NIGERIA BUILDING AND ROAD RESEARCH INSTITUTE

ABUCONS
AHMADU BELLO UNIVERSITY, ZARIA

Tectonics
Engineering & Consults Ltd.
RC NO: 1391625 UK: 09683878

Final Report

On

Evaluation of Novocrete® Binding Material for the Stabilisation of Soils in Nigeria.

Prepared By:

Nigerian Building and Road Research institute

Ahmadu Bello University Consultancy Services

Tectonics Engineering and Consults Ltd

January 2018.

LEFT BLANK INTENTIONALLY

Endorsements:

Evaluation of Novocrete Stabilisation Technology for the stabilisation of Soils across six Zones of Nigeria.

Endorsement

NIGERIA BUILDING AND ROAD RESEARCH INSTITUTE

Name RAPHAEL MENEGBE
Organization NBRRI, ABUJA
Signature
Date 31/1/18

NIGERIAN BUILDING AND ROAD RESEARCH INSTITUTE, (NBRRI)
Plot 449 Samuel Ogbanghe Crescent, Asst. Abuja
SIGN..... DATE.....

ABUCONS
AHMADU BELLO UNIVERSITY, ZARIA

Name Engr. Dr. J. M. Kaura
Organization ABUCONS (NIG) LTD
Signature
Date 31/1/2018

OFFICE OF THE MANAGING DIRECTOR
ABUCONS (NIG) LTD
AHMADU BELLO UNIVERSITY
ZARIA

Tectonics Engineering & Consults Limited
TEC
Tectonics
Engineering & Consults Ltd.
RC NO: 1391625 TIN: 09683878

Name Alhaji Yahaya Gombe
Organization Tectonics Engineering
Signature
Date 31st January 2018

Executive Summary

The provision of infrastructure has become a reoccurring feature in the country.

Often, the insufficient infrastructure currently provided experiences wear too soon and rarely meet its design lifespan.

In the face of dwindling resources, a rethink of approach is necessary for Nigeria to overcome these infrastructural challenges. Such approach should be sustainable and capable of delivering more while reducing the cost of constant maintenance and arrest rapid infrastructural decay.

The present study is directed towards optimizing site conditions to suit desired characteristics and therefore reducing pavement thickness, cost and construction overrun. This will be achieved by improving the soil strength.

The aim of this investigation is to ascertain the suitability of a stabilizing material (Novocrete) through proper tests in the Nigerian conditions.

This was done by determining the properties of the native materials in unblended states and then compared with the properties exhibited with cement only and cement blended with Novocrete®.

Novocrete® is a powder mineral used as a concrete add mixture in Portland cement. Novocrete® combined with Portland cement at optimal water content is intended to increase crystallized formations during the hydration process, resulting in higher strengths. It also neutralizes pH levels and provides water impermeability.

OPIS NG is the only company with exclusivity rights licensed to distribute and use the Novocrete stabilization technology in Nigeria and six other African countries.

In the present study, Ordinary Portland Cement (**Dangote**) – Grade 42.5 was used.

The testing team consisted of members from the OPIS NG Team, Nigerian Institute of Building and Road Research Institute **NBRRI**, Ahmadu Bello University Consultancy Services **ABUCONS** as well as Tectonics Engineering and Consults Ltd.

Tests:

All tests were carried out in the laboratories of Nigerian Institute of Building and road research institute NBRRI Jabi, Ahmadu Bello University Consultancy Services ABUCONS as well as Tectonics Engineering and Consults Ltd, Kado Abuja.

Findings:

Furthermore, it is shown that Novocrete, due to its evident consistent and significant higher initial strength and bearing capacity, allows a faster construction. This results in saving resources and saving costs since Novocrete® infrastructure can be reopened earlier for use.

Additionally, Novocrete® reduces overall construction costs by requiring less pavement thickness and provide lasting transport facilities. It also enhances soil stability in irrigation and drainage projects.

Although stabilization is an effective alternative for improving soil properties, the engineering properties derived from stabilization vary widely due to heterogeneity in soil composition.

These variations necessitate the consideration of site-specific treatment options which must be validated through testing of soil-stabilizer mixtures.

However, more studies to discover a more economic binding content is required. It is advised that a binding content between 3% and 8 % be targeted.

This is achievable by increasing the Novocrete content and reducing the cement content to getting a better mix balance. Reducing the cement content will also reduce the chances of cracks as well as further drive down construction costs.

Table of Contents

INTRODUCTION

Transport infrastructures such as road and rail have received extra attention by the present administration in a bid to connect more cities and encourage access to agricultural produce. It is therefore pertinent to devise alternative means of construction with a view to doing more with lesser resources.

The idea behind this study is aimed towards stabilizing the base course layer of the loadbearing layers of soil and increasing the loadbearing capacity.

Novocrete® stabilizing agent was evaluated to ascertain if added value can be derived and to achieve objectives as stated below.

It is desired that the approach should provide the following advantages:

- ✓ Stabilization of in-situ materials to be used instead from borrows pits. This is with a view to reduce construction costs.
- ✓ Use of Novocrete® and Cement blended soil as pavement layer for highways and Rural roads without necessarily using bituminous mix.
- ✓ Use of Novocrete® and Cement blended soil layer below track underlays for rail Transport on weak soil formation to facilitate high speed train networks construction.
- ✓ Stabilization of embankments.
- ✓ Used for dam construction, irrigation canals.
- ✓ Construction of pavements on soft soils or in areas where borrow pits are far from the sites.
- ✓ Usage of recyclable aggregates and old asphalt pavement aggregate, etc.,

The impact on the improvement of **California Bearing ratio** and **Unconfined Compressive Strength** of soils are investigated.

These two parameters are key to a successful engineering design. Local (Federal Ministry of Works Design Manual) codes of practice are relied on as well as the British Standards (BS) and American Association of State Highway and Transportation Officials (AASHTO) standards.

All laboratory tests reference relevant guides in the method of test applied.

The evaluation of the effect of cement and Novocrete® mineral blend in the improvement of soil for construction purposes has been completed.

Samples were recovered for ex-situ examination in the laboratory.

The results of the sampling and its analysis are included in this report.

The Novocrete® team, led by Dipl. Geol. Jasmine Al-Obaidi (Germany) were in Nigeria to monitor the evaluation of the blended material alongside staff of participating agencies as listed below:

- ✓ Tectonics Engineering and Consults ltd
- ✓ Ahmadu Bello University Zaria
- ✓ Nigerian Institute of Building and Road Research Institute (NIBRRI)
- ✓ Federal Capital Development Agency (Engineering Design Department)
- ✓ Federal Ministry of Works, Engineering Design Department

This report describes the procedures followed in the evaluation, presents the test results obtained, and provides recommendations for use in in the design of infrastructure.
All relevant laboratory tests were performed in accordance with relevant standards as stated in the laboratory results attached as appendices.
Prior to the commencement of the program, a meeting was held at **Tectonics House** Kado, Abuja, Nigeria, with key members of the evaluation committee in attendance to adopt the approach as well as emphasize expected outcome.
In attendance were:

S/NO	NAMES	ORGANISATION
1	Prof. Ibrahim Garba	V.C . A.B.U Zaria
2	Prof. D.S. Matawal	DG. NBRRI-FMST Abuja
3	Onwubuya Ken	Procurement SPEC.
4	Josh Adagiri	Tectonics Engineering & Consults LTD
5	Solomon Godsi	Kamdax Nig Ltd.
6	Engr. Odinaka Ogbonnu	Tectonics Engineering & Consults LTD
7	Anthony Joseph Terna	ABUCONS
8	Engr Dabo .M. Idris	FMPW & H (Works)

9	Sa'ad .A. Bello	Tectonics Engineering & Consults LTD
10	Jasmin Alobaidi	OPIS AG
11	Odofin Micheal	Tectonics Engineering & Consults LTD
12	Joey Samuel	OPIS NG
13	Aisha Kawu Gombe	Tectonics Engineering & Consults LTD.
14	Engr. Jimoh Babatunde	Tectonics Engineering & Consults LTD
15	Muhammad Musaddiq Muhammed	Tectonics Engineering & Consults LTD
16	Ibrahim .k. Elizabeth	Tectonics Engineering & Consults LTD

The managing partner of Tectonics Engineering ltd, DG NBRRI (Prof. Mattawal) and the Novocrete team

Program Inception and deliberations

Novocrete representatives & VC ABU (Prof. Garba)

Dipl. Geol. Jasmin Al-Obaidi – OPIS AG, Germany







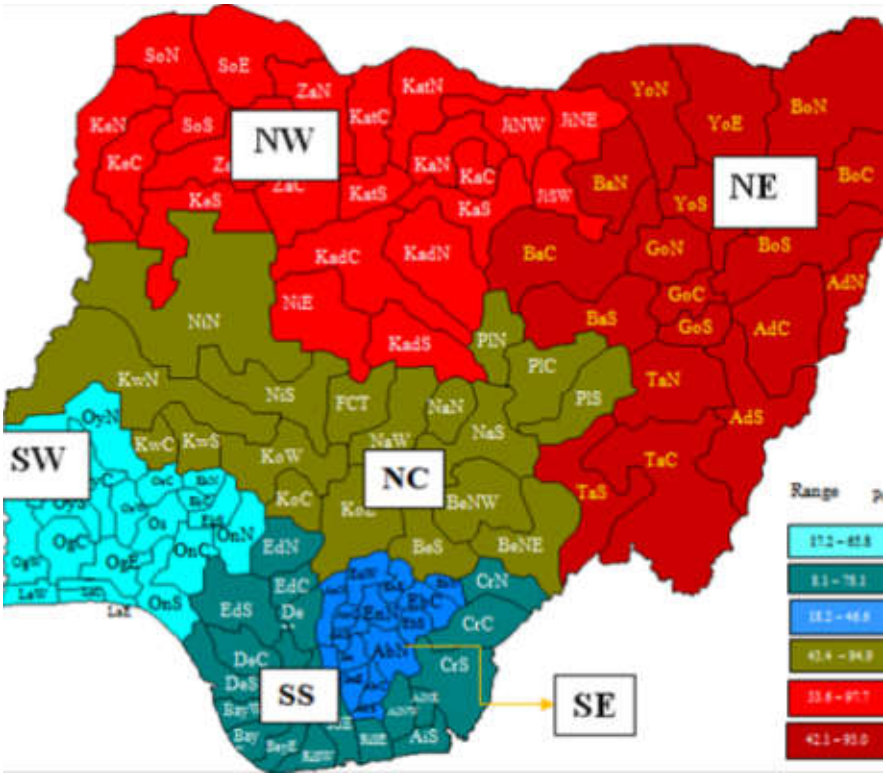

Test program

The program was designed to experiment with various types of existing soils prevalent in Nigeria and the spread covering the six major zones were adopted.
The samples were taken from the locations as below:

