Comparative Study on Consolidation Parameters and Settlement Potentials of Cement Stabilized Black Cotton and Lateritic Soils on Sedimentary Formation of Part of South-Western Nigeria

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Abstract: *This research investigates the impact of cement stabilization on Black Cotton Soil (BCS) and Lateritic Soil. It also examines how varying cement proportions (10%, 20%, and 30%) affect their settlement potentials and compaction characteristics. Given the tendency of BCS to swell when wet and shrink when dry, along with the inconsistent strength of Lateritic Soil, this study highlights the need for effective soil stabilization methods in civil engineering, especially in areas where these soils are commonly found. In accordance with BS 1377 (1990), experimental tests such as compaction and consolidation were performed to analyze the modifications in soil properties. The pre-consolidation pressure fell from 3600 kN/m² to 466.37 kN/m² at 30% cement substitution in black cotton soil. In contrast, the pre-consolidation pressure rose from 110 kN/m² to 2000 kN/m² with 20% cement substitution and more in lateritic soil. The results demonstrated notable enhancements of maximum dry density, shear strength, and moisture retention in both soil types, with Lateritic Soil showing better performance and needing less cement for effective stabilization. These findings are significant for road construction and civil engineering infrastructure development, offering insights into optimal cement content to improve soil performance.*

Keywords: *Cement, Stabilization, Black Cotton Soil, Lateritic Soil, Compaction, Consolidation and Pre-consolidation.*

Introduction

Black Cotton Soil (BCS), found predominantly in arid and semi-arid regions, is a regionalized weak soil with a high swell-shrink potential, which can lead to significant structural damage. The Nigerian expansive soil, characterized by its dark grey to black color, is referred to as "black cotton soil" due to its favorable conditions for cotton cultivation (Adamu et al. 2014). Typically, this soil lacks organic material, and its black color is likely attributed to the presence of iron and titanium. Primarily composed of the clay mineral montmorillonite, BCS is among the most problematic soils in Africa, covering an estimated area of 104,000 km² in Nigeria. The expansive nature of BCS causes it to swell during the wet season and shrink during the dry season, resulting in vertical movements within the soil mass that lead to various forms of structural damage. Furthermore, BCS's swelling-shrinkage potential is greatly influenced by factors such as clay mineralogy, environmental stress conditions, and soil properties, which collectively define the functional relationship of the soil's behavior in different conditions (Akpan et al., 2022). This high expansiveness may require more intensive stabilization to achieve the desired structural integrity, making it a focal point for comparative studies on soil stabilization techniques. On the other hand, lateritic soil, formed through intense weathering processes, is primarily found in tropical and subtropical regions and is less prone to expansion compared to black cotton soil. Its abundance, particularly in regions like Africa, has led to its historical and ongoing use in building materials, earning it the nickname "brick earth". This soil is rich in iron and aluminum oxides, giving it a distinctive reddish color, and its particle size distribution ranges from clay to gravel, often coated with sesquioxide-rich concretions. While lateritic soil is generally more stable in its natural state, its engineering properties, such as strength and moisture susceptibility, can vary widely depending on its specific composition and location. This variability can pose challenges for construction, as the soil's performance can be unpredictable without proper stabilization. However, when properly stabilized, particularly through methods like cement stabilization, lateritic soil might achieve the desired strength with lower cement content compared to BCS, making it an efficient option for construction.

