DEFINITION OF EXPANSION POTENTIAL FOR EXPANSIVE SOIL

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Abstract: Expansion potential of an expansive soil is most commonly expressed in terms of the amount of swelling that occurs during inundation in the consolidation-swell test. In Colorado, USA, swell potential is classified as low, medium, high or very high based solely on the percent swell. However, the risk of foundation or slab movement relates to the amount of heave that will occur, and heave is more closely associated with the product of the percent swell times the swelling pressure, not just the percent swell. Therefore, a variable termed the "Expansion Potential", EP, is defined in this paper to express the actual expansion potential of a soil. Values of EP were computed using a database collected from results of more than 1,100 consolidation-swell tests. It is shown that a very good correlation is observed between predicted heave and EP. It is believed that the use of EP will provide a more accurate description of the actual risk of the potential for slab or foundation movement. No correlation was found between the expansion potential and other parameters such as plasticity, dry density, or natural water content.

1. INTRODUCTION

The expansion potential of a soil or sedimentary bedrock formation is used to define the severity of risk related to foundation or slab movement at a site. Typically it is expressed in terms of low, moderate, high, or very high, where these terms generally relate to risk.

Historically these terms have been defined solely on the basis of the amount of swell (Percent Swell) that occurs when a soil is inundated in a consolidation-swell oedometer test. However, the risk of foundation or slab movement relates to the amount of heave that will occur, and that depends on more than just the Percent Swell. Calculations of predicted heave must also take into account the stress applied to the sample when it is inundated in the consolidation-swell oedometer test, and the swelling pressure that the soil is capable of generating when it is prevented from swelling in the constant-volume oedometer test.

A variable termed the "Expansion Potential", EP, is defined in this paper that includes all of those parameters. It is shown that this variable correlates better with predicted heave than either percent swell, at a given inundation pressure, or the swelling pressure. Attempts to correlate the expansion potential with other parameters such as plasticity, dry density, or natural water content have shown very poor correlation. Although plasticity may be used to indicate the possible expansive nature of a soil, there are many other factors that will influence the actual expansion potential. Thus, actual testing is required to define the actual expansion potential.

It is believed that the use of the variable, EP, will provide a more accurate description of the actual risk of the potential for slab or foundation movement at a site.

2. SOIL PROPERTY DATABASE

Over the past four years the authors have collected data on more than 1,100 consolidation-swell tests conducted on a variety of material types ranging from non-expansive sand to highly expansive claystone. A database was developed that included (1) soil type, (2) sample depth, (3) natural water content, (4) dry density, (5) inundation pressure, (6) percent swell, (7) swelling pressure, and (8) Atterberg Limits.

Soil samples collected in the database generally represent alluvial, colluvial and residual soils, cretaceous and tertiary sandstone, siltstone, and claystone bedrock. Typically these bedrock materials comprise the Pierre, Denver, Arapahoe, and Dawson formations. The claystones may be described as very highly overconsolidated sedimentary clay materials. The sandstones and siltstones generally are poorly to moderately cemented. The primary area from which these samples were taken is called the Front Range area of Colorado and extends for about 80 miles to the north and south of Denver, Colorado along the east flank of the Rocky Mountains.

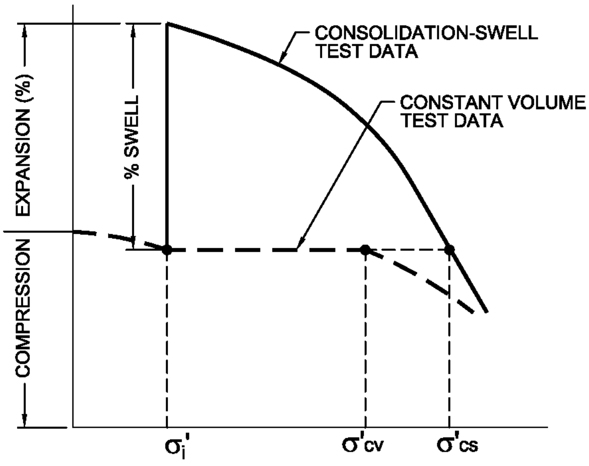

Figure 1. Oedometer Test Results.

