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PREDICTION OF ELASTIC MODULUS FROM COMPESSIVE MODULUS OF LIME STABILIZED LATERITIC SOIL FOR MECHANISTIC DESIGN USING THE SPLIT CYLINDER

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ABSTRACT

In recent years there has been a change in philosophy in flexible pavement design from the more empirical approach to the mechanistic approach based on the elastic theory. The mechanistic approach is in the form of layered elastic theory which is being used by many agencies. Elastic theory based design methods require as input, the elastic properties of these pavement material for an effective design. In this study laterites were gotten from seven (7) local government areas in Rivers state. The laterites were classified using the AASHTO classification system, the properties obtained from the laterites indicates that it is an A-5 soil which is a silty-clay material. The material was mixed with different lime contents of 0,2,4,6,and 8% and compacted at the energy of Standard Proctor in 100mm diameter by 80mm long split cylindrical moulds, the compacted specimens were moist- cured and tested after 7, 14 ,21 and 28days. The CBR machine was used to load the specimen to failure through static load application. The failure loads as well as the horizontal and vertical strains were measured and used to predict Elastic modulus from compressive modulus using the SPSS programme, the result show that the Elastic and Compressive modulus increases with an increase in lime content up to 8% lime content, also the predicted values were close to the measured values with an average R^2 value of 92%, indicating that the predicted Elastic modulus can be used for mechanistic design of flexible pavement.

KEYWORDS: Prediction, Elastic Modulus, Compressive Modulus, Lateritic Soil, Mechanistic Design, Split Cylinder.

1. INTRODUCTION

In recent years there has been a change in philosophy in flexible pavement design from the more empirical approach to the mechanistic approach based on the elastic theory [7], [9] and [8]. Proposed by [11], this mechanistic approach in the form layered elastic theory is being used by increasing numbers of agencies. Elastic theory based design methods require as input the elastic properties of these pavement materials for an effective design. In contemporary flexible pavement design ,methods based on elastic theory requires that the elastic properties of the pavement material be known [5] concluded from their work that among the common methods of measurement of elastic properties which are (youngs, shear, bulk, complex, dynamic, double punch, resilient, and shell nomograph moduli) the resilient modulus is more appropriate for use in multilayer elastic theories. Pavement materials include Portland Cement Concrete; Asphalt Concrete Cement bound materials, compacted soils, rocks and sub-grades. They are materials that terminate by fracture at or slightly beyond the yield stress generally referred to as brittle materials. They are isotropic (ie displays the same properties in all directions) and are assumed to be linearly elastic up to a certain stress level (referred to as the elastic limit). Therefore knowledge of the elastic properties of pavement is very essential in elastic theory for the mechanistic design of flexible and rigid pavements, including overlays, in this design method the pavement structure is regarded as linear elastic multilayered system in which the stress-strain solutions of the materials are characterized by the Young's Modulus of Elasticity (E) and poisons ratio (µ). The stress strain behaviour of a pavement material is normally expressed in terms of an elastic or resilient modulus. For cementitious stabilized materials, the selection of an appropriate modulus value to represent the material for design is complicated not only because of the difficulty in testing but also because different test methods give different values [12] and [13]. The relationship above is generally nonlinear. Because of these difficulties [14] recommended using a relationship between flexural strength and the modulus of elasticity in lieu of testing. Numerous investigators have reported data relating strength and the modulus of elasticity of various cementitious stabilized materials.

[15] Examined the data published by [16][17][18] and others. From their examination they concluded that different relationships exist dependent upon the quality of the material been stabilized. They classified the material reported as lean concrete; cement bound granular material and fine grained soil cement. For a given strength level, they found the lean concrete to have the highest modulus and fine grain soil cement to have to have the lowest. [19][20][21] investigated the stress strain behavior of several soil cements, from their work an equation was developed that relates the resilient modulus in flexure to the compressive strength, cement content and a material constant which must be established for each material. The equation is as presented below;

$$E_r = K_f * 10^{\mu(CS)}$$

compressive strength and durability tests. Laterites are a group of highly weathered soils formed by the concentration of hydrated oxides of iron and aluminum [6].The soil name "**Laterites**" was coined by Buchanan, in India, from a Latin word "**later**" meaning brick. This first reference is from India, where this soft, moist soil was cut into blocks of brick size and then dried in the sun. The blocks became irreversibly hard by drying and were used as building bricks. Soils under this classification are characterized by forming hard, impenetrable and often irreversible pans when dried [4]. Laterites and lateritic soils form a group comprising a wide variety of red, brown, and yellow, fine-grained residual soils of light texture as well as nodular gravels and cemented soils [3]. They are characterized by the presence of iron and aluminum oxides or hydroxides, particularly those of iron, which give the colors to the soils. However, there is a pronounced tendency to call all red tropical soils Laterites and this has caused a lot of confusion.

The term Laterites may be correctly applied to clays, sands, and gravels in various combinations while "lateritic soils" refers to materials with lower concentrations of oxides. [1] states that the correct usage of the term Laterites is for "a massive vesicular or concretionary ironstone formation nearly always associated with uplifted peneplams originally associated with areas of low relief and high groundwater".

[2] named Laterites based on hardening, such as "ferric" for iron-rich cemented crusts, "alcrete" or bauxite for aluminum-rich cemented crusts, "ealcrete" for calcium carbonate-rich crusts, and "secrete" for silica rich cemented crusts . Other definitions have been based on the ratios of silica (SiO_2) to sesquioxides ($Fe_2O_3 + Al_2O_3$). In Laterites the ratios are less than 1.33. Those between 1.33 and 2.0 are indicative of lateritic soils, and those greater than 2.0 are indicative of non-lateritic soils. Most Laterites are encountered in an already hardened state. When the Laterites are exposed to air or dried out by lowering the groundwater table, irreversible hardening occurs, producing a material suitable for use as a building or road stone. The lateritic soils behave more like fine-grained sands, gravels, and soft rocks. Laterites typically have a porous or vesicular appearance which may be self-hardening when exposed to

drying; or if they are not self- hardening, they may contain appreciable amounts of hardened Laterites rock or lateritic gravel.

The behaviour of laterite soils in pavement structure has been found to depend mainly on their particle-size characteristics, the nature and strength of the gravel particles, the degree to which the soils have been compacted, as well as the traffic and environmental conditions. Well-graded laterite gravels perform satisfactorily as unbound road foundations. However, their tendency to be gap-graded with depleted sand-fraction, to contain a variable quantity of lines, and to have coarse particles of variable strength which may break down, limits their usefulness as pavement materials on roads with heavy traffic [6]. Lateritic gravels that possess adequate strength, are not over compacted, and are provided with adequate drainage do perform well in pavement structures.

