International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

Swelling Potential of Compacted Expansive Soils

Magdi Zumrawi
Department of Civil Engineering, University of Khartoum Khartoum Sudan

ABSTRACT: Determination of swelling potential is quite important in design of foundations on expansive soils. In this paper an attempt has been made to develop a correlation for Swelling Potential, S_q accounting both soil state and soil type representative parameters. The soil state is reflected by placement conditions factors namely Moisture Content, Dry Density, Void Ratio and Surcharge Pressure whereas the soil type is reflected by the compositional parameters namely Plasticity Index and Clay Content. The Swelling Potential was measured for compacted samples prepared at different water contents and dry densities. Specimens were allowed to swell under various surcharge loads. Analysis of the experimental results demonstrates very clearly a strong linear relationship of S_q with the Factor of initial soil state, F_i, combination of water content, dry density and void ratio. The coefficients of this linear relationship (i.e. constant and slope) were found to depend on clay content, plasticity index and surcharge pressure. It is shown that predicted values of Swelling Potential using the developed equation agree closely with the experimental results of this study and those reported in the literature.

KEYWORDS: Swelling Potential, Placement Conditions, Initial State Factor

1 INTRODUCTION

The Swelling tendencies of expansive soils are quantified by the swelling potential and/or free swell. Swelling potential or volume change is defined as the ratio of increase in thickness to the initial thickness of the soil sample compacted at optimum moisture content in a consolidation ring and soaked under a token surcharge of 6.9 k Pa, Seed et al. (1962) so that the sample undergoes free swell.

Holtz and Gibbs (1956) developed a simple test called free swell test for the determination of swell potential of a soil. The test is performed by pouring $10cm^3$ of soil passing 425µm sieve into a graduated cylinder glass jar of 100ml capacity filled with water. The swollen volume of the soil is observed after 24 hours. The free swell is expressed as a percentage increase in the volume to the original volume of the soil. Soils having a free swell of 100% or more damage lightly loaded structures while those having free swell of less than 50% don't pose serious problems to structures.

The swelling potential can be directly determined in the laboratory by performing one-dimensional swell-consolidation test in an oedometer or indirectly predicted from classification index properties such as plasticity index, clay content, activity, and shrinkage index which have only an indirect bearing on the degree of swelling, Seed et al. (1962), Rao et al. (2004). Some researchers based on experimental data proposed relationships for swelling potential involving both placement conditions and index properties.

The aim of this paper is to predict swelling potential of soil from its index properties such as Atterberg limits, clay content and placement conditions or initial soil state parameters such as water content, dry density, void ratio and surcharge pressure.

2 PREVIOUS INVESTIGATIONS

Recently greater attention has been given to empirical investigations of the swelling behavior of compacted and natural soils, Seed et al. (1962);

* The author E-mail address: magdi.zumrawi@yahoo.com

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

Chen (1988); Nayak and Christensen (1974); Rao et al. (2004). As a result of these investigations, various forms of empirical equations have been proposed which relate swelling potential to certain physical properties of soils, such as consistency limits, clay content, initial moisture content and density.

Seed et al. (1962) proposed a linear relationship between swell percent, S under a surcharge of 6.9 kPa (1 psi) and plasticity index, PI as:

$$S = 2.16 \times 10^{-3} (PI)^{2.44} \quad (1)$$

Seed et al. (1962) gave another expression for swell percent, S in terms of activity, A and clay content, C as:

$$S = 3.6 \times 10^{-5} (A)^{2.44} (C)^{3.44} \quad (2)$$

Chen (1988) proposed a relationship for percentage swell, S of undisturbed soils in terms of plasticity index, PI in the form:

$$S = B \times e^{A(PI)} \quad (3)$$

where A and B are constants equal to 0.0838 and 0.2558 respectively. For the development of this correlation, the surcharge pressure used was 6.9 kPa. The water content varied between 15% to 20% and dry density between 16 and 17.6 KN/m^3.

Some researchers, Chen (1975) and Kassif et al (1965) based on experimental data proposed relationships for swelling potential and initial soil state parameters such as initial dry density and initial water content. They found that swelling potential depends on both initial water content and dry density. It increases with increasing initial dry density and decreases with increasing initial water content as shown in Figures 1, 2& 3.

