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Experimental Study of Some Factors Affecting Swelling Pressure

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Abstract: The main objective of this paper is to study the influence of placement and intrinsic parameters on swelling pressure and evaluate factors combining intrinsic and placement parameters for its prediction. The expansive soil samples were collected, from Alfao in Eastern Sudan (Soil 1) and Abeyi in Southern Kordofan (Soil 2). Soil 1 has a very high swelling potential whereas Soil 2 has a moderate potential for swelling. The basic soil properties were measured and the suction moisture content relationship was determined for the two soils using the filter paper method. Statically compacted specimens with different initial moisture contents and different dry densities were prepared in the Oedometer ring. The swelling pressure of the two soils was accurately measured using the constant volume method. The test results have shown that there is a direct linear relationship between swelling pressure and dry density. Excellent relationship exists between swelling pressure and soil suction. The relationship between swelling pressure and liquidity Index is excellent for the tested soils when the samples are prepared at the same dry density. A new factor, soil consistency factor (Fc) which is a combination of the consistency index CI, dry density and void ratio is introduced. The factor combines intrinsic and placement parameters. Very good relationship was found between swelling pressure and Fc for the same soil. This factor could be used for the prediction of the swelling pressure of compacted soils with excellent results when the water content is low.

Keywords*:* *Consistency factor; Expansive soils; Swelling pressure; Soil intrinsic properties*; *Soil suction.*

1. INTRODUCTION

Expansive or swelling soils are soils, because of their mineralogical composition, exhibit large volume changes or volumetric strains when subjected to moisture changes. They swell on wetting and shrink on drying. These soils cover large areas in central, southern and eastern Sudan as well as in many other countries in all the continents.

The swelling phenomenon is known to be function of two basic variables; the intrinsic soil properties and placement factors. The intrinsic soil properties are those related to the mineralogical composition of the clay fraction, soil gradation and its pore water chemistry. The placement factors are the density, water content and loading whereas the environmental factors are related to the increase and loss of water. Intrinsic swelling is the inherent expansiveness resulting from the intrinsic properties of a soil and the potential of a soil for swelling is explained by combination of the intrinsic soil properties and its placement and environmental conditions [1]. An intrinsically high potential expansive soil would not swell if it is below the ground water level, or subjected to loads greater than or equal to its swelling pressure.

The potential of a soil for swelling is assessed, mainly in the laboratory, using different types of test methods. These tests are normally carried out in the Oedometer apparatus and include percentage swell tests and the swelling pressure test. The latter is more standardized and is often used for quantifying the swell potential of swelling clays.

The classification of expansive soils is performed on the basis of its intrinsic expansiveness. The parameters used are therefore combination of intrinsic parameters such as Atterberg limits, clay fraction, activity and shrinkage index, [2]. However, classifying the soils according to their swelling potential or predicting swell potential test parameter will necessitate using combination of intrinsic parameters and placement parameters.

Swelling pressure is defined as the pressure applied to a soil to keep its initial volume constant when it is allowed to come into contact with water and the water content increases from its initial state to saturation, [2]. This definition led to various methods of determining swelling pressure. Among the methods is the constant volume test for which the volume of the soil sample is maintained constant in the Oedometer ring, throughout the test, by varying the loads on the sample or suppressing its tendency to swell. The final equilibrium pressure is the swelling pressure.

The factors which influence swelling pressure could be grouped into compositional ‘intrinsic” factors such as clay mineralogy, clay content, gradation and pore water chemistry; environmental or placement factors such as water content, density, soil structure, stress history and temperature and procedural factors such as size and shape of the tested specimen, its level of disturbance, methods of swell and load measurements, [2]. Previous studies have shown that for a certain soil type, swelling pressure is function of dry density and initial moisture content [3]–[6].

Attempts have been made to predict swelling pressure and percentage swelling using a single factor that combines more than one soil intrinsic or placement parameter. Mohamed [7] introduced the placement condition factor (F) which combines two placement parameters, dry density and moisture content and is defined as:

$$F = \frac{\gamma d}{mc} \quad (1)$$

where: γd is dry density and m.c is moisture content. He applied "F" to swell percent data of compacted swelling soils from Sudan and found that "F" predicts very well the swell percent for the same soil. Zumrawi [6] modified the placement factor (F) to a new one called the initial state factor, Fi and is defined by:

$$Fi = \frac{\gamma d}{\gamma w\, mc\, x\, e} \quad (2)$$

where γw is density of water and e is the void ratio. A linear relationship was found between "Fi" and swelling pressure for the same soil, the coefficients of which depends on plasticity index and clay content. It is noted that the two factors (F and Fi) considered only placement parameters, i.e, moisture content, dry density and void ratio. Several statistical multiple regression relationships using intrinsic and placement parameters were developed by Zumrawi [6] for the prediction of swelling pressure and California Bearing Ratio.

