

Session (3)
**Materials for Road
Construction**

Characterisation Of Expansive Soils And Use In Design

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Abstract:

This paper is concerned with the study of swelling behaviour and strength characteristics of expansive soils in order to develop new design charts. Expansive soil samples with high plasticity have been compacted at a wide range of water content and different dry densities. A new characterisation concept was developed. This is called the soil state factor which was developed for the initial and soaking state. The initial state factor is a combination of the dry density, water content and void ratio, while the soaking state factor is a combination of the saturated dry density, saturated water content and amount of swelling during the soaking period. On basis of this concept, characterisation charts for swelling and initial state behaviour as well as strength and initial state behaviour were developed. The use of these charts in pavement design, evaluation and field compaction control on expansive soil areas is demonstrated.

Introduction

In road construction, specifications and standards normally do not permit expansive soils to be used in embankments or fill below formation level; moreover excavation below the embankment of expansive soil and replacing it by better quality materials may also be required. This is because of the large volume changes that can occur as a result of wetting and drying with seasonal changes of climate. Few roads constructed through these areas have proved satisfactory, but the majority especially in Africa and southern Asia has failed completely.

In Sudan black cotton soils cover a wide strip along the river Nile and its tributaries, where most of the main economical and agricultural schemes and production factories are located. Most of our major highways are constructed on black cotton clays. These major engineering structures consequently suffer from series distresses and damages. According to records, the annual estimated economical losses caused by expansive

soils exceed a million dollar.

When considering expansive soils as road subgrade, one of the main concerns of the design engineer should be concentrated on swelling behaviour and strength of this soil as main factors of design. Thus, the main objective of this paper is to study swelling behaviour and strength characteristics of this soil so as to improve current design and construction standards used.

Experimental work

The laboratory tests were carried out to investigate the swelling behaviour and strength of expansive soil samples prepared at a wide range of water content and compacted to different dry densities and subjected to different testing conditions. These samples were then used to perform soil tests such as swelling, CBR and undrained triaxial tests. The measurements from these tests were able to give a useful indication of the relationship between the combination of the soil initial state parameters (water content, dry density and void ratio) and the measured swell percent, swelling pressure, CBR and shear strength. The soaking state parameters (saturated water content, saturated dry density and amount of swelling) and the measured soaked CBR were also illustrated.

Results and discussion

The tests results and the data reported by the previous researchers as indicated in Figures 3.1 to 3.11 show that the swelling of this soil is influenced by the surcharge pressure imposed on the soil as well as the initial state of the soil as described by dry density, water content and void ratio. On the other hand, the CBR and shear strength of this soil is greatly influenced by the initial dry density, water content and void ratio of soil as well as testing conditions.

The initial state factor

Analysis of the experimental results indicated that it is possible to combine the initial state parameters such as dry density, water content and void ratio in a way reflecting

the influence of each of them on the swell percent, swelling pressure, unsoaked CBR and shear strength. Therefore a new concept was developed; this is called the initial state factor.

$$F_i = \frac{\rho_d}{\rho_w} \cdot \frac{1}{\omega \cdot e} \quad 3.1$$

Where:

F_i is the initial state factor

ρ_d is the initial dry density of soil

ρ_w is the density of water

ω is the initial water content

e is the initial void ratio.

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

- The results of swell percent data and those reported by Chen ^[5] and Kassif et al ^[8] and shown in Figures 3.1 and 3.2 clearly indicate that a linear relationship can be drawn between the swell percent (or volume change) and the initial dry density of the samples of the same soil, having the same moisture content and subjected to the same surcharge pressure. Hence, the swell percent (S) can be assumed to be directly proportional to the dry density (ρ_d) i.e.

$$S \propto \rho_d \quad ; \quad \omega \text{ is constant} \quad 3.2$$

- The experimental results and the data reported by Chen ^[5] as indicated in Figure 3.3 suggest that an inverse linear relationship exists between swell percent and moisture content of samples of the same soil, having the same dry density and subjected to the same surcharge pressure. Hence, it can be assumed that the swell percent (S) is inversely proportional to the initial moisture content (ω) i.e.

$$S \propto \frac{1}{\omega} \quad ; \quad \rho_d \text{ is constant} \quad 3.3$$

- An inverse linear relationship exists between the swell percent and the void ratio of the samples of the same moisture content as in Figure 3.4. So it can be assumed that the swell percent (S) is inversely proportional to the void ratio (e) i.e.