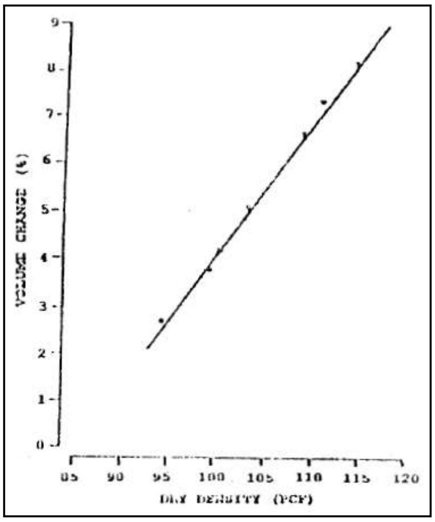

Figure 1. The relationship between volume change and initial dry density of expansive soil samples compacted at constant moisture content, Chen (1975).

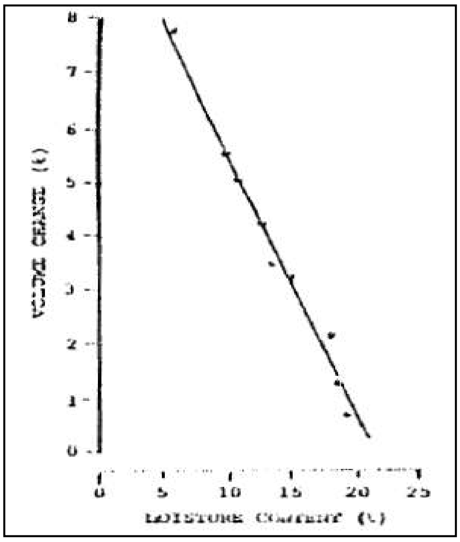

Figure 2. Volume change versus moisture content for samples compacted at constant dry density, Chen (1975).

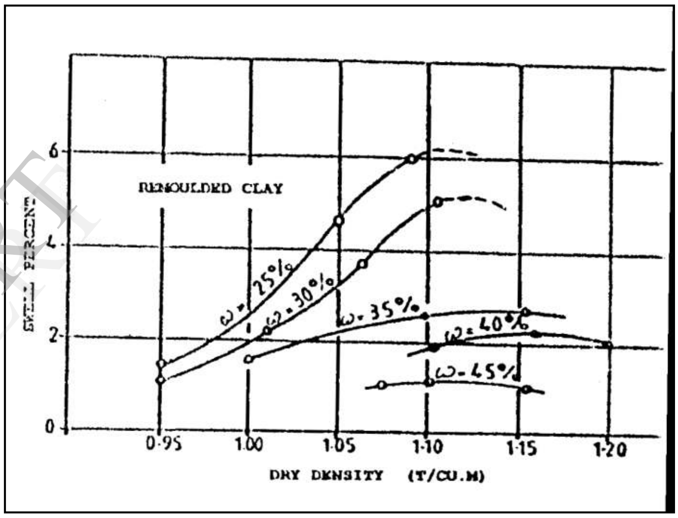

Figure 3. Swell percent versus dry density of samples compacted at constant moisture content values, Kassif et al (1965).

Nayak and Christensen (1974) who studied the swelling behavior of compacted expansive soils, indicated that the swell potential can best be related to plasticity index, clay content and water content and gave statistical relationships for swelling potential as:

$$S = (2.29 \times 10^{-2})(I_P)^{1.45} \times C/w_i + 6.39 \quad (4)$$

where, S: is the percent swell, I_P: is plasticity index, C: is the clay content, w_i: is the initial water content.