Weak indurate gravels generally have a tendency to break down during compaction and under repeated traffic loading. The situation may be worsened by the presence of water due both to its softening effect on the soil and to the strength reduction it causes. The laterized soils work well in pavement construction particularly when their special characteristics are carefully recognized. Laterites, because of their structural strength, can be very suitable sub-grades. Care should be taken to provide drainage and also to avoid particle break-down from over compaction. Subsurface investigation should be made with holes at relatively close spacing, since the deposits tend to be erratic in location and thickness. In the case of the lateritic soils, sub grade compaction is important because the leaching action associated with their formation tends to leave behind a loose structure. Drainage characteristics, however, are reduced when these soils are disturbed. The harder types of Laterites should make good base courses. Some are even suitable for good quality airfield pavements. The softer Laterites and the better lateritic soils should serve adequately for sub base layers. Although Laterites are resistant to the effects of moisture, there is a need for good drainage to prevent softening and breakdown of the structure under repeated loadings.

Laterites can provide a suitable low-grade wearing course when it can be compacted to give a dense, mechanically stable material for earth roads; however, it tends to corrugate under road traffic and becomes dusty during thy weather. In wet weather, it scours and tends to clog the drainage system. To prevent corrugating, this is associated with loss of fines; a surface dressing may be used. Lateritic soils are products of tropical weathering with consistency varying from very soft to extremely hard varieties . The hardness of these materials changes with the continuous cycles of wetting and drying. The presence of these soils ovetheir use as a highway road airfield construction material very convenient and economical. However there is a deart of information on the tensile and elastic properties of the stabiled material, this has resulted in the use of field performance and empirical or semi empirical tests like the Califonia Bearing Ratio (CBR) and unconfined compression test for pavement designs in these regions of the world .The CBR is entirely empirical and cannot be considered as even attempting to measure any basic property of the soil.The CBR of a soil can only be considered as an undefinable index of its strength, which for any particular soil is dependent on the condition of the material at the time of testing. In the modern world today many agencies are beginning to use pavement systems based on the elastic theory where the material will be characterized in terms of its tensile and elastic strength. However in this paper some lateritic soils have been obtained in Rivers State stabilized with with lime and tested using one indirect tensile testing technique SPLIT CYLINDER (SC) to predict their elastic modulus from compressive modulus for use in pavement design.

II. MATERIALS AND METHOD

The laterite used were obtained from existing borrow pits in seven (7) local government area in Rivers State namely Emohua, Obio/Akpor, Ikwerre, Port Harcourt, Eleme, Etche, and Oyigbo. The properties of the laterites are indicated in Table 1.

Table 1: Properties of Lateritic soils from the seven Local Government Areas in Rivers State

Properties	**Values**						
	Emohua	Obio/ Akpor	Ikwerre	Port Harcourt	Eleme	Etche	Oyigbo
Liquid limit %	43	47	45	53	40	38	34
Plastic limit %	25	32	25	32	21	17	19
Plasticity Index (PI)	18	15	20	21	19	21	15
Group index (GI)	11	11	10	11	13	11	15
AASHTO Class	A-5	A-5	A-5	A-5	A-4	A-4	A-5
Natural moisture content (%)	16	18	15	21	17	17	18
Optimum moisture content %	14.25	13.50	14.00	15.50	14.20	15.60	14.50
Maximum Dry Density (kg/m^3)	1820	1780	1835	1958	1835	1790	1840
% passing No. 200 sieve size (75µn(	43	40	45	50	38	40	38

Table 2: Chemical Analysis of Lime

Composition	$Ca(OH)_2$	CaO	$CaCO_3$	I_2O_3	Fe_2O_3	S_1O_2	mgO	H_2O
Percent	71.3	6.0	6.3	0.18	0.04	11.0	4.19	0.09

Prior to the tensile and compressive strength tests, the dry density-moisture content relationships for the laterites were determined by compaction test, since all the laterites obtained from the various Local Government Areas fall in the same soil group using the AASHTO classification system. A-5 and A-4 soils which are all silt clay materials with more than 35% passing the 75µm sieve. The proctor method was adopted and the specimens were prepared and tested in accordance with BS 1377:1975. Before the preparation of the specimens, the laterites were all air dried and broken down to smaller form/units, with utmost care being taken as not to reduce the size of the individual particles. The samples were prepared by adding the required quantity of the stabilizer and water and then properly mixed by hand. Efforts were made to prepare the specimens to the maximum dry density and optimum moisture content of the respective mixtures. The required numbers of experimental units were prepared for each mix by the same personal so that strict control on quality could be maintained.

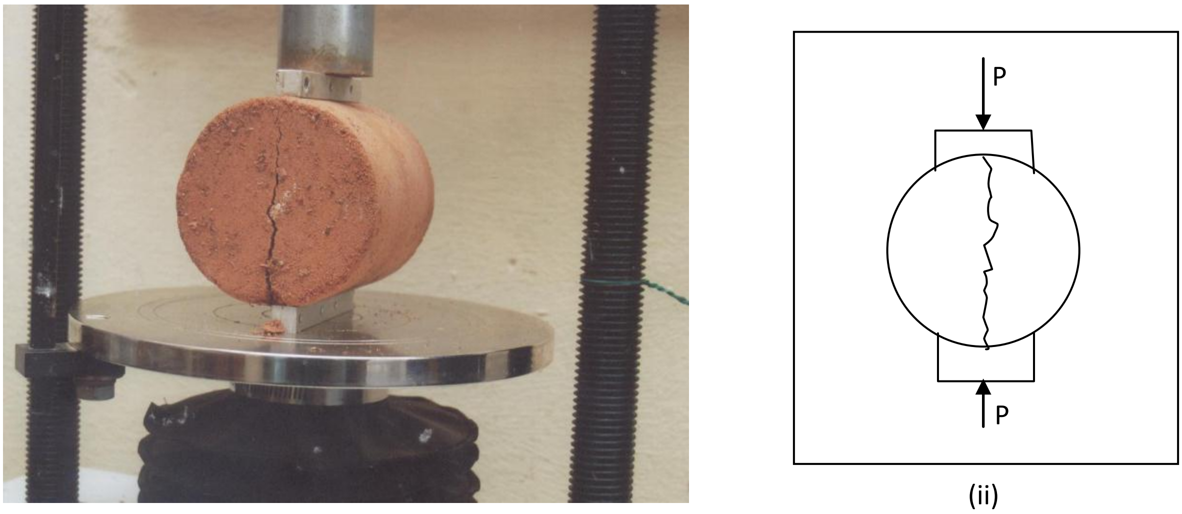
The test specimen had the dimensions of 100mm diameter by 80mm height and a total of 60 samples were prepared for the different levels of stabilization and a breakdown of the specimen into test units is shown in Table 3.

