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Original Research Article

Reliability of Soil and Ground Improvement Techniques in Niger Delta Region of Nigeria

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Abstract

This research work presents a study of the reliability of ground improvement methods in three states of the Niger Delta Area of Nigeria namely: Rivers, Bayelsa and Akwa –Ibom states. Natural soil which is peaty clay in nature was obtained from different locations in the area of study and improved with different percentages of chemicals, cement, ranging from 2% to 10% and geotextile materials after which reliability analysis was carried out on them for CBR and UCS tests. Results show that geotextile materials are not suitable for improving the peaty clay soils in the locations under study due to poor values of reliability while the reliability values obtained for soil improved with cement increases with increase in percentage addition of cement and curing period. Reliability values for soil improved with chemicals shows some variability but increase as curing period increases at percentage addition of chemicals from 2% to 6% for Calcium Oxide, Calcium Chloride, Calcium Hydroxide and Aluminium Hydroxide before a decrease in value. Sodium silicate reliability peaked at 8% while the optimal value of reliability for cement was realised at 10%.

Keywords: Reliability, Ground Improvement, Natural Soils, Geotextiles, Cement, Calcium Oxide, Calcium Chloride.

INTRODUCTION

The Soil in Niger delta area of Nigeria has a lot of foundation problems which includes high ground water table, deformation of highly compressive clays and peat. Most areas of this zone are water logged, swampy and characterized by weak soils thereby making it difficult at times to place structures on them without addressing the stability of such structures.

A land based structure is as strong as its foundation. In view of this, soil is a critical element that influences the success of any structure placed on it. Due to the nature of the soils in the Niger delta and its attendant foundation problems like deformation, consolidation of highly compressible clays and settlement just to mention a few, ground improvement is needed for some projects with a view to maximize the durability of the natural soil for a given construction purpose.

Soil improvement increases strength, bearing capacity and resistance to deteriorating forces of nature and manmade environment. It decreases the volume change tendency, settlement, controls permeability, and provides long term durability over decades of service under severe environmental conditions as can be witnessed in the Niger Delta region of Nigeria. In a nutshell, soil improvement changes the engineering properties of the soil to allow for field construction to take place on poor soils.

Although there are other decisions that can be taken when the underlying soil is unsuitable for engineering purposes among which are finding a new construction site, redesigning of structures so that it can be placed on the poor soil, the use of soil improvement in solving this problem is better because it reduces cost, conserves energy and allow engineers to distribute a larger load with less material over a longer life cycle.

In view of the challenges posed by the nature of soils in Niger delta region of Nigeria which makes it necessary in some cases to improve the soils before structures can be placed on them, there is a need to investigate modern trends in ground improvement techniques like the use of geosynthetic materials, chemicals and compare them to the conventional techniques like addition of cement in order to determine their reliability i.e. the probability that the methods perform satisfactorily under specified operational and environmental conditions in the Niger delta region of Nigeria.

Location of Study Area

Akwa Ibom, Bayelsa and Rivers states which all lies within the Niger Delta area in the South – South geopolitical zone of Nigeria is the Area of study for the research work. The entire Niger Delta is located at elevation of 96m above sea level with coordinates 40 49' 60" N and 6^0 0" E. other states in the Niger Delta Area apart from the three that forms the study area are: Abia, Cross River, Delta, Edo, Imo, Ondo. Fig. 1.1 shows the map of the Niger Delta Area.

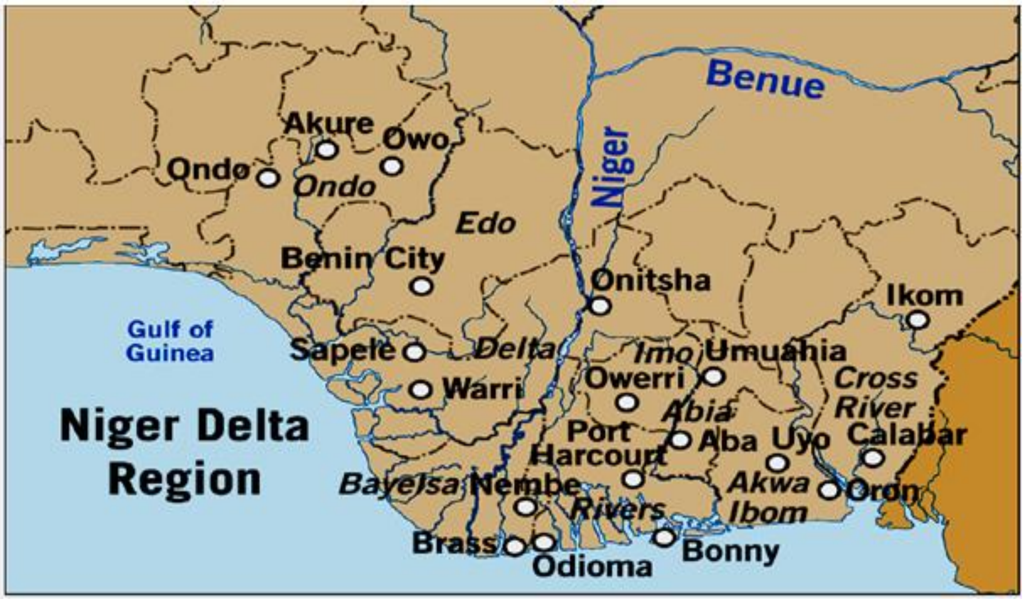

Fig. 1.1: Map showing the Niger Delta Region of Nigeria

MATERIALS AND METHODS

The materials used in this research are:

Soil sample, Cement, Chemicals and Geotextiles

Soil Sample

Soil samples (marine clay), which is peaty in nature, were obtained from three different areas in three states of the Niger Delta Area of Nigeria namely: Rivers, Bayelsa and Akwa Ibom states. With the use of hand Augers, soil samples were taken at the locations at depths of 1m for the California Bearing Ratio (CBR) tests while the samples for the unconfined compressive strength tests (UCS) were taken at depths of 1m to 1.5m. The disturbed soil samples taken at the locations were sealed with a wrapping paper as a precautionary measure to prevent loss or gain of moisture. The average physical and engineering properties of the soil from laboratory tests of samples taken from the various locations in the three states are shown in tables 4.1 to 4.3.

