EFFECT OF FINES CONTENT ON THE COMPACTION CHARACTERISTICS OF LATERITIC SOILS

By

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ABSTRACT

Index and compaction tests were conducted on fifteen reconstituted samples of a natural lateritic soil. The samples had fines content ranging between 59.84% and 98.88%. Results of the index tests conducted show that the fines content of the soil samples can be related to some derived parameters, namely grading modulus, plasticity modulus, and plasticity product as well as shrinkage modulus. The fines content, grading modulus and plasticity product at the energy levels of the West African compaction and British Standard Light compaction, respectively, were in turn related to the maximum dry density and optimum moisture content The regression analyses conducted show that the compaction characteristics can best be estimated from the combination of grading modulus, plasticity product and compaction energy represented by a compactive effort index. The practical applications of the regression equations obtained to the construction of compacted lateritic soils liners and covers for waste containment are discussed.

INTRODUCTION

The soil compaction process constrains soil particles to pack more closely through a reduction in the air voids by mechanical means thus reducing the sensitivity of compacted soils (with respect to volume changes and strength) to changes in moisture in the environment. The compaction process also tends to increase the strength and bearing capacity as well as reduce the compressibility and permeability or hydraulic conductivity of the soil (Gidigasu 1976). In using soils for the construction of road bases, highway embankments, airfield pavements as well as earth dams, where adequate strength and permissible compressibility are of primary concern, some degree of compaction control and proper selection of materials are necessary.

Laterite soils have been successfully used in the construction of embankments and earth dams in various parts of the tropics, the degree of success being dependent on the genetic characteristics and the specific purpose for which they have been used (Gidigasu 1976). Compaction characteristics of these soils are a function of the genetic characteristics of the soils, their degree of weathering and clay mineralogy (Little 1967, Cruz 1969). The response of a particular soil to compaction (i.e. the maximum dry density achieved and the corresponding optimum moisture content) depends to a significant extent on the particle size distribution (CIRIA 1988). Studies on the compaction characteristics of laterites suggest that the grading characteristics and plasticity of the fines determine their compaction characteristics. Gidigasu (1976) reported a significant correlation between the maximum dry density and the fineness index (F.I.), which is defined as:

$$F.I. = \frac{\% < \text{sieves (mm)} (19.05+9.52+4.76+2.4+0.6+0.075}{6} \quad \ldots\ldots\ldots\ldots(1)$$

The amount of clay-size fraction in the fines of the fine-grained laterite soils appears to influence the compaction characteristics. Some correlation has been found to exist between the clay-size content and the maximum dry density as well as the optimum moisture content for some fine-grained residual laterite soils (Gidigasu 1972). The effect of fines content (consisting of silt-size and clay-size fractions) on the compaction characteristics of fine-grained laterite soils is not yet fully understood. This understanding is necessary as fine-grained laterites are being considered for use as compacted soil liners and covers (i.e. hydraulic barriers) in waste-containment structures. Compacted fine grained soils are generally used in landfills and other waste-containment facilities as barriers to water and contaminant flow (Daniel and Benson, 1990; Daniel and Wu 1993; Benson et al., 1994b; 1999; Benson and Trast 1995; Howel et al 1997; Abrecht and Benson 2001).

The purpose of this paper is to present results of a compaction study aimed at identifying the trends in maximum dry density (MDD) and optimum moisture content (OMC) for reconstituted lateritic soil samples containing varying percentages of fines. The reconstitution of the samples simulates the variation in the grading characteristics of laterite soils as reported by Gidigasu (1980a,b)as well as Gidigasu and Kuma (1987). The degrees of initial saturation at optimum compaction conditions for the various soils are also reported as it is an important parameter when evaluating compacted fine-grained soils with respect to their hydraulic conductivity, which is the propetty of primary concern in clay soil liners and covers.

MATERIALS AND METHODS

The lateritic soil used in this study is a natural material obtained from a borrow pit in Zaria area (longitude 7°45'E and latitude 11°15'N) precisely along the Zaria-Sokoto road in Nigeria. The lateritic soil in this area belongs to the group of ferruginous tropical soils derived from acid igneous and metamorphic rocks (Osinubi 1998a). A clay mineralogy study conducted by Osinubi (1998b) on this lateritic soil shows that it contains kaolinite with quartz.

Index properties of the air-dried sample were determined based on procedures outlined in BS 1377 (1990) and Head (1992). Compaction tests were performed on air-dried specimens to obtain compaction curves corresponding to West African standard compaction (WASC) and British Standard Light Compaction (BSLC) energies. Procedures for the WASC, which is the conventional energy level adopted in the West African sub-region, are described by Ola (1980) and Osinubi (1998a).

