INTERNATIONAL SOCIETY FOR
SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:

https://www.issmge.org/publications/online-library

This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.

Swell pressure prediction by suction methods

Prédiction de la pression de gonflement par la méthode de succion

A. Kandemir & O. Erol – *Department of Civil Engineering, Middle East Technical University, Turkey*
Y. Erzin – *Department of Civil Engineering, Cumhuriyet University, Turkey*

ABSTRACT: Soil suction is the most relevant soil parameter for characterization of the swell behaviour. An attempt has been made to predict the swell pressures from soil suction measurements. Bentonite-Kaolinite clay mixtures were prepared to obtain soils in a wide range of plasticity indices. Suction measurements using thermocouple physchrometer technique and constant volume swell tests in oedometers were made on statically compacted specimens. Soil suction is correlated to plasticty index, water content and dry density and a multiple regression equation were developed. A linear relationship is found between log suction and the swell pressure. However a satisfactory correlation between initial soil suction and the swell pressure does not exist to propose a simple regression equation for a quick prediction of swell pressures from suction measurements.

RESUME: On a proposé un moyen de prediction de la pression du gonflement a partir des mesures de succion du sol. On a preparé des melanges des argiles bentonite-kaolinite pour obtenir des sols dans une large gamme d'indice de plasticité. On a effectué des mesure de succion en utilisant la technique de "psychrometer" et des tests de gonflement a volume constant sur les echantillons statiquement serrés. On a essayé une corrétion entre la succion du sol et l'indice de plasticité, la tenneur en eau, et la densite seche. Une equation de regression multiple ont été devoloppée. Une relation lineér entre la pression du gonflement et le logarithme de la succion ont été obtenu. L'analyse de regression multiple a révélé que la corrélation entre la succion initiale et la pression de gonflement h'été pas satisfesant.

1 INTRODUCTION

The swell behavior is characterized by three parameters: i. free swell; ii. swell pressure and iii. swell under load. These parameters are usually determined using standard oedometer tests. After the application of simple techniques such as the physchrometers in measurement of soil suction , several methods have been proposed to predict swell parameters from measured suction values. These methods mostly include determination of swell deformations. However there are only limited research work on swell pressure vs. suction behavior.

Kassiff and Shalom (1971) studied swell pressure - soil suction relationships using a modified oedometer cell where swell pressures were measured under controlled suctions gradients. The authors concluded that the swell pressures reaches to 95% of its ultimate value after a moisture intake of only one third that required to saturate the sample. The experimental data indicated that the swell pressure developed upon wetting is approximately equal to the difference between suction of a sample in constant volume swell test at its final water content and the freshly prepared sample under the same water content under zero confining pressure. For samples at dry side of optimum the swell pressure is only a fraction of this suction difference.

Johnson and Snethen (1978) stated that the swell pressure may be estimated from the slope, B and intercept, A of the linear log-suction versus water content behavior; and the authors proposed the following relationship for prediction of swell pressure, P_s, from soil suction measurements :

$$\log P_s = A - \left(\frac{100Be_0}{G_s}\right) \qquad (1)$$

where e_o is the initial void ratio, and G_s is the specific gravity. Kandemir (1996) has shown that this relationship highly overestimates the swell pressures of compacted clays as measured in oedometers.

In this study an attempt has been made to relate the swell pressures of expansive clays to the initial soil suctions and to develop correlations between the two characteristics swell parameters.

2 EXPERIMENTAL WORK

Commercially processed kaolinite and bentonite mineral clays were mixed in preselected proportions to obtain clays possessing a wide range of plasticity index. The plasticity characteristics of the four clay mixtures are shown in Figure 1 .

