Stabilization of active soils using nanomaterial: Effect on index properties and free swell

Amadise S Ogboin [1], **John A Trust God** [2*]
[1-2] Department of Civil Engineering, Faculty of Engineering, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

Corresponding Author: **John A Trust God**

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Abstract
In this study the effect of nanomaterial as an additive on the index properties of active soil with various water; nanomaterial mix ratios have been presented. Active soil samples containing mixtures of water to nanomaterial of 1:250, 1:200, 1:150, 1:100 and 1:50 was prepared and the shrinkage limit, liquid limit, plasticity index, plastic limit, and free swell index were conducted using common engineering standards. Statistical test results show significant effect on free swell at 95% confidence limit in addition of different proportions of nanomaterial to the active soil. Using nanomaterial as stabilizer decreases the index properties of soil except plastic limit. The results show that liquid limit, decreased from 63.2% - 47.9%, plasticity index dropped from 43.0% - 24% and shrinkage limit values dropped from 9.6% - 6.8% with increase in nanomaterial percentage respectively. However, plastic limit results obtained increased from 20.6% - 25.4% with the increase nanomaterial percentage. The test show that nanomaterials reduce the free swell, thus changed the swell potential from above average to moderate.

Keywords: Active soil, Nanomaterial, Stabilizer, Index Properties, free swell or swell potential

Introduction

The use of chemical admixtures to improve soil properties is the oldest and reliable means of ground stabilization for construction activities. According to Winterkorn and Pamukcu, (1990), soil stabilization is intending to improve and control stress-strain behaviour, permeability and durability. Active soil in southern region of Nigeria covers regularly flooded zone known as Niger Flood Zone as presented in the Figure 1. In these areas the high yearly precipitation is in surplus of 2000mm but the ground is almost flat consequently, obstructed drainage and inadequate laterization. The region as elucidated by Akpokodje (1987) [1] is characterized superficially by extremely active silty-clay and due to their characteristic in soak with water, swell and shrink when dry which cause critical surface distortions and structural failures. Quite a lot of efforts are being put forward to solve the swell-shrink behaviour of active soils by improving using admixture with adequate drainage system to guarantee good performance of road courses. Taha (2009) [9] described nanomaterial as organosilane mixture with non-functional organic alkyl group and trialkoxy groups.

The existence of active-soils is irreplaceable within the fresh water region of the Niger Delta and are consider to be unsuitable in their natural states for various construction purposes. To prevent the affluent transportation of suitable base material from a far distance for replacement which constitutes serious environmental challenges due to vast hips and borrow pits that take up vast regions. This study envisages the effect of nanomaterial as additive on the index properties of an active soil.

There are quite a number of studies on the use of stabilizing agents to enhance the behaviour of active soil. Arumala and Akpokodje (1987) [1] made an attempt to solve a problem stated that a road pavement engineered design involving of well consolidated and compacted sub grade/sub base would guarantee suitable performance and prevent the affluent transfer of improved base materials from long distances. Olurunfemi (1983) in relation with geotechnical problems in the road pavement, recommended the potential for lime stabilization and lime-cement mixtures. He concluded that swelling capacity of the soil specimens reduced with percentage increase of stabilizer, consequently increases the strength.