$$S \propto \frac{1}{e} \quad ; \quad w \text{ is constant} \quad 3.4$$

Hence from the above equations and using $\frac{\rho_d}{\rho_w}$ instead of ρ_d to make the term dimensionless results in:

$$S \propto \frac{\rho_d}{\rho_w} \cdot \frac{1}{\omega \cdot e} \quad 3.5$$

From the above equation 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:

$$S \propto F_i \quad 3.6$$

The soaking state factor

It was found that saturation due to soaking has great influence on the soaked CBR values of expansive soils. Therefore the factor in the soaking state is formed by a combination of the saturated dry density, saturated water content and amount of swelling due to soaking. This factor is termed the Soaking state factor.

$$F_s = \frac{\rho_{d_{sat}}}{\rho_w} \cdot \frac{1}{\omega_{sat}(1+S)} \quad 3.7$$

Where:

$\rho_{d_{sat}}$ is the saturated dry density

ω_{sat} is the saturated water content

ρ_w is the density of water

S is the amount of swelling during the soaking period.

The soaking state factor F_s was developed on basis of the following reasons:

- ◆ The data of Bissada and Yoder^[18] as shown in Figures 3.5 and 3.6 indicate that the soaked CBR values decrease with increasing in saturated water content values (i.e. the water content values at wet of optimum side) of samples having the same saturated dry density. hence, it can be assumed that the soaked CBR is inversely proportional to the saturated water content (ω_{sat}) i.e.

$$\text{Soaked CBR} \propto \frac{1}{\omega_{sat}} \quad ; \quad \rho_{d_{sat}} \text{ is constant} \quad 3.8$$

- ◆ Based on the data reported by Yoder^[18] as indicated in Figure 3.6, it can be suggested that a linear relationship may exist between the soaked CBR and saturated dry density of samples having the same saturated water content. thus, the soaked CBR can be assumed to have a direct proportional relationship with the saturated dry density ($\rho_{d_{sat}}$) i.e.

$$\text{Soaked CBR} \propto \rho_{d_{sat}} \quad ; \quad \omega_{sat} \text{ is constant} \quad 3.9$$

- ◆ As reported by Yoder^[18] and shown in Figure 3.6. It can be seen that increasing in the amount of swelling of expansive soils during the soaking period reduces the soaked CBR value. Whereas in granular soils swelling has no influence on the soaked CBR values during the soaking period. Hence, for different types of soil, it can be assumed that the soaked CBR is inversely proportional to the amount of Swelling (S)(as a fraction of one) as given by the term (1+S) and expressed thus:

$$\text{Soaked CBR} \propto \frac{1}{1+S} \quad 3.10$$

Hence from the above relationships and using $\frac{\rho_{d\ sat}}{\rho_w}$ instead of $\rho_{d\ sat}$ to make the term dimensionless results in:

$$Soaked\ CBR \propto \frac{\rho_{d\ sat}}{\rho_w} \cdot \frac{1}{\omega_{sat}(1+S)} \quad 3.11$$

From the above equation it can be suggested that the soaked CBR is directly proportional to the soaking state factor (F_s). This relationship can be expressed thus:

$$Soaked\ CBR \propto F_s \quad 3.12$$

The linear relationship of the factor

The results of analysis as indicated by Figures 3.7 ~ 3.11 proved that this factor has a very good linear relationship with swell percent, swelling pressure, CBR and shear strength. This linear relationship for the swell percent and soaked CBR as examples can be expressed as follows:

$$S = M * (F_i - F_0) \quad 3.13$$

Where:

S is the swell percent

F_i is the initial state factor

F_0 is the value of F_i at which no swelling occurs

M is the gradient of the straight line.

$$Soaked\ CBR = M * (F_s - F_0) \quad 3.14$$

Where: F_s is the soaking state factor

Characterisation of swelling and strength

The linear relationship exists between swell percent, swelling pressure, CBR or shear strength and soil state factor (F_i or F_s)(as described in section 3) can be of great use in

ω is the initial water content(%)

e is the initial void ratio.

Charts to show the relationship of CBR and shear strength characterisation lines with water content and dry density variations are plotted in Figures 4.3 and 4.4, respectively. When comparing calculated CBR and shear strength values that were indicated on isolines and measured values located alongside data points, their values seem to be equal. This result verifies the validity of the iso-CBR and iso-shear lines produced.