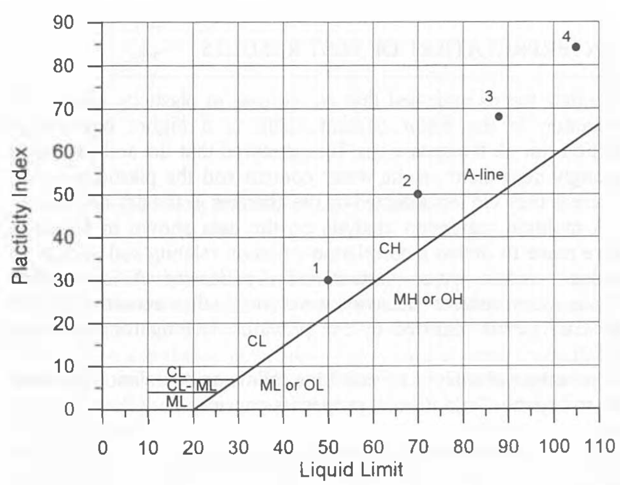

Figure 1. Plasticity characteristics of the clays

From the each clay mixture five or more disc shaped specimens having diameter of 36 mm and height of 15 mm were prepared at predetermined dry densities ranging from 1.5 g/cm^3 to 1.8 g/cm^3 at a constant water content of 10% , using static compaction. Then the specimens were gradually wetted to reach various water contents without any confinement. Adequate time was allowed in constant temperature and humidity environment for the specimens to attain equilibrium water contents. After the wetting phase the volume change of the specimens were measured to determine the final dry densities using a specially designed device. Then the thermocouple psychrometers were inserted into the wetted specimens to measure the final equilibrium soil suction values.

The experimental data included numerous soil suction and volumetric swell measurements for specimens with plasticity indices ranging from 30 to 84, dry densities from 1.25 g/cm^3 to 1.78 g/cm^3; and water contents 10% to 35%. The suction versus water content behavior of all the clay mixtures are shown in Figure 2 .

Standard constant volume swell tests (ASTM D 4546-85) were conducted on statically compacted samples of the clay mixtures in conventional oedometer cells ; and the swell pressures of each specimen, possessing plasticity indices, water contents and dry densities comparable to the ones obtained in the suction measurement tests, were directly measured.

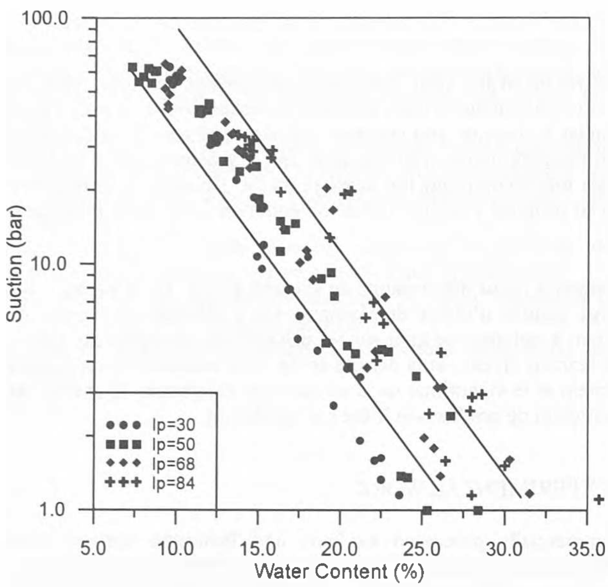

Figure 2. Log suction - water content behavior

3 INTERPRETATION OF TEST RESULTS

The data trends indicated that an increase in plasticity index or a reduction in the water content result in a higher equilibrium suction for all the specimens. It is observed that the soil suction is strongly dependent on the water content and the plasticity index; whereas they are less affected by the changes in the dry density.

A multiple regression analysis on the data shown in Figure 2 were made to obtain a correlation equation relating soil suction to plasticity index, water content and dry density. A log suction versus water content behavior were analyzed in accordance with the data trends reported by the previous investigators (Snethen 1980).

The statistical analysis revealed the following correlation between the soil suction and the soil properties considered:

$$\text{Log}\ \tau = 2.40 + 0.0069\ I_p - 0.0905\ w - 0.100\ \rho_{dry} \quad (2)$$

with the coefficient of multiple determination being R^2 = 92%. In Equation 2, τ = soil suction in bar; I_p= plasticity index; w = water content in %; ρ_{dry} = dry density in g/cm^3. The same units and symbols will be used in the subsequent analysis.

