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Effects of Soil-Cement Stabilization on the Index Properties of Subgrades of Three Selected Roads in the Niger Delta Region of Nigeria

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Abstract

In this study, the impact of soil-cement stabilization on the index properties of the subgrade of roads was investigated. Efforts were on the means of improving the bearing capacity of the subgrade of a flexible pavement structure. Three selected roads (Ogbia-Nembe, section of the East-West Road and section of Port Harcourt-Aba Road) in the Niger Delta Region of Nigeria were examined to determine the effect of sand-cement stabilization on the compaction index property of their undisturbed subgrade and the optimal ratio of soil-cement on the expansive soils at which the California Bearing Ratio (CBR) is optimized. Disturbed soil samples were collected from twenty trial pits on each of the three study roads using a hand ulger and tested for their respective compaction index properties. It was discovered that their California Bearing Ratio (CBR) was very low. Some of the collected specimen materials were stabilized with varying percentages of soil-cement contents ranging from 6% - 14% in order to ascertain its effects on the compaction index properties of the sample soils. Results of the various stabilization test procedures show that: Stabilization of the soil using Soil-Cement Stabilization affected the Compaction Index properties of the soil and further improved the California Bearing Ratio (CBR). On the Ogbia-Nembe Road; Soil-Cement stabilization improved the CBR and is optimized at a 10% sand-cement ratio with optimum moisture content ranging from 6.2% - 14%, maximum dry density ranges from 1700 - 1780 kg/m^3, yielding an average CBR of 42.7% for soaked samples. On the section of East-West Road from Eleme Junction to Etteh Junction; Soil-Cement stabilization improved the CBR and is optimized at a 14% sand-cement ratio with optimum moisture content ranging from 6.2% - 14.2%, maximum dry density ranges from 1660 - 1800 kg/m^3, yielding an average CBR of 43.9% for soaked samples. On the section of Port Harcourt-Aba Express Road from Eleme Junction to Osisioma Junction;

Soil-Cement stabilization improved the CBR and is optimized at a 12% sand-cement ratio having an optimum moisture content ranging from 5.4% - 17.3%, maximum dry density ranges from 1610 - 1740 kg/m^3, and an average California Bearing Ratio for soaked samples at 40%.

Keywords

Soil-Cement Stabilization, Expansive Soils, Maximum Dry Density, Disturbed Soil Samples, Index Properties, Optimum Moisture Content

1. Introduction

The long-term performance of flexible pavement structures depends largely on the quality of road materials that carry the traffic-imposed load on the pavement. Every imposed load on a road pavement structure is transmitted to the subgrade which by extension is the foundation of a road structure [1]. The extent to which a pavement structure can sustain the imposed load on it without failing is therefore dependent on the index properties of the subgrade on which the road pavement structure is built. Every engineering structure is proposed to be sited on stable soil which is able to withstand the load and for this, every road is designed to have a subgrade with soil of acceptable load-bearing capacity [2]. According to [3], soils that fail to meet the recommended standards for construction of flexible pavement in terms of load-bearing capacity require improvement in their engineering properties. The Niger Delta region of Nigeria is a region characterized by the soil of dynamic index property [4], as a result of their unstable water table which indirectly affects their moisture content and also impacting on the high clay content. The presence of clay material in subgrade makes the subgrade soil vulnerable to failure by swelling and shrinkage [5].

According to [6], soils that have properties which cannot be safely and economically used for road construction without improvement are called problem soils. Consequently, to ensure that road pavement structures, which are considered as the most important of all public assets [7] do not fail earlier than their design life, adequate measures are being considered to improve the overall bearing capacity of the soil either by direct replacement or stabilization. Soil stabilization is the process of improving the physical and engineering properties of soil with a view to obtaining some predetermined targeted bearing capacity on the soil. In this paper, the option of sand-cement stabilization was explored along the failed sections of the Ogbia-Nembe, East-West and Port Harcourt-Aba Road in order to ascertain its effectiveness on the index properties of road material.

2. Methodology

2.1. Study Area

The specific study roads are Ogbia-Nembe in Bayalsa State, A section of East

West Road from Eleme Junction to Akwa Ibom, and Section of Port Harcourt-Aba expressways from Eleme Junction to Osisioma Junction Aba, Abia State; all of which are located in within the Niger delta region of Nigeria. The Niger delta lies along the delta of the Niger River and considered sitting directly on the Gulf of Guinea on the Atlantic Ocean transversing Nigeria. It is rich in oil mineral deposit and therefore plays a vital role in the economy of Nigeria. States within this study region includes Abia, Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Imo Ondo, and Rivers and are otherwise identified as the Nine (9) Niger Delta state (See **Figure 1**). According to available records, the Niger Delta extends over about 112,000 kms and constitutes 7.5% of the Nigerian landmass considering the size of the nine states that forms part of the region. The region lies within the geographical coordinates of Latitude 5˚19'20.40"N and Longitude 6˚28'8.99"E and made up of various ethnic tribes notable among which includes Itsekiri, Urhobo, Isoko, Ijaw, Ogbia, Kalabari, Ahua, Ibani, Andoni, Ogoni, Ikwerre, Ndoki, Omuma, Ogba Egbema, Etche, Esan, Bonny Ukwani, Auchi, Esako Igara, Ilaje, Igbo, Ibibio among others. **Figure 2** shows three study alignments on any enlarged map of the region.

2.2. Materials and Methods

Disturbed soil samples were collected at equal depths (0.3 m - 1.3 m) at twenty points along the failed sections of each of the study alignments viz: Ogbia-Nembe road, the study section of East-West Road and study section of Port

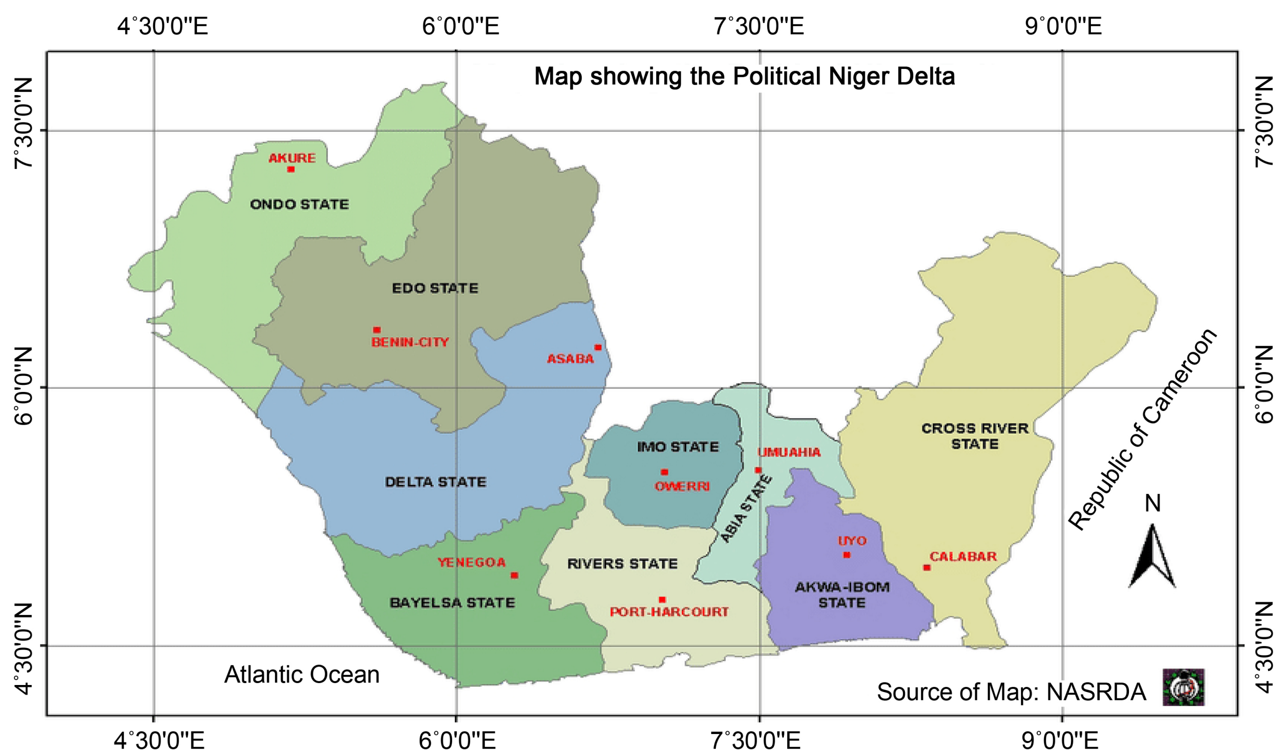

Figure 1. Map showing states in the Niger delta region of Nigeria.