In order to simulate the variability in fines content of fine-grained laterite soil deposits, the natural material was processed by separating between soil fractions retained on British Standard (BS) sieve No. 200 (75 μm aperture) and those passing the same sieve size. Materials passing the BS No. 200 sieve were in turn mixed at different proportions with the portions of soil material retained on the No. 200 sieve to yield fifteen (15) different samples having fines content ranging between 59.84% and 98.88%. These percentages fall within the range of fines content of soil that have been used as compacted soil liners for waste-containment facilities in agreement with Benson et al.(1994b; 1999). Laboratory tests were subsequently conducted on the fifteen (15) samples of reconstituted lateritic soil to determine their index properties and compaction characteristics. Two compactive efforts, the WASC and BLSC were utilized in defining the compaction curves for the soil samples. The method of sample re-use was adopted for the compaction tests in this study.

RESULTS AND DISCUSSION

Properties of the Natural Soil

The natural lateritic soil used in this study was collected during the dry season and had a natural moisture content of 2.89%. The basic geotechnical properties of this soil are summarized in Table 1. The particle size distribution test on the soil showed that the soil has a fines content of 71.782%. The soil has a liquid limit of 41.11% and a plasticity index of 26.06%. The soil can be classified as a clay of low plasticity in accordance with the unified soil classification system, USCS,(Annual, 1992) and as an A-7-6 soil according to AASHTO classification system (Standard, 1986).

The BSLC test on the soil yielded a MDD of 1.768 Mg/m^3 and its corresponding OMC of 15.00%. Graphical plots of the compaction data for this reddish brown lateritic soil are shown in Fig. 1. As would be expected, the WASC energy gave a higher MDD value and a corresponding lower OMC than was the case with the BSLC energy, thus indicating that the compaction characteristics of these soil samples are affected by compactive effort.

Characterization of the Fines Content

The index properties of the fifteen (15) reconstituted lateritic soil samples are summarized in Table 2. The liquid limit, plastic limit, plasticity index and linear shrinkage values range between 34.5 and 43.9%, 16.44 and 19.56%, 15.54 and 26.18% as well as 8.89 and 13.35%, respectively, for the 15 reconstituted soil samples. All the soil samples classify as clays of low plasticity in accordance with USCS. The specific gravity values range between 2.52 and 2.69. The grading modulus is defined as (TRRL 1990):

Grading modulus, GM

$$\frac{\{300-(\%<2.00\text{mm}+\%<425\mu\text{m}+\%<75\ \mu\text{m})\}}{100} \quad \ldots\ldots\ldots\ldots\ldots(2)$$

and its value for the reconstituted soils considered in this study range between 0.111 and 0.6345. However, since sieve size 2.4 mm (or 2.38 mm) is sometimes used in some soil testing laboratories it was used in the absence of the 2.0 mm sieve. The grading modulus decreased as the fines content increased (see Table 2). The grading modulus is related to the fines content as follows:

$GM = -0.0166F + 1.6492;$

$(R^2 = 0.9945)$ (3)

where GM = grading modulus, F = fines content and R^2 = the coefficient of determination.

The fines content is intrinsically linked with the plasticity of the material as a whole (CIRIA 1988). Fines content here is defined as the portion of soil material passing BS No. 200 sieve (or 75 μm). Some engineers often link the proportion of material passing the 425-μm-diameter sieve size to the plasticity of the soil. In definitive plasticity tests conducted in accordance with ASTM standards (ASTM D.421), air-dried soil samples passing through 425 μm sieve are used (Head, 1992). The equivalent wet preparation recognized by BS 1377 (1990) - Part 2: 4.2.4 - also employs material passing 425 μm sieve for plasticity tests. The following parameters, which are associated with soil plasticity are defined (CIRIA 1988):

1. Plasticity modulus (PM) = Plasticity index X percentage passing 425 μm test sieve.
2. Plasticity product (PP) = Plasticity index X percentage passing 75 μm test sieve.
3. Shrinkage modulus (SM) = linear shrinkage x percentage passing 425 μm test sieve.

Benson and Boutwell (1992) define the product of plasticity index and percentages of fines as the "clay index (CI)@ and consider it as the best characterization of soil composition. The clay index, which is related to hydraulic conductivity is a measure of the quantity and type of hydrated fine-grained particles in a soil and increases as the percentage of fines increases or as the clay component becomes more active (Benson and Boutwell 1992). Whichever term is used it represents the effective contribution of the plasticity of the fines to the performance of the whole material, which depends on the proportion of fines (CIRIA, 1988).

