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Effect of Lime on Some Geotechnical Properties of Igumale Shale

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ABSTRACT

This paper reports the outcome of an investigation into the effect of lime on some geotechnical properties of Igumale shale, to ascertain its suitability for use as a modifier or stabilizer in the treatment of the shale. Classification tests, compaction test, California bearing ratio (CBR) and unconfined compressive strength (UCS) tests, were conducted on specimen of Igumale shale. Results of tests showed that Igumale shale was an A-7-6 soil, according to the AASHTO classification system. Liquid limit reduced from 72 % at 0 % lime to 60 % at 14 % lime content by dry weight of shale, the plastic limit increased from 27 % at 0 % lime to 41 % at 14 % lime content while the plasticity index reduced from 45% at 0% lime to 19% at 14% lime. The maximum dry density reduced from 1.51 Mg/m^3 to 1.35 Mg/m^3 at 14 % lime. The Unconfined Compressive Strength (UCS) results recorded maximum values of 1263 kN/m^3, 1400 kN/m^3 and 1480 kN/m^3 at 8 % lime content for 7, 14 and 28 days curing period respectively. At the optimum lime content, a maximum CBR value of 37 % was achieved. The improvements noticed in some of the geotechnical properties of Igumale Shale were not adequate for its use in roadwork. However, lime can be used as a modifier, in the stabilization of Igumale shale with cement or other additives. A third order polynomial model was found to predict reasonably well the relationship between strength indices (CBR and 7 day UCS) and the percentages of lime used.

KEYWORDS: Igumale shale, Lime stabilization, Modifier, Roadwork, Strength indices, Models.

INTRODUCTION

Infrastructural development in areas where problem soils are identified has been a major source of concern to the engineer. As such, infrastructures like roads, buildings, bridges to mention but a few within such areas normally undergo foundation problems, which lead to a reduction in the life span of such facilities.

Igumale town is the headquarters of Ado Local Government Area of Benue State in Nigeria. it is about 150 km from Makurdi, the State capital. It lies between latitude 6^0 30′ and 7^0 North, and longitude 7^0 30′ and 8^0 East, on the geological map of Nigeria

Igumale is a town underlain by shale as confirmed by Agbede (1998). Shale is a problems soil, especially the soft non-indurate type, which undergoes volumetric changes when subjected to changes in moisture content as a result of the annual rainy and dry season. This volumetric problem is well pronounced at Igumale as evident in cracks on buildings and roads within the town. Since there is an increasing shortage of good construction materials within localities where problem soils are encountered in addition to the high cost of haulage, what readily comes to mind is making the unsuitable materials fit for use.

GEOLOGY OF THE STUDY AREA

Geological study revealed that Igumale lies on Turonian Sediments. The Turonian was a period of wide marine transgression in Nigeria, the sea covered large parts of Eastern and Northern Nigeria. The sediments of this stage are mainly shale, limestone and less common sandstone; marls occur locally. Shale and limestone occur in alternating series.

Kogbe (1975) stated that in the Precambrian times, Nigeria consisted of uplifted continental landmass made up of basement sediments. The earliest marine transgression occurred during the middle –Albian and was mainly confined to southeastern Nigeria and Benue valley. During this tectonic phase, Abakaliki-Benue trough was formed (Raiment and Tait, 1983).

Reyment and Bengston (1985) described the sedimentation in the Abakiliki – Benue trough to occur in three cycles: The Asu river cycle (Mid – Albian to Cenomanian), Ezeaku cycle (Late Cenomanian to Mid- Turonain), The Awgu Cycle (Late Turonian to early Santonian).

Reyment and Bengston (1985) pointed out that the middle turonian limestones and shales of Igumale Division of the lower Benue region belong to the regressive phase of Ezeaku cycle.

SHALE AND ITS ASSOCIATED ENGINEERING PROBLEM

Shale, an abundant geological material accounting for approximately half the stratigraphic column (Kuenen, 1941) is frequently encountered in road cuts and other construction sites where economic and environmental considerations often recommend its use in the construction of embankments. O' Flaherty (1974) described shale as essentially a clayey material, which is very likely to break down in the presence of moisture and frost. Since shale is highly clayey in nature, it is subjected to swelling during the rainy season and shrinking during the dry season. Abeyesekera et al (1978) described shale as a notoriously unpredictable material, in which a number of failures have been reported involving settlement and shear failure of compacted shale embankments.

