A Laboratory Investigation into the Effect of Water Content on the CBR of a Subgrade soil

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Summary. Residual soils, most of which are lateritic serve as subgrade and even sub-base and base layers for road and highway pavements in the subregion. However, the material is known to undergo substantial strength reduction when they become saturated with water. An understanding of the dependence of the CBR strength of local soils on water content will contribute towards better design and maintenance practices. Samples of soil from a study site were prepared by laboratory compaction at the optimum water content using different levels of compaction to obtain samples at different densities. The remoulded samples were then subjected to different levels of wetting in a water tank and different degrees of drying in the laboratory and the CBR determined. The variation of the CBR with the water content is presented and discussed and related to the matric suction.

Key words: CBR, subgrade, matric suction, water content, remoulded sample, compaction

Introduction

The road pavement structure in many developing countries consists of relatively thin sub-base and base layers made of lateritic gravel with very thin water proofing surfacing, founded on a residual soil subgrade. The residual soils which are the decomposition products of the local geology occur at various degrees of laterization (Charman 1995) and are known to undergo substantial strength loss on soaking (Ampadu 2006).

The most common parameter used to evaluate pavement layer strength is the California Bearing Ratio (CBR). Even though the CBR is not a fundamental soil property, its significance lies in the fact that it is the basis of the CBR Method of Pavement design which is still, by far, the most popular pavement design method used in developing countries. The details of the CBR test are covered in ASTM D 1883-91. The CBR value is influenced by the water content and the dry density as well as the texture of the soil. Normally, the CBR test in the laboratory is conducted on test samples prepared at the dry density and water content likely to be achieved in the field. Whereas the field dry density can be fairly well predicted the difficulty is to determine the stable moisture content at which to conduct the test. The local practice which is also used in many other countries is to use the 4-day soaked CBR. In other countries like the UK the design CBR is the CBR corresponding to the equilibrium water content. Recently, there have been attempts to interpret the results of CBR test in terms of concepts of unsaturated soil mechanics (Sanchez-Leal 2002).

The influence of the moulding water content on the CBR of local lateritic soils has been studied by Hammond (1970) This investigation seeks to contribute further towards a better understanding of the effect of water content on the CBR of local soils. Samples of a subgrade material were prepared by compaction using three different compactive efforts and then subjected to different conditions of drying and wetting. The CBR corresponding to each condition was determined. The soil-water characteristics were also estimated. The results of the CBR variation with the water content for the different dry densities are presented and discussed and modelled in terms of the matric suction.

Methodology

Bulk samples of decomposed granite were obtained from depths of 0.3 m to about 0.6 m in a trial pit. The samples were air-dried for two days and the index properties determined in accordance with BS 1377: Part 2:1990 using the wet sieving method for the grading analysis. The compaction characteristics were also obtained by ASTM D 1557-91 commonly referred to as the Modified AASHTO compaction using 55 blows of the rammer.

Three different test series were conducted. For Test Series 1, using the optimum moisture content (OMC) obtained from the compaction test, eight samples were prepared in the CBR mould by ASTM D 1557-91 except that 5 blows of the rammer per layer were used. After preparation, the first sample, designated "OMC", was covered in a black polythene bag to prevent moisture loss and stored for 24 hours to ensure moisture equilibriation. The next four samples, designated "wetting" were soaked in water for 1, 2, 3 and 4 days respectively while the last batch of three samples, designated "drying" was subjected to various degrees of drying by allowing the samples to dry out for 4, 6 and 8 days respectively. After each period of soaking and of drying, the samples were covered in black polythene bags for 24 hours to prevent further moisture loss and to equilibrate the moisture distribution within the sample. After that each sample was subjected to the CBR test in accordance with ASTM D 1883-91. After each test, the water contents at the top, middle and bottom of the specimen were determined. For Test Series 2 and Test Series 3 the same procedure was repeated except that 20 blows and 55 blows respectively of the rammer per layer were used in preparing the samples.

Discussion of Results

The index properties of the soil used for the investigation are shown in Table 1. In this study gravel is defined as particles larger than 2 mm. The soil used in this study may be described as a sandy clay of medium plasticity.