Table 4.1: Average Soil Physical Properties for Rivers State Locations

S/N	PHYSICAL PROPERTIES	VALUE
1	Depth of sample	1m
2	Bulk unit weight	$13.95KN/M^3$
3	Specific gravity	2.40
4	Natural moisture content (%)	86.8
5	Liquid limit	113.4
6	Plastic limit	45.6
7	Plasticity index	67.8
8	Grain size distribution:	
	1. Clay size % (<0.002mm)	42
	2. Silt size % (>0.002mm<0.075mm)	39
	3. Sand size % (>0.075mm)	19

Table 4.2: Average Soil Physical Properties for Bayelsa State Locations

S/N	PHYSICAL PROPERTIES	VALUE
1	Depth of sample	1m
2	Bulk unit weight	14.5KN/M^3
3	Specific gravity	2.14
4	Natural moisture content (%)	87.6
5	Liquid limit	116.4
6	Plastic limit	46.5
7	Plasticity index	69.9
8	Grain size distribution:	
	1. Clay size % (<0.002mm)	44
	2. Silt size % (>0.002mm<0.075mm)	38
	3. Sand size % (>0.075mm)	18

Table 4.3: Average Soil Physical Properties for Akwa Ibom State Locations

S/N	PHYSICAL PROPERTIES	VALUE
1	Depth of sample	1m
2	Bulk unit weight	14.78KN/M^3
3	Specific gravity	2.36
4	Natural moisture content (%)	88.9
5	Liquid limit	117.6
6	Plastic limit	45.7
7	Plasticity index	71.9
8	Grain size distribution:	
	1. Clay size % (<0.002mm)	46
	2. Silt size % (>0.002mm<0.075mm)	35
	3. Sand size % (>0.075mm)	19

Cement

The cement used in this research is Ordinary Portland Cement (OPC) grade 42.5.

Chemicals

Chemicals that are multivalent and monovalent cationic species like Calcium Oxide (Cao), Sodium Silicate (Na_2O_3Si), Aluminum Hydroxide (Al_2OH), Calcium Chloride and Calcium Hydroxide were used in the research to improve the engineering properties of the various soil samples in order to determine their reliability.

Sodium silicate (Na_2O_3Si) is a white powder that belongs to the family of sodium metasillicate. It is readily soluble in water, thereby an alkaline solution. It is non-polluting, environmentally safe and non – hazardous to human health (Yonekura and Kaja (1992) [1], Karol (2003) [2].

Calcium oxide (Cao) otherwise known as quicklime is a chemical reagent which can effectively control the swelling of soils by modifying its properties especially the swelling and plasticity characteristics. The ability of quicklime to form alkaline solutions and suspensions in water is very key to its modification of soils in a beneficial way to engineers. Its improvement of soil is majorly due to pozzolanic reactions which allow it to improve the long – term performance of soils significantly (Khattab and others (2007) [3], Rogers and Papadimitrou (2006) [4]. Naturally, it is found in rocks and shells of marine organisms like pearls, coal balls, snails and egg shells.

Calcium hydroxide $Ca(OH)_2$ is also referred to as slaked or hydrated lime, a name it got through the process of mixing calcium oxide with water (slaking) at temperatures below 350^0 C. It is an inorganic compound that is colourless and crystal white in colour.

Aluminium hydroxide ($Al(OH_3)$) is found in nature as hydragillite (Gibbsite), it is very environmentally friendly and does not appear to be extremely sensitive to moisture content variations. Freshly precipitated type of this chemical forms gel, which crystallizes with time and can be hydrated to form an amorphous (Solid) Aluminium hydroxide powder.

Calcium chloride $Cacl_2$ is the combination of calcium and chloride, which behaves like an ionic halide. It is solid at room temperature. Due to the solubility of calcium chloride, it can be a source of calcium ions in a solution.

All chemicals for the research were procured through Halden Nigeria Limited, Trans Amadi, Port Harcourt. Figs. 4.1 – 4.4 shows some of the chemicals in their bottles before the laboratory tests. The physical and chemical properties of the chemicals are shown in table 4.4.

Fig. 4.1: Sodium Silicate Powder

Fig. 4.2: Aluminium Hydroxide gel

Fig. 4.3: Calcium Oxide powder

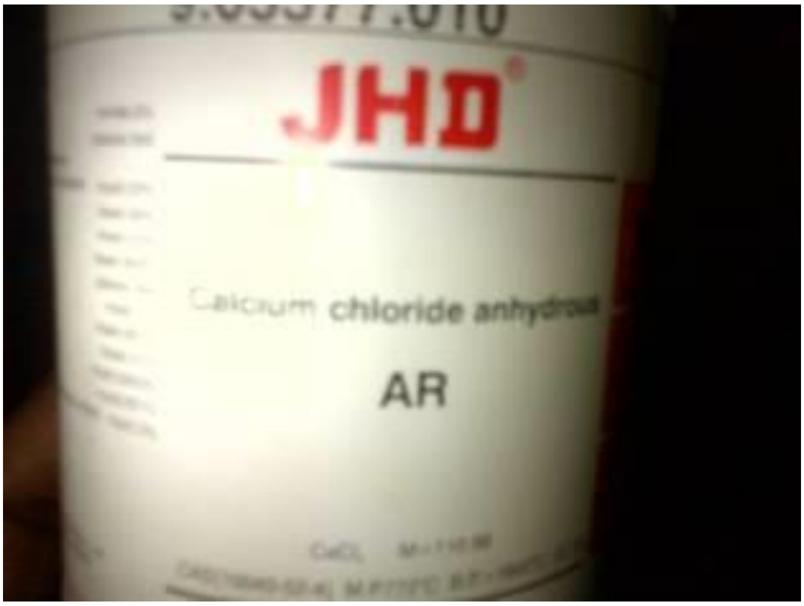

Fig. 4.4: Calcium Chloride powder

Table 4.4: Properties of Chemicals for Ground Improvement

Chemicals	Molar Mass g/mol	Melting Point ^{0}C	Density g/cm^3	Solubility	Acidity
Calcium Oxide	56.08	2572.00	3.35	In water and glycerol	
Sodium Silicate	122.06	1.09	2.15	In watr	
Aluminium Hydroxide	78.00	300.00	2.42	in Acids & Alkaline	> 7
Calcium Chloride	110.98	772.00	1.94	In water & Acetic Acid	
Calcium Hydroxide	74.09	580.00	2.21	In water, Acid & glycerol	12.40

Geotextiles

Woven and non – woven types of geotextiles were used in the research for CBR test in other to determine their reliability on the various soil samples. The geotextile materials were procured from Geotextile and Gabions Limited in Kaduna. Figs. 4.5 to 4.6 shows the geotextile materials used while table 4.5 shows their properties.

Fig. 4.5: Woven geotextile (WN450)

Fig. 4.6: Non - Woven geotextile (Geo400s)

Table 4.5: Properties of Geotextile Materials

			GEOTEXTILE MATERIALS	
PROPERTIES	**UNIT**	**VALUE**	**WW450**	**GEO 400S**
MECHANICALS				
Tensile strength (MD/CMD)	KN/m	Mean	1.00	0.76
Tensile strength (MD/CMD)	KN/m	Min	1.00	1.00
Resistance to static puncture	N	Mean	6700.00	5000.00
Dynamic Perforation resistance	mm	Mean	6.00	10.00
HYDRAULIC				
Characteristic opening size	mm	Mean	240.00	78.00
Water permeability normal to the plane	mm/s	Mean	13.60	40.00
Water flow rate	$1/m^2$*S	Mean	13.60	40.00
PHYSICAL				
Mass/Unit Area	gr/m^2	Mean	240.00	400.00
Thickness	mm	Mean	1.17	3.90
ENDURANCE				
UV Resistance	% retained @ 500hr	Mean	80.00	90.00

Proctor and CBR Compaction test with chemicals and cement

Chemicals used for the research: Calcium chloride, Sodium silicate, Calcium hydroxide, Aluminium hydroxide, Calcium oxide and Cement were added to prepared samples of the soil passing sieve 425μ from various locations, in different percentages of soil: 2% 4%, 6%, 8% and 10%. The improved soil samples were cured for 7, 14 and 28 days with the use of polythene bags after maximum dry density and Optimum moisture content have been determined from the standard proctor compaction tests while CBR tests were carried out for both soaked and unsoaked conditions in accordance with BS 1377 (1990) [5]. Figs. 4.7 and 4.8 show the soil sample before the commencement of tests and Fig. 4.9 shows the set-up of the laboratory experiment for CBR.

