Performance Characteristics Of Some Nigerian Problem Soils Stabilized With Ionic Stabilizer

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Abstract: This work involves stabilization of some Nigerian problem soils with Ionic stabilizer for strength improvement. The work was carried out by collection of soil samples from six locations within Nigeria. The natural geotechnical properties of the collected samples were determined in the laboratory after which they were mixed with the soil materials and their response monitored by testing. The test carried out on both the natural and treated samples are classification which includes Atterberg limits, particle size distribution; and strength characteristics through compaction and California Bearing ratio determination. The soil materials tested are classified as A-2-6, A-3 and A-7-6 with natural California Bearing Ratio (CBR) values ranging from 7.7% to 32.5%, indicating weak subgrade to fair subbase materials. All the soil materials were naturally unsuitable for road bases. On stabilization, the plasticity indices of the soils were reduced considerably with remarkable improvement on compaction and strength characteristics. The CBR values increased from between 23.8% - 87%, giving a percentage increase by up to 325%. The unsuitable materials were thus improved to suitable base materials.
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Key words: stabilization, laterite, black cotton soils, ionic stabilizer, Atterberg limits, compaction, strength, characteristics

Introduction

Road transport is a key component of the economic and social development process, and often a time, a large proportion of a nation budgets are been absorbed by road transport system. Not only does poor transportation due to failure of roads frustrate social goals and limits the opportunities people have to travel from one place to the other. Pavement failure is a global problem, which could be attributed to poor design, poor construction, use of poor construction materials and maintenance problems (Owolabi *et. al*, 2004). When unsuitable soils are encountered on construction sites, the engineer is left with the choice of replacing the weak soils with suitable ones; adapting the design to site conditions or improving the strength of available materials known as soil stabilization.

Soil stabilization in the broadest sense is the alteration of any property of a soil to improve its engineering characteristics. In Nigeria, the use of stabilizing agent in road construction has been in practice for long. Portland cement has been used with great success to improve existing gravel roads as well as to improve the properties of weak natural soils but can't be used in organic soils (Oluyemi and Adeyeri, 2006). Another cementing agent which has been used is lime, which increases soil properties by pozzolanic action by forming cementations silicates and aluminates, but this material is generally suitable for granular materials and lean clay. Bitumen has also been used successfully for road works particularly in the North Eastern part of the country due to lack of naturally available soil materials that meet acceptable standards. The type and degree of stabilization required in any given instance are largely a function of the availability and cost of the required material as well as the use that it is to be made of the stabilized soil (Ibrahim, 1983).

However, the increasing costs of these conventional stabilizing agents have limited their use and have made research into the use of other good and economical materials imperative. Some of these materials are sodium silicate, Base seal, Topshield and Polyvinyl acetate and they have proofed to be effective in improving the geotechnical characteristics of soils (Oluyemi and Ola, 2015; Oluyemi, 2015). It is against this background that this work is brought up to stabilize some weak soils in Nigeria with Ionic stabilizer (ISS), a chemical stabilizer imported into the country from south Africa and monitor performance for onward use for road construction and maintenance in Nigeria.

ISS is a chemical stabilizer good for improving both the subgrade, subbase and base materials. It is suitable for very weak lateritic soils that would have been discarded, thus eliminating borrowing of materials for road works. This will eliminate or reduce haulage cost and cost of road rehabilitation, construction and maintenance and improve construction expediency (Trade page Net, 2007).

In an unsealed road, ISS neutralizes the negative aspects of clay contents in the soil and allows far greater densities to be achieved during construction. This higher density results in a greater resistance to abrasion and lowering material loss at the surface and thus reducing dust. With a sealed road, the main requirement for the selection of a suitable material is its bearing capacity. ISS corrects the problem of materials with clay content which has the tendency to absorb water after compaction so that these materials will retain their compacted densities and become suitable.

Advantage of using ISS are:

- Improve road standards--Stabilized and dust-controlled road surfaces ensure safer and more comfortable driving
- Cost-effective--Requires the minimum construction and road preparation efforts to create a positive life cycle/cost ratio.
- Easy use-- Without specialized equipment, spray with standard spray equipment.
- Easy and affordable maintenance--Normal maintenance of the surface can be achieved with the minimum expertise and standard equipment.
- Quick drying--Penetrates rapidly and the road can be opened to traffic immediately and
- Improve quality of life.

Aim and Objectives of the research

The aim of this research is to stabilize some Nigerian problem soils with the chemical stabilizer and assess performance for onward use for road construction and maintenance purposes. The objectives are to determine the physical and chemical properties of the chemical stabilizer in the laboratory; ascertain the constituent materials and use it for stabilizing some weak soil materials collected from selected locations within the country to determine their strength characteristics and effectiveness.

Materials and Method

The research work involved the characterization of the selected product by analyzing it in the laboratory to identify the primary active ingredients. This was done by carrying out physical and chemical analysis of the material to determine the chemical composition of each using a variety of chemical test methods. Some of the physical and chemical tests carried out are pH, conductivity, ion chromatography, spectroscopy, electron microscopy and total organic carbon analysis. ASTM specifications and test procedures D2190-2193 were used for the tests.

Representative soil samples were collected from different locations within the country as marked on Figure 1 and their natural geotechnical properties determined in the laboratory by performing relevant tests on them. The soil samples were collected from the following areas:

(a) Residual Black Cotton Soils collected from three locations namely; Numan Jalingo road; Numan – Yola road and Numan - Gombe road, all in the North – Eastern Nigeria

(b) Coastal soils from Igbokoda- Ayetoro road in the riverine area of Ondo State, Nigeria

(c) Lateritic soil samples from Ayede-Ogbese – Ago Dada and Oda road, the suburbs of Akure town in Ondo State, Nigeria

Results and Discussion

Chemical Analysis

The Ionic stabilizer was analyzed in the laboratory and was also found to contain 12.6% copolymers with 28ppm of iron, 2ppm magnesium, 3ppm of calcium, 34ppm of aluminum, 0.5ppm of zinc and 0.4ppm of copper. It has a specific gravity of 0.90 while the density is 1.210g/cm^3. The material also contains about 65% of water. The result of the analysis is also shown on Table 1.

Table 1: Summary Result of Physical and Chemical Analysis of the Materials

Parameter	Ionic Stabilizer
Physical form	Liquid
Appearance	Greenish Dark
Odour	Offensive
pH	6.8
Specific gravity	0.90
Volatility	0.12
Density	1.210g/cm^3
Copolymer	12.6%
Vinyl acetate (Total solids) Other Ingredients:	22.7% Fe = 28ppm Mg = 2ppm Ca = 3ppm Al = 34ppm Zn = 0.5ppm Cu = 0.4ppm
Water	64.7%

Characteristic of Natural And Stabilized Soil Samples

To evaluate the engineering characteristics of the natural soil samples collected, classification tests which include particle size analysis, Atterberg limits determination and strength tests which are compaction and determination of California Bearing ratio for the samples were carried out on them. These were carried out in accordance with the West Africa Compaction method. Table 2 shows the summary results of the Atterberg's limits; Table 3 is the summary of the particle size distribution while Table 4 shows the compaction and strength characteristics of the natural samples. After the determination of the natural soil characteristics, Ionic stabilizer was mixed with the soil using 2% as recommended by the manufacturer and the effects monitored in the laboratory. The stabilized results are as presented in Tables 5 and 6.