Brackley (1973) studied the variation of the swell percent with the void ratio for samples compacted at equal moisture content values and observed that the swell percent is inversely proportion with void ratio as shown in Figure 4

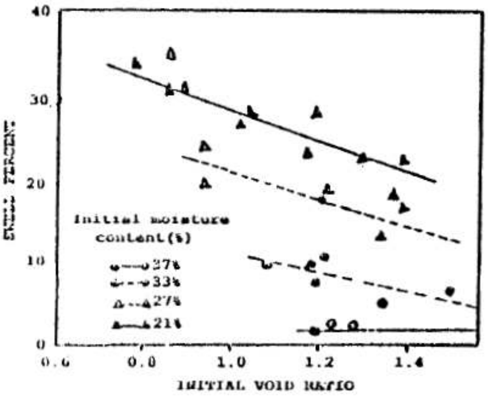

Figure 4. Variation of swell percent with void ratio of samples having equal moisture content values, Brackley (1973).

The previous empirical equations, (1) to (4) give reasonably good results when applied to the particular soils for which they were developed. Furthermore, they are easy to apply as they relate the swelling behavior to simple index properties of soils which can be easily determined in any soil laboratory. Consequently, these equations are apparently lack the generality necessary to cover a broad range of soil types.

3 A CONCEPT TO PREDICT SWELLING

Previous investigations of swelling behavior have revealed that the following factors influence swelling potential:

a) Initial soil state parameters or placement conditions.
b) Surcharge pressure under which swelling is measured.
c) Type and amount of clay
d) Consistency limits

In order to develop quantitative expression for swelling potential, the initial soil state parameters such as dry density, water content and void ratio can best be combined in a way reflecting the influence of each of them on the swelling potential. Therefore a new concept was developed; this is called the initial state factor and can be expressed thus:

$$F_i = \frac{\rho_d}{\rho_\omega} \cdot \frac{1}{\omega \cdot e} \quad (5)$$

where F_i = the initial state factor; ρ_d = the initial dry density of soil; ρ_w = the density of water; ω = the initial water content of soil; e = the initial void ratio of soil.

$$e = \frac{G_s}{\rho_d} - 1 \quad (6)$$

where G_s = the specific gravity of soil.

The initial state factor was empirically formulated on basis of the following reasons:

- As reported by Chen (1975) and Kassif et al (1965) and shown in Figures 1 and 3 that a linear relationship exists between the swell percent and the initial dry density of the soil samples compacted at constant moisture content. Hence, the swell percent, S can be assumed to be directly proportional to the dry density, ρ_d

$$S \propto \rho_d \quad ; \quad \omega \text{ is constant} \quad (7)$$

- The experimental data reported by Chen (1975) and Kassif et al (1965) and shown in Figure 2 and 3 indicated that an inverse linear relationship drawn between the swell percent, S and the moisture content, w of the soil samples having the same dry density.

$$S \propto \frac{1}{w} \quad ; \quad \rho_d \text{ is constant} \quad (8)$$

- Brackley (1973) proposed an inverse linear relationship between the swell percent, S and the void ratio, e of the samples having the same moisture content as shown in Figure 3.

$$S \propto \frac{1}{e} \quad ; \quad w \text{ is constant} \quad (9)$$

Hence from the above equations and using ρ_d/ρ_w instead of ρ_d to make the term dimensionless results in:

$$S \propto \frac{\rho_d}{\rho_\omega} \cdot \frac{1}{w \cdot e} \quad (10)$$

From the above equation (10) it can be concluded that the swell percent, S is directly proportional to the initial state factor, F_i. This relationship can be expressed as:

$$S \propto F_i \quad (11)$$

4 EXPERIMENTAL WORK

The primary objective of this paper is to predict the swelling potential of expansive soils using index properties such as water content, dry density, void ratio, clay content and plasticity index. To achieve this objective an experimental testing program was conducted on soil samples collected from different locations of expansive soils in Sudan. Soil samples were compacted with wide range of water content and dry density.

ISSN: 2278-0181
Vol. 2 Issue 3, March - 2013

Preliminary tests were carried out to determine consistency limits (i.e. liquid limit and plastic limit), clay content and specific gravity all carried out in accordance with BS 1377 (1990).

The Swell potential was measured in the conventional oedometer cell performed on compacted soil samples. The prepared specimens were inundated with water and full swelling attained within 24–36 hours. The specimens were permitted to swell under various surcharge pressures of 2.5, 7, 25 and 40 Kpa. Forty eight tests were performed for measuring the swelling potential.