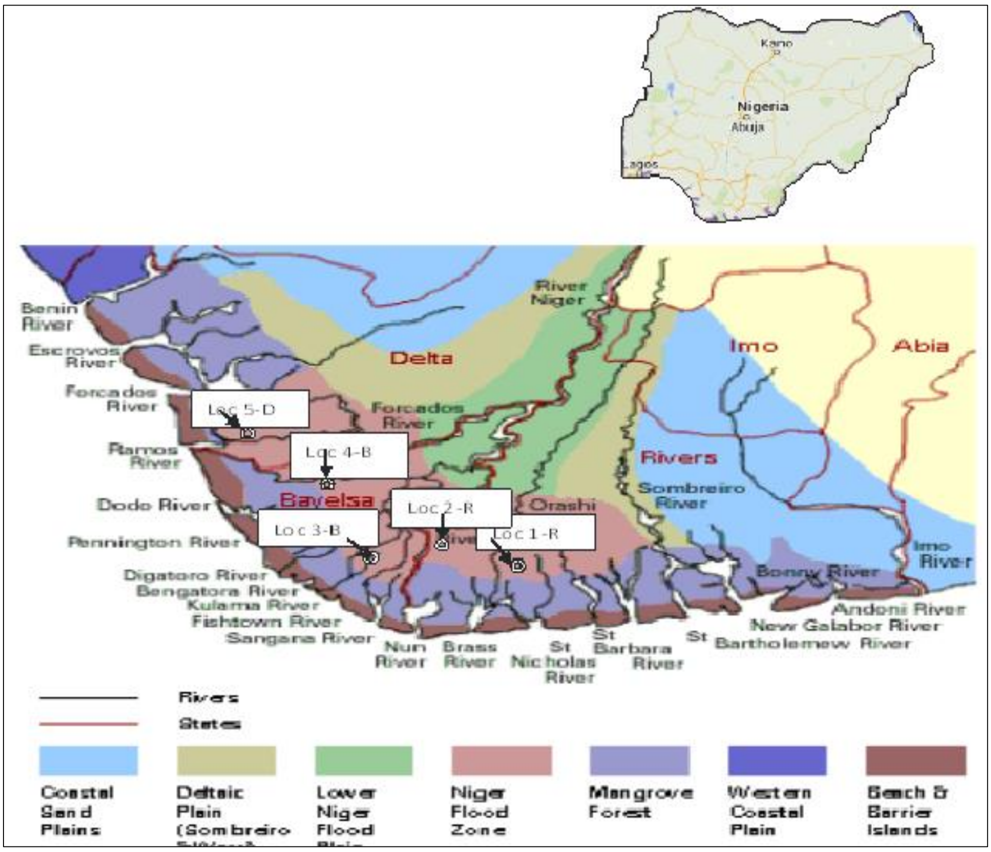

Fig 1: Active soil regions in Niger Delta, Nigeria

Ola (1983) [3, 4] studied the behaviour of the various mechanisms of stabilization. He found that as the plastic limit increases, liquid limit, linear shrinkage and plasticity index decreases for an increase in lime content. Similarly, the lime mainly averts the swelling of road base course while cement is to improve the capacity or strength of the road base. Omotosho and Ogboin (2008) studied the effectiveness of calcium chloride and calcium hydroxide (slaked- lime) on active soil. They concluded that stabilizing active soil with calcium chloride (CaCl2) reduces swelling significantly beyond required limit while cement addition was seen to enhance strength noticeably for road works.

2. Materials and Methods

2.1. Materials

The active soil samples employed in this investigation were sourced from five different Niger Flood Zone in Southern Nigeria. The locations include Atese and Mbiama in Rivers State, Opokuma and Kaima in Bayelsa State and Patani in Delta State as depicted in Figure 1. Samples studied were generally dark brown in colour with bluish grey mottling. They are predominantly of soft to stiff clays interceded with seams of fine sand. The nanomaterial used was sourced from a local vendor in Lagos. All test were conducted in geotechnical laboratory in the University of Nigeria, Nsukka where samples were sun-dried and pounded before subjecting to specified classification tests as well as gradation, Atterberg Limits (Liquid and Plastic Limit) and 24-h free swell as specified by Sridharan, *et al*. 1986) [8]. Figure 2 and Table 1 summarizes the classification test results of the untreated samples.

Percentage passing through sieve number 200 really increases from Delta State to Rivers State Location 1-R while in Location. 5-D, the percentage passing through sieve number 200 decreases from 95% to 74%. There was a constant decreased observed in plasticity starting from Rivers state towards Delta State in Location 1-R to Location 5-D. All the specimens from five (5) locations were classified as CH, (showing inorganic clay of high plasticity). Furthermore, all specimens were seen active because data of activity are over 1.25 indicating as organic alluvial clay and calcium mortimorillonite as specified by Barnes, (2000) [2]. Table 1 and Figure 2 depicted that clay content reduced from the Location 1-R down to Location 5-D. The modified free swell index for all the study locations could be referred to as high swelling potential as proposed by Sivapullaih *et al* (1987).