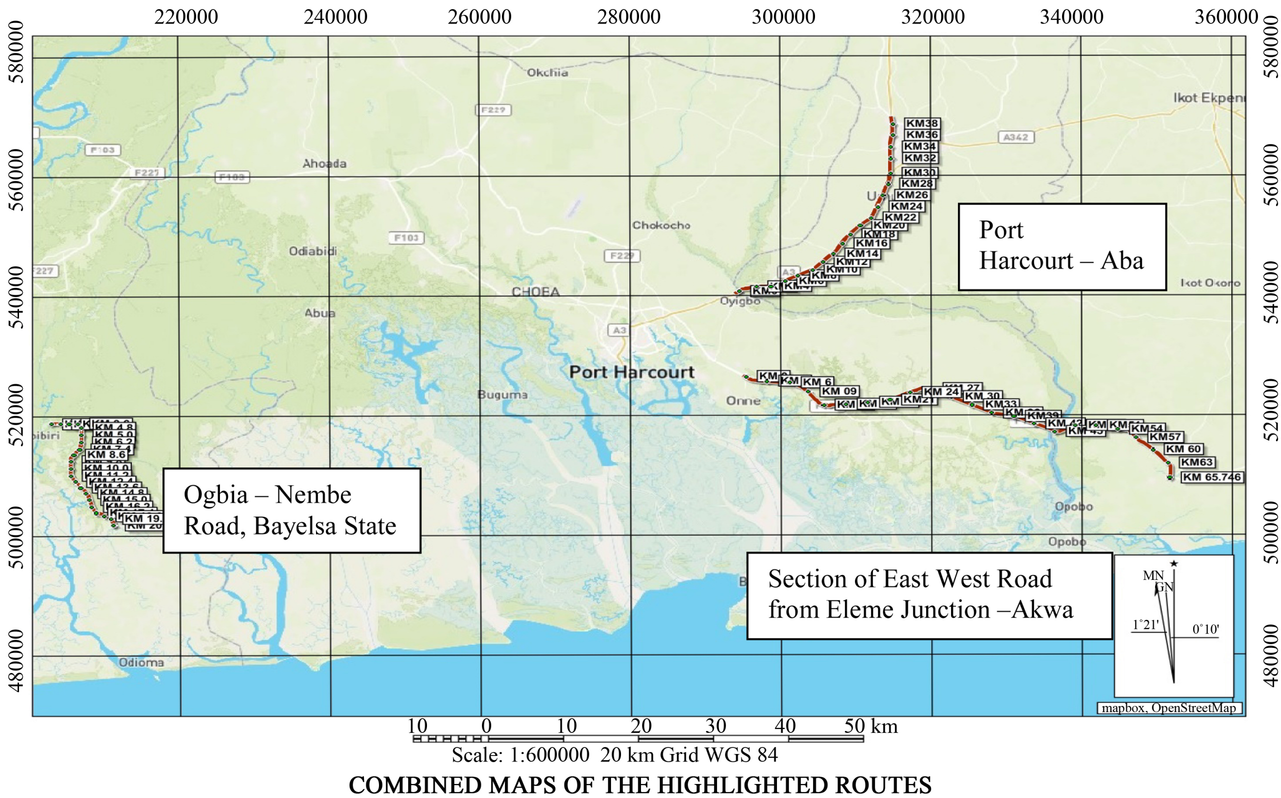

Figure 2. Map showing the three selected alignments for the study [8].

Harcourt-Aba Road at different chainages below the pavement surface using hand Alger.

Laboratory test investigations was carried out on the collected soil samples which included; Standard Compaction Test, and California Bearing Ratio (CBR) Test. Results obtained from these experimental tests formed part of the data used in this research. 3 kg of dry soil sample was used to carry out compaction test. From the compaction test carried out, the optimum moisture content of the soil was determined and the CBR value of the soil corresponding to this optimum moisture content was determined. The soil was stabilized by adding 6%, 8%, 10%, 12% and 14% of cement by weight to the collected soil samples. After stabilization, the laboratory tests were carried out to determine the new index properties of the soil samples.

3. Results

Tables 1-3 showed the result of the Standard Compaction test and the CBR of the untreated soil samples obtained from the respective study alignments. The 20 sample points which were divided into five sub-sections on each of the three selected roads are labelled A, B, C, D and E from Table 1. From it, the untreated soil samples from Ogbia-Nembe Road in sections A, B, C, D, and E had CBR values of 26.6%, 17.7%, 27.0%, 30.4%, and 15.1% respectively. The untreated soil samples from Section of the East-West Road in sections A, B, C, D, and E had

Table 1. Result of the geotechnical investigation on Ogbia-Nembe road.

Geotechnical Investigation Result on Ogbia-Nembe Road										
Point	Atterberg Limit				Moisture Content %	Specific Gravity.	Standard Compaction		California Bearing Ratio (CBR) (%)	
									CBR Soaked	
	SEC. DIV.	Plastic Limit (%)	Liquidity Limit (%)	Plasticity Index			Maximum Dry Density (g/cm³)	Optimum Moisture Content (OMC) %	Av. Moisture Content (%)	CBR Value (%)
1	A	29	54	25	17.00	2.61	1.68	8.50	9.2	26.6
2		12	22	10	15.00	2.62	1.74	8.80		
3		33	55	20	16.80	2.6	1.67	10.70		
4		11	22	9	19.40	2.62	1.67	8.60		
5	B	37	63	26	15.20	2.61	1.70	11.20	10.7	17.7
6		32	62	30	29.80	2.6	1.62	12.80		
7		25	46	21	13.20	2.63	1.66	10.30		
8		26	46	20	15.10	2.62	1.71	8.50		
9	C	26	52	26	20.60	2.61	1.60	13.90	14.2	27
10		30	56	26	14.10	2.61	1.66	14.10		
11		32	62	30	23.30	2.61	1.72	14.40		
12		29	49	20	20.00	2.59	1.68	14.60		
13	D	34	60	26	14.70	2.62	1.69	13.90	14.6	30.4
14		32	63	31	16.30	2.61	1.73	14.10		
15		30	58	28	19.20	2.58	1.68	15.20		
16		24	40	16	22.10	2.59	1.80	15.20		
17	E	25	45	20	19.20	2.58	1.84	14.40	16.5	15.1
18		28	41	23	18.50	2.53	1.77	18.20		
19		30	54	24	52.20	2.55	1.82	16.20		
20		23	46	23	46.20	2.56	1.79	17.20		

Table 2. Result of the geotechnical investigation on section of East-West road.

