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Some Geotechnical Properties of Selected Sub-Base Materials for Road Construction

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Abstract
This article presents a laboratory investigation on selected soil samples in relation to their use as road construction material. Soil samples were collected from three different locations and their index, compaction properties (Optimum Moisture Content, OMC and Maximum Dry Density, MDD) were determined. Derived parameters such as activity ratio, grading modulus, plasticity product, plasticity modulus and shrinkage modulus were also determined. The California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS) and the undrained shear strength (S_u) of each soil sample were determined. Models relating each of MDD and S_u to the OMC were developed. The results showed that the rating of the samples as sub-base material is fair to poor based on CBR values that range from 5 to 12% and S_u values that range from 29 to 51 kN/m^2. The derived parameters also showed that the soil samples are poor construction materials with one having marginal properties. The models developed showed good correlation between both MDD and S_u and OMC based on a correlation coefficient (R^2) of 0.934 and 1.000, respectively.
Keywords: California Bearing Ratio, Correlation, Derived Parameters, Lateritic Soil, Road Construction,

1. Introduction

The importance of proper geotechnical investigation of soil to be used for road work cannot be overemphasised. Lateritic soil is the most common road construction material in the tropics. They occur as a result of intense weathering occurring under tropical and subtropical conditions and they are rich in secondary oxides of iron, aluminium or both (Attoh-Okine, 2004). Studies have been carried out to ascertain the suitability of lateritic soil as road material in Nigeria (Ogunsanwo, 1990; Ayetey and Frempong, 1996; Adeyemi and Wahab, 2008); most of these researches have concluded that with proper investigation lateritic soils are invaluable construction material. There are general requirements presented by the Federal Republic of Nigeria Highway Manual (1992) for lateritic soil to be suitable as a road construction material. These requirements are as presented in Table 1.

Some important geotechnical properties usually investigated before construction are paricle size distribution; plasticity properties which include liquid limit (LL), plastic limit (PL) and plasticity index (PI); compaction properties (also moisture density relations) which include Maximum Dry Density (MDD) and Optimum Moisture Content (OMC); undrained shear strength (S_u) and California Bearing Ratio (CBR). The particle size distribution (PSD) gives an indication of the various particle sizes (i.e clay, silt, sand and gravel) present in the whole soil sample. The plasticity of soil gives an indication of its sensitivity to water and a possibility of the type of clay mineral present in the soil (Das, 2006). The plasticity of the soil sample is also affected by the amount of fines (i.e clay and silt) present in the soil which in turn affect how the soil will perform when used as construction material (Ayodele et al., 2009). Both the PSD and the plasticity characteristic are used for soil classification. Some parameters are derived from both the PSD and plasticity characteristics of soil to further evaluate the performance of the soil. Derived parameters such as Group index (GI) are obtained from both the PSD and the plasticity to further evaluate the quality of the soil sample as subgrade material. Derived parameters obtained based on the plasticity such as plasticity modulus and plasticity product represent the effective contribution of the plasticity of the fines to the performance of the whole soil sample, which depends on the proportion of fines (Nwaiwu et al., 2006)

The moisture density relationship (MDD and OMC) are usually determined in the laboratory to simulate field conditions. The obtained OMC are used to compact soil from which the laboratory CBR and S_u are obtained. The CBR value has been the most important parameter that engineers used to assess the suitability of soil for road pavement. Materials with high CBR are generally considered superior materials for pavement construction (Madu, 1977; Gidigasu, 1982). The S_u gives an indication of the resistance of soil to loading. Some researchers such as Sridharan and Nagaraj (2004); Ayodele et al. (2009) have developed correlations between the index properties (which are relatively easier to determine) and the geotechnical properties. These correlations can help in determining some geotechnical properties which require more effort, time and other resources to determine for preliminary analysis.

The objectives of this paper are to: present data on the index properties and derived parameters of some soil samples which have being used as borrow materials for road construction; give a description of the compaction, S_u and CBR of the soil samples as sub-base construction material and to determine some correlation between the OMC, MDD, CBR and S_u of the soil samples.

