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Comparative study of the influence of cement and lime stabilization on geotechnical properties of lateritic soil derived from pegmatite in Ago-Iwoye area, southwestern Nigeria

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Abstract

Samples of pegmatite-derived lateritic soil around Ago-Iwoye, southwestern Nigeria, were differently stabilized with varying quantities of lime and cement. This was aimed at establishing the influence of types and quantities of the stabilizers, if any, on the geotechnical properties of the soil. The plasticity, moisture-density relationship, CBR and unconfined compressive strength of the unstabilized samples and those that were stabilized with 2, 4, 6, 8 and 10% by weight of cement and lime respectively were studied. Stabilization of the studied soil with between 2 and 10% cement produced percentage increase of 7.26%, 97.38%, 31.15% and 68.18% in the maximum dry density (MDD), unsoaked California bearing ratio (CBR), soaked CBR, cured unconfined compressive strength and uncured unconfined strength respectively. Percentage reduction of 13.40%, 58.20%, 59.90%, 66.67%, 75.71%, 21.27% and 40.79 % were obtained respectively in the MDD, cured and uncured unconfined compressive strengths, linear shrinkage, plasticity index, plastic limit and liquid limit of the samples stabilized with between 2 and 10% of lime. While addition of cement improved all the geotechnical properties, addition of lime reduced the MDD, uncured and cured unconfined compressive strengths. The investigation has thus confirmed that cement is more appropriate than lime in the stabilization of the studied soil, with optimum amount of stabilizer needed being 8%.

Introduction

Soil stabilization as a means of improving physical and/or engineering properties of soils for different engineering utilities has continued to gain increasing popularity in the tropical part of the world, including Nigeria. Studies by some workers including Croft (1968), Ola (1974), Olowe (1985), Akpokodje (1985), Bell (1988), Abolurin (1992) and Adeyemi *et al* (2003) have shown that the physical and the engineering properties of soils can be modified for different utilities through the use of chemical stabilizers. Such studies have shown among other things that these stabilizers help in improving some geotechnical properties of soils such as linear shrinkage, plasticity index, maximum dry density, optimum moisture content and unconfined compressive strength. Cement has been used as an effective stabilizer for a wide range of materials resulting in increase in the particle size distribution and the compressive strength of the soils due to the presence of calcium disilicate, calcium trisilicate and free lime in cement. Lime stabilization on the other hand involves the use of oxides and hydroxides of calcium and magnesium in improving the engineering properties of soils. The reaction of lime to soils depends on the types of clay mineral present in them.

In spite of the large deposits of lateritic soils in Nigeria and the well known documented problems associated with some of these soils, relatively few studies have been carried-out on ways of improving the geotechnical properties of these soils. In addition, little effort has been made to determine the response of different soils to the addition of varying quantities of different stabilizers, taking into consideration the influence of geology on engineering properties of soil as shown by many studies (Mesida, 1985, Adeyemi, 1995;).

This study therefore focused principally on the response of lateritic soils developed over pegmatite to varying quantities of two different chemical stabilizers; cement and lime.

Location and geology of the study area

The soil investigated is developed over pegmatite around Ago-Iwoye area of southwestern Nigeria (Fig. 1). Ago-Iwoye area is located within longitudes $3^0 50'$ to $3^0 56'$E and latitudes $6^0 55'$ to $6^0 58'$ N. The climate is tropical, while the natural vegetation is of the rainforest type. The relief of the study area is a direct expression of the geology, with relatively flat topography. The area as described by Shannu (1991), is underlain mainly by porphyroblastic gneiss, biotite-hornblende gneiss, biotite granite gneiss, granite gneiss, porphyritic granite, Aplite and pegmatite (Fig 1). The pegmatite is massive in some part of the study area where they contain well-developed crystals of black tourmaline. They also occur as intrusion mostly in the granite gneiss in few places. The presence of well formed garnet crystals in the pegmatite indicates that they have been metamorphosed.

The pegmatite is pinkish in colour, extremely coarse grained, rich in alkali feldspar (55%), with little proportion of plagioclase feldspar (10%), quartz (20%) and muscovite (10%). The pegmatite will likely weather to clayey soil because of the preponderance of feldspars, and as such the soil may be poor as subbase/subgrade material. Thus, there is the need for the stabilization of the residual soil.

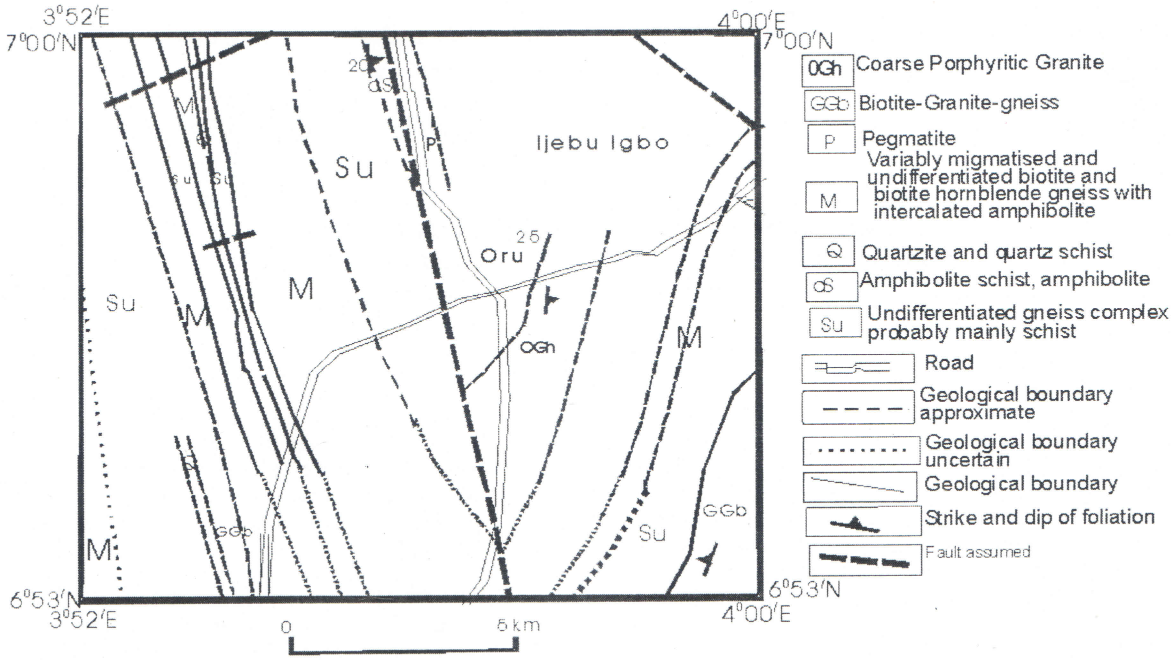

Fig. 1. Location map of Ago-Iwoye area showing the study area.