Geotechnical Investigation Result on Ogbia-Nembe Road										
Point	Atterberg Limit				Moisture Content %	Specific Gravity.	Standard Compaction		California Bearing Ratio (CBR) (%)	
									CBR Soaked	
	SEC. DIV.	Plastic Limit (%)	Liquidity Limit (%)	Plasticity Index			Maximum Dry Density (g/cm³)	Optimum Moisture Content (OMC) %	Av. Moisture Content (%)	CBR Value (%)
1	A	43	62	19	30.60	2.56	1.8	12.00	14.0	4.5
2		22	45	23	33.70	2.52	1.86	14.10		
3		20	41	21	29.90	2.49	1.82	16.00		
4		23	46	23	27.10	2.53	1.83	13.90		
5	B	34	66	32	31.20	2.51	1.77	14.10	16.0	6.3
6		20	26	6	16.60	2.49	1.86	16.00		
7		20	40	20	30.90	2.47	1.75	18.30		
8		26	43	17	28.20	2.49	1.78	15.60		
9	C	27	46	19	29.50	2.48	1.78	15.60	16	5.1
10		23	46	23	31.70	2.51	1.80	14.00		
11		21	42	21	30.30	2.49	1.85	16.20		
12		25	50	25	34.80	2.42	1.76	18.30		
13	D	23	45	22	29.00	2.47	1.76	18.30	14.0	2.5
14		25	47	22	31.90	2.54	1.76	12.30		
15		34	67	33	33.10	2.51	1.83	14.30		
16		36	64	28	34.50	2.47	1.71	16.40		
17	E	33	60	27	46.90	2.58	1.71	9.70	10.5	10.4
18		31	65	34	34.20	2.59	1.70	8.10		
19		32	61	29	50.30	2.56	1.82	10.10		
20		35	60	25	46.70	2.55	1.76	12.20		

Table 3. Result of the geotechnical investigation on section of port Harcourt-Aba road.

Geotechnical Investigation Result on Port Harcourt-Aba Road										
Point	Atterberg Limit				Moisture Content %	Specific Gravity.	Standard Compaction		California Bearing Ratio (CBR) (%)	
									CBR Soaked	
	SEC. DIV.	Plastic Limit (%)	Liquidity Limit (%)	Plasticity Index			Maximum Dry Density (g/cm^3)	Optimum Moisture Content (OMC) %	Av. Moisture Content (%)	CBR Value (%)
1	A	27	55	28	34.20	2.53	1.8	12.00	13.0	9.2
2		30	54	24	37.10	2.55	1.77	11.20		
3		26	43	17	32.70	2.51	1.82	13.10		
4		26	44	18	32.50	2.45	1.73	15.20		
5	B	19	38	19	30.80	2.49	1.74	14.30	15.0	5.0
6		32	56	24	34.10	2.49	1.76	13.40		
7		33	53	20	36.20	2.42	1.83	15.30		
8		23	45	22	36.90	2.37	1.67	17.20		
9	C	26	52	26	30.90	2.55	1.72	11.50	13	3.5
10		28	54	26	30.80	2.54	1.71	11.30		
11		31	51	20	31.00	2.5	1.80	13.20		
12		30	49	19	33.30	2.41	1.62	15.30		
13	D	25	46	21	31.20	2.43	1.70	15.30	15.0	8.9
14		27	46	19	33.30	2.41	1.71	13.30		
15		28	53	25	40.40	2.46	1.85	15.10		
16		29	55	26	32.60	2.38	1.66	17.10		
17	E	31	64	33	33.70	2.41	1.76	15.70	16	4.5
18		31	52	21	30.00	2.47	1.66	14.20		
19		39	64	25	33.50	2.4	1.83	16.10		
20		29	61	32	38.10	2.35	1.62	18.20		

CBR values of 4.5%, 6.3%, 5.1%, 2.5%, and 10.4% respectively, while the untreated soil samples from Section of Port Harcourt-Aba Express Road in sections A, B, C, D, and E had CBR values of 9.2%, 5.0%, 3.5%, 8.9%, and 4.5% respectively. Table 4 Shows the result of the Geotechnical Test of Sand-Cement Improved Subgrade material from the three Study locations at different proportions of Sand-Cement Ratios.

Table 4. Result of the geotechnical test of sand-cement improved Subgrade material from the three study locations.

Geotechnical Investigation Result on Section of Ogbia-Nembe Road for Improved Soil Sample				Geotechnical Investigation Result on Section of Ogbia-Nembe Road for Improved Soil Sample				Geotechnical Investigation Result on Section of Ogbia-Nembe Road for Improved Soil Sample			
Sample Point	Standard Compaction		California Bearing Ratio (CBR) (%)	Sample Point	Standard Compaction		California Bearing Ratio (CBR) (%)	Sample Point	Standard Compaction		California Bearing Ratio (CBR) (%)
	Maximum Dry Density (g/cm³)	Optimum Moisture Content (OMC) %	Soaked CBR Value (%)		Maximum Dry Density (g/cm³)	Optimum Moisture Content (OMC) %	Soaked CBR Value (%)		Maximum Dry Density (g/cm³)	Optimum Moisture Content (OMC) %	Soaked CBR Value (%)
At 6% Cement Content on a sand-cement stabilization				At 10% Cement Content on a sand-cement stabilization				At 10% Cement Content on a sand-cement stabilization			
A	1.66	8.30	27.30	A	1.56	9.30	26.40	A	1.52	10.30	31.00
B	1.74	10.10	21.80	B	1.69	11.20	28.10	B	1.68	12.00	33.10
C	1.78	12.30	29.70	C	1.78	13.10	36.80	C	1.75	14.20	32.00
D	1.71	14.30	31.30	D	1.74	15.20	31.30	D	1.67	16.10	36.00
E	1.62	16.20	17.30	E	1.58	17.20	32.40	E	1.52	18.30	36.40
At 8% Cement Content on a sand-cement stabilization				At 12% Cement Content on a sand-cement stabilization				At 12% Cement Content on a sand-cement stabilization			
A	1.59	6.20	33.40	A	1.61	8.40	38.60	A	1.61	9.20	38.70
B	1.69	8.20	29.80	B	1.76	10.30	38.10	B	1.69	11.30	39.20
C	1.70	10.20	33.70	C	1.84	12.10	43.20	C	1.74	13.20	37.60
D	1.63	12.00	35.20	D	1.73	14.10	39.90	D	1.67	15.30	41.90
E	1.49	14.20	29.20	E	1.61	16.00	44.40	E	1.57	17.30	42.80
At 10% Cement Content on a sand-cement stabilization				At 14% Cement Content on a sand-cement stabilization				At 14% Cement Content on a sand-cement stabilization			
A	1.64	6.20	43.00	A	1.66	6.20	42.10	A	1.65	5.40	42.30
B	1.70	8.30	42.60	B	1.78	8.20	43.60	B	1.70	7.30	41.70
C	1.73	10.10	43.30	C	1.86	10.10	44.80	C	1.72	9.40	39.00
D	1.65	12.20	45.20	D	1.80	12.20	40.90	D	1.67	11.30	35.10
E	1.58	14.00	39.40	E	1.64	14.20	48.20	E	1.61	13.10	45.20

4. Discussion

4.1. Results of the Standard Compaction Test and the CBR of the Untreated Soil on the Three Locations

From the result of the Standard Compaction test and the CBR of the untreated soil samples obtained from the respective study alignments on **Tables 1-3**; the untreated soil samples from Ogbia-Nembe Road in sections A, B, C, D, and E had CBR values of 26.6%, 17.7%, 27.0%, 30.4%, and 15.1% respectively. Section of the East-West Road at sections A, B, C, D, and E had CBR values of 4.5%, 6.3%, 5.1%, 2.5%, and 10.4% respectively, while the Section of Port Harcourt-Aba Express Road in sections A, B, C, D, and E had CBR values of 9.2%, 5.0%, 3.5%, 8.9%, and 4.5% respectively. These values signify low CBR values on each of the five sub-sections of the separate three selected roads [9] making the soil unfit for road engineering work purpose. In order to make the soil good for engineering work purpose, the option of stabilization or replacement of the soil may be considered [10]. This resulted to the stabilization of the soil to improve the CBR of the soils using cement content of different percentages in each section. The results of the stabilization various percentage cement contents are tabulated in **Table 4** for the various sub-sections of the three study road alignment.