5 RESULTS AND DISCUSSION

The experimental results of the measured swell percent with the measured index properties, initial water content, dry density, void ratio and their combination, initial state factor of the tested samples are given in Table 1. The index properties of the soils and the surcharge pressures under which the swell tests were conducted are presented in Table 2. The measured swell percent of the soils samples were observed to be influenced by the initial dry density and water content as well as the clay content, plasticity index and the surcharge load under which the sample was tested.

5.1 *The Linear Relationship*

To investigate the relationship between the initial state factor, F_i and the swell percent, S the tests results obtained in this study were analysed as given in Table 1. The relationship of the analysed data are shown in Figure 5. The plots in this figure and the values of the correlation coefficient, R^2 as listed in Table 2 have clearly shown a linear relation between the swell percent, S and the initial state factor for all the data analysed. The straight lines shown in the plots of Figure 5 can be expressed as:

$$S_q = M * (F_i - F_0) \qquad (12)$$

where: F_0 is the value of F_i at zero swell percent, M is the gradient of the straight line.

For the swelling potential data, the relationship of F_0 and M with surcharge pressure, clay content and plasticity index was plotted in Figure 6. It can be noted that in this figure, increasing in surcharge load will increase F_0 and decrease M values, while increase in clay content and plasticity index will increase F_0 and M values. The equation of the best fit line are expressed thus:

$$F_0 = 7.1(q)^{0.22} * (PI * C)^{0.78} \qquad (13)$$

$$M = 24.5(q)^{-0.26} * (PI * C)^{1.26} \qquad (14)$$

By substituting the above equations (13) and (14) in the general equation (12) and rearranged to express swell percent as:

$$S_q = 24.5 * (q)^{-0.26} (PI * C)^{1.26} \left[F_i - 7.1 * (q)^{0.22} * (PI * C)^{0.78}\right] \qquad (15)$$

where: F_i : is the initial state factor, q: is the surcharge pressure (KPa), PI: is the plasticity index, C: is the clay content.

Table 1. The measured and predicted swell percent and initial state data analysed of the four soils tested.