The dependence of the soil suction on the dry density and the plasticity index are shown in Figures 3 and 4 respectively for all ranges of I_p and ρ_{dry}. The behavior shown in Figures 3 and 4 clearly illustrates the relatively strong dependence of the soil suction on I_p, and insignificant effect of the dry density on the soil suction.

The initial soil suctions of the specimens tested in the oedometer for direct measurement of swell pressures were determined from Equation 2 . The typical suction versus swell behavior were then obtained as shown in Figure 5 for the clay mixture with plasticity index of 68. The data trends were similar for the entire range of plasticity indices covered, indicating an existence of a linear relationship between log initial suction and the swell pressure. It is noted that the swell pressures of the samples having relatively lower water contents (i.e. approximately 10%) deviates from the linear log suction versus swell pressure behavior as shown in Figure 5 .

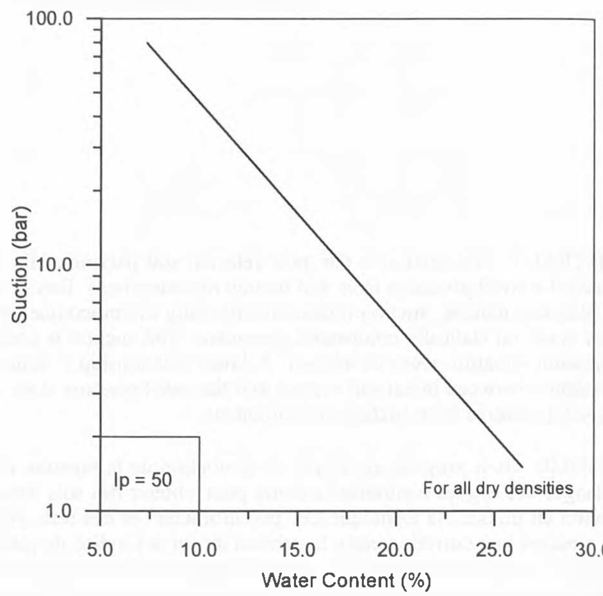

Figure 3. Dependence of suction on dry density

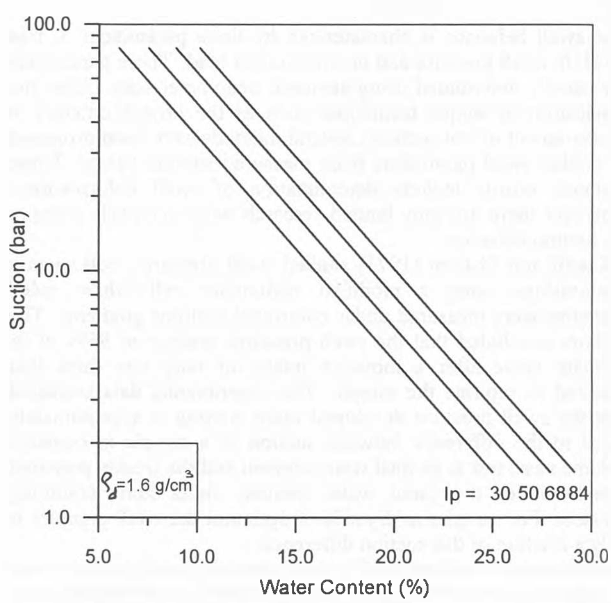

Figure 4. Variation of soil suction with plasticity index

The multiple regression analyses made on the swell pressure - suction data has revealed the following correlation equation:

$$P_s = -5.70 + 3.52\ \rho_{dry} + 0.685\ \log \tau \quad (3)$$

It is expected that the swell pressure of a clay soil could be predicted using Equation 3 provided that the initial soil suction and the dry density are determined using simpler techniques than the constant volume tests in oedometers in a shorter period of time. If suction measurement equipment are not available, then the correlations between soil suction, and I_p ,w and ρ_{dry} as given in Equation 2 could be used to estimate the initial suction from easily determined soil properties.