Richardson and Wiles (1990) described shale as any geologic material that is indurated, non-metamorphosed sediment composed mainly of clay or silt. Thus, shale will include siltstones, mudstones, mudshales, claystones, clayshales, arenaceous shales, siliceous shales, bituminous shales, and gypsiferrous shales. Here, indurated denotes a rock hardened by pressure, cementation or heat.

According to De Graft – Johnson et al (1973) shale is the product of highly consolidated clays, silts and sands or a mixture of all the three fractions of soil derived from the weathering of rocks. These fractions of soil are deposited in sea or riverbeds in layers and subjected to high overburden pressures, which lead to consolidation and diagenesis.

SOIL STABILIZATION/MODIFICATION

Attom et al (2000) described soil stabilization as the improvement of soil engineering and physical properties such as increasing its strength and reducing or eliminating its expansion.

According to Johnson et al (1988) stabilization infers improvement in both strength and durability. Osinubi and Katte (1991) referred to soil stabilization as the alteration or control of any soil property. It covers not only the increase or decrease of any soil property, but also the variation of any property with changes in environmental condition, namely moisture or pressure.

In soil modification, strength may or may not increase and the procedure is carried out to make the soil in question workable, through the modification of soil properties. Modifiers that are often used include cement, lime and bitumen, of which lime is the most commonly used. When lime is used as a modifier, it makes the soil workable for subsequent stabilization with cement or other agents.

Eades and Grim (1960) found that there exists a chemical reaction between lime and pure clay minerals (Kaolinite, illite and montmorillonite) with accompanying increase in bearing value. The quantity of lime needed to effectively treat a soil to develop increased strength varies with the type of clay mineral present. Akawwi and Al-Kharabsheh (2002) the swelling and shrinkage potential of soils are affected by mineralogical constituents and surrounding environment. Ingles and Metcalf (1972) as well as Kedzi (1979) recommended

2 - 3 % of hydrated lime for soil modification. Whereas Yoder and Witczak (1975) recommended ½ - 4 % lime for the same process.

The optimum amount of lime for maximum strength gain in stabilizing soil with lime according to Eades and Grim (1960) is 4 - 6 % for Kaolinite, about 8 % for illite and montmorillonite. Ola (1978) found a linear relationship between the strength of lime – stabilized black Cotton soil and lime content (up to 10 % lime). Akawwi and Al-Kharabsheh (2002) recorded best result when 3.5 – 5 % quicklime by dry weight of soil was used to improve and stabilize expansive soils in Amman, Jordan.

Mechanism Of Lime Stabilization

According to Chen (1975) and Brown (1996), addition of lime to clay soil provides an abundance of calcium ions (Ca^{2+}) and magnesium ions

(Mg^{2+}). These ions tend to displace other common cations such as sodium (Na^{+}) or potassium (K^{+}), in a process known as cation exchange. Replacement of sodium or potassium ions with calcium significantly reduces the plasticity index of the clay. A reduction of plasticity is usually accompanied by reduced potential for swelling. The addition of the lime increases the soil p^{H}, which also increases the cation exchange capacity. The above reaction is accompanied by pozzolanic reaction, which is a slower or long-term reaction. The reactions are little understood, but apparently involve interaction between hydrated lime and siliceous and aluminous minerals in soils. The resulting gel cement the soil and may be similar to certain reaction products from the hydration of Portland cement. A major difference is that under normal curing conditions considerably more time is required for Pozzolanic – Cementation reactions to contribute much strength.

The suitability of lime for the stabilization of shale will be ascertained using a liquid limit (LL) <45 and plasticity index (PI) < 20 for fill and embankments material, LL <45 and PI < 15 for sub-base material and LL< 30 and PI < 9 for base material. (Nigerian General Specification for Road and Bridges, 1997) A minimum CBR value of 40 %, 80 % and 100 % (standard Proctor) for lime treated soils for sub-base; base (highly trafficked roads) and base (heavily trafficked roads) respectively as used by Osinubi (1999) will be adopted. An unconfined compressive strength value of 1034.25kN/m^2 will be used as UCS criterion. The conventional criterion of a maximum allowable loss in strength of 20% suggested by Ola (1974) will be used as durability requirement.