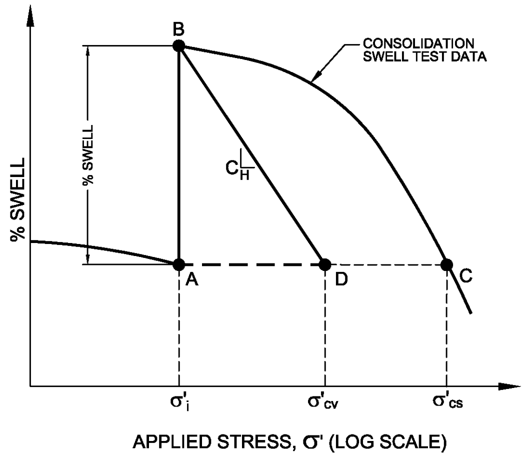

Figure 2. Determination of Heave Index C_H.

3. OEDOMETER TESTS

The oedometer tests are described in Nelson and Miller (1992). There are two general types of oedometer tests, viz., the consolidation-swell test and the constant volume test. In the consolidation-swell test, a vertical stress is applied to the sample (the inundation pressure, σ'_i), and water is added to the sample. The amount by which the sample swells is termed the percent swell. Additional load is applied to the sample and the stress required to compress the sample to its initial thickness at which it was inundated is termed the consolidation-swell swelling pressure, σ'_{cs}.

In the constant volume test, the sample is confined such that it cannot swell, and the stress required to prevent any swelling, i.e., to maintain a "constant value", is termed the constant volume swelling pressure, σ'_{cv}. All tests were performed in general conformance with ASTM standard methods of test. Typical test results for both types of tests are shown in Figure 1.

4. COMPUTATION OF HEAVE

The equation for computing heave is,

$$\rho = C_H \Delta z \log\left(\frac{\sigma'_{cv}}{\sigma'_f}\right) \tag{1}$$

where:

- ρ is the amount of heave,
- Δz is the thickness of the soil layer for which heave is being computed,
- σ'_{cv} is the constant value swelling pressure,
- σ'_f is the vertical stress at the midpoint of the soil layer for the conditions under which heave is being computed, and
- C_H is the heave index of the soil, a parameter that will be discussed below.

The term C_H represents a relationship between the percent swell that will occur in a sample of soil, and the vertical stress applied at the time of inundation. As such it is not the slope of a stress-strain curve but must be developed from two or more oedometer tests. For purposes of discussion it is convenient to consider the test results for a consolidation-swell test and for a constant-volume test as shown in Figure 2.

In the constant-volume test the percent swell corresponding to the particular value of σ'_i shown is %S. At an inundation pressure of σ'_{cv} the percent swell would be zero. Thus, points B and D fall on the line representing the desired relationship between σ'_i and %S. If it is assumed that this relationship is represented by a straight line on a semi-logarithmic plot, the line BD will represent the desired relationship. The parameter C_H is the slope of that line. Thus,

$$C_H = \frac{\%S}{\log\sigma'_{cv} - \log\sigma'_i} = \frac{\%S}{\log\left(\frac{\sigma'_{cv}}{\sigma'_i}\right)} \tag{2}$$

To facilitate use of Equation (2) and to determine both %S and σ'_{cv} from a single oedometer test, a relationship has been developed between σ'_{cs} and σ'_{cv} so that the constant volume swelling pressure, σ'_{cv}, can be determined from the same oedometer test in which %S was determined. This relationship is of the form:

$$\sigma'_{cv} = \sigma'_i + \lambda\left(\sigma'_{cs} - \sigma'_i\right) \qquad (3)$$

where λ is a coefficient that needs to be determined for the general soil materials being encountered. For the Colorado claystones, the authors have found that a value of 0.6 is appropriate (Nelson, et al., 2006).

5. EXPANSION POTENTIAL

In consideration of Equations (1) and (2), it is evident that the parameters %S, σ'_{cv}, and σ'_i will influence the computed value of heave. For two samples with the same value of %S but different values of σ'_{cv}, the one with the larger value of %S will heave more. Similarly for two samples with the same value of σ'_{cv}, the one exhibiting the higher value of %S will heave more. This is demonstrated in Figure 3 in which the sample with the shaded area under the C_H line represents the one with the lesser heave potential.

It is clear that the larger the area under the C_H line, the higher will be the Expansion Potential, EP. Thus, a reasonable definition of EP would be to base it on that area, or

$$EP = 2 \times Area = \%S\left(\log \sigma'_{cv} - \log \sigma'_i\right)$$

Or $$EP = \%S \times \log\left(\frac{\sigma'_{cv}}{\sigma'_i}\right) \qquad (4)$$

From Figure 3, it is obvious that for the same soil having the same value of σ'_{cv} but tested at a higher inundation pressure, σ'_i, a lower value of EP would be computed. Therefore, in comparing soils for different values of EP, it is important that they all be tested at the same inundation pressure.

