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Development of Mathematical Model for Evaluation of Compaction Characteristic of Lateritic Soil- Using Quadratic Equation

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Abstract: *The research focused on experimental evaluation of compaction characteristic of laterite soil using quadratic function. This was with a view to obtain empirical relationships between optimum moisture content and maximum dry density. Six samples of lateritic soils were obtained. The samples were subjected to laboratory analysis in their natural states and there compaction characteristics were determined. Quantitative relationships between optimum moisture content and maximum dry density of the soil samples were developed using second order polynomial function. From the findings of this project work, the following conclusions are made in relation to the objectives of the project: the dry density of the studied soil samples generally decrease with decrease in moisture content, the best fitting between the moisture content and dry density of the soil samples was found by the polynomial expression for sample 1 – 6 :* ($Y_d = -0.0002w^2 + 1.0545w + 1.7281$; $Y_d = 0.0036w^2 - 0.1995w + 4.3646$; $Y_d = -0.0019w^2 + 0.0641w + 1.3800$; $Y_d = -0.0209w^2 + 0.8455w - 5.7607$; $Y_d = -0.0102w^2 + 0.2402w + 0.6922$; $Y_d = -0.0361w^2 + 1.1431w - 6.9188$), *where* Y_d *is dry density in gm/cm*^{3} *and w is moisture content in %.*

Key words*: Compaction, dry density and moisture content*

I. Introduction

A soil classification system is the arrangement of different soil when similar properties into groups and subgroups based on their application. Classification system provides a common language to briefly express the general characteristics of soil, which are infinitely varied without detailed description. Most of the soil classification system that have been developed for engineering purposes are based on simple index properties, such as particles size distribution and plasticity. Although there are several classification system now in use, There is no total definitive of any soil for all possible application because of the wide diversity of the soil properties (Braja. 2000).

In a general way, it has been found that soil can be classified into group within each of the significant engineering properties are somehow similar. Consequently, proper classification of subsurface materials is an important step in connection with any foundation job, because it provides the first clues to the experience that may be anticipated during and after construction. The ability to identify and classify soil property is therefore basic to the analyses of all engineering problems dealing with earth materials (Raph et al, 2003).

The aim of this project is to determine the evaluation of compaction characteristic of lateritic soil using polynomial function. The study aimed development of relationship between, moisture content and maximum dry density.

II. Materials and Method

Description of study area

The study area chosen for this study is Ogbomoso-South, in Western part of Nigeria and samples were collected in 6 locations within the study area and subjected to laboratory tests

Laboratory test

There are many test to be carried out on the soil samples to ascertain their compaction characteristics and also suitability for required purposed. This is necessary because some soils possess physical characteristic which are of engineering importance but do not posses other engineering properties that qualify them to be used from the proposed project.

Particle size analysis

This was carried out to analyze the soil particle according to their aggregate. Using a set of sieve (ranging from 8mm sieve to sieve no. 75microns).

The finest available material was washed over 75mm sieves with water. The coarse portion was kept in the oven for 24hours at 105^0c before sieving was carried out on it with set of sieves containing sieve of different diameter (ranging from 8mm sieve to sieve no. 75microns) and a base pan receiver.

After sieving, the portion retained on each sieve was weighted and the percentage passing each sieve was calculated. (Smith and Smith, 1998)

Moisture Content

The natural moisture content can be easily measured in the laboratory by the following procedures;

i. The empty moisture can be hold be sample be weighted and weight record was W_1
ii. The sample placed into the can would be weighted and weight recorded as W_2
iii. The sample would be oven dry with constant temperature of about 110^0C until it is completely dried
iv. The mass of the dry sample would be weighted and weight recorded as W_3
v. The moisture content would be computed using

$$\mathbf{W} = \frac{\mathbf{W2 - W3}}{\mathbf{W3 - W1}} \ \mathbf{x\ 100\%} \quad \mathbf{W} = \frac{\mathbf{W2 - W3}}{\mathbf{W3 - W1}} \ \mathbf{x\ 100\%}$$

equ 1

Atterberg limit test

This is aimed at determining the liquid limit and plastic limit of soil. Liquid limit is described as the water content at which soil posses an arbitrary fixed small amount of shear strength and it is the water content that represents the boundary between the liquid limit and plastic state of soil while plastic limit is the moisture content at which a thread of the soil sample (about 3mm diameter), begins to rupture or crumble when it is being tried to be mould. The thread was put in the oven for 24hours at 105^oC to determine moisture content as usual using labelled moisture can.