A well-known consistency factor combining placement parameter (m.c) and Atterberg limit is the liquidity index (LI). Liquidity index is a good indicator of where the soil moisture content lies in relation to its Atterberg limits and is defined as:

$$LI = \frac{mc - PL}{PI} \quad (3)$$

The LI is negative when the moisture content is lower than the plastic limit and is zero when the moisture content equals to the plastic limit. A less often known consistency indicator is the consistency index, CI. This index is defined as:

$$CI = \frac{LI - m.c}{PI} \quad (4)$$

It is arithmetically 1-LI. The indicator CI is 1.0 when moisture content equals the plastic limit and zero when moisture content equals the liquid limit. It is noted that the consistency factors LI and CI do not include the dry density which is a major parameter affecting swelling. This study was performed to improve our understanding of the swelling behavior of expansive soils and to develop some models or factors which combine both soil placement conditions and soil intrinsic parameters for predicting swelling pressure.

2. MATERIALS AND METHODS

The constant volume swell test was used to determine the swelling pressure of the studied soils. Two soils were studied. Soil 1 is highly plastic clay with very high potential for swelling and was obtained from Alfao in eastern Sudan whereas Soil 2 was obtained from Abyei in Southern Kordofan state and has moderate potential for swelling. Mineralogical analysis from previous research has shown that the clay fraction of Soil 1 is predominantly montmorillonitic (90% montmorillonite and 10% kaolinite) whereas the clay fraction of Soil 2 has approximately 30% montmorillonite, 60% kaolinite and 10% illite, [8]. The test program constituted:

- Determination of the basic soil properties; i.e., grain size distribution, clay content, specific gravity and Atterberg limits (Table 1).
- Statically compacted specimens with different initial moisture contents and different dry densities were tested and their swelling pressure was measured.

2.1 Specimen Preparation and Test Procedure

The two soils were initially air dried, crushed into small sizes and pulverized. The test samples were prepared by sieving the two soils through sieve No.4 (4.75mm). The fine material passing sieve No.4 was used in the experimental work. The soil samples were oven dried at 105-110 °C for 24 hours. The samples were subdivided and each sub-sample was mixed with distilled water to bring the sub-sample to the desired moisture content.

The test program constituted preparing each soil at five different target moisture contents (20%, 25%, 30%, 35% and 40%). An error in moisture content of ± 0.2 was allowed. For each water content, the test specimens were manually compacted in the Oedometer ring to three dry density levels (about 1.25g/cm³, 1.35g/cm³ and 1.45g/cm³), i.e. fifteen test specimens were prepared, for each soil, for the swelling pressure test. The exact moisture content and dry density were measured and recorded for each test specimen. Distilled

Table 1: Index properties of the tested soils

Soil ID	Soil 1	Soil 2
Specific gravity	2.70	2.61
Liquid limit (LL)%	66	61
Plastic limit (PL)%	29	29
Plasticity Index (PI)%	37	32
Grain size distribution		
Gravel (%)	2	-
Sand (%)	9	14.4
Silt (%)	65	47.6
Clay (%)	24	38
Linear Shrinkage	19	20
Unified classification system	CH	CH

water was used to moisten the tested soils during the whole sample preparation process. In the Oedometer cell, two filter papers were placed between the soil sample and the upper and lower porous stones to distribute the water evenly. The cell was then placed in the load frame of triaxial testing machine type (Controls triax50) and a 350 kg digital load cell was placed at the top of the specimen. The load cell reading was set to zero and the specimen was inundated by adding distilled water. The load cell readings were recorded at 1, 2, 4, 8, 16, 64, 128 and 1440 minutes. All tests were stopped when negligible increase in load cell readings was observed. The swelling pressure was computed using Excel spreadsheet. The swelling pressure values are reported in Table 2.