The relationships between the plasticity modulus (PM), plasticity product (PP) and shrinkage modulus (SM) on one hand and fines content on the other hand are shown in Fig.2. These parameters generally increase as the fines content in the soil increases. Using a third order polynomial expression, the following relationships between these parameters and fines content are obtained:

$PM = -0.047F^3 + 12.607F^2 - 1077.6F + 31336,\ (R^2 = 0.8575)$ (4)

$PP = -0.0324F^3 + 8.9335F^2 - 765.8F + 22231,\ (R^2 = 0.9048)$ (5)

$SM = 0.0126F^3 - 2.3309F^2 + 137.22F - 1675$, ($R^2$ = 0.7999) (6)

The plasticity product or clay index gave the highest R-squared value of 0.9048 when correlated with the fines content. In general, the R-squared values obtained in the equations (4) to (6) are fairly high and suggest good relationships between plasticity modulus, plasticity product as well as shrinkage modulus and fines content. These parameters generally increased as fines content increased.

Compaction Characteristics of the Soils

Compaction data obtained by using the BSLC and WASC energies were used to determine the MDD and OMC for each soil sample and are summarised in Table 3. The values of degree of saturation at optimum compaction conditions are also presented in Table 3. As would be expected, the MDD values from the BSLC energy are lower than the corresponding values obtained from the WASC energy. Similarly, the OMC values from the BSLC energy are higher than those obtained from the WASC energy. In general, values of the degree of saturation obtained from the BSLC energy were greater than those obtained from the WASC energy. This is probably due to the lowered OMC values resulting from the use of the WASC energy. Typical compaction curves for soil samples S-1 (fines content = 59.84%) and S-15 (fines content = 98.88%) are shown in Fig. 3. The usual shift in peak points on the compaction curves as a result of the use of a higher compactive effort can be observed in the Fig. 3.

Effect of Fines Content on Compaction Properties

Maximum dry density (MDD)

Two forms of functional relationships were developed to reflect the effect of fines content on the MDD of the soils tested. One form involved a direct relationship between MDD values and fines content while the other involved relationships between MDD and the parameters used in characterising the fines content of the soils. In each case, the MDD of the soils obtained from the two compactive efforts are shown together.

The MDD decreased with increases in fines content (see Table 3). This behaviour can be partly due to possible increases in the clay portions of the fines as the fines content increased. Gidigasu (1976) reported trends of decreasing MDD with increasing clay content of fine-grained residual lateritic soils.

A third order polynomial expression gave the following equations for the variations of MDD with fines content:

$MDD_{BSLC} = 6E\text{-}06F^3 - 0.0015F^3 + 0.1252F - 1.6251$, ($R^2$=0.8079) (7a)

$MDD_{WASC} = 1E06F^3 + 0.0003F^2 + 0.029F + 2.7367$, ($R^2$=0.7913) (7b)

Generally, MDD increased with higher grading modulus values but decreased as PM, PP and SM increased. The grading modulus reflects the effect of the various particle sizes of a soil on its behaviour in general. Equations (8a) and (8b) describe the relationships between MDD and grading modulus for both BSLC and WASC energies.

$MDD_{BSLC} = 1.3372GM^3 + 0.8688GM^2 + 0.0722GM + 1.6805$, ($R^2$ = 0.771) (8a)

MDD_{WASC}=0.4192GM^3-0.2972GM^2+0.1704GM+1.7568,
(R^2 = 0.785) (8b)

The observed general trends of decreasing MDD with higher values of PM, PP and SM are similar to those observed for the relationships between MDD and fines content. This is expected as the parameters, which are associated with the plasticity characteristics of soil samples, increase with higher fines content.

Optimum moisture content (OMC)

An increase in fines content gave corresponding increase in OMC. This was so because an increase in fines content resulted in increased total specific surface, which required more water to achieve the mobilization of soil particles during the compaction process. The specific surface is the ratio of the surface area of a material to either its mass or volume. Specific surface according to Mitchell (1976) as well as Holtz and Kovacs (1981) is inversely proportional to the grain size (or some effective particle diameter) of a soil. From the concept of specific surface, larger moisture contents for fine-grained soils are expected than for coarse-grained soils, all other things such as void ratio and soil structure being equal. As the moisture content of the soils increased due to higher fines content, the MDD decreased. The relationships between OMC and fines for the two compactive efforts based on third-order polynomial expressions are as follows:

$OMC_{(BSLC)}$ = -1E-05F^3+0.0021F^2-0.1128F+15.928;
(R^2 = 0.2529) (9a)

$OMC_{(WASC)}$ = -9E-05F^3+0.0211F^2-1.5822F+51.396;
(R^2 = 0.3039) (9b)

The relationships are not particularly very strong when compared to the corresponding relationships for MDD.

Equations describing the relationships between OMC and GM are given as follows:

OMC_{BSLC} = -6.9862GM^3+5.6059GM^2-3.3106GM+16.287,
(R^2 = 0.2439) (10a)

OMC_{WASC} = 16.667GM^3-19.04GM^2+4.4149GM+13.371, (R^2 = 0.2905) (10b)

The values of OMC decreased with increase in grading modulus but increased as the values of Pm, PP, and SM increased.

