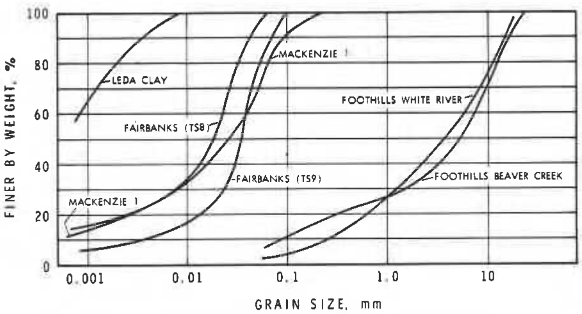

FIG. 3. Mechanical analysis of soils.

TABLE 1. Test conditions and coefficients of correlation of results in Fig. 2

Soil	Overburden range, P (kPa)	Cold-side range, T (°C)	Correlation coefficient	Intercept* (eq. [1])	Slope (eq. [1])
Mackenzie Valley soil No. 1					
1A-6A	25–425	−0.62 to −0.72	0.95	59.2×10^{-4}	0.004384
1B-6B	25–425 (second step)	−1.15 to −1.27	0.95	59.2×10^{-4}	0.004384
7A-9A	25–425	−1.10 to −1.27	0.95	59.2×10^{-4}	0.004384
Fairbanks silt					
TS8	34–123	−1.05 to −1.12	0.98	101.2×10^{-4}	0.014615
TS9	34–123	−1.07 to −1.16	0.99	38.8×10^{-4}	0.016880
White River	39–123	≈ −1.1	0.99	31.4×10^{-4}	0.014046
Beaver Creek	39–123	≈ −1.1	0.99	31.4×10^{-4}	0.014046
Leda clay	225–425	−0.4 to −3.92	0.96	55.9×10^{-4}	0.002207

*The value of the intercept, while mathematically correct, should not be taken literally since values of P/T near zero are difficult to determine experimentally. The author believes that as zero is approached the heave rates increase radically.

sidered. These results support the relationship [1] proposed earlier by Penner and Ueda (1978) and indicate the validity of a quick two-step freezing procedure that can be used to define the relationship between heave rate and the P/T ratio.

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