Matric suction values for different moisture contents (soil water characteristic curve, SWCC) were determined in a previous study for the two soils, [9]. The SWCC for the two soils was determined using the filter paper method, [10]. The method has the advantage of its ability to indirectly measure the high suction values of the tested soils. The SWCC curves are shown in Fig.1.

3. RESULTS AND DISCUSSION

The analysis will first consider the relationship between swelling pressure and moisture content, dry density and matric suction as important soil parameters that are known to affect swelling potential. Then factors combining intrinsic and placement parameters, e.g. consistency factors LI and CI and Fi will be considered. The swelling pressure moisture content relationship is given in Figs 2 and 3 whereas swelling pressure dry density relationship is plotted in Figs 4 and 5 for Soil 1 and Soil 2 respectively. It is observed from the figures that swelling pressure decreases as moisture content increases.

Table 2. Swelling pressure test results for Soil 1 and Soil 2.

Dry density (g/cm³)	Initial moisture content %	Maximum swelling pressure (kPa)	
		Soil 1	Soil 2
1.25	6.5 (air dried)	47.74	20.02
	20	46.51	16.33
	25	41.27	14.48
	30	34.80	12.63
	35	28.95	7.09
	40	14.48	2.46
1.35	6.5 (air dried)	136.14	41.59
	20	89.32	37.58
	25	80.08	32.96
	30	63.45	19.10
	35	30.80	8.63
	40	16.94	4.93
1.45	6.5 (air dried)	158.31	55.14
	20	135.52	49.29
	25	124.43	44.97
	30	71.76	27.11
	35	61.91	9.55
	40	24.33	*

*This test was not carried due to technical difficulties

The relationship for the same dry density value is not linear as swelling pressure slightly decreases with moisture increase when the soil is relatively dry and then the decrease in swelling pressure becomes more like-linear and more pronounced as moisture increases. The measured values are less sensitive to variations in dry density when the moisture content is 40 for soil 1 and 35 and 40% for Soil 2 (i.e. soil pores contain large quantity of water).