In order to evaluate the reasonableness of using the definition presented in Equation (4) as opposed to only the Percent Swell (%S) or the Swell Pressure (σ'_{cv}), the heave of a uniform deposit of soil or bedrock of depth greater than the depth of potential heave for a representative number of points in the database was computed. In the computation the depth of potential heave was divided into 35 layers and heave was computed using Equation (1).

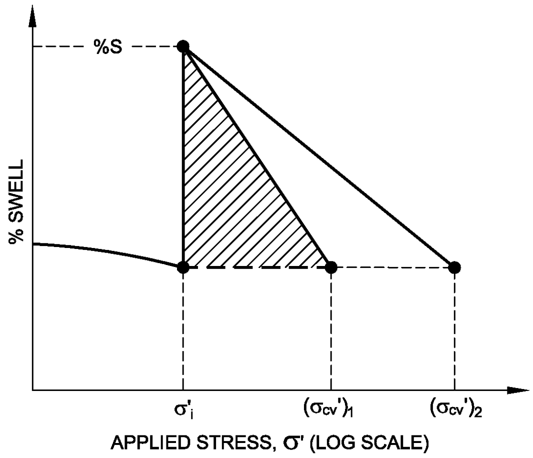

Figure 3a – Same %S

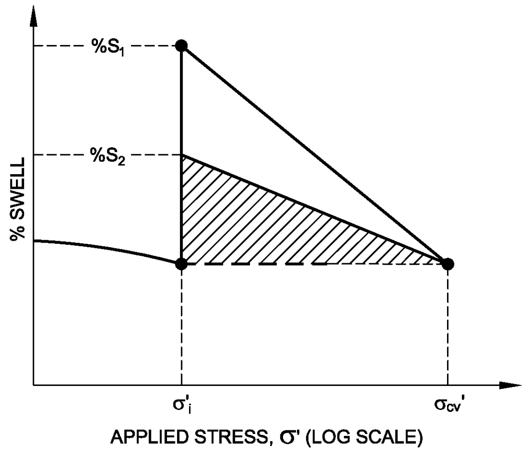

Figure 3b – Same Swelling Pressure

Figure 3. Comparison of Expansion Potential.

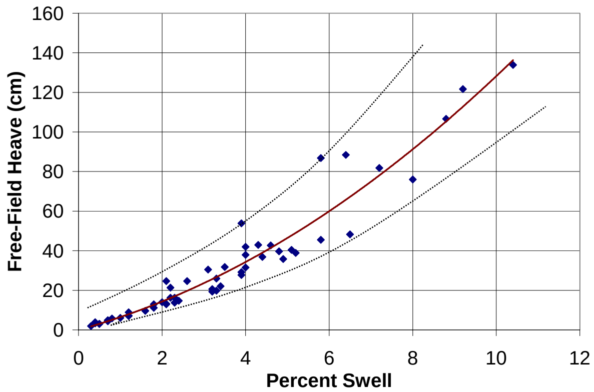

Figure 4. Free-Field Heave as a Function of Percent Swell.

Figure 4 shows the computed values of heave plotted as a function of percent swell only. A general relationship is apparent, but there is significant scatter in the results. There are several cases in which comparison of two selected points would show more heave computed for the point with a lower value of %S.

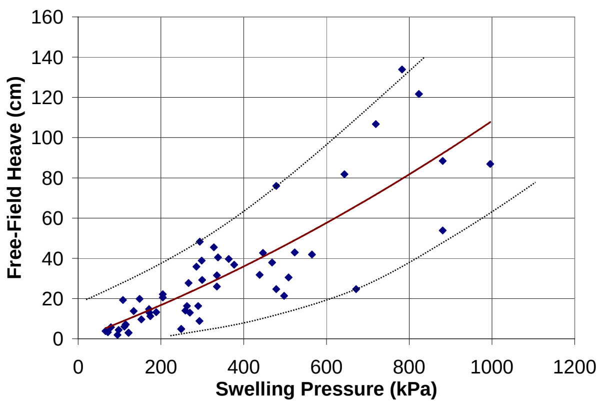

Figure 5. Free-Field Heave as a Function of Swelling Pressure.

