SOIL CONSISTENCY AND SWELL POTENTIAL USING STATIC CONE PENETRATION MACHINES

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SUMMARY: The use of static cone penetration test (CTP) as a site investigation tool for classifying potentially expansive soil has been outlined. The objective is to find a field a field method for classification of expansive soils. Four swell potential zones were identified in a plot of qc (cone resistance) versus fs (skin) friction. These potential zones are: non-expansive, low to medium, high and very high swell potential zones.

Ranges of fs and Rf= (fs/qc)x 100), termed friction ratio) that define the bounderies between these zones were also given.

In addition, the cone resistance qc was related to the relative consistency, Cr of the penetrated soil. A good correlation is found to exist between these two parameters. Again, limits of cone resistance values were obtained to enable estimates of the consistency of the soil.

Key Words: Swelling soils, swell potential, soil consistency, static cone penetrometer, field testing.

INTRODUCTION

Recently the static cone penetration test has gained wide acceptance as a good and reliable insitu site investigation tool giving a fair idea about soil type and properties. There is an increasing use of the quasi-static (Dutch) cone penetration test (CTP) to identify and classify soils and provide a quantitative prediction of strength characteristics of soils. The Building and Road Research Institute (BRRI) has introduced Sudanese experience with CPT machine. As part of a comprehensive research programme on Sudanese expansive soil that was formulated at the (BRRI), the machine was introduced in an attempt to provide a means for field identification and classification of these soils. This paper summarizes the findings of this study.

MATERIALS AND METHODS

The material known as Sudanese expansive soils cover according to Osman and Charlie (1984) one million square kilometers. This area includes most of the population centers and development projects. The annual estimated cost of repairs due to damages exceeds 6 million dollars. A survey made recently by Osman and Hamadto (1984) on lightly loaded structures in Sudan revealed that the improper drainage systems are the major cause of soil expansion. The recognition of this material form a major part of the soil engineers work. Many methods and techniques for expansive soil identification and classification have been proposed by researchers, e.g. Seed *et al.* (1962). Van Der Merwe (1964). Dakshanamurthy and Raman (1973), Chen (1975), Driscoll (1983), Ömer (1983), Burland (1984), Snethen (1984), Arnold (1984). These methods and techniques range from visual inspection of the soil institu to sophisticated methods of testing the soils in the laboratories. None of these methods, however, utilized the static CPT measured insitu parameters for expansive soil identification or classification.

The work described here consists of drilling of boreholes using an Acker rotary drilling rig from which soil samples were collected and transported to the laboratories where they are furtherly tested. A ten ton Dutch static cone penetration machine coupled with an adhesion jacket cone type was used to conduct the static cone penetration test. The static cone penetration tests were conducted near the boreholes and at a distance of 2 m away from them. The distance 2

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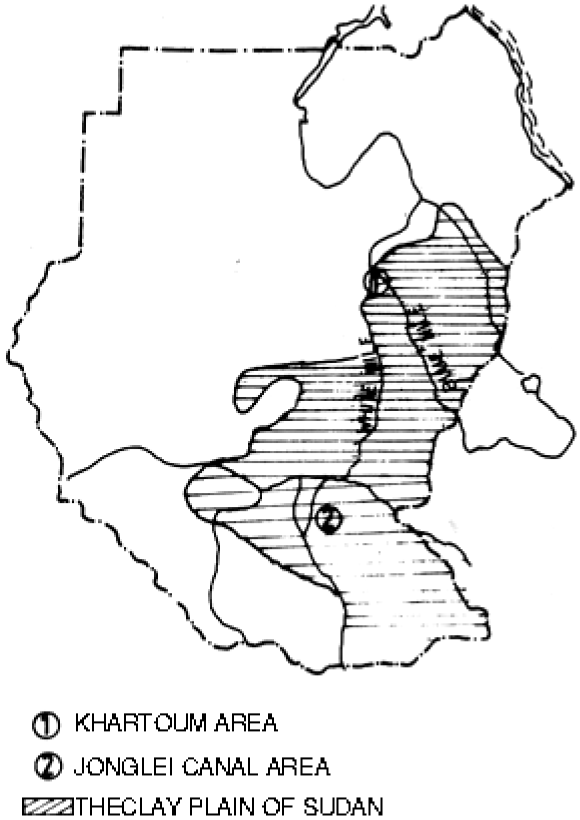

Figure 1: Location of study area on country map.