4.2. Results of Soil Stabilization from the Three Road Locations

The outcome of the soil to improve process on the CBR of the soil was done using cement content of different percentages in each section and are as follows:

Stabilization results of the soil sample collected from the Ogbia-Nemeb Road with 6%, 8%, and 10% cement content is presented in **Figure 3**. From **Figure 3**, it can be seen that CBR Value of the untreated soil samples in sections A, B, C, D, and E improved as follows: Stabilization with 6% cement content increases the CBR value in each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 27.3%, 21.8%, 29.7%, 31.3% and 17.3% as against the CBR value of the untreated soil, representing the following percentage increment 2.63%, 23.16%, 10%, 2.96% and 14.57% respectively. From **Figure 4**, it can be seen that the average percentage increase in the soil CBR for all five (5) sections was 10.66%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in Ogbia-Nembe with 6% cement content will increase the CBR value by about 11%. Similarly with 8% cement content stabilization as shown in **Figure 5**, each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 33.4%, 29.8%, 33.7%, 35.2%, and 29.7% as against the CBR value of the untreated soil, representing the following percentage increment 25.56%, 68.36%, 24.81%, 15.79% and 96.69% respectively.

From **Figure 5**, it can be seen that the average percentage increase in the soil CBR for all the five (5) sub-sections was 46.24%. The result gives an indication

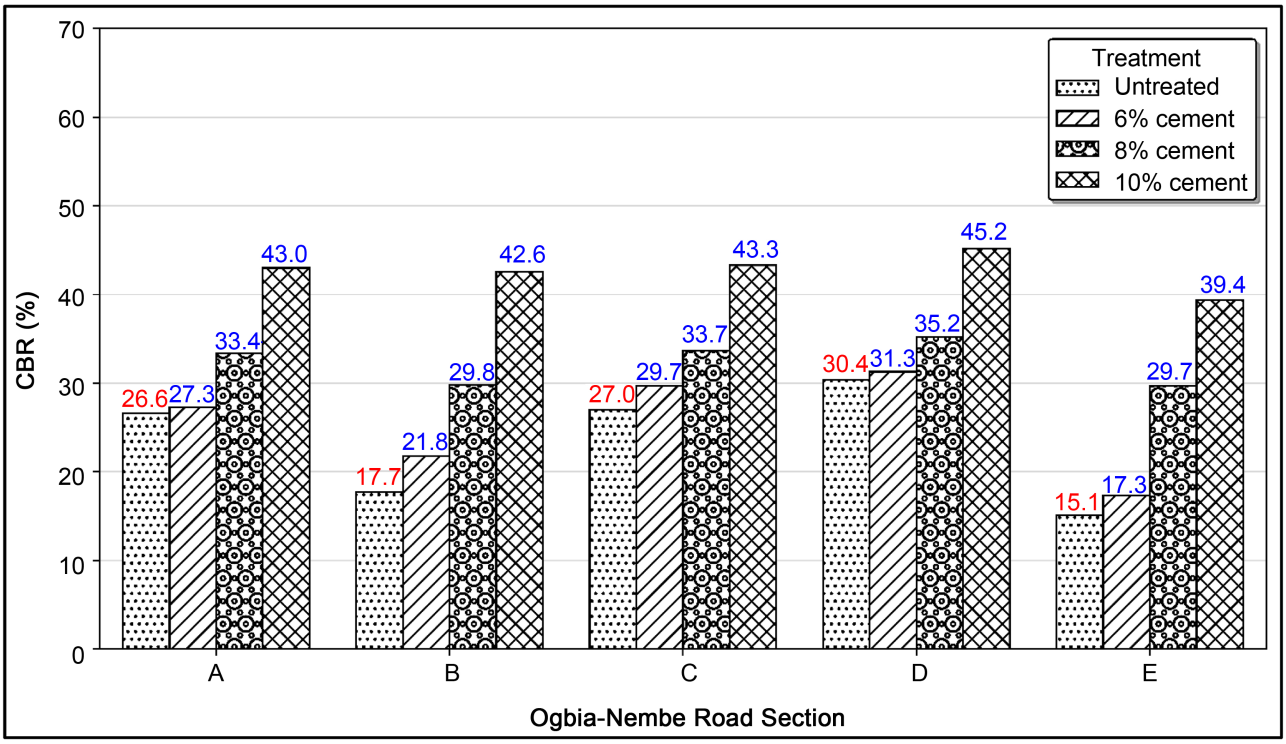

Figure 3. California bearing ratio for various section of Ogbia-Nembe road section before and after stabilization with cement content.

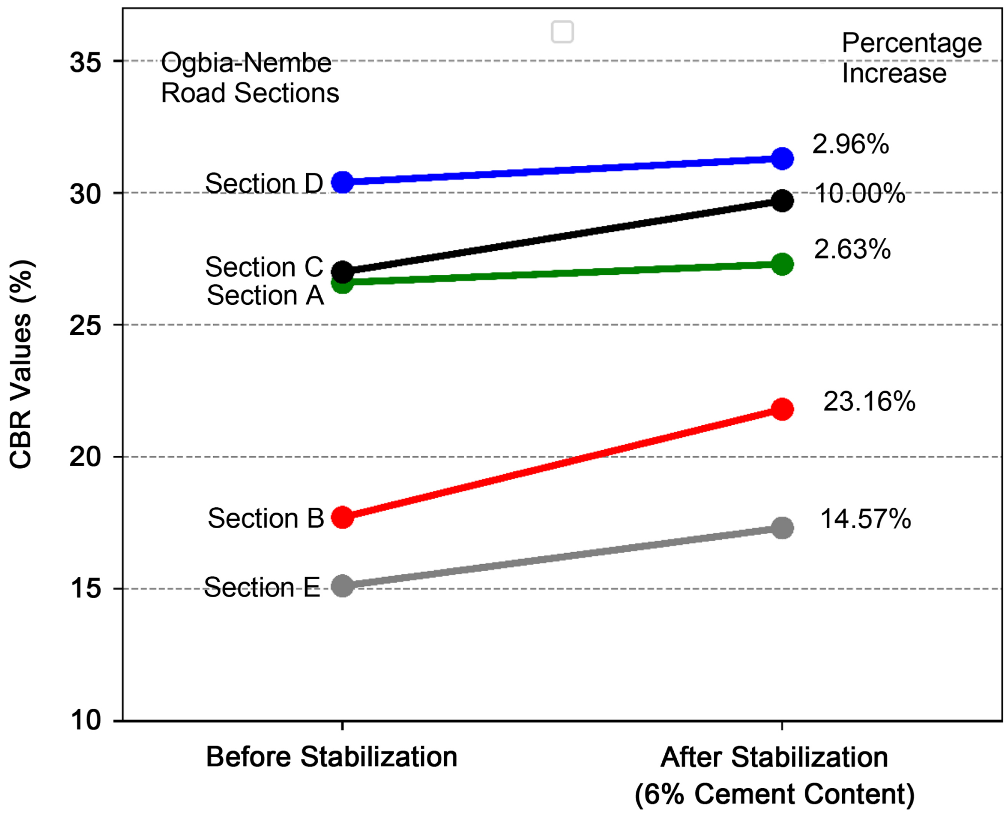

Figure 4. Percentage increase in the CBR after Stabilization with 6% cement content.