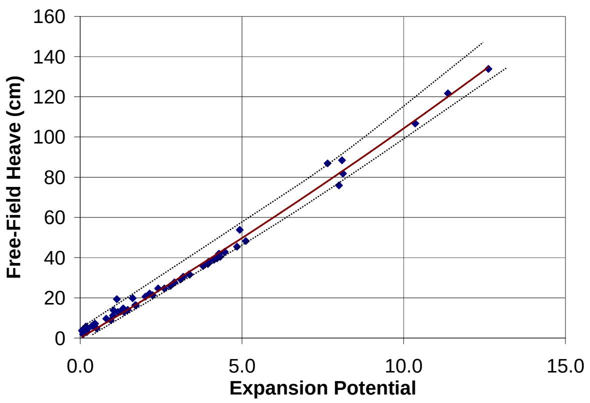

Figure 6. Free-Field Heave as a Function of Expansion Potential.

Figure 5 shows the computed heave plotted as a function of Swelling Pressure, σ'_{cv}, only. A similar criticism of this data is also apparent and a wider band of scatter is apparent.

Figure 6 shows the computed heave as a function of Expansive Potential, EP. The observed band of scatter in this figure over that in Figures 4 and 5 is evident. A very good correlation is observed between heave and EP.

Figure 7 shows an enlargement of the lower portion of Figure 6. The values of EP were divided into four groups including values (1) less than 0.5, (2) 0.5 to 1.0, (3) 1.0 to 1.5, and (4) greater than 1.5 based on the free-field heave values indicated in Figure 6. The level of risk of slab and foundation movement is classified as low, moderate, high, and very high in accordance with the free-field values and is shown in Table 1. It is believed that for a structure with a potential free-field heave of less than 5 cm, the risk of movement that could damage the structure is low, whereas the risk of movement is high or very high if a structure has a potential heave of 10 or 15 cm, respectively.

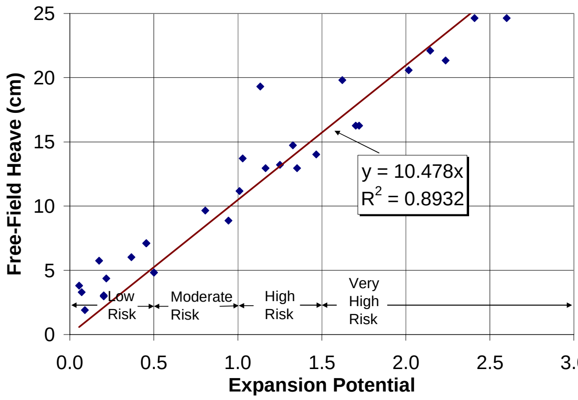

Figure 7. Definition of Risk Level Based on Free-Field Heave.

Table 1. Level of Risk of Slab and Foundation Movement based on EP.

Range of Expansion	Potential Free-Field Heave (cm)	Level of Risk
0 – 0.5	0 – 5	Low
0.5 – 1.0	5 – 10	Moderate
1.0 – 1.5	10 – 15	High
> 1.5	> 15	Very High

6. EFFECT OF MATERIAL TYPE

Histograms showing the number of computed values of EP as a percentage of the total points for that material type were computed. The histograms for claystone (the most expansive material) and sandstone and sands (the least expansive materials) are shown in Figures 8 and 9. For the claystone samples, it is seen that the values of EP are skewed to the left but some values even greater than 20 were computed.

On the other hand, in Figure 9 it is seen that for the sand and sandstone few values greater than 1 were computed.

The cumulative frequency is shown for all material types in Figure 10. As may be expected the more clay that existed in the samples, the broader was the range of EP values. For sandy and silty materials, hardly any values over 3 were computed, whereas for claystone materials 40% of the values were greater than 3, and a few values greater than 20 were computed.

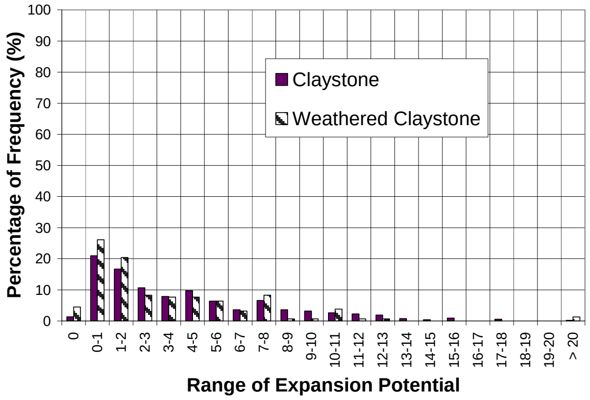

Figure 8. Histogram of Expansion Potential for Claystone Material.