Table 3: Break down of specimen into test units silty clay materials (A-5) soil

		AGE (DAYS)			
TEST METHOD	LIME CONTENT (%)	7	14	21	28
Split Cylinder (SC)	0%	3	3	3	3
	2%	3	3	3	3
	4%	3	3	3	3
	6%	3	3	3	3
	8%	3	3	3	3

The specimens were moist cured for 7, 14, 21 and 28 days at constant moisture content and at laboratory temperature of about 28°C. The specimens were stored in plastic containers with moist sawdust to prevent moisture loss during curing period and to preserve the moulding as much as possible.The CBR machine was used for all tests

Brazilian Split-Cylinder Test



(ii)

(i) test

Figure 1: Brazilian split-cylinder test (i) Test (ii) arrangement

In the Brazilian split-cylinder test a compressive strip load was applied to the cylindrical specimen along two opposite generators. This condition set up an almost uniform tensile stress over the vertical diametrical plane, and fracture (splitting) of the specimen occurred along the loading plane (Figure 1). The indirect tensile strength at failure is given as in equation 1

$$\sigma_t = \frac{2P}{\pi dt} \qquad (1)$$

Where;

P = load at failure in N

d = specimen diameter in mm

t = specimen thickness in mm

After obtaining the tensile strength of the material using the indirect tensile strength test methods. The strains (vertical and horizontal) were measured using strain gauges Demec No. 3463 strain gauge, to load the specimen the bearing strips were first positioned and aligned. The plunger of the CBR machine was then made to site on upper bearing strip before the load gauge was set on zero. The strain measuring tags were attached to each of the ends along the axes using super glue". Load was continuously applied (With few seconds shock to allow for strain gauging). The loading was done until failure load was obtained. Gage readings were taken at both ends so that the average of two vertical and two horizontal strain measurements were determined for each increment of load, the vertical and horizontal strains were recorded directly from Deme 3463 strain gage.Equations (1) was used to generate the tensile strength of the soil-lime mixture for the indirect tensile strength testing technique used.

III. DEVELOPED MODELS FOR PREDICTING ELASTIC MODULUS USING SPSS

The following were the steps undertaken to develop the models that can be used to predict elastic modulus from compressive modulus of lateritic soils stabilized with lime content;

1. Determine the elastic modulus of the soil mixture using the different indirect tensile testing techniques for the various lime contents
2. Determine the compressive modulus of the soil mixture using the different indirect tensile testing techniques for the various lime content
3. Obtain the logarithm of both elastic and compressive moduli for the different indirect tensile testing techniques for the various lime content
4. Write a non-linear regression equation that satisfies the condition of the proposed general form of the elastic - compressive model
5. Input stringed variables into the SPSS software for non linear analysis
   Note: the proposed model is of the form;

$$E_M = a * C_M^{0.435 \ln b} \qquad 2$$

Where;

E_M = elastic modulus

C_M = compressive modulus

a, b, c = experimentally determined co-efficient from non linear regression.

From equation 4.1, the logarithm form can be expressed as,

$$Log(E_M) = Log\left[a * C_M^{0.435 \ln b}\right] \qquad 3$$

For convenience of use in the SPSS software the independent variable was expressed in the natural logarithm form. That is,

$$Log(E_M) = \frac{1}{2.3} Ln\left[a * C_M{}^{0.435 \ln b}\right] \qquad 4$$

Developing Proposed Elastic - Compressive Moduli Models Using Non Linear Regression Approach in SPSS

A non linear model is one in which at least one of the parameters appear nonlinearly (Prajneshu, No Date). More formally, in a nonlinear model, at least one derivative with respect to a parameter should involve that parameter. To solve the non linear regression using SPSS the variables (dependent and independent) were first of all collated into different cells in the "**Data View**" dialogue box. Next these variables were stringed and coded into another dialogue box called the "**Variable View Cell**". Finally model syntax was developed that satisfies the condition of the general form of the non linear model (Draper and Smith, 1998).

- **Non Linear Model Syntax**

The non linear model syntax is of the form as shown below;

$$Y = 0.435 * Ln\left[a * (C_M ** (0.435 * \ln b))\right] \qquad 5$$

Where,

Y = dependent variable = Log (E_M)

C_M = independent variable

a and b are co-efficients to be determined from the non linear regression equation.

Equation 5 is the non linear syntax model that is synonymous with the general form of the proposed model used for analysis in the SPSS program.

Finally, in SPSS the command (**) means raising a variable to the power of the coefficient in the same bracket while the command (*) means multiplication.

IV RESULT AND DISCUSSION

Split Cylinder Test

Table 4: Variations @ 7 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Elastic Modulus, E (MPa)
0	1333.333	1100
2	1536.364	1253.521
4	2557.522	1506.998
6	2761.905	1735.219
8	2814.081	1887.805

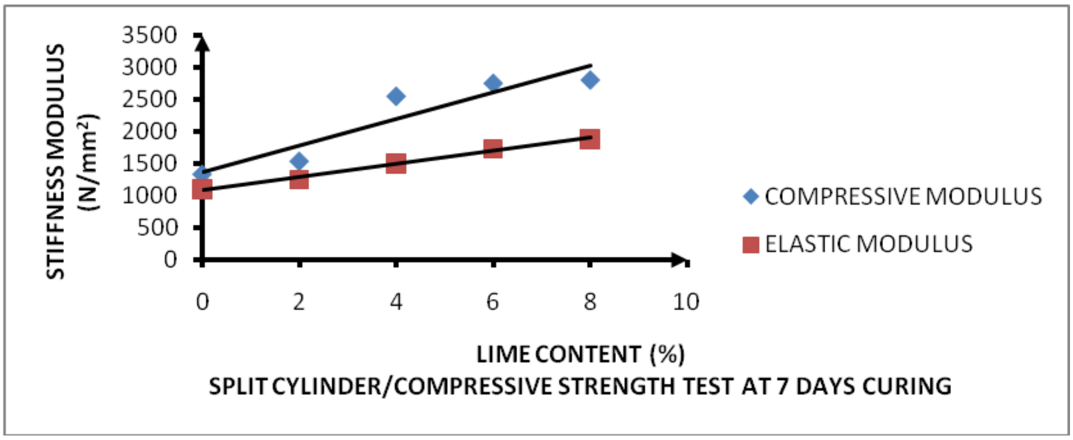


Figure 2 : Split Cylinder Stiffness Variation with Lime Content @ 7 Days Curing

Table 5: Variations @ 14 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Elastic Modulus, E (MPa)
0	1364.706	851.3514
2	2096.33	910.5691
4	2533.793	1578.488
6	2818.408	1764.331
8	2900	1982.885