Table 2: Summary Results of the Atterberg's Limits of Natural Soil Samples

Samples/ Location	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Linear Shrinkage,%
A. Igbokoda/Ayetoro	-	-	-	-
B. Oda Road	38	20.1	17.9	6.5
C. Ayede-Ogbese	36.5	19.7	16.8	5.8
D. Yola – Gombe road	58.4	32.5	25.9	9.8
E. Numan-Jalingo Road	53.3	31.7	21.6	9.2
E. Nurman – Yola Road	51.5	32.5	19.0	8.9

Table 3: Summary of Particle Size Distribution of Soil Samples

Sample location	**Gravel Fractions, %**	**Sand Fractions, %**	**Silt fractions, %**	**Clay Fractions, %**	**Soil Classification**
Igbokoda – Ayetoro	0.0	95.8	4.2	-	A-3
Oda road	2.5	57.5	17.0	23.0	A-2-6
Ayede–Ogbese road	1.5	52.5	15.0	31.0	A-2-6
Yola – Gombe road	0.1	10.2	32.0	57.7	A-7-6
Numan–Jalingo road	0.2	13.0	30.0	56.8	A-7-6
Numan – Yola road	0.2	16.0	27.0	56.8	A-7-6

Table 4: Summary of Compaction Characteristics and California Bearing Ratio of Natural Soil Samples

Samples/ Location	Optimum Moisture Content, OMC %	Maximum Dry Density, MDD, KN/m^3	California Bearing Ratio, % (unsoaked)
A. Igbokoda/Ayetoro	9.0	15.6	7.7
B. Oda Road	13.5	19.7	20.0
C. Ayede-Ogbese	13.9	16.4	23.4
D. Yola – Gombe Road	15.5	18.9	28.7
E.Numan-Jahingo Road	15.5	21.4	28.7
F. Nurman – Yola road	14.9	18.2	32.5

Table 5: Effect Of Ionic Stabilizer On Plasticity Of Soil Samples

Samples	**Liquid Limit, %**	**Plastic Limit,%**	**Plasticity Index, %**	**Linear Shrinkage,%**
IONIC STABILIZER (2% MIX)				
Igbokoda – Ayetoro				
Akure-Oda Natural soil sample	Not	Not	Not	Not
Akure-Oda road Stabilized soil	Applicable	Applicable	Applicable	Applicable
sample	38.0	20.1	17.9	6.5
Ayede – Ogbese Natural soil sample	29.3	23.6	5.7	3.7
Ayede – Ogbese stabilized soil	36.5	19.7	16.8	5.8
sample	30.5	25.2	6.5	3.9
Yola - Gombe Natural soil sample	58.4	32.5	25.9	9.8
Yola - Gombe stabilized soil sample	35.1	17.3	17.8	6.2
Numan - Jalingo Natural soil sample	53.3	31.7	21.6	9.2
Numan - Jalingo stabilized sample	36.4	18.3	18.1	5.0
Numan –Yola Natural Soil Sample	51.5	32.5	19.0	8.9
Numan – Yola Stabilized Soil	32.3	25.0	7.3	4.6
Sample				

Table 6: Effect Of Ionic Stabilizer On Strength Characteristics Of Soil Samples

Samples	Omc, %	Mdd, Kn/M^3	Cbr, %
IONIC STABILIZER AT 2% MIX			
Igbokoda-Ayetoro natural soil sample	9.0	15.6	7.7
Igbokoda-Ayetoro stabilized sample	9.5	16.1	23.8
Akure-Oda road Natural soil sample	13.5	19.7	20.0
Akure-Oda road Stabilized soil sample	13.0	21.2	85.0
Ayede - Ogbese Natural soil sample	13.9	16.4	23.4
Ayede - Ogbese stabilized samples	13.5	20.4	65.0
Yola - Gombe Natural soil sample	15.5	18.9	28.7
Yola - Gombe stabilized samples	13.1	20.3	80.0
Numan - Jalingo Natural soil sample	15.5	21.4	28.7
Numan - Jalingo stabilized samples	13.8	21.7	63.0
Numan - Yola Natural soil sample	14.9	18.2	32.5
Numan - Yola stabilized samples	14.6	20.2	87.0

(i) Igbokoda Ayetoro Samples

The summary results of the laboratory tests on the natural soil samples are shown in Tables 2, 3 and 4 with the particle size curves shown in Figure 2. The results show that Igbokoda – Ayetoro samples are generally fine grained with partially no gravel fractions and a very small amount of non plastic silt. The materials contain 0.02% of coarse grained soil, 95.82% of sand fractions and 4.16% of silty materials. With these results, the sample is classified as A-3 according to American Association of State Highway and Transport Officials (AASHTO) soil classification system.

The relationship between the dry densities and moisture contents for the soil are shown in Table 4. The compaction characteristics gave a maximum dry density, MDD of 15.6kN/m^3 and Optimum Moisture Content, OMC of 9% and the strength test gave an average California Bearing ratio, CBR value of 7.7%, which indicates a very poor subgrade soil.

After the addition of Ionic stabilizer to this sample as shown in Table 6, an average MDD of 16.1kN/m^3 and OMC of 9.5% resulted. Also, the CBR had a natural value of 7.7% and this increased to 23.8% with Ionic stabilizer as shown in Figure 9.

(ii) Akure-Oda Road Soil Samples

Grain size analysis of Akure-Oda road soil samples as shown in figure 2 gave values of 2.5% coarse size, 57.5% sand size, 17% silt and 23% clay fractions. The Atterberg limits as shown in Table 2 are 38% liquid limit, 20.1% plastic limit and 17.9% plasticity index with linear shrinkage of 6.5. The material is classified as A-2-6. The MDD, OMC and CBR values from Table 4 are 19.7kN/m^3, 13.5% and 20% respectively. This implicates that the material in its natural state is good for the subgrade but unsuitable for either a subbase or a base material unless otherwise improved.

On the addition of Ionic stabilizer, the Atterberg limits gave a value of 29.3% liquid limit with a plasticity index of 5.7% and reduction in linear shrinkage from a natural value of 6.5 to 3.7 (Table 5).

For the compaction characteristic as shown in Figure 4, a MDD of 21.2kN/m^3 resulted for the Ionic stabilized soil with OMC of 13%. For the strength test as shown in Table 6 and Figure 10, the CBR increased from a natural value of 20% to 85% for the lonic stabilized soil. This gave an increase in strength of 325%.