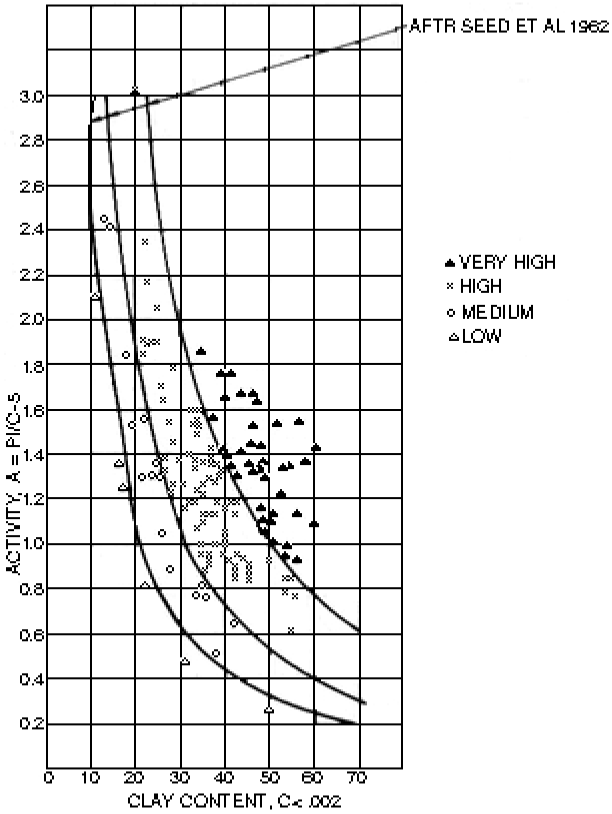

Figure 2: Distribution of the experimental points in the classification chart.

m is chosen in such a way as to ascertain soil homogenity and prevent soil distrubance that may arise due to vibration of penetrating tubes of the Acker machine during the drilling process. Records of cone resistance, qc and skin friction, fs were taken at 0.2 m intervals throughout the depth of penetration. The penetration speed was maintained constant at 2 cm/sec.

Two aeas were considered in this study; namely Khartoum (Manshia, Lamab Nasir and Khartoum west) and Junglei canal area. The two areas fall within the clay plain of Sudan (Figure 1). The clay plain of Sudan is known to exhibit expansive soil properties and contain about 40% montmorillonite, Osman and Charlie (1984). In Khartoum area the soil changes its colour and composition with depth from greyish sandy clay to yellow clayey sand underlain by the Nubian formation. The exploratory boreholes drilled along the aligment of the Junglei canal indicate that the deposits are formed of a clay layer followed by sandy layers. Cone penetration tests were carried out near power auger drilled boreholes from which soil samples were collected and transported to the laboratory where they were tested. The tests consisted of liquid limit, plastic limit, grain size distribution and natural moisture content. These tests were performed in accordance with the British Standard B.S. 1377-1975. Also records of qc and fs throughout the penetration depth were obtained at 0.2 m intervals.

RESULTS AND DISCUSSION

a) Classification of Expansive Soils:

From the test results the values of the plasticity index and clay contents for each soil were used to evaluate the swell potential of the soil using the method described by Seed *et al.* (1962). Using this method as a reference the investigated soils were found to fall within the four zones of Seed *et al.* chart. Figure 2 shows the distribution of all the points in the chart.