Fig. 4.7: Typical soil sample for laboratory test

Fig. 4.8: Pulverized soil sample for laboratory test

Fig. 4.9: CBR machine set up for CBR test

Proctor and CBR Compaction test with Geotextile materials

Two types of geotextile materials, one woven and the other unwoven were used in this case. After the proctor compaction test and curing, the geotextile materials were placed in between the surcharge rings of the CBR machine and the top of the soil sample in the mould before the experiment is carried out for both soaked and unsoaked conditions in accordance with BS 1377 (1990) [5].

Unconfined Compressive Strength Tests

The unconfined compressive strength tests were carried out on the undisturbed soil samples in accordance with BS 1377.

Cylindrical soil samples of the natural soil and the ones treated with various percentages of cement and chemicals: 4, 6, 8 and 10% of the weight of soil were prepared at the natural moisture content and dry unit weight. After the compaction test, the samples were cured for 7 and 14 days before the UCS test was carried out with a cell pressure of 50KN/ m^2 and100KN/m^2. Figs. 4.10 to 4.11 show the set-up of the experiment and the images of sheared improved soil samples after the test.

Fig. 4.10: UCS test set up and ongoing experiment

Fig. 4.11: Some Improved Soil samples after UCS test

Formulation of Reliability Model

The reliability model adopted for the research work is: First Order Second Moment method of analysis. This method of analysis uses the first terms of a Taylor's series expansion of the performing function in estimating the expected value (mean) and variance of the performing function. The variance is the highest order of the statistical result used in the analysis. Once the expected value and the variance are obtained for the load and resistance, obtaining the reliability of the geotechnical system or the probability of failure as the case may be will no longer be a cumbersome affair.

Assumptions in Reliability Model

The basic assumptions in adopting this method of analysis are:

1. The load Q is normalized
2. The resistance R is normalized
3. The safety margin M which is the performance function of the geotechnical system is normalized by virtue of assumptions 1 and 2.

First Moment (Expected Mean)

The mean or expected value of a random variable is one of the central value measure of the variable, the others being mode and median. The mean, which is obtained from the probability distribution of the random variable like PDF is normally called the first central moment of the area of the distribution of the function and reveals an important characteristics of this distribution.

Mathematical Expression:
For a random variable X the mean or expected value (μ) when X is discrete is:
$\mu = E(X) = \sum_i xip(xi)$ ……………………… (3.1)

The mean of a discrete random variable X having possible values: X_1, X_2, X_3,…………….X_n can also be defined as:
$\mu = E(X) = \frac{x1+x2+x3+.........+xn}{n}$ ……………..….. (3.2)

(3.2) is termed arithmetic mean or average value and it is normally computed from given observations and for a random variable X that is continuous, the mean or expected value (μ) is:
$\mu = \int_{xmin}^{xmax} Xfx\,(x)dx$ ……………………..……… (3.3)

Second Moment (Variance)

Variance of a random variable X is called the second central moment. Normally denoted by σ^2x or σ^2, it is the most common measure of dispersion of a distribution about its mean and its large value implies a large spread in the distribution of X about its mean while small value implies the opposite.

It is referred to as the second central moment of the area of the distribution function with respect to its center of gravity because it is the squares of distances from the center of gravity (mean) of the shape defined by the distribution function.

Mathematical Expression:
For a random variable X the variance (σ^2) when X is discrete is defined as:
$\sigma^2 = E\{(X–m)\} = \sum_i (x-m)Px(xi)$ ……………(3.4)

For a given set of observed data, the sample variance is defined as:
$\sigma^2 = \frac{1}{n-1} \sum_i (x-m)^2$ ……………………….. (3.5)

When X is continuous, for a random variable, the variance is defined as:
$\sigma^2 = \int_{xmin}^{xmax} Xfx\,(x-m)^2\,dx$…………………. (3.6)

From the equations above, it can be deduced that the variance has a relationship with the mean as follows:
Variance $\sigma^2 = E(x^2) – [E(x)]^2 = E(x^2) - \mu^2$……(3.7)

Standard Deviation

Standard deviation σ or σ_x is the positive square root of the variance, which makes it dependant on the shape of the distribution function with the same units as the mean of the random variable. The fact that it has the same units as the mean of the random variable is of great advantage as it can then be compared with the mean in the same scale to gain some measure of the degree of spread of the distribution.

Mathematical Expression:
Since standard deviation is the positive square root of variance, it follows that it can be derived from (3.6) and (3.7) above thus:
$\sigma = \sqrt{\sigma^2} = \sqrt{\sum_i (x-m)Px(xi)}$ …..…………… (3.8)

For a random variable in which X is discrete and
$\sigma = \sqrt{\sigma^2} = \sqrt{\frac{1}{n-1} \sum_i (x-m)^2}$……………… (3.9)

For a given set of observed data and for a continuous random variable,
$\sigma = \sqrt{\sigma^2} = \sqrt{\int_{xmin}^{xmax} Xfx\,(x-m)^2 dx}$ ……… (3.10)

However, there is need to mention that apart from the computational method represented by (3.8) to (3.10), there are other methods of estimating the standard deviation of parameters in geotechnical engineering, especially when the amount of data available is limited. The methods are:

1. Published values, which are expressed in terms of the coefficient of variation V thus:

$V = {}^{\sigma}/_{\bar{x}}$ ……………………………………. (3.11)
From which $\sigma = V\bar{X}$
Where V = Coefficient of Variation
σ = Standard Variation and $\bar{X}$ = Average Value or mean.

2. Three - Sigma Rule in which the difference between highest and lowest conceivable values of the parameter is divided by 6 to obtain the standard deviation as shown below:

Standard deviation $\sigma = \frac{HCV-LCV}{6}$ …………… (3.12)

3. Graphical Three – Sigma Rule which is an extension of the Three – Sigma Rule.

Reliability Index

The Reliability Index β is the major means of expressing reliability in geotechnical engineering systems. The index, which is a complement of probability of failure, can be expressed in terms of the mean or expected value of a random variable and its standard variation.