that stabilization of the soils which have similar soil index properties as those found in Ogbia-Nembe with 8% cement content will increase the CBR value by about 46%. Again with 10% cement content stabilization as shown in **Figure 6**,

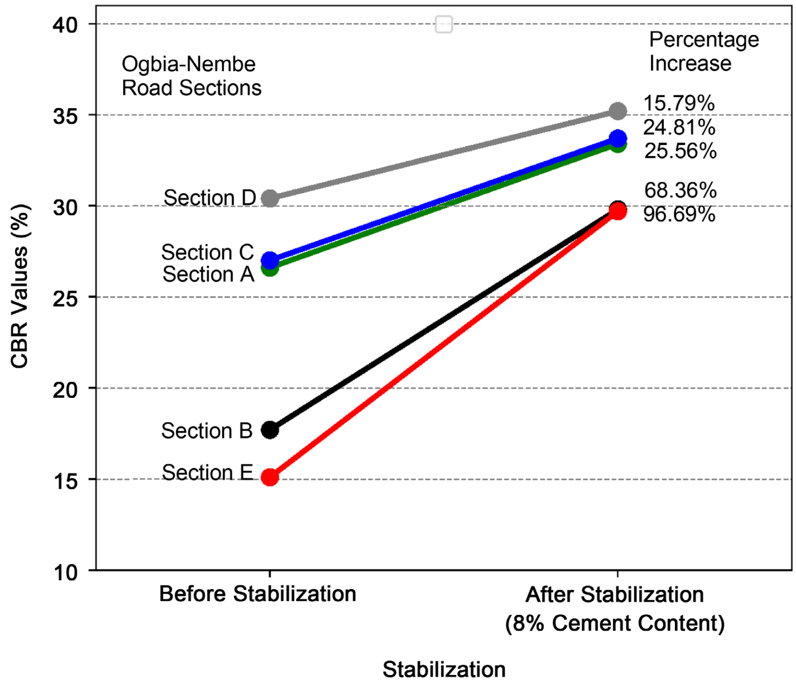

Figure 5. Percentage increase in the CBR after Stabilization with 8% cement content.

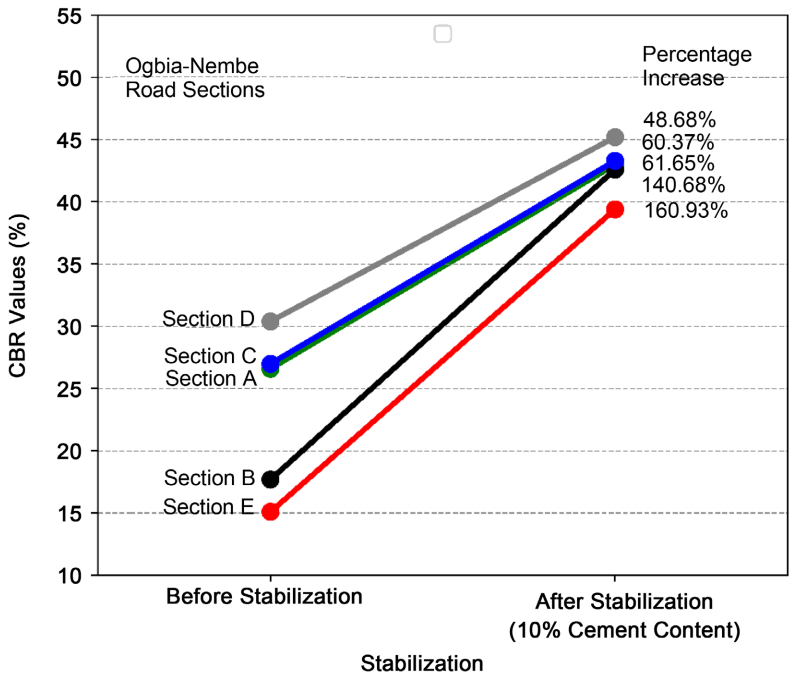

Figure 6. Percentage increase in the CBR after Stabilization with 10% cement content.

each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 43.0%, 42.6%, 43.3%, 45.2% and 39.4% as against the CBR value of the untreated soil, representing the following percentage increment 61.65%, 140.68%, 60.37%, 48.68% and 160.93% respectively. From **Figure 6**, it can be seen that the average percentage increase in the soil CBR for all the five (5) sub-sections was 94.46%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in Ogbia-Nembe with 10% cement content will increase the CBR value by about 94%. The effect of the stabilization process also shows an increased in the soil density which has a direct proportional relationship to the soil strength. Also, the results on the optimum moisture content indicates a decreased with increasing cement content showing that the subgrade material is improved by the stabilization process and is optimized at a 10% sand-cement ratio with optimum moisture content ranging from 6.2% - 14%, maximum dry density ranging from 1700 kg/m^3 - 1780 kg/m^3, delivering an average CBR of 42.7% for soaked samples.

Stabilization results of the soil sample collected from the section of East-West Road from Eleme Junction to Etteh Junction with 10%, 12%, and 14% cement content is presented in **Figure 7**. From **Figure 7**, it can be seen that CBR Value of the untreated soil samples in sections A, B, C, D, and E improved as follows: Stabilization with 10% cement content increases the CBR value in each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 26.4%, 28.1%, 36.80%, 31.3% and 32.4% as against the CBR value of