(iii) Ayede –Ogbese Road Soil Samples

Also as seen in Table 2, samples of soil from Ayede – Ogbese have liquid limits of 36.5%, plastic limit of 19.7% and plasticity index of 16.8% with linear shrinkage of 5.8%. In Table 3, the result gave 1.5% gravel size, 52.5% sand, 15% silt and 31% clay fraction. The soil is thus classified as A-2-6 according to AASHTO. The MDD and OMC are 16.4kN/m^3 and 13.9 % respectively with average unsoaked CBR value of 23.4% as shown in Table 4. This shows that the soil is a poor subbase and base material which should have minimum standard values of 30% and 80% unsoaked CBR.

Addition of the ionic stabilizer to this soil material also caused reduction in the plasticity of the soil sample. The liquid limit obtained was 30.5% with plastic limit of 25.2%, plasticity index of 6.5%, and linear shrinkage of 3.9 (Table 5).

From Table 5 and Figure 5, the compaction of soil samples from Ayede-Ogbese gave MDD value of 16.4kN/m^3 and OMC of 13.9% for the natural soil and MDD of 20.4kN/m^3 and OMC of 13.5% for the Ionic stabilized soil and the CBR increased from 23.4% to 65% as shown in Table 6 and Figure 11. This shows that addition of Ionic stabilizer greatly improves the compaction and strength of the natural subgrade material to a very good subbase material.

(iv) Yola Gombe Road

For the black cotton soils from Northern Nigeria, samples of soil from Yola – Gombe gave liquid limit of 58.4%, plastic limit of32.5% and plasticity index of 25.9% with linear shrinkage of 9.8 as shown in Table 2. It has 0.1% gravel sizes, 10.2% sand fractions and 32% of silt and 57.74% clay fractions (Table 3) and thus, the soil is classified as A-7-6 material. This shows a soil with high shrinkage characteristics. The MDD and OMC are 18.9kN/m^3 and 15.5% respectively with a CBR value of 28.7% as shown in Table 4. From this result, the soil is not recommended for either the subbase or base layers due to the high clay content, which will result to high swelling and eventual failure of the pavement if used naturally.

On treating with ionic stabilizer, the plasticity index reduced from 25.9% to 17.8% while the linear shrinkage reduced from 9.8 to 6.2. Aslo, as shown in Table 6, MDD of 20.3kN/m^3 and OMC of 13.1% resulted with CBR value which increased from a natural unsuitable subbase value of 28.7% to a suitable base value of 80% (Figure 12).

(v) Numan – Jalingo Road

The Atterberg limits are 53.3% liquid limit, 31.7% plastic limit and 21.6% plasticity index and linear shrinkage of 9.2% as shown in Table 2. The soil contains 0.2% gravel, 13.0% of sand fraction, 30% of silt and 56.86% clay fractions (Table 3). Based on these results, the soil is also classified as A-7-6. The strength characteristics gave an MDD of 21.4kN/m^3, OMC of 15.5 % and CBR of 28.7% (Table 4), which also confirms an unsuitable subbase and base materials with high shrinkage and swelling characteristics. Upon treating with Ionic stabilizer, the Atterberg limits were improved to 36.4% liquid limit, 18.3% plastic limit; plasticity indiex of 18.1% with linear shrinkage of 5.0 showing reduction in the plasticity of the soil (Table 5).

From Figure 7, Ionic stabilized soil gave MDD of 21.7kN/m^3, with OMC of 13.8%. Also as shown in Figure 13, the CBR value for Ionic stabilized soil increased to 63% from the 28.7% natural value. The material was improved to a very good subbase material.

(vi) Numan - Yola Road

The Atterberg limits are 51.5.0% liquid limit, 32.5% plastic limit, plasticity index of 19% and linear shrinkage of 8.9% (Table 2). In Table 3, the particle size analysis gave 0.2% gravel size, 16.0% sand fractions and 27.0 % of silt and 56.8% of clay fractions. The sample is classified as A-7-6. The MDD and OMC are 18.2 kN/m^3 and 14.9 % respectively while the CBR value is 32.5% (Table 4). From the strength characteristics result, the material is a good subgrade and subbase material but unsuitable for base layers of roads.

Treatment of this sample with Ionic stabilizer as shown in Table 5 gave a liquid limit of 32.3% with plastic limits of 25%. This reduced the plasticity index to 7.3% from a natural value of 19% with linear shrinkage also reducing from a natural value of 8.9 to 4.6. Compaction characteristics gave average MDD of 18.2kN/m^3 for the natural value; 20.2kN/m^3 for Ionic stabilized soil with OMC values of 14.9% natural and 14.6% upon stabilization as presented in Table 6 and Figure 8.

The strength test in Table 6 and Figure 14 sgave the average CBR value for the natural sample to be 32.5%, and upon stabilization, a CBR value of 87% was achieved. This shows that stabilization of this sample with Ionic stabilizer is highly beneficial by improving the soil to a suitable base material.

Conclusion

Laboratory test results on the tested soil samples confirm that soil materials from Igbokoda – Ayetoro road, which are silty sand, are very poor materials and are unsuitable for road construction. The samples are generally fine grained with little or partially no gravel fractions. With these results, the sample is classified as A-3 according to American Association of State Highway and Transport Officials (AASHTO) soil classification system.

Soil samples from Akure-Oda road and Ayede – Ogbese road are classified as A-2-6. They are weak lateritic soils, which are poor subbase materials and unsuitable for the base course. The use of these types of soils will cause early failure of the road due to the poor engineering characteristics.

The black cotton soils contain high proportions of clay and silt fractions. They are classified as A-7-6. They will be susceptible to swelling and cracking of road pavements. They are thus naturally unsuitable for road construction without improvement. .

The Atterberg limits of the soil samples show that the samples except Igbokoda – Ayetoro samples are highly plastic with wide linear shrinkage properties which will result to swelling, volumes changes and cracking if used directly for road works without improvement.

On mixing the soil samples with Ionic stabilizer, great reduction in the plasticity and shrinkage characteristics of the treated soil samples were achieved. Also general improvement on the strength characteristics resulted with an increase of up to 325%. With the use of this stabilizer, some of the unsuitable widely available soil materials in Nigeria would be improved and made suitable for road construction works.