Sample source	State	Zone
Abakaliki	Ebonyi state	South-east Nigeria
Sapele	Delta state	South-South Nigeria
Oshogbo	Osun state	South-West Nigeria
Abuja	Federal capital Territory	North-Central, Nigeria
Gombe	Gombe	North-East Nigeria
Sokoto	Sokoto	North-West, Nigeria

Novocrete® samples were provided to OPiS NG .Key features of Novocrete® are:

- Novocrete is applicable to all types of cohesive and non-cohesive soil, as well as soil types with high organic contents up to 15 % loss on ignition which are usually unsuitable for construction.
- Improves soil properties
- Creating base course layers with high loadbearing capacity by reducing cracking
- Stabilization and immobilization of hazardous materials in one step



Map showing the six regions in Nigeria

SAMPLE COLLECTION

As stated above, samples were collected from the six zones across the country. Below are pictures during the collection:


TOYOTA

The scope of the investigation involves evaluating the properties of the types of soils to ascertain:

- Unblended physical and strength properties of soil
- Strength properties of soil when stabilized with cement only
- Strength properties of soil when stabilized with cement and Novocrete mineral blend
- Ascertain the benefit of the mineral blend

Test Scope

Tests on Unblended Sample (each Sample)		
a) Natural Water Content	Each	2
b) Grain size analysis (Sieve)	Each	1
c) Atterberg Limits	Each	1
d) Loss of Ignition (in case of suspected organic content)	Each	1
e) Compaction (Proctor)	Each	1
f) CBR (Unsoaked)	Each	1
g) CBR (Soaked)	Each	1
Tests on Cement Mixed Sample (each Sample)		
a) Compaction (Proctor)	Each	1
b) CBR (Unsoaked)	Each	1
c) CBR (Soaked)	Each	1
d) Unconfined Compression Strength Test	Each	1
Tests on Novocrete-Cement Mixed Sample (each Sample)		
a) Compaction (Proctor)	Each	1
b) CBR (Unsoaked)	Each	1
c) CBR (Soaked)	Each	1
d) Unconfined Compression Strength Test	Each	1

To evaluate the CBR and the UCS (Unconfined Compressive Strength Test) values, the samples with and without cement and mineral blend were moist-compacted at their respective maximum dry unit weight and optimum moisture contents.
To determine the effect of cement and mineral additive (i.e. NOVOCRETE®) on the above-mentioned properties, samples of Abuja Jahi, Abakaliki, Gombe and Sokoto location were evaluated for CBR improvements in both the Unsoaked and Soaked states, due to the range of expansive clay minerals types in the fine sieve spectrum; soaked state was tested on the top and the bottom end of the specimen.
While the CBR samples of the locations Oshogbo and Sapele were measured only in the Unsoaked state due to their grain size distribution (main soil type was fine sand).
The measurements on the top and the bottom end of the specimens were also executed here.
The CBR of all measured soaked specimens were carried out after 48 hours soaking period.

The prepared specimens for the determination of the unconfined compressive strength were stored moist for 3 days.
Their unconfined compressive strength was determined after a total setting time of 7, 14 and 28 days (residual storage was carried out under room temperature conditions).
From the results of unconfined compressive strength tests, the objective was to determine the average percentage increase in strength.
Note: for Sapele and Gombe soil an organic content was indicated.
During the laboratory procedures, it was mentioned that a "loss on ignition" test results will be submitted.

TESTING OF UNBLENDED MATERIALS

This part summarizes the preliminary results conducted before the arrival of the arrival of the Novocrete® team.

It is the determination of material properties in its unblended states.

The testing team included staff of Tectonics Engineering, NBRRI and the Ahmadu Bello University.

Natural Water Content results

The natural water contents were conducted on samples in their natural state and the results obtained are as below.

Test Method:	BS 1377: Part 2: 1990: 3: 2					
	Water Content test result					
Sample Source	North Central (Abuja)	Abakaliki (South East)	Sapele (South South)	Oshogbo (South West)	Sokoto (North West)	Gombe (North East)
Average Water Cont.	19.5 %	23.3 %	25.9 %	17.6 %	39.9 %	32.2 %

Sieve Analysis results

This refers to the particle gradation of the soil samples, which is determining by the sizes of soils particles .

This is achieved by passing a soil sample through a set of sieves and weighing the amount of material retained on each sieve.

The wet sieving method is adopted and subsequently oven-dried it using the standardized method.With this test, the composition of gravel , sand and Silt/Clay combination can be defined.

Primarily, soil particles having more than 50 % passing through sieve 200 are classified as **Fine-Grained Soils** while that having less than 50 % passing through sieve no 200 are classified as **Coarse-Grained soils**.

			Particle Size Analysis									
	Sieve No	3/8 in	No.4	No.6	No.10	No.16	No.30	No.40	No.50	No.70	No.100	No.200
Sample Location	Sample source :	9.5 mm	4.75mm	3.35 mm	2.0 mm	1.18 mm	0.6 mm	0.425 mm	0.3 mm	0.25 mm	0.15 mm	0.075 mm
ABUJA.(NORTH CENTRAL)	Test Pit No:	96.3 %	93.7 %	89.2 %	88.4 %	84.8 %	71.8 %	62.0 %	52.1 %	44.0 %	37.9 %	33.0 %
ABAKALIKI, EBONYI STATE (SOUTH EAST)	Test Pit No:	100%	100%	90.2 %	88.3 %	84.1 %	79.3 %	76.8 %	74.2 %	71.6 %	68.5 %	64.2 %
OSOGBO, OSUN STATE (SOUTH WEST)	Test Pit No:	100%	100%	86.7 %	84.5 %	76.3 %	65.4 %	58.8 %	51.0 %	44.3 %	39.2 %	36.0 %
SAPELE, DELTA STATE (SOUTH-SOUTH)	Test Pit No:	100%	100%	98.7 %	98.4 %	96.4 %	88.0 %	77.9 %	61.4 %	43.7 %	33.7 %	31.0 %
GOMBE (NORTH-EAST)	Test Pit No:	100%	100%	80.6 %	79.2 %	73.8 %	68.4 %	65.7 %	62.5 %	59.0 %	55.1 %	53.5 %
SOKOTO(NORTH-WEST)	Test Pit No:	100%	100%	97.6 %	97.0 %	92.1 %	79.8 %	73.5 %	66.2 %	59.3 %	52.6 %	47.0 %

Atterberg Limits Results

Atterberg limit comprises of three constants: plastic limit, liquid limit and the plasticity index. The liquid limit is defined as the water content at which the soil passes through the solid state to liquid state.

Two methods of conducting the liquid limits test are the Casagrande and the cone penetration method. The cone penetrometer method was used for all the soils and the water content obtained is factored with respect to the penetration recorded. The plastic limit is defined as the water content at which the soil passes from the liquid state to plastic state.

Atterberg Limit Results Table:

		Constituent Percentages			Atterberg Limits		
Sample Location	Sample source:	Percentage Gravel	Percentage sand	Percentage Fines	Plastic Limit	Liquid limit	Plasticity index
ABUJA. (NORTH CENTRAL)	Test Pit No: 1	6.3 %	60.7 %	33.0 %	17	24	7
ABAKALIKI, EBONYI STATE (SOUTH EAST)	Test Pit No: 2	0.0%	35.8 %	64.2 %	21	34	13
OSOGBO, OSUN STATE (SOUTH WEST)	Test Pit No: 3	0.0%	64.0 %	36.0 %	Non-Plastic	72	72
SAPELE, DELTA STATE (SOUTH-SOUTH)	Test Pit No: 4	0.0%	69.0 %	31.0 %	Non-Plastic	32	32
GOMBE (NORTH-EAST)	Test Pit No: 5	0.0%	46.5 %	53.5 %	56	85	29
SOKOTO(NORTH-WEST)	Test Pit No: 6	0.0%	53.0 %	47.0 %	35	72	37

Compaction and CBR results

This is the densification of the soil by removing the air void.

The British standard method of compaction was used as stipulated in BS 1377 part 4.

The standard compaction method is used to obtain the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) of the various soil samples obtained.

				CBR (Unsoaked)		CBR (Soaked)	
Sample Location	Sample source:	Position No	MDD (Mg/m^3)	Top	Btm	Top	Btm
ABUJA (NORTH CENTRAL)	Test Pit No:	1	2002.8	51.1	68.3	22.1	16.0
ABAKALIKI, EBONYI STATE (SOUTH EAST)	Test Pit No:	2	1816.1	12.2	14.4	4.5	2.7
OSOGBO, OSUN STATE (SOUTH WEST)	Test Pit No:	3	1529.3	22.6	14.6	8.3	13.1
SAPELE, DELTA STATE (SOUTH-SOUTH)	Test Pit No:	4	1587.5	2.7	2.4	2.9	5.6
GOMBE (NORTH-EAST)	Test Pit No:	5	1385.6	5.6	5.3	0	0
SOKOTO(NORTH-WEST)	Test Pit No:	6	1402.1	4.9	4.0	0	0

Classification results

Soils are basically classified by their geologic origin, mineralogy, and particle size and plasticity index.More robust and more comprehensive systems have been standardized such as the Unified Soil Classification System (**USCS**) and the American Association of Highway and Transportation officials (**AASHTO**).

These are all-purpose system mostly used because of its flexibility and ease of use. Soils with more than 50% passing through sieve No. 200, is classified as "**fine-grained**" while those with less than 50% passing through sieve No. 200 is classified as "**coarse-grained**". A combination of these criteria, the liquid limit and plasticity index gives a complete classification based on these systems.

	AASHTO Classifications				USCS Soil Classification (ASTM D2487)	
Sample Location	Group Index	Group Classification	Significant Constituent material	Rating as Sub-Grade	Group Symbol	Group Name
ABUJA (NORTH CENTRAL)	A - 2 - 4	A - 2 - 4 (0)	Excellent to Good	Excellent to Good	SC-SM	Silty, Clayey Sand
ABAKALIKI, EBONYI STATE (SOUTH EAST)	A - 6	A - 6 (6)	Fair to poor	Fair to poor	CL	Sandy Lean Clay
OSOGBO, OSUN STATE (SOUTH WEST)	A - 7	A - 7 (13)	Fair to poor	Fair to poor	SM	Silty Sand
SAPELE, DELTA STATE (SOUTH-SOUTH)	A - 2 - 6	A - 2 - 6 (4)	Excellent to Good	Excellent to Good	SM	Silty Sand
GOMBE (NORTH-EAST)	A - 7	A - 7 (15)	Fair to poor	Fair to poor	MH	Elastic silt
SOKOTO (NORTH-WEST)	A - 7	A - 7 (13)	Fair to poor	Fair to poor	SM	Silty sand

TESTING WITH MINERAL BLENDING LABORATORY PROCEDURES:

This part summarizes results of tests carried-out on in December 2017.

The testing team included staff of Tectonics Engineering, NBRRI and the Ahmadu Bello University under the supervision of Dipl. Geol. Jasmine Al-Obaidi the Novocrete® Expert.