Table 1. Summary of Index Properties

Gravel (%)	Sand (%)	Silt (%)	Clay (%)	LL	PI	Gs	OMC (%)	MDD (Mg/m^3)
9	28	14	49	49	24	2.65	16.8	1.80

The summaries of results are shown in Tables 2 to 4 for Test Series 1 to 3, respectively. The initial states of the samples for the CBR tests are plotted on the compaction characteristics in Fig. 1. The dry densities refer to the values achieved after sample preparation which means that any effects of volumetric changes arising from drying and from wetting have been neglected. The mean dry densities achieved were 1.355, 1.649 and 1.706 Mg/m^3 with standard deviations of 0.013, 0.047 and 0.028 Mg/m^3 for Test Series 1, 2 and 3 corresponding to 75%, 92% and 95% level of compaction respectively based on the maximum dry density (MDD). The scatter in the dry density values may be due to variations in the moulding water content during compaction. It may be noted that in Test Series 3 the same 55 blows of the rammer achieved only a 95% level of compaction. This observation is consistent with the results of studies (Ampadu 1997) which show that at the optimum moisture content, this material gives lower MDD values when fresh samples are used for compaction than when samples are reused for each test point. The results of the water content distribution across the sample during testing showed that on the average the difference in water content across the sample was less than 6% and for Test Series 2 and 3, drying appeared to produce a more uniformly distributed water content across the sample than wetting. The water content values in the Tables are the average values across the samples.

The variation of the CBR with water content for all three test series are shown in Fig. 2. The similar values of CBR at higher water contents for both Series 2 and Series 3 may be due to similar dry density values. The results show that as the soil dries from the OMC condition, initially there is a rapid increase in CBR but this slows down as the water content reduces further especially for lower density samples. The rate of reduction in the CBR during wetting is relatively slower. In fact the rate of change in CBR per percentage change in water content was 3 to 7 times larger for drying than for wetting from the OMC. The practical implication of this is that there is tremendous benefit in terms of increase in CBR in ensuring that the subgrade is well drained to achieve equilibrium water content below the optimum value. The results also show that on soaking from the OMC condition, the CBR of the

Table 2. Summary of Test Results for Test Series 1

Test Condition	Average Water Content (%)	Dry Density (Mg/m^3)	Degree of Saturation (%)	CBR
Drying	9.56	1.377	27.4	34
	11.73	1.371	33.3	33
	13.37	1.362	37.4	25
OMC	16.58	1.348	45.5	8
Wetting	26.54	1.346	72.6	0.8
	26.81	1.348	73.6	0.6
	27.03	1.354	74.8	0.4
	28.88	1.338	78.0	0.3

Table 3. Summary of Test Results for Test Series 2

Test Condition	Average Water Content (%)	Dry Density (Mg/m^3)	Degree of Saturation (%)	CBR
Drying	10.51	1.622	43.9	95
	12.66	1.579	49.5	79
	13.54	1.643	58.5	52
OMC	16.09	1.595	64.5	28
Wetting	18.30	1.669	82.5	18
	19.35	1.684	89.4	16
	20.22	1.703	96.4	16
	21.26	1.694	99.8	15

Table 4. Summary of Test Results for Test Series 3

Test Condition	Average Water Content (%)	Dry Density (Mg/m^3)	Degree of Saturation (%)	CBR
Drying	12.10	1.697	57.1	94
	13.73	1.674	62.4	79
	14.89	1.670	67.2	59
OMC	16.45	1.743	83.8	28
Wetting	18.22	1.733	91.2	20
	18.30	1.719	89.5	18
	18.59	1.726	92.0	17
	21.63	1.688	100	15

subgrade drops and the relative reduction in CBR is between 46% and 98% for dry densities ranging between 1.71 and 1.36 Mg/m^3.