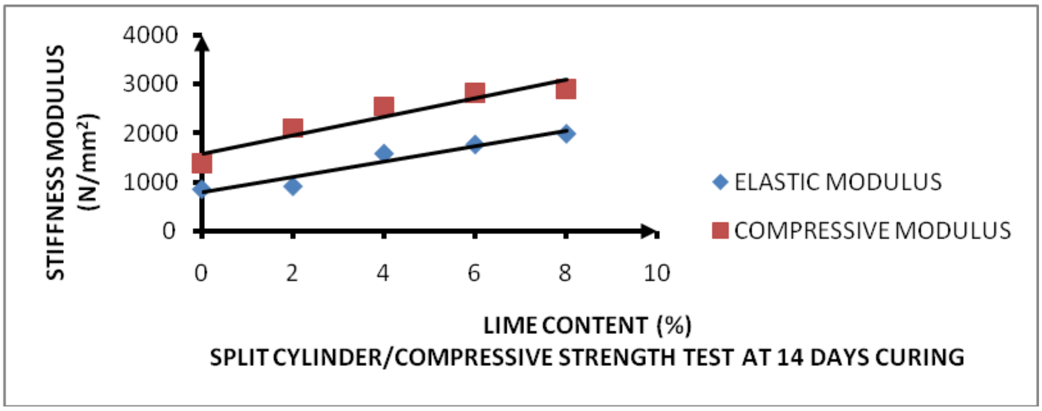


Figure 3: Split Cylinder Stiffness Variation with Lime Content @ 14 Days Curing

Table 6: Variations @ 21 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Elastic Modulus, E (MPa)
0	1273.585	794.7368
2	1692.41	889.5582
4	2013.17	1569.604
6	2125	1748.466
8	2279.767	1775.201

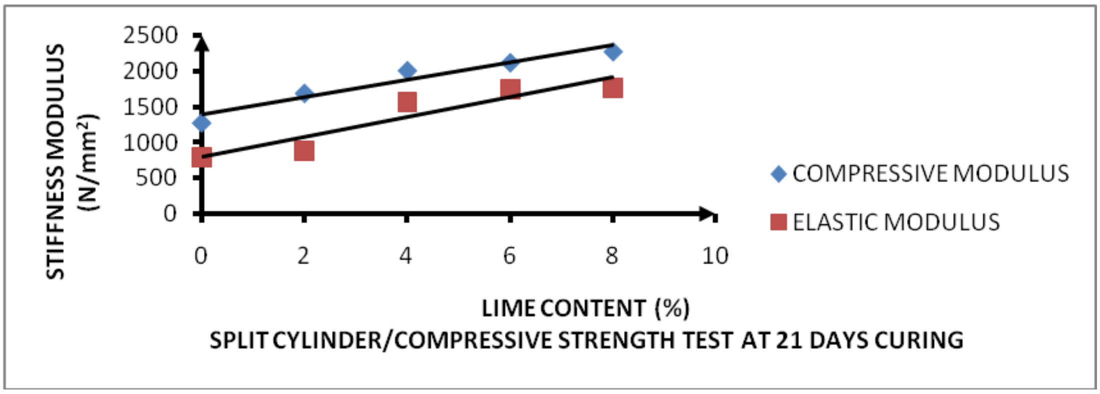


Figure 4: Split Cylinder Stiffness Variation with Lime Content @ 21 Days Curing

Table 7: Variations @ 28 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Elastic Modulus, E (MPa)
0	1166.667	783.5052
2	1611.86	883.4842
4	1871.93	1456.763
6	1980.952	1621.711
8	2233.032	1945.931

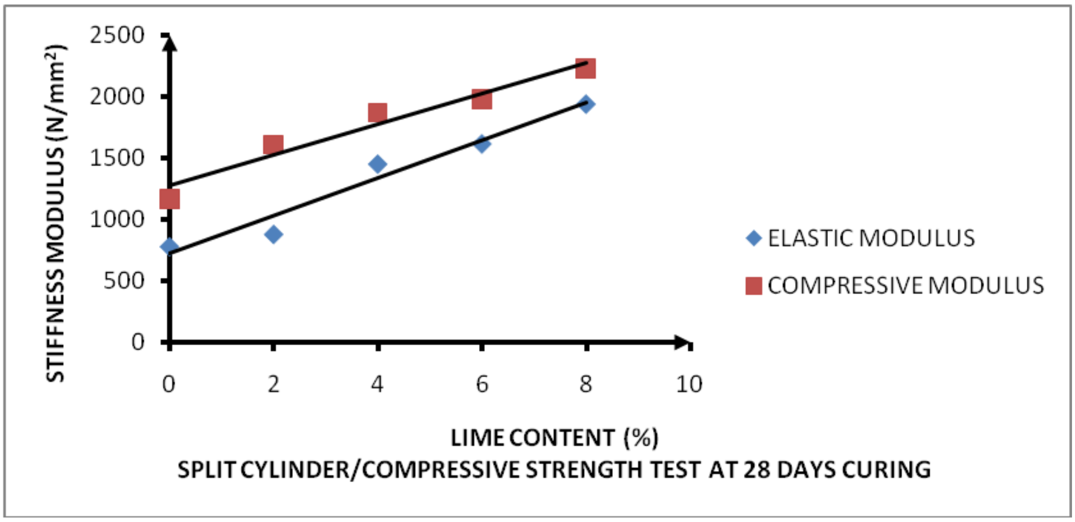


Figure 5: Split Cylinder Stiffness Variation with Lime Content @ 28 Days Curing

variation of Elastic Modulus (Em) and compressive modulus (Cm) of lateritic soil with lime content .

_For the various ages of curing the elastic modulus was increasing with increasing lime content, this goes to show that at 0% lime content the elastic modulus was low, but with the addition of lime it was increased see table(4-7) and fig(2-5) which means that lime increases the elastic modulus of lateritic soil. More so the tensile stress, compressive strain, and tensile strain were all increasing with increasing lime content as in (table 8-12), this finding is in line with Miller et al (2006), Thompson(1989). However the increase in elastic modulus was linear up to the highest lime content of 8% this could be as a result of the chemical reactions that took place during the process of stabilization, the addition of lime supplied an excess Ca^{+2} which goes to replace the weaker metallic cat-ions from the exchange complex of the soil. The exchange of this cat ions causes a reduction in the diffused water layer there by allowing clay particles to approach each other closely or flocculate, this finding is in line with Little et al(1995) the same trend was observed for all other ages of curing. Also the compressive modulus was increasing linearly with an increase in lime content, though the compressive modulus was higher than elastic modulus as shown in the table (4-7) and fig(2-5), This shows that compressive modulus is a very important parameter in the soil which is to be used as a pavement material, the compressive modulus needs to be higher since soils for highway pavement generally are good in compression this finding is in line with Larsen and Nussbaum (2005).

