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APPLICATION OF SOIL SUCTION IN DALLAS/FORT WORTH

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ABSTRACT

Measurement of soil suction has proven to be valuable in evaluation of subsurface conditions and in engineering analysis in diverse areas such as ground water flow and potential movement associated with expansive soils. This paper presents information regarding interpretation of suction tests on a routine project basis.

The authors' firm has performed approximately 20,000 suction tests using procedures outlined in ASTM Method D-5298 over a five-year period. The procedures used and observed correlations between suction and undrained shear strength, suction and moisture content, suction and percent swell at overburden pressure are presented for a weathered clay-shale.

Differences in suction test values are more indicative of slight changes in the degree of saturation than differences in soil moisture. This sensitivity aids in defining variations in saturation within the vadose zone.

Two applications of suction for evaluation of ground water in clay soils of low permeability are presented. The first example uses suction values to delineate the upper and lower boundaries of saturated lenses within an expansive soil. The second example illustrates typical results obtained where ground water is encountered.

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INTRODUCTION

Although the measurement of soil suction was developed over 30 years ago, its use has not been widely embraced by the engineering profession. The purpose of this paper is to present information regarding the measurement and application of suction on a routine commercial basis within North Texas. It is important to emphasize that the information presented is based on observation of test results within the North Texas geology. The geology within this area consists predominantly of CL and CH fine-grained clay soils which undergo expansion and shrinkage associated with changes in soil moisture.

The method used to evaluate suction is discussed in the following section. This paper does not evaluate the various methods used to determine suction, nor does it allege to present the only method of interpretation of the results.

Evaluation of suction is relevant for a wide range of geotechnical engineering applications, to include ground water studies, behavior of expansive and collapsing soil, permeability, and slope stability. Illustrations included herein involve the use of suction values in evaluating saturated lenses within the vadose zone.

Suction Concept

The method used to evaluate suction in this paper consists of the "filter paper" method as defined by ASTM D-5298. Specifically, the data presented are based on the measurement of total suction by use of the "non-contact" method. This method measures total suction, and does not distinguish between the matric and osmotic components. It is worth noting, however, that after analysis of over 20,000 tests, the lower threshold of the total suction for a particular geologic setting can often be identified. The lower threshold appears to represent the value of osmotic suction.

Numerous publications discuss the concept, measurement and use of the suction component. One of the more thorough discussions is presented by Fredlund & Rahardjo (1993). Additional discussions on the use of suction in expansive soils have been presented by Johnson and Snethen (1978) and Snethen and Huang (1992).

The results presented in the following correlations and in the two case studies are based on testing with Schleicher & Schuell #589 filter paper as discussed in ASTM D-5298. Houston, Houston and Wagner (1994) have questioned the validity of the ASTM calibration curve used to calculate the suction value and suggest use of alternative papers and calibration curves. Specifically, Houston, et al. indicate that the ASTM calibration curve was developed using a mixture of total and matric suction calibration data. The validity of this argument is beyond the scope of this discussion. However, it is emphasized that regardless of the actual value of suction, the relative changes in the magnitude of suction can still be used in engineering practice.

That said, however, the authors' firm has been actively evaluating the variance between total suction as measured by following ASTM D-5298 using two types of filter papers discussed in the ASTM standard. Figure 1 presents the values of total suction using Schleicher & Schuell #589 and Whatman #42 papers.

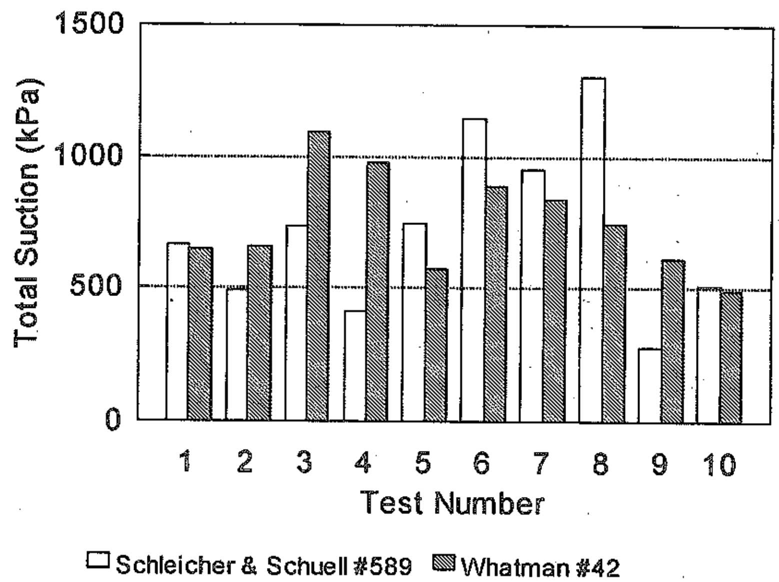

Figure 1. Variation in measured total suction between filter papers for weathered shale.