2. Materials and Method

Soil samples were collected from three selected locations in Table 2. ER1 and ER2 are Gneiss derived while MR is Amphibolite derived according to Ige et al. (2005). The soil samples were classified using the results from index tests such as natural moisture content (w), specific gravity (G), sieve analysis, hydrometer analysis (of particles passing sieve No. 200), atterberg limits (plastic and liquid limit) of particles passing sieve size 425 µm. Derived parameters including Plasticity index (Eq. 1), Activity Ratio (Eq. 2), Grading modulus (Eq. 3), Plasticity modulus (Eq. 4) and plasticity product (Eq. 5) were determined. Eq. 3 was determined according to TRRL (1990), while Eqs. 4 and 5 were determined according to CIRIA 1988.

$$PI = LL - PL \quad (1)$$

$$A = \frac{PI}{\%\ \text{of clay fraction}} \quad (2)$$

$$\text{Grading modulus} = 300 - \frac{\% < 2\ \text{mm} + \% < 0.425\ \text{mm} + \% < 0.075\ \text{mm}}{100} \quad (3)$$

$$\text{Plasticity modulus} = PI \times \%\ \text{passing}\ 0.425\ \text{mm} \quad (4)$$

$$\text{plasticity product} = PI \times \%\ \text{passing}\ 0.075\ \text{mm} \quad (5)$$

The Group indices were determined using either Eq. 6 or 7.

$$GI = 0.01(F_{200}-15)(PI-10) \quad (6)$$

$$GI = (F_{200} - 35)[0.2+0.005(LL-40)] + 0.01(F_{200} - 15)(PI - 10) \quad (7)$$

Where F_{200} is the percentage of particles passing sieve No. 200.

The optimum moisture content (OMC) and maximum dry density (MDD) were determined using standard proctor compaction method, California Bearing Ratio (CBR), Unconfined Compression Strength (UCS) of the soil samples were determined in the laboratory using standard methods as stated in literature (AASHTO, 1986). The Undrained shear strengths (S_u) of the soil samples were determined from Equation 8.

$$S_u = \frac{UCS}{2} \quad (8)$$

The soil sample with the lowest fines content was also mixed with the soil sample with the highest content in varying ratios starting from 1:9 and 4:6 in 10% increments and compacted using West Africa laboratory compaction method. The obtained OMC for both the natural soil and the mixed soils were correlated with the MDD, S_u and CBR using linear regression analysis. The MDD was also correlated with the S_u and CBR. The validity of the models developed from the correlations was verified by the coefficient of determination (R^2), which compares estimated and actual y-values, and ranges in value from 0 to 1. If it is 1, there is a perfect correlation in the sample i.e. there is no difference between the estimated y-value and the actual y-value. The closer the R^2 to 1, the better the representations of the relationship between the x-value and the y-value of the models developed.

3. Results and Discussion

The results from this study are presented in the following subheadings: index properties, moisture density relations, correlations of undrained shear strength and California bearing ratio with compaction properties.

3.1 Index Properties

3.1.1 Preliminary Analysis of soil samples

The results of the preliminary analysis of the soil samples are presented in Table 3. The specific gravities of the soil samples range from 2.6 to 2.88. According to Indraratna and Nutalaya (1991), the specific gravity of lateritic soil falls within a wide range of 2.5 and 3.6. Mahalinger-Iyer and Williams (1985) obtained specific gravity of 2.76 and 2.89 for two lateritic soils developed from basalt and sandstone, respectively. Bello and Osinubi (2010) reported specific gravity range of 2.61 to 2.64 for some lateritic soils from Ibadan, South Wstern Nigeria. These results show that the tested soil in this study have specific gravity values that are typical of lateritic soils. Indraratna and Nutalaya (1991) also stated that the specific gravity of soil is dependent on the particle sizes as well as the iron content, furthermore, the larger the clay fraction and the alumina concentration, the lower the specific gravity. This is in agreement with Fall et al. (1997) which stated that higher specific gravity is obtained in coarser particles due to a greater concentration of iron oxides in the concretions or the pisoliths. Based on the specific gravity obtained, samples ER1 and ER2 probably contain higher iron contents than sample MR since they have higher specific gravities. A higher clay content in ER2 than ER2 is also probably responsible for the lower specific gravity in ER2 than ER1. Das (2006) stated that the specific gravity of solids of light-colored sand, which is mostly made of quartz, may be estimated to be about 2.65; for clayey and silty soils, it may vary from 2.6 to 2.9. It can thus be inferred that the soil samples are clayey or silty soils.