The range of water content at which the soil behaves like plastic materials, that is difference between liquid limit and plastic material, (LL- PL) is term the plasticity index.(Bell, 2004)

Compaction test

This test was carried out to determine the soil shear strength and compaction energy employed was West Africa Standard (WAS) which involved application of 25 blows per layer of 5 inch a mould of volume $2305cm^3$ with a 4.5 kg rammer. The dry unit weight of the compacted soil is computed using expression in equation 1(Donald 1999)

$$\mathbf{Y}d = \frac{\mathbf{Y}}{(\mathbf{1 + W})} \quad \mathbf{Y}d = \frac{\mathbf{Y}}{(\mathbf{1 + W})}$$

equ 2

Where: Y_d is dry unit weight
Y is wet or bulk unit weight and
w is moisture content

California Bearing Ratio (CBR) test

This was carried out to determine the bearing capacity ratio of the soil to use in sub- grade and base courseThe reading at 2.5 penetrations and 5.0 penetrations are the two point of most important. The correct reading at 2.5 penetrations was multiplied by 0.0212 due to calibration of the machine. The process would be carried out for both top and bottom of the compacted soil and average of value in both top and bottom penetration is the actual CBR at the point. The same operation would be carried out until there is a fall in the load gauge reading. (John, 1993)

Quadratic function for the compaction

Specimens for each soil mixture were compacted in accordance with standard compaction procedures (ASTMD 698). The optimum water content, w_{opt} and the maximum dry unit weight, $Y_{d\ max}$, for the resulting compaction data were determined by regressing the measure data with a second- order polynomial equation of the following form. (Stroud,1992)

$$Y_d = Aw^2 + Bw + C \qquad \text{Equ 3}$$

Where Y_d is the dry unit weight, g/cm^3
W is the corresponding moulding (compaction) water content A,B, and C are constant resulting from the fitting process .

III. Results

Natural moisture Content

Soil samples with low moisture content indicates a dry soil, while high moisture content is an indication of a wet soil. The value of moisture content of the samples ranges from 2.49% - 11.08% which are less compare to the value in the field (3 – 70%). Table 1

Table 1: Natural Moisture Content with dept

Sample No	Depth(m)	N.M.C (%)
1	1.0	2.49
2	1.0	11.08
3	1.0	6.39
4	1.0	6.83
5	1.0	5.25
6	1.0	7.22

Grain Size Analysis

The particle size distribution curve shows not only the range of particle sizes present in soil but also the type of distribution of various size particles.

The grain size analysis shows that the samples are well graded. The result of the well graded samples shows that the smaller particles filled the space between the larger particles, giving highly dense mass interlocking particles with higher shear strength and low compressibility.(Table 2)

Table 2: Summary of sieve analysis result

	Percentage passing					
Sieve No	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
8	100	100	100	100	100	100
4	99.7	99.12	98.73	99.38	97.33	98.42
2	54.41	55.88	58.12	51.34	50.66	71.84
1	21.58	26.76	32.74	14.50	11.33	43.16
0.425	6.08	12.35	14.97	8.33	8.00	23.42
0.250	3.04	5.59	4.82	3.08	1.33	6.31
0.125	0.61	1.18	1.27	0.62	0.00	1.05
0.075	0.00	0.00	0.00	0.00	0.00	0.00

Atterberg Limit Test: Table 3 gives a summary of the values of liquid limit, plastic limit and plasticity index at various fines content of the soil samples. Sample 1, 2 and 4 has lowest value of liquid limit 9%, 8%, and 9% respectively while sample 6 has intermediate plasticity of 13%, sample 3 and 5 has high plasticity due to their liquid limit more than 40% plasticity index (PI) of 22% and 21% respectively, which implies that sample 3 and 5 has the highest inherent swelling potential shrinkage tendency

Table 3: Atterberg Limit for Sample 1- 6

Sample No	Moisture Content	No of blows	Average PL (%)	LL (%)	P.I (%)
1	37 33 44 35 41	45 39 30 24 14	27	36	9
2	52 50 54 39 32	46 41 31 24 12	27	35	8
3	40 33 37 52 43	47 38 32 25 13	30	52	22
4	43 43 34 49 47	44 34 25 18 11	25	34	9
5	43 44 49 43 54	48 38 31 21 18	28	46	21
6	49 44 38 34 43	45 38 27 18 12	25	38	13