Tests were performed on thin-walled tube samples (ASTM D-1587) split vertically to obtain companion samples. The soil consisted of a relatively uniform weathered shale. As observed in Figure 1, some variation in the measured value occurs between the two papers and the recommended calibration curves in the ASTM standard. Further research in this area is recommended if the absolute value is important.

Observed Correlations

Correlations between suction values measured using Schleicher & Schuell papers and identification and classification tests have been observed. The correlations are important from the perspective of understanding the behavior of unsaturated soils and in supplementing other types of laboratory testing. In addition, suction testing using filter paper on a routine basis is simple, relatively inexpensive (approximately the same cost as for natural moisture content) and provides an additional means of laboratory quality control. For example, in CH clays, a low suction value would indicate a relatively moist sample. Conflicting data can be evaluated as to validity.

Observed correlations between the undrained shear strength measured with a hand penetrometer and suction, between suction and moisture content, and between suction and linear swell restrained at overburden pressure are presented in Figures 2 through 4. The materials tested consisted of CH residual clays weathered from a clay-shale. The soil is fine-grained, with 95 to 98 percent passing a No. 200 sieve. Plasticity Index (PI) values for materials shown in the correlations are summarized in Table 1. All tests were conducted on undisturbed thin-walled tube samples.

Project	Tests	Range		Average		Variance	
		LL	PI	LL	PI	LL	PI
Anselm	19	72 - 88	44 -58	79.3	51.4	4.8	4.3
Carpenter	4	76 - 92	46 - 64	85.2	58.5	7.3	6.2
Milner	4	75 - 91	41 - 53	82.2	45.5	6.7	5.2

Table 1. Summary of Plasticity Indices for soils used in correlation.

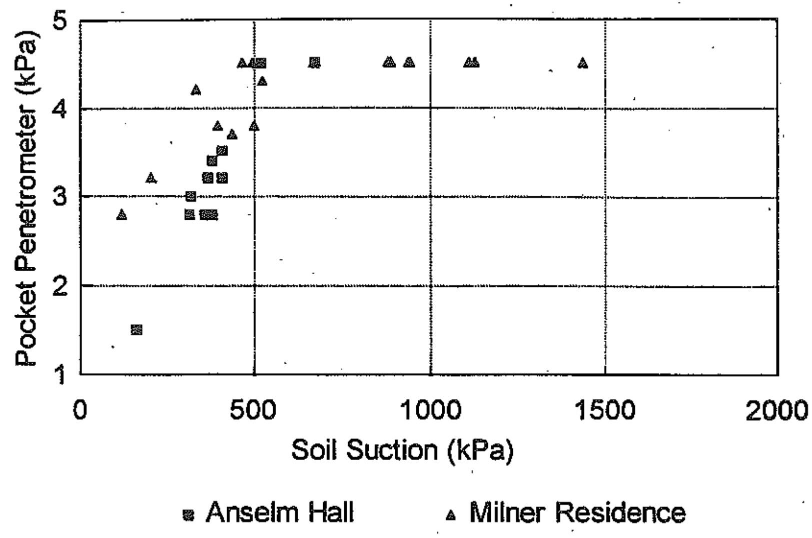

Figure 2. Comparison of suction with pocket penetrometer values, weathered clay-shale.

Figure 2 illustrates the observed trends on two sites between undrained shear strength measured with a pocket penetrometer and total suction within a weathered clay-shale. A summary of the PI data is provided in Table 1. As noted in Figure 2, the suction values plot horizontally at a value of 4.5 kPa. This value represents the maximum value on the pocket penetrometer and correlations between the penetrometer value and suction above this value are meaningless.

Establishing this trend aids in rapidly estimating the total suction, based on penetrometer values, where 7 to 10 days may not be available to allow for laboratory testing. This condition routinely occurs for example in expansive soils where pre-swelling is used to reduce heave prior to foundation construction.