Table8: Split Cylinder Test Results @ Failure Loads For 7 Days Curing

Lime Content (%)	Elastic Modulus, E (MPa)	Tensile Stress (MPa)	Compressive Strain (10^{-4})	Tensile Strain (10^{-4})
0	1100	0.0044	0.08	0.4
2	1253.521	0.0089	0.25	0.71
4	1506.998	0.0969	1.41	6.43
6	1735.219	0.135	1.72	7.78
8	1887.805	0.1548	2.24	8.2

Table9: Split Cylinder Test Results @ Failure Loads For 14 Days Curing

Lime Content (%)	Elastic Modulus, E (MPa)	Tensile Stress (MPa)	Compressive Strain (10^{-4})	Tensile Strain (10^{-4})
0	851.3514	0.0063	0.16	0.74
2	910.5691	0.0112	0.31	1.23
4	1578.488	0.1086	1.51	6.88
6	1764.331	0.1385	1.73	7.85
8	1982.885	0.1622	2.46	8.18

Table10: Split Cylinder Test Results @ Failure Loads For 21 Days Curing

Lime Content (%)	Elastic Modulus, E (MPa)	Tensile Stress (MPa)	Compressive Strain (10^{-4})	Tensile Strain (10^{-4})
0	848.3146	0.00755	0.21	0.89
2	889.5582	0.0443	0.62	4.98
4	1569.604	0.1229	1.51	7.83
6	1748.466	0.1425	1.79	8.15
8	1949.07	0.199	3.13	10.21

Table11: Split Cylinder Test Results @ Failure Loads For 28 Days Curing

Lime Content (%)	Elastic Modulus, E (MPa)	Tensile Stress (MPa)	Compressive Strain (10^{-4})	Tensile Strain (10^{-4})
0	783.5052	0.0076	0.21	0.97
2	883.4842	0.0781	1.01	8.84
4	1456.763	0.1314	1.7	9.02
6	1621.711	0.1479	2.01	9.12
8	1945.931	0.3491	3.93	17.94

Table 12:Split Cylinder Test Calibration for Lime – Lateritic Soil Mixture

@ 7 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Log C_M (MPa)	Elastic Modulus, E (MPa)	Log E (MPa)
0	1333.333	3.124939	1100	3.041393
2	1536.364	3.186494	1253.521	3.098132
4	2557.522	3.407819	1506.998	3.178113
6	2761.905	3.441209	1735.219	3.239354
8	2814.081	3.449337	1887.805	3.275957

By applying equation 5 in the SPSS program, the experimental co-efficients were determined from table 1a(ii) is as follows;

a = 12.793; b = 4.16; [See appendix A: Table 1a (i)]

The resulting prediction model equation in syntax form becomes;

$$Y = 0.435 * Ln\left[12.793 * (C_M **(0.435 * \ln 4.6))\right] \qquad 6$$

Since Y = Log (E_M), the actual prediction model equation can be written as;

$$LogE_M = Log\left[12.793\left(C_M\right)^{0.435 \ln b}\right] \qquad 7$$

$$E_M = 10^{0.435 Ln\left[12.793 (C_M)^{0.435 \ln 4.16}\right]} \qquad 8$$

Equation 8 can be used to predict elastic modulus of lime – lateritic soil mixtures cured at 7 days curing for given compressive modulus with a correlation value of $R^2 = 0.903$.

Table 13:Split Cylinder Test Calibration for Lime – Lateritic Soil Mixture

@ 14 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Log C_M (MPa)	Elastic Modulus, E (MPa)	Log E (MPa)
0	1364.706	3.135039	851.3514	2.930109
2	2096.33	3.32146	910.5691	2.959313
4	2533.793	3.403771	1578.488	3.198241
6	2818.408	3.450004	1764.331	3.24658
8	2900	3.462398	1982.885	3.297298

By applying equation 5 in the SPSS program, the experimental co-efficients were determined from table (2aii) is as follows;

a = 0.025; b = 25.399; [See appendix A: Table 2a (i)]

The resulting prediction model equation in syntax form becomes;

$$Y = 0.435 * Ln\left[0.025 * (C_M **(0.435 * \ln 25.399))\right] \qquad 9$$

Since Y = Log (E_M), the actual prediction model equation is can be written as;

$$LogE_M = Log\left[0.025 (C_M)^{0.435 \ln 25.399}\right] \qquad 10$$

$$E_M = 10^{0.435 Ln\left[0.025 (C_M)^{0.435 \ln 25.399}\right]} \qquad 11$$

Equation 11 can be used to predict elastic modulus of lime – lateritic soil mixtures cured at 14 days curing for given compressive modulus with a correlation value of $R^2 = 0.874$.

Table 14:Split Cylinder Test Calibration for Lime – Lateritic Soil Mixture

@ 21 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Log C_M (MPa)	Elastic Modulus, E (MPa)	Log E (MPa)
0	1273.585	3.105028	848.3146	2.928557
2	1692.41	3.228506	889.5582	2.949174
4	2013.17	3.30388	1569.604	3.19579
6	2125	3.327359	1748.466	3.242657
8	2279.767	3.35789	1949.07	3.289827

By applying equation 5 in the SPSS program, the experimental co-efficients were determined from table (3aii) is as follows;

a = 0.003; b = 51.401; [See appendix A: Table 3a (i)]

The resulting prediction model equation in syntax form becomes;

$$Y = 0.435 * Ln\left[0.003 * (C_M **(0.435 * \ln 51.401))\right] \qquad 12$$

Since Y = Log (E_M), the actual prediction model equation is can be written as;

$$LogE_M = Log\left[0.003\left(C_M\right)^{0.435\ln 51.401}\right] \qquad 13$$

$$E_M = 10^{0.435Ln\left[0.03(C_M)^{0.435\ln 51.401}\right]} \qquad 14$$

Equation 14 can be used to predict elastic modulus of lime – lateritic soil mixtures cured at 21 days curing for given compressive modulus with a correlation value of $R^2 = 0.907$

Table 15:Split Cylinder Test Calibration for Lime – Lateritic Soil Mixture

@ 28 Days Curing

Lime Content (%)	Compressive Modulus, C_M (MPa)	Log C_M (MPa)	Elastic Modulus, E (MPa)	Log E (MPa)
0	1166.667	3.066947	783.5052	2.894042
2	1611.86	3.207327	883.4842	2.946199
4	1871.93	3.27229	1456.763	3.163389
6	1980.952	3.296874	1621.711	3.209973
8	2233.032	3.348895	1945.931	3.289127

By applying equation 5 in the SPSS program, the experimental co-efficients were determined from table (4aii) is as follows;

a = 0.003; b = 52.165; [See appendix A: Table 4a (i)]

The resulting prediction model equation in syntax form becomes;

$$Y = 0.435 * Ln\left[0.003 * (C_M **(0.435 * \ln 52.165))\right] \qquad 15$$

Since Y = Log (E_M), the actual prediction model equation is can be written as;

$$LogE_M = Log\left[0.003\left(C_M\right)^{0.435\ln 52.165}\right] \qquad 16$$

$$E_M = 10^{0.435Ln\left[0.03(C_M)^{0.435\ln 52.165}\right]} \qquad 17$$

Equation 17 can be used to predict elastic modulus of lime – lateritic soil mixtures cured at 28 days curing for given compressive modulus with a correlation value of $R^2 = 0.924$.

