A COMPARATIVE STUDY OF CALIFORNIA BEARING RATIO AND UNCONFINED COMPRESSION TESTS FOR STABILIZED LATERITE

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ABSTRACT

A laboratory testing programme was carried out to compare the Unconfined Compression Strength (UCS) and the California Bearing Ratio (CBR) test methods for characterising cohesive soils for pavement design and analysis using bitumen stabilized laterite, cement stabilized laterite and lime stabilized laterite. The UCS and CBR specimens were prepared to the mixture optimum moisture content and maximum dry density values following relevant BS standards. Possible linear relationships between UCS and CBR were investigated and a predictive equation estimating CBR from measured UCS values is presented.

1. INTRODUCTION

Some of the factors affecting the design of pavement structures for highways and airports are anticipated traffic, strength of foundation or supporting materials (that is, subgrade) and quality of pavement materials (that is, subbase, base and surface courses). It is therefore a usual procedure to characterize materials used for the various layers of the pavement structure in terms of engineering strength indices that would adequately predict the response of the prototype pavement to external loading and environmental effects. Some of these test parameters are the California Bearing Ratio (CBR), the modulus of subgrade reaction (k), the resistance value (R), etc. Of these the CBR appears to be the most widely used design parameter. This is because of the widespread use of the CBR design procedure in various modified versions for highway and airport flexible pavements.

The CBR deisgn procedures which are entirely empirical are usually preceded by laboratory CBR tests. Although the CBR test procedure which is agelong in use is relatively simple, there are certain shortcomings, especially when compared to other tests considered appropriate for estimating the strength parameters of cohesive materials. One such test is the Unconfined Compression Strength (UCS) test.

The objective of the study reported in this Paper is to compare the CBR and the UCS tests for characterising cohesive soils. Although a field performance evaluation is considered essential, the comparison is based on the results of a laboratory testing programme using both tests on identical sets of mixture. Because of the advantages of theoretical development and economy of the UCS test over the CBR test, a strong correlation between the two tests may suggest a possible substitution of the UCS test for the CBR test for characterising cohesive soils for pavement design and analysis.

2. THE CBR AND THE UCS TESTS

2.1 The UCS Test

The unconfined compression test is a special case of the triaxial compression test. Thus, it has a theorectical basis and can be used to measure the unconfined compression strength of cohesive soils. It can also be used to estimate the approximate ultimate shear strength, the angle of internal friction, the cohesion and, perhaps, the modulus of elasticity of soils. The test has also been used to measure the sensitivity of clays. Detailed description of the test, its theory and applications are readily available in standard books on soil mechanics.

2.2 The CBR Test

On the other hand, the CBR test is a purely empirical test which measures the resistance to penetration of a suitably compacted soil (1). The development of the test, detailed description and applications are also readily available in the literature.

2.3 Comparison of CBR and UCS Tests

Both the CBR and UCS tests have been widely used in characterising soils. Both tests enjoy the advantages of simplicity and availability for routine testing and analysis of soils. However

in relation to characterising cohesive soils for pavement design and analysis, the UCS test can be seen to possess some merits over the CBR test. These include:

(a) Theoretical development - the UCS is based on well developed theory while the CBR is mainly empirical in nature.

(b) Economy - the CBR test is more expensive with respect to

(i) materials used: the size of the CBR specimen (152mm diameter by 127mm high) is about eleven times the size of the UCS specimen (51mm diameter by 102mm high);

(ii) time of preparing specimens and testing:

about four times longer to prepare CBR specimen and four times longer to test a CBR specimen;

(iii) compactive energy per volume: much higher for CBR;

(iv) availability of moulds/turnover of specimens in moulds: higher for UCS;

(v) number of specimens for statistical analysis: easier to obtain adequate number for UCS;

(vi) uniformity of test results: this is believed to be suspect for CBR test with certain types of soils such as clayey gravels and clean sands. However, results of this study (as will be later presented) did not indicate any significant difference in the uniformity of results from the two tests for stabilized laterite.

Nevertheless, because of the several advantages of the UCS test over the CBR test as stated above, a strong correlation between the two tests may suggest the need to replace the CBR test with the UCS test for characterising cohesive soils for pavement design and analysis. One obvious limitation of the UCS test, however, is the uniaxial state of stress applications which is different from the actual loading condition of pavement materials in the field.

3. EXPERIMENTAL PROGRAMME

3.1 Experimental Design

The basic experiment design was a factorial design considering two test types (CBR and UCS), three mixture types (bitumen stabilized laterite, cement stabilized laterite and lime stabilized laterite), four stabilizer contents for bitumen - and cement stabilized laterite (1,2,3, & 4 % by weight of laterite), five stabilizer contents for lime stabilized laterite (2,4,6,8 & 10% by wieght of laterite) and two test conditions (soaked and unsoaked). Three specimens were tested for each of the treatment combinations.

The factors selected and their levels were based on experience from past studies and practical field conditions. All tests were performed at room temperature of approximately 28°C which was reasonably maintained throughout the tests.