The soil–cement technique has been practiced almost for 100 years (Firoozi et al., 2017). Based on the literature, black cotton soil and fly ash stabilized with cement are low-cost and effective for soil stabilization (Rai et al., 2021). However, Calcium hydroxide is another hydration product of Portland cement that further reacts with pozzolanic materials available in stabilized soil to produce further cementitious material (Makusa, 2012). Because of the high costs of disposal and environmental protection, the use of fly - ash in the construction and agriculture sector may be a feasible choice (Oluremi et al., 2012). In light of this, the need to bring down the cost of waste disposal and the growing cost of soil stabilizers has led to intense global research towards economic utilization of wastes for engineering purposes. This comparative study focuses on the effects of cement stabilization on these two soil types, examining their performance in terms of strength, durability, and suitability for construction. The aim of this research is targeted at the comparison of the effectiveness of cement stabilization on Black Cotton Soil (BCS) and Lateritic Soil, focusing on improvements in their engineering properties. To achieve this aim, the study focuses on the following objectives: determine the compression index (Cc), coefficient of volume compressibility (Mv), preconsolidation pressure (P), Oedometer settlement (Soed), coefficient of consolidation (Cv) and coefficient of permeability (K) of both soil samples at each proportion (10%, 20% ,30% cement substitutions). In developing nations, sourcing appropriate road building materials presents a significant challenge for highway engineers. This issue is exacerbated in regions where locally available materials are unsuitable for road construction. Black Cotton Soil (BCS) and Lateritic Soil pose significant challenges in civil engineering due to their inherent properties—BCS with its high swell-shrink potential and Lateritic Soil with its variable strength and moisture susceptibility. This study aims to fill this gap by conducting a comparative analysis of BCS and Lateritic Soil, assessing their behaviour under varying cement stabilization proportions (10%, 20%, and 30%), and identifying the most efficient cement content necessary to achieve optimal stabilization. The findings are expected to provide clearer guidelines for soil stabilization, ultimately improving construction outcomes and resource efficiency in regions where these soils are prevalent. This study delves into the comparative efficacy of cement stabilization on Black Cotton Soil (BCS) and Lateritic Soil. Its objective is to refine stabilization methodologies by assessing the response of these two distinct soils to cement treatment, with a specific emphasis on enhancing their engineering properties on sedimentary formation of part of South Wester Nigeria to yield superior construction outcomes. The results will yield valuable insights for infrastructure advancement, optimal resource utilization, and the formulation of more efficacious engineering protocols, particularly in regions where these challenging soils are predominant. While several studies have explored the impact of several stabilizers on both soils, there is limited research examining only cement as stabilizers, Additionally, existing research primarily focuses on cement and other stabilizers in proportions, leaving a gap in understanding how cement only influences both soils. This study aims to address this gap by using cement as stabilizer added in 10%, 20% and 30% proportions, which will contribute to a broader understanding of this research.