Materials and methods

The studied soil was collected at a location within Ago-Iwoye where residual soil developed over pegmatite (Fig. 2). The soil sample was collected from the laterite horizon because soil from the horizon is preferred to soils from the other soil horizons as sub-base and subgrade material. The bulk soil sample collected was air-dried for 2 weeks.

The basic index properties of soil including grading characteristic, liquid limit, plastic limit, plasticity index and linear shrinkage were determined by following the procedures stipulated by the British Standard 1377 of 1975. In order to effect adequate segregation of the grains of the

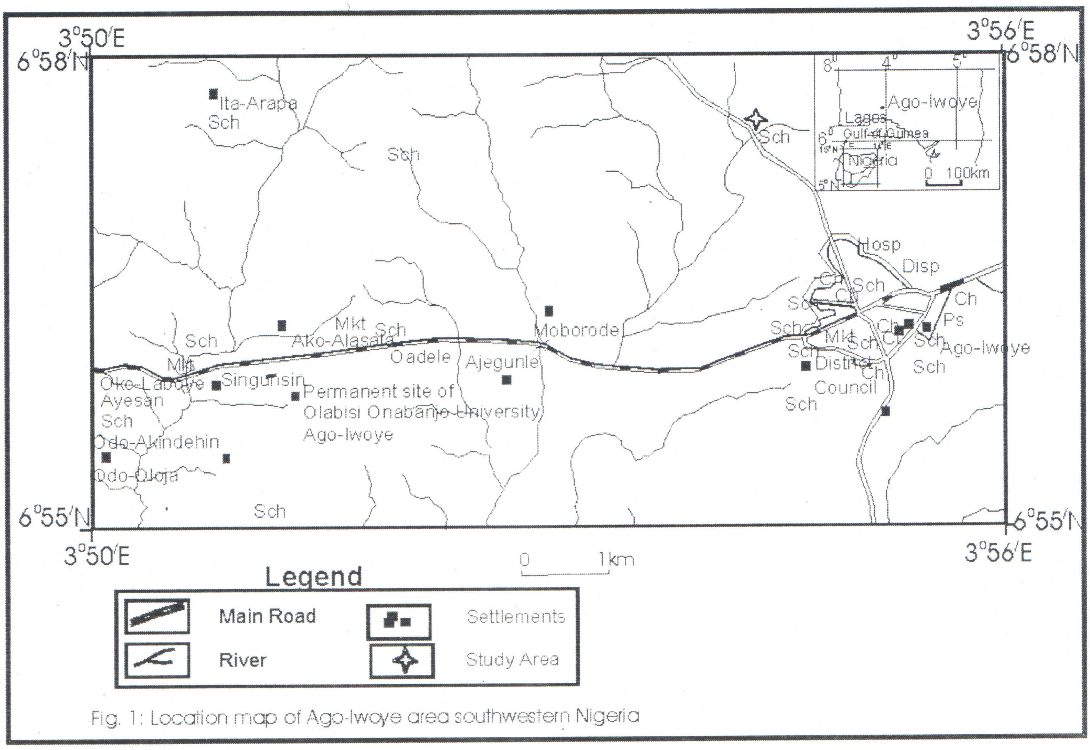

Fig. 2. Geological map of Ago-Iwoye area.

soil for sieve analysis, each soil sample was soaked in weak calgon solution for 24hours, during which it was regularly agitated before being wet sieved. Some geotechnical properties such as cured and uncured Unconfined Compressive Strength as well as unsoaked and soaked California Bearing Ratio were also determined.

The soil samples were then compacted at the modified American Association of State Highway and Transportation Official (AASHTO) level. The soils were subsequently stabilized with 2%, 4%, 6%, and 8% and 10% cement and lime respectively in order to determine the influence of quantity and/or choice of stabilizers (cement and lime) on the basic index and engineering properties of the studied soil. The cement employed was Portland cement.

The compaction test involved the application of dynamic load on soil samples divided into five layers. Each of the five layers of soil in a mould (0.002124m^3) was subjected to 55 blows of a 44.5N rammer falling through a height of 0.46m. This was done repeatedly for the unstabilized soil and those stabilized with 2%, 4%, 6%, and 8% and 10% cement and lime respectively. The unconfined compressive strength (uncured and cured) and the (unsoaked and soaked) California Bearing Ratio (CBR) of the compacted soil samples was determined.

Samples cured for 48 hrs were also tested in order to determine the relative sensitivity, in terms of strength changes to curing while samples soaked for 48 hrs were used for the determination of soaked CBR, In order to simulate field condition.

Result and discussion

Grading and plasticity characteristics

The grain size distribution curves of the cement and lime stabilized soils are presented in Figs. 3 and 4 respectively. The unstabilized samples of the pegmatite derived soil on the average contain 14% gravel-size grains, 29% sand-size grains, and 57% fines. It has an average liquid limit of 58.4% and average plasticity index of 20.9. With these properties the soil is placed in the group A-7-5(1) of the AASHTO classification system, the class of the soils is described as fair to poor clayey soils.

Stabilization of the soil with between 2 and 10% by weight of cement did not produce any significant change in the grain size distribution of the soil, while the liquid limit and the plasticity index were reduced to 45.3% and 4.5 respectively. On the other hand stabilization of the soil with between 2% and 10% by weight of lime produced no significant changes in the grain size distribution