Compaction Test

The main aim of carrying out the compaction test is to determine the optimum moisture content (OMC) and maximum dry density (MDD). From the result obtained for W.A.S compaction test, sample 2 has the higher OMC, which is 33.75% while sample1 has the lowest OMC which is 9%. For the maximum dry density, sample 1 has the highest MDD, which is 2.20 g/cm^3 while sample 2 has the lowest MDD, which is 1.75g/cm^3.(Table 4)

Table 4: Dynamic compaction for West African Standard (WAS)

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6

Dry Density (g/cm3)	1.89 1.95 2.11 1.94	1.62 1.75 1.57 1.52	1.83 1.93 1.95 1.80	1.72 1.73 1.78 1.70	1.90 2.10 2.06 1.96	1.88 1.91 1.76 1.60
Moisture Content (%)	3.01 4.65 9.12 16.74	26.19 33.74 49.16 49.17	9.49 14.23 18.08 22.72	13.07 23.32 27.18 27.45	7.30 11.46 13.72 15.51	13.20 18.28 32.97 33.49

California Bearing Ratio Test

The result of un- soaked California bearing ratio test on soil samples revealed that sample 1 and 2 has C.B.R values suitable for sub-grade as shown in Table 5

Table 5: Summary of California Bearing Ratio Test Result for WAS Compaction

Pen	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6	
(mm)	Base	Top	Base	Top	Base	Top	Base	Top	Base	Top	Base	Top
0.5	0.382	0.106	0.212	0.148	0.085	0.042	0.148	0.212	0.127	0.064	0.297	0.127
1	0.488	0.191	0.318	0.297	0.254	0.170	0.170	0.254	0.212	0.191	0.572	0.318
1.5	0.742	0.233	0.551	0.445	0.382	0.212	0.191	0.339	0.254	0.233	0.657	0.424
2	0.848	0.445	0.678	0.572	0.424	0.254	0.318	0.509	0.424	0.339	0.912	0.509
2.5	0.933	0.530	1.039	0.678	0.551	0.318	0.403	0.594	0.530	0.403	1.060	0.806
3	0.996	0.615	1.378	0.848	0.594	0.424	0.509	0.721	0.615	0.466	1.420	0.954
3.5	1.060	0.700	1.567	0.912	0.678	0.572	0.572	0.806	0.700	0.509	1.548	1.060
4	1.124	0.763	1.823	1.208	0.742	0.615	0.700	0.912	0.784	0.572	1.738	1.187
4.5	1.251	0.848	1.908	1.442	0.784	0.657	0.848	1.039	0.848	0.678	1.844	1.314
5	1.314	0.890	2.078	1.866	0.848	0.700	0.912	1.081	0.912	0.763	1.908	1.442
5.5	1.378	0.975	2.226	1.950	0.975	0.806	0.954	1.145	0.996	0.848	1.993	1.569
6	1.484	1.124	2.311	2.035	1.060	0.912	1.060	1.230	1.166	0.954	2.035	1.738
6.5	1.548	1.230	2.374	2.056	1.124	0.933	1.124	1.336	1.272	0.975	2.099	1.823
7	1.590	1.272	2.460	2.078	1.166	0.975	1.166	1.378	1.442	1.039	2.120	1.910

Table 6: California Bearing Ratio values for W.A.S compaction of samples.

Sample	CBR (%)
1	12
2	10
3	4
4	5
5	4
6	9

Polynomial function for the compaction

The results of the correlations between moisture content and dry density of the soil samples are as shown in Figs. 1 to 6, while Table 7 gives a summary of the equations representing relationships between moisture content and dry density of soil samples.