This involves:

- Compaction characteristics of soil with Cement (OPC) alone. Binder content for OPC is stated in the tables below.
- Compaction characteristics of soil with and with Cement (OPC) and Novocrete®. Binder content for OPC and Novocrete® are stated in the tables below
- CBR characteristics of soils with Cement (OPC) alone in the soaked and Unsoaked states
- CBR characteristics of soils with Cement (OPC) and Novocrete® mineral blending in the soaked and Unsoaked states
- UCS characteristics of soils with Cement (OPC) alone.
- UCS characteristics of soils with Cement (OPC) and Novocrete mineral blending
- Effect of binder types and their percentage contents (OPC and Novocrete®)

Since the objective of this investigation was to achieve the effect of Novocrete® in cement-stabilized soils compared to conventional cement-stabilized without additive and to reduce the extensive range of tests, the execution of the tests was limited to one cement type and respectively one Novocrete®-cement – mix content per soil type.

The cement content recommendation was based on the present laboratory results of the unblended soils as well as on experience by OPIS AG, Switzerland.

The table below lists the recommended cement contents for each tested soil. For the test series with Novocrete®, a Novocrete® content of **2 %** (calculated on the recommended cement amount) was added.

Sample location	Recommended cement content (kg/m^3)
Jahi, Abuja (North Central)	170
Abakaliki, Ebonyi (South East)	190
Oshogbo, Osun State (South West)	200
Sapele, Delta State (South South)	180
Gombe (North East)	210
Sokoto (North West)	200

Cement type

In the present study, Ordinary Portland Cement (OPC) – Grade 42.5 was used.
The manufacturer **Dangote** Portland cement and available nationwide.

1) The Type of cement used in the study is the ordinary Portland cement – Grade 42.5

2) Blending procedures for the binders are batched by weight

3) Required quantity of water (optimum moisture content, OMC, of the mix) was mixed to the soil, as determined in the proctor tests, and thoroughly mixed.

4) The wet mix was allowed to react by keeping it aside for one hour.

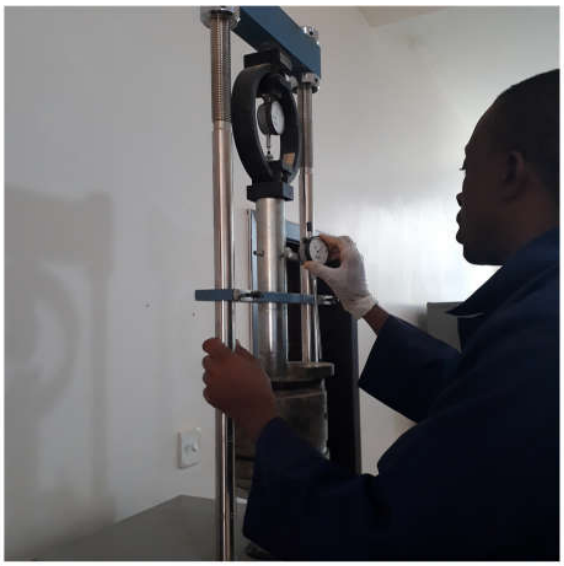
5) After one hour, the reacted mix was used to prepare required CBR or UCS samples.

It was also ensured that proper judgment of moisture in mix by touch with hands was done before compaction.

Curing Procedure

All UCS samples of 100 mm diameter and 150 mm height were compacted to their respective maximum dry unit weight and optimum water content and allowed for curing of 7, 14 and 28 days respectively.
The prepared samples were kept inside the desiccator and cured for a period of three days initially.
Water was sprayed on the sample regularly 2 times a day during this span.
After completion of 3 days of curing, these samples were taken out of desiccator and air dried for 4 days, till the date of testing i.e., for 7 days.
The remaining 14 days samples were air dried for 11 days.
The remaining 28 days samples were air dried for the 25 days.

Sample Preparation in Progress



Laboratory tests in progress

Loss of Ignition results:

Test Method	ASTM D2974		
	Organic Content test result		
Sample Source	**Sapele (South South)**	**Sokoto (North West)**	**Gombe (North East)**
Average Organic Matter Cont.	**7.9%**	**5.3%**	**4.5%**

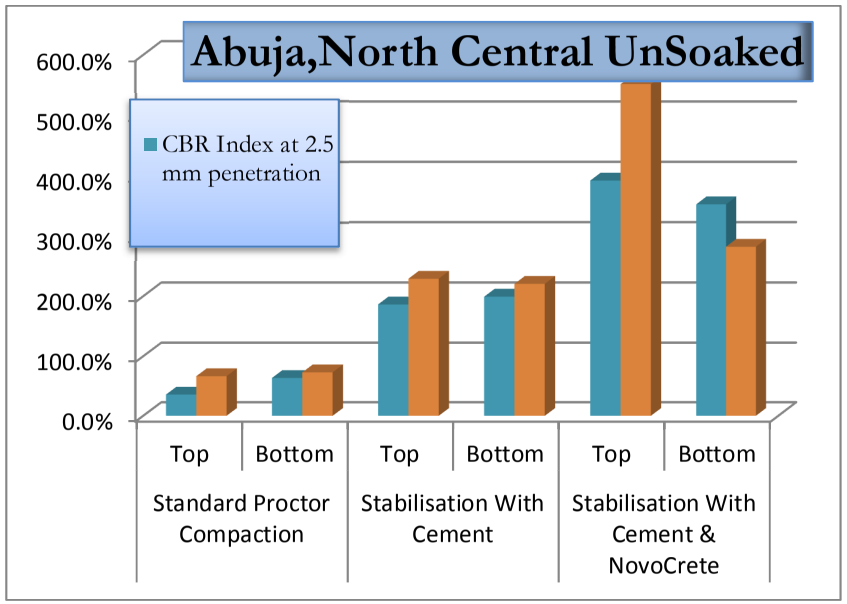
Abuja

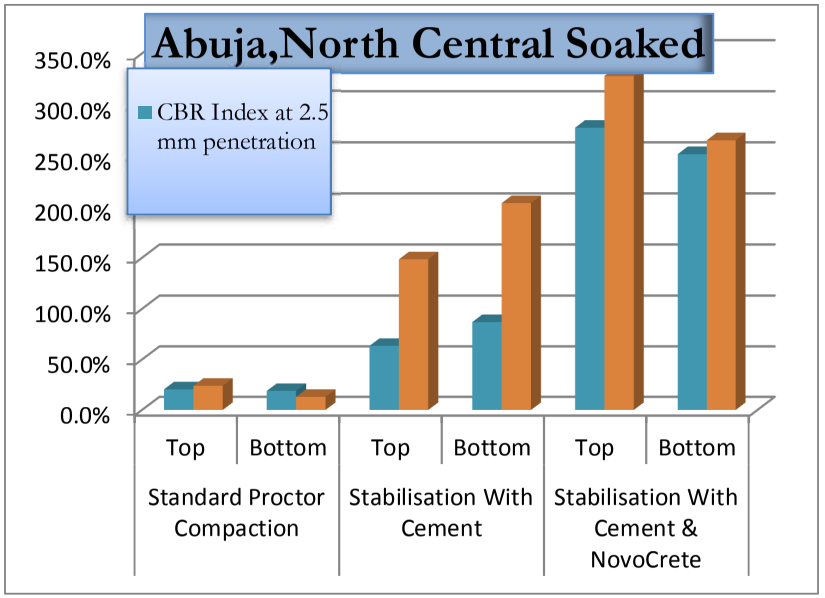
CBR Results and Conclusions:

Location:	Abuja (North Central)							
Trial Pit:	# 1		**Percentage Cement added**				8.49%	170 Kg/M3
Sample depth	1 meter		**Percentage Cement +Novocrete**				8.66%	173.4 Kg/M3
Vol of mould (cm3)	942		**Weight of Rammer:**		2.5 Kg			
Number of Blows:	25		**Number of Layers:**		3			
	COMPACTION TEST RESULT							
Soil Type (USCS) SC-SM		**Test Samples**						
Unblended Soils	Ave. Water Cont. %	8.3	11.5	13.9	17.4		O.M.C	9.0%
	Dry Density g/Cm3	1990	1947	1825	1752		M.D. D	2002.8
Cement Stabilization Only	Ave. Water Cont. %	1.7	4.6	7.6	10.7	13.3	O.M.C	10.0%
	Dry Density g/Cm3	1918	1873	1794	2021	2000	M.D. D	2045.1
Cement & Novocrete	Ave. Water Cont. %	7.6	10.7	13.3	15	18.4	O.M.C	11.5%
	Dry Density g/Cm3	1794	2021	2000	1922	1825	M.D. D	2030.7

Abuja: Compaction Comparison Results:

Abuja, North Central		Cbr Index Unsoaked		Cbr Index Soaked	
		2.5mm	5.0mm	2.5mm	5.0mm
Percentage increase on Cement Stabilisation	Top	110%	54%	336%	121%
	Btm	177%	28%	3%	1%
Average Percentage increase on Cement Stabilisation		143%	41%	170%	61%





Abuja CBR Compaction Comparison Results

Abuja , North Central						
Percentage Cement added		8.5%	**Percentage Cement +Novocrete**			8.7%
Mass per unit Volume (Kg/m^3)		170.0 Kg/m^3	**Mass per unit Volume (Kg/m^3)**			173.4 Kg/m^3
		Cbr Index UnSoaked			**Cbr Index Soaked**	
		2.5mm	5.0mm		2.5mm	5.0mm
Standard Proctor Compaction	Top	35.6%	66.5%	Top	20.5%	24.0%
	Btm	63.6%	73.0%	Btm	18.9%	13.0%
Stabilisation With Cement	Top	186.4%	229.0%	Top	63.6%	148.5%
	Btm	199.2%	220.5%	Btm	87.1%	203.5%
Stabilisation With Cement & NovoCrete	Top	391.7%	352.3%	Top	277.3%	328.0%
	Btm	551.5%	282.0%	Btm	251.5%	265.0%

Abakaliki:

Percentage increase on Unblended Soil	Top	1000%	430%		1253%	1267%
	Btm	767%	286%		1231%	1938%
% increase on Cement Stab.	Top	110%	54%		336%	121%
	Btm	177%	28%		3%	1%
Ave. % increase on Cement Stabilisation		**143%**	**41%**		**170%**	**61%**