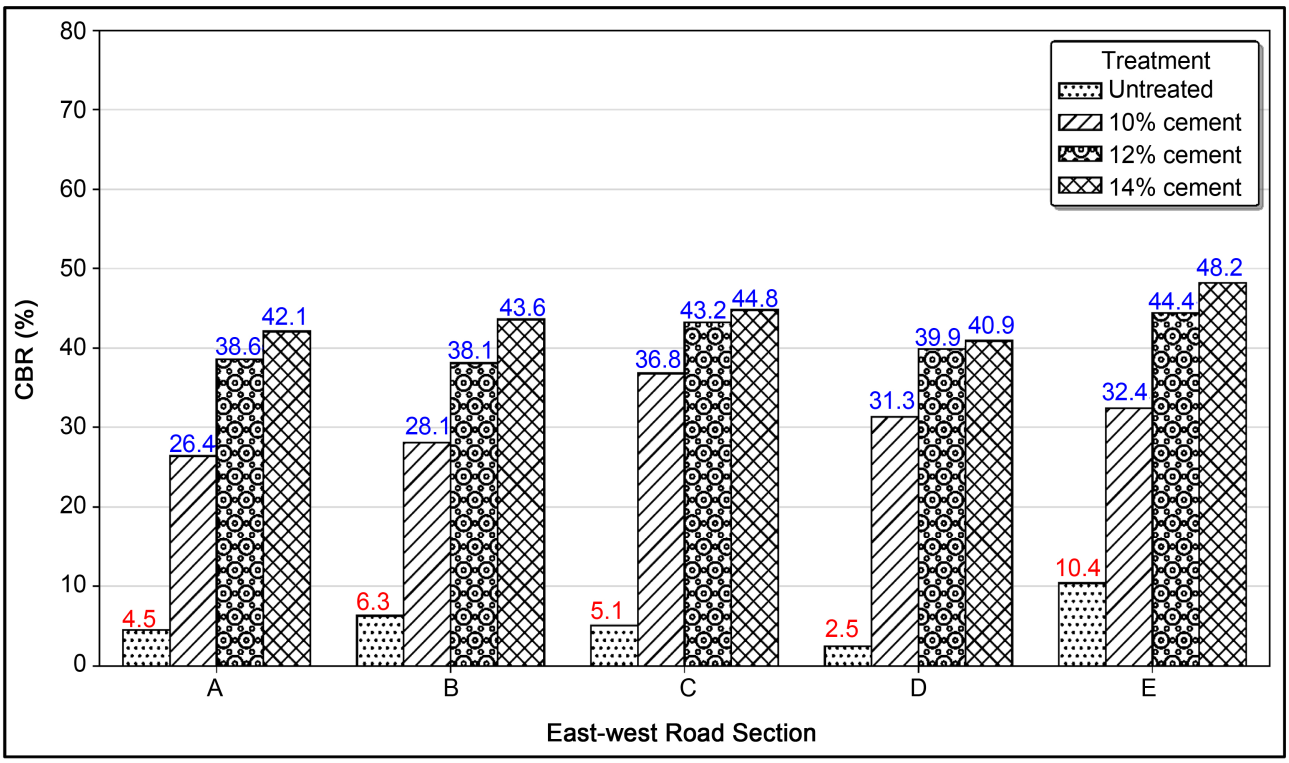

Figure 7. California bearing ratio for various section of east-west road section before and after stabilization with cement content.

the untreated soil, representing the following percentage increment 486.67%, 346.03%, 621.57%, 1.152% and 211.54% respectively. From Figure 8, it can be seen that the average percentage increase in the soil CBR for all sections was 563.562%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in section of East-West Road from Eleme Junction to Etteh Junction with 10% cement content will increase the CBR value by about 563% and yield an average CBR value of 31%. Similarly with 12% cement content stabilization as shown in Figure 9, each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 38.6%, 38.1%, 43.2%, 39.9% and 44.4% as against the CBR value of the untreated soil, representing the following percentage increment 747.06%, 757.48%, 504.76%, 1,496.0% and 326.92% respectively. From Figure 9, it can be seen that the average percentage increase in the soil CBR for the five (5) sub-sections was 766.44%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in section of East-West Road from Eleme Junction to Etteh Junction with 12% cement content will increase the CBR value by about 766% yield an average CBR value of 40.88%. Again with 14% cement content stabilization as shown in Figure 10, each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 42.1%, 43.6%, 44.8%, 40.9% and 48.2% as against the CBR value of the untreated soil, representing the following percentage increment 835.36%, 592.06%, 778.43%, 1,536% and 363.46% respectively. From Figure 10, it can be seen that the average

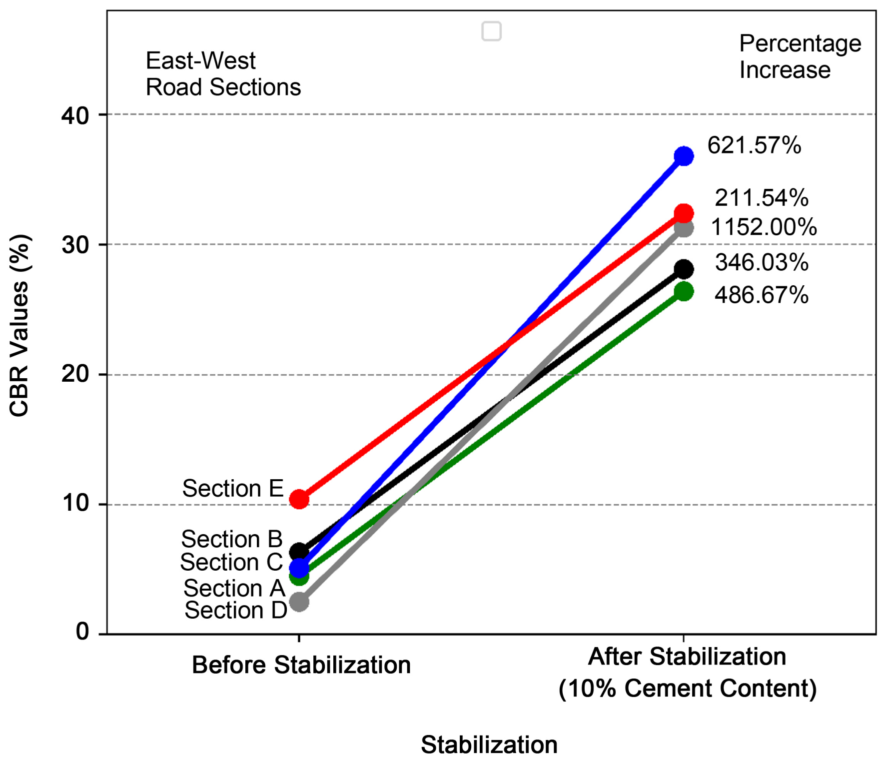

Figure 8. Percentage increase in the CBR after Stabilization with 10% cement content.

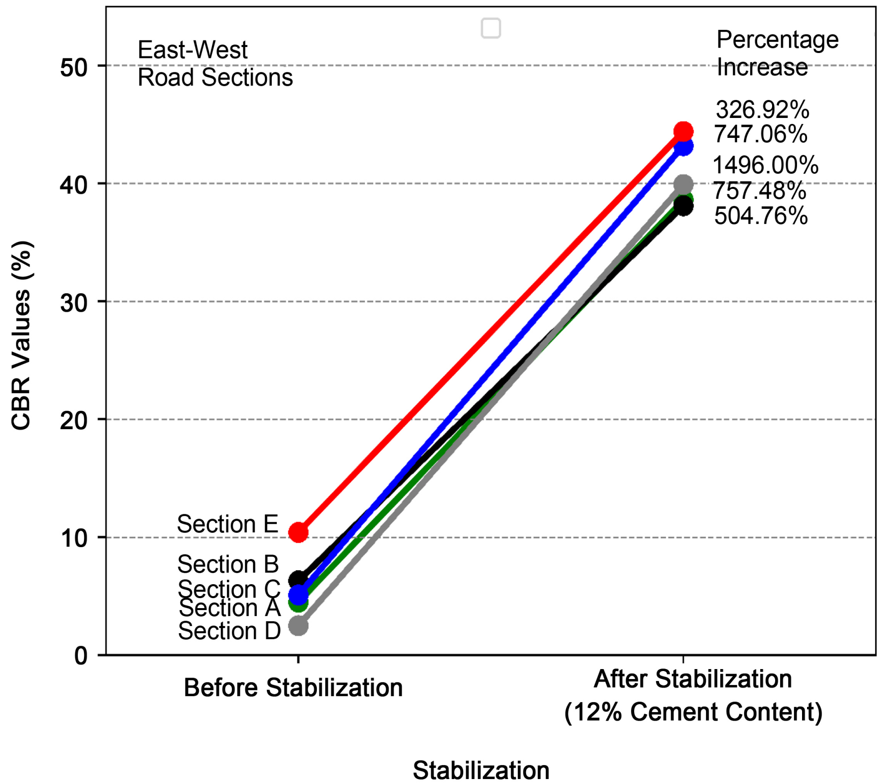

Figure 9. Percentage increase in the CBR after Stabilization with 12% cement content.