3.2 Materials

Laterite: The laterite used was obtained from an existing borrow pit at Ojota in the Lagos metropolis. The laterite is of clayey sand type and reddish to dark brown in colour with properties as indicated in Table 1. The sieve analysis of the sample shows that the particle size distribution curve is within the Asphalt Institute specifications for hot-mix sand asphalt base course (Fig. 1).

Bitumen: The bitumen used was an MC-3000 cutback bitumen produced at the Kaduna refinery (Table 2). As was noted, the bitumen appears to be out of specification on flash point and barely satisfactory with respect of distillation (2).

Cement: The cement was a type I portland cement produced at Ewekoro Cement Factory by the West African Portland Cement Company (WAPCO). Typical test results on bagged cement samples obtained from WAPCO are contained in Table 3.

Lime: The lime was hydrated lime purchased locally from the market. Typical test results of the lime are shown in Table 4.

3.3 Mixtures

Prior to UCS and CBR tests, the dry density-moisture content relationships for mixtures containing various proportions of stabilizers (bitumen, cement and lime) were determined by performing the compaction test. For the particular materials in this study, the British Standard Compaction procedure was adopted and this was consistent with recommendations by the Federal Ministry of Works and Housing (3). The preparation and testing of specimens were in accordance with BS 1377: 1975 (for laterite) (4) and BS 1924: 1975 (for stabilized laterite) (5) specifications. Compaction test results are presented in Table 5.

Values of maximum dry density ranged between 1634 and 1755 kg/m^3. Although these values are generally low, they were reasonably comparable to in-situ values obtained by the core cutter method on subgrades of similar materials on some roads in Metropolitan Lagos (6).

Table 1: **CHARACTERISTICS OF THE LATERITE**

Property	Value
Specific gravity	2.68
Liquid limit, %	49
Plastic limit, %	21
Plasticity index, %	28
Shrinkage limit, %	11.3
Group index	0
Cohesion, kN/m^2	48
Angle of internal friction, degrees	12.5

Table 2: **PROPERTIES OF CUTBACK BITUMEN**

Property	Value
Penetration at 25°C, 100g, 5 sec, in 0.1mm	140*
Kinematic Viscocity at 25°C, stokes	3300
Softening point (R&B), °C	35*
Specific gravity at 25°C	0.96
Flash point (Cleveland Open Cup), °C Distillate	50
at 360°C (Volume), %	16
Solubility in CS_2, % wt.	99*

* Test performed on residue after distillation.

Table 3: **PROPERTIES OF PORTLAND CEMENT**

Property	Value
Physical	
Specific gravity	3.15
Specific surface area, m^2/kg	320
Fraction + 90 μm, %	10
Compressive strength (100mm cube), MN/m^2	
3 days	0.9
7 days	24
28 days	34
Initial set, min	180
Final set, min	215
Expansion, mm	2
Chemical	
Loss on ignition, %	1.4
SO_3, %	1.4
Free lime, %	2.5

Table 4: **PROPERTIES OF LIME**

Property	Value
Physical	
Specific gravity	2.39
Amount passing 53 μm sieve, %	99.3
Linear shrinkage, %	3.2
Free swell (24 hrs), %	11.1
Absorbed moisture content, %	0.57
Chemical	
pH	10.20
Alkalinity, mg/1	370
Calcium hardness, mg/1	620