Background Study

Soils under this classification are characterized by forming hard, impenetrable and often irreversible pans when dried (Arora, 2010). However, there is confusion in the use of the term, because a variety of materials with many type of compositions and various origins have been called laterite, ranging from iron capping found on the plateau of southern India to the zonal soils of the humid tropics and from the whole weathered profile beneath a laterite of Buchanan's meaning to the iron-rich breccias and slope wash accumulations. Because of this confusion, most workers now prefer to use the definitions based on hardening, such as "ferric" for iron-rich cemented crusts, "accrete" or bauxite for aluminum-rich cemented crusts, etc, Other definitions have been based on the ratios of silica to sesquioxides. In laterite, the ratios are less than 1.33. Those between 1.33 and 2.0 are indicative of laterite soils, and those greater than 2.0 are indicative of non-lateritic soils (Amu et al., 2011). This is because: they are the most common naturally-occurring materials in the tropics, weathering is intense, and hence there is lack of good quality crushed aggregate. Long haulage distances and the association high costs involved in the transportation of good quality aggregates, make the utilization of laterite gravels economically attractive. The widespread evidence of the deterioration of laterite roads in Nigeria and probably other developing tropical countries emphasize the need for careful assessment of lateritic gravel to be used for road construction. Geotechnical properties of lateritic soils are influenced by the degree of weathering, the amount of sesquioxides and degree of desiccation in the soil, the clay-size content and the mineralogy. A critical assessment of the above factors may give a basis to predict the behavior of a given laterite soil in the field. A proper understanding of the geotechnical properties of soil is required in the selection of suitable base for the high way construction (Amu et al., 2010). The black cotton soil is very hard when dry, but loses its strength completely in wet condition.40-60% of the black cotton soil (BC Soil) has a size less than 0.001 mm. (Prerna & Singh, 2021)The Black Cotton (B.C) soil is expansive in nature and possess high swelling and shrinkage properties. The B.C. soil is hard so long as it is dry but loses its stability almost completely when it becomes wet. When again it becomes dry it shows lots of cracks on its surface. Expansive soil undergoes extensive volumetric change when subjected to fluctuating moisture. Considerable damage has taken place over the years to canals, roads, buildings and other existing structure, constructed on or with the use of black cotton soil. The present thrust is on the construction of road on the expansive soil. Soil, a dynamic mixture of minerals, organic matter, gases, and microorganisms, supports life and provides foundational stability for construction (Firoozi et al., 2017). Its properties are shaped by weathering and erosion processes, which can affect its suitability for construction (Firoozi et al., 2017). Soil stabilization is critical for enhancing soil properties, especially in soils with expansive or variable characteristics. This process involves modifying soil to improve its strength, load-bearing capacity, and durability, addressing challenges posed by high moisture sensitivity or organic content (Sherwood, 1993; Ahmed & Jasim, 2024). The chief properties of soil which are of interest to engineers are volume stability, strength, compressibility, permeability and durability (Afrin, 2017).To an engineer there are basically two methods of stabilization which are important to a civil engineer; they are mechanical and chemical stabilizations. Mechanical stabilization according to Lemougna et al., (2011) involves compacting the soil with the aim of improving its resistance to shearing, compressibility, permeability and porosity. Troy (2021) refers Chemical stabilization as the alteration of soil properties by changing its chemical make – up with different additives like lime, cement, fly ash. *Some stabilization techniques are* *listed as:* Mechanical Stabilization and Stabilization by using different types admixers Stabilization by using different types admixers includes; Lime Stabilization, Cement Stabilization, Chemical Stabilization, Thermal Stabilization, Electrical Stabilization, Bituminous Stabilization, Fly ash Stabilization, Rice Husk Ash Stabilization, Recycle and waste product, Stabilization by Geo-textile and Fabrics etc.

Mechanical Stabilization

This process includes soil compaction and densification by application of mechanical energy using various sorts of rammers, rollers, vibration techniques and sometime blasting. Mechanical stabilization is accomplished by mixing or blending soils of two or more gradations to obtain a material meeting the required specification (Afrin, 2017).

Stabilization Using Different Types of Admixtures

Lime

Garber and Hoel (2000) defined lime as one of the oldest procedures of improving the engineering properties of soil and it is used for stabilizing base & sub base materials. While Sherwood (1993) explained lime as an economical way of soil stabilization. He further described lime modification to be increase in strength that brought about cation exchange capacity rather than cementing effect brought about pozzolanic materials react with the lime in presence of water to produce cementitious compounds. Lime-soil chemical reaction has two stages. Three main chemical reaction namely; cationic exchange, flocculation- agglomeration and carbonation occur at this stage. The second stage requires several months or years to complete and it is considered the long – term treatment. Pozzolanic reaction is the main reaction of this stage this discusses is by (Jawad& Khan, 2014).

Chemical stabilization

Chemical stabilization of soil comprises of changing the physico-synthetic around and within clay particles where by the earth obliges little water to fulfil the static imbalance.

Thermal stabilization

Thermal stabilization is done either by heating the soil or by cooling it. Freezing: cooling causes a small loss of strength of clayey soils due to an increase in inter-particles repulsion. However, if the temperature is reduced to the freezing point, the pore water freezes and the soil is stabilized (Hussein et al., 2021, Afrin, 2017).

Electrical stabilization

It occurs because of attraction of positive ions (cations) that are present in water towards cathode. The strength of the soil is considerably increased due to removal of water (Afrin, 2017). Incidentally, the properties of the soil are also improved (Singh & Yadav, 2017).