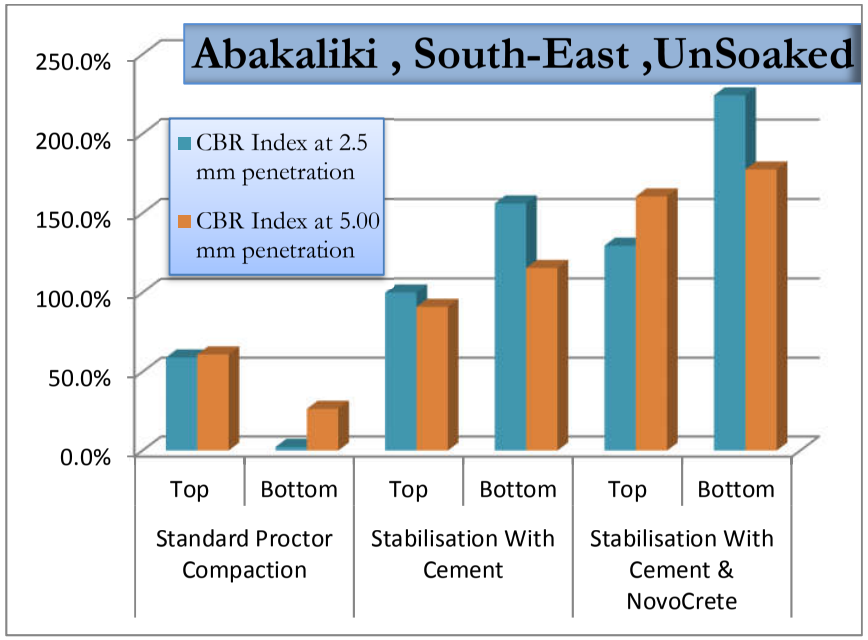
Location:	ABAKALIKI, EBONYI STATE (SOUTH EAST)							
Trial Pit:	# 2	**Percentage Cement added**					10.46%	190 Kg/M3
Sample depth	1 meter	**Percentage Cement +Novocrete**					10.67%	193.8 Kg/M3
Vol of mould (cm3)	942	**Weight of Rammer:**			2.5 Kg			
Number of Blows:	25	**Number of Layers:**			3			
	COMPACTION TEST RESULT							
Soil Type (USCS) CL		**Test Samples**						
Unblended Soils	Ave. Water Cont. %	10.8	14.2	16.9	21.2		O.M.C	13.5%
	Dry Density g/Cm3	1739	1813	1748	1619		M.D. D	1816.1
Cement Stabilization Only	Ave. Water Cont. %	8.1	11.1	14.1	16.4	18.5	O.M.C	13.5%
	Dry Density g/Cm3	1653	1676	1694	1765	1734	M.D. D	1869.8
Cement & Novocrete	Ave. Water Cont. %	11.1	14.1	16.4	18.5	20.5	O.M.C	17.5%

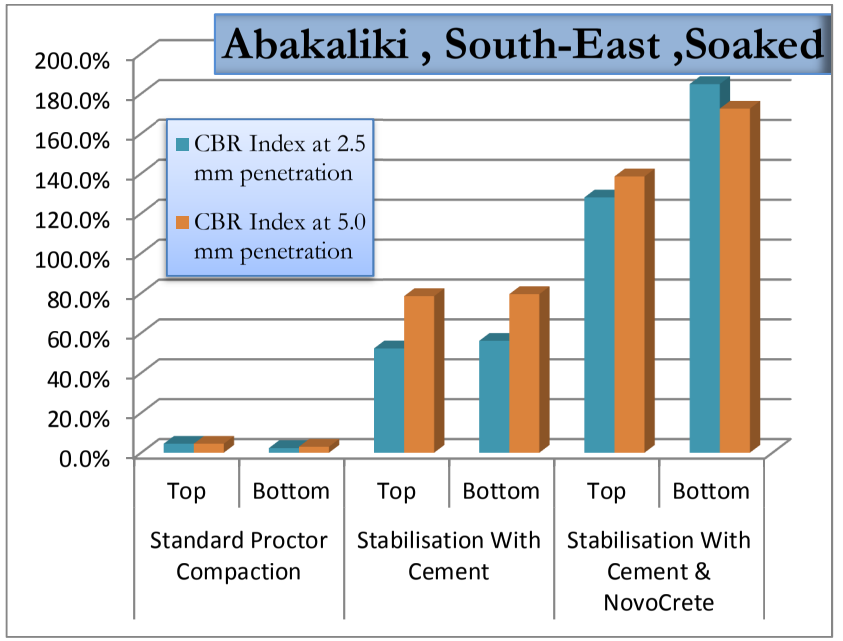
	Dry Density g/Cm3	1676	1694	1765	1734	1719	M.D. D	1784.1

CBR Results and Conclusions:

Abakaliki Compaction Comparison Results

Abakaliki, South-East		Cbr Index Unsoaked		Cbr Index Soaked	
		2.5mm	5.0mm	2.5mm	5.0mm
Percentage increase on Cement Stabilisation	Top	30%	146%	145%	76%
	Btm	3%	54%	6%	3%
Average Percentage increase on Cement Stabilisation		16%	100%	75%	40%





Abakaliki CBR Comparison Results

Abakaliki , Ebonyi state South East .						
Percentage Cement added		10.5%		Percentage Cement +Novocrete		10.7%
Mass per unit Volume (Kg/m^3)		196.0 Kg/m^3		Mass per unit Volume (Kg/m^3)		193.8 Kg/m^3
		Cbr Index UnSoaked			Cbr Index Soaked	
		2.5mm	5.0mm		2.5mm	5.0mm
Standard Proctor Compaction	Top	59.1%	61.0%	Top	4.5%	4.5%
	Btm	2.3%	26.5%	Btm	2.3%	3.0%
Stabilisation With Cement	Top	100.0%	91.0%	Top	52.3%	78.5%
	Btm	156.1%	115.5%	Btm	56.1%	79.5%
Stabilisation With Cement & NovoCrete	Top	129.5%	224.2%	Top	128.0%	138.5%
	Btm	160.5%	177.5%	Btm	184.8%	172.5%
Percentage increase on Unblended	Top	119%	268%		2744%	2978%
	Btm	6878%	570%		7935%	5650%
Percentage increase on Cement Stabilisation	Top	30%	146%		145%	76%
	Btm	3%	54%		6%	3%
Average Percentage increase on Cement Stabilisation		**16%**	**100%**		**75%**	**40%**

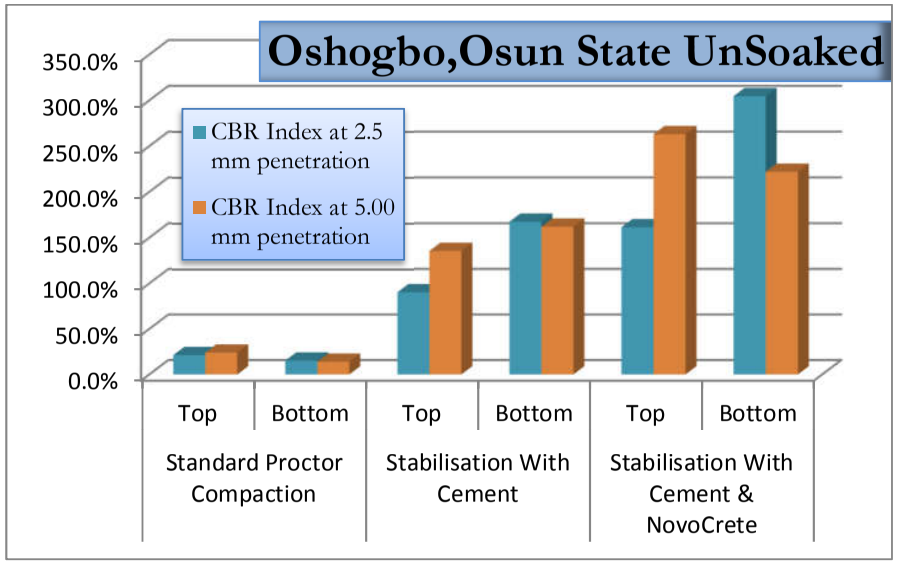
Oshogbo:

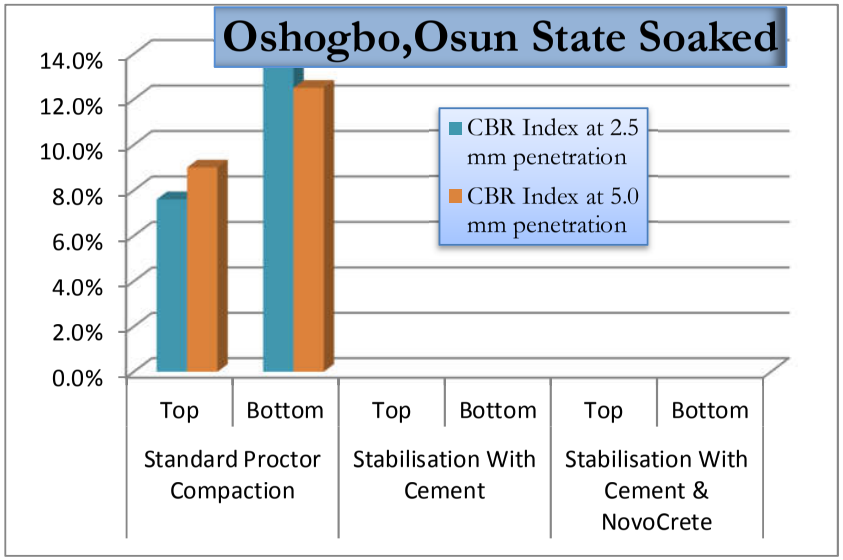
CBR Results and Conclusions

Location:	Oshogbo, Osun State (South West)							
Trial Pit:	# 3			**Percentage Cement added**			13.08%	200 Kg/M3
Sample depth	1 meter			**Percentage Cement +Novocrete**			13.34%	204 Kg/M3
Vol of mould (cm3)	942			**Weight of Rammer:**	2.5 Kg			
Number of Blows:	25			**Number of Layers:**	3			
	COMPACTION TEST RESULT							
Soil Type (USCS) SM		Test Samples						
Unblended Soils	Ave. Water Cont. %	13.1	16.2	19.9	23.1	27	O.M.C	22.0%
	Dry Density g/Cm3	1447	1481	1518	1529	1465	M.D. D	1529.3
Cement Stabilization Only	Ave. Water Cont. %	19.7	22.9	24.8	27.1	31.2	O.M.C	22.5%
	Dry Density g/Cm3	1396	1417	1411	1414	1347	M.D. D	1504.5
Cement & Novocrete	Ave. Water Cont. %	19.7	22.9	24.8	27.1	31.2	O.M.C	25.0%
	Dry Density g/Cm3	1396	1417	1411	1414	1347	M.D. D	1417.3

Oshogbo Compaction Comparison Results

Oshogbo, Osun State.		Cbr Index Unsoaked		Cbr Index Soaked	
		2.5mm	5.0mm	2.5mm	5.0mm
Percentage increase on Cement Stabilisation	Top	79%	125%	-	-
	Btm	57%	37%	-	-
Average Percentage increase on Cement Stabilisation		68%	81%	-	-





(No Soaked results due to fine grained sand samples)