The aim of this work is to assess the effect of lime on some geotechnical properties of Igumale shale, in order to determine the suitability of lime for use as a modifier or stabilizer in the treatment of Igumale shale for roadwork.

MATERIALS AND METHODS

The sample used for laboratory tests were collected at a depth of 2 metres and about 600 metres from the gate of the local government secretariat, located along Igumale – Otukpo road. The pit was located beside a double-celled box culvert, close to a gully erosion site where shale outcrops. The laboratory tests carried out on the natural soil include particle size distribution, Atterberg limits tests, Compaction test, California bearing ratio (CBR) and Unconfined Compressive Strength, (UCS) test, preformed in accordance with B.S 1377: 1990 for natural shale and B.S 1924: 1990 for shale treated with lime respectively. Specimens for unconfined compressive strength (UCS) and (CBR) were prepared at the optimum moisture contents (OMC) and maximum dry densities (MDD) at B.S light compaction of the shale lime mixtures.

CBR tests were modified to comply with the Nigerian General specification (1997), which stipulated that specimens be cured unsoaked for six days and later immersed in water for 24 hours before testing. The resistance to loss in strength was determined as a ratio of the Unconfined Compressive Strength (UCS) of specimens cured for 7 days under controlled conditions, which were subsequently immersed in water for another 7 days to the UCS of specimens cured for 14 days. The clay mineral present in Igumale shale was assessed by X-ray diffraction analysis (XRD).

TEST RESULTS AND DISCUSSION

Identification of sample

The geotechnical index properties of shale before the addition of lime, is as summarized in Table 1. The grain size distribution of the untreated shale sample is as shown in Figure 1. The index properties of the shale sample shows that it falls below the standards recommended for most geotechnical construction works and would therefore require modification before stabilization.

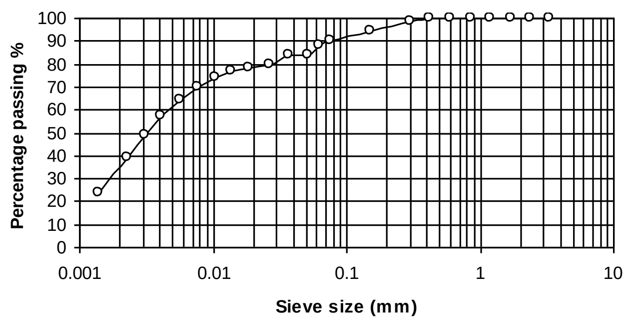

Fig.1 Particle size distribution of Igumale shale.

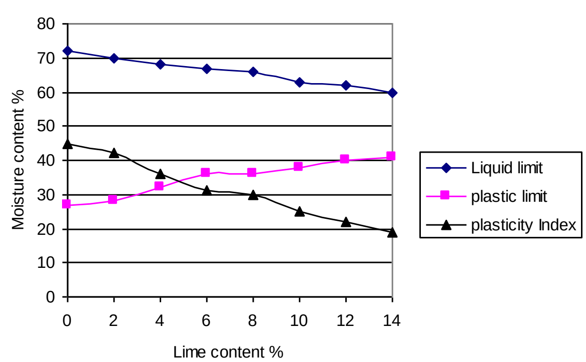

Fig.2 Variation of Atterberg limits indices with lime content.

Table 1: Results of tests on natural Igumale shale

PROPERTY	QUANTITY
Percentage Passing BS Sieve No 200%	90
Liquid Limit, %	72
Plastic Limit, %	27
Plasticity Index, %	45
Linear Shrinkage, %	21.0
AASHTO Classification	A – 7 – 6
USCS Classification	CH
Maximum Dry Density, Mg/m3	1.51
Optimum Moisture Content, %	22
Unconfined Compressive Strength KN/m2	360
California bearing ration, % (after 24 hrs soaking)	0.68
PH	6.83
Free Swell, %	50
Specific gravity	2.55
Concentration of water –soluble sulphate (mg/L)	1.5
Organic Content %	0.10
Colour	Grey
Natural moisture content (%)	25

The concentration of soluble sulphate in Igumale shale and its organic content values allow for use of ordinary Portland cement, without any negative effect (BRE, 240). X – ray diffraction analysis test result on the fraction of the soil passing B.S.sieve No. 200 summarized in Table 2 confirmed the presence of mixed layer Illite/Smectite. Oxide composition analysis of lime used is as shown in Table 3.