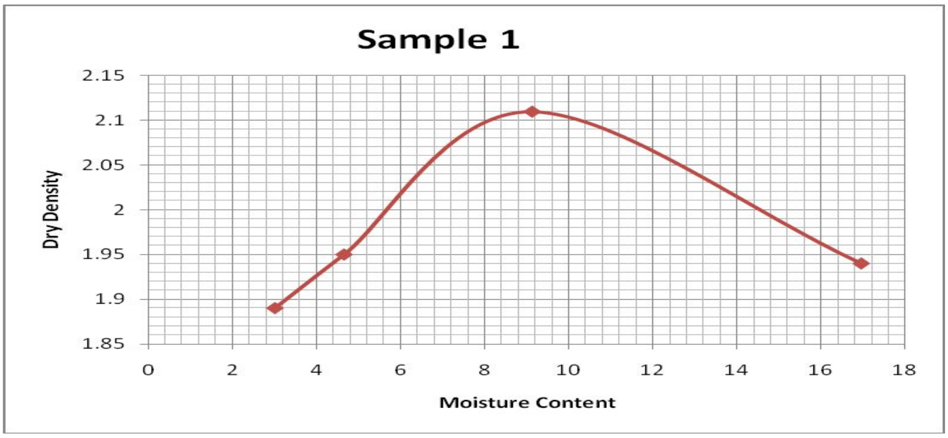

Figure 1: Dry density vs Moisture content for Sample 1

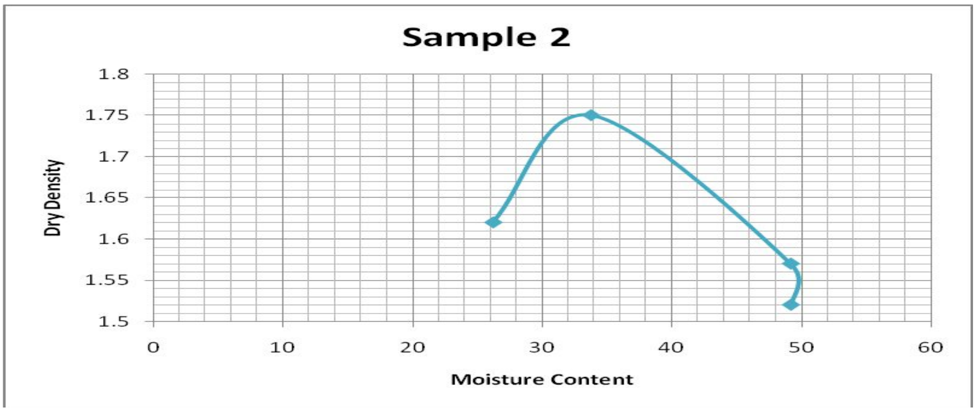

Figure 2: Dry density vs Moisture content for Sample 2

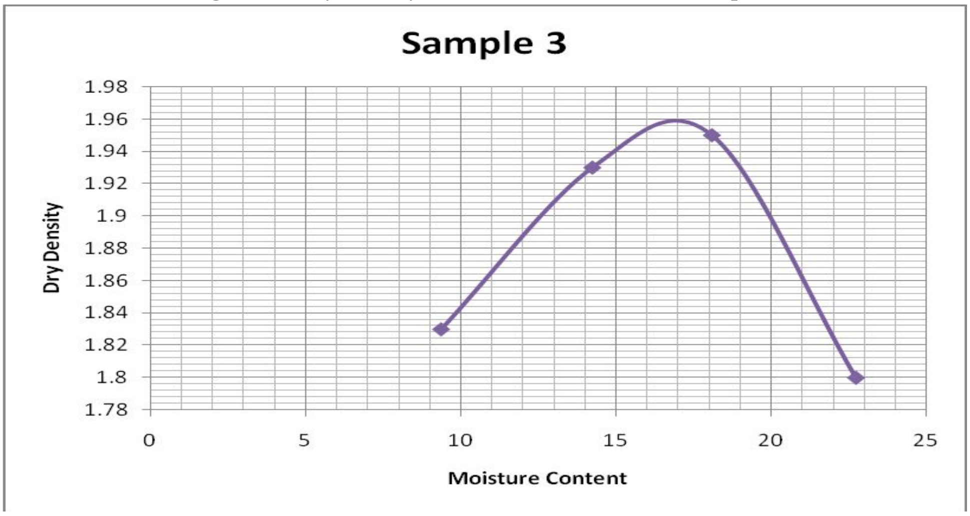

Figure 3: Dry density vs Moisture content for Sample 3

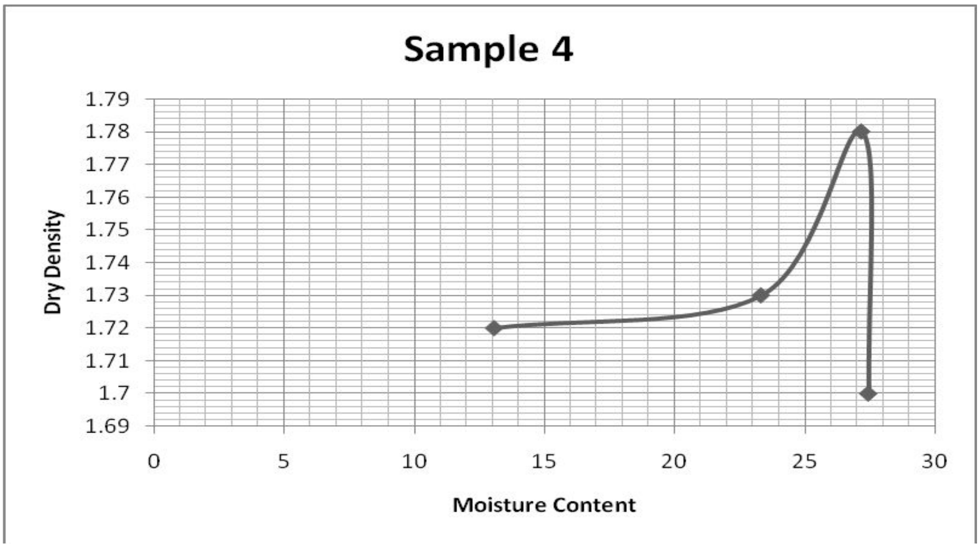

Figure 4: Dry density vs Moisture content for Sample 4

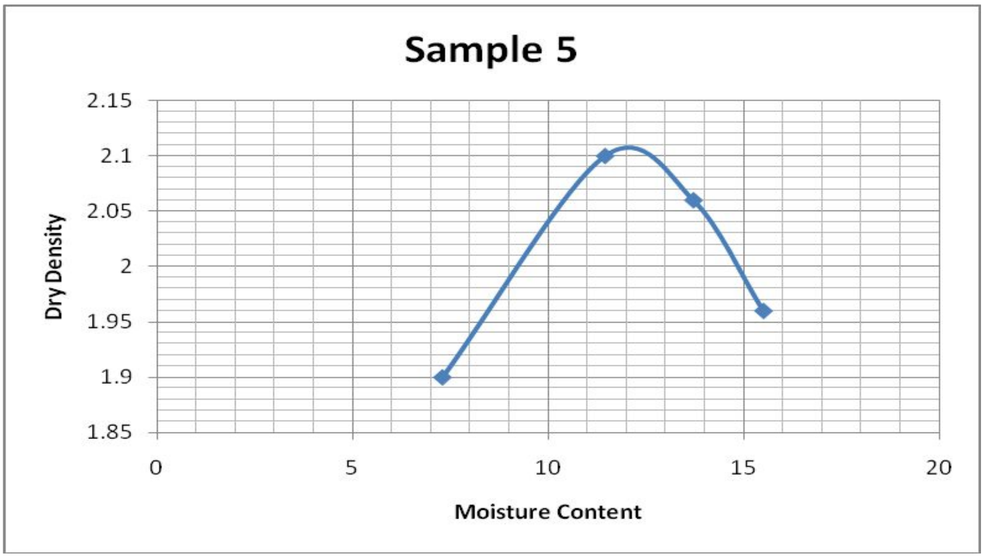

Figure 5: Dry density vs Moisture content for Sample 5

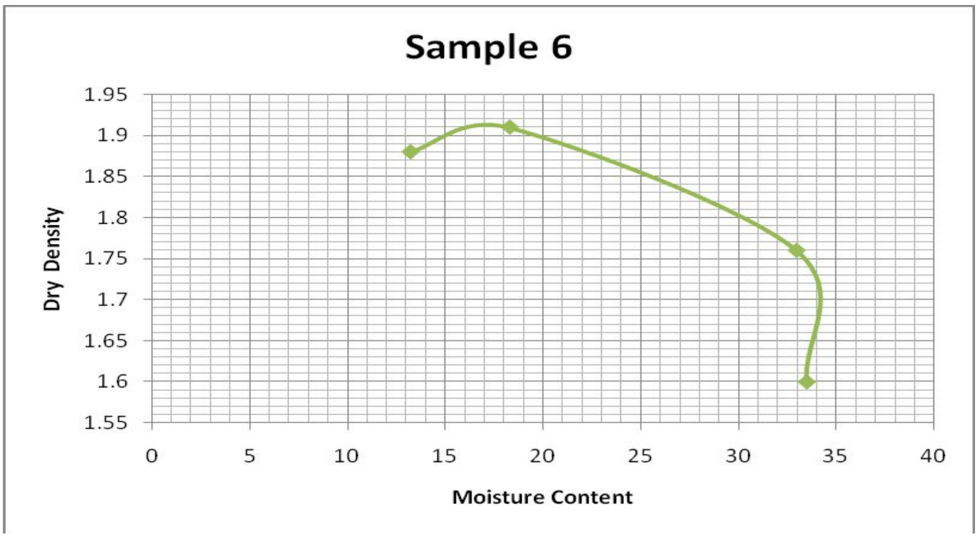

Figure 6: Dry density vs Moisture content for Sample 6

The local maximum and minimum of a second – order polynomial fit can be ascertained by setting the derivatives of Eqn 3, with respect to w equal to zero or

$$\frac{d(Yd)}{dw} = \frac{d(Yd)}{dw} = 2Aw + B = 0$$
Equ 4

and solving the resulting quadratic equation for the two roots of w, or

$$w = \frac{B}{3A} \pm \sqrt{\frac{4B^2 - 12AC}{6A}}$$ Equ 5

The value of w corresponding to $Y_{d\ max}$ is w_{opt} and $Y_{d\ max}$ is determined by substituting w_{opt} into
$Y_{d\ max} = Aw^2_{opt} + Bw_{opt} + C$ Equ 6