Table 1: Physical Properties of Studied Soil (Untreated)

Samples No	Location Name	NMC (%)	LL (%)	PI (%)	C (%)	A (%)	Soil Classification		24h Free Swell %
							USCS	AASHO	
Loc. 1-R	Atese Rivers State	26	63.2	42.6	31.6	1.35	CH	A-7	18.2
Loc. 2-R	Mbiama Rivers State	27	67.9	42.2	30.1	1.34	CH	A-7	17.6
Loc. 3-B	Opokuma Bayelsa State	23	56.0	38.9	28.2	1.38	CH	A-7	17.1
Loc. 4-B	Kiama Bayelsa state	24	61.0	37.5	26.2	1.43	CH	A-7	17.2
Loc. 5-D	Patani Delta State	19	51.0	31.9	24.9	1.28	CH	A-7	15.0

NMC, LL, C, A, PI are Moisture Content, Liquid Limit, Clay Content, Activity, Plasticity Index,

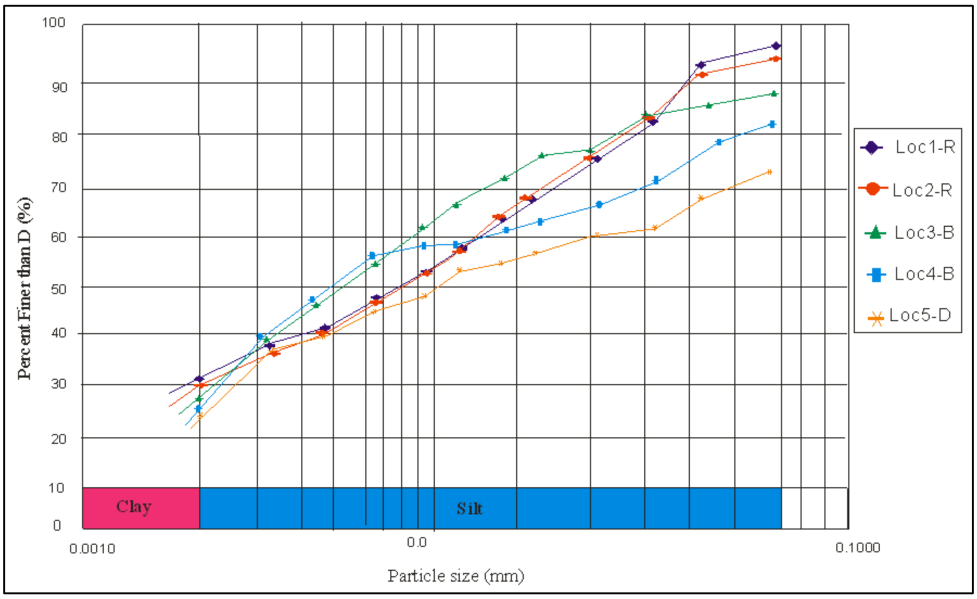

Fig 2: Grain Size distribution curves of Location Sample

2.2. Methods

The active soil was treated with nanomaterial and soaked for a period of 4days. Tests were conducted with different mixtures as specified below:

Table 2: Mixture for Experimental Study

Sample	Active Soil (%)	Water: Nanomaterial Ratio
Sample Loc. 1	100	-
1.250	100	1:250
1.200	100	1.200
1:150	100	1:150
1:100	100	1:100
1:50	100	1:50

Table 3: Gradation of Soil Samples Stabilized with Nanomaterial'