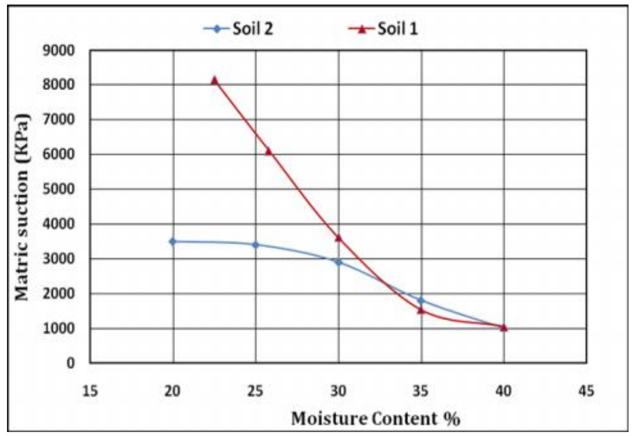

Fig. 1. Soil water characteristic curve for Soil 1 and Soil 2

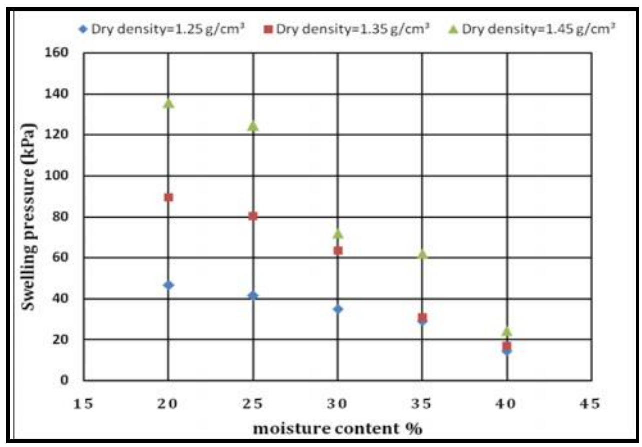

Fig. 2. Swelling pressure moisture content relationship for Soil 1

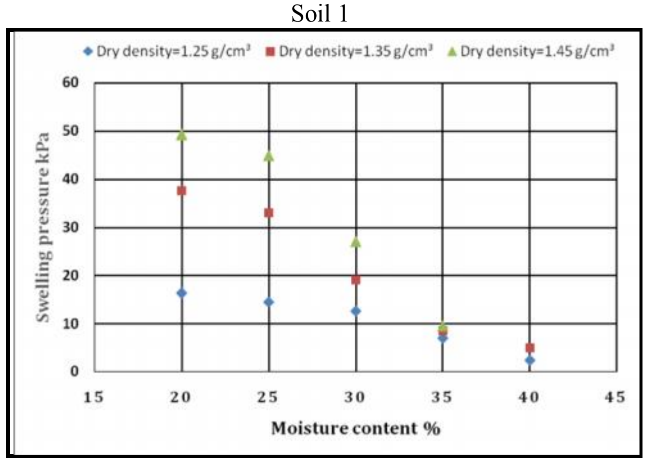

Fig. 3. Swelling pressure moisture content relationship for Soil 2

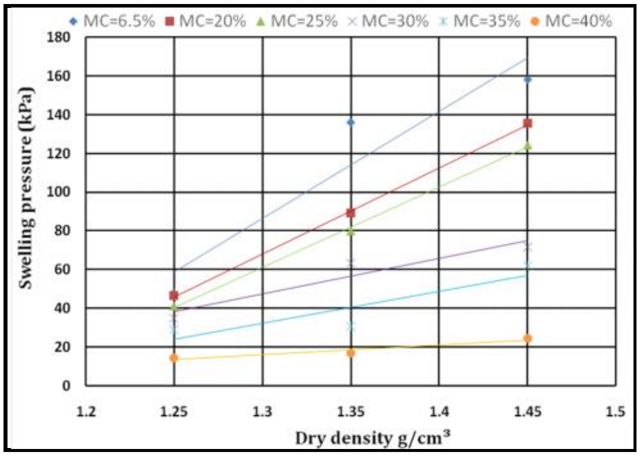

Fig. 4. Swelling pressure dry density relationship for Soil 1

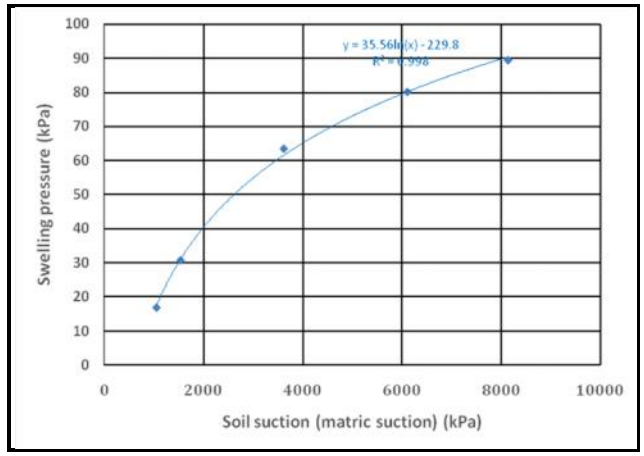

Fig. 6. Swelling pressure matric suction relationship for Soil 1

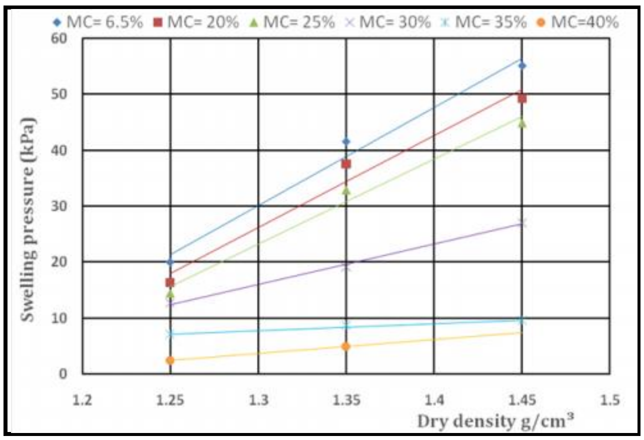

Fig. 5. Swelling pressure dry density relationship for Soil 2

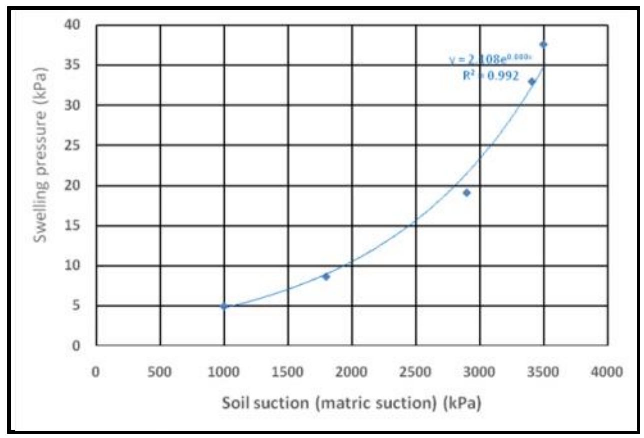

Fig. 7. Swelling pressure matric suction relationship for Soil 2

Swelling pressure versus dry density plot is given in Fig. 4 and 5. It is apparent form the figures that swelling pressure increases linearly with dry density for the same water content or matric suction value. The slope angle of the line is relatively flat when the soil pores contain large quantity of water and the slope increases as moisture decreases.

The swelling pressure matric suction relationship is given in Figs 6 and 7 for Soil 1 and Soil 2, respectively and for dry density equals 1.35 g/cm^3. Soil matric suction was measured for the same dry density. The relationship is natural logarithmic (nearly concave shape) for Soil 1 and exponential (nearly convex shape) for Soil 2. Smooth relationship was obtained and the degree of correlation is excellent for the two soils. This confirms the dependence of swelling pressure on soil matric suction which is a result of combinations of intrinsic properties and placement conditions of the tested soil. The convex versus concave shapes of the two curves could be attributed to the shapes of the SWCC of the two soils.