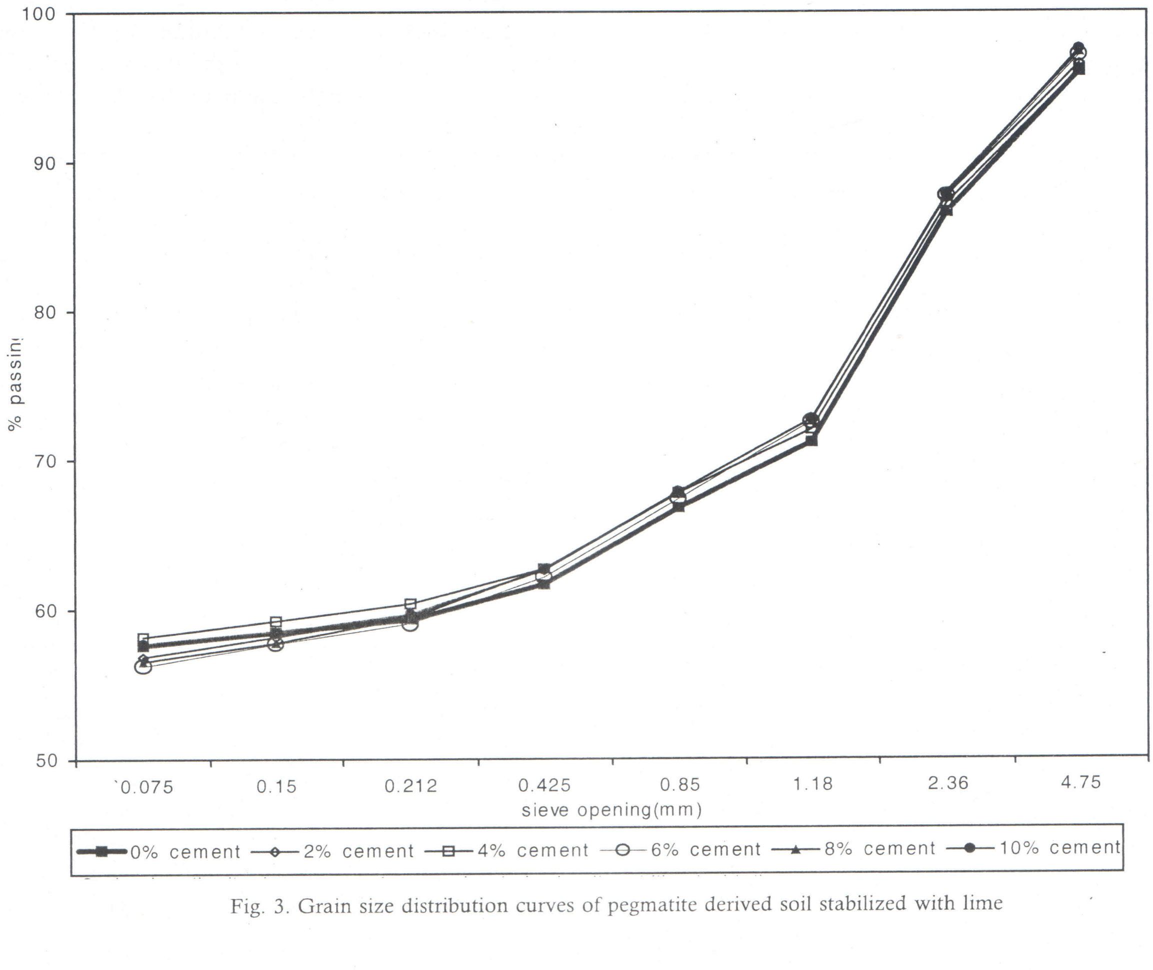

Fig. 3. Grain size distribution curves of pegmatite derived soil stabilized with lime

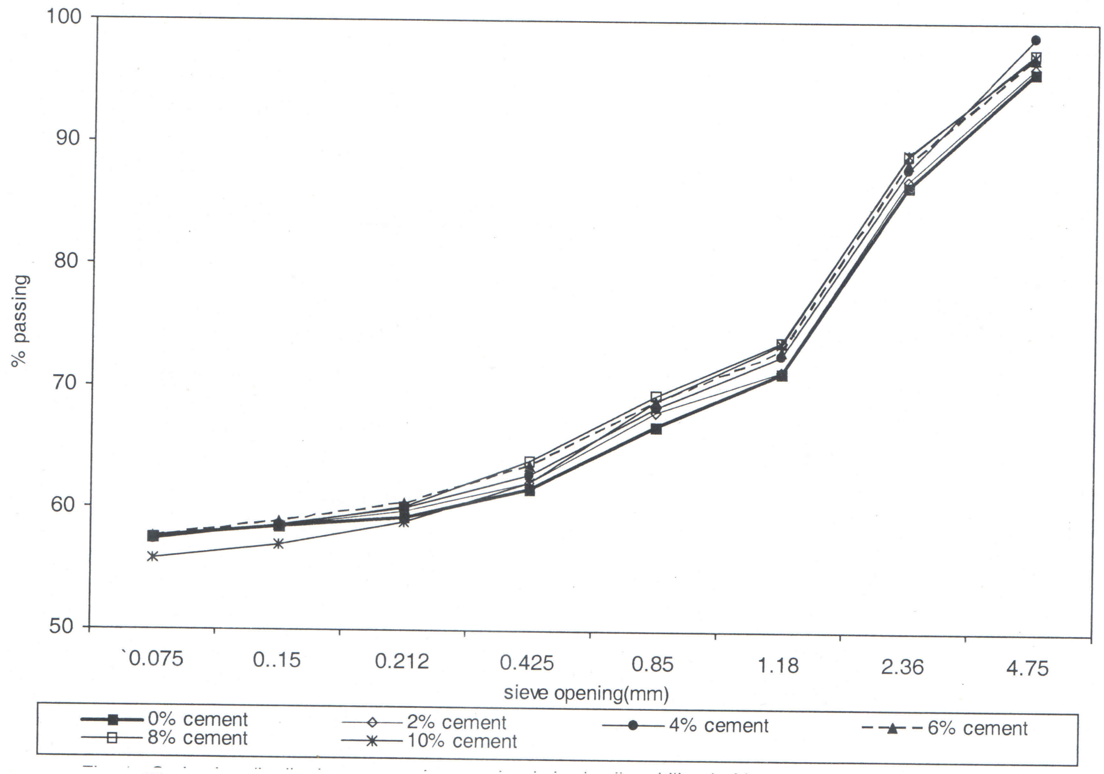

Fig. 4. Grain size distribution curves of pegmatite derived soil stabilized with cement

characteristics of the soil but the liquid limit and the plasticity index of the soils were reduced to 43.2% and 6.5 respectively. While stabilization of the soil with 8% by weight of cement produced optimal value of plasticity index (3.0), the optimal value of plasticity index was produced upon stabilization by 2% by weight of lime.

Comparatively, there seems to be little or no difference in the effect of each of the stabilizers on the grading characteristics, liquid limit and the plasticity index of the soil, although there is variation in the quantities of each of the stabilizers that produced the optimal effect on the stabilized soil.