Development of empirical chart

An important feature of the type of characterisation lines approach developed in the previous section is the possibility that the data regarding swelling behaviour (i.e. swell percent and swelling pressure) and soil strength (i.e. CBR and shear strength) of expansive soils can be superimposed in one characterisation line. Thus characterisation lines (isolines) of CBR, shear strength, swelling pressure and swell percent at different surcharge pressures (P_1, P_2, P_3 , etc.) - Initial state (water content and dry density) behaviour of a given expansive soil could be produced. By using the procedure described in Section 4 and selecting different values of F_i and calculating corresponding F_s values using equation 4.1, characterisation lines indicate swell percent, swelling pressure, CBR (as soaked or unsoaked) and shear strength values can be produced. Then a chart of characterisation lines indicating swelling and strength relationship with soil initial water content and dry density variations can be plotted.

The experimental results were analysed and used to demonstrate the validity of the developed chart. The result of analysis was plotted in Figure 5.1. Comparison of measured and calculated values in this figure clearly demonstrates validity of the chart produced.

Utilization of developed empirical chart

As the aim of this paper was to improve the current specifications used in design and construction of roads on expansive soils, the empirical chart developed can be of great use in the following areas: pavement design, evaluation and field compaction

control as detailed below. The methods suggested take care of both swelling behaviour and strength characteristics of expansive soils as road subgrade.

Pavement design

The pavement design method developed will be described in the following design steps:-

- 1) The road should be divided into sections, for each section take soil samples to measure the CBR and the swell percent at a surcharge pressure equivalent to an anticipated overburden pressure (i.e. the pressure exerted by the pavement layers above the subgrade). Then the empirical design chart could be produced as described in Section 5.
- 2) The permissible swell percent as specified by the Highway Authorities 1% to 2% depending on the class of the road is determined.
- 3) From the empirical chart the design CBR is determined. The design CBR should be the CBR at an initial state around which the swell percent is 50% less than the permissible swell percent.

Evaluation of pavement

In evaluation of embankment and subgrade material to check performance and strength of the road, the method suggested here as outlined below:-

- 1) The road is divided into different sections depending on expansive soil properties.
- 2) Three soil samples are taken from each section to measure swelling, shear and CBR.
- 3) Characterisation lines chart is performed as described in Section 5.
- 4) The field density and moisture content along each section are measured.
- 5) The density and moisture content data obtained in step (4) are used to determine the swelling, shear strength and CBR from the chart.
- 6) Comparing the determined values of the swelling and strength with the

design values then sections with excessive swelling and low strength will be excluded out.

Compaction control in the field

This method is used for the material quality control of compacted embankment and subgrade. A new method is briefly described below: -

- 1) Three soil samples are taken from the field to the laboratory to determine compaction characteristics such as optimum moisture content and maximum dry density and to measure the swelling and strength of soil samples.
- 2) A chart of dry density versus moisture content showing characterisation lines of both swelling and strength is formed as described in Section 5.
- 3) After field compaction of embankment and/or subgrade, the field density and moisture content of the material are measured.
- 4) A point is drawn in the chart developed in step (2) to indicate the measured field density and moisture content.
- 5) The point indicated in the developed chart in the above step (4), if it is located within the range of design strength and permissible swelling then the compaction is to be accepted otherwise will be rejected.

Conclusions

1. It has been demonstrated that the swelling behaviour of expansive soil compacted over a wide range of water content and different dry densities depends on: soil initial state (water content, dry density and void ratio) and applied surcharge pressure.
2. A study of the strength by the CBR and shear strength measurements of compacted expansive soil at different water contents and dry densities was conducted. It was found that the soil initial state and testing conditions greatly influenced the unsoaked CBR and shear strength. The results of the soaked (saturated) soil samples suggested that the soil soaking state (saturated

moisture content, saturated dry density and amount of swelling during the soaking period) greatly influenced the soaked CBR value.

3. Initial water content, dry density and void ratio were combined in a way reflecting the influence of each of them on swell percent, swelling pressure, unsoaked CBR and shear strength. This combination was termed the initial state Factor (F_i). On the other hand the combination of the saturated water content, saturated dry density and amount of swelling during the soaking period was termed the soaking state Factor (F_s).
4. It has been proved that a direct linear relationship between swell percent, swelling pressure, unsoaked CBR or shear strength and the initial state Factor (F_i). Similarly the relationship between soaked CBR and the soaking state Factor (F_s) was verified to be linear relationship as well. Based on this relationship, design chart of swelling and strength variations with initial water content and dry density were developed. This chart can be applied in design and evaluation of pavement as well as in compaction control in the field.

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