3.1.2 Particle size analysis

The particle size distribution of the soil samples are presented in Figure 1. Table 3 also shows the percentages of different soil fractions present in the soil. Gravel are soil fraction with particle size of greater than 4.75 mm, sand are soil fraction with particle size between 4.75 mm and 0.075 mm, silt are soil fraction with particle size between 0.075 mm and 0.002 mm, while clay are soil fraction with particle size of less than 0.002 mm according to both AASHTO and USCS classification systems. Sample ER2 has the highest fines content of 48.1% and lowest gravel content of 6%. Sample MR on the other hand, has the lowest fines content of 32.6% and the highest gravel content of 14%. The particle size curves of samples ER1 and MR are similar and they contain less clay particles than sample ER2 as shown in Figure 1. The distribution curves show that the soil samples are well graded (i.e. the particle sizes are distributed over a wide range) with ER2 being a little gap graded. These results indicate that the soil samples will possess good compaction properties i.e. the soil particles will pack together well to fill all the voids (Powrie, 1997). Based on the fines content, only sample MR satisfy the requirement for fines content of less than 35% as indicated in Table 1. The plasticity characteristics of the soil samples are needed for further classification since more than 50% of the soil samples pass sieve No. 40 (with 0.425 mm opening).

3.1.3 Plasticity Characteristics

The results of plasticity characteristics indicate that sample ER2 has the highest liquid limit (LL) of 37%, plastic limit of 29% and plasticity index (PI) of 21%. Sample MR has the lowest LL of 38% and plastic limit (PL) 20%. Sample ER1 has LL, PL and PI that are close to that of MR as shown in Figure 2. None of the soil samples satisfy the requirements of LL < 35% and PI <12% for subbase material. The LL can be related to the compressibility of soil according to Nagaraj and Murthy (1985) who shows that the higher the LL of soil, the higher the compressibility and swell index of soil as presented in Eqs. 9 and 10, respectively. Based on the LL of the soil samples, sample ER2 will have the greatest compressibility. The results of PI indicate that the soil samples are of medium plasticity according to Das (2006).

$$C_c = 0.2343\left(\frac{LL(\%)}{100}\right)G_s \tag{9}$$

Where C_c is the compressibility index, G_s is the specific gravity of soil solids

$$C_s = 0.0463\left(\frac{LL(\%)}{100}\right)G_s \tag{10}$$

Where, C_s is the swell index

3.1.4 Derived parameters

Bello and Osinubi (2010) stated that the derived parameters are often used to show the contribution of soil's plasticity and particle size distribution to its behaviour. The activity ratio can be used to identify the type of clay mineral in a soil sample according to Mitchell (1993) and it is ≈ 0.5 for kaolinite, 0.5 ≤ A ≤ 1 for illite and 1 < A ≤ 7 for smectite. The activity ratio obtained for the soil samples therefore indicate that the soil samples contain smectite minerals. This shows that the soil samples are not good construction materials because of excessive swelling and shrinking (depending on the moisture content) associated with smectite minerals (Das, 2006). The grading modulus values obtained for the soil samples are presented in Table 3. These values are less than 1.5 which is the minimum value required for road bases receiving traffic volumes of less than 0.3 x 10^6 equivalent standard axle (esa) according to Nwaiwu et al. (2006). The values therefore do not satisfy the criterion with only MR having a value (1.42) close to 1.5. These values are however, higher than those (ranging from 0.61 to 0.67) obtained by Bello and Osinubi (2010). The plasticity modulus values are greater than 250 therefore satisfying the minimum requirement for road bases (Nwaiwu et al., 2006). Bello and Osinubi (2010) also obtained higher values (ranging from 1121.4 to 1304.8) for the same soil samples with lower grading modulus. These results indicate that the derived parameters cannot be used alone to determine the suitability of a soil sample for engineering construction. Nwaiwu et al. (2006) obtains plasticity product ranging from 133.44 to 196. 77, Bello and Osinubi (2010) obtained values ranging from 889.7 to 982.4 while the values obtained in this study vary over a wide range of 586.8 and 1010.1.