<u>Verification of derived model for split cylinder test for lime lateritic soil mixture</u>

<u>Table 16: 7 Days Curing</u>

Lime Content(%)	C_M	E_M(Measured)	E_M(Predicted)
0	1333.333	1100	1108.428
2	1536.364	1253.521	1207.67
4	2557.522	1506.998	1643.805
6	2761.905	1735.219	1722.07
8	2814.081	1887.805	1741.679

The predicted E_M values was obtained by applying equation 8 while the measured was obtained from lab

theL laboratory

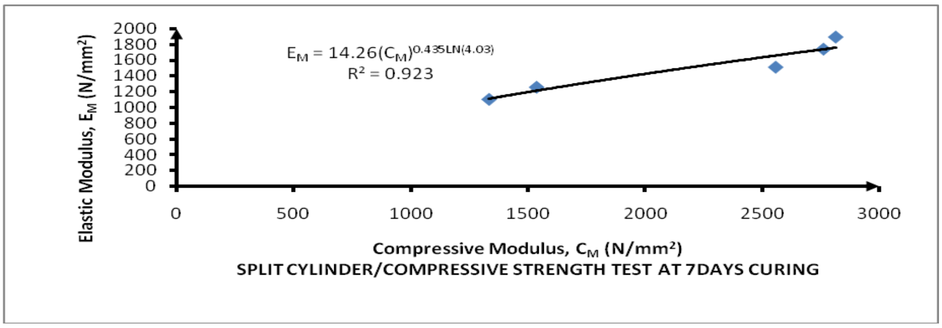


Figure :6 Prediction of Elastic Modulus from compressive strength using SC @ 7DAYS

Verification of derived model for split cylinder test for lime lateritic soil mixture

Table 17: 14 Days Curing

Lime Content(%)	C_M	E_M(Measured)	E_M(Predicted)
0	1364.706	851.3514	750.2398
2	2096.33	910.5691	1219.63
4	2533.793	1578.488	1511.488
6	2818.408	1764.331	1705.062
8	2900	1982.885	1761.045

The predicted E_M values was obtained by applying equation 11 while the measured was obtained from the laboratory.

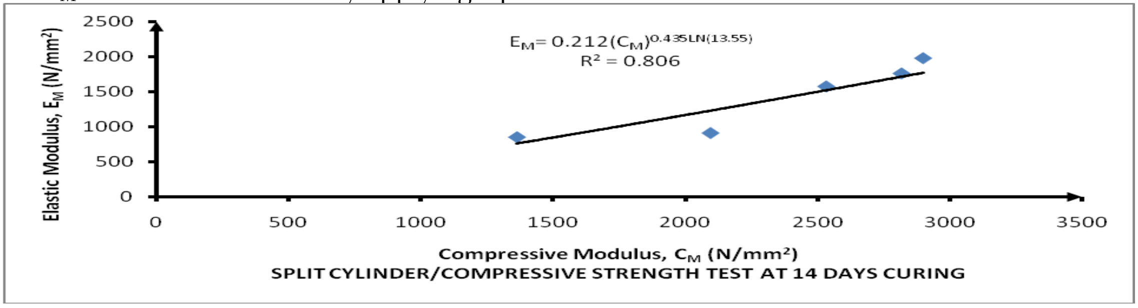


Figure:7 Prediction of Elastic Modulus from compressive strength using SC @ 14 days

Verification of derived model for split cylinder test for lime lateritic soil mixture

Table 18: 21 Days Curing

Lime Content (%)	C_M	E_M (Measured)	E_M (Predicted)
0	1364.706	851.3514	750.2398
2	2096.33	910.5691	1219.63
4	2533.793	1578.488	1511.488
6	2818.408	1764.331	1705.062
8	2900	1982.885	1761.045

The predicted E_M values were obtained by applying equation 14 while the

measured was obtained from the laboratory.

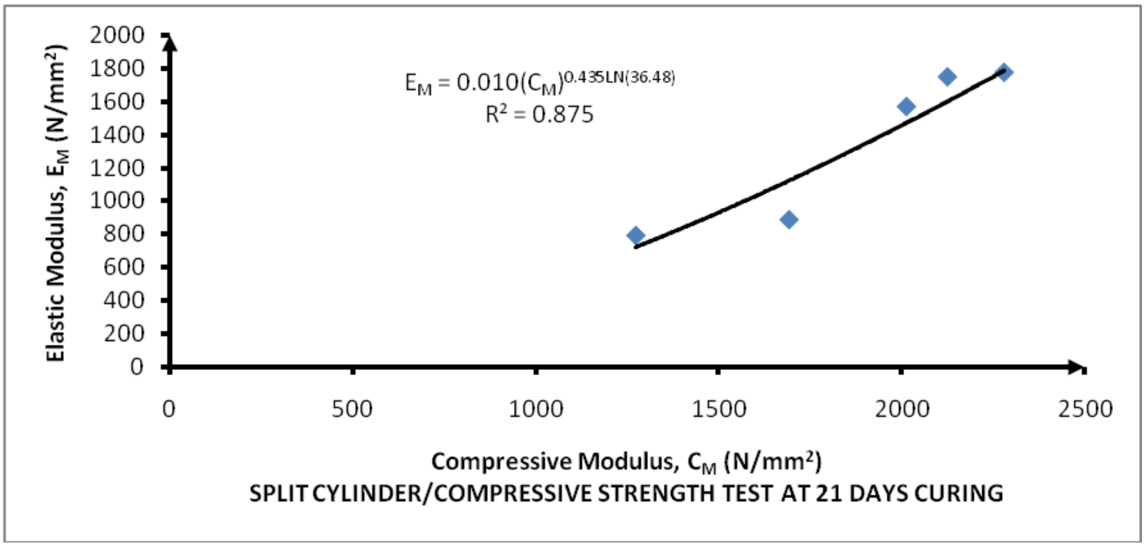


Figure:8 Prediction of Elastic Modulus from compressive strength using SC @ 21 days

Verification of derived model for split cylinder test for lime lateritic soil mixture

Table 19: 28 Days Curing

Lime Content (%)	C_M	E_M (Measured)	E_M (Predicted)
0	1166.667	783.5052	701.4001
2	1611.86	883.4842	1129.866
4	1871.93	1456.763	1408.79
6	1980.952	1621.711	1531.47
8	2233.032	1945.931	1827.424

The predicted E_M values was obtained by applying equation 17 while the measured was obtained from the laboratory.