A general overview of the soils reveal that the soil when unstabilized, is fair to poor sub-grade materials, hence the need for thorough stabilization of the soil, in order to improve its engineering properties.

Plasticity index

The influence of cement and lime on the consistency limits of the studied soils is shown in Table 1. Addition of between 2 and 10% by weight of cement and lime to the pegmatite derived soil reduced the plasticity index of cement stabilized soil consistently from 20.9 to 4.5. While for the lime stabilized soil, it was initially reduced to its optimal value on addition of 2% by weight of lime. However, increase in % by weight of lime employed for stabilization unexpectedly increase the plasticity index to 8.2 (8% by weight of lime) before dropping to 6.5, upon stabilization with 10% by weight of lime. The influence of addition of different percentages of cement and lime is shown in Fig. 5

The plasticity index of cement stabilized soil was reduced by as much as 85.46% (optimum effect) upon addition of 8% cement but further increase in % of cement (10%) resulted in a reduction in percentage reduction to 78.43%. Hitherto, the % reduction has increased with increase in percentage of cement, indicating strong influence of the variation in percentage of stabilizer on the plasticity index. On the contrary, addition of 2 % lime caused the highest reduction in plasticity index (75.71%). Further increase in percentage of lime produced a weaker effect in the plasticity index, resulting in lower % reduction in plasticity index.

These further confirm the variation in response of engineering soils consequent upon the application of varying quantities and types of stabilizers.

Linear shrinkage

Table 1 and Figure 6 show the influence of cement and lime on the linear shrinkage of the studied soils. The table reveals a linear shrinkage of 15% for unstabilized soil, a value that suggest that the studied soil has high swelling potential. The linear shrinkage of the soil is much higher than 8% recommended by Madedor (1983) for highway sub base materials thus the need for stabilization of the soil. Increase in cement content in the soil was accompanied by a consistent reduction in linear shrinkage. Addition of

Table 1. Influence of cement and lime on the plasticity characteristics and linear shrinkage of the studied soil.

% of stabilizer (Cement)	Liquid limit %	Liquid limit % reduction	Plastic limit %	Plastic limit % reduction	Plasticity index %	Plasticity index % reduction	Linear Shrinkage %	Linear Shrinkage % reduction
0	58.35		37.43		20.92		15.00	
2	56.10	3.86	40.28	7.61	15.88	24.09	13.00	13.33
4	54.78	6.11	41.49	10.85	13.29	36.47	12.00	20.00
6	48.00	17.74	43.21	15.44	4.79	77.1	11.00	11.00
8	46.95	19.53	43.91	17.31	3.04	85.46	9.00	40.00
10	45.25	22.45	40.72	8.78	4.53	78.34	7.00	53.33
% of stabilizer (Lime)	**Liquid limit %**	**Liquid limit % reduction**	**Plastic limit %**	**Plastic limit % reduction**	**Plasticity index %**	**Plasticity index % reduction**	**Linear Shrinkage %**	**Linear Shrinkage % reduction**
0	58.35		37.43		20.92		15.00	
2	34.55	40.79	29.47	21.27	5.08	75.71	5.00	66.67
4	39.25	32.73	32.76	12.48	6.49	68.98	7.00	53.33
6	41.80	28.36	34.15	8.76	7.65	63.43	8.00	46.67
8	43.40	25.62	35.20	5.96	8.20	60.80	9.00	40.00
10	43.20	25.96	36.67	2.03	6.53	68.79	10.00	33.33

10% by weight of cement is required to reduce the linear shrinkage of pegmatite derived soils to 7%, a value less than what was suggested by Madedor (1983). Addition of 2% by weight of lime reduced the linear shrinkage to 5%. However, further increase in lime resulted in consistent increase in the linear shrinkage which reached 10% on addition of 10% by weight of lime.

Progressive increase in the % of cement used in stabilizing the soil progressively led to increasing % reduction in linear shrinkage (Table 1), reducing by 13.33% on addition of 2% cement to 53.33% on addition of 10% cement. Addition of 2 % of lime led to optimal % reduction (66.67%) while further increase in percentage of lime resulted in a decrease in the % reduction of linear shrinkage.

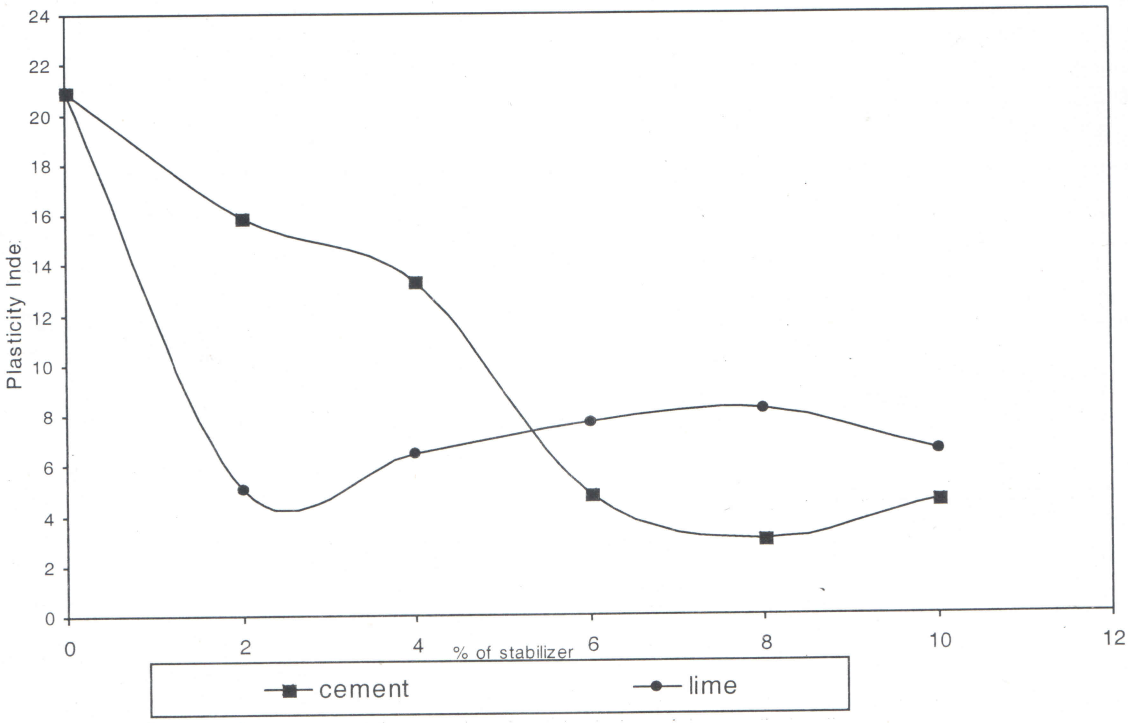

Fig. 5. The influence of cement and lime on the plasticity index of the studied soil.