Sample	w %	ρ_d g/cm^3	e	F_i	S_m* %	S_c* %	S_c / S_m
A_1	11.9	1.686	0.69	18.9	13.4	13.7	1.02
A_2	12.0	1.610	0.53	27.3	21.6	20.4	0.94
A_3	15.0	1.609	0.67	15.7	10.1	11.1	1.10
A_4	15.3	1.448	0.48	24.3	19.9	18.0	0.91
A_5	15.5	1.492	0.68	14.9	11.5	10.5	0.91
A_6	16.8	1.500	0.69	13.7	9.4	9.5	1.01
A_7	16.8	1.590	0.83	10.3	7.8	6.8	0.87
A_8	17.4	1.521	0.53	18.9	15.8	13.7	0.87
A_9	19.8	1.673	0.57	14.9	8.7	10.5	1.21
A_{10}	19.8	1.817	0.65	12.6	8.4	8.7	1.04
A_{11}	23.0	1.561	0.65	10.8	7.1	7.2	1.02
A_{12}	23.6	1.472	0.83	7.4	6.0	4.5	0.76
A_{13}	28.7	1.648	0.78	6.7	5.3	3.9	0.74
B_1	11.8	1.500	0.77	16.5	8.3	8.2	0.98
B_2	13.3	1.590	0.67	17.9	7.9	8.9	1.13
B_3	13.5	1.521	0.74	15.1	6.4	7.3	1.15
B_4	14.7	1.673	0.58	19.4	10.7	9.8	0.92
B_5	16.2	1.817	0.46	24.4	13.3	12.7	0.96
B_6	17.4	1.561	0.70	12.9	6.6	6.0	0.92
B_7	19.0	1.472	0.80	9.7	3.8	4.2	1.11
B_8	19.0	1.648	0.61	14.2	5.9	6.8	1.16
B_9	21.4	1.721	0.54	14.9	6.4	7.2	1.12
B_{10}	22.6	1.598	0.66	10.8	4.2	4.8	1.15
B_{11}	26.3	1.580	0.68	8.9	3.4	3.7	1.12
B_{12}	26.4	1.489	0.78	7.2	3.2	2.8	0.87
B_{13}	28.9	1.460	0.82	6.2	2.8	2.2	0.80
C_1	14.3	1.549	0.77	14.1	29.8	28.7	0.96
C_2	16.9	1.465	0.87	10.0	18.8	18.5	0.99
C_3	20.8	1.358	1.02	6.4	12.6	9.8	0.78
C_4	20.5	1.460	0.88	8.1	14.5	14.1	0.97
C_5	20.7	1.568	0.75	10.1	17.2	19.0	1.10
C_6	23.9	1.370	1.00	5.7	10.6	8.1	0.77
C_7	23.8	1.458	0.88	7.0	10.7	11.2	1.05
C_8	29.0	1.371	1.00	4.7	5.8	5.7	0.98
C_9	28.4	1.445	0.90	5.7	5.2	8.0	1.54
C_{10}	33.0	1.376	0.99	4.2	3.8	4.4	1.16
D_1	13.6	1.553	0.76	14.9	13.1	12.5	0.73
D_2	14.8	1.520	0.80	12.8	11.8	10.0	0.65
D_3	17.0	1.457	0.88	9.8	8.2	6.3	0.61
D_4	20.7	1.362	1.01	6.5	3.7	2.4	0.56
D_5	20.7	1.453	0.89	7.9	5.4	4.1	0.62
D_6	20.7	1.558	0.76	9.9	6.9	6.6	0.75
D_7	20.5	1.645	0.67	12.1	8.4	9.1	0.84
D_8	23.4	1.369	1.00	5.8	2.8	1.6	0.53
D_9	23.9	1.452	0.89	6.8	3.8	2.8	0.62
D_{10}	24.5	1.550	0.77	8.3	4.4	4.5	0.83
D_{11}	29.2	1.352	1.03	4.5	1.1	0.8	0.73
D_{12}	28.3	1.457	0.88	5.9	1.3	1.7	1.28

* S_m: the measured swelling potential value
* S_c : the calculated swelling potential value.

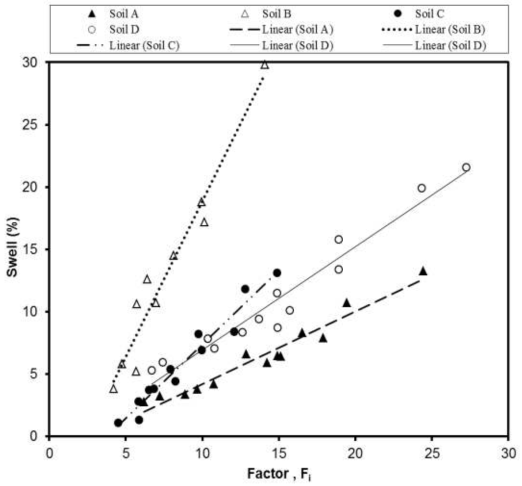

Figure 5. The linear relationship between swell percent and initial state factor, F_i for the data analyzed of present tests results.

Table 2. The tested soils index properties and analysis results.

Sample	PI %	C %	q KPa	G	F_{i0}	M_i	R^2
Soil A	33	30	7.0	2.65	1.66	0.83	0.948
Soil B	33	30	25.0	2.65	2.80	0.58	0.951
Soil C	32	61	2.5	2.74	2.50	2.44	0.951
Soil D	32	61	40.0	2.74	3.77	1.18	0.954

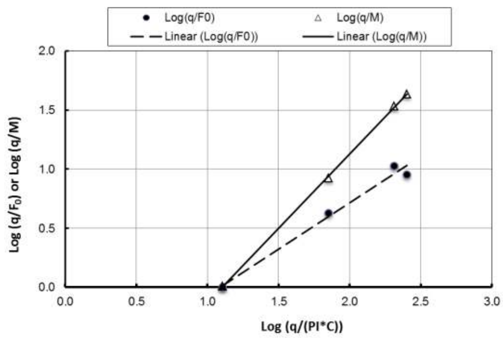

Figure 6. The variation of F_0 and M with clay content, C, plasticity index, PI and surcharge pressure, q

5.2 *Verification With The Reported Data*

The validity of the linear relationship and the proposed correlation for Swelling Potential is assessed by comparing the results obtained in this investigation with the analysis results of the experimental data reported by previous investigators for different soils from literature.