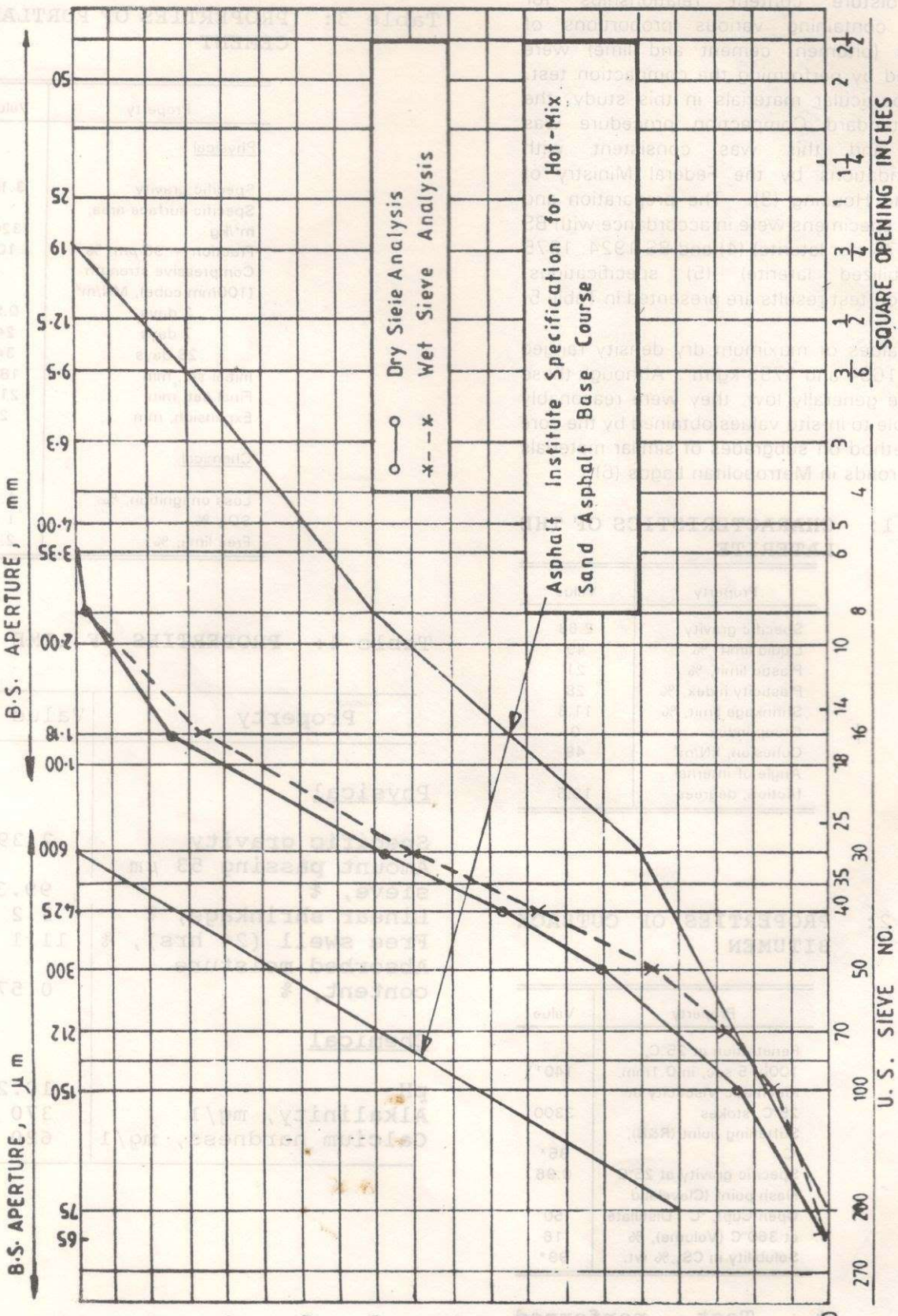


Fig. 1 Particle Size Distribution of Ojota Laterite

TABLE 5: COMPACTION TEST RESULTS

Mixture	Stabilizer content, % by wt.	Maximum Dry Density		Optimum Moisture Content	
		Mean*, kg/m³	CV, %	Mean*, %	CV, %
Laterite	0	1755	0.70	17.5	0.93
Laterite-Bitumen	1	1712	0.74	17.0	2.54
	2	1690	1.28	16.6	1.30
	3	1654	0.75	16.0	1.35
	4	1637	1.62	15.7	1.38
Laterite-Cement	1	1738	0.76	17.6	0.80
	2	1721	3.09	18.2	1.19
	3	1718	2.09	18.4	0.77
	4	1705	2.98	19.5	1.83
Laterite-Lime	2	1717	1.72	18.1	1.19
	4	1683	3.00	18.4	2.22
	6	1672	2.35	19.6	2.20
	8	1662	1.31	20.5	1.83
	10	1634	1.48	21.2	0.77

*Average for 3 Specimens

TABLE 6: AVERAGE BULK DENSITY VALUES

Mixture	Stabilizer content, % by wt.	UCS test specimens				CBR test specimens			
		Unsoaked		Soaked		Unsoaked		Soaked	
		Mean*, kg/m³	CV, %	Mean*, kg/m³	CV, %	Mean*, kg/m³	CV, %	Mean*, kg/m³	CV, %
Laterite	0	2058	0.27	2098	0	2061	0.10	2075	0.17
Laterite-Bitumen	1	2015	0.14	2129	0.23	2020	0.10	2050	0.10
	2	1998	0.17	2122	0.49	2001	0.24	2040	0.08
	3	1969	0.15	2052	0.27	1967	0.06	2004	0.06
	4	1956	0	2058	0	1956	0.16	1985	0.10
Laterite-Cement	1	2019	0.38	2093	0	2044	0.10	2069	0.06
	2	2008	0.75	2090	0.14	2029	0.23	2050	0.10
	3	2002	0	2083	0.24	2032	0.15	2052	0.12
	4	1997	1.12	2072	0	2036	0.11	2048	0.10
Laterite-Lime	2	2024	0.14	2080	0.14	2027	0.09	2032	0.06
	4	1984	0.15	2080	0.28	1990	0.13	1997	0.15
	6	1995	0.32	2076	0.14	1996	0.10	2013	0.22
	8	1993	1.14	2070	0.14	2001	0.09	2017	0.06
	10	1973	1.15	2061	0.14	1980	0.06	1995	0.15