Sample No	Mix Proportion Water /Nano Ratio	Percentage passing sieve openings in millimeters											
		0.002	**0.003**	**0.004**	**0.006**	**0.009**	**0.013**	**0.019**	**0.024**	**0.03**	**0.04**	**0.05**	**0.06**
	0	31.6	39	42.2	47	53	58	64	67.8	76	82	93	94.7
	1:250	26.5	33.5	38.5	43	49	56	61.8	66	70	73	79	80
Loc 1- R	1:200	24.8	22	37	41.5	47	53	60	64	68	72	78	79
	1:150	21.9	29.8	35	39	46	52	58	53	67	72	76	77
	1:100	20.1	28	33	38	45	51	57	63	66	72	75	76
	1:50	18.9	26	30	36	32	50	55	60	63	68.5	72.5	73
	0	30.1	37	42	46.5	52	58	65	68	75	85.5	91.3	92
	1:250	25.4	33	38	43	48.5	55	61	66	71.5	73.5	78.5	79.5
Loc 2- R	1:200	22.2	29.5	36.4	41.5	47	55	59	64	69	73.5	78.5	79
	1:150	20.2	29	35	39	46	53	57	62	67	73.5	78.5	78
	1:100	18.2	26	31.5	36	43	50	54	58.5	64	68.5	72.5	73
	1:50	16.9	25	31	34	42	47	53	57	63	67.1	70	71.5
	0	28.2	37.1	47.2	54	62.1	67.6	71.9	76.8	78.2	82.1	85	89.4
	1:250	26.3	33.5	43.2	50.8	58.4	64	68.5	72.5	76.4	79	82	86.1
Loc 3- B	1:200	22.3	30.1	40.5	48	56	63	65.2	70	74.1	78.2	82	85
	1:150	26.7	28.4	36	43.2	52.8	60	63.1	65.5	70.1	73	75	76.4
	1:100	18.6	27	34.5	43	57	58.1	62.2	65.5	70.1	73	74	75
	1:50	17.6	26.7	33	42	50	57.6	61.5	64.2	69	72	73	74.5
	0	26.2	39	48	53	57.5	58.5	62.5	66.5	68.3	72.5	78.2	81
	1:250	23.8	37	44	49	52.5	57	60	62.5	66	70	74	76
Loc 4- B	1:200	19	30	42	48	50	52.2	57	60	63	68	71.5	73
	1:150	17.6	29	41	47	48.5	51	56	59	62	66	71	72.5
	1:100	14.2	23	30	38	42	47	51.1	53.5	56.2	59	66.2	66.9
	1:50	14	22	28	37	41	46	51	52	54.5	58	65	66
	0	24.9	38.1	42.5	44	48.5	52.8	55.2	57	60	63.1	68	74.2
	1:250	23.5	36	40	42	46.5	48.5	51.6	53.4	57.2	59	63	68.5
	1:200	22.1	26.8	29.7	32.5	34	37.8	40	43.7	47.2	50	52.8	54
Loc 5-D	1:150	20	25.6	28.9	30	33.5	36.7	39	42.1	46.3	48.7	51.2	53.1
	1:100	15.2	24.1	27.2	29	31.5	35.2	39	41.5	45.5	46.2	50	51.6
	1:50	13.2	23.4	27	28.2	30	34	38.2	41	44.3	46	49	51

Table 4: Properties of Specimens, Location

Sample		Clay (%)	Silt & fine sand (%)	LL	PL	PI	USCS	Activity	Swelling Potential	Shrinking limits
Loc 1	0	31.6	66	63	21	43	CH	1.4	High	9.6
	1:250	26.5	74	57	22	35	CH	1.3	High	9.1
	1:200	24.8	75	55	24	32	CH	1.3	High	8.7
	1:150	21.9	78	52	24	28	CH	1.3	High	8.2
	1:100	20.1	89	51	25	26	CH	1.3	High	7.5
	1:50	18.9	81	48	24	24	CL	1.3	Medium	6.8
Loc 2	0	30.1	68	60	20	42	CH	1.3	High	9.2
	1:250	25.4	75	54	21	33	CH	1.3	High	8.9
	1:200	22.2	78	51	23	28	CH	1.3	High	8.6
	1:150	20.2	80	51	25	26	CH	1.3	High	7.2
	1:100	18.2	82	49	26	23	CL	1.3	Medium	6.7
	1:50	16.9	83	47	26	21	CL	1.3	Medium	6.4
Loc 3	0	28.2	72	56	17	39	CH	1.4	High	10.2
	1:250	26.3	74	52	19	35	CH	1.3	High	9.8
	1:200	22.3	78	50	21	29	CH	1.3	High	9.6
	1:150	20.7	79	48	22	26	CL	1.3	High	8.4
	1:100	18.6	71	47	23	24	CL	1.3	Medium	7.6
	1:50	17.6	72	46	24	22	CL	1.2	Medium	6.8
Loc 4	0	26.2	74	61	24	38	CH	1.4	High	10
	1:250	23.8	76	59	28	31	CH	1.3	High	9.1
	1:200	19	81	53	29	24	CH	1.3	Medium	7.4
	1:150	17.6	82	52	30	22	CL	1.3	Medium	6.7
	1:100	14.2	86	49	30	18	CL	1.3	Medium	6.4
	1:50	14	86	48	30	18	CL	1.3	Medium	6.2
Loc 5	0	24.9	74	51	17	32	CH	1.3	High	8.6
	1:250	23.1	77	50	21	29	CH	1.3	High	7.8
	1:200	22.6	78	50	21	28	CH	1.3	High	7.6
	1:150	20.5	80	47	21	26	CL	1.3	High	6.5
	1:100	16.4	84	45	25	21	CL	1.3	Medium	6.3
	1:50	13.9	86	44	27	17	CL	1.2	Medium	5.8