Table 2: Summary of X-ray diffraction Analysis Result of Igumale shale

Angle [2ϴ]	d-value α L[Å]	Peak Intensity [counts]	Minerals Identified
6.345	13.9185	185	Illite/Smectite
12.895	6.8596	376	Microcline
18.230	4.8624	64	-
21.395	4.1497	219	Microcline and Goethite
25.440	3.4983	231	Illite/smectite
27.190	3.2770	762	Quartz
28.540	3.1250	119	Pyrite
35.495	2.5270	48	Gbonate
37.080	2.4225	85	Pyrite
40.025	2.2508	48	Goethite
43.015	2.1010	56	Goethite
46.375	1.9563	37	Muscovite
50.670	1.8001	100	Orthoclase/ Dolomite
55.555	1.6528	16	Quartz
60.435	1.5305	69	Kaolinite
62.525	1.4843	18	-
66.100	1.4124	12	-
68.240	1.3732	45	Fluorite
68.720	1.3648	48	-

Table 3: Oxide Composition of Lime used

Chemical composition	Concentration (%by weight)
SiO_2	1.54
Al_2O_3	0.50
Fe_2O_3	0.03
TiO_2	0.32
MnO	0.05
MgO	1.26
CaO	67.08
Na_2O	0.02
K_2O	0.05
P_2O_5	-
Loss on ignition	26.85

Effect of Lime on consistency limits

Atterberg limits indices variation with lime content is as shown in Figure 2. Liquid limit decreased with lime content, while the plastic limit increased with lime content, thereby resulting in a decrease in plasticity index. A possible explanation for the above mentioned trend is not unconnected with the addition of lime, which aids flocculation, and aggregation of the clay particles. The agglomeration of clay particles due to lime addition according to Osinubi (1995) turns a clayey soil to a silty soil and this by itself will decrease the liquid limit of the soil because of the lower surface area, in addition to the highly plastic nature of lime.

Effect of lime on Compaction Characteristics

Figure 3 shows the variation of the maximum dry density (MDD) and optimum moisture content (OMC) with lime content. The maximum dry density (B.S light) compaction of Igumale shale was substantially reduced from 1.51 Mg/m^3 at 0% lime content to 1.35 Mg/m^3 at 8% lime content. But the optimum moisture content increased with lime content.

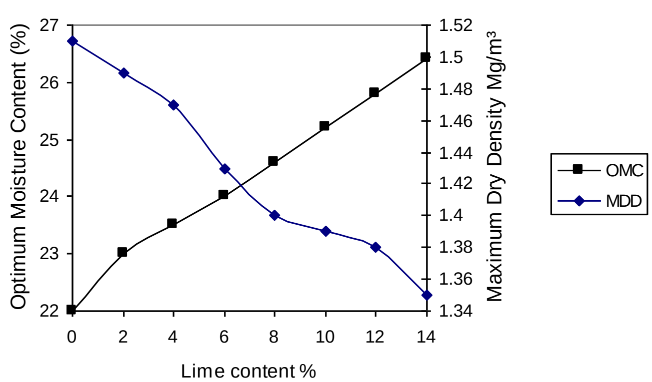

Fig.3 Variation of Maximum dry density and optimum Moisture content with lime content

The decrease in density according to Ola (1977) and Lees et al (1982) is as a result of the flocculated and agglomerated clay particles occupying larger spaces leading to a corresponding decrease in dry density. The increasing OMC with increasing lime content is as a result of the extra water required for the pozzolanic reactions.

Effect of lime on Unconfined Compressive Strength /CBR Indices and Durability

Figure 4 shows the variation of compressive strength with various lime contents for 7, 14 and 28 days curing. The samples were compacted to their maximum dry densities at the corresponding moisture contents. The samples were waxed cured for the different days before subjecting them to test. The result indicated an optimal lime content at 8%, which corresponds to 126 kN/m^2, 1400 kN/m^2 and 1480 kN/m^2 for 7, 14 and 28 days respectively.