CBR Comparison **Results**

Oshogbo , osun Stae South West						
Percentage Cement added		13.1%		**Percentage Cement +Novocrete**		13.3%
Mass per unit Volume (Kg/m^3)		200.0 Kg/m^3		**Mass per unit Volume (Kg/m^3)**		204.0 Kg/m^3
		Cbr Index UnSoaked			**Cbr Index Soaked**	
		2.5mm	5.0mm		2.5mm	5.0mm
Standard Proctor Compaction	Top	21.2%	24.0%	Top	7.6%	9.0%
	Btm	15.2%	14.0%	Btm	13.6%	12.5%
Stabilisation With Cement	Top	90.2%	135.5%	Top		
	Btm	167.4%	162.0%	Btm		
Stabilisation With Cement & NovoCrete	Top	161.4%	304.5%	Top		
	Btm	263.0%	222.0%	Btm		
Percentage increase on Unblended	Top	661%	1169%			
	Btm	1630%	1486%			
Percentage increase on Cement Stabilisation	Top	79%	125%			
	Btm	57%	37%			
Average Percentage increase on Cement Stabilisation		**68%**	**81%**			

Sapele

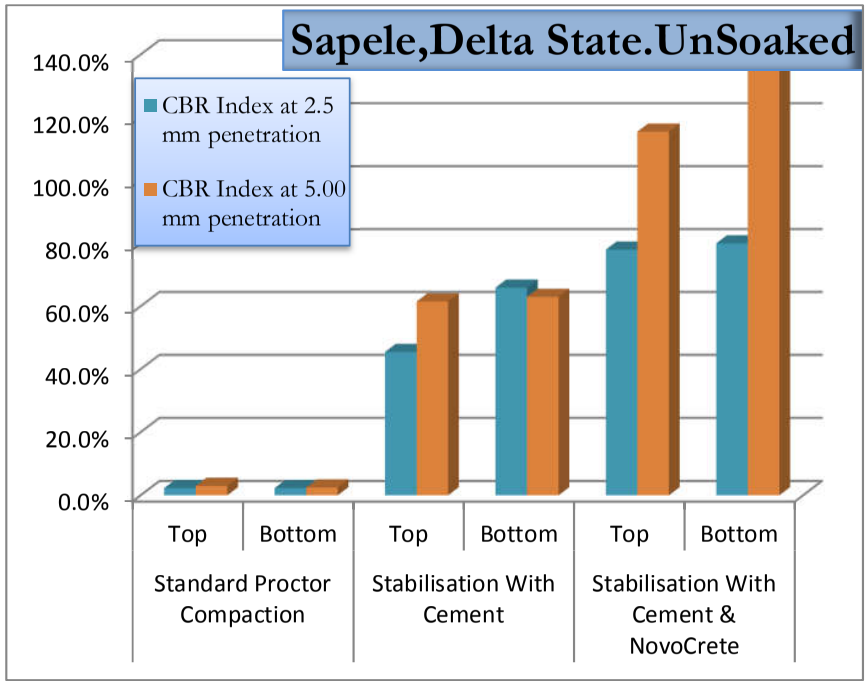
CBR Results and Conclusions

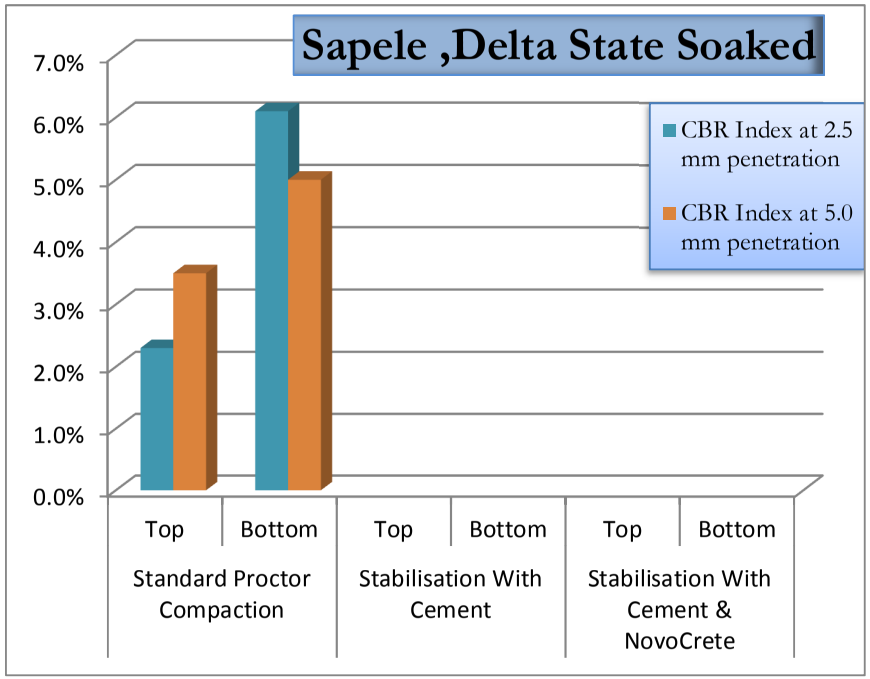
Location:	Sapele , Delta State (South South)							
Trial Pit:	# 4			**Percentage Cement added**			11.34 %	180 Kg/M3
Sample depth	1 meter			**Percentage Cement +Novocrete**			11.57 %	183.6 Kg/M3
Vol of mould (cm3)	942			**Weight of Rammer:**	2.5 Kg			
Number of Blows:	25			**Number of Layers:**	3			
	COMPACTION TEST RESULT							
Soil Type (USCS) SM		**Test Samples**						
Unblended Soils	Ave. Water Cont. %	13.7	17.7	19.1	22.2		O.M.C	20.5%
	Dry Density g/Cm3	1459	1510	1567	1510		M.D. D	1587.5
Cement Stabilization Only	Ave. Water Cont. %	20.1	21.2	25.8	28.8	30.6	O.M.C	18.0%
	Dry Density g/Cm3	1367	1451	1414	1351	1296	M.D. D	1755
Cement & Novocrete	Ave. Water Cont. %	20.1	21.2	25.8	28.8	30.6	O.M.C	23.0%
	Dry Density g/Cm3	1367	1451	1414	1351	1296	M.D. D	1473

(No soaked results due to fine grained sand sample)

Sapele Compaction Comparison Results:

Sapele, delta State South-South		Cbr Index Unsoaked			Cbr Index Soaked	
		2.5mm	5.0mm		2.5mm	5.0mm
Percentage increase on Cement Stabilisation	Top	71%	30%		-	-
	Btm	75%	116%		-	-
Average Percentage increase on Cement Stabilisation		73%	73%		-	-





Sapele CBR

Comparison Results

Sapele , Delta State . South South						
Percentage Cement added		11.3%	Percentage Cement +Novocrete			11.6%
Mass per unit Volume (Kg/m^3)		180.0 Kg/m^3	Mass per unit Volume (Kg/m^3)			183.6 Kg/m^3
		Cbr Index UnSoaked			Cbr Index Soaked	
		2.5mm	5.0mm		2.5mm	5.0mm
Standard Proctor Compaction	Top	2.3%	3.0%	Top	2.3%	3.5%
	Btm	2.3%	2.5%	Btm	6.1%	5.0%
Stabilisation With Cement	Top	45.5%	61.5%	Top		
	Btm	65.9%	63.0%	Btm		
Stabilisation With Cement & NovoCrete	Top	78.0%	80.0%	Top		
	Btm	115.5%	136.0%	Btm		
Percentage increase on Unblended	Top	3291%	2567%			
	Btm	4922%	5340%			
Percentage increase on Cement Stabilisation	Top	71%	30%			
	Btm	75%	116%			
Average Percentage increase on Cement Stabilisation		**73%**	**73%**			

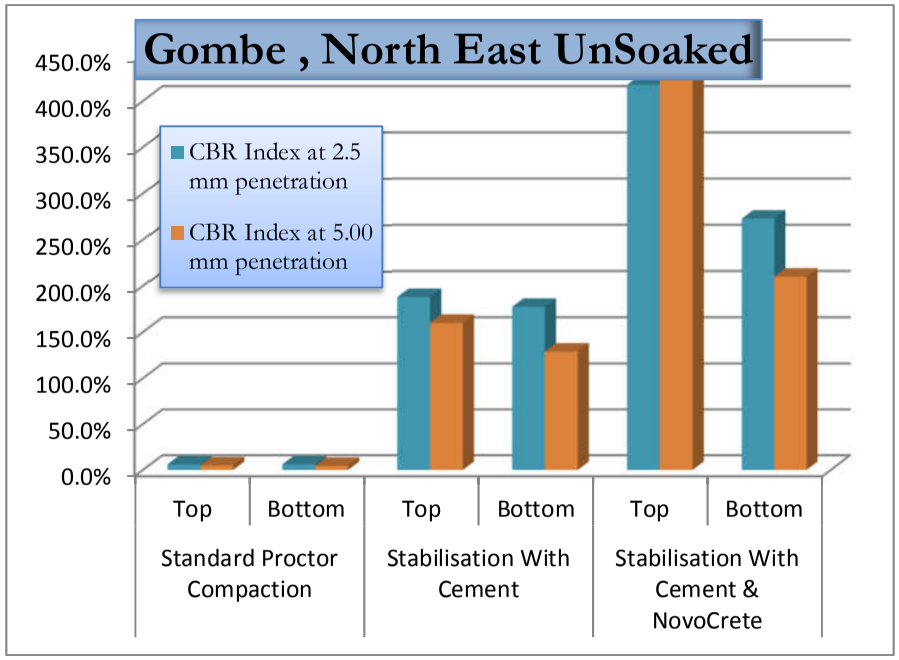
Gombe:

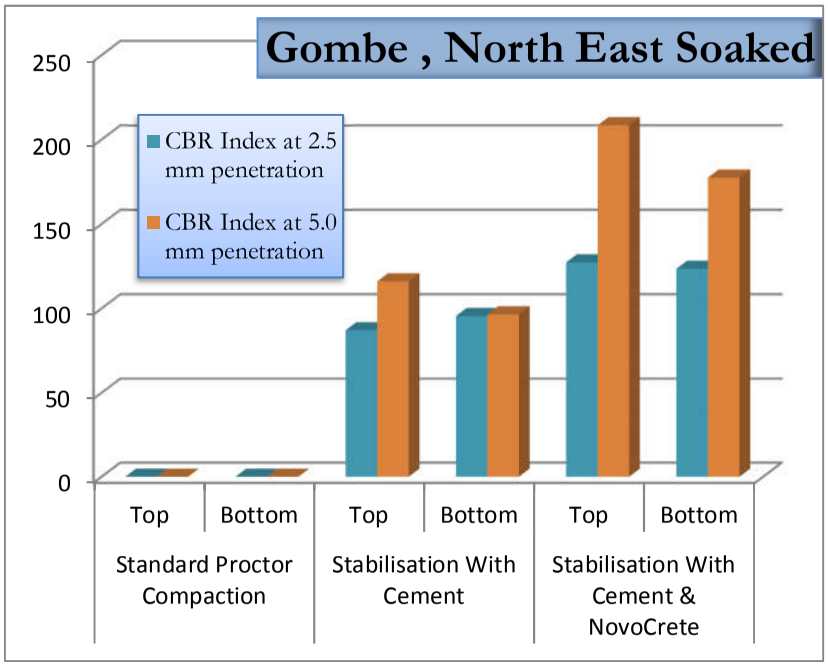
Location:	Gombe, Gombe State (North East)							
Trial Pit:	# 5			**Percentage Cement added**			15.16 %	210 Kg/M3
Sample depth	1 meter			**Percentage Cement +Novocrete**			15.46 %	214.2 Kg/M3
Vol of mould (cm3)	942			**Weight of Rammer:**	2.5 Kg			
Number of Blows:	25			**Number of Layers:**	3			
	COMPACTION TEST RESULT							
Soil Type (USCS) MH		**Test Samples**						
Unblended Soils	Ave. Water Cont. %	20.7	23.6	26.7	29.2	32.1	O.M.C	28.5%
	Dry Density g/Cm3	1365	1376	1365	1397	1360	M.D. D	1385.6
Cement Stabilization Only	Ave. Water Cont. %	15	19.3	21.8	24.9	27.4	O.M.C	23.0%
	Dry Density g/Cm3	1433	1465	1496	1474	1460	M.D. D	1486.2
Cement & Novocrete	Ave. Water Cont. %	22.5	25.4	28.1	29.8	32.5	O.M.C	24.0%
	Dry Density g/Cm3	1456	1306	1446	1406	1372	M.D. D	1461.2