The liquidity index is used for scaling the natural moisture content of a soil to its plasticity limits. It is a measure of desiccation characteristic of clay soils. It is apparent that the shape of the relationship will be reversed for swelling pressure 8 and 9 show the swelling pressure versus Liquidity index for versus CI when compared to swelling pressure versus LI. Fig Soil 1 and Soil 2 respectively. Swelling pressure decreases as LI increases. The lines tend to converge at high LI values. Excellent linear relationship (R2> 0.95) was found, for the two soils, between Liquidity Index and Swelling pressure for the same dry density when water content is greater than 20%. This linear relationship is not valid for low water content values, i.e., when the air dry data is included. The same relationship will realize for swelling pressure versus CI. The dry density tends to affect and control swelling pressure when LI is negative or the moisture content is less than the plastic limit of the soil. On the contrary, swelling pressure is less sensitive to dry density when the moisture content is greater than the plastic limit of the soil (LI>1).

The initial state factor Fi (Equation 2) is applied to the test data. Fig. 10 and 11 show the relationship between swelling pressure and Fi for Soil 1 and Soil 2, respectively. The relationship between swelling pressure and Fi, for the two soils is not linear. The modified factor of Fi is that it includes only placement parameters and does not consider intrinsic soil parameters like Atterberg Limits, clay content etc., therefore it will not be applicable to more than one soil type, combined.