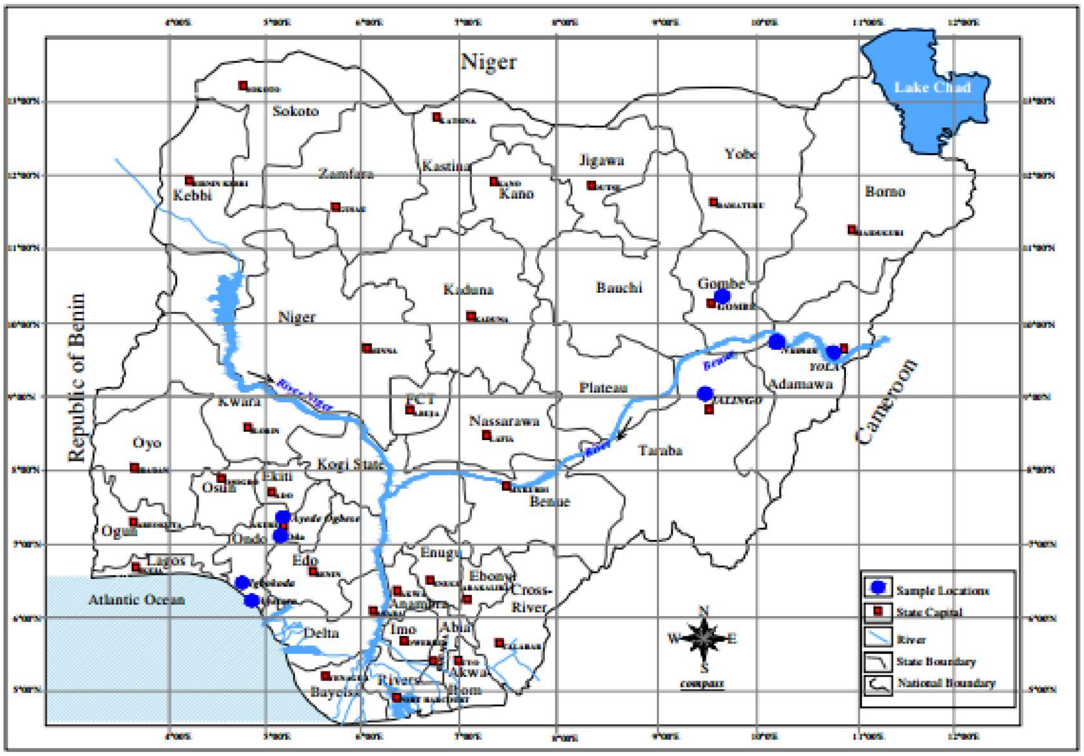
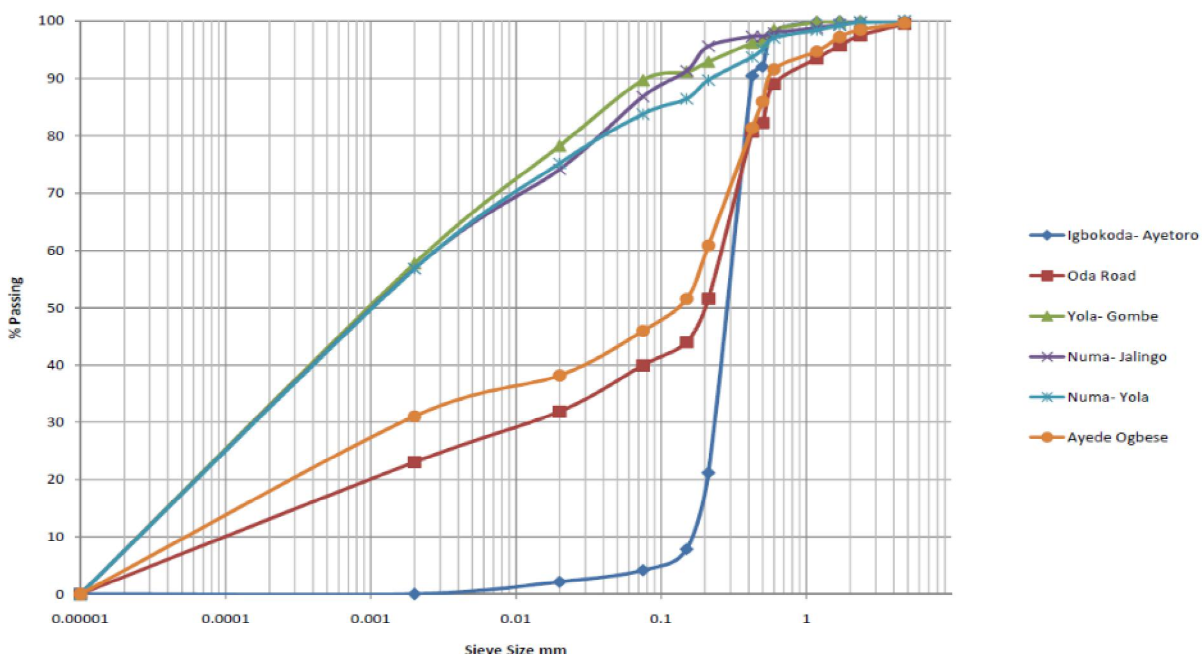


Figure 1: Map of Study locations within Nigeria



Clay	Silt			Sand			Gravel		
	fine	Medium	coarse	Fine	Medium	Coarse	fine	medium	coarse

0.002 0.006 0.02 0.06 0.2 0.6 2 6 20 60

Fig. 2: Particle Distribution Curves of the Collected Soil Samples

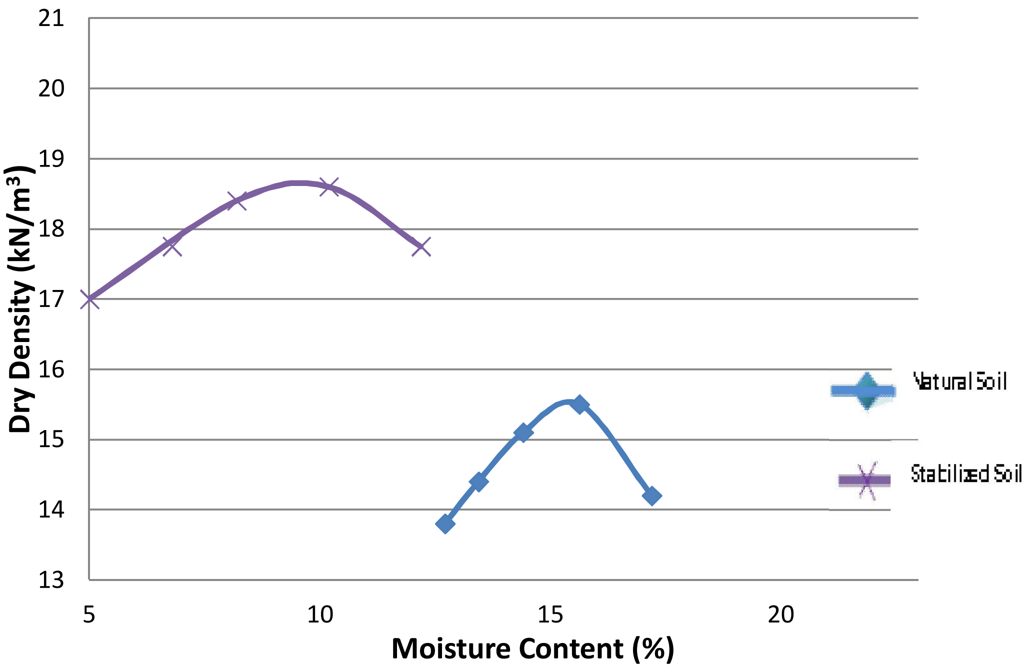


Fig. 3: Compaction Characteristics Of Igbokoda - Ayetoro Road Soil Samples Stabilized With Ionic Stabilizers