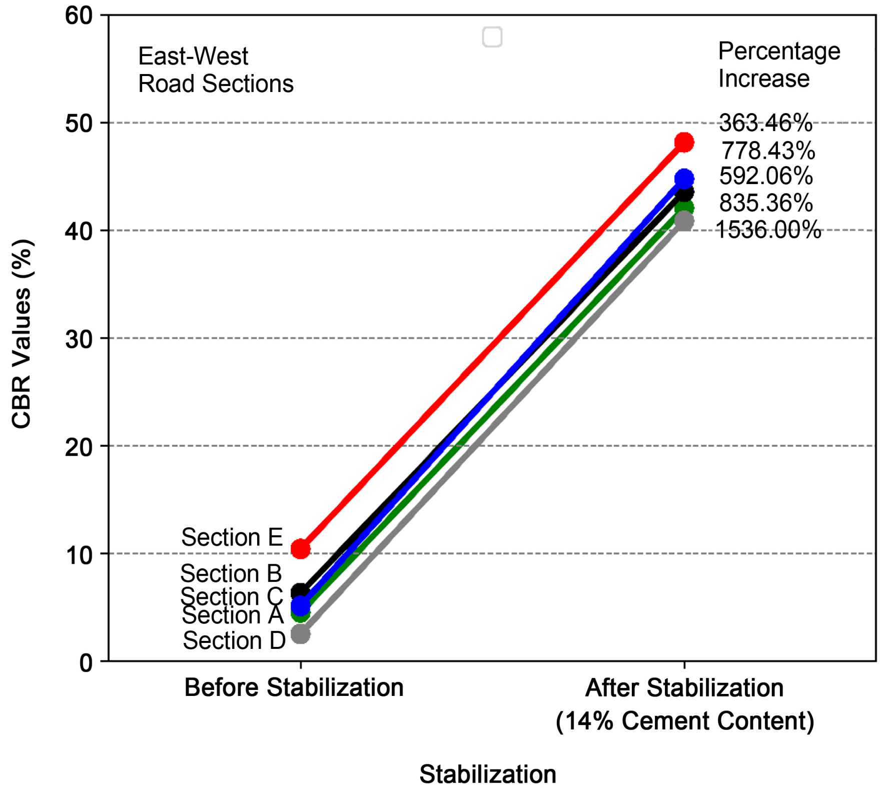

Figure 10. Percentage increase in the CBR after Stabilization with 14% cement content.

percentage increase in the soil CBR for the five (5) sub-sections was sections was 821.06% yield an average CBR value of 43.9%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in section of East-West Road from Eleme Junction to Etteh Junction with 14% cement content will increase the CBR value by about 821%. The effect of the stabilization process also shows an increased in the soil density which has a direct proportional relationship to the soil strength. Also, the results on the optimum moisture content indicates a decreased with increasing cement content showing that the subgrade material is improved by the stabilization process and is optimized at a 14% sand-cement ratio, with optimum moisture content ranging from 6.2% - 14.2%, maximum dry density ranges from 1660 kg/m^3 - 1800 kg/m^3, yielding an average CBR of 43.9% for soaked samples.

The result of stabilization of the soil sample collected from the Section of Port Harcourt-Aba Express Road from Eleme Junction to Osisioma Junction with 10%, 12%, and 14% cement content is presented in Figure 11. From Figure 11, it can be seen that CBR Value of the untreated soil samples in sections A, B, C, D, and E improved as follows: Implementing Stabilization with 10% cement content increases the CBR value in each of the Sub-Sections of the road represented as A, B, C, D and E increased respectively to 31.0%, 33.1%, 32.00%, 36% and 36.4% as against the CBR value of the untreated soil, representing the following percentage increment 236.96%, 562%, 814.29%, 304.49% and 708.89% respectively. From Figure 12, it can be seen that the average percentage increase

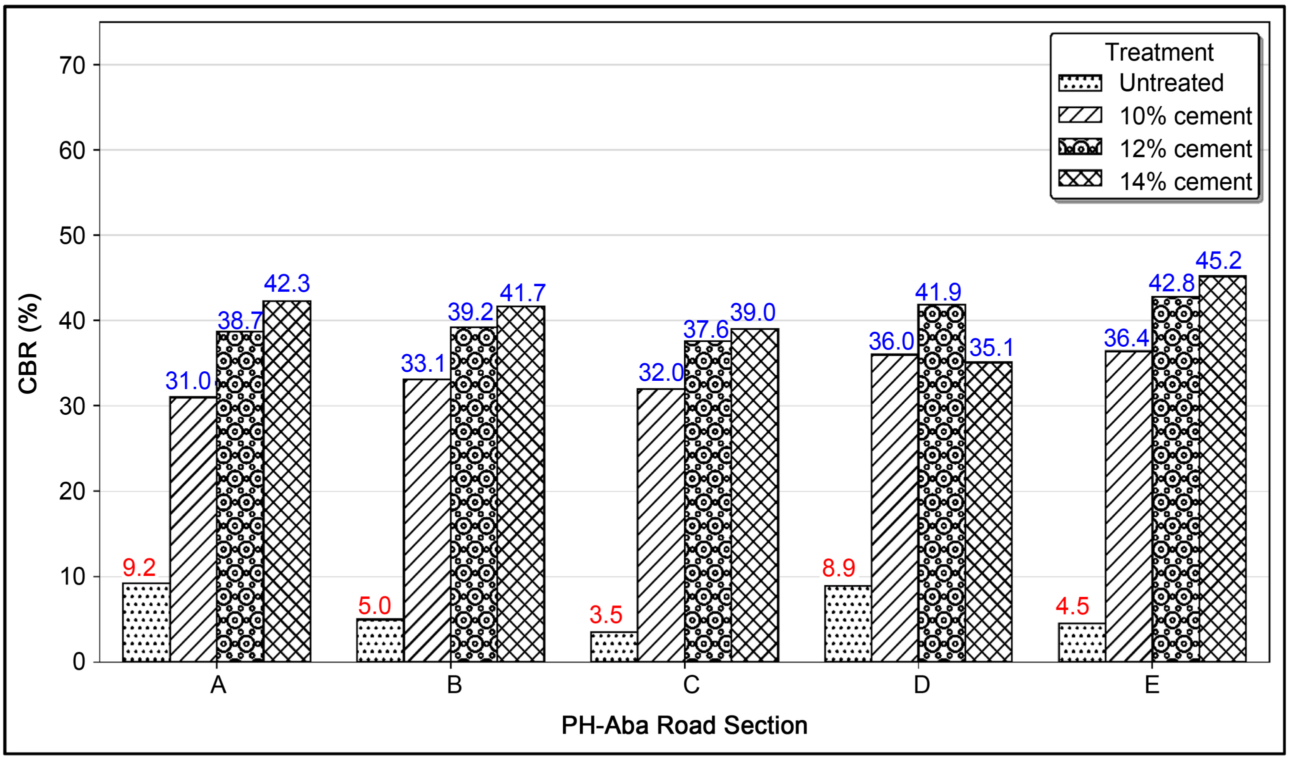

Figure 11. California bearing ratio for various section of PH-Aba road section before and after stabilization with cement content.