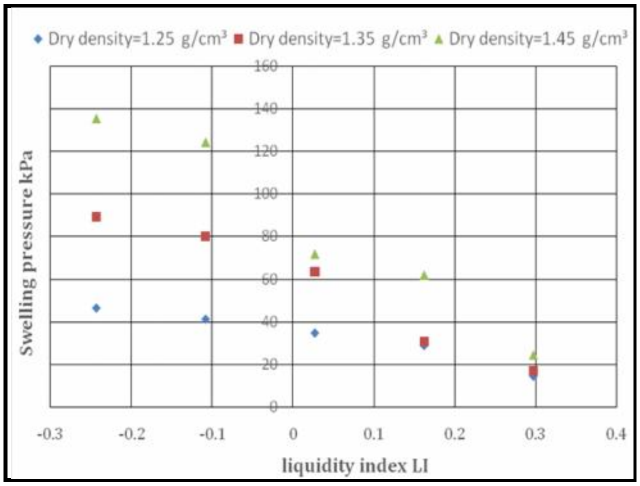

Fig. 8. Swelling pressure liquidity index relationship for Soil 1

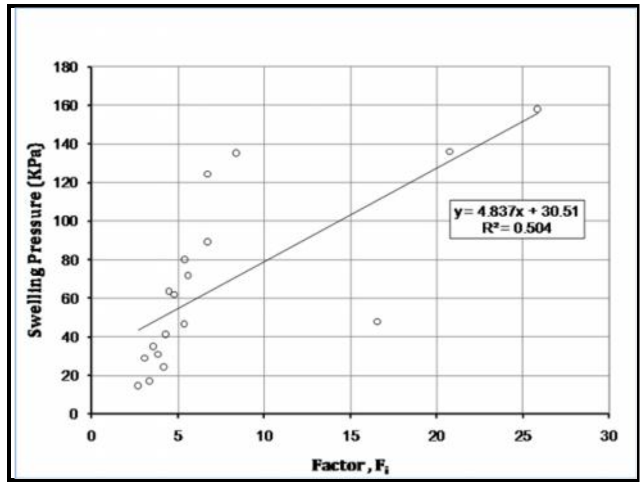

Fig. 10. Swelling pressure F_i relationship for Soil 1

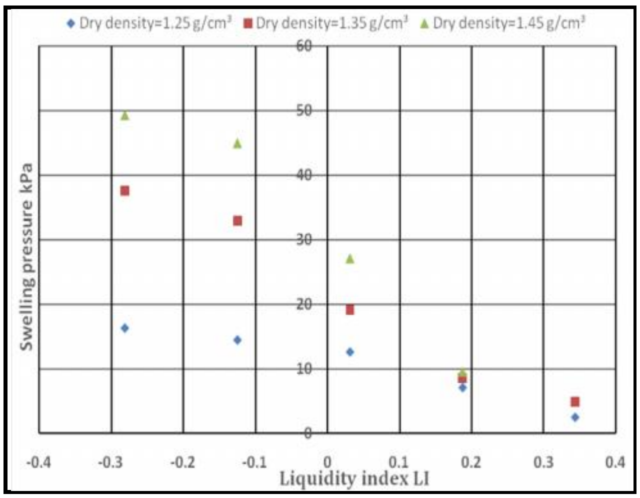

Fig. 9. Swelling pressure liquidity index relationship for Soil 2

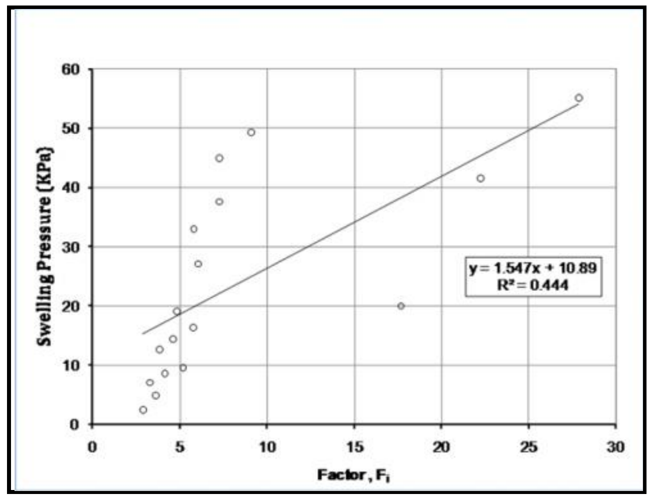

Fig. 11. Swelling pressure F_i relationship for Soil 2

A new factor is proposed which combines placement and intrinsic parameters. The factor (Fs) is a combination of consistency index (CI), dry density (γd) and void ratio (e) and is termed the soil consistency factor (Fc). The factor is presented in equation (5) and applied to the data.

$$Fc = \frac{\gamma d \times CI}{\gamma w \times e} \qquad (5)$$

This factor combines some of the intrinsic (LL and PI) and placement parameters (γ , MC and e). The Swelling pressure and Fc relationship for the generated data is plotted in Figs 12 and 13 for Soil 1 and Soil 2, respectively and in Fig 14 for the two soils, combined. Very good linear relationship is found for the whole data range and for the two soils, separately. The relationship is stronger for smaller moisture content values and showed some scatter for the specimens with relatively small moisture content and consequently high matric suction values.