Mathematical Expression:
For a geotechnical system with a load Q and resistance R, the safety margin which is the performance function of the system M is expressed as:
M = R – Q …………………………………… (3.13)

From the definitions of mean and variance earlier discussed, the mean of the safety margin (μ_M) is the difference between the mean of resistance μ_R and that of load μ_Q:

$\mu_M = \mu_R - \mu_Q$ …………………………………… (3.14)

And similarly, the variance of M ($\sigma^2 M$) is:

$\sigma^2_M = \sigma^2_R + \sigma^2_Q - 2\rho RQ\, \sigma_R\, \sigma_Q$ ………………… (3.15)

Where ρ_{RQ} is the correlation coefficient between R and Q

While the standard deviation of safety margin M is:

$\sigma_M = \sqrt{\sigma 2R + \sigma 2Q - 2\rho RQ\, \sigma R\, \sigma Q}$ ………..(3.16)

Reliability index is defined as the ratio between the mean and the standard deviation of safety margin. Therefore, from equations above, reliability index (β) is given by the expression:

$\beta = \frac{\mu M}{\sigma M}$ ……………………………………….. (3.17)

From equations 3.13 and 3.15,

$\beta = \frac{\mu R - \mu Q}{\sqrt{\sigma 2R + \sigma 2Q - 2\rho RQ\, \sigma R\, \sigma Q}}$ …………………. (3.18)

Equation 3.17 above shows the distance of the mean margin of safety from its critical value that is when safety margin (M) equals zero in units of standard deviation.

If the load and the resistance are not correlated, it then means the correlation coefficient ρ_{RQ} is zero and equation 3.17 will be reduced to:

$\beta = \frac{\mu R - \mu Q}{\sqrt{\sigma 2R + \sigma 2Q}}$ ……………………………… (3.19)

From the assumptions that the Load (Q) and Resistance (R) are both normally distributed, the safety margin M is normally distributed as well since it is a linear combination of the Load and the Resistance.

From the statement above, the reliability index (β) which will normalize the safety margin (M) with respect to its standard deviation becomes a standard normal variate (Z).

Standardized normal distribution with zero mean and unit standard deviation is shown in appendix 1. The distribution expresses the integral Φ of the standardized Normal distribution between – ∞ and positive values of the parameters Z. Probability of failure P_f is the integral between – ∞ and values of the parameter Z located below the mean value (negative values of Z). By symmetry of Normal distribution, probability of failure P_f which is a complement of Reliability is:

$P_f = 1 - \Phi(\beta)$ or $\Phi(-\beta)$ …………………… (3.20)

In equation 3.19 above, β is the reliability index.

Practical application of the mathematical formulation is such that once the reliability index (β) is calculated using appropriate formulas, if the value is negative, the reading on the standard normal distribution table is the probability of failure (P_f) of the system, from which the Reliability (R_e) of the system can be obtained thus:

$R_e = 1 - P_f$ ………………………………… (3.21)

If the value of the reliability index (β) is positive, then the reading on the standard normal distribution table becomes the Reliability (Re) of the system while the probability of failure will be:

$P_f = R_e - 1$ ………………………………… (3.22)

From these mathematical expressions it can be deduced that as the Reliability index (β) increases, the probability of failure decreases thereby making the Reliability index (β) similar in behavior to the factor of safety.

EXPERIMENTAL RESULTS AND DISCUSSIONS

Result Overview

From the research analysis and results, the peaty clay soil from the three different locations of Rivers, Bayelsa and Akwa Ibom states in the Niger Delta area of Nigeria shows some improvement in strength and Reliability to certain level which varies with the number of days for curing and the percentage of chemical or cement added to the soil for both unconfined compressive strength and California bearing ratio tests. However, the CBR test carried out with Geotextile materials, shows reliability values that even though they are greater than that of the natural soil, it is of no engineering significance due to its low values of reliability.

The Reliability analysis of the different chemicals, cement and geotextile materials is discussed thus:

Reliability of Soil improved with Calcium Chloride

Tables 5.1 to 5.6 shows the reliability values of CBR and UCS tests performed on the peaty clay soil samples with different percentages of Calcium Chloride ranging from 2% to 10% and curing days ranging from 7 days to 28 days from the three states of the Niger Delta under study.

Table 5.1: Reliability Values for CBR Test of Peaty Clay Mixed with Various Percentages of Calcium Chloride and Curing Periods (Akwa Ibom Locations)

% content of Calcium Chloride	Days of Curing		
	7 days	14 days	28 days
4	0.8212	0.8238	0.8264
6	0.8238	0.8264	0.8289
8	0.7881	0.7967	0.8023
10	0.7517	0.7549	0.7881

Table 5.2: Reliability Values for CBR Test of Peaty Clay Mixed with Various Percentages of Calcium Chloride and Curing Periods (Bayelsa State Locations)

% content of Calcium Chloride	Days of Curing		
	7 days	14 days	28 days
4	0.7967	0.7995	0.8023
6	0.7995	0.8023	0.8051
8	0.7642	0.7734	0.7764
10	0.7257	0.7324	0.7549

Table 5.3: Reliability Values for CBR Test of Peaty Clay Mixed with Various Percentages of Calcium Chloride and Curing Periods (Rivers State Locations)

% content of Calcium Chloride	Days of Curing		
	7 days	14 days	28 days
4	0.8051	0.8051	0.8106
6	0.8078	0.8078	0.8133
8	0.7734	0.7823	0.7852
10	0.7357	0.7422	0.7642

Table 5.4: Reliability Values for UCS Test of Peaty Clay Mixed with Various Percentages of Calcium Chloride and Curing Periods (Akwa Ibom Locations)

% Content of Calcium Chloride	Days of Curing		
	7 days	14 days	28 days
2	0.9633	0.9699	0.9732
4	0.9633	0.9699	0.9732
6	0.9678	0.9693	0.9761
8	0.9515	0.9591	0.9686
10	0.9292	0.9495	0.9656

Table 5.5: Reliability Values for UCS Test of Peaty Clay Mixed with Various Percentages of Calcium Chloride and Curing Periods (Bayelsa Locations)

% Content of Calcium Chloride	Days of Curing		
	7 days	14 days	28 days
2	0.9344	0.9408	0.944
4	0.9344	0.9408	0.944
6	0.9388	0.9402	0.9468
8	0.9230	0.9303	0.9395
10	0.9013	0.921	0.9366

Table 5.6: Reliability Values for UCS Test of Peaty Clay Mixed with Various Percentages of Calcium Chloride and Curing Periods (Rivers State Locations)

% Content of Calcium Chloride	Days of Curing		
	7 days	14 days	28 days
2	0.9440	0.9505	0.9537
4	0.9440	0.9505	0.9537
6	0.9484	0.9499	0.9566
8	0.9325	0.9399	0.9462
10	0.9106	0.9305	0.9463

The reliability values show high level of parity for the three states under study. The strength values of the soil sample while tested have negligible difference (not more than 3%) while the organic content is almost the same for all the locations.

Figs. 5.1 to 5.6 show the variation of the reliability with the percentage of Calcium chloride and curing days for the three states.