*Average for 3 Specimens

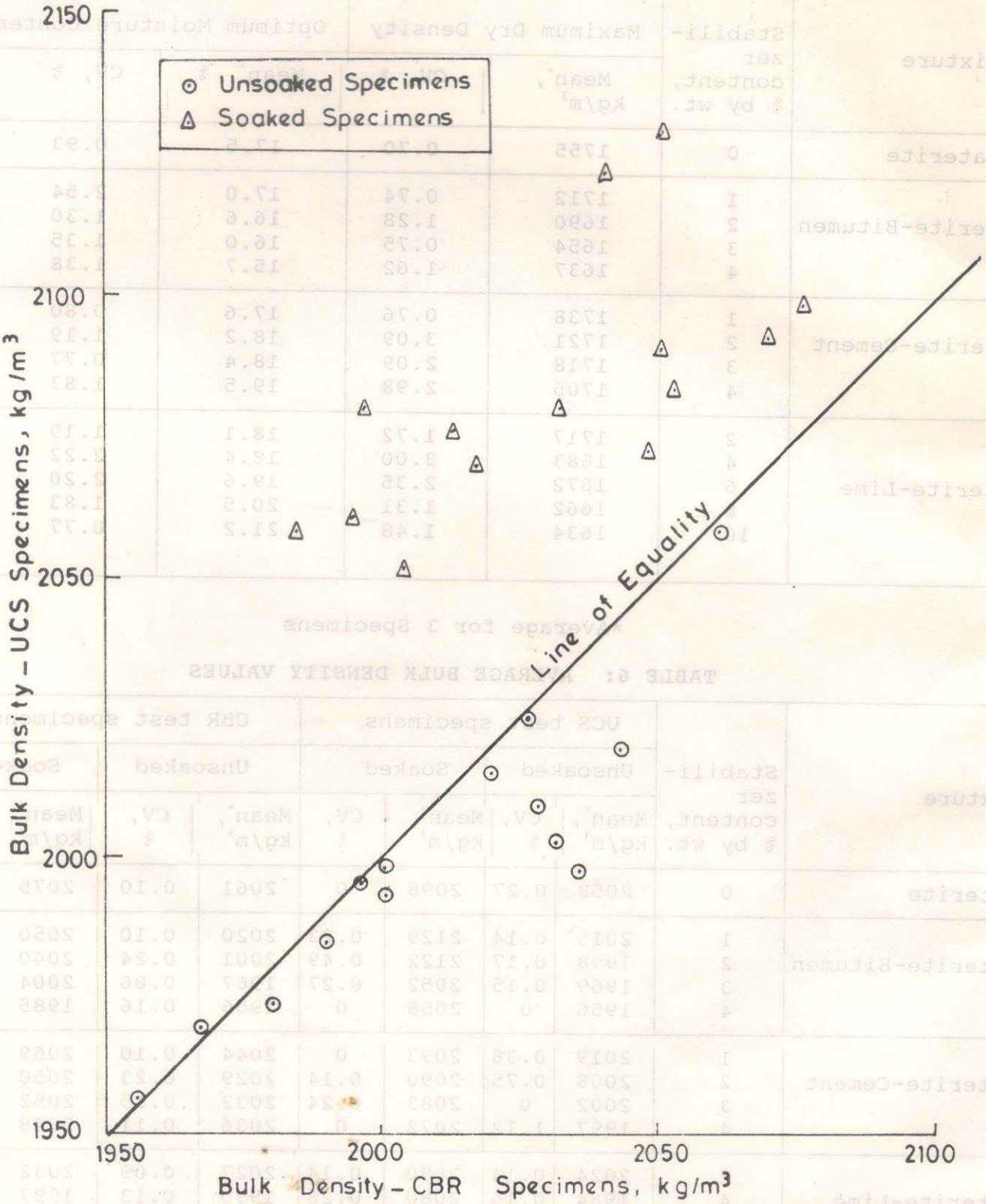


FIG. 2: Bulk Density Values for UCS and CBR Specimens

TABLE 8: UCS AND CBR TEST RESULTS

Mixture	Stabilizer content, % by wt.	UCS				CBR			
		Unsoaked		Soaked		Unsoaked		Soaked	
		Mean*, kN/m²	CV, %	Mean*, kN/m²	CV, %	Mean*, %	CV, %	Mean*, %	CV, %
Laterite	0	188.4	8.84	32.2	5.56	10.7	10.83	7.0	14.29
Laterite-Bitumen	1	312.6	4.24	15.7	44.42	20.0	5.00	13.7	11.18
	2	349.4	2.58	23.3	14.18	22.7	6.74	17.0	10.19
	3	190.6	2.23	17.8	10.04	21.0	12.60	10.7	19.52
	4	101.0	11.62	9.0	23.09	17.7	11.78	9.3	16.37
Laterite-Cement	1	298.2	9.50	56.6	11.66	26.7	7.81	19.0	5.26
	2	404.8	10.20	159.6	4.17	62.3	4.04	39.0	6.78
	3	897.1	3.24	550.1	3.04	96.0	1.04	83.7	3.01
	4	1472.7	1.06	632.1	3.82	197.7	1.27	197.0	1.05
Laterite-Lime	2	267.3	13.77	74.4	2.40	47.0	2.13	31.0	6.45
	4	836.2	1.65	450.2	5.17	156.3	0.98	123.0	1.63
	6	1683.5	1.42	922.8	6.50	173.7	0.88	132.3	1.15
	8	1446.0	0.95	783.0	1.33	164.7	1.75	120.7	1.27
	10	1162.3	3.51	768.6	1.91	157.0	1.27	111.3	2.89