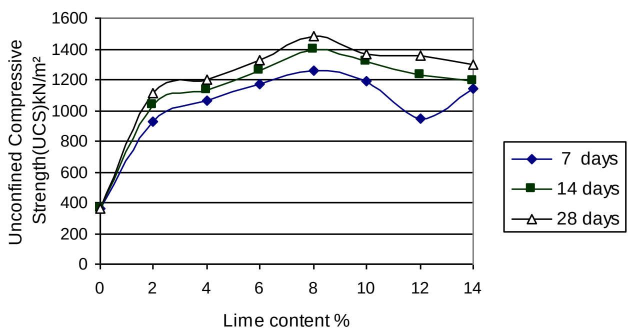

Fig 4.Variation of Unconfined compressive Strength (UCS) of Treated Igumale shale with Lime content.

The trend observed with the UCS test result was also observed with the California bearing ratio (CBR), which is shown in Figure 5, which exhibited a peak CBR value of 37 % at 8 % lime content. This peak CBR value is lower than the minimum CBR value of 40 % prescribe for use of material for sub base of lightly trafficked roads.

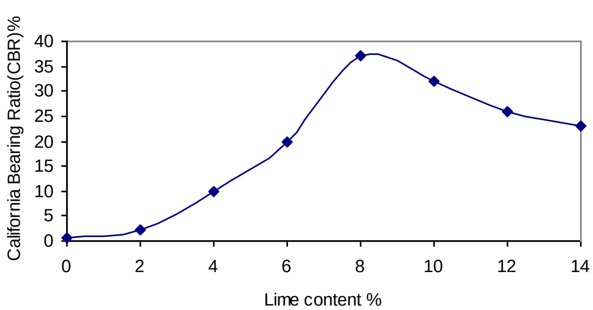

Fig.5 Variation of California Bearing Ratio (CBR) with Lime content

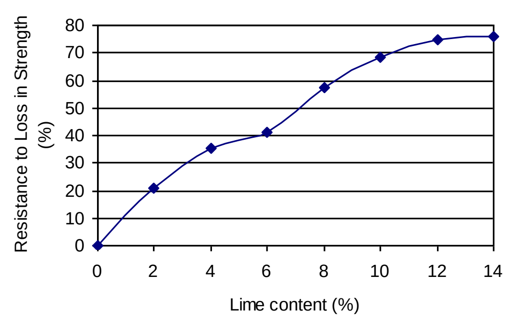

Fig.6 Variation of Resistance to Loss in strength with Lime

Durability test results showed that a maximum resistance to loss of strength value of 76 % was attained when Igumale shale was treated with lime, this value was however less than the 80 % used as our evaluation criterion. Variation of durability with lime content is as shown in Figure 6.

Modeling of Strength Indices

Models were formulated using CBR and 7–day UCS results as dependent variables, with the percentage of lime as the independent variables this was done to facilitate the application of laboratory results and to serve as a guide in predicting relationship between variables, in addition to reducing the rigors of laboratory work by facilitating extrapolation of results, thereby saving both time and energy. The validity of the correlation was established using R^2 being close to ± 1, in addition to the standard error, *F*–statistics and *t*–value of the coefficients, and model being satisfactory. The ability of the models to predict reasonable results was verified using χ^2 test as results from the models were compared with results of the same test, performed on another sample obtained from a different location at Igumale. The two outstanding models relating the percentage of lime used to CBR values are:

$$CBRL = - 5.11+6.65\,\%\,L-0.323\%\,L2 \qquad R^2 = 0.8303 \tag{1}$$

$$CBR_L = 0.661+0.829\%\,L+0.789\%L^2 - 0.0530\%L^3 \qquad R^2= 0.9158 \tag{2}$$

Where; CBR_L = California Bearing Ratio using lime

% L = Lime content in percent.

The models for 7 day UCS results are

$$7d\text{-}ucs = 370.954 + 318.716\,\%L - 37.65\,\%L^2 +1.329\%L^3 \qquad R^2 = 0.9383 \tag{3}$$

$$7d\text{-}ucs = 482.583 + 172.536\,\%\,L - 9.744\%L^2 \qquad R^2 = 0.82183 \tag{4}$$

Where

7d-ucs = 7 day unconfined compressive strength

% L = Lime content in percent.