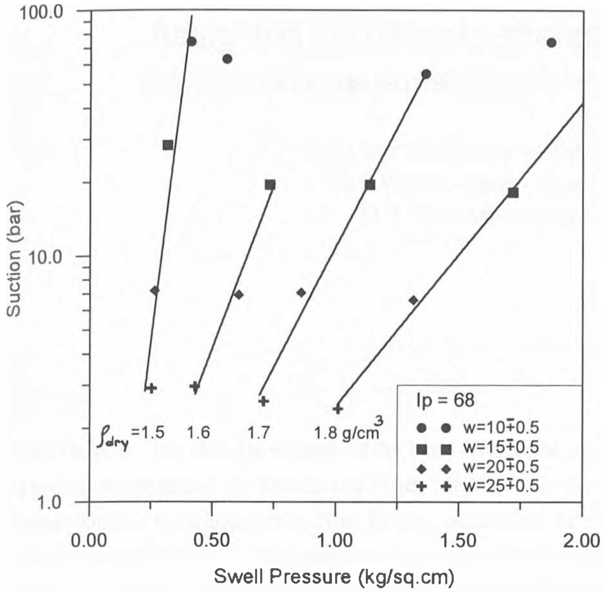

Figure 5. Typical suction - swell pressure relationships.

However the Equation 3 reveals a coefficient of multiple correlation of R^2=64.5% only, indicating a weak correlation between the two swell parameters. Therefore it is found inadvisable to use Equation 3 in routine engineering applications. The swell pressures predicted by Equations 2 and 3 are compared with the direct measurements from the oedometer constant volume swell test, as shown in Figure 6 . The level of proximity between the measured and the predicted swell pressures on Figure 6 is found as ± 50% only.

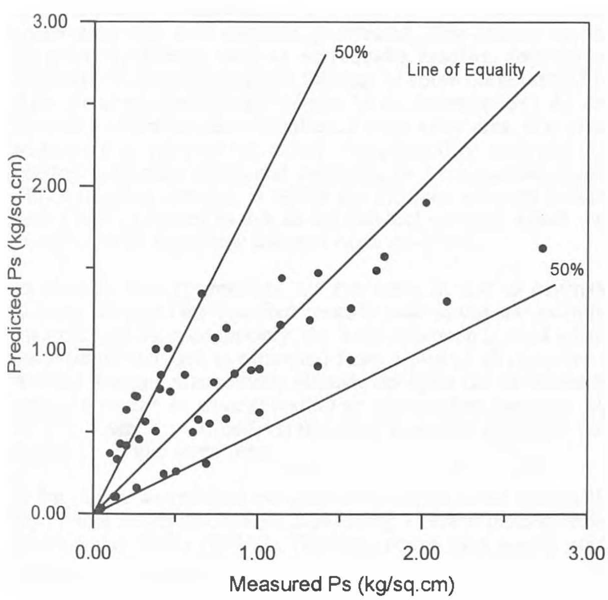

Figure 6. Comparison of measured / predicted swell pressures from soil suction

The data trends indicate that the swell pressure depends on the initial dry density and water content as well as the plasticity index as reported by previous investigators and observed in the present study as shown in Figure 5 (El-Sohby and El-Sayed 1981, Erol and Dhowian 1990). The multiple regression analyses carried out to correlate the measured swell pressures to the three soil properties revealed the following results:

For PI = 30, $P_s = -1.76 + 1.52\ \rho_{dry} - 0.027\ w \quad R^2 = 93.3\%$ (4)

For PI = 50, $P_s = -2.78 + 2.38\ \rho_{dry} - 0.036\ w \quad R^2 = 93.1\%$ (5)

For PI = 68, $P_s = -5.06 + 4.02\ \rho_{dry} - 0.039\ w \quad R^2 = 94.1\%$ (6)

For PI = 84, $P_s = -6.63 + 5.33\ \rho_{dry} - 0.048\ w \quad R^2 = 91.2\%$ (7)

A combined analyses including entire range of plasticity indices reveals the following correlation :

$P_s = -5.39 + 0.019\ PI + 3.49\ \rho_{dry} - 0.041\ w \quad R^2 = 88\%$ (8)

These analyses with high coefficients of multiple determination confirm the existence of strong correlations between the swell pressure and the soil properties I_p, w, and , ρ_{dry} which are also strongly correlated to the initial soil suction according to the analyses represented by Equation 2 . The swell pressures obtained from Equation 8 are compared with the measured swell pressures in Figure 7. It is found that the correlation between the swell pressure and the three soil properties w, ρ_{dry} and I_p given in Equation 8 is more reliable than previously tried initial suction versus swell pressure correlation.