To evaluate the quality of a soil as a highway subgrade material, one must incorporate a number called the Group Index (GI). Using the results from the Atterberg limit experiments, the group indices (GIs) of the soil samples are calculated using Equation 1 for sample MR and Equation 2 for each of samples ER1 and ER2. The results obtained as shown in Table 3 indicate that the rating of the samples as subgrade material is fair to poor for samples ER1 and ER2 and good to excellent for sample MR according to ASHTTO (1986).

3.1.5 Classifications

Based on the results of preliminary tests on the three soil samples, the AASHTO and USCS classifications of the soil samples are as shown in Table 3. The group indices of the soil samples also confirm the result from classification in regard to the rating of the soil samples as subgrade materials.

3.2 Moisture Density Relations

The OMC and MDD of the soil samples determined are presented in Figure 3. Correlations between the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) for the three soil samples are presented in Figure 4. Linear regression analysis of the data gives an R^2 value of 0.934 and a general equation given in Equation 11.

$$MDD = 2.75 - 0.0499\ OMC \quad (11)$$

This result is similar to Equation 12 which was obtained by Ayodele et al. (2009) on reconstituted samples. Equation 11 is also similar to Equation 6 which was obtained by Ackroyd (1963) on some tropical soils. These results show that a good correlation exists between the OMC and MDD of tropical soils.

$$MDD = 2.312 - 0.026\ OMC \quad (12)$$

$$MDD = 2.56 - 0.0445\ OMC \quad (13)$$

Compaction properties of the mixture of MR and ER2 using the West Africa compaction method are presented in Figure 12 while the obtained OMC and MDD are presented in Figure 6. The ratios indicated in Figure 12 are the ratios of ER2 to MR. Figure 13 shows that as the percentage of ER2 increases, the MDD decreases while the OMC increases. This is because ER2 increases the fines content of of the mixture since it contained a higher percentage of fines content.

A linear regression analysis of the results is presented in Figure 14 and the resulting equation in Equation 14 with a R^2 value of 0.9632. Equation 7 is also similar to the Equations 11 to 13.

$$MDD = 2.4959 - 0.0317\ OMC \quad (14)$$

3.3 Correlation of S_u and CBR with compaction properties

Correlations between the S_u and CBR with the OMC using second order polynomial were developed and presented in Figure 7. The results revealed a perfect correlation between the properties with a R^2 value of 1. The resulting equations for both S_u and CBR are presented in equations 15 and 16, respectively.

$$S_u = 3.2064OMC^2 - 123.62OMC + 1217.8 \quad (15)$$

$$CBR = 1.2613OMC^2 - 48.18OMC + 463.59 \quad (16)$$

Linear relationships were however developed between the S_u and CBR with the MDD as presented in Figure 9.

$$S_u = 120.85MDD - 186 \quad (17)$$

$$CBR = 39.17MDD - 65 \quad (18)$$

Equation 17 shows that good linear correlation exist between S_u and MDD with R^2 value of 0.924. Equation 18 also shows good linear correlation between the CBR and MDD with R^2 value of 0.8673. These results, however, show that MDD is better in predicting the value of Su than it is in predicting the value of CBR.

4. Conclusion

This study investigated and presented some index and geotechnical properties of three soil samples collected within Ile-Ife, Nigeria. Correlations between OMC, MDD, CBR and S_u were also determined and presented. The following conclusions are made in relation to the objectives of the study:

a. only sample MR could be used as any layer of road based on the requirement of $F_{200} < 35\%$;
b. none of the samples satisfies the condition of LL < 35% and PI < 12% to be used as subabe material;
c. the derived parameters also indicate that the soil samples will not be good as construction material for road base;
d. correlation of MDD with OMC shows agreement with existing correlations in the literature and
e. the models developed showed that a good correlation existed between the properties correlated.

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First A. Author (M'76–SM'81–F'87) and the other authors may include biographies at the end of regular papers. Biographies are often not included in conference-related papers. This author became a Member (M) of Association XXXX in 1976, a Senior Member (SM) in 1981, and a Fellow (F) in 1987. The first paragraph may contain a place and/or date of birth (list place, then date). Next, the author's educational background is listed. The degrees should be listed with type of degree in what field, which institution, city, state, and country, and year degree was earned. The author's major field of study should be lower-cased.

