PREDICTION OF SWELLING PRESSURE OF EXPANSIVE SOILS USING COMPOSITIONAL AND ENVIRONMENTAL FACTORS

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ABSTRACT

Expansive soils exhibit significant volume changes with variations in soil moisture content. Foundations constructed on these soils are subjected to considerable damage due to swelling. Determination of swelling characteristics (Swelling Pressure, Swell Potential and Swell Index) is a prerequisite for safe and economic design of structures resting on expansive soils. Direct determination of swelling characteristics is expensive in terms of time, money and services experts and skilled technicians. Hence geotechnical engineers have always been striving to evolve simple methods to predict the soil behaviour considering the soil state or soil type. This paper investigates the influence of both soil state and soil type on prediction of swelling pressure. The soil state is reflected by environmental factors namely initial Moisture Content, in-situ Dry Density and Initial Surcharge Pressure whereas the soil type is reflected by the compositional parameters namely Liquid Limit and Plasticity Index.

KEYWORDS: Expansive soils, Soil state, Soil type, Swelling Pressure, Swell Potential, Swell Index

1. INTRODUCTION

The expansive clayey soil deposits are highly moisture sensitive with respect to stress, deformation and strength. These soils exhibit extreme variation in strength and deformation such as heaving, settlement and shrinkage as the Moisture Content alters. Many attempts have been made in the past to identify Expansive Soils and to analyze the factors affecting the swelling of clayey soils based on simple laboratory and field test results (Altmeier 1953, Holtz and Gibbs 1956, Holtz 1959, Ranganathan and Sathyarayana 1965, USBR 973, Chen 1975, Dakshinamurthy and Raman 1977, Dinesh Mohan 1977, Anon 1981, Sridharan et.al. 1986). Swelling Pressure, Swell Potential, and Swelling Index are identified as three
important swelling characteristics which are required for assessment of heave and for safe and economic design of foundations resting on Expansive soils. Numerous methods have been proposed in the literature for direct laboratory measurement of swelling characteristics from one dimensional Consolidometer tests (Holtz 1959, Seed et al.1962, Sridharan et.al. 1986, Chen 1988). Several attempts have been made in the past to establish meaningful correlations between swelling characteristics and index properties. Such correlations are believed to be helpful in situations where time and money are constraints. Liquid limit, Plasticity Index, Colloid Content, Suction Pressure, Surcharge Pressure, In-situ Dry Density, and In-situ Moisture Content are some of the factors that are used in the past to predict Swelling Pressure and Swelling Potential. Some of these factors are dependent on composition of the soil (Liquid limit, Plasticity Index, Colloid Content) while others are environmental Factors (In-situ Dry Density, In-situ Moisture Content, and Surcharge Pressure). The basic motivating factor behind inclusion of Atterberg limits and Indices derived from Atterberg limits is the fact that both Atterberg limits and Engineering properties are dependent on composition of the soil. The engineering properties of soils are now said to be dependent on the composite effect of compositional and environmental factors (Mitchell, 1993). Liquid Limit and Plasticity Index are known to reflect compositional factors while in-situ Dry Density and natural Moisture Content are the important environmental factors that influence the engineering properties significantly (Mallikarjuna Rao et. al.2006).

Swelling Pressure, defined as the pressure which is required to return a swelled specimen back to its original state prior to swelling, and is one of the important swelling characteristics. Swelling Pressure is necessary for estimation of heave and for safe and economic design of Canal linings. Several investigators attempted to develop correlations for prediction of swelling characteristics in terms of either compositional factors or environmental factors or Combination of both (Komarnik & David 1969, Vijayvergiya & Ghazzaly 1973, Nayak & Christensen 1974, Yusuf Erzin 2004). Although these models are acceptable for soils based on which the models were developed and their use in general for all soils are not acceptable. General applicability of these methods is more dependent on whether all the influencing factors are accounted for in the proposed regression model or not. Hence, there is a need to understand the influence of each of the compositional factors and environmental factors on swelling characteristics, in order to develop meaningful correlations having more general applicability. The objective of this investigation is to assess the degree of association between Swelling Pressure and each of the influencing parameters namely Liquid limit (wL), Plasticity Index (Ip), Initial Dry Density (γd), Initial Surcharge Pressure (Sc) and Initial Moisture Content (mc).

2.0 EXPERIMENTAL INVESTIGATION

Representative but disturbed expansive soil samples from four different parts of India are collected from open trial pits at depths ranging from 2.5m to 3.0m. The index properties of soils used, placement conditions and Compression Index of all soils tested are presented in Table 1. From Table 1 it can be observed that for the soil samples tested, the Liquid Limit is ranging from 50% to 120%, and Plasticity Index is ranging from 24% to 88%. The range of each of the parameters considered is so wide that it covers practically most of the soils that are likely to be encountered in general practice. The four soils used in this investigation are designated as SS1, SS2, SS3, and SS4 for convenience.
Three series of free swell oedometer tests are conducted on all the four soils varying the three placement conditions (Initial Moisture Content, Initial Dry Density, Initial Surcharge Pressure), one at a time over a practical range while keeping the other two factors at one particular level. In all 46 free swell oedometer tests were conducted and Swelling Pressure ($P_S$) is obtained from the $e$-$\log p$ plots.