Regressions Analysis

Multiple linear regression analysis was conducted to further assess the effect of fines content or associated parameters on the compaction characteristics of the soils tested. Each comnaction variable was first related to fines content and the logarithm to base 10 of compaction energy. As an alternative to the logarithm to base 10 of the compaction energy, compactive effort index (E), which according to Benson and Trast (1995) is an integer categorical variable describing compactive effort, was also used. E was assigned +1 for BSLC energy and -1 for WASC energy. The rules for the use of integer categorical variables are described by Miller and Freund (1987). The multiple regression equations using fines content and logarithm of compaction energy to base 10 ($\log_{10}E$ or logE) are as follows:

MDD=1.1751-0.0023F+0.2679logE (11a)

(R^2 = 0.8115, Adj.R^2 = 0.7975; Std. Error = 0.0192)

OMC = 41.2566+0.0325F - 10.1802 logE (11b)

(R^2 = 0.7979, Adj R^2 = 0.783, Std. Error = 0.6247)

The overall F-statistic for MDD and OMC are 58.1163 and 53.309, respectively. The regression analyses were carried out at 95% confidence limits or at a 5% level of significance. In Eq. (11a) the t-statistic for fines content and log E are -6.6295 and 8.5019, respectively. For a two-tailed test involving n-2 degrees of freedom, (i.e. 30-2 = 28, since 30 observations were made) $t_{0.025}$ = 2.048. This shows that the two independent variables, fines content and logarithm to base 10 of compaction energy significantly contribute to the variation in MDD. The corresponding t-statistic for fines content and log E in Eq.(11b) are 2.9056 and -9.9084, respectively. These values of t-statistic are either less than or greater than $t_{0.025}$. A null hypothesis can therefore be rejected. The results of the analysis show that the tail probability or p-values are less than 0.01.

When only fines content and compaction energy were considered, equations similar to those of Eq.(11a) and Eq. (11b) were obtained by replacing log E with compactive effort index. The resulting equations are:

MDD = 1.7500-0.0023F-0.0297E (12a)

(R^2= 0.8119; Adj. R^2 = 0.7975; Std. Error = 0.0192)

OMC = 11.8054+0.0325F + 1.13E (12b)

(R^2=0.7979;Adj.R^2=0.783;Std.Error= 0.6247)

In this case the same values of t-statistic, F-statistic and p (the tail probability) are obtained as in Eq. (11a) and (11b). Thus the compactive effort index can be used in place of $\log_{10}E$.

Using the grading modulus and compactive effort index only, the following relationships were obtained.

MDD=1.7237+0.1372GM-0.0297E (13a)

(R^2 = 0.8126; Adj. R^2 = 0.7988; Std. Error = 0.0191)

OMC = 15.0289 - 1.9249GM + 1.13E (13b)

(R^2 = 0.7959; Adj. R^2 = 0.7808; Std. Error = 0.6277)

The overall F statistic for MDD and OMC are 58.5525 and 52.6439, respectively, at 95% confidence limits. The critical F ($F_{2,27,0.95}$ = 3,362) is less than the calculated F-values. Thus, it can be seen that the grading modulus and the compactive effort properly account for variations in the MDD and OMC values of these soil samples. The critical F value obtained here also applies to relationships in eqs. (11) and (12).

In order to account for particle grading as well as the plasticity product of the fines content multiple regression equations, were developed for both MDD and OMC incorporating grading modulus, plasticity and compaction energy which is represented by the compactive effort index. The resulting equations are:

MDD = 1.7733 + 0.0931GM - 2.085PP - 0.0297E (14a)

(R^2 = 0.08226; Adj. R^2 = 0.8021, Std. Error = 0.0189)

OMC = 17.7071 -3.768GM - 0.0009PP + 1.13E (14b)

(R^2 = 0.8134; Adj. R^2 = 0.7919; Std. Error = 0.6117)

The overall F values are 40.1749 and 37.7799 for MDD and OMC, respectively, while the critical F value ($F_{3, 26, 0.95}$) is 2.976. Considering the F values, it can be seen that they are significantly higher than the critical F-value. The R-squared values obtained in eq. (14a) and eq. (14b) are slightly higher than the corresponding values obtained in eqs. 12(a) to 13(b), respectively.

The three variables in eqs. 14(a) and 14(b) were subjected to partial -F test. The partial F test is used to assess whether or not the addition of any specific independent variable to the model significantly improves the prediction of Y, given that other variables are already in the model (Kleinbaum and Kupper 1978). The partial F values were estimated from the square of the respective t-statistic in accordance with Kleinbaum and Kupper (1978) as well as Draper and Smith (1981). The following values were obtained:

MDD - grading modulus (4.9489); plasticity product (1.4534) and compactive effort index (73.9438); and

OMC - grading modulus (7.7692); plasticity product (2.4393) and compactive effort index (102. 3798).