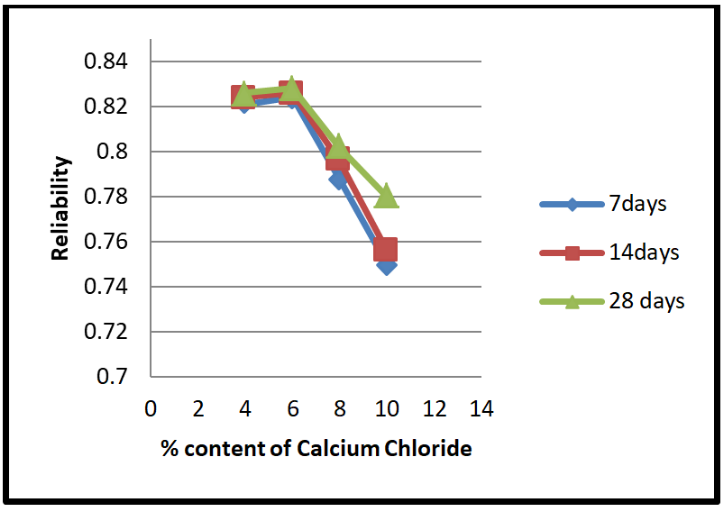

Fig. 5.1: Variation of Reliability with Percentage Content of Calcium Chloride and Curing Days for CBR Test (Akwa Ibom Locations

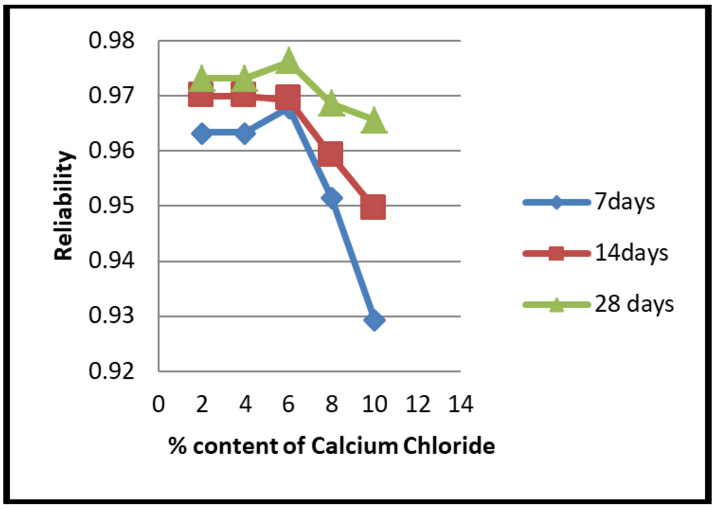

Fig. 5.2: Variation of Reliability with Percentage Content of Calcium Chloride and Curing Days for UCS Test (Akwa Ibom Locations)

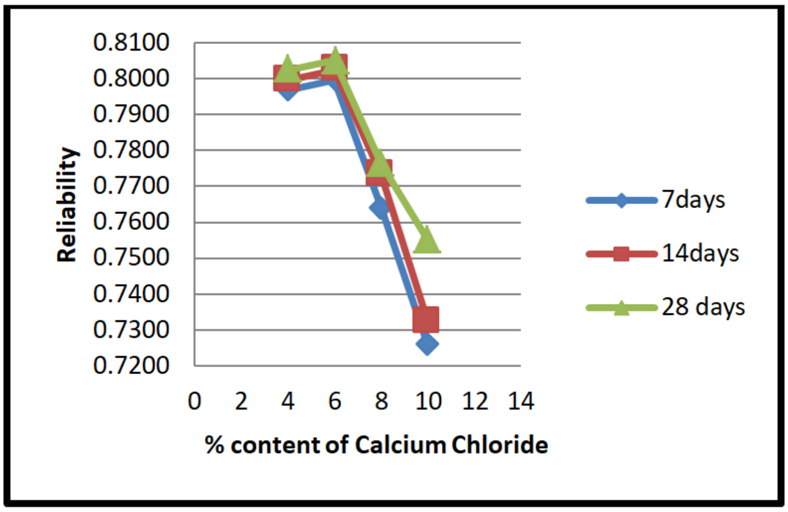

Fig. 5.3: Variation of Reliability with Percentage Content of Calcium Chloride and Curing Days for CBR Test (Bayelsa State Locations)

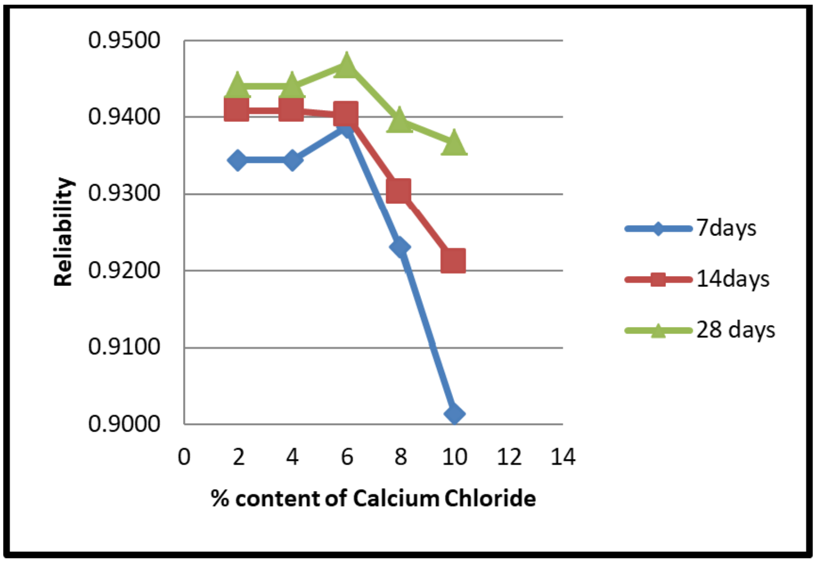

Fig. 5.4: Variation of Reliability with Percentage Content of Calcium Chloride and Curing Days for UCS Test (Bayelsa State Locations)

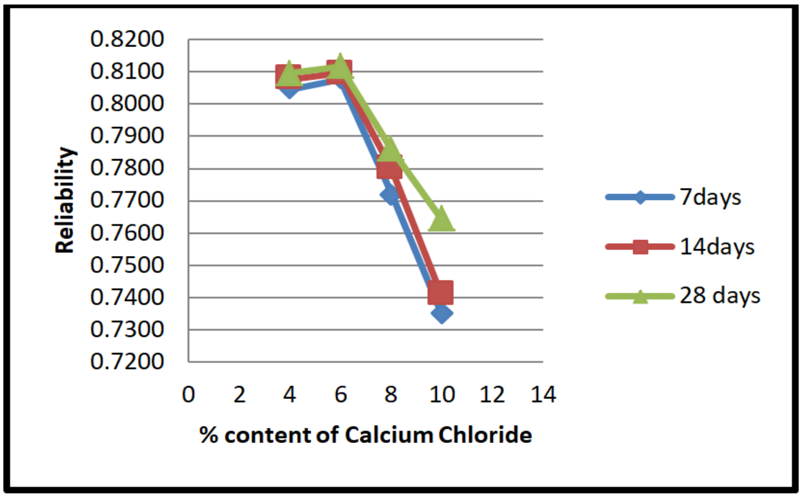

Fig. 5.5: Variation of Reliability with Percentage Content of Calcium Chloride and Curing Days for CBR Test (Rivers State Locations)