TABLE 9: EFFECT OF MOISTURE ON UCS AND CBR

Mixture	Stabilizer Content %	Reduction Factor	
		UCS	CBR
Laterite	0	0.17	0.65
Laterite-Bitumen	1	0.05	0.69
	2	0.07	0.75
	3	0.09	0.51
	4	0.09	0.53
Laterite-Cement	1	0.19	0.71
	2	0.39	0.63
	3	0.61	0.87
	4	0.43	0.97
Laterite-Lime	2	0.28	0.66
	4	0.54	0.79
	6	0.55	0.76
	8	0.54	0.73
	10	0.66	0.71

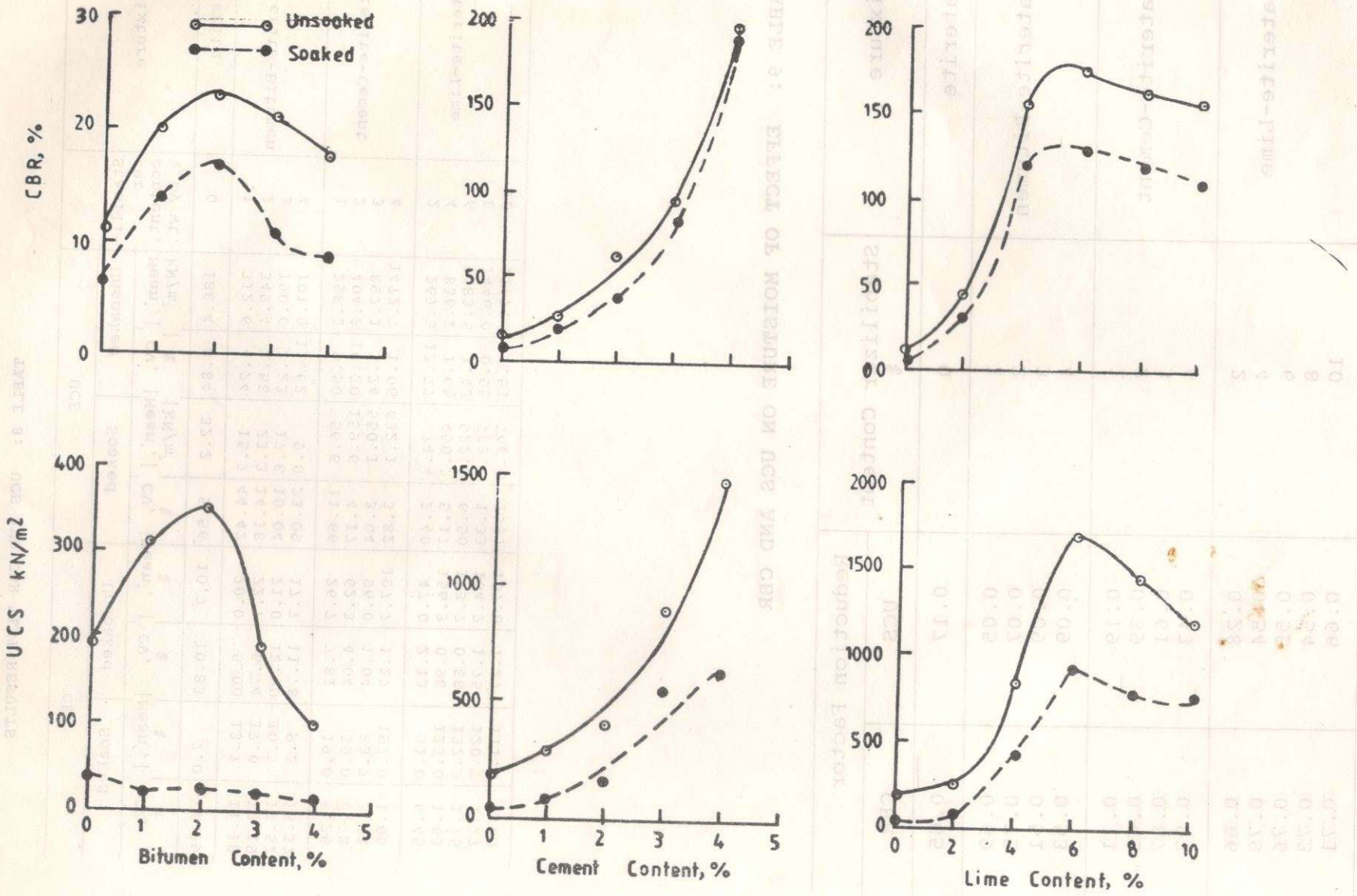


FIG. 3: UCS and CBR Test Results

TABLE 7: THREE-FACTOR EXPERIMENTS: ANALYSIS OF VARIANCE FOR BULK DENSITY*

Source of Variation**	Laterite-Bitumen			Laterite-Cement			Laterite-Lime		
	Degree of freedom	Computed f	Tabulated f (α=0.05)	Degree of freedom	Computed f	Tabulated f (α=0.05)	Degree of freedom	Computed f	Tabulated f (α=0.05)
Main effects									
A	4	1078.19	2.61	4	52.92	2.61	5	760.46	2.42
B	1	3878.59	4.08	1	659.14	4.08	1	3277.93	4.05
C	1	908.19	4.08	1	1.86	4.08	1	1158.54	4.05
Two-factor interactions									
AB	4	88.13	2.61	4	6.78	2.61	5	36.37	2.42
AC	4	31.65	2.61	4	3.54	2.61	5	28.65	2.42
BC	1	1022.23	4.08	1	225.40	4.08	1	1633.96	4.05
Three-factor interactions									
ABC	4	34.83	2.61	4	4.11	2.61	5	32.28	2.4
Error	40			40			48		
Total	59			59			71		

*This is a 3-factor design with 3 replicates for each of the treatment combinations.