CBR Results and Conclusions

Gombe Compaction Comparison Results

Gombe, North East.		Cbr Index Unsoaked			Cbr Index Soaked	
		2.5mm	5.0mm		2.5mm	5.0mm
Percentage increase on Cement Stabilisation	Top	122%	70%		46%	80%
	Btm	145%	63%		1%	2%
Average Percentage increase on Cement Stabilisation		133%	67%		24%	41%





Gombe CBR Comparison Results:

Gombe , Gombe State North East .						
Percentage Cement added		15.2%	**Percentage Cement +Novocrete**			15.46
Mass per unit Volume (Kg/m^3)		210.0 Kg/m^3	**Mass per unit Volume (Kg/m^3)**			214.2 Kg/m^3
		Cbr Index UnSoaked			**Cbr Index Soaked**	
		2.5mm	5.0mm		2.5mm	5.0mm
Standard Proctor Compaction	Top	6.1%	5.0%	Top	0	0
	Btm	6.1%	4.5%	Btm	0.0%	0.0%
Stabilisation With Cement	Top	187.9%	160.0%	Top	87.1%	116.0%
	Btm	177.3%	129.0%	Btm	95.5%	96.5%
Stabilisation With Cement & NovoCrete	Top	417.4%	272.7%	Top	127.3%	208.5%
	Btm	433.5%	210.0%	Btm	123.5%	177.5%
Percentage increase on Unblended	Top	6743%	5354%		127.3%	208.5%
	Btm	7007%	4567%		123.5%	177.5%
Percentage increase on Cement Stabilisation	Top	122%	70%		46%	80%
	Btm	145%	63%		1%	2%
Average Percentage increase on Cement Stabilisation		**133%**	**67%**		**24%**	**41%**

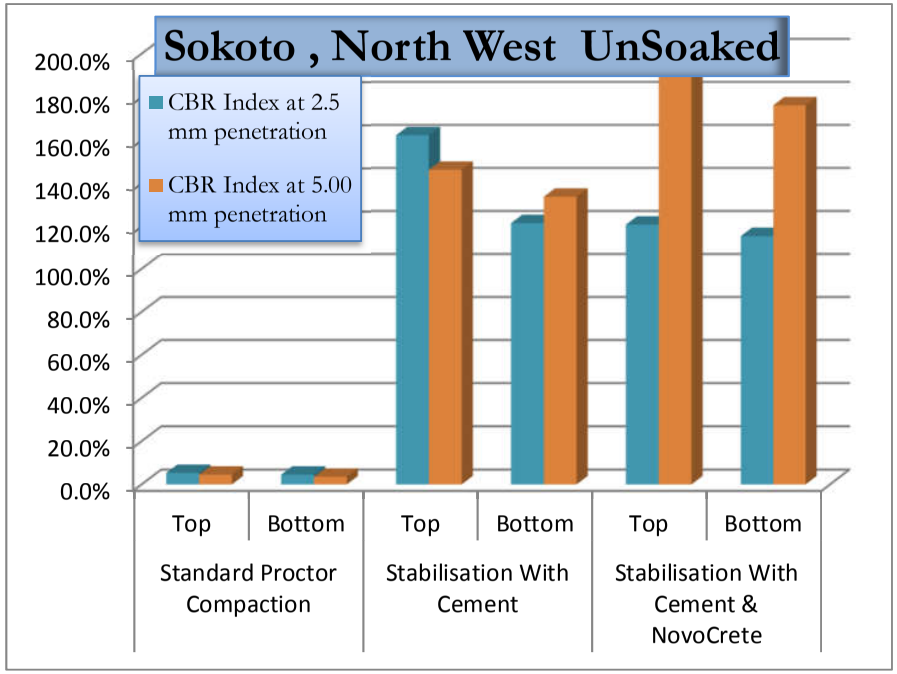
Sokoto

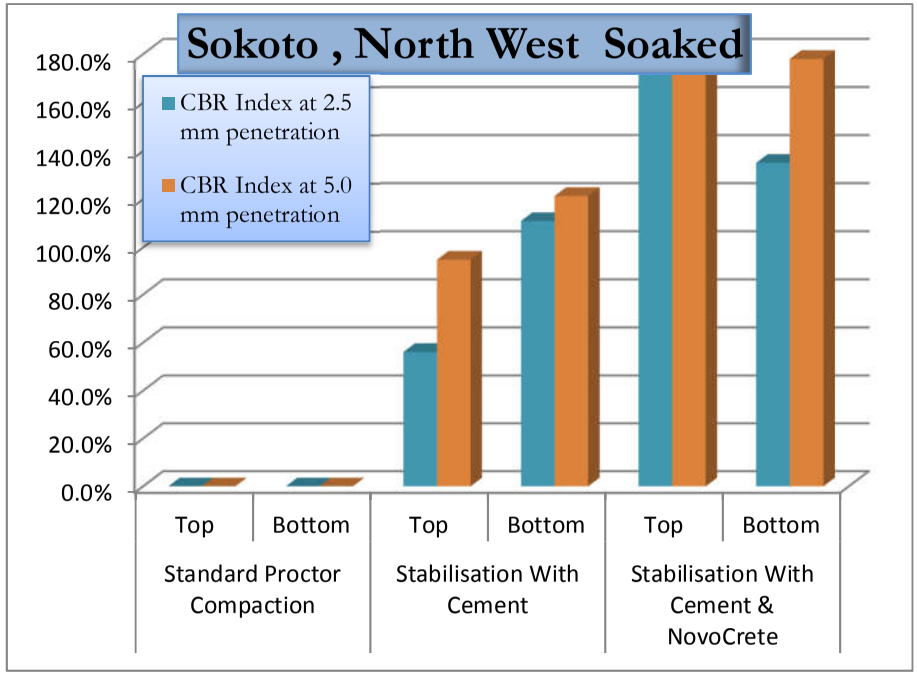
CBR Results and Conclusions

Location:	Sokoto , Sokoto State (North West)							
Trial Pit:	# 6			**Percentage Cement added**			14.26 %	200 Kg/M3
Sample depth	1 meter			**Percentage Cement +Novocrete**			14.55 %	204 Kg/M3
Vol of mould (cm3)	942			**Weight of Rammer:**	2.5 Kg			
Number of Blows:	25			**Number of Layers:**	3			
	COMPACTION TEST RESULT							
Soil Type (USCS) SM		Test Samples						
Unblended Soils	Ave. Water Cont. %	26	30.8	35.6	38		O.M.C	29.0%
	Dry Density g/Cm3	1374	1396	1317	1252		M.D. D	1402.1
Cement Stabilization Only	Ave. Water Cont. %	25.8	28.7	32.2	34.3	35.6	O.M.C	25.5%
	Dry Density g/Cm3	1484	1461	1434	1396	1374	M.D. D	1481.7
Cement & Novocrete	Ave. Water Cont. %	15.5	25.8	28.7	32.2	34.3	O.M.C	24.5%
	Dry Density g/Cm3	1396	1484	1461	1434	1396	M.D. D	1483.2

Sokoto Compaction Comparison Results:

Sokoto, North West		Cbr Index Unsoaked			Cbr Index Soaked	
		2.5mm	5.0mm		2.5mm	5.0mm
Percentage increase on Cement Stabilisation	Top	-26%	-21%		207%	89%
	Btm	60%	32%		1%	1%
Average Percentage increase on Cement Stabilisation		17%	5%		214%	168%


Sokoto , North West UnSoaked
CBR Index at 2.5 mm penetration
CBR Index at 5.00 mm penetration
200.0%
180.0%
160.0%
140.0%
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Top
Bottom
Top
Bottom
Top
Bottom
Standard Proctor Compaction
Stabilisation With Cement
Stabilisation With Cement & NovoCrete

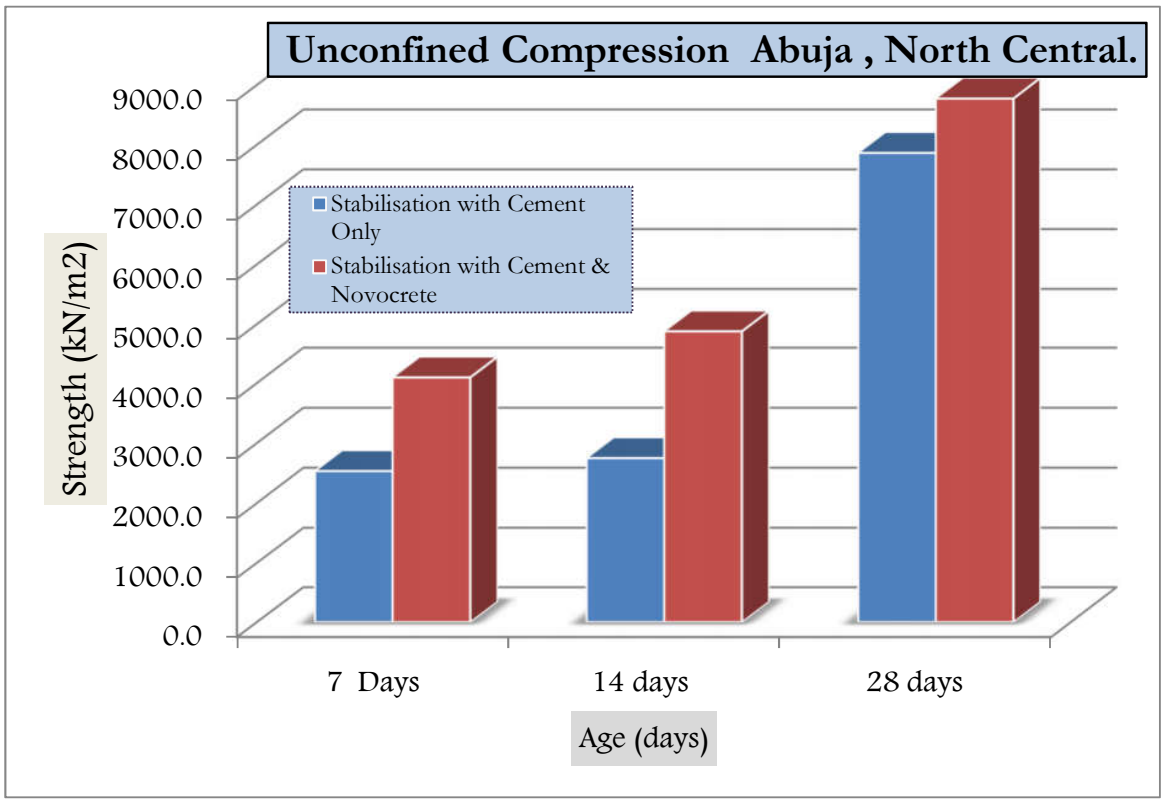

Sokoto , North West Soaked
CBR Index at 2.5 mm penetration
CBR Index at 5.0 mm penetration
180.0%
160.0%
140.0%
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Top
Bottom
Top
Bottom
Top
Bottom
Standard Proctor Compaction
Stabilisation With Cement
Stabilisation With Cement & NovoCrete