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Table 1: General Requirements for Subgrade, Sub-base and Base Course in Nigeria

	Subgrade	**Sub-base**	**Base course**
Proportion passing BS sieve No. 200 (Amount of fines, %)	≤ 35	≤ 35	≤ 35
Liquid Limit (%)	≤ 80	≤ 35	≤ 35
Plasticity index (%)	≤ 55	≤ 12	≤ 12
Soaked CBR (24hrs.)	NA	≥ 30%	≥ 80
Relative compaction (%)	≥ 100	≥ 100	≥ 100

Source: Federal Republic of Nigeria highway manual (1992)

Table 2: Description of Soil Samples from Selected Borrow Pits

Soil Sample Identification	Geographic location	Location GPS Latitude	Location GPS Longitude	Elevations (m) Above sea level	Approx-imate area (m^2)
MR	Mokuro Road	7^0 30.133’	004^0 35.662’	326	28,800
ER1	Ede Road	7^0 30.851’	004^0 39.384’	314	21,600
ER2	Ede Road	7^0 31.208’	004^0 29.100’	316	23,200

Table 3: Results of Preliminary Analysis of Soil Samples

	MR	**ER1**	**ER2**
Natural Moisture Content (%)	16.23	18.15	20.64
Specific Gravity (G_S)	2.60	2.88	2.69
Liquid Limit, LL (%)	38	39	50
Plastic Limit, PL (%)	20	24	29
Plasticity Index PI (%)	18	15	21
F_{200}*	32.60	39.90	48.10
% clay	10	9	15
% silt	22.60	30.90	33.10
% sand	53.34	49.28	45.18
% gravel	14.06	10.82	6.02
AASHTO Classification	A-2-6	A-6	A-7-5
USCS Classification	CL	ML or OL	OH or MH
Colour	Reddish brown	Brown	Yellowish brown
Group Index	1	3	7
Derived Parameters			
Activity Ratio	1.8	1.67	1.4
Grading Modulus	1.42	1.29	0.97
Plasticity Modulus	928.62	842.7	1427.79
Plasticity Product	586.8	598.5	1010.1