Bituminous soil stabilization

Bituminous soil stabilization is defined as a process by which a controlled amount of bituminous material is thoroughly mixed with an existing soil or aggregate material to form a stable base or wearing surface. In frost areas, the use of tar as binder must be avoided because of its high temperature maximum susceptibility.

Fly ash

This method is inexpensive and takes less time than any other methods. Fly ash is a by-product of coal fired electric power generation facilities; it has little cementations properties compared to lime and cement (Okonkwo, 2009). Other types of admixtures are rice husk ash, recycled and waste products and Stabilization by geo-textile and fabrics.

Methodology

In this study, experimental methodology was employed to evaluate the effects of cement stabilization on two soil types: black cotton soil and lateritic soil on sedimentary formation of part of South Western Nigeria (Figures 1 a, b and c). Consolidation and compaction tests were carried out on the soil samples at natural state in accordance with the procedures outlined in BS 1377 (1990) and stabilized state in accordance with the procedures outlined in BS 1924 (1990). The samples were collected from a site known for its typical lateritic soil properties, with attention to obtaining an undisturbed sample. Ordinary Portland Cement (OPC) was chosen for this study, given its widespread availability and proven efficacy in soil stabilization. The cement used was of Grade 42.5, consistent with the requirements for general construction use and providing a suitable strength level for the soil stabilization process. Cement was mixed with the soil samples at varying percentages (10%, 20%, and 30% cement substitutions) to evaluate the effect of different cement contents on the engineering properties of both Black Cotton and Lateritic soils. The Black cotton soil sample was obtained from Iweke, along Owode Road, Yewa South Local Government, Ogun State, while lateritic soil was collected from a borrow pit within the locality of Ilaro, Ogun State.

Figure 1: a Lateritic soil, b Black Cotton Soil and c Ordinary Portland Cement

Soil compaction is the process by which a soil is mechanically stressed. Soil is made up of solid particles and voids that are filled with water or air. When soil particles are stressed, they are re-distributed within the soil mass, resulting in densification. This test was carried out to determine the maximum dry density attainable at specified nominal compaction energy and the optimum moisture content corresponding to this density. Test was carried out using the West Africa method with test procedures according to BS 1377-4 (1990). The consolidation test consists of applying pressure to a thin soil specimen in increment and keeping every pressure increase for the amount of time needed to allow the soil specimen to consolidate and measure the vertical deformation brought on by pore water expulsion. The soil sample was trimmed with the consolidation ring of diameter 6mm while utilising a spatula, and a porous stone was place as the base place before the soil sample trimmed into the consolidation ring was placed on the porous stone, another porous stone was placed on the soil sample with a ball ring. Water was added to the reservoir to keep the soil sample saturated and loading was applied in order of 0.637kg, 1.275kg, 2.55kg, and 5.1kg for 1-Hour Soaked and 24-Hour Soaked samples and analysis was done and graphs of void were plotted against pressure.

$$C_v = \frac{0.848d^2}{t_{90}} \quad \text{Equation 1}$$

$$e = \frac{H - H_S}{H_S} \quad \text{Equation 2}$$

$$H_S = \frac{W_d}{G_S A} \quad \text{Equation 3}$$

where,
H_s = Height of solid, W_d = Weight of dry sample, G_s = Specific gravity of solids and A = Area of soil sample (cm^2)

Figure 3: Oedometer

This study examines the comparative behaviour of black cotton and lateritic soil stabilized with different proportion 10%, 20% and 30% of cement added to both samples. This study is aimed at evaluating the impact of cement stabilization on black cotton soil which was obtained from Iweke, along Owode road, Yewa South local government, Ogun State of coordinate (6º45ʾ25ʾʾN; 2º59ʾ43ʾʾE) and Lateritic soil which was obtained within the locality of Ilaro, Ogun state of coordinate (6º53ʾ58ʾʾN 3º1ʾ07ʾʾE). The experimental works carried out are Compaction test and Consolidation test.