Points falling within the boundaries of each zone were given similar symbols. These symbols were used later on the same points when comparison is made with the field cone test results. The cone resistance qc and the skin friction fs at the respective depth of each of the experimental points show in Figure 2 were calculated. Such pairs of qc and fs for all the points corresponding to a given swell potential zone were plotted in graph form as shown in Figure 3. The lines Rf= 2% and Rf= 9% roughly bound the experimental points. From Figure 3 a dependence between qc, fs and the swell potential of the investigated soil can be observed. The results show that the swell potential increases with increases in qc and in fs. The trend indicates the possibility of identifying zones that vary

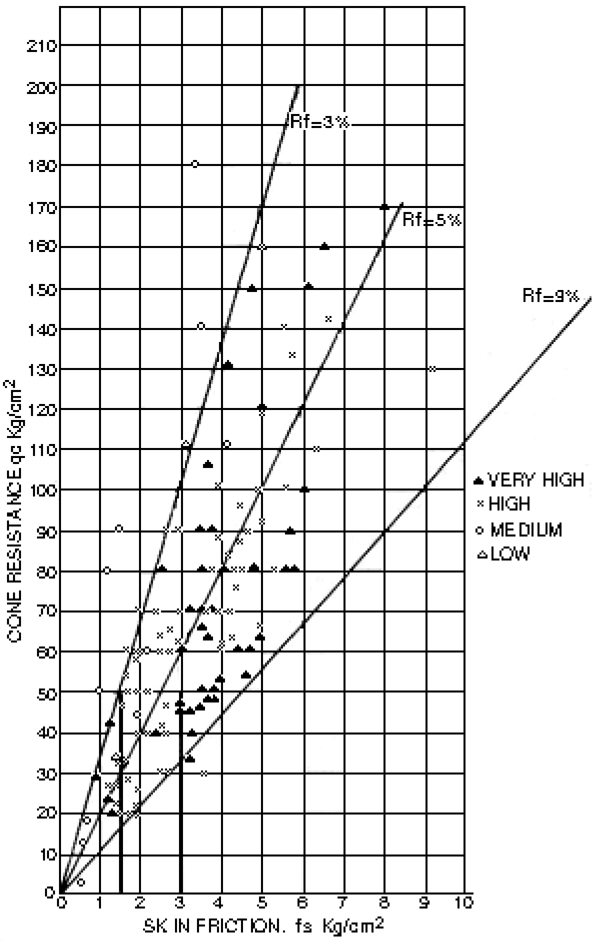

Figure 3: Plot of qc, fs with symbols showing the swell potential of the investigated soils.

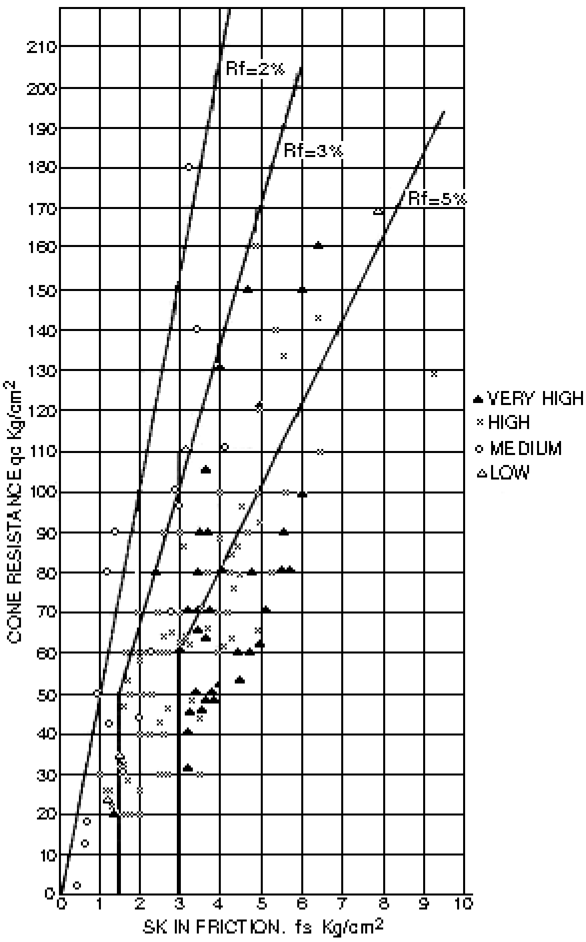

Figure 4: Swell potential classification zones.