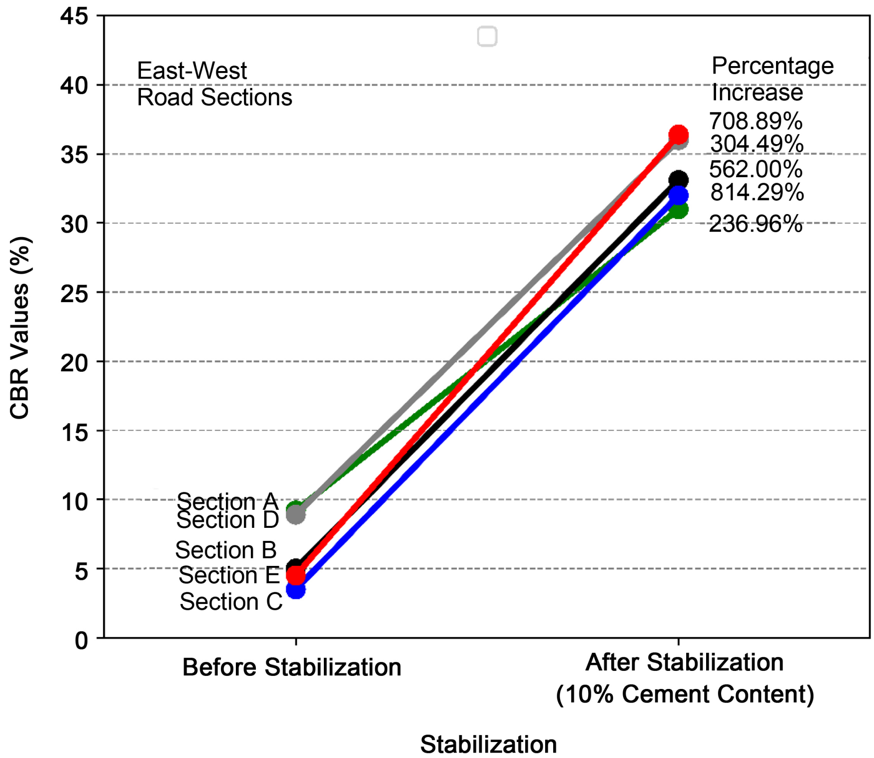

Figure 12. Percentage increase in the CBR after Stabilization with 10% cement content.

in the soil CBR for all sections was 525.33% yield an average CBR value of 33.7%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in Section of Port Harcourt-Aba Express Road from Eleme Junction to Osisioma Junction with 10% cement content will increase the CBR value by about 525.33%. Similarly for 12% cement stabilization, the CBR value in sections A, B, C, D, and E had CBR increased to 38.7%, 39.2%, 37.60%, 41.90% and 42.80% respectively. This gives an average CBR value of about 40.04%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in this section with 12% cement content will increase the CBR value to an average of 40%. In a similar vein, for 14% cement stabilization, the CBR value in sections A, B, C, D, and E had CBR increased to 42.3%, 41.7%, 39%, 35.1% and 45.20% respectively. This gives an average CBR value of about 40.6%. The result gives an indication that stabilization of the soils which have similar soil index properties as those found in this section with 14% cement content will increase the CBR value to 40.5%. Comparatively, on an economical scale at 12% cement content, the CBR on this road is said to be optimized as there is no much significant improvement in the CBR value when 14% cement content is used. The effect of the stabilization process also shows an increased in the soil density which has a direct proportional relationship to the soil strength. Also, the results on the optimum moisture content indicates a decreased with increasing cement content showing that the subgrade material is improved by the stabilization process and is optimized at a 12% sand-cement ratio, with optimum moisture content ranging from 5.4% - 17.3%, maximum dry density ranges from 1610 kg/m^3 - 1740 kg/m^3, yielding an average CBR of 40.0% for soaked samples.

5. Conclusion

The results of the soil-cement stabilization on the expansive soil samples collected from various trial pits along the failed sections of the Ogbia-Nembe road, section of East-West Road from Eleme Junction to Etteh Junction and Section of Port Harcourt-Aba Express Road from Eleme Junction to Osisioma Junction all in the Niger delta show that the process resulted in the improvement of the load-bearing capacity of the soils. The increase in the percentage soil-cement content resulted in a progressive increase in the bearing capacity of the soil which impacted the Maximum Dry Density (MDD) and the California Bearing Ratio (CBR) in a direct relationship, while it has an inverse relationship with the optimum moisture content. The result gives an indication that Stabilization of the soil using Soil-Cement Stabilization affected the Compaction Index properties of the soil and further improved the California Bearing Ratio (CBR). On the Ogbia-Nembe Road, Soil-Cement stabilization improved the CBR and is optimized at a 10% sand-cement ratio with optimum moisture content ranging from 6.2% - 14%, maximum dry density ranges from 1700 - 1780 kg/m^3, yielding an average CBR of 42.7% for soaked samples. On the section of East-West Road from Eleme Junction to Etteh Junction, Soil-Cement stabilization improved the CBR and is optimized at a 14% sand-cement ratio with optimum moisture content ranging from 6.2% - 14.2%, maximum dry density ranges from 1660 - 1800 kg/m^3, yielding an average CBR of 43.9% for soaked samples. On the section of Port Harcourt-Aba Express Road from Eleme Junction to Osisioma Junction, Soil-Cement stabilization improved the CBR and is optimized at a 12% sand-cement ratio having an optimum moisture content ranging from 5.4% - 17.3%, maximum dry density ranges from 1610 - 1740 kg/m^3, and an average California Bearing Ratio for soaked samples at 40%. This result can be applied to soils having similar properties as any of the three study roads and the economic benefit is the optimization that will eliminate the fatigue and cost implication of having to run the reiterative process for every soil type.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Jegede, G. (2004) Highway Pavement Failure Induced by Poor Geotechnical Properties along a Section of F209 Okitipupa-Igbokoda Highway Southwestern Nigeria. *Ife Journal of Science*, **6**, 41-44. https://doi.org/10.4314/ijs.v6i1.32121

[2] FGN (1997) Government of the Federal Republic of Nigeria. General Specification

(Roads and Bridges), Vol. 2.

[3] Little, D.N. and Nair, S. (2009) Recommended Practice for Stabilization of Subgrade Soils and Base Materials. NCHRP 20-07, Texas Transportation Institute, Texas.

[4] Funmilayo, A., Abir, A. and Josiah, A. (2015) Defining Niger Delta Soils: Are they Laterites? *Journal of Civil and Environmental Research*, **7**, 21-26.

[5] Ola, S.A. (1987) Laboratory Testing and Geotechnical Characterization of Black Cotton Soil and Expansive Shales in Nigeria. 9th *Regional Conference for Africa on Soil Mechanics and Foundation Engineering*, A.A Balkema/Rotterdam/Boston, Vol. 1, 991-995.

[6] Ogunrinde, E.O., Adejume, T.W.E. and Amadi, A.A. (2020) Development of an Empirical Model for A-6 Soil Stabilized with Reclaimed Asphalt Pavement. 2nd *International Civil Engineering Conference* (*ICEC 2020*), Department of Civil Engineering, Federal University of Technology, Minna.

[7] Giddings, B., Sharma, M., Jones, P. and Jensen, P. (2013) An Evaluation Tool for Design Quality: PFI Sheltered Housing. *Building Research and Information*, **41**, 690-705. https://doi.org/10.1080/09613218.2013.775895

[8] New Satellite map (Earth Maps & Maps Street View) https://www.newearthmaps.com/

[9] Charles, K., Terence, T.W. and Gbinu, S.K. (2018) Stabilization of Niger Deltaic Expansive Clay Soils using Composite Materials. *International Journal of Advances in Scientific Research and Engineering*, **4**, 21-29. https://doi.org/10.31695/IJASRE.2018.32938

[10] Ogunbiyi, M., Oluwale, S. and Olaleye, S. (2017) Assessing the Load-Bearing Capacity of Soils in Different Areas of Osogbo, Osun State, Nigeria: Case Study of Alekunwodo, Oke-Baale and Osun State University Campus, Oshogbo. *International Journal of Innovative Research in Science*, *Engineering and Technology*, **6**, No. 3.