*F_{200} is the percentage of particles passing sieve No. 200

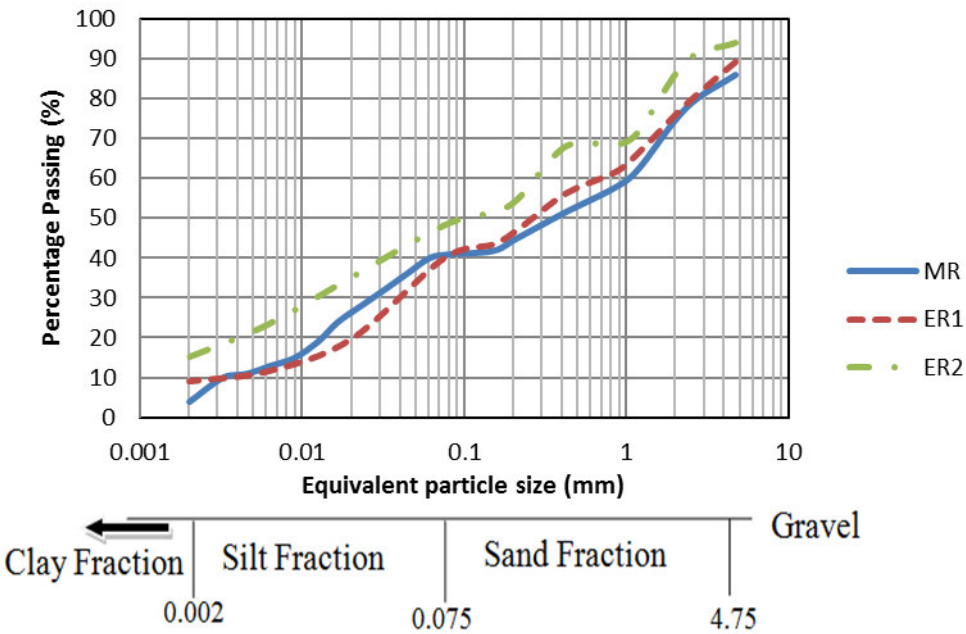

Figure 1: Particle size distribution curve for the three soil samples

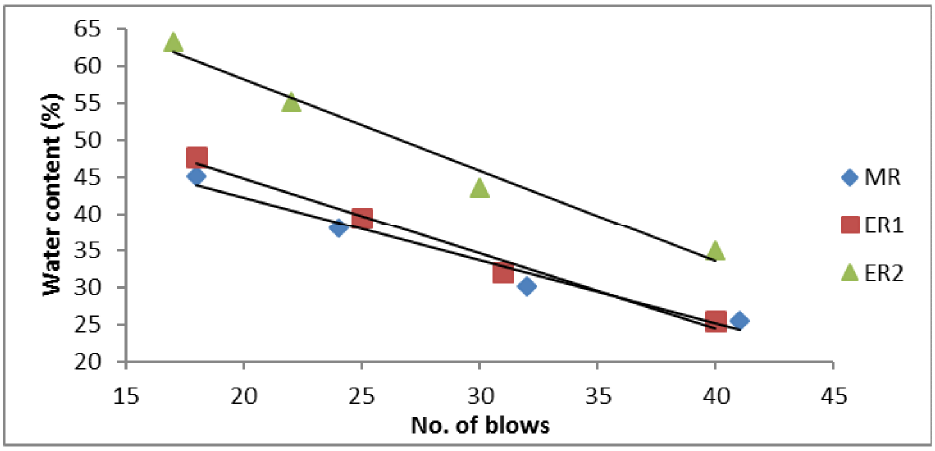

Figure 2: Liquid limit chart for the soil samples

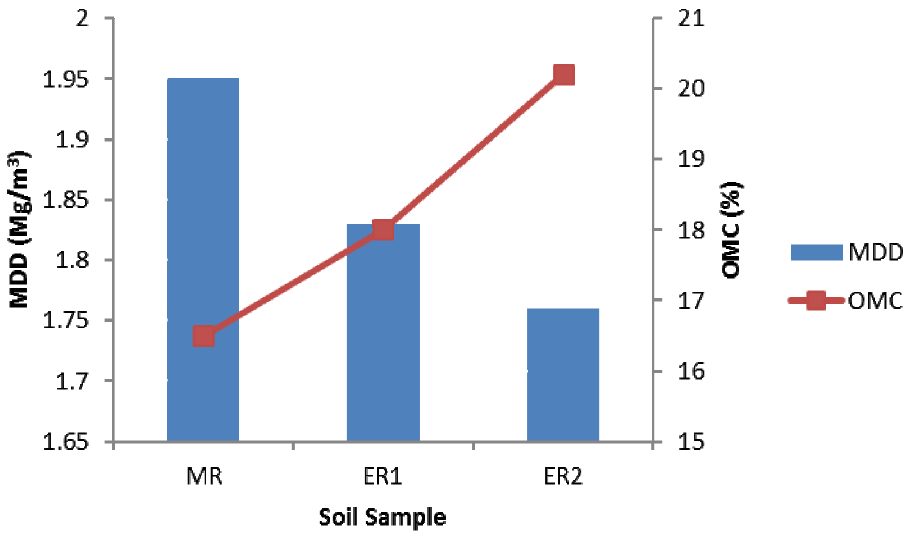