### Table 1 Properties of Tested Soils

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<td>Silt + Clay (%)</td>
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<td>Plasticity Index ($I_p$)</td>
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### 3.0 RESULTS AND DISCUSSIONS

Typical $e$-$\log p$ plots obtained from free swell oedometer tests are shown in Fig.1. Swell Pressure ($P_S$) is obtained from these plots in accordance with the relevant I.S. codes of Practice. All the test results are summarized in Table 2.
### Table 2 Details and Results of Tests conducted

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<th>S.No</th>
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<th>Plastic Limit (W_p) (%)</th>
<th>Liquid Limit (W_L) (%)</th>
<th>Plasticity Index (I_p) (%)</th>
<th>Initial Dry Density (γ_d) (kN/m³)</th>
<th>Initial Moisture Content (m) (%)</th>
<th>Initial Surcharge (S_i) (kPa)</th>
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4.0 REGRESSION MODEL FOR PREDICTION OF SWELLING PRESSURE

Based on the test results presented in Table 2 it can be concluded that the Swelling Pressure is dependent on all the placement conditions namely initial Moisture Content, initial Dry Density and initial Surcharge Pressure and also the Liquid Limit and Plasticity Index of the soil. Placement conditions reflect environmental factors whereas Liquid Limit and Plasticity Index reflect compositional factors. Hence Swelling Pressure can be said to be dependent on both environmental factors and compositional factors and may be expressed as given below.

\[ P_S = f (w_L, I_P, \gamma_d, m_c, S_i) \]  

(1)

Swelling Pressure is observed to bear a nonlinear relationship with all the influencing factors \((\gamma_d, m_c, \text{ and } S_i)\) as the Swelling Pressure is observed to increase more sharply with Dry Density than with \(m_c\) and \(S_i\). Hence no linear relationship between the independent and dependent variable is possible. In order to make the relationship linear, logarithm of Swelling Pressure \((\text{Log} P_S)\) and logarithm of initial Dry Density \((\text{Log} \gamma_d)\) are considered in the development of relationships. Hence, the functional relationship between Swelling Pressure and initial Moisture Content, initial Dry Density, initial Surcharge, Liquid Limit and Plasticity Index can be expressed as given below.

\[ \text{Log} (P_S) = (a_0 + a_1 w_L) + a_2 I_P + a_3 \text{Log} \gamma_d + a_4 m_c + a_5 S_i \]  

(2)

The numerical values of regression coefficients \(a_0, a_1, a_2, a_3, a_4\) and \(a_5\) can be obtained from multiple regression analysis. Microsoft-Excel software provides a subroutine for multiple regression analysis and the same is used here to obtain the regression coefficients \(a_0, a_1, a_2, a_3, a_4\) and \(a_5\) as well as the regression model and correlation coefficient, \(R^2\). The regression model so obtained is given below

\[ \text{Log} (P_S) = (-4.3341) + (0.0071 * w_L) + (0.0006 * I_P) + (5.2802 * \text{Log} \gamma_d) - (1.7900 * m_c) - (0.0037 * S_i) \]  

(3)

Where

\(\gamma_d\) = Initial Dry Density in kN/m\(^3\)
\(m_c\) = Initial Moisture Content in fraction
\(w_L\) = Liquid Limit (%)
\(I_P\) = Plasticity Index (%)
\(S_i\) = Initial Surcharge Pressure kPa

Swelling Pressure can be predicted using above equation knowing the placement conditions, Liquid Limit and Plasticity Index. The regression analysis yielded a correlation coefficient of \(0.979\) indicating good correlation between the variables and the Swelling Pressure. Any attempt to correlate Swelling Pressure with either compositional factors alone or environmental factors alone or any other combination other than the one presented in equation (3) did not yield any fruitful regression models. Hence the same were not presented here.
5.0 APPLICABILITY OF THE PROPOSED CORRELATION

The applicability of the proposed correlation for Swelling Pressure is assessed by comparing the predicted values of Swelling Pressure for the results reported in this investigation as well as using the test results reported in the literature. The Swelling Pressure so predicted is plotted against observed Swelling Pressure for the results of this investigation and for the reported data. These plots are shown in Figs. 7 and 8. The solid lines in these plots indicate the line of equality. The points are found to fall close to the line of equality in case of results of this investigation indicating good prediction. This is expected because it is the data used for development of proposed regression model. However, for other’s data, though many points are falling close to the line of equality, some of the points are dispersed away from line of equality. In other words, prediction is good for many soils but not for all soils. This may be attributed to the fact that coarse fraction which can influence swelling characteristics has not been accounted for in the proposed regression model. In all the four soils namely SS1, SS2, SS3 and SS4 the coarse fraction is less than 5%, hence the proposed regression models are valid only if coarse fraction is less than 5%. Therefore, there is a need to modify the regression model developed in order to account for the coarse fraction.

Fig. 2 Observed Vs Predicted Swelling Pressure
(Results of Present Investigation)
Fig. 3 Observed Vs Predicted Swelling Pressure (Literature data)

REFERENCES