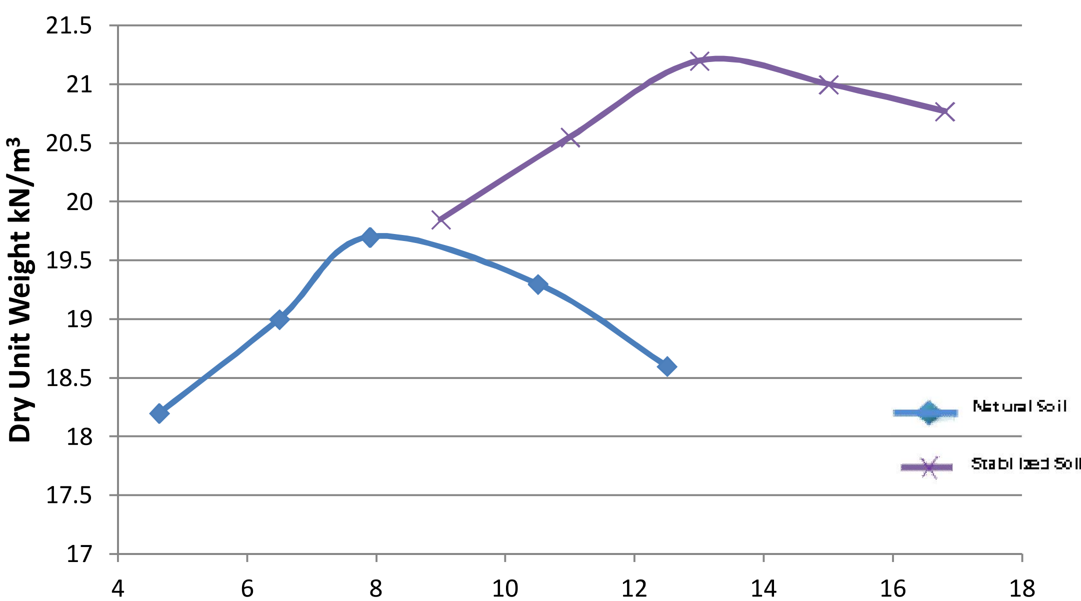


Fig. 4: Compaction Characteristics Of Akure-Oda Road Soil Samples Stabilized With Ionic Stabilizer

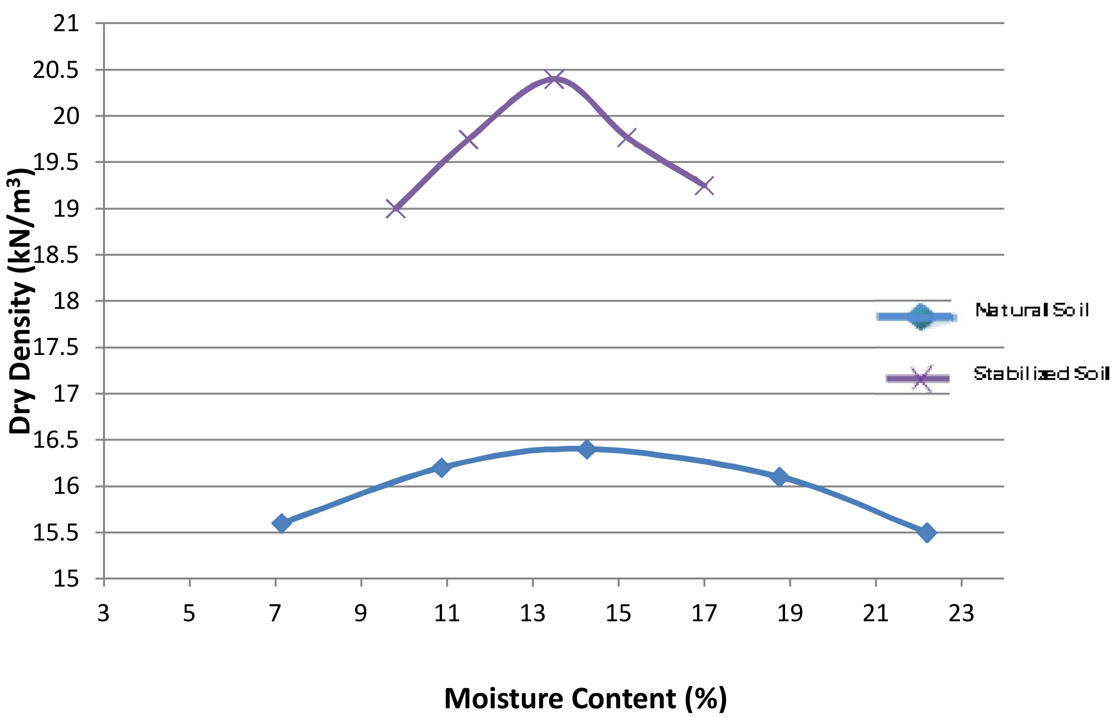


Fig. 5: Compaction Characteristics Of Ayede-Ogbese Road Soil Samples Stabilized With Ionic Stabilizer

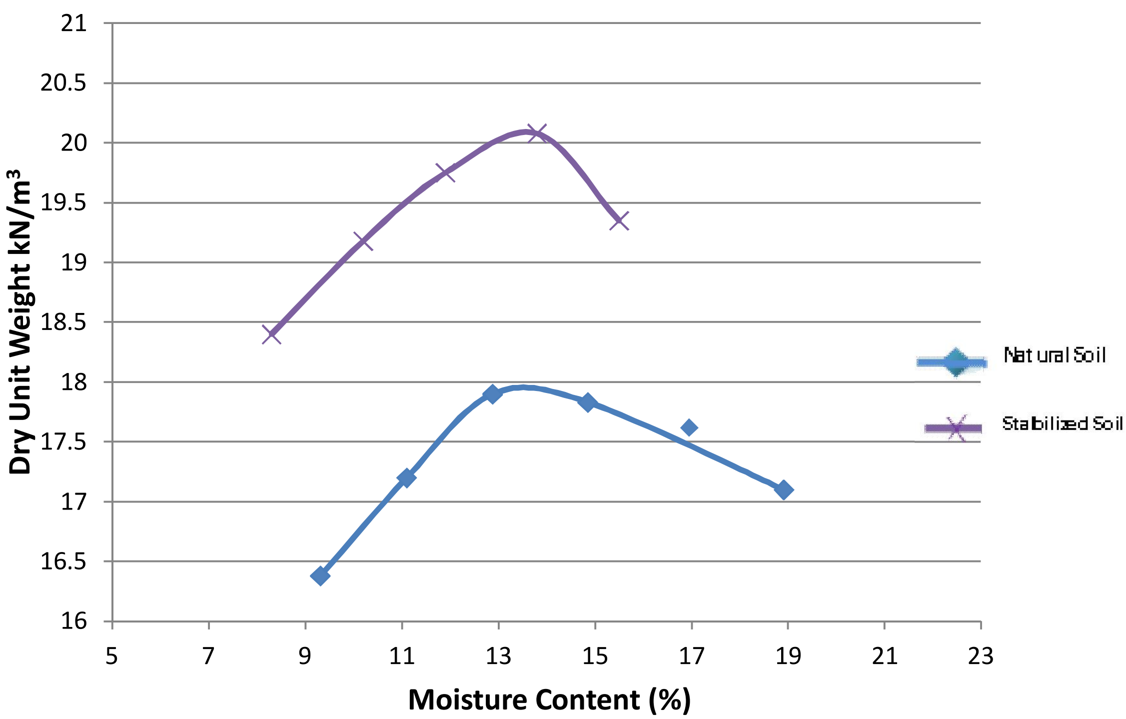


Fig. 6: Compaction Characteristics Of Yola-Gombe Road Soil Samples Stabilized With Ionic Stabilizers