with skin friction fs and friction ratio Rf, Rf= (fs/qc) x 100. It was found possible to define three regions of points having similar symbols. These regions are separated by two lines: one passes vertically through fs=1.5 kg/cm^2 up to qc=50 kg/cm^2 and then extends along the line representing Rf=3%, the second line passes vertically through fs=3kg/cm^2 up to qc=60kg/cm^2 and the proceeds along the line Rf=5%. This illustration is shown in Figure 4. The line Rf=2% bounds non-expansive soils as previous investigations relate this value to sand (Begemann 1965, Schmertmann 1969 and Sangelrat 1975).

Table 1.

Skin friction fs kg/cm^2	Friction Ratio Rf %	Degree of Expansion
>3	>5	Very high
>1.5	5>Rf>3	High
<1.5	3>Rf>2	Medium to low
All	<2	Non-expansive

The lines thus constructed divide the graph of qc-fs into four zones: non-expansive, low to medium, high and very high swell potential zones. There is however considerable scatter of data at the boundaries. Again distinction between low and medium swell potential zones is not possible. This can, when needed, be attained by providing more data and further investigations in that area. The results of the static C.P.T. classification as obtained from Figure 4 are summerized in Table 1.

To data no data have been encountered to show that the static C.P.T. can be used to classify potentially expensive soils. The results presented here may require further investigations. Nevertheless, the results show in Figure 4 and summarized in Table 1 show very useful identification criterion of swelling soils using the static C.P.T. The friction ratio value can be used to give a first trial on identification of the soils that possess swelling characteristics. This is because low values of Rf are associated with non-expansive soils, Schmertmann (1969), Sangelrat (1975), and

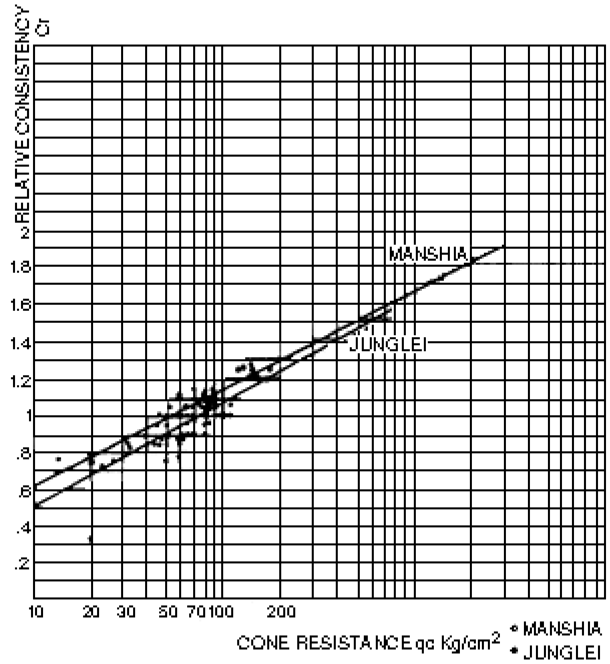

Figure 5: Variation of relative consistency with the cone resistance.

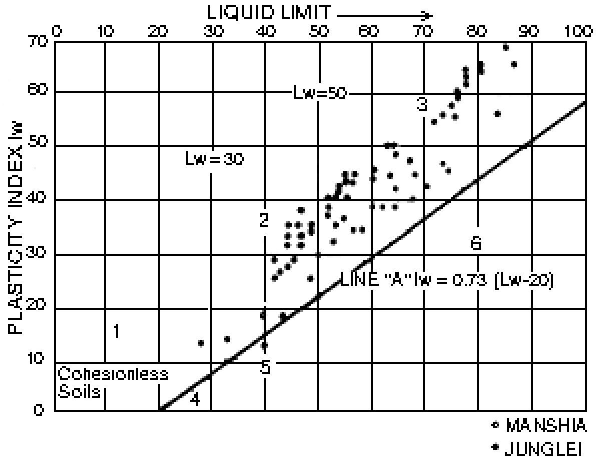

Figure 6: Distribution of junglei and manshia soils in cassagrande placticity chart.