Many investigators have conducted swelling potential on compacted expansive soils, Chen (1975); Seed et al.,(1962); Nayak and Christensen (1974). Unfortunately, in most cases, the given data are insufficient to apply the proposed equation to their soils. However, the data reported by Chen (1975), Kassif et al (1965) and Brackley (1973) in the literature were selected for comparison.

To evaluate the linear relationship between the initial state factor, F_i and the swell percent, S, the experimental data reported by previous investigators were analysed and drawn in Figure 7. As can be seen the trend lines shown in plot indicate that there is a direct linear relationship exists between swell percent and the Factor, F_i.

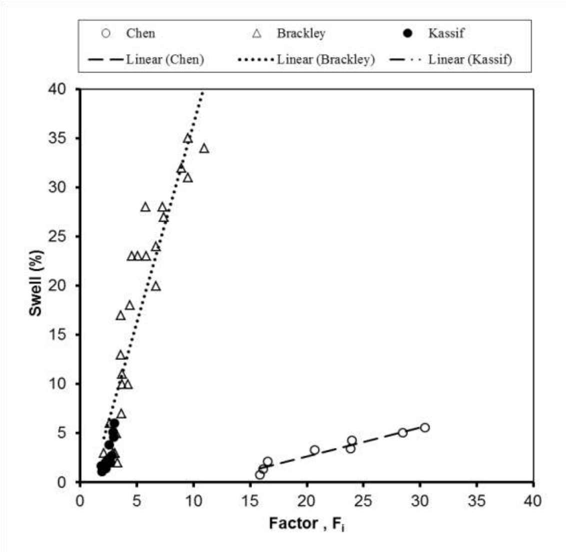

Figure 7. The relationship between swell percent and initial state factor, F_i for the data reported by previous investigators.

To check the validity of the present proposed correlation, the swell percent values obtained from the proposed equations 15 are compared with the measured swell percent values as given in Figure 8 and also in the Table 1. As can be seen from the tabulated results the ratio between the calculated swelling, using the equation 15 and the measured swelling values are in the range 0.80 ~ 1.30. In Figure 8 the points are found to fall close to the line of equality indicating good prediction. This is expected because it is the data used for development of proposed regression correlation.

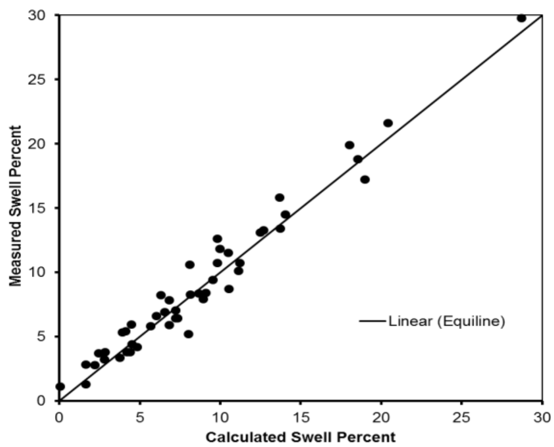

Figure 8. Comparison of measured / predicted Swell Percent for tests results.

The data experimental data reported by Chen (1975), Kassif et al (1965) and Brackley (1973) and shown in Figures 1 to 4 were analysed. The Swelling Potential predicted using the proposed equation 15 is plotted against the measured Swelling Potential for all the data reported. The plot is shown in Figure 9. Many points are falling close to the line of equality, some of the points are dispersed away from line of equality. This result indicate that there is a good agreement between the measured and predicted swell percent values and this has proved the validity of the developed equation.