Figure 3: Compaction parameter of the soil samples

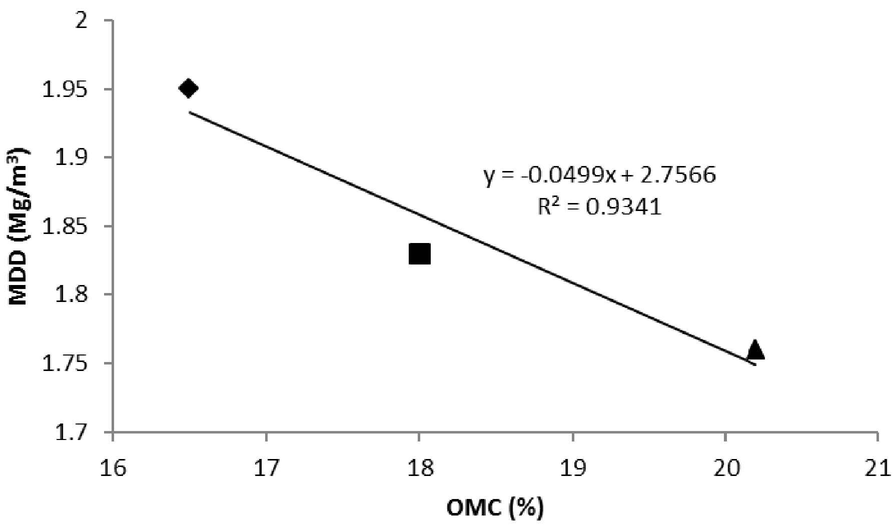

Figure 4: MDD versus OMC of the natural soil samples

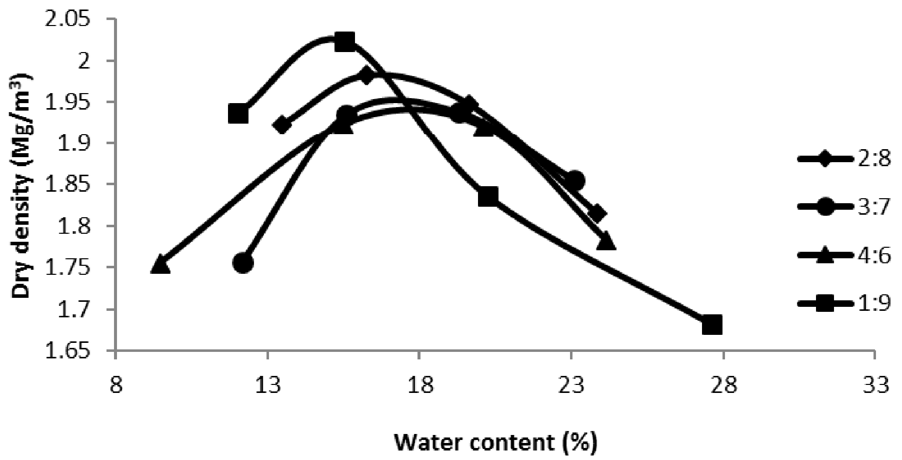

Figure 5: Compaction results of mixture of samples MR and ER2

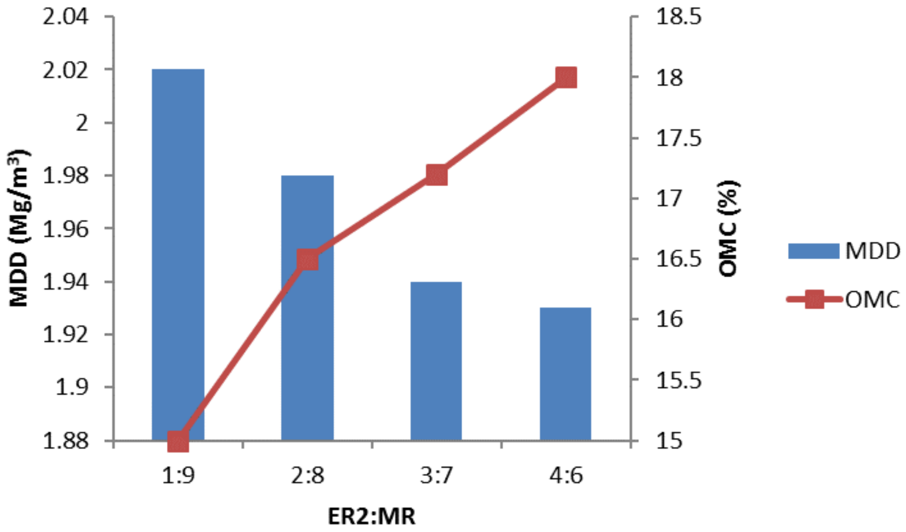