To predict CBR results, Eq. 2 with a higher R^2 value and lower χ^2 value, in addition to its CBR value of 0.661 at 0 % lime content being close to a value of 0.61 obtained from laboratory test, could be suggested for use. However, both Eq. 1 and Eq. 2, having χ^2 and R^2 value of 9.30 and 0.8303; 5.54 and 0.9158 respectively, satisfied χ^2 test criterion, as their χ^2 values were less than the corresponding χ^2 value of 12.6, obtained from χ^2 distribution table, at a probability of 0.95 and the appropriate degree of freedom. The satisfaction of χ^2 criterion is an indication that eq.2 can be used as a generalized model for predicting CBR result of Igumale shale treated with cement. The relationship between predicted results using the different models and the results obtained from the laboratory test is as shown in Figure 7.

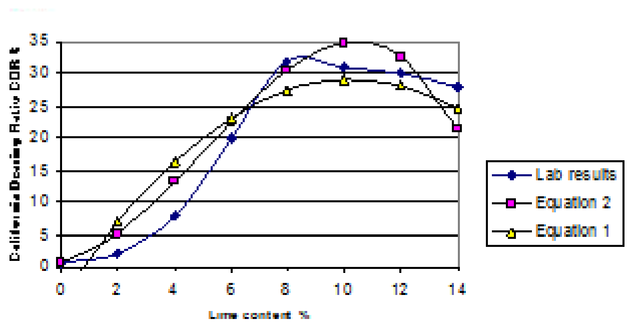

Fig.7 Plot of Predicted CBR value using eq. 2 and results of Laboratory test carried out on sample obtained from another location at Igumale.

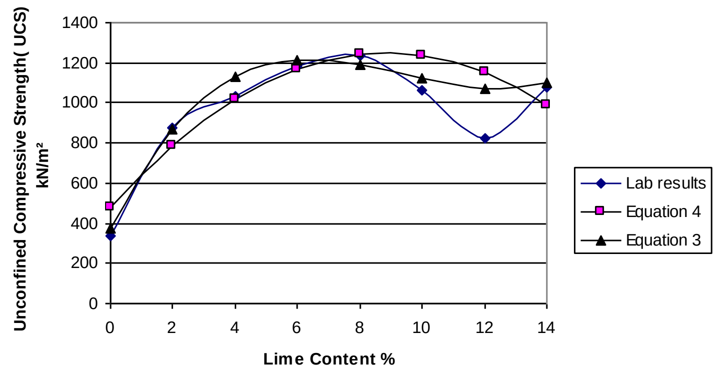

Fig.8 Plot of predicted 7-day UCS value using eq 3 and results of Laboratory test carried out on sample obtained from another location at Igumale.

Following the same line of reasoning eq. (3) with R^2 value of 0.9383 could be recommended for use in the prediction of 7 day UCS results, The χ^2 values of 73.165 and obtained using Eq. 3 and Eq.4 respectively are higher than the corresponding value of 12.60 obtained from statistical table, at a probability of 0.95 and the appropriate degree of freedom. The high R^2 value of the model in addition to its coefficients satisfying F and t –tests, indicated that the model described well enough the relationship between cement and the 7 day UCS test results of the sample used in model formulation. The non-satisfaction of χ^2 criterion showed that the model cannot predict accurately test results carried out on samples from another location. Hence it cannot be used as a generalized model for the prediction of 7day UCS result of Igumale shale, treated with cement. However, results from the model can give fair and close results of shale from another location within Igumale. The relationship between predicted values and values obtained from laboratory test on another sample obtained from a different location at Igumale are as shown in Figure 8.

CONCLUSIONS

From the results of this study, the following conclusions can be drawn.

Igumale shale tested falls under the A-7-6 subgroup of the AASHTO classification system.

The results presented in this paper have confirmed that the addition of lime to Igumale Shale affect some geotechnical properties; the liquid limit, plastic limit, plasticity index, the unconfined compressive strength and California bearing ratio (CBR).

An optimal lime content of 8 % was obtained, when Igumale shale was treated with lime and beyond this point the advantages previously gained appear to be lost. This might be an indication that lime could be an effective modifier and not a stabilizer in the treatment of Igumale shale.

At the optimum lime content, the improved geotechnical properties of the lime treated, Igumale shale did not satisfy the combined strength indices evaluation criteria (i.e. CBR, 7 day UCS and durability) for use as sub-base and base materials in road construction. However lime could be used as an effective modifier in the stabilization of Igumale shale with stabilizing agents like cement, bitumen, etc.

A polynomial model of the third order was found to predict reasonably the relationship between strength indices (CBR and 7 day UCS) and the percentage of lime used.

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