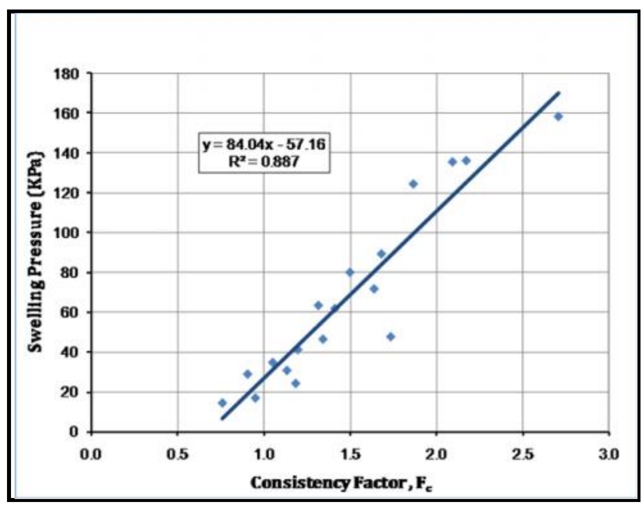

Fig. 12. Swelling pressure versus consistency Factor (F_c) for Soil 1

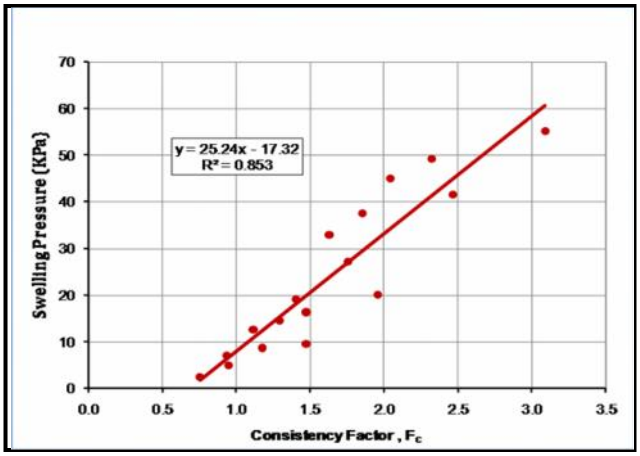

Figure 13: Swelling pressure versus consistency Factor (F_c) for Soil 2

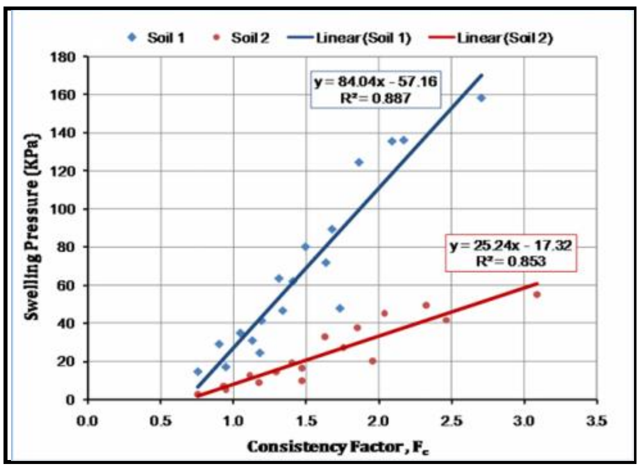

Fig. 14. Swelling pressure versus consistency Factor (F_c) for the two Soils

CONCLUSIONS

- This paper presented results of constant volume swelling pressure tests carried out on two potentially expansive soils, a highly expansive soil from Alfao (Soil 1) and a moderate expansive soil from Abyei (Soil 2). The objective is to study the influence of placement and intrinsic parameters on swelling pressure and evaluate factors combining intrinsic and placement parameters for its prediction.
- The basic soil properties were determined for each soil. Data for the soil water characteristic curve (SWCC) was obtained for the two soils from a previous study.
- Statically compacted test specimens were prepared, for each soil, at different dry densities and moisture contents. Swelling pressure was measured using 350 kg digital load cell connected to a load frame.
- The test results have shown that swelling pressure increases with decrease in moisture and increase in soil suction. A smooth and excellent relationship exists between swelling pressure and soil suction for the same dry density.
- Swelling pressure decreases with increase of Liquidity index (LI). The relationship is very good and linear for the same dry density. This applies to the range of water content for which the swelling pressure was measured.
- The initial state factor was used to predict the data. The relationship between swelling pressure and Fc was not linear for the whole range of data.
- A new factor termed soil consistency factor Fc which is ($\frac{\gamma d \times CI}{\gamma w \times e}$) is introduced. The factor takes care of placement and intrinsic parameters which affect swelling. Very good relationship was found between swelling pressure and Fc for the two soils.

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