Figure 6: Compaction parameters of mixture of ER2 and MR

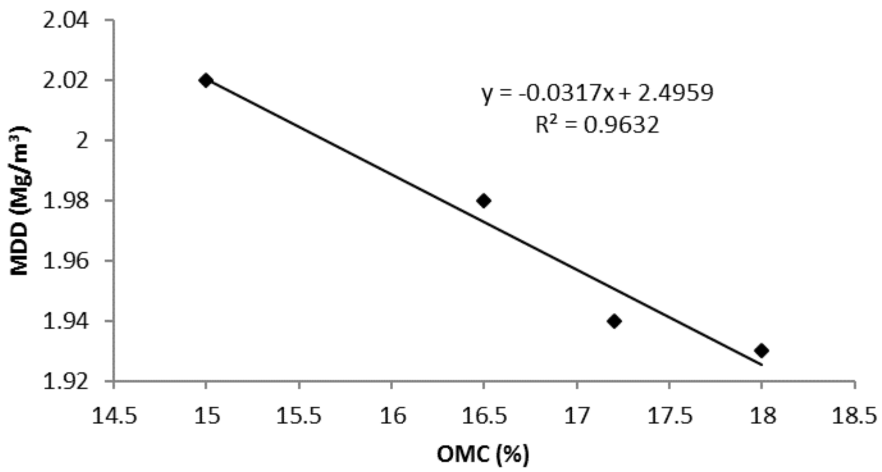

Figure 7: MDD versus OMC of mixture of MR and ER2

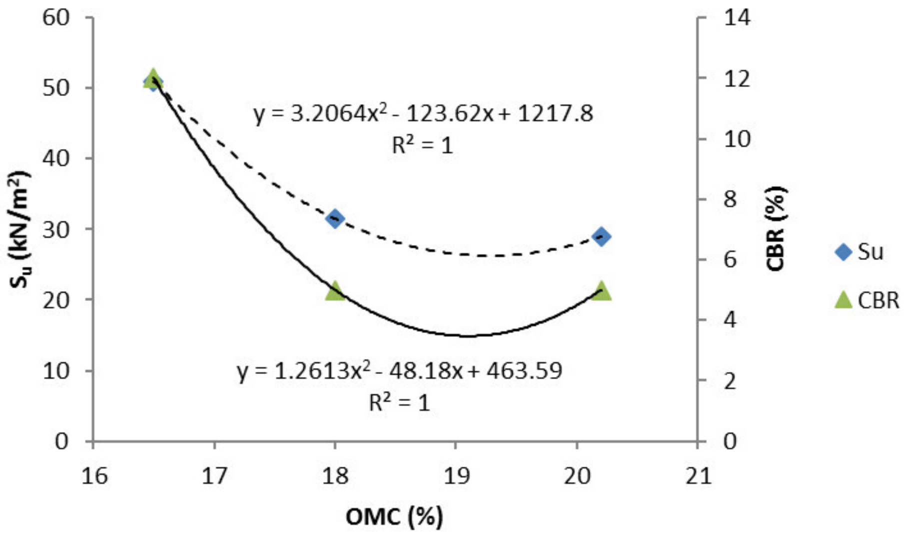

Figure 8: Correlations of S_u and CBR with OMC

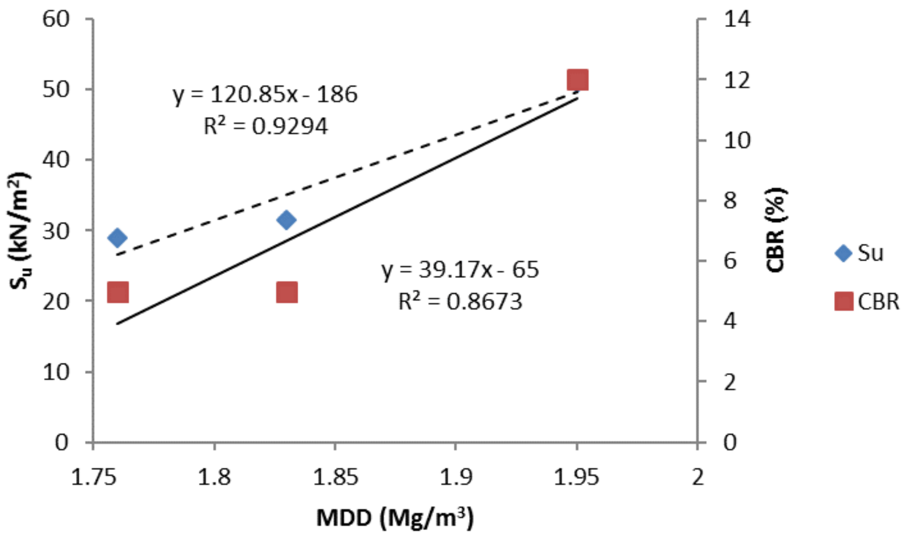

Figure 9: Correlation of S_u and CBR with MDD