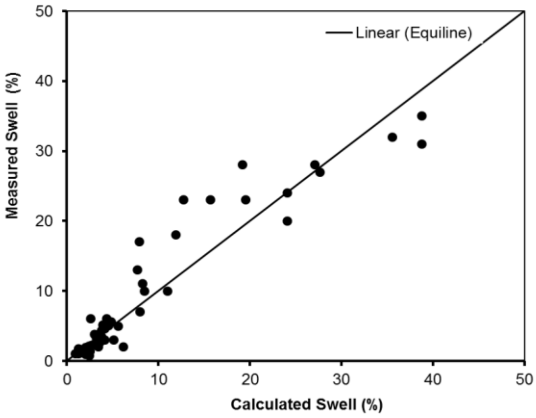

Figure 9. Comparison of measured / predicted Swell Percent for data reported by previous investigators.

6 CONCLUSIONS

Experimental work has been carried out to predict the swelling potential of expansive soils from measured soil properties. Several tests to measure the swell potential and index properties were performed on samples compacted to a wide range of water content and dry density.

The initial state parameters of soil such as water content, dry density and void ratio were combined in a way reflecting the influence of each of them on swelling potential. This combination was termed the initial state Factor, F_i. Analysis of the tests results clearly demonstrates a direct linear relationship existing between swell percent and the Factor, F_i.

Based on the linear relationship, strong and reliable correlation has been established for swell percent with initial state factor, clay content, plasticity index and surcharge pressure.

Comparison of the measured and predicted swelling potential values for tests results and the data reported by previous investigators, indicates that there is a good agreement between the measured and predicted swelling values.

The swelling potential and the soil properties seemed to exist in good relationship. Simple regression equation for quick prediction of swell percent from the index properties was developed.

7 ACKNOWLEDGMENTS

The author would like to thank the technical staff of soil mechanics laboratory of civil engineering department, faculty of engineering, university of Khartoum for their excellent support during the soil testing.

8 REFERENCES

British Standards Institution, BS 1377 (1990). “Methods of Test for Soils for Civil Engineering Purposes”. BSI, London.

Brackley, I. J. (1973). “Swell pressure and free swell in a compacted clay”. Proc. 3rd Int. Conf. Expansive Soils, Haifa 1, 169–176.

Brackley, I.J.A. (1975). “Swell Under Load”, Proc. 6th Reg. Conf. for Africa on SM and FE, Curban, S.S., 65–70.

Chen, F.H. (1975). “Foundations on Expansive Soils”. Elsevier Scientific Publishing Co., Amsterdam.

Chen, F.H. (1988). “Foundation on expansive soils”. Developments in Geotechnical Eng. Elsevier Publg. Co.

Holtz, W. G. and Gibbs, H. J. (1956). “Engineering properties of expansive clays”. Transactions, ASCE 121, 641-677.

Kassif, G., Komornik, A., Wiseman, G. and Zeitlen, J. G. (1965). “Studies and design criteria for structures on expansive clays”. Proc. 1st Res. Conf. on Exp. Soils, Texas.

Mohamed, A. E .M. (1986). “Microstructure and swelling characteristics of an untreated and lime-treated compacted black cotton soil”. Ph.D thesis. University of Strathclyde, Glasgow.

Nayak, N.V. and Christensen, R.W. (1974). “Swelling Characteristics of Compactedexpansive Soils”, Clays and Clay Minerals, Vol. 19, No. 4, pp. 251–261.

Ranganatham, B. V. and Satyanarayan, B. (1965). “A rational method of predicting swelling potential for compacted expansive clays”. Proc. 6th Inter. Conf. Soil Mechanics Foundation Eng. Vol. 1, pp. 92-96.

Rao, A.S., Phanikumar, B.R. and Sharma, R.S. (2004). “Prediction of Swelling Characteristics of Remoulded and Compacted Expansive Soils Using Free Swell Index”, Quarterly Journal of Engineering Geology and Hydrogeology, 37: 217–226.

Seed, H. B., Woodward, R.J., and Lundgren, R. (1962). “Prediction of swelling potential for compacted clays”. J. ASCE, Soil Mechanics and Foundation Division, Vol. 88, No. SM-3, Part 1, pp. 53-87.

Zumrawi, M. M. E. (2000). “Performance and design of expansive soils as road subgrade”. Ph.D. thesis, Chang’an Univ., China.