Table 5: Summary of 24 Hours Free Swell Test

Sample No	Location	Nano- Material Dilution Ratio	W_s (g)	G_s	$\gamma_{w\,(g/cm^3)}$	$V_{s\,(cm^3)}$	V (cm³)	Modified free swell index (sf)	Swelling potential (sw)
Loc1-R	Rivers Atese	0	10ee	2.63	1	3.92	52.7	18.2	High
		1:250	10	2.65	1	3.86	50.8	17.7	High
		1:200	10	2.63	1	3.92	48.6	17.0	High
		1:150	10	2.60	1	3.97	40.1	13.9	High
		1:100	10	2.56	1	4.21	36.2	12.5	High
		1:50	10	5.45	1	4.96	28.7	9.7	moderate
Loc2-R	Rivers Mbiama	0	10	2.68	1	3.84	51.0	17.6	High
		1:250	10	2.66	1	3.91	49.2	17.0	High
		1:200	10	2.62	1	4.00	44.0	15.3	High
		1:150	10	2.57	1	4.21	39.3	13.7	High
		1:100	10	2.50	1	4.53	26.1	8.6	moderate
		1:50	10	2.42	1	4.92	21.7	6.9	moderate
Loc 3-B	Bayelsa Opokuma	0	10	2.65	1	3.92	49.1	17.1	High
		1:250	10	2.61	1	3.99	46.5	16.3	High
		1:200	10	2.58	1	4.21	40.0	13.9	High
		1:150	10	2.56	1	4.43	33.2	10.2	High
		1:100	10	2.52	1	4.62	28.3	9.4	moderate
		1:50	10	2.50	1	4.71	25.1	8.2	moderate
Loc 4-B	Bayelsa Kiama	0	10	2.57	1	3.92	48.2	17.2	High
		1:250	10	2.54	1	4.31	45.7	16.3	High
		1:200	10	2.52	1	4.68	36.2	12.5	High
		1:150	10	2.48	1	4.74	28.1	9.4	moderate
		1:100	10	2.41	1	4.82	25.4	8.5	moderate
		1:50	10	2.70	1	4.90	22.0	7.2	moderate
Loc5-D	Rivers Mbiama	0	10	2.56	1	3.71	42.1	15.0	High
		1:250	10	2.51	1	4.28	36.3	12.8	High
		1:200	10	2.48	1	4.42	32.8	11.4	High
		1:150	10	2.40	1	4.53	25.4	9.4	moderate
		1:100	10	2.35	1	4.61	23.0	8.6	moderate
		1:50	10	2.32	1	4.68	21.2	7.9	moderate