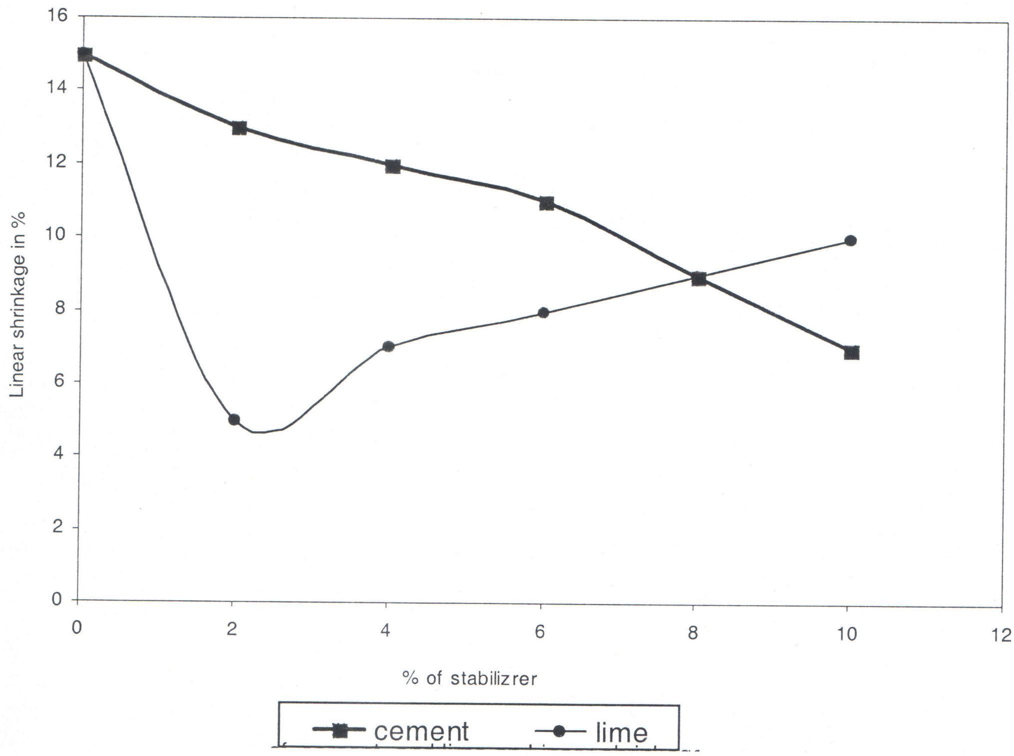

Fig. 6. The influence of cement and lime on Linear shrinkage of the studied soil.

These values indicate a strong influence of cement as a stabilizer for improving the linear shrinkage of pegmatite-derived soil.

Maximum dry density

The influence of cement and lime on the compaction parameters of the studied soils when subjected to the modified AASHTO level of compaction are shown in Table 2. The influence of increase in percentage by weight of cement and lime employed for stabilization is shown in Fig. 7. The addition of between 4% and 10% by weight of cement led to progressive increase in the maximum dry density (MDD). The MDD increased from 17.90 KN/m³ to a maximum of 19.20 KN/m³ upon the addition of 8% by weight of cement, representing a percentage increase of 7.26. Further increase in the percentage of cement (10 % by weight of cement) added resulted in the reduction of percentage increase in MDD to a meager 1.67. This indicates that increase in percentage by weight of cement content has positive influence on the soil density, and invariably the soils strength. On the contrary, increase in percentage by weight of lime used in stabilization of the

Table 2. Influence of cement and lime on the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the studied soil.

% Stabilizer	Cement stabilized samples				Lime stabilized samples			
	MDD		OMC		MDD		OMC	
	KN/m³	% Increase	%	% Reduction	KN/m³	%Reduction	%	% Increase
0	17.90		14.40		17.90		14.40	
2	17.07	4.64	15.00	4.16	17.10	4.46	15.00	4.17
4	18.30	2.23	14.60	1.39	17.00	5.02	15.50	7.68
6	18.80	5.03	13.60	5.56	16.80	6.14	16.00	11.11
8	19.20	7.26	13.00	9.72	16.20	9.49	17.00	18.05
10	18.20	1.67	14.00	2.78	15.50	13.4	18.00	25.00

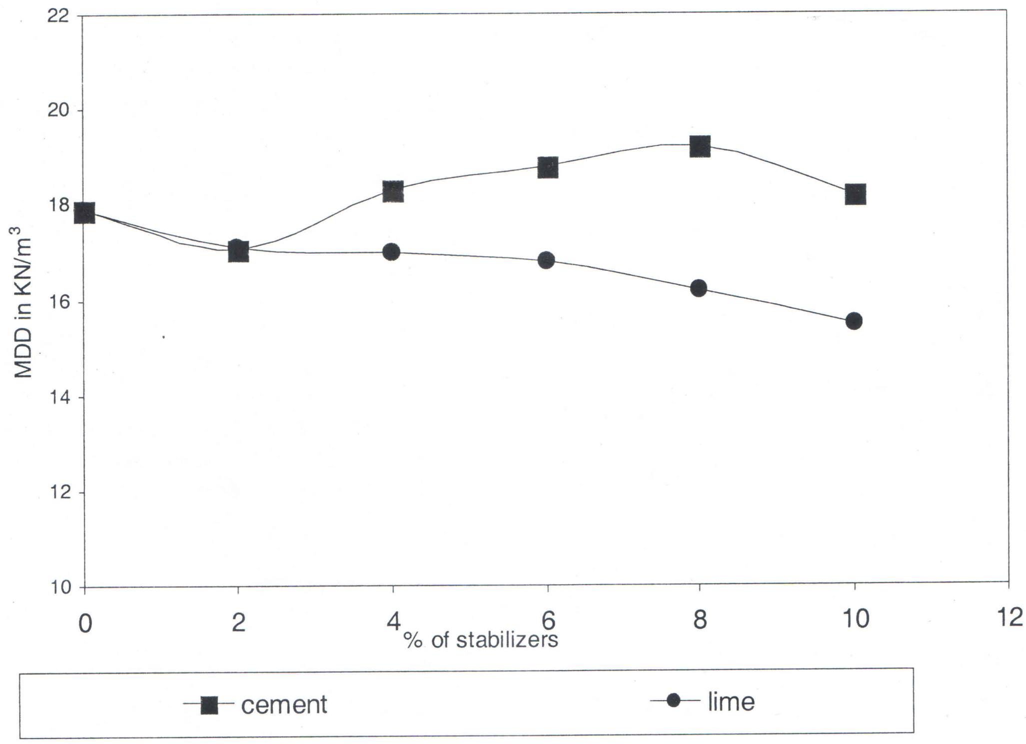

Fig. 7. The Influence of cement and lime on the Maximum Dry Density of the studied soils.

studied soil resulted in decrease in density and possibly strength of the soil. The addition of lime as stabilizer resulted in the reduction of the Maximum Dry Density from 17.90 KN/m^3 (unstabilized sample) to a minimum of 15.50 KN/m^3 (representing 13.4 % reduction in density).