The partial-F values obtained show that the compaction energy mostly contributes to the prediction of either MDD and OMC, followed by grading modulus and plasticity product, respectively. The partial-F values for plasticity product are not significant at $\alpha = 0.05$ level. The corresponding p-values for compaction energy for MDD (1.8E -09) and OMC (5.1 E - 11) are significantly less than 0.001. On the basis of the calculated R-squared values as well as the accompanying reduced standard error of estimate, eqs. (14a) and (14b) can provide good estimates of compaction properties of fine-grained lateritic soils containing kaolinite.

Practical Application

Compacted fine-grained soils are widely used as hydraulic barriers in waste-containment structures such as landfill liners and covers, caps at hazardous waste sites, and liners for surface impoundments and sewage lagoons (Daniel and Benson 1990; Benson and Othman 1993; Benson et al., 1994b; Benson and Trast 1995). Hydraulic barriers are used to minimise flow rate because hydraulic conductivity (k) is one of the most important factors governing their performance (Benson and Boutwell 1992; Benson and Trast 1995). Hydraulic conductivity depends on soil composition (plasticity characteristics and grading characteristics, especially the contents of clay fraction and fines) as well as soil structure defined by moulding water content and compactive effort (Benson et al., 1994b).

Sampling and testing are performed as part of quality control (Benson et al., 1994a). Testing may include "hard" measurements of hydraulic conductivity and/or "soft" measurements of other soil properties (such as water content, dry unit weight, and plasticity index) that are correlated to hydraulic conductivity (Boutwell and Hedges 1989). Soft measurements are quite appropriate for fine-grained lateritic soils considering the variability of their properties. The minimum value of dry density obtained from laboratory compaction tests below which compaction should not be carried out in the field is often specified for a given liner soil in order to achieve hydraulic conductivities less than the regulatory maximum value of $1x10^{-7}$cm/s. Low values of dry density were shown by Benson and Daniel (1990) to correspond to hydraulic conductivity values greater than $1x10^{-7}$cm/s.

Equations (14a) and (14b) provide a quick way of estimating the MDD and corresponding OMC of fine-grained laterite soils to be used as compacted liners and covers in engineered landfills. According to Benson and Boutwell (1992) soil liners are commonly required to be compacted at 0 to 4% wet of optimum in order to achieve low hydraulic conductivity (i.e. less than $1x10^{-7}$cm/s).

CONCLUSIONS

Results of laboratory tests conducted to evaluate the index properties and compaction characteristics of a natural lateritic soil and fifteen (15) reconstituted samples of the same soil were presented. Reconstitution of soil was carried out in order to simulate the variability in compositional factors occurring in lateritic soil deposits, especially for fine-grained laterites.

Examination of the results of the index tests revealed that the fines content could be related to some derived parameters (i.e. grading modulus, plasticity modulus, plasticity product and shrinkage modulus), which describe the contribution of either the entire particle size distribution or the plasticity of the fines to the performance of the whole material. The fines content or the derived parameters were then related to the compaction properties of the reconstituted soil samples.

Regression analyses conducted showed that MDD and OMC can be predicted from the fines content or any of the derived parameters as well as compactive effort. The best estimate of the compaction properties can be made from grading modulus, plasticity product and compaction energy. This regression equation is valid for fine-grained laterite soils having fines content ranging between 50 and 100% as well as compaction energies between the BSLC and WASC.

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Table 1: Physical Properties of Natural Lateritic Soil

Natural moisture content, %	2.89
Percentage passing BS No. 200 sieve	71.78
Liquid limit, %	41.11
Plastic limit, %	15.05
plasticity index, %	26.06
Linear shrinkage, %	10.30
USCS classification	CL
MDD_{BSLC} (kN/m^3)	1.768
OMC_{BSLC} (%)	15.00
MDD_{WASC} (kN/m^3)	1.805
OMC_{WASC} (%)	14.40
Colour	Reddish brown