Zein (1980). It is worthmentioning that higher values of Rf (Rf>5%) with low skin friction fs (fs<1.5) represent clays of low to medium expansive soils. This is shown in Figure 4 by a triangle whose sides are: fs=0 - - 1.5, qc=0 - - 30 and the line Rf=5%. This conforms to the fact that not all clays have expansive properties.

b) Estimation of soil Consistency:

The consistency of the soil is usually described in terms such as soft, medium, stiff or hard. The relative consistency (also termed consistency index) is defined as the ratio of the liquid limit minus the water content to the plasticity index i.e.

$$Cr = (LL - W) / P \quad (1)$$

Where Cr = relative consistency
LL = liquid limit
W = moisture content
PI = plasticity index

Thus if the relative consistency is requal to unity the soil is at the plastic limit. If Cr exceeds unity the soil is in semi-solid state and will be stiff. A negative Cr indicates that the soil has water content greater than the liquid limit and hence behave just like liquid. Attempts to describe the consistency of the soil based on other soil parameters when compared to this index were made by various authors, e.g. Melzer (1975). In this study the experimental test results of from Junglei and Manshia areas were used to evaluate the relative consistency as defined by eq (1).

Again values of cone resistance at the corresponding depths of Cr were computed. This cone resistance value was plotted against the relative consistency in a semi logrithmic form as shown in Figure 5. The plot gives the cone resistance in the logrithmic scale and the relative consistency in the linear one. Regression analysis were carried out an each set of points sperately. For soils encountered in the Junglei canal area the regression analysis yielded the following equation:

$$Cr = 0.54 \log qc - 0.02 \quad (2)$$

With qc in kg/cm^2 and a correlation factor of 0.74. For Manshia soils the relation between Cr and qc as obtained from the regression analysis was found to be as follows:

$$Cr = 0.53 \log qc + 0.08 \quad (3)$$

Again with qc in kg/cm^2 and a correlation coefficient 0.85. The relationship between Cr and qc is known to be affected by the soil type, Melzer (1975). Figure 6 shows the distribution of the experimental points on the Cassagrande chart. It is noted that the soils under study can generally be classified as inorganic soils of medium to high plasticity. In view of the close agreement between eq (2) and eq (3) and that all the experimental points are distributed along lines passing parallel to the A line, a single relationship for the combined data is developed using regression analysis. The relationship can be written as follows:

$$Cr = 0.6 \log qc - 0.11 \quad (4)$$

Again with qc in 4kg/cm^2 and a correlation coefficient of 0.82.

A good correlation is seen to exist between Cr and qc. Some scater of the plotted data is however expected. This may be due to some or all of the following:

- The investigated soils ranges between inorganic soils of medium plasticity to inorganic soils of high plasticity. More strong correlation could be established if each soil group is analyzed separately.

- The effect of the overburden pressure on qc values has been ignored.

- Inaccuracy in measured field and laboratory results.

Nevertheless, the cone resistance can be used to given an idea of the relative consistency using eq (4). Making use of eq (1) and eq (4) if Cr=1 then qc=70 kg/cm^2 and the soil is at the plastic limit. If Cr > 1 then qc > 70 kg/cm^2 and the soil is considered to be stiff. Values of qc less than 70 kg/cm^2 represent medium to soft soils. Furthermore, a limit can be introduced between soft and medium soils and also subdivisions are possible. This may be taken arbitrarily as shown in Table 2.

Table 2.