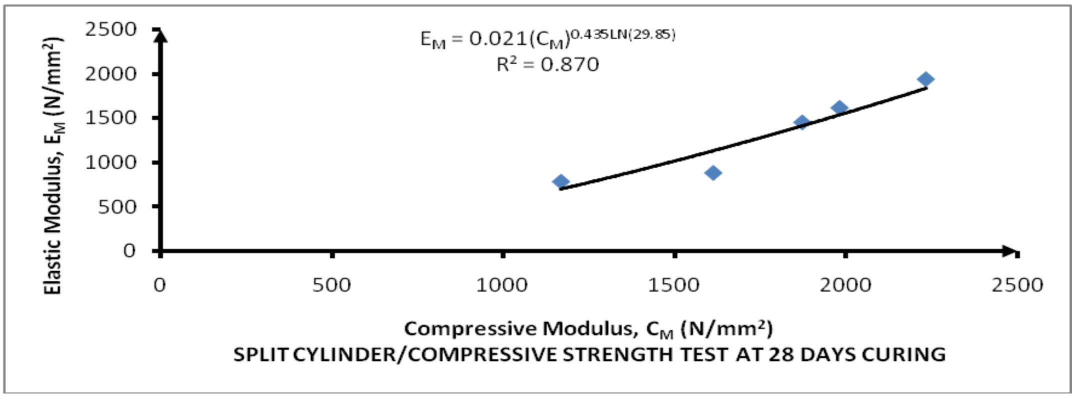


Figure:9 Prediction of Elastic Modulus from compressive strength using SC @ 28 days

Verification of derived Predictive Models

Part of the work was devoted to the verification of the derived models developed by comparison with measured values. The method of verification was done through the use of multiple correlations by determining R^2 values as shown in the graphical plots, fig(6-9) the determination of R^2 was found to be very good with an average of 92% and above recalling that the model prediction for the elastic modulus is ok, since in highway engineering Elastic modulus is very essential mainly in the sub-base layer of the pavement.

V. CONCLUSIONS

The following conclusions can be drawn from this study

1. The Elastic and Compressive modulus increases with an increase in lime content up to 8% lime content.
2. The predicted values were close to the measured values with an average R^2 value of 92%
3. The models developed from this work can be used to predict Elastic modulus from compressive modulus using the Split cylinder at different days of curing using lime.
4. The predicted Elastic Modulus can be used for the Mechanistic design of pavement.

LIST OF ITERATION TABLES USED FOR CALIBRATION OF LIME-LATERITIC SOIL MIXTURE FOR SPLIT CYLINDER

Table 1a (i): Iteration History for 7Days Curing

Iteration Number(a)	Residual Sum of Squares	Parameter	
		a	b
0.1	11587515.216	14.260	.605
1.1	41548.360	14.303	4.025
2.1	41548.032	14.295	4.025
3.1	41458.156	13.584	4.085
4.1	41419.791	13.538	4.090
5.1	41387.877	13.097	4.130
6.1	41376.761	13.022	4.138
7.1	41372.959	12.830	4.156
8.1	41372.211	12.819	4.158
9.1	41372.154	12.795	4.160
10.1	41372.153	12.793	4.160
11.1	41372.153	12.793	4.160

Derivatives are calculated numerically.

a. Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b. Run stopped after 11 iterations. Optimal solution is found.

Table 1a (ii) Parameter Estimates

	Parameter	Estimate	95% Confidence Interval	
			Lower Bound	Upper Bound
Asymptotic	a	12.793	-27.261	52.846
	b	4.160	.303	8.017
Bootstrap(a,b)	a	12.793	12.793	12.793
	b	4.160	4.160	4.160

a Based on 30 samples.
b Loss function value equals 41372.153.

Table 1a (iii) ANOVA

Source	Sum of Squares	df	Mean Squares
Regression	11585777.907	2	5792888.954
Residual	41372.153	3	13790.718
Uncorrected Total	11627150.060	5	
Corrected Total	426467.017	4	

Dependent variable: ELASTIC MODULUS
a R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .903.

Table 2a (i) Iteration History for 14 Days Curing

Iteration Number(a)	Residual Sum of Squares	Parameter	
		a	b
0.1	156489.898	.212	13.550
1.1	155705.343	.217	13.550
2.1	151304.385	.183	14.178
3.2	151280.085	.181	14.217
4.1	150855.677	.179	14.286
5.1	149341.506	.158	14.783
6.1	147824.859	.155	14.915
7.1	146532.955	.142	15.282
8.1	146233.271	.136	15.461
9.1	145021.582	.130	15.679
10.1	143867.609	.121	16.021
11.1	142501.406	.112	16.435
12.1	141533.655	.101	16.884
13.1	141327.555	.104	16.759
14.1	140860.916	.100	16.936
15.1	140466.554	.095	17.186
16.1	140084.836	.093	17.320
17.1	138960.963	.087	17.672
18.1	138596.988	.083	17.910
19.1	138210.524	.079	18.157
20.1	137283.998	.074	18.476
21.1	136999.360	.071	18.738
22.1	136210.079	.066	19.151
23.1	136053.327	.064	19.332
24.1	135138.509	.059	19.743
25.1	135094.580	.058	19.844
26.1	134908.154	.057	19.949

27.1	134383.941	.054	20.343
28.1	133961.010	.051	20.637
29.1	133693.751	.048	20.943
30.1	133559.193	.047	21.127
31.1	133113.498	.044	21.484
32.1	132987.836	.043	21.735
33.1	132625.296	.040	22.181
34.1	132505.757	.040	22.232
35.1	132313.823	.037	22.633
36.1	132222.958	.037	22.719
37.1	132144.077	.035	22.979
38.1	131934.775	.034	23.229
39.2	131883.979	.033	23.436
40.1	131794.074	.032	23.627
41.1	131699.669	.031	23.818
42.1	131632.176	.030	24.134
43.1	131602.282	.030	24.128
44.1	131538.752	.029	24.384
45.1	131508.925	.028	24.597
46.2	131458.391	.027	24.763
47.1	131442.473	.027	24.933
48.1	131410.295	.026	25.109
49.1	131395.263	.026	25.251
50.1	131384.541	.025	25.399

Derivatives are calculated numerically.

a Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b Run stopped after 50 iterations because it reached the limit for the number of iterations.