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Results and Discussion

The results of the experimental work which include compaction and consolidation tests for black cotton and lateritic soils are presented blow. The results of compaction tests for black cotton and lateritic soils are presented in Tables 1 and 2. Results of moisture content, specific gravity (Gs), and various load variations for 1-hour soaked and 24-hour soaked samples during *oedometer* tests (compression and expansion) on black cotton and lateritic soils are presented in Tables 3 to 8 while the results of settlement potentials and consolidation parameters for black cotton and lateritic soils are presented in Tables 9 and 10.

Table 1: Compaction Test Results for Black Cotton Soil

Sample No	1		2		3		4		5	
Water Content (%)	6		8		10		12		14	
Weight of mould + wet soil (g)	5810		5868		6146		6105		6034	
Weight of empty mould (g)	2800		2800		2800		2800		2800	
Weight of wet sample (g)	3010		3068		3346		3305		3234	
Bulk Density (kg/m^3)	1396		1423		1552		1533		1500	
Container number	1		2		3		4		5	
Weight of container + wet soil (g)	107.1	98	111	108	98	87.5	100	90	115	106
Weight of container + dry soil	105	94.9	108.1	105..1	95.0	82.5	95.1	86.3	108.1	100.5
Weight of water	2.1	3.1	2.9	2.9	2.0	5.0	4.9	3.7	6.9	5.5
Average	2.6		2.9		3.5		4.3		6.2	
Weight of container (g)	49.6		49.6		49.6		49.6		49.6	
Weight of dry soil	48.9	43	50.5	42.8	42.3	32.7	43.6	34.0	56.5	47.7
Average	45.95		46.65		37.5		38.80		52.10	
Percentage Moisture Content (%)	5.7		6.2		9.3		11.1		11.9	
Dry Density (kg/m^3)	1320		1340		1420		1380		1340	

Volume of Mould = 2156cm^3

The specific gravity (Gs) tables for various percentage substitutions of cement in black cotton and lateritic soils were determined (BS 1377, 1990; Bowles, 1981) and are presented in Tables 10 and 11 respectively. These were used along with Compression tables. The compression tables (1-hour and 24-hour soaked samples) for both black cotton and lateritic soils showing pressure load variations and behaviors were used to determine the relevant consolidation parameters and settlement potentials using relevant equations in Bowles (1982), Craig (1987) and Knappett and Craig (2012). The expansion tables (1-hour and 24-hour soaked samples) for both black cotton and lateritic soils showing pressure load variations and behaviors upon gradual removal of pressure loads, These will assist interested researchers and professionals to predict the expansive behaviors of cement stabilized black cotton and lateritic soils, especially on sedimentary formations.

Table 2: Results of Compaction Test on Lateritic Soil

Sample No	1		2		3		4		5	
Water Content (%)	4		6		8		10		12	
Weight of mould + wet soil (g)	7180		7744		7723		7576		7480	
Weight of empty mould (g)	2800		2800		2800		2800		2800	
Weight of wet sample (g)	4380		4944		4923		4776		4680	
Bulk Density (g/cm^3)	2032		2293		2283		2215		2171	
Container number	1		2		3		4		5	
Weight of container + wet soil (g)	83.7	78.11	94.11	95.22	108.71	107.60	128.50	136.29	90.14	92.05
Weight of container + dry soil	80.45	75.44	88.29	88.45	101.40	100.50	117.81	122.28	83.64	86.35
Weight of water	3.25	2.67	6.48	6.77	7.31	7.10	10.69	14.01	6.5	5.7
Average	2.96		6.63		7.21		12.35		6.10	
Weight of container (g)	43.5		43.5		43.5		43.5		43.5	
Weight of dry soil	36.95	31.94	44.79	44.95	57.9	57.0	74.31	78.78	40.41	42.85
Average	34.45		44.87		57.45		76.55		41.63	
Percentage Moisture Content (%)	8.58		14.77		12.55		16.09		14.75	
Dry Density (kg/m^3)	2032		2293		2283		2215		2171	

Volume of Mould = 2156cm^3

Black cotton soil attains maximum dry density and bulk density of 1420 and 1552 (kg/m^3) at 10% water content. In the case of lateritic soil, it attains maximum dry density and bulk density of 2293 (kg/m^3) at 6% water content. It shows that black cotton soil due to its clay content, swelling potentials and water retention capacity absorbs and retain more water compared to lateritic sol.