The results reveal a very distinct variation in response of the soil to different stabilizers. The reduction in MDD when 10% by weight of cement was employed for stabilization of the soil (Table 2) suggests 8% by weight of cement as the optimum % needed to improve the soil's MDD.

Optimum moisture content

The influence of the stabilization of the studied soil with varying percentage by weight of cement and lime on the Optimum Moisture Content (OMC) of samples compacted at Modified AASHTO level are shown in Fig. 8. The stabilization of the soil with cement resulted in gradual

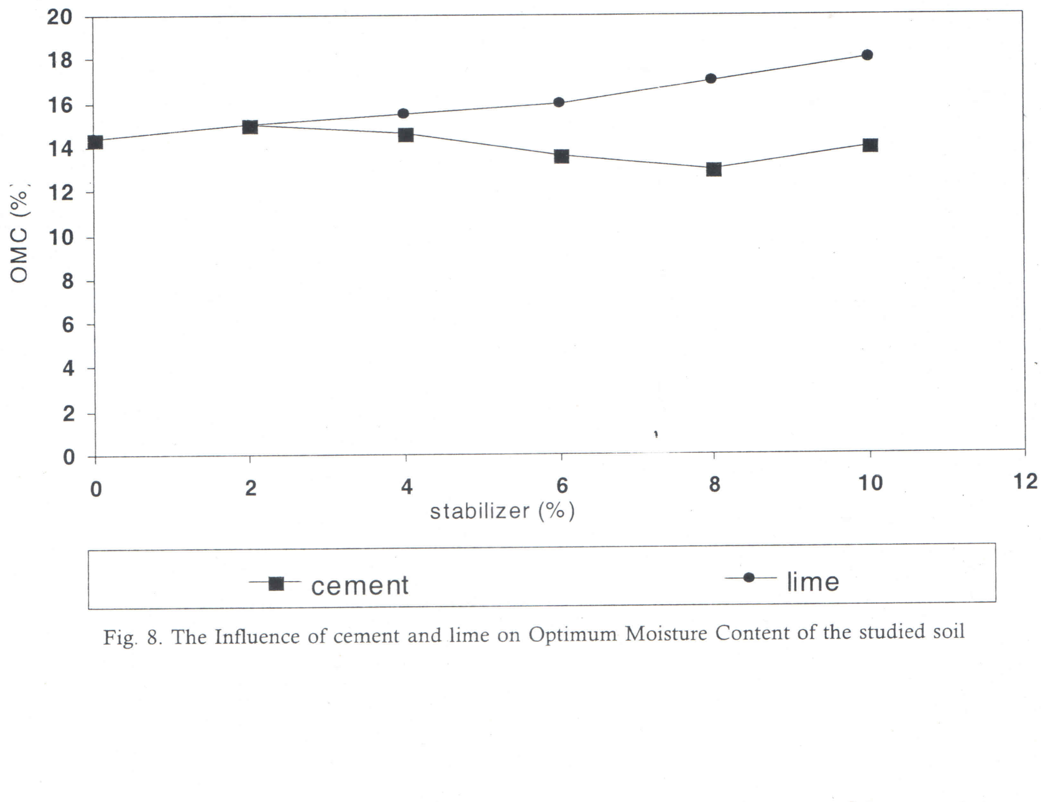

Fig. 8. The Influence of cement and lime on Optimum Moisture Content of the studied soil

reduction of the optimum moisture content from 14.40% to a minimum of 13.00% upon the addition of 8% by weight of cement. This represents a percentage reduction of 9.72. As observed with MDD, increase in the percentage by weight of cement to 10% resulted in decrease in percentage reduction from 9.72 to a meager 2.78. The decrease in percentage reduction in OMC to 2.78% when 10% by weight of cement was employed for stabilization of the soil (Table 2) suggest that it is not necessary to stabilize the soils with more than 8% by weight of cement. This finding agrees with that of Adeyemi et al (2003).

The stabilization of the studied soil with lime increased the OMC by as much as 25%, from the initial 14.40% of the unstabilized soil to 18.00% for sample stabilized with 10% by weight of lime. The progressive increase in the OMC with increase in percentage by weight of lime, and the corresponding decrease in MDD on the other hand clearly indicate that lime is not a good stabilizer for the soil.

California bearing ratio (CBR)

The results of unsoaked and soaked CBR tests are presented in Table 3. Fig. 9 presents the effect of varying the percentages of stabilizers on the studied soils on the unsoaked and soaked CBR. The CBR is a semi-empirical test for evaluating highway subbase/subgrade soils .The soaked CBR test is a simulation of the condition that soils are exposed to in-situ upon ingress of water. The values of the soaked CBR reveal the variation in response of the soil to different stabilizers (cement and lime).

Table 3. Influence of cement and lime on the Unsoaked and Soaked California Bearing Ratio (CBR) of the studied soil.