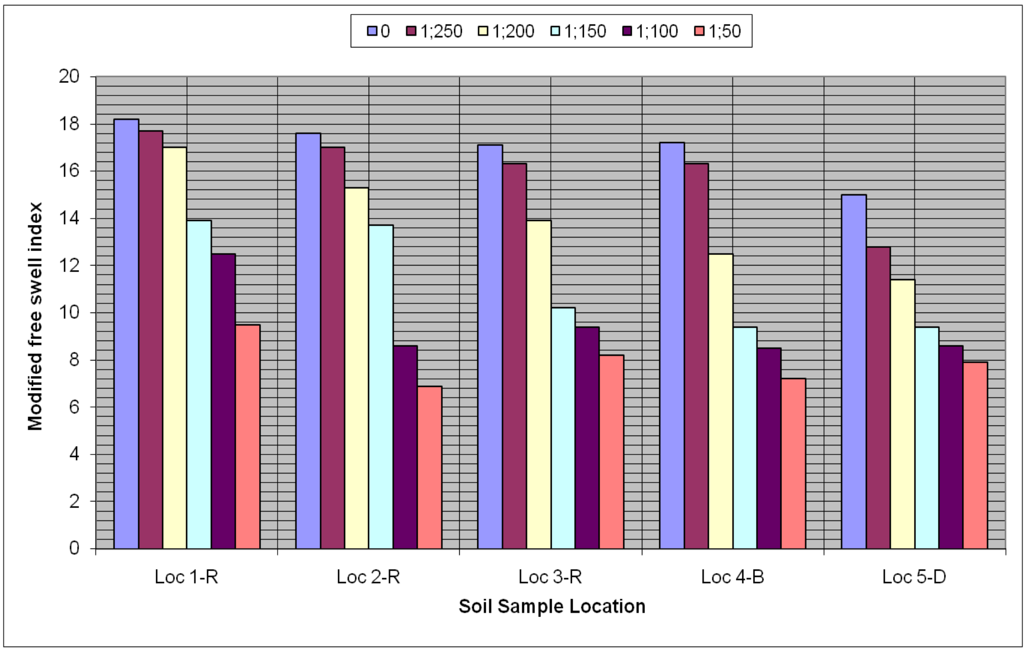

Fig 3: Modified free Swell Index against Soil sample location

3. Results and Discussion

The test results for gradation, Atterberg limits and free swell are summarized in Tables 3-5 The effect of stabilizer and percentages variations in the consistency limits and modified free Swell index are shown in Table 8-9 and Figure 3 respectively. All the location samples revealed significant enhancements with the addition of nanomaterial. The data obtained from the investigation depicted that Liquid Limit, Plastic Limit, Shrinkage Limit, and plasticity index for Location 1-R enhanced approximately by 9.5, 7.3, 5.2 and 18.1% respectively for a 1:250 ratio of nanomaterial dilution with liquid (water). Similar development was obtained in all the soil specimens as presented in Table 6 and 7.

Also, from Table 6, the changes (clays) in the swell shrink of soil after the application nanomaterial at 1:50 ratio of dilution, the activity value shifted from high to medium for Location 1 and 2. Correspondingly, the same variation in site swell shrink level from high to medium was seen from Location 2 at nanomaterial dilution ratio 1:100. The effect of flocculation and aggregation phenomena is predominant and can be adduced for these results.

As specified by Skempton (1953), the swell shrink (activity) of studies soil range from 1.25 -1.35 in all the studied areas indicating the soils are active. They have the same mineral levels that refer them as organic alluvial clay and calcium montmorillonite (Barnes, 2000) [2]. Table 6 summarizes the nanomaterial dilution levels that attain the least acceptable variation in each study location.

Table 6: Effect of Stabilizer on Classification

Loc. No	Sample Location	Stabilizer Content	Change In Property	
			Activity	USCS
LOC 1 –R	Rivers -ATESE	1:50	1.25	CL
LOC 2-R	Rivers - Mbiama	1:100	1.25	CL
LOC 3-B	Bayelsa- Opokuma	1:100	1.25	CL
LOC 4-B	Bayelsa - Kiama	1:150	1.25	CL
LOC 5-D	Delta- Patani	1:150	1.25	CL

Table 7: Properties of Samples from various Locations

Sample	Clay (%)	Silt& Fine Sand (%)	Ll	PL	PI	USCS	Activity	Swelling Potential	Shrinking Limit
Loc 1	31.6	66.4	63.2	20.6	42.6	CH	1.35	High	9.6
1:250	26.5	73.6	57.0	22.1	34.9	CH	1.32	High	9.1
1:200	24.8	75.2	55.0	23.7	32.1	CH	1.29	High	8.7
1:150	21.9	78.1	52.0	24.2	27.8	CH	1.27	High	8.2
1:100	20.1	89.1	50.9	25.4	25.5	CH	1.26	High	7.5
1:50	18.9	81.1	47.9	24.4	23.6	CH	1.25	Medium	6.8
Loc 2	30.1	67.9	60.4	20.2	42.2	CH	1.34	High	9.2
1:250	25.4	74.6	54.2	21.1	33.1	CH	1.30	High	8.9
1:200	22.2	77.8	51.3	23.0	28.3	CH	1.28	High	8.6
1:150	20.2	79.8	50.9	25.4	25.5	CH	1.26	High	7.2
1:100	18.2	81.8	48.5	25.6	23.0	CH	1.25	Medium	6.7
1:50	16.9	83,1	47.2	26.0	21.2	CH	1.25	Medium	6.4