**A: Stabilizer content, % (0, 1, 2, 3, 4, for laterite-bitumen and laterite-cement, 0, 2, 4, 6, 8, 10 for laterite-lime)

B: Specimen condition (unsoaked, soaked)

C: Test type (UCS, CBR).

TABLE 10: SUMMARY OF RELATIONSHIPS EQUATION: CBR = A + B (UCS)

Mixture	Number of Points	A	B	Correlation Coefficient R	Test of Significance*	
					Calculated Z Statistic	Linear Relationships at $\alpha = 0.50$?
Laterite-Bitumen, unsoaked	5	13.1047	0.0233	0.5034	0.78	No
Laterite-Bitumen, soaked	5	12.8436	-0.0665	-0.1485	-0.21	No
Laterite-Cement, unsoaked	5	-10.9116	0.1374	0.9853	3.47	Yes
Laterite-Cement, soaked	6	-0.4563	0.2390	0.9084	2.15	Yes
Laterite-Lime, unsoaked	6	20.4508	0.1051	0.9158	2.71	Yes
Laterite-Lime, soaked	6	23.3304	0.1291	0.9146	2.69	Yes
All Mixtures, unsoaked	14	0.4403	0.1215	0.9510	6.11	Yes
All Mixtures, soaked	14	14.6247	0.1566	0.8939	4.78	Yes
All Mixtures, soaked and unsoaked	28	13.9947	0.1198	0.8939	7.32	Yes

*Tabulated Z statistic at $\alpha = 0.05$ ($Z_{0.025}$) = 1.96

3.4 Specimens

Preparation: Samples and specimens were prepared in accordance with BS 1377: 1975 and BS 1924: 1975. Prior to preparing the specimens, the laterite material was oven-dried and broken down to smaller fragments, care being taken not to reduce the size of the individual particles. The samples were then kept in sacks for moisturization. The required amount of water was incorporated into the laterite by mixing with hand, care being take to minimize loss of moisture. The moist soil was then stored in a polythene bag for about 24 hours to attain equilibrium. The required quantity of stabilizer was later added to the soil and mixed thoroughly by hand.

Specimens for the UCS tests were prepared according to BS 1377: 1975 and BS 1924: 1975. Efforts were made to prepare the specimens to the maximum dry density and optimum moisture content values of the respective mixtures.

For the CBR tests, all specimens were prepared according to BS 1377: 1975 using static compaction method. This method was chosen because it is similar to that used for the UCS test. Efforts were also made to prepare the specimens to the respective maximum density and optimum moisture content values of the mixtures.

Characteristics: All UCS test specimens were nominally 51mm in diameter and 102mm high generally. For the CBR test, specimens were nominally 152mm in diameter and 127mm high. The bulk density values of UCS and CBR specimens are presented in Table 6.

A comparison of the bulk desity values of the UCS specimens with the corresponding values of the CBR specimens for similar mixtures is shown in Fig. 2. It is apparent from Fig. 2 that for unsoaked condition, CBR specimens were generally denser than UCS specimens whereas when soaked, UCS specimens were denser than CBR specimens. An analysis of variance based on a three-factor design with three replicates for each of the treatment combination indicated that for cement stabilized laterite, there were no significant differences at the 5 per cent level although the effects of stabilizer content and specimen condition (soaked/unsoaked) were generally more significant (Table 7). It can also be observed that for all the mixtures, the effects of the main factors as well as their 2-factor and even 3-factor interactions on bulk density were generally significant at the 5 per cent level.

Curing: All specimens were cured for 7 days at constant moisture content and at room temperature (about 28°C) after which half of them were subjected to 24 hours soaking in water in order to evaluate the possible influence of moisture on the mixtures. For the UCS test, specimens were stored in polytene bags to prevent drying during the curing period. For the CBR specimens, curing was ensured by fixing the end caps of the moulds and sealing them with petroleum jelly.

The amount of moisture absorbed was evaluated by weighing all specimens before and after soaking and then specimens were allowed to drain for about 15 minutes before testing.

3.5 Testing

Equipment: The Wykeham Farrance compression machine was used for the CBR and UCS tests. A spirit level was employed to ensure that the plunger penetrated the specimens at right angle.

CBR Test: The CBR test was performed following standard procedure (4). The specimen was placed on the lower platen of the testing machine and the plunger was seated under a force of 50N to prevent impact loading and to ensure that the plunger firmly rests on the specimen.