Table 2a (ii) Parameter Estimates

	Parameter	Estimate	95% Confidence Interval	
			Lower Bound	Upper Bound
Asymptotic	a	.025	-.214	.264
	b	25.399	-45.085	95.883
Bootstrap(a,b)	a	.025	-.154	.204
	b	25.399	13.285	37.514

a Based on 30 samples.

b Loss function value equals 131384.541.

Table 2a (iii) ANOVA

Source	Sum of Squares	df	Mean Squares
Regression	10958874.102	2	5479437.051
Residual	131384.541	3	43794.847
Uncorrected Total	11090258.643	5	
Corrected Total	1043372.660	4	

Dependent variable: ELASTIC MODULUS

a R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .874.

Table 3a (i) Iteration History for 21 Days Curing

Iteration Number(a)	Residual Sum of Squares	Parameter	
		A	b
0.1	90086.066	.010	36.480
1.1	88618.544	.010	36.480
2.1	88188.492	.009	37.166
3.1	88083.668	.009	37.679
4.1	87826.254	.009	37.778
5.2	87416.891	.008	38.564
6.1	87074.229	.008	39.143
7.1	86775.360	.008	39.686
8.1	86492.322	.007	40.405
9.1	86389.416	.007	40.611
10.2	86124.202	.007	41.215
11.1	85864.900	.006	41.922
12.1	85802.386	.006	42.195
13.1	85505.683	.006	42.974
14.1	85355.107	.006	43.385
15.1	85280.840	.006	43.825
16.1	85184.865	.005	44.246
17.1	85002.741	.005	44.789
18.1	84939.868	.005	45.339
19.1	84880.406	.005	45.434
20.1	84809.033	.005	46.327
21.1	84728.890	.005	46.216
22.1	84665.543	.004	46.627
23.2	84636.679	.004	46.982
24.1	84606.647	.004	47.179
25.2	84529.930	.004	47.649
26.1	84509.205	.004	48.051
27.1	84477.795	.004	48.218
28.1	84456.089	.004	48.880
29.1	84414.191	.004	48.929
30.1	84388.554	.004	49.329
31.1	84383.282	.004	49.543
32.1	84372.157	.004	49.682
33.1	84354.210	.004	50.020
34.1	84343.881	.003	50.333
35.1	84340.667	.003	50.677
36.1	84329.487	.003	51.161
37.1	84328.281	.003	51.066
38.1	84327.914	.003	51.099
39.1	84326.843	.003	51.287
40.1	84326.629	.003	51.340
41.1	84326.573	.003	51.390
42.1	84326.569	.003	51.397
43.1	84326.568	.003	51.402
44.1	84326.568	.003	51.401
45.1	84326.568	.003	51.401

Derivatives are calculated numerically.

a Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b Run stopped after 45 iterations. Optimal solution is found.

Table 3a (ii) Parameter Estimates

	Parameter	Estimate	95% Confidence Interval	
			Lower Bound	Upper Bound
Asymptotic	a	.003	-.027	.033
	b	51.401	-92.210	195.012
Bootstrap(a,b)	a	.003	.003	.003
	b	51.401	51.401	51.401

a Based on 30 samples.

b Loss function value equals 84326.568.

Table 3a (iii) ANOVA(a)

Source	Sum of Squares	df	Mean Squares
Regression	10010722.750	2	5005361.375
Residual	84326.568	3	28108.856
Uncorrected Total	10095049.318	5	
Corrected Total	907968.778	4	

Dependent variable: ELASTIC MODULUS

a R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .907.

Table 4a (i) Iteration History for 28 Days curing

Iteration Number(a)	Residual Sum of Squares	Parameter	
		a	b
0.1	100612.262	.021	29.550
1.1	87857.501	.022	29.550
2.1	86488.139	.019	30.779
3.1	86119.348	.019	30.670
4.1	85187.092	.018	31.412
5.1	84972.718	.017	31.811
6.1	84344.929	.017	32.095
7.1	83523.697	.015	32.890
8.1	82489.189	.014	33.590
9.1	81809.729	.013	34.250
10.1	81699.964	.013	34.727
11.1	81155.379	.013	34.883
12.1	80484.394	.012	35.704
13.1	79885.823	.011	36.350
14.1	79429.431	.010	36.933
15.1	78774.503	.010	37.751
16.1	78713.948	.009	38.006
17.2	78417.711	.009	38.332
18.1	77924.752	.009	39.007
19.1	77552.111	.008	39.782
20.1	76649.520	.007	41.334
21.1	76618.383	.007	41.479
22.1	76427.664	.007	42.033
23.1	76175.551	.006	42.693
24.1	75919.381	.006	43.207

25.1	75713.929	.006	43.992
26.2	75641.108	.006	44.023
27.1	75458.666	.005	44.981
28.1	75329.921	.005	45.073
29.1	75195.955	.005	45.949
30.1	75113.031	.005	45.999
31.1	74998.496	.005	46.873
32.2	74921.803	.005	46.949
33.1	74838.711	.004	47.783
34.1	74784.165	.004	47.794
35.1	74711.122	.004	48.435
36.1	74680.019	.004	48.965
37.1	74612.616	.004	49.221
38.1	74581.714	.004	49.699
39.1	74563.663	.004	49.996
40.1	74526.887	.004	50.378
41.1	74514.210	.004	50.726
42.2	74506.208	.004	50.901
43.1	74492.605	.004	51.191
44.1	74486.208	.003	51.503
45.1	74483.562	.003	51.590
46.1	74479.635	.003	51.844
47.1	74478.622	.003	51.888
48.2	74477.523	.003	52.127
49.1	74477.273	.003	52.107
50.1	74477.153	.003	52.165

Derivatives are calculated numerically.

a Major iteration number is displayed to the left of the decimal, and minor iteration number is to the right of the decimal.

b Run stopped after 50 iterations because it reached the limit for the number of iterations.

Table 4a (ii) Parameter Estimates

	Parameter	Estimate	95% Confidence Interval	
			Lower Bound	Upper Bound
Asymptotic	a	.003	-.024	.030
	b	52.165	-75.391	179.721
Bootstrap(a,b)	a	.003	-.016	.023
	b	52.165	29.420	74.909

a Based on 30 samples.

b Loss function value equals 74477.153.

Table 4a (iii) ANOVA

Source	Sum of Squares	df	Mean Squares
Regression	9858697.171	2	4929348.586
Residual	74477.153	3	24825.718
Uncorrected Total	9933174.324	5	
Corrected Total	978225.001	4	

Dependent variable: ELASTIC MODULUS

a R squared = 1 - (Residual Sum of Squares) / (Corrected Sum of Squares) = .924.

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