Table 2: Index properties of reconstituted samples of the lateritic soil

S/N	Fines Content (%)	Grading Modulus	Percentage Passing 0.425mm(%)	Specific gravity	Liquid limit (%)	Plastic Limit (%)	Plasticity Index (%)	Linear shrinkage (%)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1	59.84	0.6345	79.10	2.64	41.4	17.4'1	23.99	11.60
2	67.81	0.5277	82.82	2.63	37.0	17.13	19.87	9.32
3	71.70	0.4833	83.38	2.64	35.6	17.35	18.25	9.45
4	72.63	0.4431	85.35	2.65	378.1	17.76	19.34	10.38
5	73.52	0.4461	84.84	2.58	38.2	17.66	20.54	10.81
6	74.52	0.4188	85.95	2.66	36.8	17.46	19.34	9.44
7	76.17	0.3837	88.07	2.69	345	18.96	15.54	8.89
8	77.17	0.3585	89.09	2.59	35.7	19.56	16.14	9.32
9	80.53	0.3411	87.98	2.64	38.7	17.57	21.13	9.59
10	83.63	0.2706	90.96	2.60	40.8	18.32	22.48	11.57
11	86.10	0.2264	92.56	2.58	37.8	17.99	19.81	8.97
12	88.93	0.1692	95.02	2.63	40.8	16.44	24.26	9.63
13	90.50	0.1452	95.65	2.565	42.0	17.74	24.26	10.73
14	93.87	0.0831	98.10	2.52	42.4	19.13	23.27	10.96
15	98.88	0.0111	100.00	2.54	43.9	17.72	26.18	13.35

Table 3: Compaction characteristics of reconstituted samples of the lateritic soil

S/N	Fines Content (%)	BS Light Compaction			West African Standard Compaction		
		MDD	OMC	S_r	MDD	OMC	S_r
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	59.84	1.730	15.00	75.28	1.858	12.90	80.92
2	67.81	1.772	14.25	77.40	1.798	13.00	73.89
3	71.70	1.765	15.50	82.54	1.817	12.50	72.86
4	72.63	1.756	14.50	75.47	1.814	12.70	73.03
5	73.52	1.773	15.50	87.86	1.841	12.70	81.63
6	74.52	1.786	15.00	81.53	1.808	13.00	73.38
7	76.17	1.749	16.20	80.997	1.801	13.70	74.66
8	77.17	1.782	15.72	82.79	1.805	13.25	78.91
9	80.53	1.725	16.50	82.12	1.784	14.20	78.13
10	83.63	1.722	15.00	76.49	1.787	13.51	78.55
11	86.10	1.710	18.70	84.69	1.772	13.52	76.498
12	88.93	1.740	14.50	74.56	1.783	14.00	77.51
13	90.50	1.711	15.50	80.60	1.781	12.49	73.76
14	73.87	1.690	16.75	85.95	1.775	14.00	84.06
15	98.88	1.676	16.25	80.07	1.755	13.50	76.66