The logarithm of the CBR is plotted against water content in Fig. 3. The results quoted in Croney and Croney (1998) for soil B showing a linear variation of log CBR with water content over the likely field water content are superimposed. The limited results from this study do not show such a linear

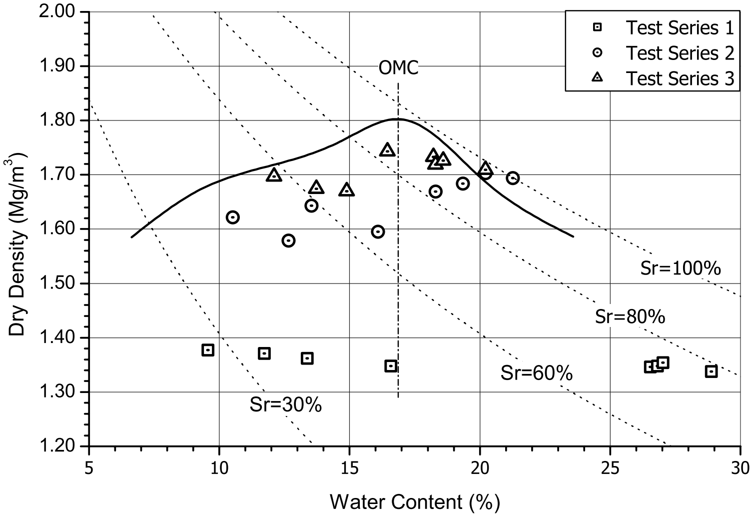

Fig. 1. Compaction characteristics and initial states of test samples

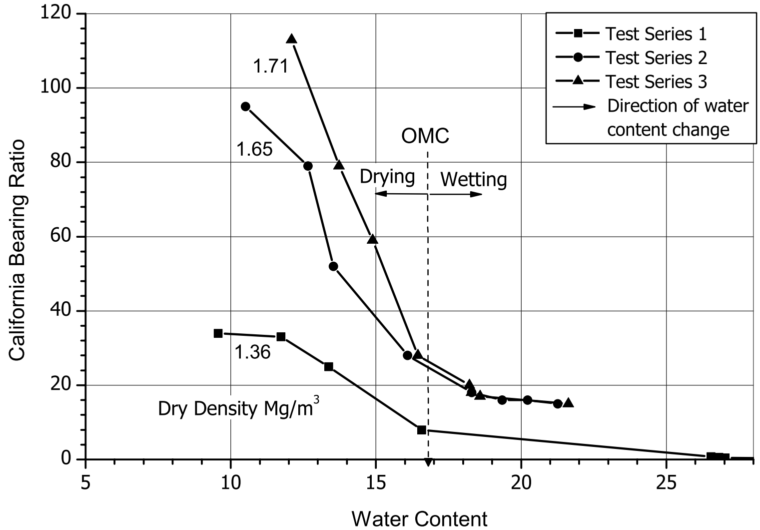

Fig. 2. Variation of CBR with water content for constant dry densities

relationship and suggest that hysteresis effect from wetting or drying may be important in defining the relationship.

The soil-water characteristics of the same material obtained from a parallel test programme using the filter paper method (ASTM D-5298-03) are shown in Fig. 4 for dry densities of 1.79 and 1.51 Mg/m^3. A linear relationship may be assumed within the range of saturation investigated with an average air entry