UCS Test: The UCS test was performed following standard procedure (4,5). The specimen was placed centrally on the lower platen of the compression machine taking care to avoid damaging the specimen.

For both the CBR and UCS, all tests were performed at room temperature (about 28°C) which was reasonably maintained throughout the tests.

4. TEST RESULTS

4.1 UCS Test

Average UCS values ranged between 101 and 1684kN/m^2 for unsoaked specimens, and between 9 and 923kN/m^2 for soaked specimens (Table 8). Values are lowest for bitumen stabilized laterite and highest for lime stabilized laterite. The coefficient of variation, defined as the ratio of the standard deviation to the mean value CV, ranged between 1% and 14% for unsoaked specimens, and between 1% and 44% for soaked specimens.

The variation of UCS with bitumen, cement and lime contents are shown in Fig.3. There appears to be an optimum stabilizer content for maximum UCS except for cement stabilizer laterite where the UCS increases continuously with increasing cement content probably because of the cement-water reaction. For lime stabilized laterite the optimum lime content of 6% is consistent with that obtained in a previous study (7) but higher than the 4% obtained by Jackson (80.

Values of UCS were much lower than earlier values presented by Obaji for the same lime stabilized laterite compacted to the same range of densities and cured for 7 days (7). Whereas the maximum UCS for lime stabilized laterite in this study was 1684kN/m^2 (at 6% lime content), five out of the six average values presented by Obaji were higher than 2590kN/m^2, the maximum being 4510kN/m^2 (at 6% lime content).

The UCS of the soaked specimens show that water has a serious damaging effect, particularly on bitumen stabilized laterite. Table 9 shows reduction factor values, defined as the ratio of the average UCS for soaked specimens to the corresponding values for unsoaked specimens. The factors ranged between 0.1 and 0.7, with bitumen stabilized laterite having the lowest values.

Bituminous stabilization is generally used for non-cohesive granular materials where the bitumen adds cohesive strength, and sometimes for cohesive materials (such as the laterite used in this study) where the bitumen "water-proofs" the soil thus reducing loss of strength. However, because of the small size of the specimens and the low level of bitumen content, the soaking was probably too severe and the water-proofing ability of the bitumen was not appreciably developed.

4.2 CBR Test

Average CBR values ranged from 1% to 198% for unsoaked specimens, and from 7% to 191% for soaked specimens (Table 8). As was observed for UCS, CBR values are lowest for bitumen stabilized laterite and generally highest for lime stabilized laterite. The CV values are also in the same order of magnitude as for UCS. The CBR values indicate that both the cement stabilized laterite and lime stabilized laterite are excellent base course materials for highway pavements (4).

The relationships between CBR and stabilizer contents are illustrated in Fig. 3. Again there appears to be an optimum stabilizer content for maximum CBR except for cement stabilized laterite which has continuous increase in CBR with increasing cement content for reasons similr to that advanced for UCS.

The damaging effect of water is most pronounced in the case of bitumen stabilized laterite (Table 9). However, this is not as severe as in the case of UCS due to the larger size of CBR specimens and therefore smaller percentage of water absorbed. It should be noted too that water entered into the CBR specimens through perforations on the top and bottom plates whereas the UCS specimens were completely immersed in water.

4.3 Correlation between UCS and CBR

Attempts were made to establish possible correlations between CBR and UCS using least squares regression analysis. The results (Table 10) indicated strong correlations between CBR and UCS for each of the mixtures except the bitumen stabilized laterite. Infact an analysis combining results for all the mixture also indicated a strong correlation between UCS and CBR. A test of significance analysis confirmed linear relationships between UCS and CBR at the 5 per cent level of significance (Table 10).

4.4 Predictive Equation

From the above correlations, it would appear that appropriate values of CBR can be estimated from measured values of UCS using the following relationship:

$$CBR = 13.9947 + 0.1198 (UCS)$$

where

CBR = California Bearing Ratio, % and

UCS = Unconfined Compression Strength, kN/m^2.

The scatter diagram for the relationship between CBR and UCS, together with the 95 per cent confidence interval for prediction, is illustrated in Fig. 4. It can be observed that the relationship obtained above can not predict CBR values less than 14%.

In a rather limited study for lime stabilized laterite (unsoaked specimens), Obaji (7) obtained the following relationship between UCS and CBR:

$$CBR = 52.5142 + 0.0285 (UCS)$$

Fig. 5 shows the relative positions of the regression lines from this study and that earlier obtained by Obaji. Obaji's regression line is definitely flatter. The apparent differences in the regression lines may be due to the rather high UCS values obtained by Obaji as earlier observed in this paper.

5. CONCLUSIONS

On the basis of the limited tests in the study reported in this paper, it is concluded that strong relationships exist between CBR and UCS of stabilized laterite. However, further work is required in the range of higher UCS values in order to perfect the relationship between CBR and UCS. Besides, the state of uniaxial stress in the UCS test which does not resemble the actual field conditions must be recognised.