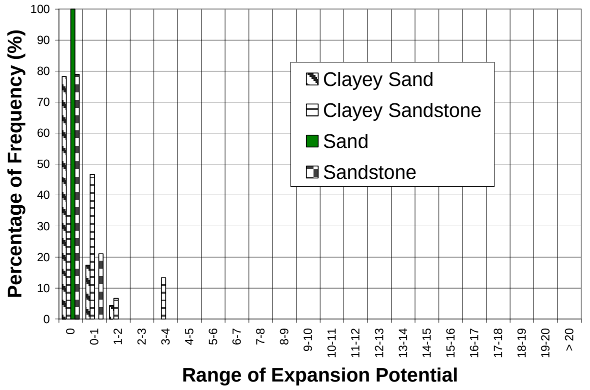

Figure 9. Histogram of Expansion Potential for Sandstone and Sand Materials.

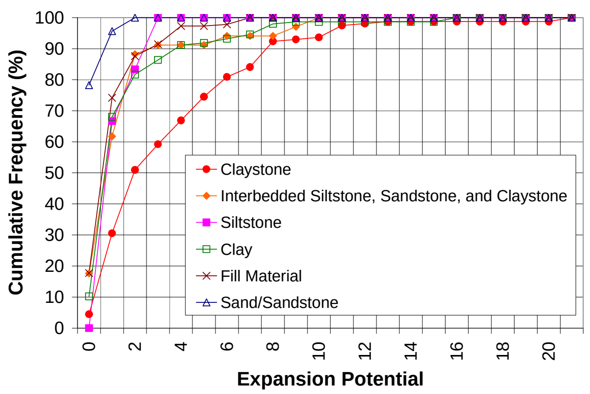

Figure 10. Cumulative Frequency of Expansion Potential for All Material Types.

7. EFFECT OF PLASTICITY

In the past many attempts have been made to correlate plasticity with expansive potential. The range of values of EP were divided into four groups, values less than 0.5, 0.5 to 1.0, 1.0 to 1.5 and values greater than 1.5. The Atterberg Limits for each sample were plotted on Plasticity Charts as shown in Figure 11.