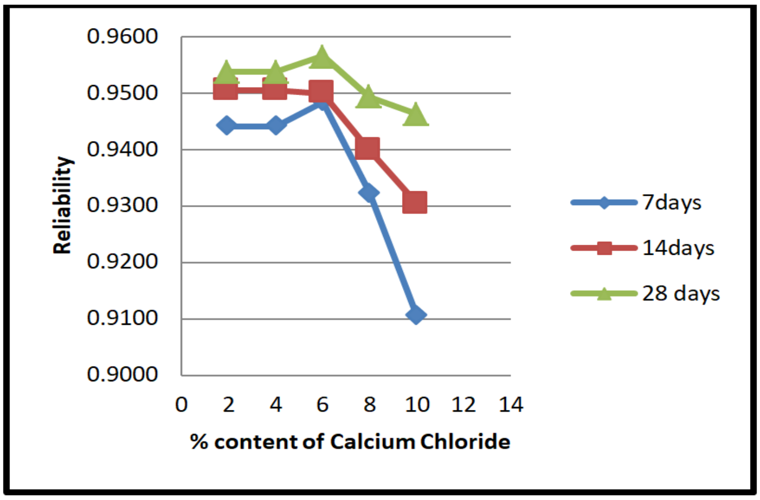

Fig. 5.6: Variation of Reliability with Percentage Content of Calcium Chloride and Curing Days for UCS Test (Rivers State Locations)

From the figures above, the reliability of the soil sample mixed with Calcium Chloride shows that it peaked at 6% for all curing days (7, 14 and 28), with the reliability values for the UCS tests equal at 2% and 4% while the reliability starts reducing from 6% to 10% for both tests carried out. For the CBR test, there is a negligible difference between reliability values for all periods of curing. At the peak value of reliability (6%) for UCS tests, there is a large disparity between 28 days and 14 days of curing but the difference between the values for 7 and 14 days is negligible. However, this was not the case in CBR test as all the values for all curing days show negligible differences especially between 4% and 6 % addition of the chemical to the soil.

Reliability of Soil improved with Calcium Oxide

Tables 5.7 to 5.12 shows the reliability values of CBR and UCS tests performed on the peaty clay soil samples with different percentages of Calcium Oxide ranging from 2% to 10% and curing days ranging from 7days to 28days from the three states of Niger Delta under study.

Table 5.7: Reliability Values for CBR Test of Peaty Clay Mixed with Various Percentages of Calcium Oxide and Curing Periods (Akwa Ibom Locations)

% content of Calcium Oxide	Days of Curing		
	7 days	14 days	28 days
4	0.8577	0.8869	0.9115
6	0.9278	0.9850	0.9981
8	0.9177	0.9406	0.9525
10	0.8508	0.8554	0.9049

Table 5.8: Reliability Values for UCS Test of Peaty Clay Mixed with Various Percentages of Calcium Oxide and Curing Periods (Akwa Ibom Locations)

% content of Calcium Oxide	Days of Curing		
	7 days	14 days	28 days
2	0.9778	0.9871	0.9898
4	0.9838	0.9893	0.9911
6	0.9878	0.9901	0.9913
8	0.9783	0.9842	0.9881
10	0.8907	0.9798	0.9846

Table 5.9: Reliability Values for CBR Test of Peaty Clay Mixed with Various Percentages of Calcium Oxide and Curing Periods (Bayelsa State Locations)

% content of Calcium Oxide	Days of Curing		
	7 days	14 days	28 days
4	0.8315	0.8599	0.8849
6	0.9015	0.9554	0.9678
8	0.8907	0.9115	0.9207
10	0.8238	0.8289	0.8770

Table 5.10: Reliability Values for UCS Test of Peaty Clay Mixed with Various Percentages of Calcium Oxide and Curing Periods (Bayelsa State Locations)

% Content of Calcium Oxide	Days of Curing		
	7 days	14 days	28 days
2	0.9440	0.9505	0.9537
4	0.9440	0.9505	0.9537
6	0.9484	0.9499	0.9566
8	0.9325	0.9399	0.9462
10	0.9106	0.9305	0.9463

Table 5.11: Reliability Values for CBR Test of Peaty Clay Mixed with Various Percentages of Calcium Oxide and Curing Periods (Rivers State Locations)

% Content of Calcium Oxide	Days of Curing		
	7 days	14 days	28 days
4	0.8413	0.8686	0.8925
6	0.9099	0.9656	0.9783
8	0.8997	0.9207	0.9319
10	0.8340	0.8389	0.8869

Table 5.12: Reliability Values for UCS Test of Peaty Clay Mixed with Various Percentages of Calcium Oxide and Curing Periods (Bayelsa State Locations)

% Content of Calcium Oxide	Days of Curing		
	7 days	14 days	28 days
2	0.9582	0.9674	0.97
4	0.9641	0.9695	0.9713
6	0.9680	0.9703	0.9715
8	0.9587	0.9645	0.9683
10	0.8729	0.9602	0.9649

Reliability values obtained in the research for soil samples mixed with various percentages of Calcium Oxide shows an appreciable result with the peak at 6% as observed in that of Calcium chloride. The variation of the reliability with the various curing periods and percentage mix of Calcium oxide for the three states are shown in figs. 5.7 to 5.12.

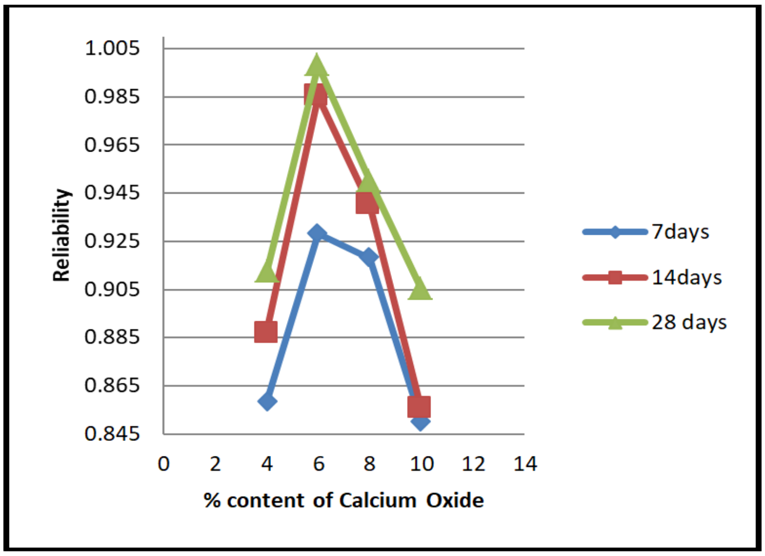

Fig. 5.7: Variation of Reliability with Percentage Content of Calcium Oxide and Curing Days for CBR Test (Akwa Ibom Locations)