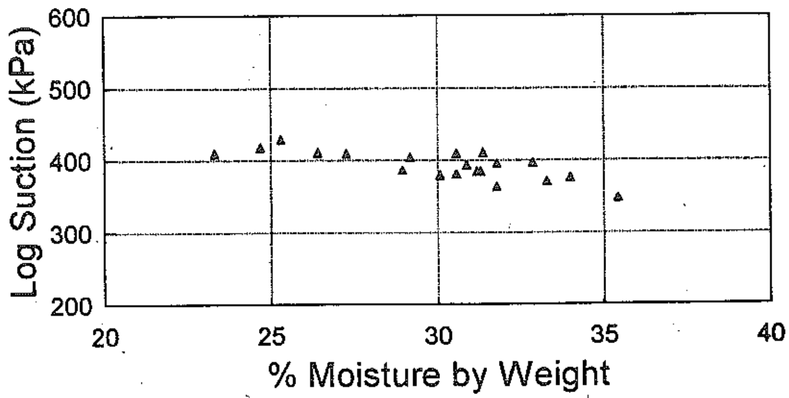

Figure 3. Comparison of total suction versus moisture content, weathered shale, Milner Case.

Figure 3 is a plot of moisture content versus total suction (moisture-retention curve) for a weathered shale. This comparison can be used in evaluating the historical behavior of expansive soil profiles. For example, in evaluating structures distressed by expansive soils, pre-construction soil moisture content tests can be use to estimate the pre-construction suction values. The historical changes in suction can then be used to evaluate soil movement and potential sources of water.

A comparison between total suction and percent swell at overburden pressure is shown in Figure 4. This type of correlation is used to evaluate the applicability of particular swell tests to samples where only suction data is available.

Although Figures 2 through 4 indicate a moderate scattering of data points, it should be emphasized that the natural variation in soil properties likely accounts for some of the scatter. Testing variations also contribute to the observed variance.

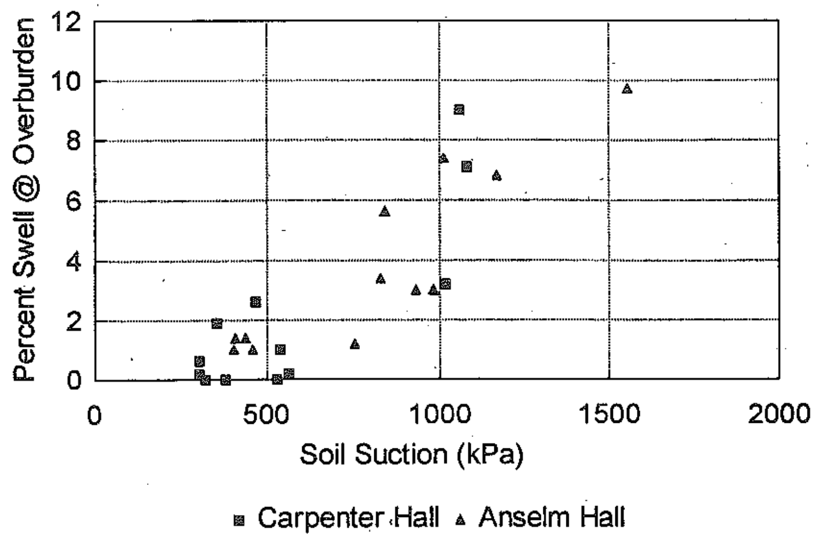

Figure 4. Comparison of suction and percent swell at overburden pressure, weathered shale.

APPLICATIONS

Two applications of the use of soil suction measurements are presented. Both involve evaluation of ground water by comparing changes in the relative value of suction with depth. The first illustrates the value of suction tests and their ability to identify saturated lenses in the vadose zone. The second provides an example of evaluating the depth to ground water in low permeability soils.

Identification of Saturated Lens

Identification of saturated lenses within the vadose zone is pertinent to the work of geotechnical engineers and hydrogeologists. Identification is complicated within geologic settings where permeability is low. Although construction of multiple piezometers can aid in evaluation of the presence of the saturated lenses, difficulties arise in attempting to identify the bottom of the saturated zone. Calculation of the percent saturation could be performed to obtain the desired information. This, however, requires more expensive testing (moisture content, unit dry weight and specific gravity) than a simple suction test.

Piezometers situated in clay soils of low permeability can take a considerable amount of time to stabilize. Measurement of soil suction values can rapidly identify both the upper and lower boundaries of any saturated lenses, as well as the capillary fringes.