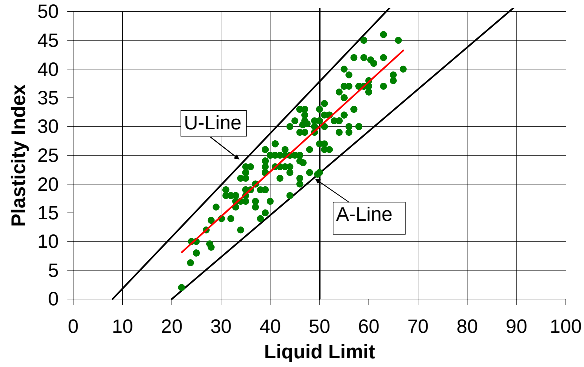

Figure 11a - EP < 0.5

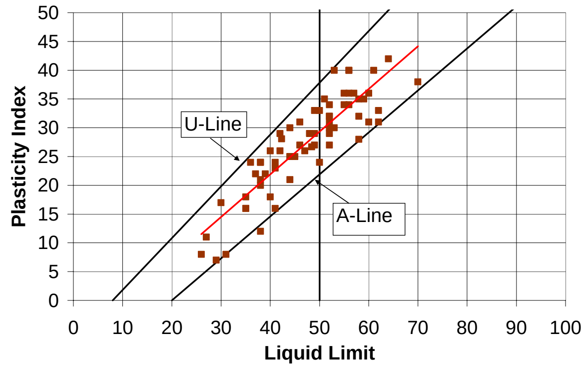

Figure 11b - EP = 0.5 to 1.0

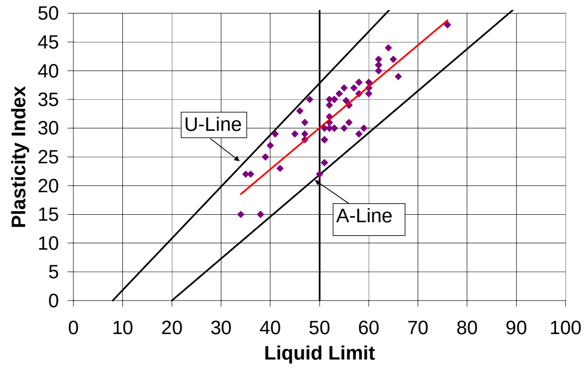

Figure 11c - EP = 1.0 to 1.5

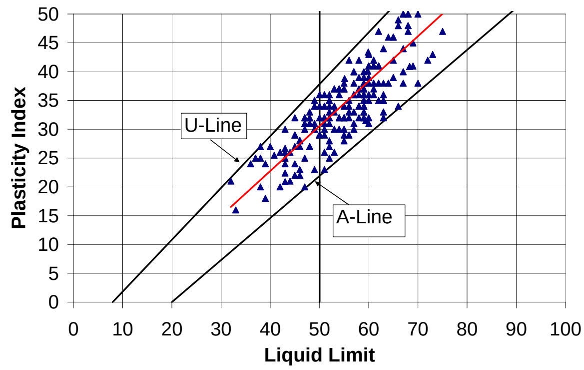

Figure 11d - EP > 1.5

Figure 11. Effect of Plasticity on Expansion Potential.

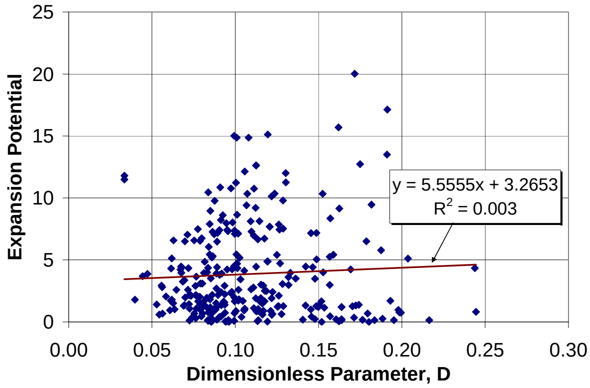

Figure 12. Effect of Dry Density and Water Content on Expansion Potential.

Comparison of Figures 11a through 11c shows that the points fall uniformly distributed in the space between the A line and the U line for all four groups of EP values. The group with the higher values of EP (>1.5) tend to fall more in the zone for CH soils, whereas the group with the lower values of EP (<0.5) fall more within the zone for CL soils. This is to be expected. There does not appear to be any clear correlation between plasticity and EP.

All points in the database are from the same general geographic area, the Front Range area of Colorado. Thus they all have similar geologic history, and most likely, similar mineralogical characteristics. It is expected that different mineralogical characteristics would yield different results.

8. EFFECT OF DRY DENSITY AND NATURAL WATER CONTENT

For a remolded sample of soil, the higher the density to which the sample is compacted, the greater will be the expansion potential. Similarly, the higher the water content, the lower the swell potential. To investigate any relationship between these parameters and Expansion Potential, the values of EP were plotted as a function of the dimensionless parameter, D:

$$D = \frac{\gamma_d}{\gamma_w \times w} \tag{5}$$

where:

D is a dimensionless parameter,
γ_d is the dry density,
γ_w is the unit weight of water, and
w is gravimetric nature water content.

The plot of EP as a function of D is shown in Figure 12. It is clear that no correlation exists. The plots for EP as a function of only dry density or only nature water content are similar.

9. CONCLUSIONS

The Expansion Potential, EP, was defined in terms of the Percent Swell, %S, and the Swelling Pressure, σ'_{cv}, relative to the inundation pressure, σ'_i. A very good correlation was observed between the calculated heave of a uniform stratum of material and its value of EP. This parameter was shown to be a significantly better indication of risk of heave than either the value of %S or σ'_{cv} alone.

As noted with respect to Figure 3 and the definition of EP, when comparing values of EP for different soils, it is important that they be tested at the same value of inundation pressure, σ'_i. This indicates the importance of standardizing test procedures within the laboratory.

The Atterberg Limits for all points in the database plot between the A-Line and the U-Line in a Plasticity Chart. Although the points corresponding to samples with higher values of EP plot more within the zone for CH materials, this is to be expected. Other than that, there appeared to be no correlation between plasticity and EP.

No correlation between dry density or water content with EP was observed. It is believed that EP is a function of not only dry density/water content, but also mineralogical characteristics of the soil and the amount of sand, silt, and clay contained in the soil.

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