Polynomial function for the compaction
Sample 1
$Y_d = Aw^2 + Bw + C$ Equ 7

$\frac{dY_d}{dw} = 2Aw + B$ Equ 8

$2Aw + B$ Equ 9

At maximum dry density and optimum moisture content and substituting for Y_d and w in equation 7.
$2.2 = A9^2 + B9 + C$ Equ 10
$2.0 = A81^2 + B81 + C$ Equ 11
$1.89 = A3.01^2 + B3.01 + C$ Equ 12
A = -0.00023
B = 1.05446
C = 1.72812

Table 7: Equation representing relationship between moisture content and dry density of soil samples.

Samples	Equation
1	$Y_{d} = -0.0002w^2 + 1.0545w + 1.7281$
2	$Y_{d} = 0.0036w^2 - 0.1995w + 4.3646$
3	$Y_{d} = -0.0019w^2 + 0.0641w + 1.3800$
4	$Y_{d} = -0.0209w^2 + 0.8455w - 5.7607$
5	$Y_{d} = -0.0102w^2 + 0.2402w + 0.6922$
6	$Y_{d} = -0.0361w^2 + 1.1431w - 6.9188$

IV. Conclusion

Based on the results obtained from the laboratory tests carried on the six(6) samples from various locations within the study area it were established that

i. Soil sample 1, 2 and 4 belongs to group A-2-5 and samples 6 belongs to group A-2-7 respectively from the AASHTO soil classification system, and they are generally rated as excellent to good construction material with good drainage characteristic. Sample 3 and 5 belongs to group A-7-5 from the AASHTO soil classification system and are therefore described as highly compressible soil and therefore not satisfactory as a road construction material.
ii. Liquid limits for sample1, 2, 4 and 6 are less than 40 percent. This value is also an indication of a good sub grade rating and suitability of the soil for road construction.
iii. The grain size analysis test on samples shows that all the samples are well graded.
iv. The dry density of the studied soil samples generally decrease with decrease in moisture content, the best fitting between the moisture content and dry density of the soil samples was found by the quadratic

expression for sample 1 – 6 : ($Y_d = -0.0002w^2 + 1.0545w + 1.7281$; $Y_d = 0.0036w^2 - 0.1995w + 4.3646$; $Y_d = -0.0019w^2 + 0.0641w + 1.3800$; $Y_d = -0.0209w^2 + 0.8455w - 5.7607$; $Y_d = -0.0102w^2 + 0.2402w + 0.6922$; $Y_d = -0.0361w^2 + 1.1431w - 6.9188$), where Y_d is dry density in gm/cm^3 and w is moisture content in %.

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