% Stabilizer	Cement stabilized samples				Lime stabilized samples			
	Unsoaked CBR		Soaked CBR		Unsoaked CBR		Soaked CBR	
	%	% Increase	%	% Increase	%	% Increase	%	% Increase
0	5.81		3.81		5.81		3.81	
2	6.51	12.05	3.01	21.00	5.46	5.46	3.41	10.49
4	8.12	39.76	4.26	11.81	6.51	12.05	4.51	18.37
6	18.04	210.50	7.26	90.55	14.78	154.39	4.51	18.37
8	22.24	282.79	7.52	97.38	7.41	27.53	5.41	41.99
10	8.52	46.64	5.61	47.00	7.18	23.58	3.56	6.56

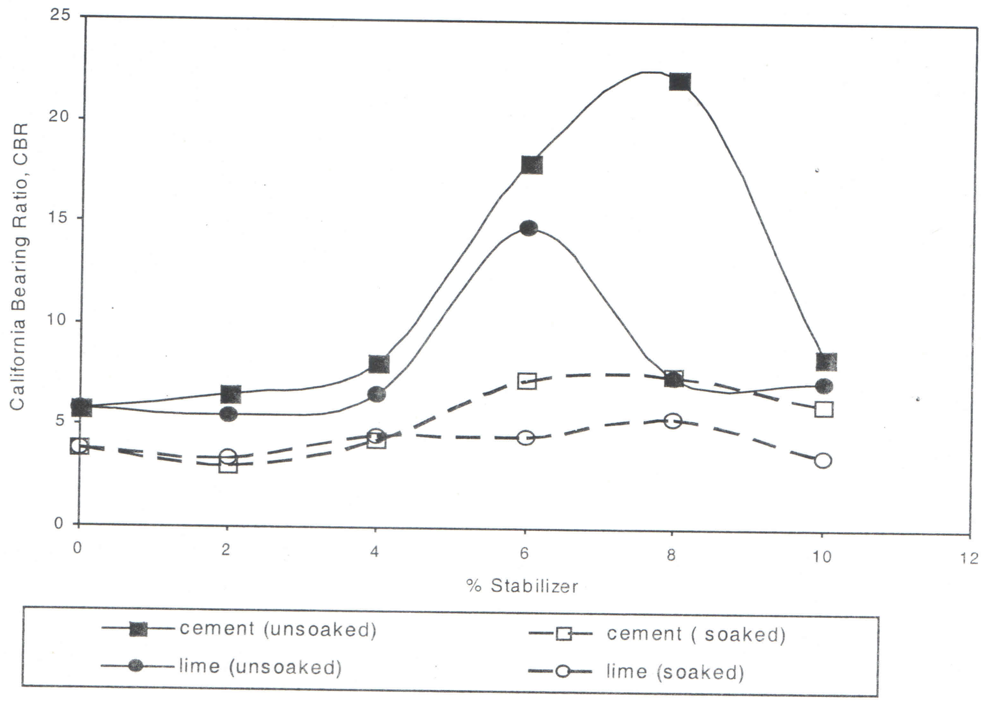

Fig. 9. The influence of cement and lime on the soaked and unsoaked CBR of the studied soil

Stabilization of the studied soil with cement revealed a progressive increase in both the unsoaked and soaked CBR with progressive increase in the percentage of cement. Addition of 8% cement produced the optimum percentage increase of the unsoaked CBR (282.79%) with a CBR value of 22.24%. Similarly, an optimum percentage increase of 97.38% of the soaked CBR was obtained upon the addition of 8 % cement, with the soaked CBR increasing from 3.81% gradually to 7.52 %. Stabilization of the soil with lime also resulted in the increase in both unsoaked and soaked CBR, with the values respectively increasing from 5.81% and 3.81% to optimal values of 14.78% and 5.41. These optimal values obtained upon the addition of 6% lime for unsoaked CBR and 8% lime for the soaked CBR respectively represent percentage increase of 154.39% and 41.99%.

From the above statistical figures, it can be inferred that cement produces a stronger positive influence on the strength measured in terms of soaked and unsoaked CBR.

Table 3 further confirms that cement is a more effective stabilizer of the studied soil and 8% by weight of cement as the optimum percentage required for the stabilization of the studied soil.

Unconfined compressive strength

As shown in Table 4 and Fig. 10, the uncured and cured unconfined compressive strength were positively influenced by percentage by weight of cement. Conversely, increase in percentage by weight of lime employed for stabilization is accompanied by a corresponding decrease in cured and uncured unconfined compressive strength. The result

Table 4. Influence of cement and lime on the Uncured and Cured Unconfined Compressive Strength (UCS) of the studied soil.

% Stabilizer	Cement stabilized samples: Unscured CBR		Cured CBR		Lime stabilized samples: Unsoaked CBR		Soaked CBR	
	KN/m²	% Increase	KN/m²	% Increase	KN/m²	% Reduction	KN/m²	% Reduction
0	22.00		61.00		22.00		61.00	
2	24.00	9.09	65.00	6.56	21.00	4.55	50.00	18.03
4	26.00	18.18	63.00	3.27	18.00	18.18	50.00	18.03
6	32.00	45.45	67.00	9.83	14.00	36.36	48.00	21.13
8	37.00	68.18	68.00	11.48	11.00	50.00	27.00	55.74
10	28.00	27.27	80.00	31.15	9.00	59.09	25.50	58.20