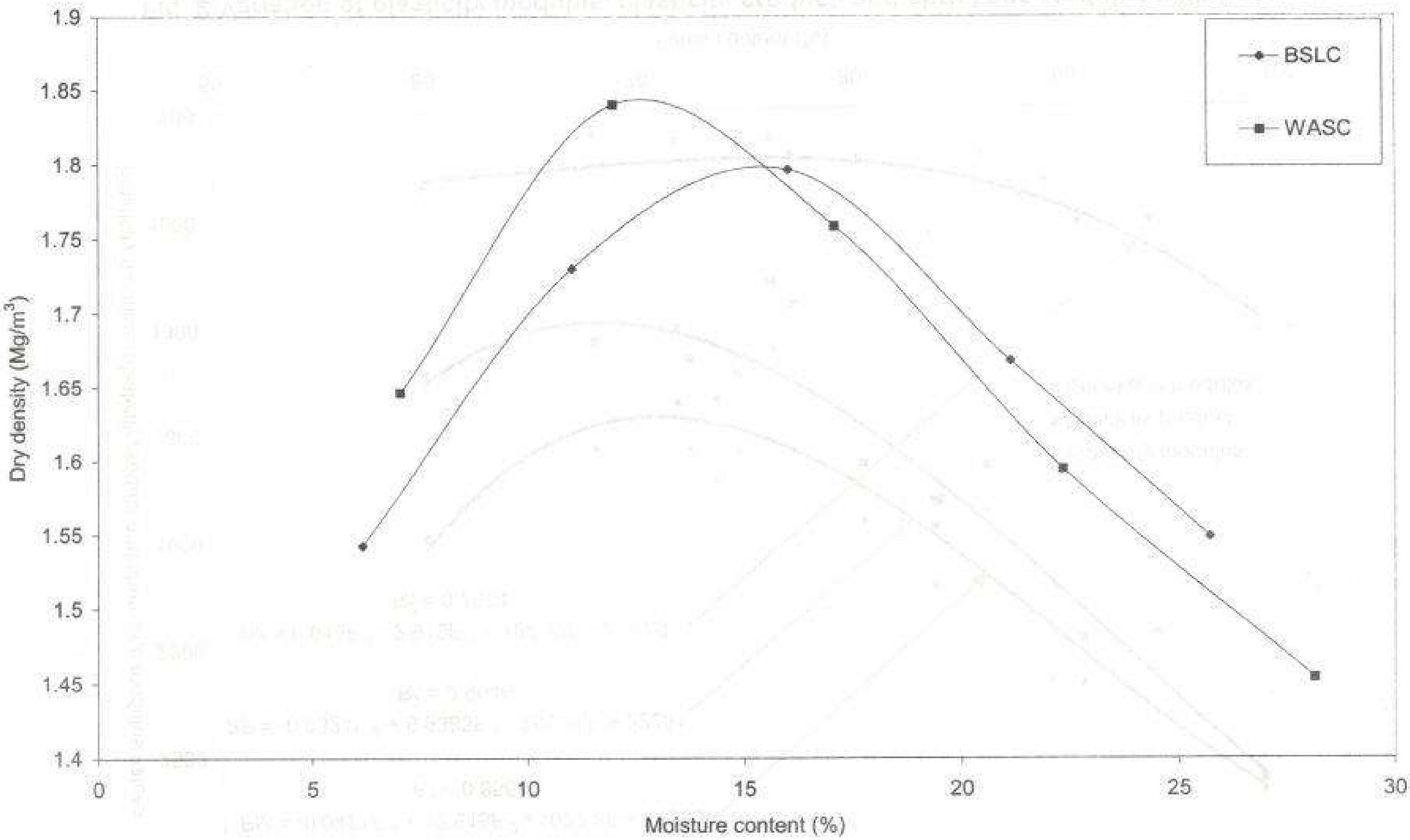

Fig. 1 Compaction curves for the natural lateritic soil

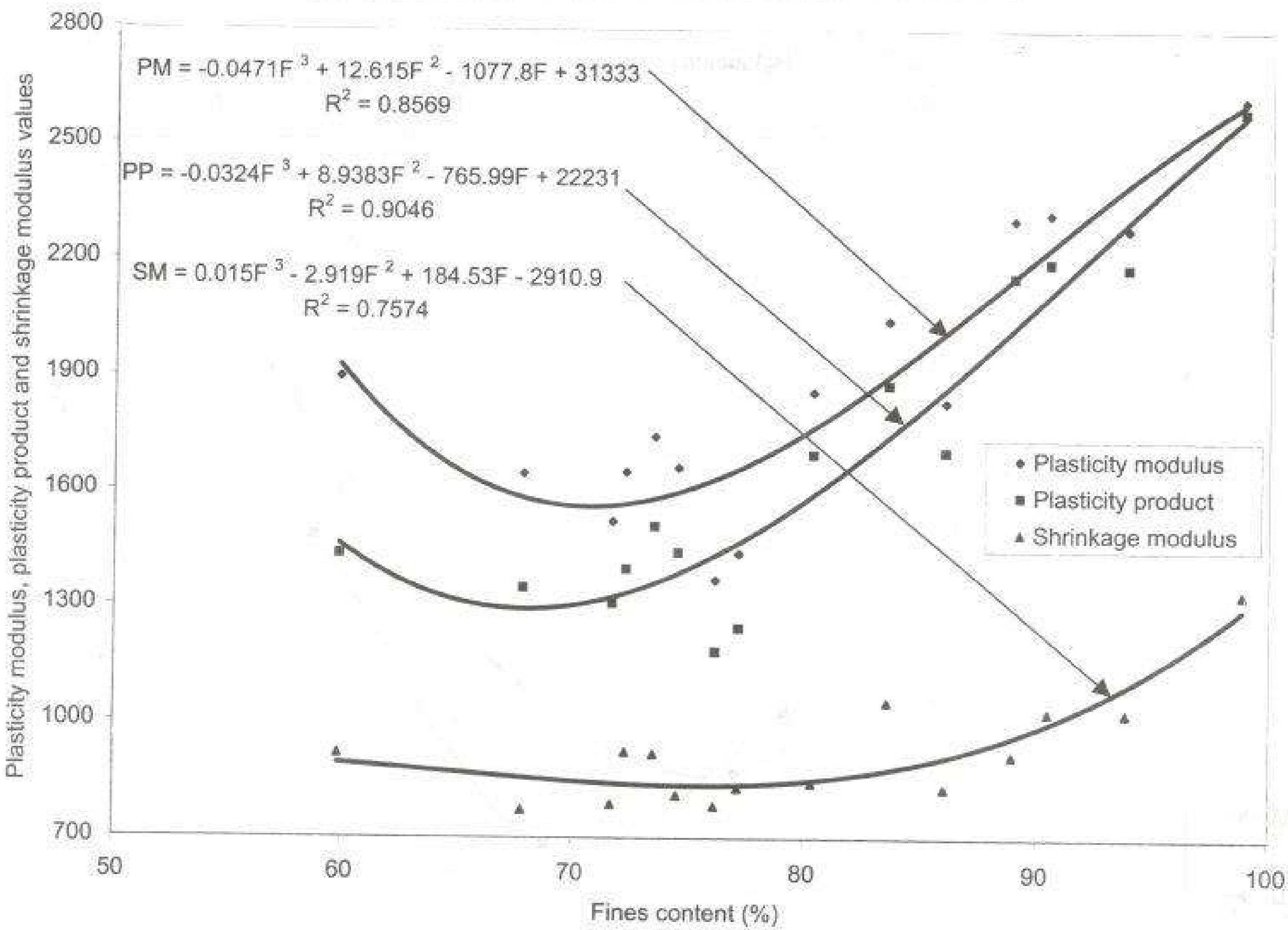

Fig. 2:Variation of plasticity