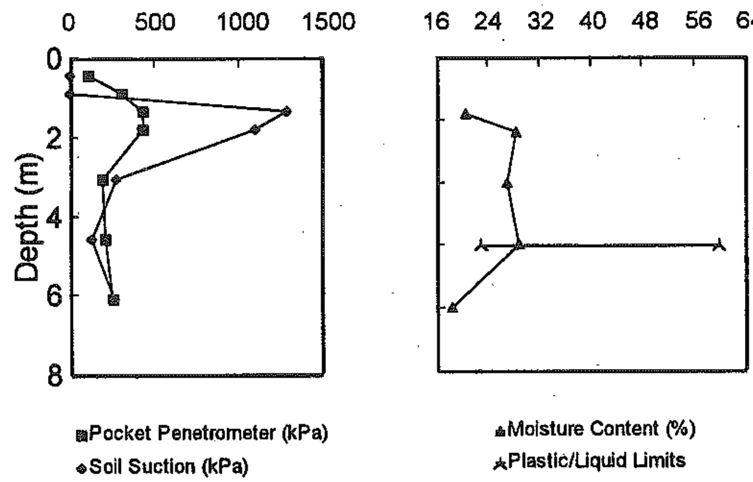

Figure 5. Application 1, evaluation of saturated lenses.

An example of identification of a saturated lens within weathered clay-shale is shown in Figure 5. The upper surface is moist to a depth of approximately 3 meters; whereupon, higher values of suction are observed. Observation of the moisture content profile indicates a corresponding decrease in moisture at the 3.5-meter level; however, the decrease in moisture is less dramatic. In profiles where variations in soil characteristics exist, changes in moisture would not necessarily indicate a saturated lens. A decrease in the suction values at the 8-meter level indicates the lower boundary of the lens to be between 6 and 8 meters. Use of continuous sampling and testing could have been used to further delineate the lower boundary. A piezometer installed in the bore hole confirmed the presence of ground water at a depth of 7 meters.

Information from the suction tests was used to delineate the zone of unsaturated soils between 4 and 7 meters. This information, coupled with swell tests, was used to estimate the magnitude of movement associated with expansion of this zone.

Identification of Phreatic Surface

Suction values also are useful to evaluate the depth to ground water. On small projects where the cost of installing and reading piezometers may be prohibitive, suction values can define the depth to water relatively cheaply. An example of a typical profile in an alluvial soil is provided in Figure 6. Analysis of Figure 6 indicates a significant decrease in the suction value below a depth of 3 meters, remaining constant to the upper surface of a confining boundary at 6 meters. A piezometer installed in the bore hole confirmed the phreatic surface at 2.9 meters below ground. Due to the low permeability of the soils, the piezometer required 26 days to stabilize.

Information of this type aids in designing for hydrostatic pressure on below-grade walls and landfill liners. Use of suction and moisture content test correlations in uniform profiles can also be used to evaluate historical changes in the percent saturation.

CONCLUSIONS

Measurement of soil suction has been possible for many years but has not been widely embraced by the geotechnical community. Use of the filter paper method, however, provides a fast and inexpensive means of measurement of the total suction. This information can be used to characterize variations in the soil moisture and degree of saturation, which in turn aids in the evaluation of the behavior of unsaturated soils.

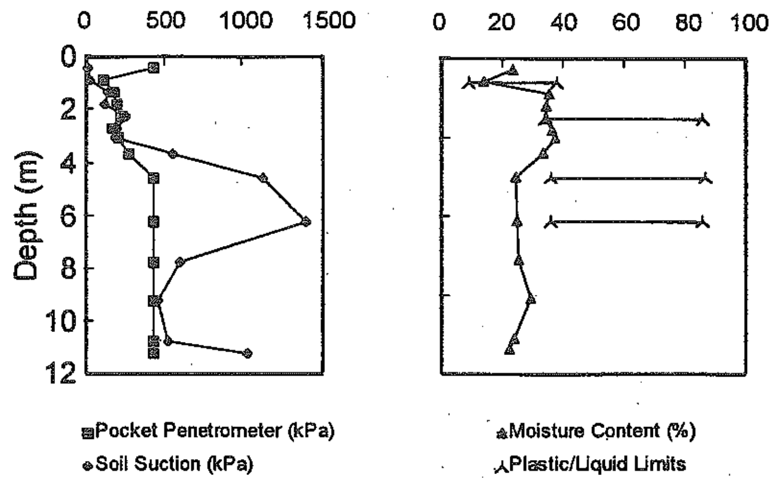

Figure 6. Application 2, identification of ground water level.

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