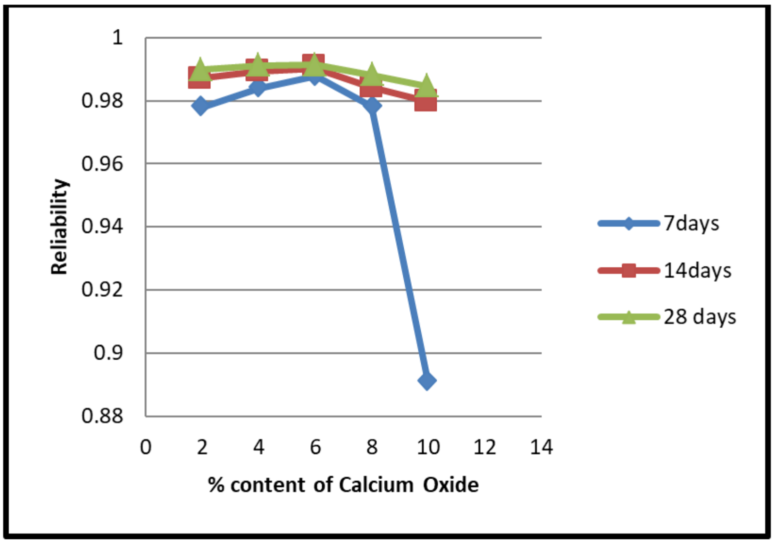

Fig. 5.8: Variation of Reliability with Percentage Content of Calcium Oxide and Curing Days for UCS Test (Akwa Ibom Locations)

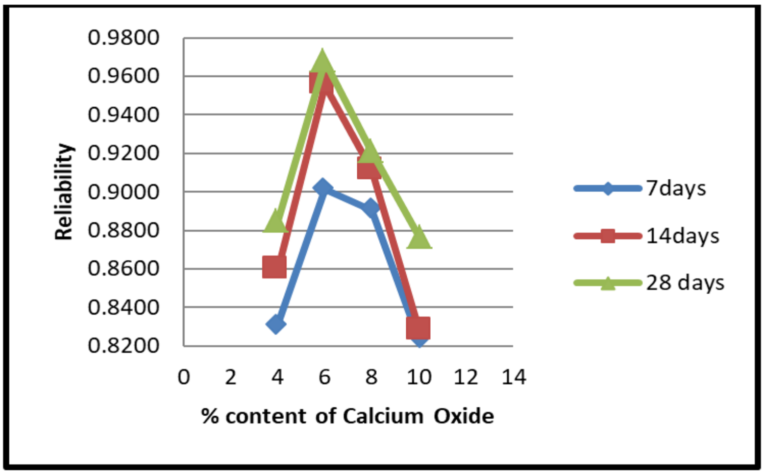

Fig. 5.9: Variation of Reliability with Percentage Content of Calcium Oxide and Curing Days for CBR Test (Bayelsa State Locations)

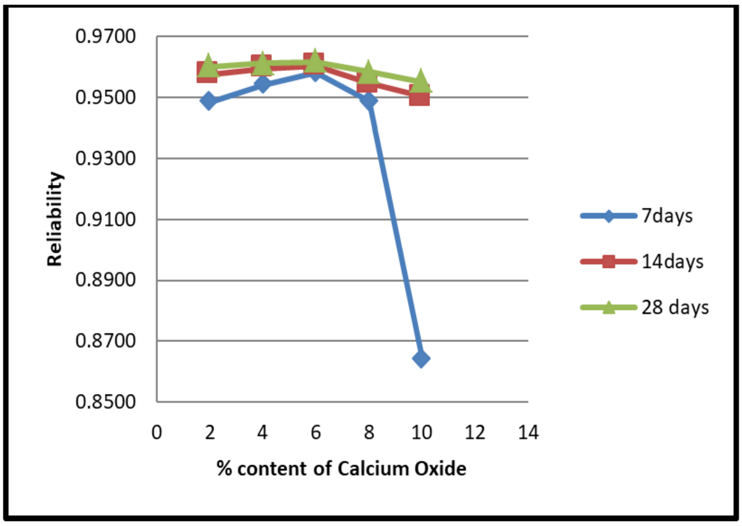

Fig. 5.10: Variation of Reliability with Percentage Content of Calcium Oxide and Curing Days for UCS Test (Bayelsa State Locations)

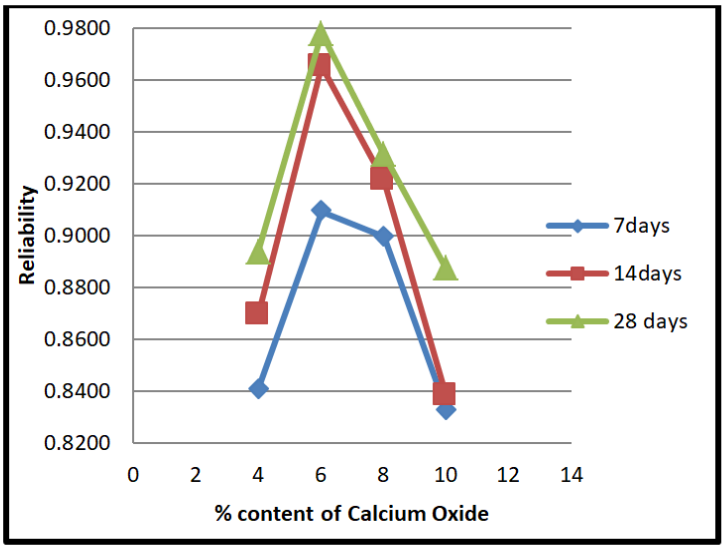

Fig. 5.11: Variation of Reliability with Percentage Content of Calcium Oxide and Curing Days for CBR Test (Rivers State Locations)

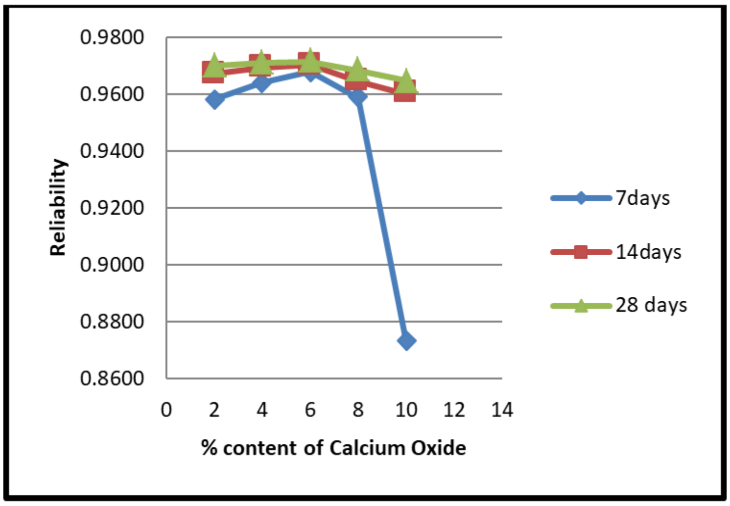

Fig. 5.12: Variation of Reliability with Percentage Content of Calcium Oxide and Curing Days for UCS Test (Rivers State Locations)

As observed from figs. 5.7 to 5.12, the difference in reliability value between 7 days and 14 days curing periods shows some disparity, in comparison with that of 14 and 28 days curing period. However, Calcium Oxide shows the maximum reliability of all the chemicals used in the research but it should be noted as shown clearly in the plots that the optimal reliability occurred at 6% with a sharp decrease observed from 8% to 10% especially for 7 days curing period in the UCS test. The reliability values for all the three locations are almost at parity.

Reliability and Cost

Cost of execution of projects is an important factor in Engineering. In view of this, reliability can be a means of optimizing, to choose a level of safety that will reduce cost and achieve the selection of a suitable structural configuration.