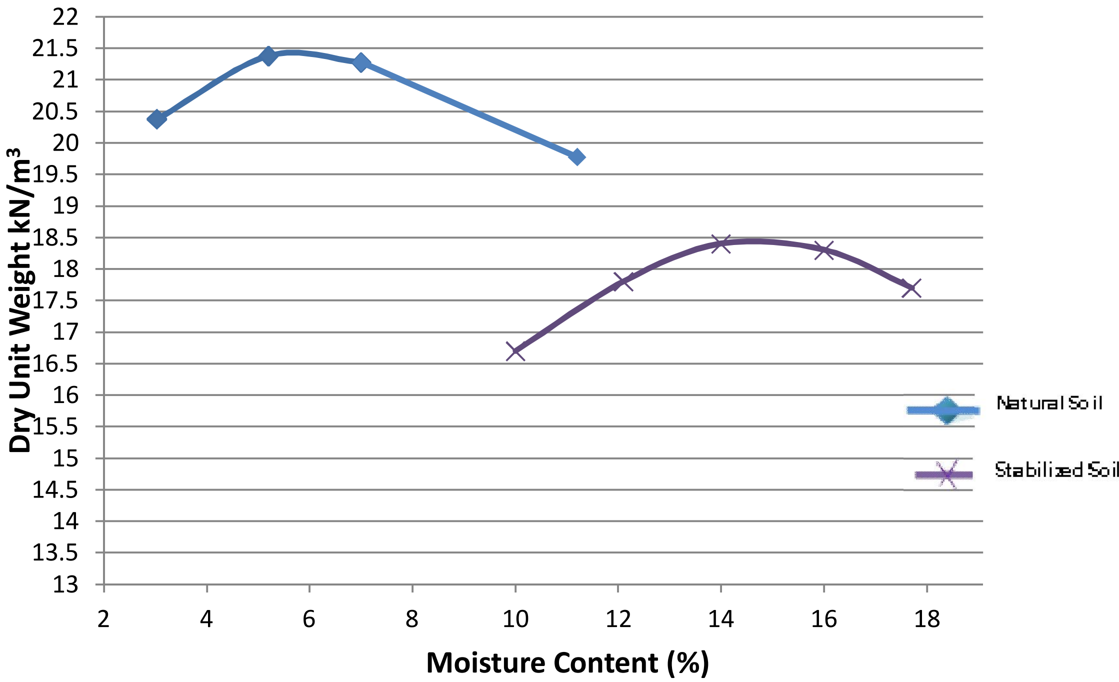


Fig. 7: Compaction Characteristics Of Numan-Jalingo Road Soil Samples Stabilized With Ionic Stabilizers

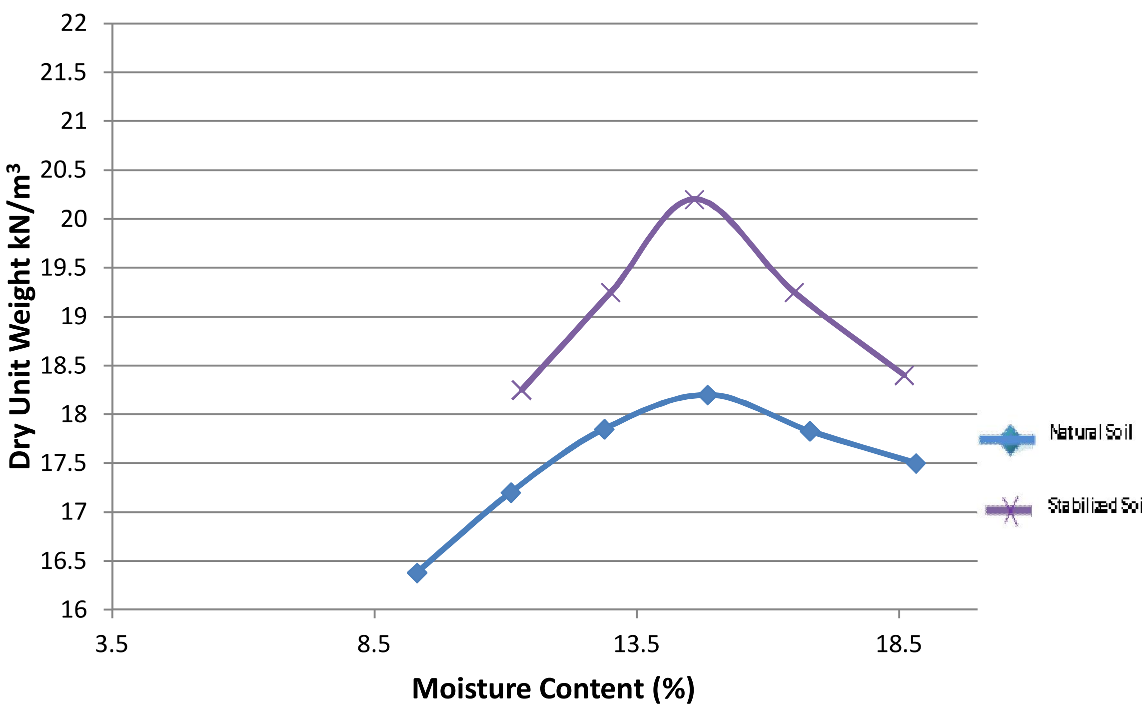


Fig. 8: Compaction Characteristics Of Numan-Yola Road Soil Samples Stabilized With Ionic Stabilizers