modulus, plasticity product, and shrinkage modulus with fines content

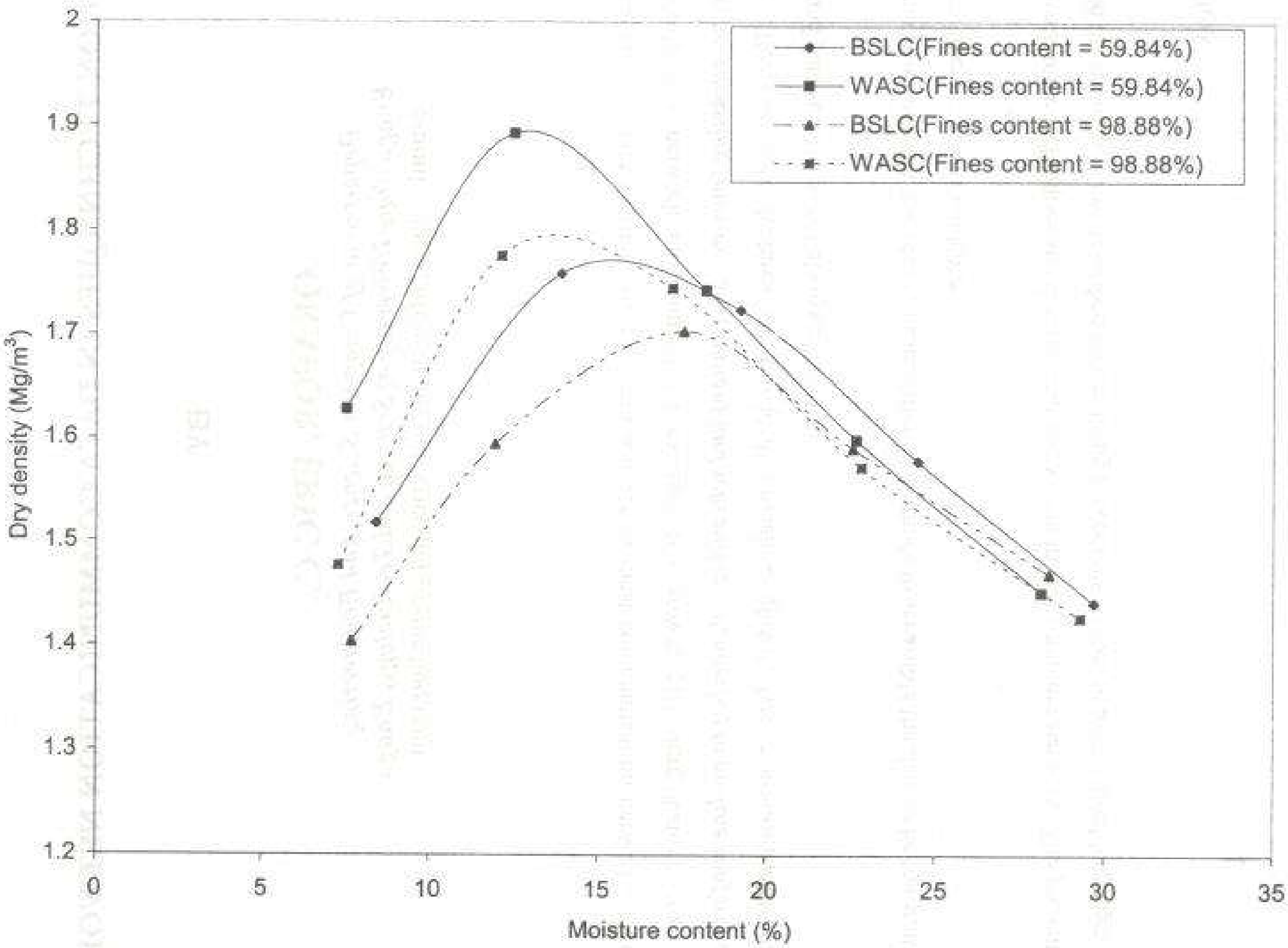

Fig. 3 Compaction curves for reconstituted soil samples