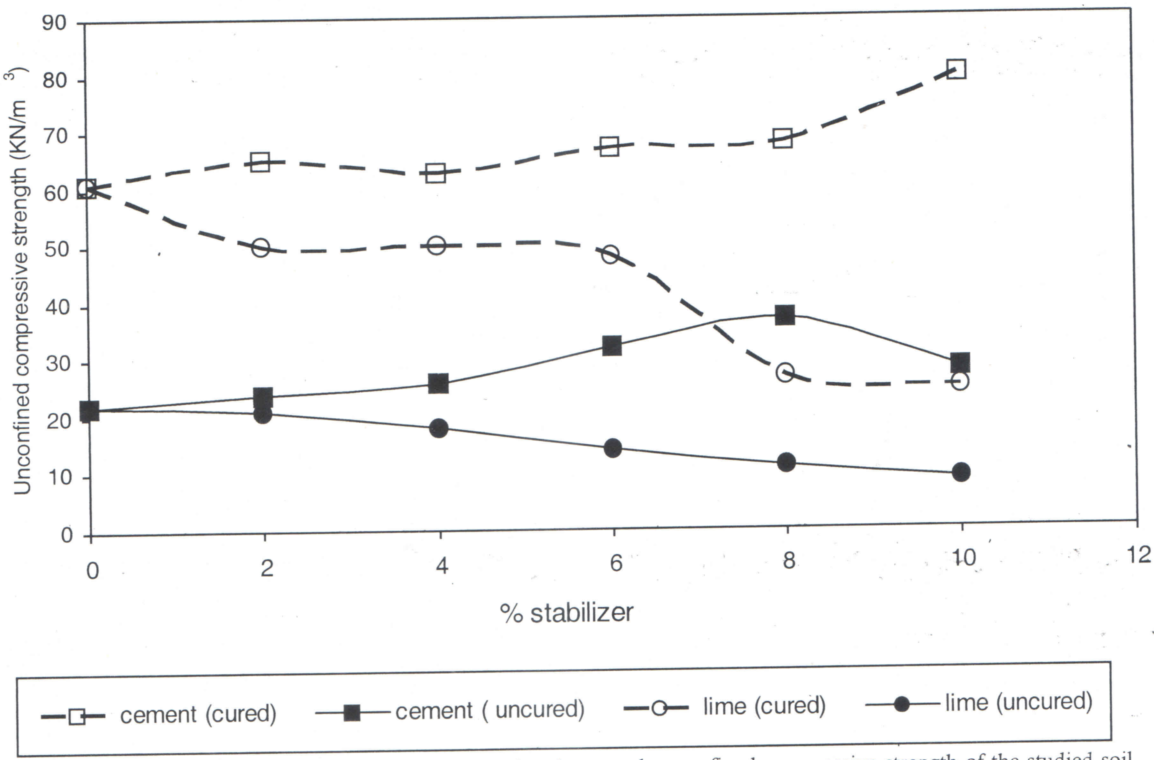

Fig. 10. The influence of cement and lime on the cured and uncured unconfined compressive strength of the studied soil.

obtained for both cement and lime stabilized soil also show that curing has positive influence on the strength of the studied soil. Furthermore, addition of between 2 and 10% by weight of cement has a strong positive influence on both the cured and uncured unconfined compressive strength of pegmatite derived soils, increasing the uncured Unconfined Compressive strength from 22.00 to 37.00 KN/m^2 and the cured Unconfined Compressive strength from 61.0 to 80.00 KN/m^2. These represent a percentage increase of 68.18% for the uncured unconfined compressive strength and 31.15 % for the cured unconfined compressive strength. On the other hand, uncured and cured unconfined compressive strength of the lime stabilized soil were respectively reduced from 22.00 to 9.00 KN/m2 and 61.00-25.00 KN/m^2. These correspondingly represent percentage reduction of 59.09% and 58.20% for uncured and cured unconfined compressive strength. This is an indication of negative influence of addition of lime to the strength of the studied soil.

As noticed in the maximum dry density, optimum moisture content and the California bearing ratio (both soaked and unsoaked), addition of more than 8% by weight of cement led to reduction in the uncured unconfined compressive strength of the studied soils (Table 4). This further confirms cement as a better stabilizer and 8% as the optimum % by weight of cement for the stabilization studied soils.

Influence of quantity of stabilizer on the studied soil

In order to quantitatively assess the effect of the response of the studied soil to variation in the quantity of the applied stabilizer using well established statistical method, regression coefficients between the determined geotechnical properties and the quantity of the applied stabilizer were determined. Regression coefficient is a well known mathematical parameter for establishing relationship between two set of parameters.

The result of the regression analysis is presented in Table 5. Strong positive correlation indicates that increase in quantity of stabilizer will result in increase in the geotechnical parameter. Similarly, strong negative correlation indicates that increase in quantity of stabilizer will lead to reduction in the geotechnical parameter.

Strong positive correlation of 0.62, 0.79, 0.82, 0.85 were obtained for the MDD, soaked CBR, Uncured and cured Unconfined Compressive Strength respectively for the cement stabilized soil. For the lime stabilized soil a strong positive correlation of 0.99 was obtained for Optimum Moisture Content while 0.32 and 0.33 were respectively obtained for the Unsoaked and Soaked CBR.

Strong negative correlation of -0.96,-0.93, -0.99 and -0.66, were respectively obtained for liquid limit, plasticity limit, linear shrinkage and Optimum Moisture Content of the cement-stabilized soil. These mathematically reveal that increasing the quantity of cement used for stabilization of the soil has strong influence on the geotechnical properties. On the contrary, strong negative correlation of -0.97 was obtained for the MDD of lime stabilized soil and the quantity of stabilizer. As earlier mentioned, this value reveals that increase in the percentage by weight of lime resulted in consistent decrease in soil density and invariably, the strength of the soil. The negative effect of increase in % of lime on the strength of the studied soil is further confirmed mathematically by the negative strong correlation of -0.99 and -0.93 obtained for the Uncured and Cured Unconfined Compressive Strength of lime stabilized soil, compared with 0.72 and 0.85 obtained for the same parameters.

Table 5. Correlation coefficients established between % of stabilizers and the geotechnical properties of the studied soil.

Geotechnical properties	Stabilizers	
	Cement	Lime
Liquid Limit	-0.96	-0.31
Plastic Limit	0.67	0.27
Plasticity Index	-0.93	-0.56
Linear Shrinkage	-0.99	-0.19
Maximum Dry Density	0.62	-0.97
Optimum Moisture Content	-0.66	0.99
Unsoaked CBR	0.55	0.32
Soaked CBR	0.79	0.33
Uncured Unconfined Compressive Strength	0.72	-0.99
cured Unconfined Compressive Strength	0.85	-0.93

Conclusions

The following conclusions can be drawn from the present study:

* The linear shrinkage, plasticity index, optimum moisture content, maximum dry density, soaked and unsoaked CBR and cured and uncured unconfined compressive strengths of the studied soils are optimally improved on addition of cement whereas, addition of lime have negative influence on optimum moisture content, maximum dry density, soaked and unsoaked CBR and cured and uncured unconfined compressive strengths
* There is a variation in the response of the studied soils to cement stabilization and lime stabilization with cement having stronger positive influence on all the studied properties of the soils.
* Addition of more than 8% by weight of cement was observed to cause reduction in maximum dry densities and the strengths of the studied soil. Therefore, of the two stabilizers employed and varying percentages of stabilizers studied, addition of 8% by weight of cement is the most appropriate for improving the properties of the studied soil.
* The choice and/or quantity of stabilizers needed to improve the engineering properties of stabilized soil may vary from one soil to the other. Therefore it is highly necessary to subject different soils to varying quantities of different stabilizers, to be able to determine the stabilizer(s) and the quantity of such stabilizer(s) that will produce optimum improvement in the engineering properties of the soil.

Recommendations

Similar studies should be extended to soils developed over parent rocks of widely different mineralogy and texture, employing different types of stabilizers (lime, cement, bitumen, etc) and compacting at other levels. Furthermore, attempt should be made to combine both cement and lime for the stabilization of different soils. These will shed more light on the appropriate choice and quantity of stabilizer required to improve the engineering properties of different soils.

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