Table 3 (a-f): 0% CEMENT SUBSITUTION IN BLACK COTTON SOIL (CONTROL)

a. 1-HOUR SOAKED

MOISTURE CONTENT

Can No	1
Weight of can (g)	43.42
Weight of dry soil (g)	97.58
Weight of water (g)	16.45
Percentage Moisture content (m) %	16.86

b. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	0	0	0	3	11	37
15	0	0	0	3	12	38
30	0	0	0	3	12	39
60	0	0	0	3	13	40
120	0	0	0	4	13	42
240	0	0	0	4	16	43
480	0	0	0	4	20	44
900	0	0	0	5	21	44
1800	0	0	0	5	21	45
3600	0	0	1	5	22	46

c. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	46	43	39	35	30	27
15	46	43	39	35	30	27
30	46	43	39	35	30	27
60	46	43	39	35	30	27
120	46	43	39	34	30	27
240	46	43	39	34	30	26
480	46	43	39	34	30	26
900	46	43	39	33	28	26
1800	46	43	38	32	28	25
3600	46	43	38	32	27	24

24-HOUR SOAKED

d. MOISTURE CONTENT

Can No	1
Weight of can (g)	45.40

Weight of dry soil (g)	91.10
Weight of water (g)	17.08
Percentage Moisture content (m) %	18.75

e. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	2	6	24	48	82	120
15	2	6	25	49	84	125
30	2	8	28	50	85	128
60	2	8	29	52	87	131
120	2	9	30	54	89	134
240	2	9	31	55	89	136
480	2	10	33	57	91	138
900	2	10	33	58	93	140
1800	2	11	35	60	94	141
3600	2	11	36	61	95	143

f. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	140	136	131	127	122	115
15	140	136	131	126	121	115
30	140	136	131	126	121	115
60	140	136	131	126	120	115
120	140	136	131	126	120	115
240	140	135	131	125	120	115
480	140	135	131	124	119	114
900	140	135	130	124	118	114
1800	140	134	129	123	117	113
3600	140	134	129	122	116	1119

Table 4 (a-f): 10% CEMENT SUBSITUTION IN BLACK COTTON SOIL
1-HOUR SOAK

a. MOISTURE CONTENT

Can No	1
Weight of can (g)	43.52
Weight of dry soil (g)	79.50
Weight of water (g)	24.96
Percentage Moisture content (m) %	31.40

b. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	2	17	41	60	94	134
15	2	18	42	60	95	135
30	2	18	43	61	97	137
60	2	19	43	62	98	138
120	2	19	44	63	99	139
240	2	19	45	63	101	140
480	2	20	45	63	101	141
900	2	20	46	64	102	144
1800	2	20	46	64	103	147
3600	2	21	46	65	104	150

c. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	148	145	142	140	138	137
15	148	145	142	140	138	137
30	148	145	142	140	138	137
60	148	145	142	140	138	136
120	148	145	142	140	138	136
240	148	145	142	140	138	136

480	148	145	142	140	138	136
900	148	145	142	140	137	135
1800	148	145	142	139	137	135
3600	148	144	142	139	137	135

24-HOUR SOAK

d. MOISTURE CONTENT

Can No	1
Weight of can (g)	44.63
Weight of dry soil (g)	83.07
Weight of water (g)	21.90
Percentage Moisture content (m) %	26.36

e. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	1	10	23	43	72	100
15	1	10	24	44	72	101
30	1	10	24	44	73	102
60	1	10	25	44	73	102
120	1	10	23	45	73	103
240	1	10	26	45	74	104
480	1	10	26	46	74	104
900	1	10	27	46	75	105
1800	1	10	27	47	75	105
3600	1	13	27	49	76	106

f. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	106	104	102	101	99	115
15	106	104	102	101	99	115