In this research work, a cost analysis has been carried out to relate the initial cost of the materials used with their level of reliability, to ascertain alternatives that can be used due to non-availability of a particular product or change in purchasing cost due to economy.

Figs. 5.13 and 5.14 shows the plots of average initial cost of materials used in the reliability analysis and their reliability values.

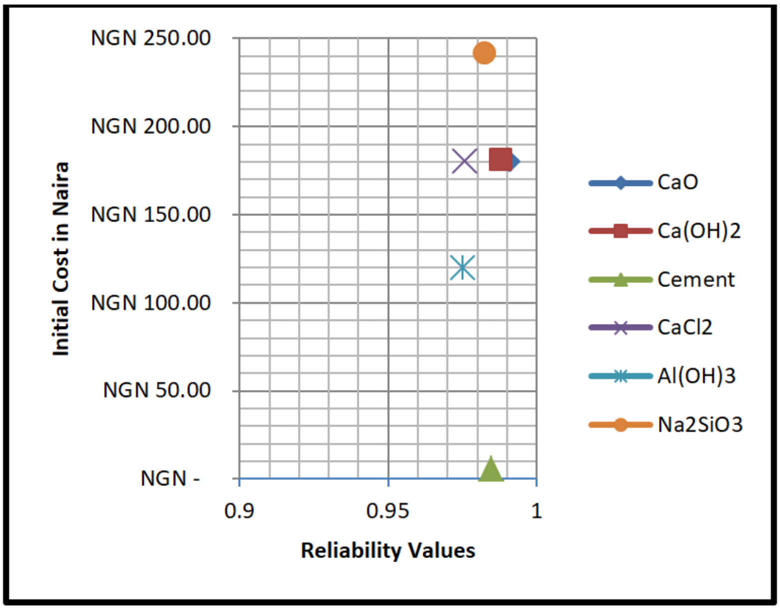

Fig. 5.13: Average Initial Cost of Materials and Reliability Values for UCS Test

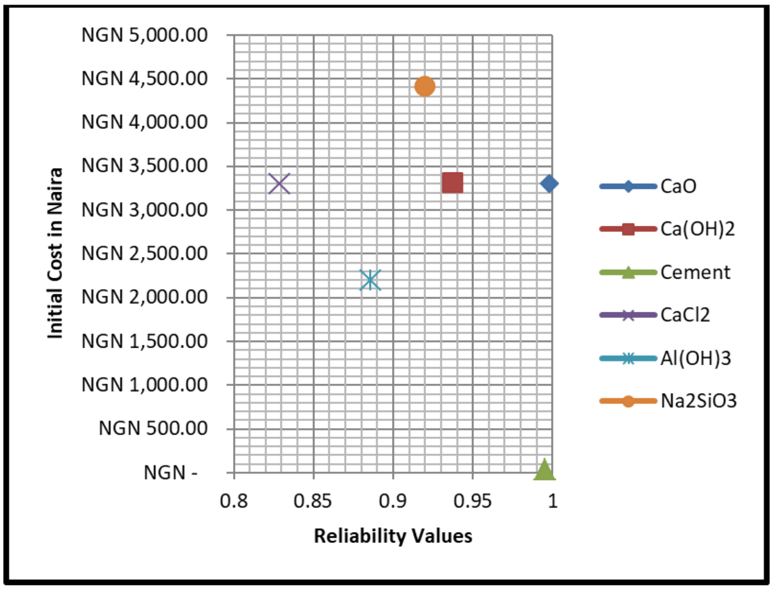

Fig. 5.14: Average Initial Cost of Materials and Reliability Values for CBR Test

From the two figures shown above, it can be seen clearly that of all the materials used, cement has the lowest cost, with an appreciable value of reliability for both UCS and CBR tests. Calcium Oxide, Calcium Hydroxide and Calcium Chloride all have the same cost of execution but with varying reliability values while Sodium Silicate has the highest values of initial cost in both tests carried out.

VI. CONCLUSION

Reliability analysis using CBR and UCS tests, carried out on the peaty clay soil samples obtained from three different locations in Akwa Ibom, Bayelsa and Rivers state of the Niger Delta region of Nigeria and improved with Cement, Calcium Oxide, Calcium Hydroxide, Aluminium Hydroxide, Calcium Chloride and Sodium Silicate shows some difference in behaviour among the improved soils at different percentages of chemical added to the soil sample for improvement and at different curing days. The difference in reliability values of the improved soil for the three states studied is negligible, with a nominal value of 3% difference between the highest and the lowest for most of the tests carried out. However, the optimal value of reliability for the two tests: CBR and UCS occurred at 6% addition of chemical for most of the chemicals used while that of Cement occurred at 10%.

By virtue of the outcome of this research work, the following conclusions can be drawn:

1. Reliability of peaty clay soil improved with cement, chemicals and geotextile materials in Akwa Ibom, Bayelsa and Rivers states of the Niger Delta area using UCS and CBR tests is directly proportional to the strength obtained through such improvement as the reliability increases with increase in strength.
2. Reliability of the soil sample is also directly proportional to the organic content in the soil.
3. Reliability of improved soil using the two tests increases with increase in percentage of chemicals and cement added to the soil sample but to a certain level (6% in most cases) before the reliability value starts falling.
4. Of all the chemicals used in the research, Calcium Oxide gave the highest value of reliability for both tests carried out,
5. Reliability increases with increase in the number of days of curing improved soil samples before tests were run.
6. Cement behaved differently in comparison with the chemicals used, as its reliability value for both tests increase with increase in chemical added till the last percentage (10%).
7. Sodium Silicate reliability peaked at 8%, as against 6% for other chemicals.
8. Reliability of geotextile materials in CBR test increases with increase in the tensile strength of the material.
9. The reliability of Woven geotextile is higher than that of Non – Woven geotextile.
10. Geotextile materials are not really suitable to improve the strength of the peaty clay of the Niger Delta Region of Nigeria due to their poor values of reliability in CBR test.
11. When cost of execution is compared with the reliability values for optimization purpose, cement is the best option followed by Calcium Oxide while Sodium Silicate comes last.

REFERENCES

1. Yonekura, R., & Kaga, M. (1992). Current Chemical Grout Engineering in Japan. Pp. 725 – 736.
2. Karol, R. H. (2003). Chemical Grouting and Soil Stabilization. Marcel Decker inc. New Jersey.
3. Khattab, S., Al – Mukhtar, M., & Fleurean, J. M. (2007). Long Term Stability Characteristics of a Lime – Treated Plastic Soil. *J mater, Civil Engineering*, 19, 358.
4. Rogers, C, Boardman D, Papadimitriou, G (2006): Stress Path Testing Of Realistically Cured Lime And Lime/Cement Clay. J. Mater Civil Engineering. Vol. 18, Pp. 259.
5. Rogers, C. D., Boardman, D. I., & Papadimitriou, G. (2006). Stress Path Testing Of Realistically Cured Lime And Lime/Cement Stabilized Clay. Journal Of Materials In Civil Engineering, 18(2), 259-266.
6. British Standards Institute (1990). Methods Of Test For Soils For Civil Engineering Purposes. Bs 1377, Bsi, London. Parts: 1, 2, 4, 7 And 8.