Sokoto CBR Comparison Results:

SOKOTO , NORTH WEST .						
Percentage Cement add		14.3%		**Percentage Cement +Novocrete**		14.6%
Mass per unit Volume (Kg		200.0 Kg/n		**Mass per unit Volume (Kg/m^3)**		204.0 Kg
		Cbr Index UnSoaked			**Cbr Index Soaked**	
		2.5mm	5.0mn		2.5mm	5.0mn
Standard Proctor Compaction	Top	5.3%	4.5%	Top	0.0%	0.0%
	Btm	4.5%	3.5%	Btm	0.0%	0.0%
Stabilisation Witl Cement	Top	162.1%	146.0%	Top	56.1%	94.5%
	Btm	121.2%	133.5%	Btm	110.6%	121.0%
Stabilisation Witl Cement & NovoCre	Top	120.5%	115.2%	Top	172.0%	178.5%
	Btm	194.0%	176.0%	Btm	134.8%	178.0%
Percentage increase Unblended	Top	2174%	2460%		172.0%	178.5%
	Btm	4211%	4929%		134.8%	178.0%
Percentage increase Cement Stabilisatic	Top	-26%	-21%		207%	89%
	Btm	60%	32%		1%	1%
Average Percentage incre on Cement Stabilisatio		**17%**	**5%**		**104%**	**45%**

Abuja UCS:

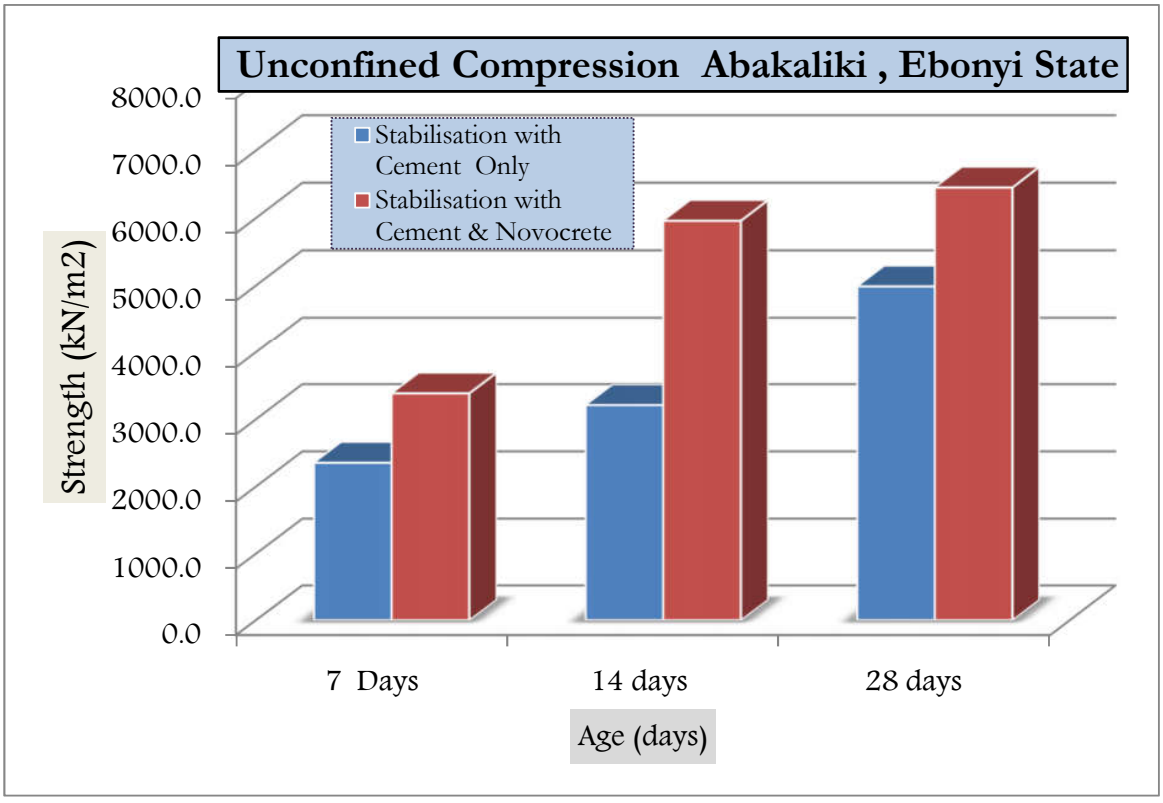
Unconfined Compression Results and Conclusion



ABUJA,(NORTH CENTRAL)			
Sample Age	7 days	14 days	28 days
Stabilisation with Cement Only	2532.0 KN/m²	2748.1 KN/m²	7863.4 KN/m²
Stabilisation with Cement & Novocrete	4093.7 KN/m²	4878.3 KN/m²	8772.55 KN/m²
Percentage Difference	62%	78%	12%
Average Difference	**50.7%**		

Abakaliki UCS:

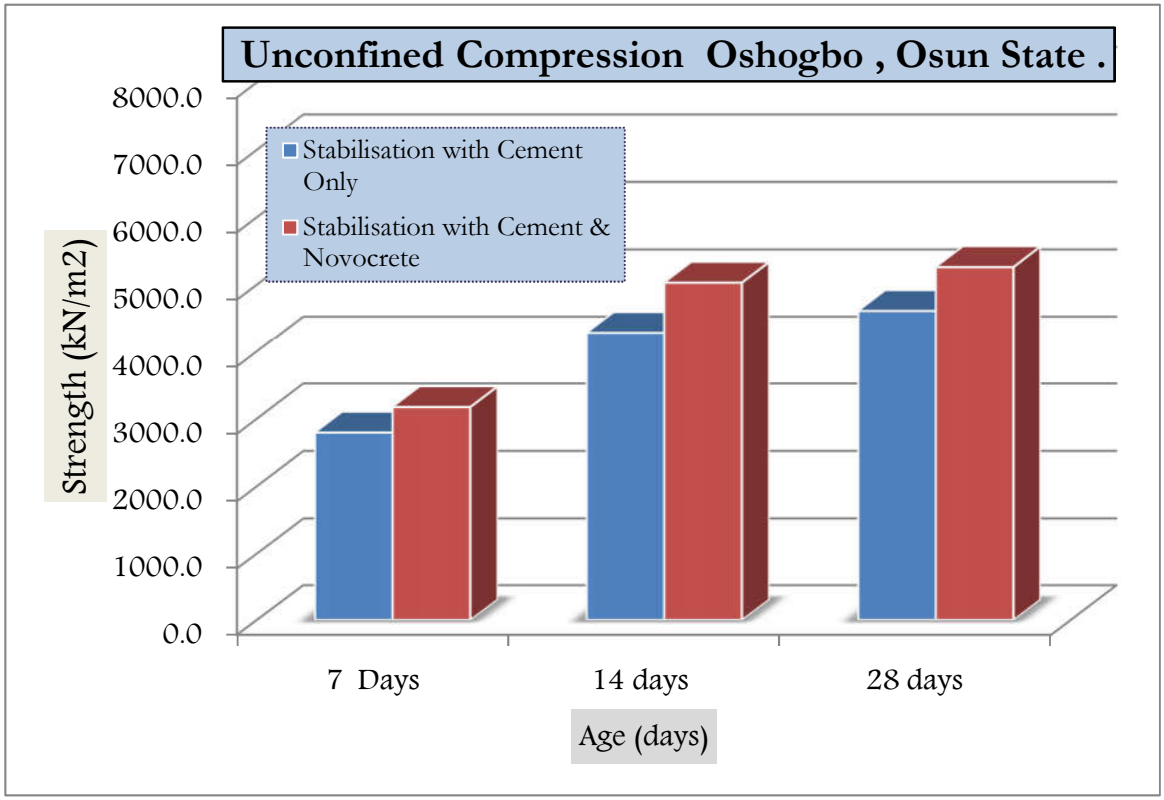
Unconfined Compression Results:



ABAKALIKI,EBONYI (SOUTH EAST)			
Sample Age	7 days	14 days	28 days
Stabilisation with Cement Only	2355.2 KN/m²	3211.1 KN/m²	4986.9 KN/m²
Stabilisation with Cement & Novocrete	3384.9 KN/m²	5959.7 KN/m²	6452.07 KN/m²
Percentage Difference	44%	86%	29 %
Average difference	**53%**		

Oshogbo UCS:

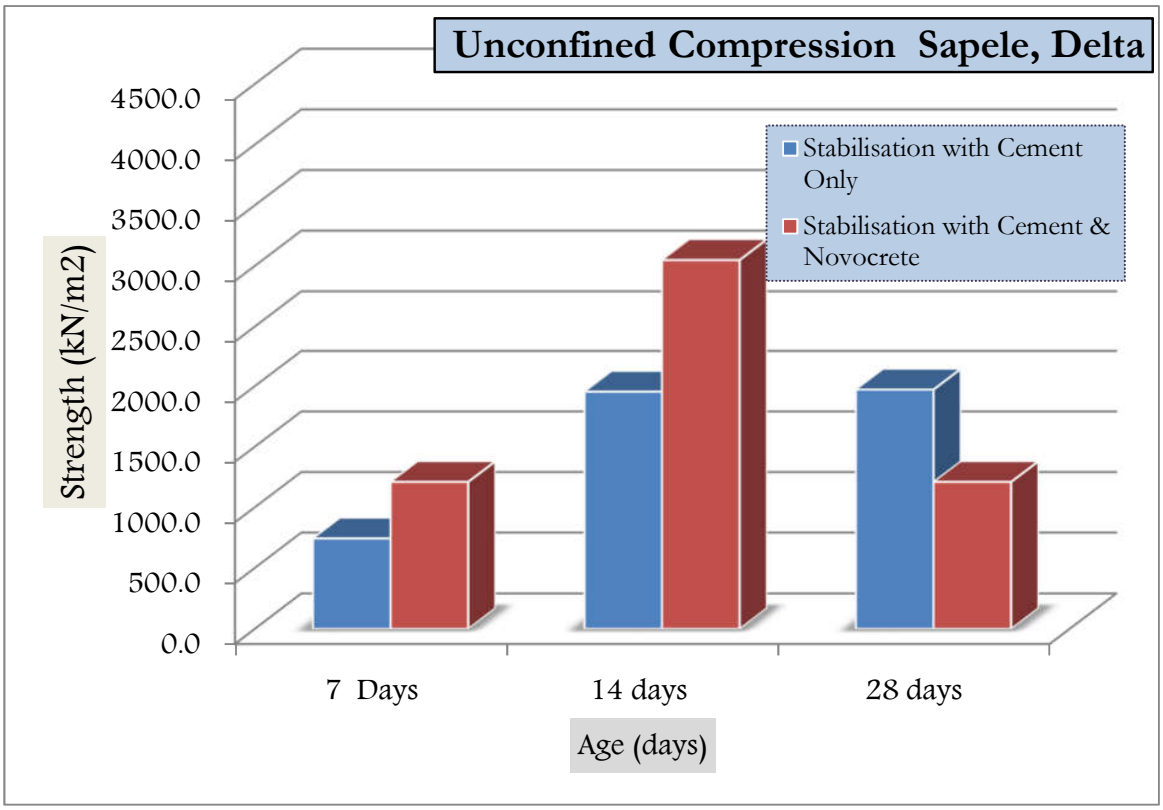
Unconfined Compression Results:



OSHOGBO, OSUN, (SOUTH WEST)			
Sample Age	7 days	14 days	28 days
Stabilisation with Cement Only	2793.7 KN/m²	4282.0 KN/m²	4608.8 KN/m²
Stabilisation with Cement & Novocrete	3171.2 KN/m²	5028.3 KN/m²	5259.6 KN/m²
Percentage Difference	14%	17%	14%
Average difference	**15%**		

Sapele UCS

Unconfined Compression results:



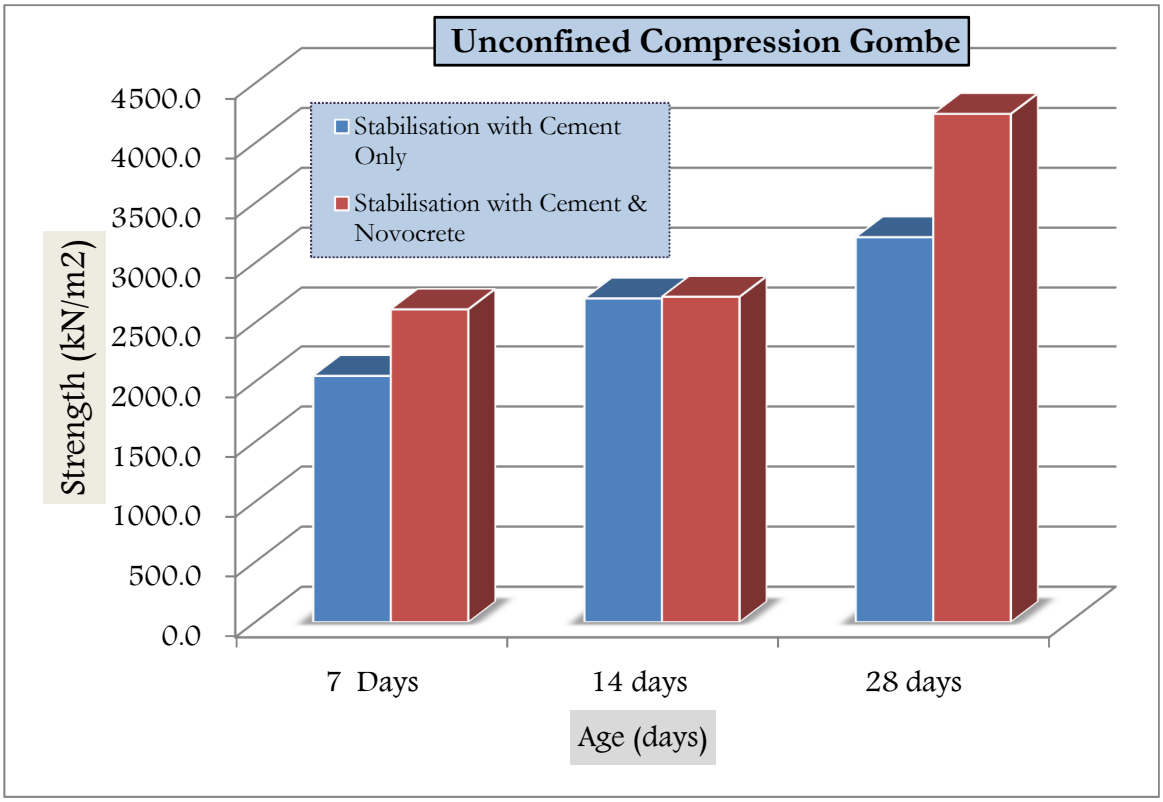
(Result is indicative of high organic content and possibly leaching and chemicals in the soil (sulphates) that reduce the efficiency of the cement hydrolysis process)

SAPELE, DELTA, (SOUTH SOUTH)			
Sample Age	**7 days**	**14 days**	**28 days**
Stabilisation with Cement Only	1971.1 KN/m²	1953.4 KN/m²	742.0 KN/m²
Stabilisation with Cement & Novocrete	4144.0 KN/m²	3048.1 KN/m²	1208.7 KN/m²
Percentage Difference	63%	56%	61%

Average difference	60%

Gombe UCS

Unconfined Compression Results



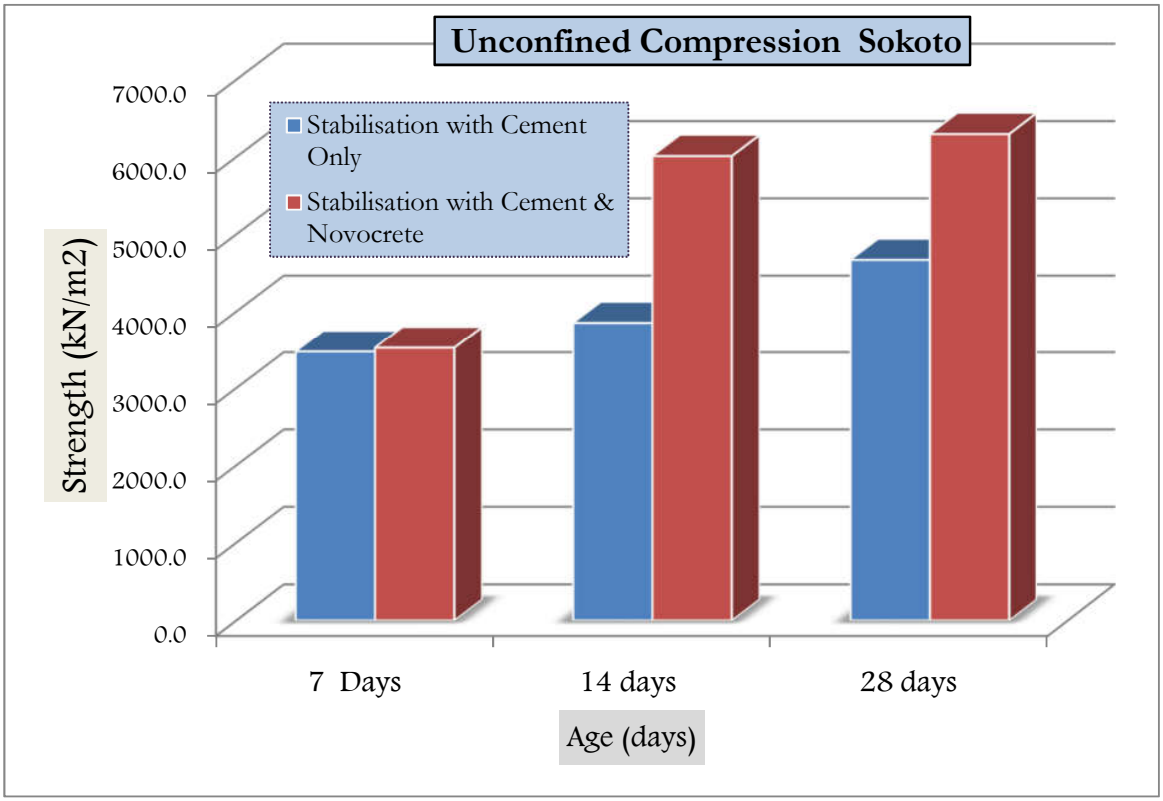
(Result is indicative of high organic content and possibly leaching and chemicals in the soil (sulphates) that reduce the efficiency of the cement hydrolysis process)

GOMBE, (NORTH EAST)			
Sample Age	7 days	14 days	28 days
Stabilisation with Cement Only	2048.2 KN/m²	2701.8 KN/m²	3213.6 KN/m²
Stabilisation with Cement & Novocrete	2611.2 KN/m²	2716.0 KN/m²	4243.7 KN/m²

Percentage Difference	27 %	1%	32 %
Average difference	**20%**		

Sokoto UCS:

Unconfined Compression Results:



SOKOTO,(NORTH WEST)			
Sample Age	**7 days**	**14 days**	**28 days**
Stabilisation with Cement Only	3473.9 KN/m²	3851.6 KN/m²	4668.6 KN/m²
Stabilisation with Cement & Novocrete	3524.2 KN/m²	6011.7 KN/m²	6296.4 KN/m²
Percentage Difference	1%	56 %	35 %
Average difference	**31 %**		

RECOMMENDATIONS.

A major finding is that only an addition of 2% (two percent) binding content of Novocrete® to OPC (**Dangote**) cement brought an average increment of **70%** in the CBR value of soils and an average of **38.3%** increment for the unconfined compressive strength of soil.

This difference was obtained by comparing strengths derived from cement blend to that of Cement-Novocrete® blend.

Notably however, as only the effect of Novocrete® in cement-stabilized soils was shown as the target of this present investigation, it is recommended to carry out laboratory tests with at least two different binder quantities for future projects to determine the exact and economic binder content for the soils in the respective project.
Knowing that each soil type is unique: Generally, a "loss of ignition test" will be carried out to ensure that the organic content would be less than 15%.
Having assessed the correct mixture amounts of binder (Maximum 4% Novocrete®) and the correct cement quantity it is also necessary to consider the chemical characteristics of each soil to determine if one should use SRC (Sulfate Resistant Cement) which again will vary the mixtures of binder additives to the existing soil.
Also, attempts must be made to introduce the material locally to make Novocrete® easily accessible to local contractors. Other areas the blending material, Novocrete® will be relevant are:

- Highway rehabilitation and new road construction
- Irrigation projects and erosion control
- Pipeline routes and distribution pipelines
- Ports, railway tracks and other infrastructure
- Dams and canals
- Walkways
- Logistic depots
- Environmental encapsulation

- Impermeable barriers

APPENDICES