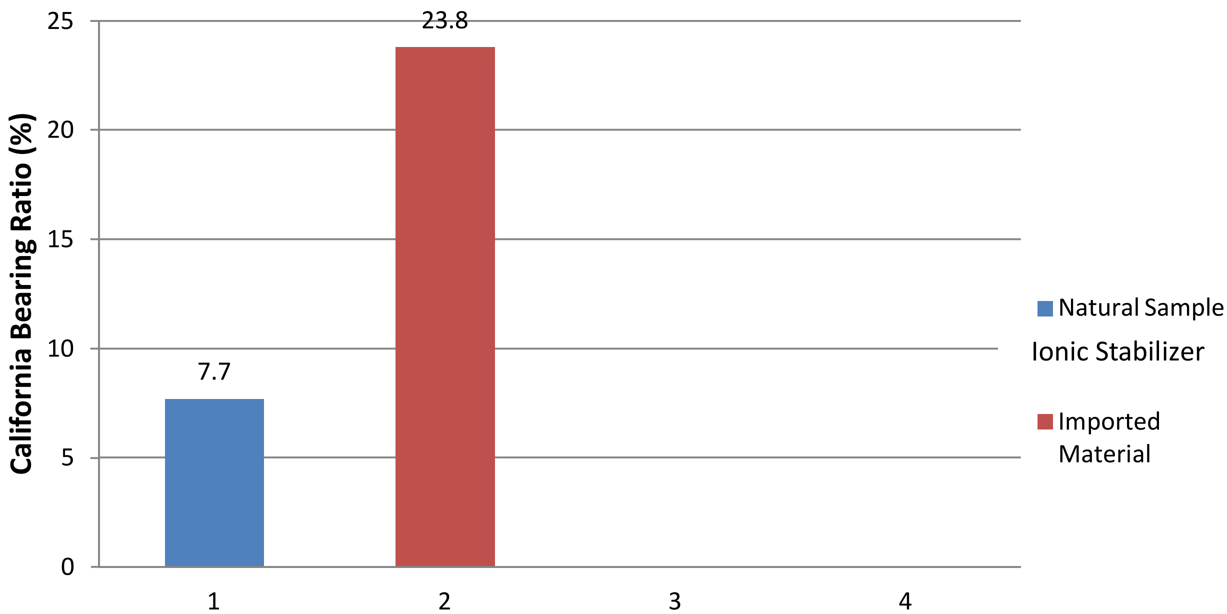


Fig.9: Variation Of California Bearing Ratio For Igbokoda-ayetoro Road Samples

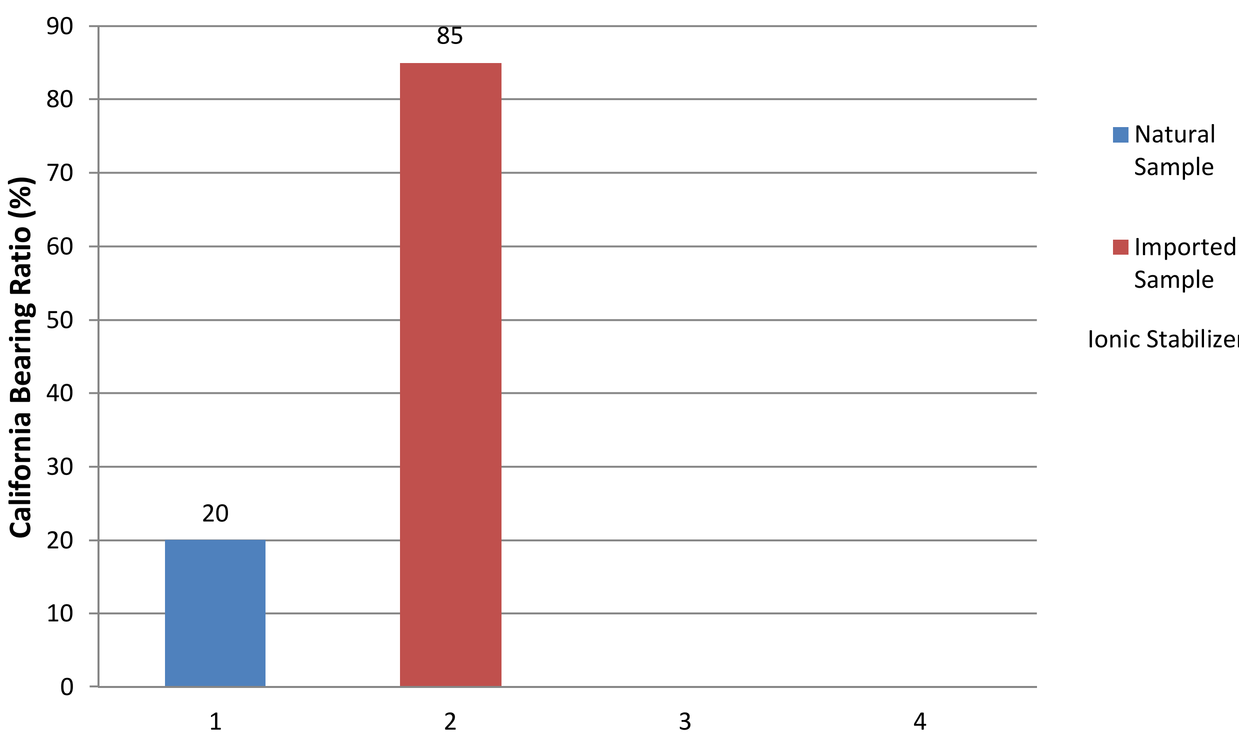


Fig.10: Variation Of California Bearing Ratio For Oda Road Samples

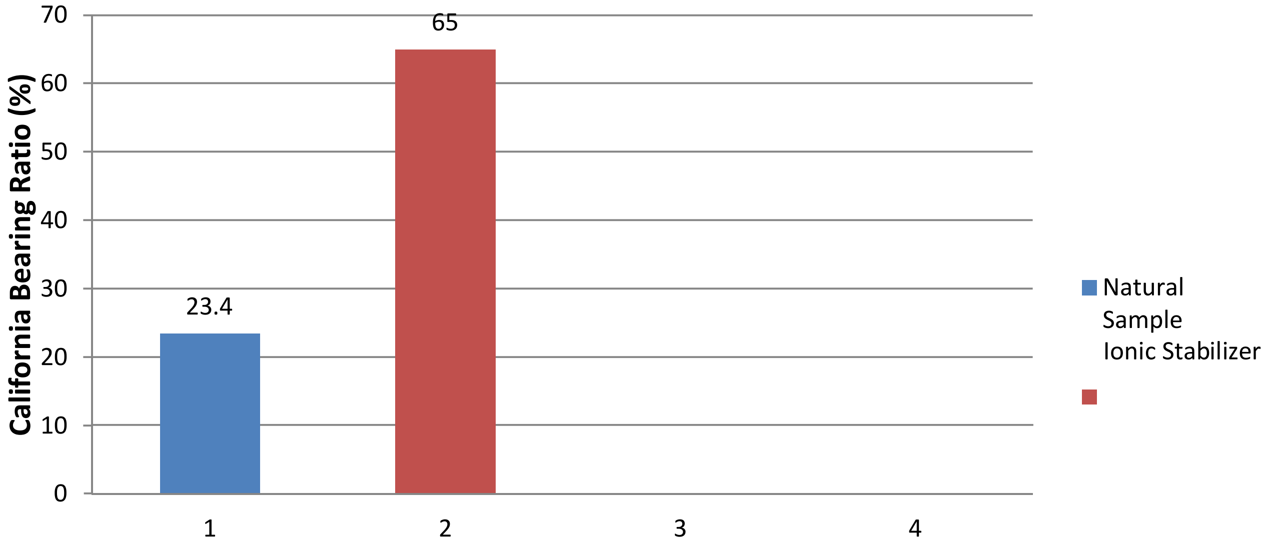


Fig.11: Variation Of California Bearing Ratio For Ayede-ogbese Road Samples

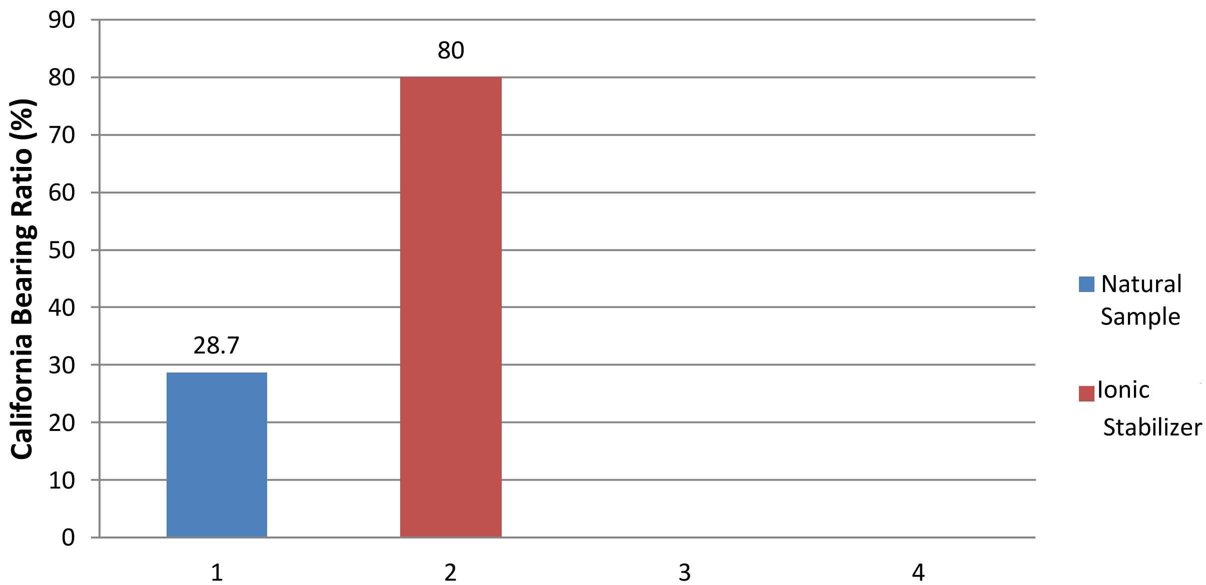