30	106	104	101	101	99	115
60	106	104	101	101	99	115
120	106	104	101	101	99	115
240	106	104	101	101	99	115
480	106	104	101	101	99	114
900	106	104	101	101	99	114
1800	106	104	101	100	99	113
3600	106	104	101	100	99	112

Table 5 (a-f): 20% CEMENT SUBSITUTION IN BLACK COTTON SOIL
1-HOUR SOAK

a. MOISTURE CONTENT

Can No	1
Weight of can (g)	45.70
Weight of dry soil (g)	85.72
Weight of water (g)	16.07
Percentage Moisture content (m) %	18.75

b. COMPRESSION (LOADING)

LOAD (G)	100	200	400	800	1600	3200
TIME(SEC)						
6	2	4	13	27	52	86
15	2	4	13	27	53	87
30	2	4	13	28	54	88
60	2	4	14	28	55	88
120	2	4	14	29	56	89
240	2	4	14	29	57	91
480	2	4	14	30	58	91
900	2	4	14	30	59	92
1800	2	4	20	30	60	93
3600	2	5	21	31	61	94

c. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	91	89	86	85	84	83
15	91	89	86	85	84	83
30	91	89	86	85	84	83
60	91	89	86	85	84	83
120	91	89	86	85	84	83
240	91	89	86	85	84	83
480	91	89	86	85	84	83
900	91	89	86	85	84	83
1800	91	89	86	85	84	83
3600	91	89	86	85	84	83

24-HOUR SOAK

d. MOISTURE CONTENT

Can No	1
Weight of can (g)	44.70
Weight of dry soil (g)	76.33
Weight of water (g)	23.31
Percentage Moisture content (m) %	30.54

e. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	0	6	17	31	55	82
15	0	6	18	32	55	82
30	0	6	18	32	56	83
60	0	6	19	32	56	83
120	0	7	19	33	56	84
240	0	7	20	33	57	84
480	0	7	20	33	57	84

900	0	7	20	34	57	85
1800	0	7	21	34	58	86
3600	0	7	21	35	58	86

f. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	86	84	81	80	80	80
15	86	84	81	80	80	80
30	86	84	81	80	80	80
60	86	84	81	80	80	80
120	86	84	81	80	80	80
240	86	84	81	80	80	80
480	86	84	81	80	80	80
900	86	84	81	80	80	80
1800	86	84	81	80	80	80
3600	86	84	81	80	80	80

Table 6 (a-c): 0% (CONTROL) CEMENT SUBSITUTION IN LATERITIC SOIL
24-HOUR SOAK

a. MOISTURE CONTENT

Can No	1
Weight of can (g)	42.13
Weight of dry soil (g)	102.61
Weight of water (g)	14.88
Percentage Moisture content (m) %	14.50

b. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	2	16	52	72	112	162
15	2	17	53	73	116	165
30	2	17	54	73	118	168

60	2	18	55	73	120	168
120	2	19	57	74	121	170
240	2	20	58	76	123	172
480	3	20	59	77	125	173
900	3	21	63	78	126	176
1800	3	22	65	79	128	176
3600	5	23	66	79	129	177

c. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	175	173	170	168	165	163
15	175	173	170	168	165	163
30	175	173	170	168	165	163
60	175	173	170	168	165	163
120	175	173	170	168	165	163
240	175	173	170	167	165	163
480	175	173	170	167	165	163
900	175	173	169	167	165	162
1800	175	173	169	167	164	161
3600	175	173	169	167	164	161

Table 7 (a-f): 10% CEMENT SUBSITUTION IN LATERITIC SOIL
1-HOUR SOAK

a. MOISTURE CONTENT

Can No	1
Weight of can (g)	43.86
Weight of dry soil (g)	82.76
Weight of water (g)	11.58
Percentage Moisture content (m) %	13.99

b. COMPRESSION (LOADING)