The Atterberg Limits confirm variations in plasticity features of the treated and untreated soil specimens. It could be seen from Table 7 above, an increase in the nanomaterial stabilizer led to the decrease in activity, liquid limit, plasticity index, shrinking limits. An increase in nanomaterial content also led to an increase in the plastic Limit.

Positive ion (Cation) exchange reactions developing in the cluster and flocculation of soil elements with reduction in value of clay-particle material and subsequently, the surface area of the soil which unavoidable quantity for reducing plasticity (Terzaghi and Peck 1967).

Figure 3 shows that the 24-hr free swell decreases with an increase in nanomaterial addition. It's possible that this is as a result of chemical reaction. The stabilizing agent (nanomaterial) was efficiently absorbing the soaked water producing swelling at the face-face boundary and probably close up the boundary as such water entrance is avoided, also the nanomaterial attracts and absorbs the penetrating water in an irretrievable reaction, forming additional stable and lasting precipitation to close up the plate-to-plate interface. That is to say;

$$Ca_2^+ + O_2 + H_2O = Ca\,(OH)_2 \quad (1)$$

In terms of mineralogy, the bivalent Ca2+ion replaces and forms the monovalent K+ ions and Na right away. This clarifies the soils' improved physical and mechanical qualities (Lambe and Whitman, 1969 and Zydex Industries, 2012). Table 8 illustrates Sivapulliaiah's (1987) recommendation of a maximum tolerable 24-hour free swell of roughly 2.5 percent (1987).

Table 8: Nanomaterial content for 2.5% free swell (24-hrs).

Samples No	Sample's location	Nanomaterial /water ratio	Swelling Potential
Loc 1-R	Rivers-Atese	1:50	Moderate
Loc 2-R	Rivers -Mbiama	1:100	Moderate
Loc 3-B	Bayelsa - Opokuma	1:100	Moderate
Loc 4-B	Bayelsa Kiama	1:150	Moderate
Loc 5-D	Delta - Patani	1:150	Moderate

Finally, statistical test was performed on the discussed free swell. The statistical test involves studying the data of the soil samples before and after the addition of nanomaterial, comparing the level of significance of the change after treatment. The analysis of variance (ANOVA) test was done at 95% confidence. The results of the test with observation and/or comments are shown in Table 9 below.

Table 9: ANOVA on Free Swell

Source of Variation	SS	d_f	M_S	F	P-value	F_{crit}
Between Groups	328.5267	5	65.70533	20.41912	6.13E-08	2.620654
Within Groups	77.228	24	3.217833			
Total	405.7547	29				

Comment: Since the value of F (20.42) is greater than Fcritical (2.62) then the addition of different proportions of nanomaterial to the soil has significant effect on free swell at 95% confidence limit. Finally, analysis of variance (ANOVA) study done at 95% confidence, validating the effect of stabilizing agent (nanomaterial) to decrease the swelling behaviour.

Table 10: ANOVA on Water Absorption

Source of Variation	SS	df	M_S	F	P-value	F_{crit}
Between Groups	502.6427	5	100.5285	6.784141	0.000451	2.620654
Within Groups	355.636	24	14.81817			
Total	858.2787	29				

4. Conclusions

Founded on the results of the current examination on the active soil strengthened with nanomaterial, the following deduction can be established:

- The liquid limit reduced with increasing nanomaterial mix ratio.
- The used of nanomaterial increased the Plastic limit.
- The shrinkage limit reduced with increasing nanomaterial mix ratio.
- With the inclusion of a nanomaterial stabilizer, the modified free swell decreased, and the swell potential was changed from high to moderate.

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