Fig.12: Variation Of California Bearing Ratio For Yola-gombe Road Samples

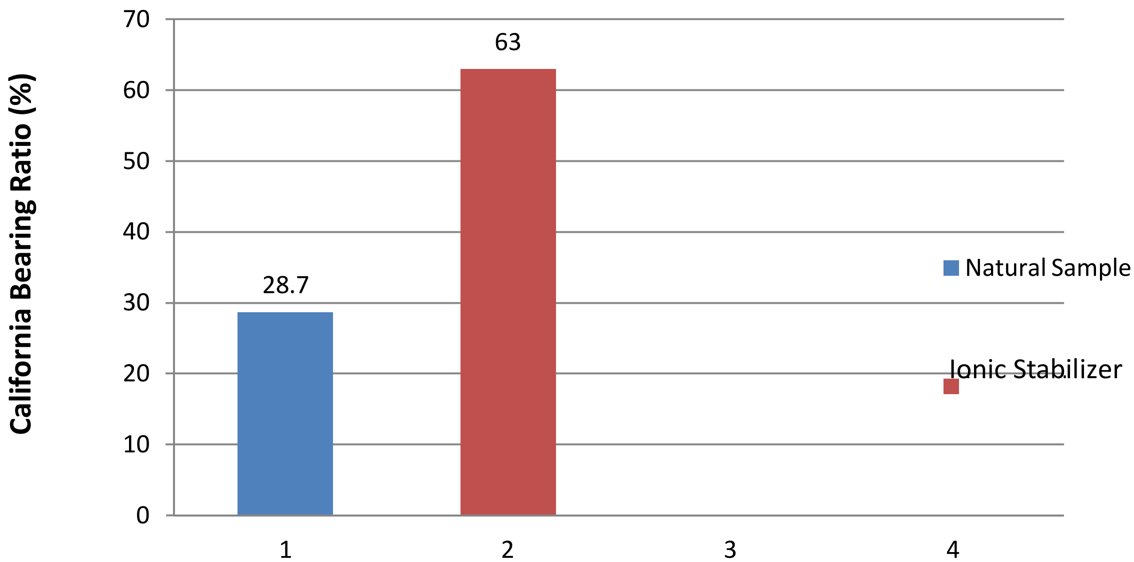


Fig.13: Variation Of California Bearing Ratio For Numan-jalingo Road Samples

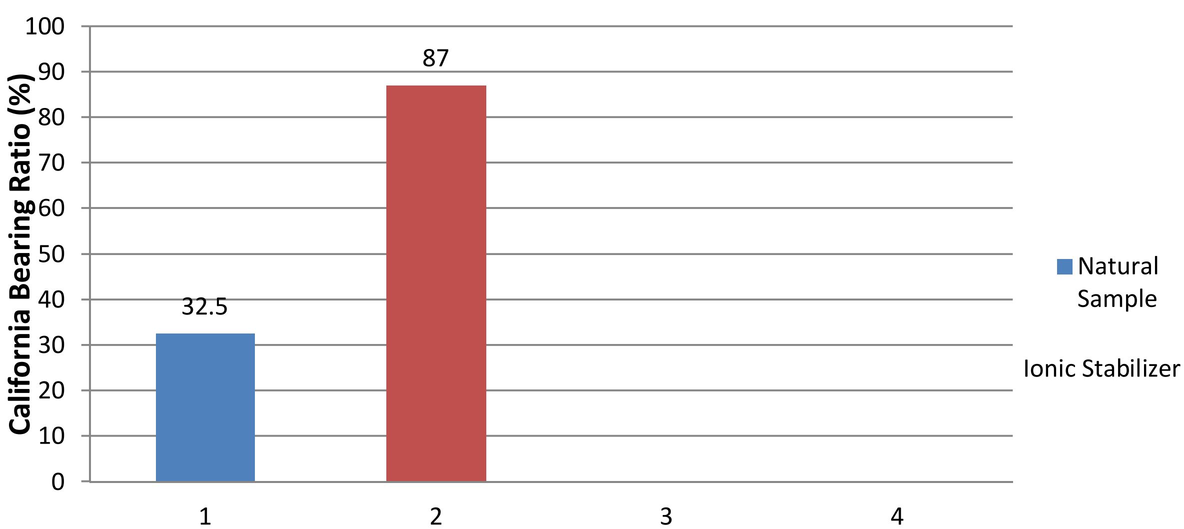


Fig.14: Variation Of California Bearing Ratio For Numan-yola Road Samples

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