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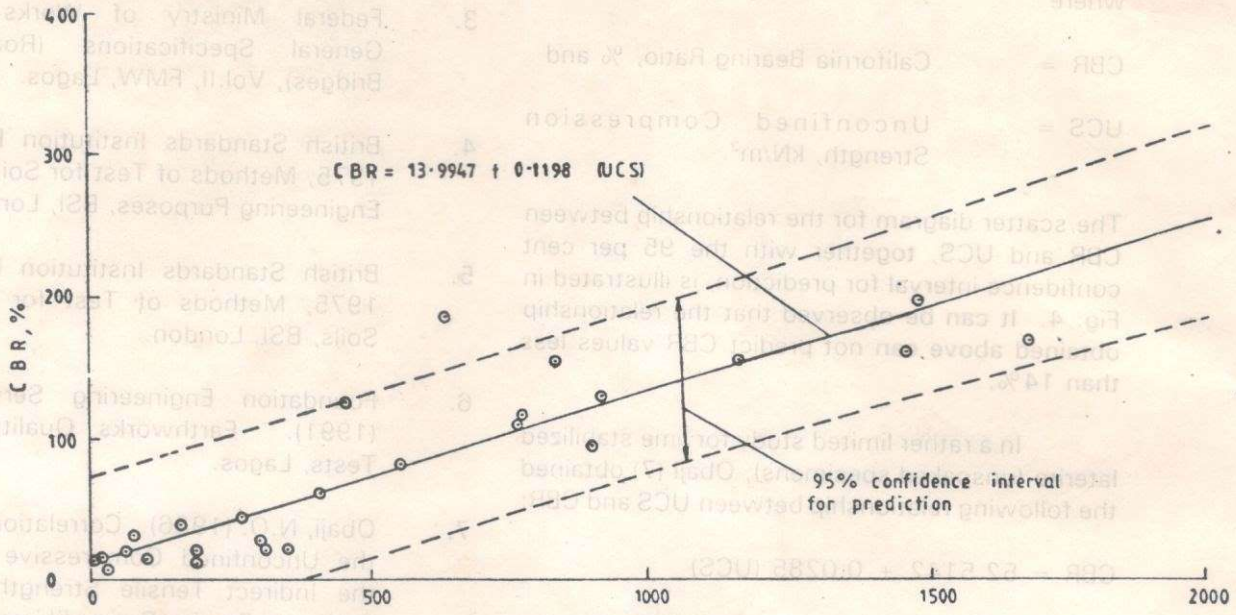


FIG. 4: Relationships between CBR and UCS

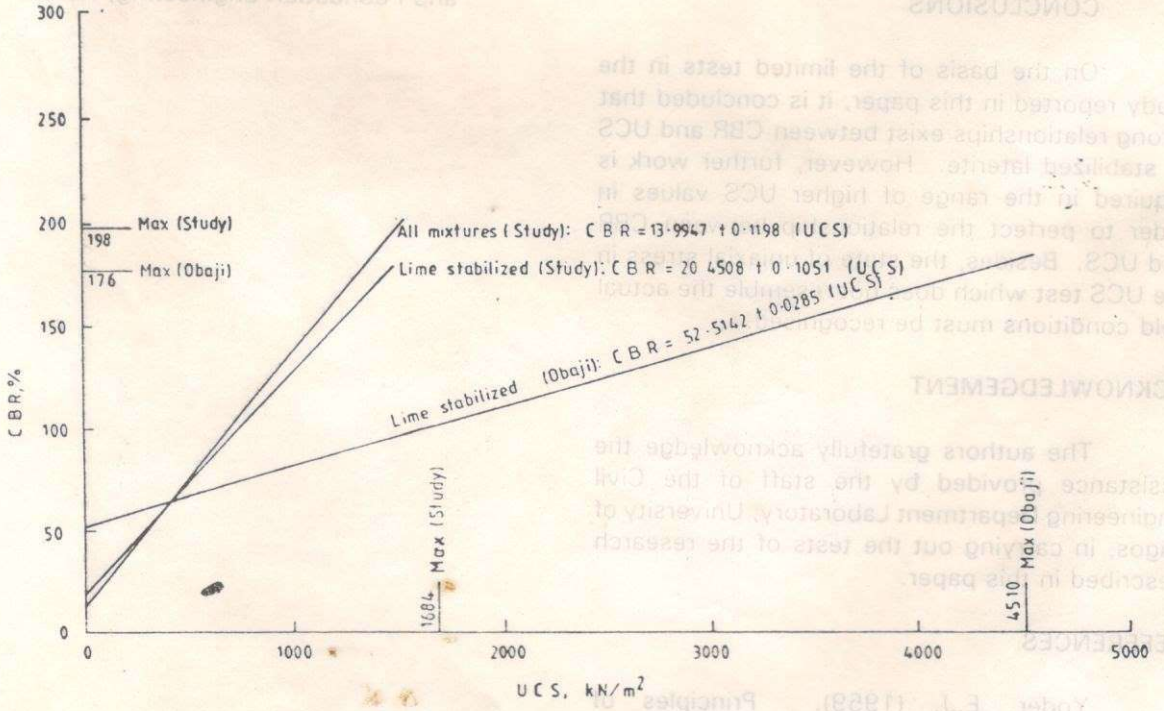


FIG. 5: Comparison of Regression Lines