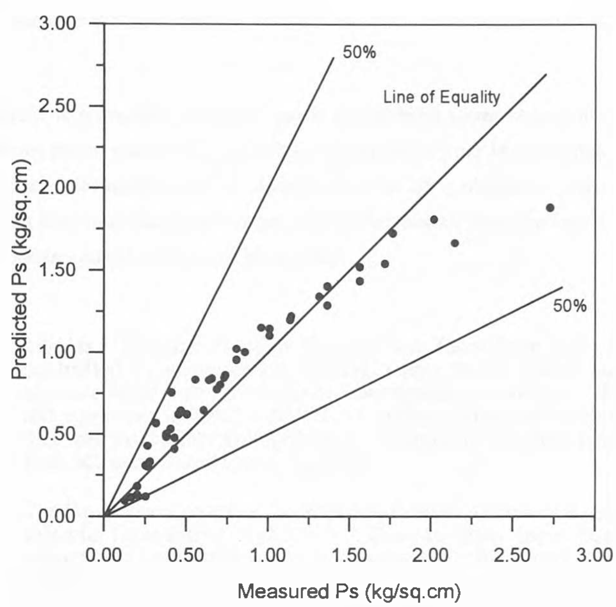

Figure 7. Swell pressure predictions from w, ρ_{dry} and I_p.

The data trends and the statistical analysis presented throughout the study indicate that both the soil suction and the swell pressure are strongly correlated to the soil properties w, ρ_{dry} and I_p. However a significant correlation between the swell pressure and the initial soil suction which would reveal a simple procedure to predict swell pressures, could not be established. Therefore it may be concluded that the initial soil suction is not the most relevant state of suction which characterizes the potential swell pressures, but probably a state of suction other than the initial value may reflect the possible magnitude of swell pressures more reliably as suggested by Kassiff and Shalom, (1971) .

4 CONCLUSIONS

The statistical evaluation of soil suction data from thermocouple psychrometers and the swell pressures measured in oedometers reveals the followings:

1. The soil suction is strongly dependent on water content and plasticity index, but less affected by dry density.

2. Significant correlation can be established between the swell pressure and the water content, dry density and plasticity index. The soil suction is also primarily controlled by these three soil properties.

3. It is found that an experimental relationship which would directly relate the initial soil suction to the swell pressure could not be established, the swell pressure is not solely characterized by the initial state of soil suction.

REFERENCES

ASTM,1990. Test methods for one-dimensional swell or settlement potential of cohesive soils.*ASTM Method D*.

El - Sohby, M.A. & A.R. El - Sayed 1981. Some factors affecting swelling of clayey soils . *Geotechnical Engineering* 12 : 19-39.

Erol, O. & A. Dhowian 1990. Swell behavior of arid climate shales from Saudi Arabia. *QJEG* 23: 243-254.

Johnson, L.D. & D.R. Snethen 1978. Prediction of potential heave of swelling soil. *ASTM Geotechnical Testing Journal* Vol.1, No.3: 117-124.

Kandemir, A. 1996. Swell prediction by suction measurements. *M.S. Thesis*,Middle East Technical University, Ankara, Turkey.

Kassif, G. & A. Ben Shalom 1971. Experimental relationship between swell pressure and suction. *Geotechnique* Vol.21, No.3:245-255.

Snethen, D.R. 1980. Characterization of expansive soils using soil suction data. *Proc. 4th Int. Conf. on Expansive Soils, Boulder,Colorado*: 54-75