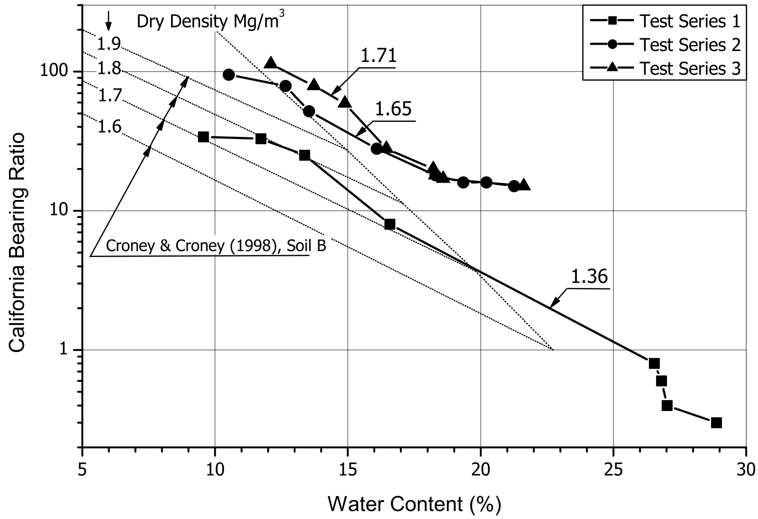

Fig. 3. Variation of log CBR with water content

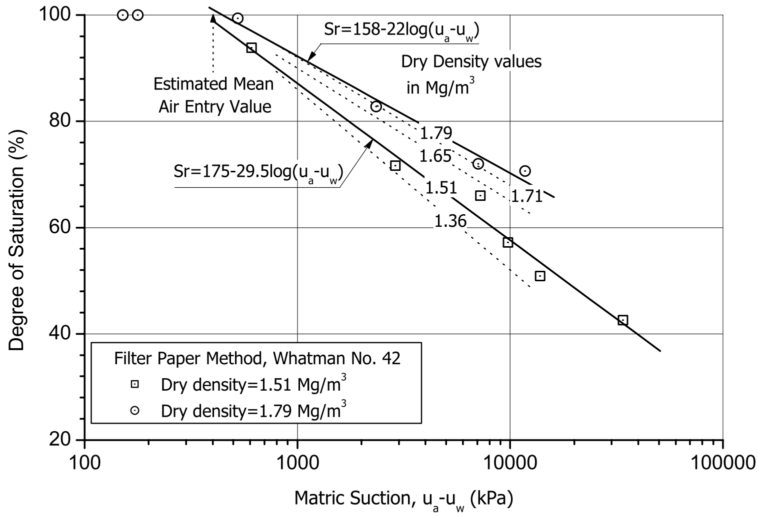

Fig. 4. Soil-Water characteristics for different densities

pressure of about 420 kPa. Based on this and interpolating and extrapolating for dry densities used in this study, the corresponding matric suction values, $(u_a - u_w)$, for all the test points were estimated. These are plotted against the unsaturated CBR, CBR_u on a log-log scale in Fig. 5. The results suggest a linear log-log model which can be expressed as

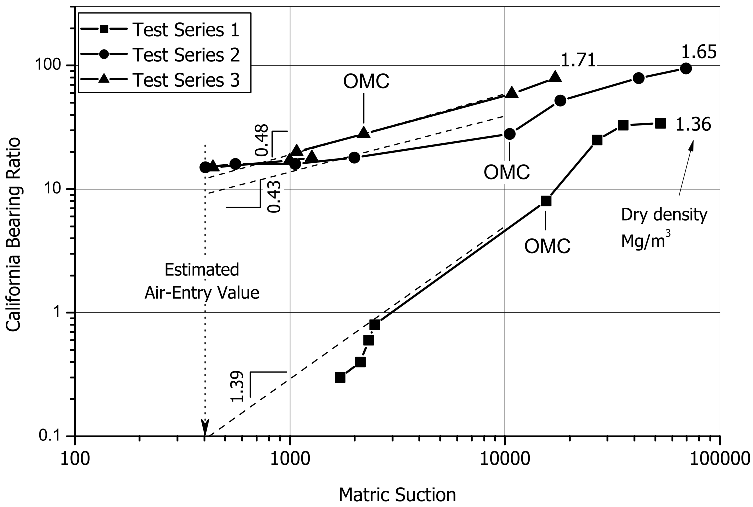

Fig. 5. CBR-matric suction relationship

$$\mathrm{CBR}_u = \mathrm{CBR}_s \times \left(\frac{u_a - u_w}{u_e}\right)^n$$

where CBR_s is the soaked CBR, u_e is the air-entry value and n is a constant which depends on the suction and the dry density.

For this study, n was of the order of 1.4 and about 0.5 for the lower and for the higher dry densities respectively, and constant for suction values up to about 15,000 kPa.

Conclusion

From the laboratory CBR test results on a subgrade material at different water contents for three different dry densities, it may be concluded that the rate of change in CBR per percentage change in water content during drying from the OMC was 3 to 7 times larger than during wetting from OMC. Soaking from the OMC condition, leads to a relative reduction in CBR of between 46% and 98% for dry densities ranging between 1.71 and 1.36 $\mathrm{Mg/m^3}$. A linear log-log relationship between CBR and matric suction is suggested for matric suction values of up to about 15,000 kPa.

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