Cr	<25	25-5	5-75	75-1	1-1.25	1.25-1.5	1.5
qc	<4	4--10	10--27	27--70	70--85	185--480	480
	ext. soft	very soft	soft	medium	stiff	very stiff	hard

Using the broad ranges of qc in Table 2 it is possible to classify soil consistency from field CPT data only. The classification is intended to given estimates of soil consistency based on values of the cone resistance observed during field static CPT.

CONCLUSION

From the present study the following concluding remarks can be drawn:

- It is possible to classify potentially expensive soils using the static CPT data. Four swell potential zones could be identified from the plot of qc versus fs. Ranges of skin friction and friction ratio representing these zones have been established.

- A good correlation was found to exist between the cone resistance and the relative consistency of the penetrated soils. This relationship could be presented by

$$Cr= 0.6 \log qc - 0.11$$

q measured in kg/cm^2.

- Bounderies of qc that describe soil consistency based on the above equation was constructed.

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REFERENCES

1. Arnold G: The Genesis, Mineralogy and Identification of Expansive soils. Proc 5th In Conf on Expansive Soils. Adeloide pp 32-36, 1984.

2. Begemann HKP: The Friction Jacket Cone as an Aid in Determining the Soil Profile. Proc. 6th Int Conf on S.M.F.E. Montreal 1:17-20, 1965.

3. Burland JB : Building on Expansive Soils. Theme Lecture Presented at the First National Conference on Science and Technology of Building With Special Reference to Building in Hot Climate. S.E.S. Khartoum 1984.

4. Chen FH : Foundations on Expansive Soils. Elsevier Publishing Company, Amsterdam, 1975.

5. Dakshanamurthy V and Raman V: A Simple Method of Identifying an Expansive Soil. Soils and Foundations, Jap. Soc of Soil Mech. and Foundation Engineering Vol. 13 No. 1 pp 97-104, 1973.

6. Driscoll R : Physical Properties of Clay Soils. Seminar, Building on Clay Soils in Jordan. Royal Scientific Society, Amman. 1983.

7. Melzer KJ: Use of the WES Cone Penetrometer in Cohesive Soils Proc of the European Symp on Penetration Testing ESPOT July (1984), Vol 2 2 pp 263-268, 1975.

8. Ömer OM: Properties of Expansive Clayey Soils in Sudan. Prof of the Seminar on Expansive Clay Soils in Sudan. Problems in Sudan Hydraulic Research Station, Wad Medani pp 51-60, 1983.

9. Osman MA and Charlie : Engineering Properties of Expansive Soils in Sudan. Proc 5th Int Conf on Expansive Soils Adelaide pp 311-315, 1984.

10. Osman MA and Hamadto MEM : Damage Assessment of Resedential Houses Built on Expansive Soils Areas in Sudan Proc 5 th In Conf on Expansive Soils Adelaide pp 222-226, 1984.

11. Sangelrat G Nhiem, TV Sejour and Andina Z : Direct Soil Classification by static cone Penterometers with Special Friction Sleave. Proc First European Symp on Penetration Testing ESPOT Stockholm, Vol 2. 2 pp 337-344, 1974.

12. Schmertmann JH: Diutch Friction Cone Penetrometer Exploration of Research Area at Field 5, Eglin Air Force Base, Florida Contract Repot, S-69-4.

13. Seed HB, Woodward RJ and Lundgren R: Prediction of Swelling Potential for Compacted Clays. ASCE Journal SMF Div SM3 Vol 88 pp 53-87, 1962.

14. Senthen DR: Evaluation of Expedient Methods of Identifiction and Classification of Potentially Expansive Soils Proc 5th Int Conf on Expansive soils. Edelaide pp 22-26, 1984.

15. Van Der Merwe DH: The Prediction of Heave from the Plasticity index and Percentage Clay Fraction of Soils. The Civil Engineering in South Africa, Vol. 6 No. 6, 1964.

16. Zein AM: Correlation Between Static Cane Penteration and Recognised Standard Test Results for Some Local Soil Types. A Thesis Submitted for the Degree of Msc (Eng), in the University of Khartoum 1980.