LOAD (G)	100	200	400	800	1600	3200

TIME(SEC)						
6	-9	-5	12	25	40	53
15	-9	-5	12	25	40	54
30	-9	-5	12	25	40	54
60	-9	-5	12	25	40	54
120	-9	-5	13	25	40	54
240	-9	-5	13	25	41	55
480	-9	-5	13	25	41	55
900	-9	-5	13	26	41	55
1800	-9	-5	13	26	41	56
3600	-9	-5	13	26	41	56

c. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	56	55	54	52	31	29
15	56	55	54	52	31	29
30	56	55	54	52	30	29
60	56	55	54	52	30	29
120	56	55	54	52	30	29
240	56	55	54	52	30	29
480	56	55	54	52	30	29
900	56	55	54	52	30	29
1800	56	55	54	51	30	29
3600	56	55	54	51	30	29

24-HOUR SOAK

d. MOISTURE CONTENT

Can No	1
Percentage Moisture content (m) %	13.90

e. COMPRESSION (LOADING)

- / TIME(SEC)	100	200	400	800	1600	3200
6	0	2	5	10	21	38
15	0	2	5	10	21	38
30	0	2	5	10	21	39
60	0	2	5	10	22	39
120	0	2	5	10	22	39
240	0	2	5	10	23	40
480	0	2	5	10	23	40
900	0	2	5	10	23	41
1800	0	2	5	10	23	41
3600	0	2	5	10	23	41

e. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	41	39	37	36	35	34
15	41	39	37	36	35	34
30	41	39	37	36	35	34
60	41	39	37	36	35	34
120	41	39	37	36	35	34
240	41	39	37	36	35	34
480	41	39	37	36	35	34
900	41	39	37	36	35	34
1800	41	39	37	36	35	34
3600	41	39	37	36	35	34

Table 8 (a-f): 20% CEMENT SUBSITUTION IN LATERITIC SOIL
1-HOUR SOAK

a. MOISTURE CONTENT

Can No	1

Percentage Moisture content (m) %	-

b. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	1	1	10	20	31	52
15	1	2	10	20	32	53
30	1	2	10	20	32	54
60	1	2	10	20	33	54
120	1	2	10	21	33	55
240	1	2	10	21	34	56
480	1	2	10	21	34	57
900	1	2	10	21	35	57
1800	1	2	10	22	35	58
3600	1	2	10	22	35	58

c. EXPANSION (OFFLOADING)

LOAD (G) / TIME(SEC)	1600	800	400	200	100	0
6	57	54	52	51	49	48
15	57	54	52	51	49	48
30	57	54	52	51	49	48
60	57	54	52	51	49	48
120	57	54	52	51	49	48
240	57	54	52	51	49	48
480	57	54	52	51	49	48
900	57	54	52	51	49	48
1800	57	54	52	51	49	48
3600	57	54	52	51	49	48

d. COMPRESSION (LOADING)

LOAD (G) / TIME(SEC)	100	200	400	800	1600	3200
6	0	0	1	13	20	26
15	0	0	1	13	21	27
30	0	0	1	13	21	28
60	0	0	2	13	21	29
120	0	0	2	13	21	29
240	0	0	2	13	21	30
480	0	0	2	13	21	30
900	0	0	3	14	21	-
1800	0	0	3	14	21	-
3600	0	0	3	14	21	-

Table 9: Results of consolidation parameters and settlement potentials for black cotton soil from 0% to 30% cement substitutions

PARAMETERS	**CONTROL (0% CEMENT)**		**10% CEMENT**		**20% CEMENT**		**30% CEMENT**	
SOAKED HOUR	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
PRECONSOLIDATION PRESSURE (PC) (KN/M^2)	3600	2700	600	507	950	438.46	466.37	700
COMPRESSION INDEX (CC)	0.091	0.229	0.189	0.095	0.119	0.097	0.073	0.054
COEFFICIENT OF CONSOLIDATION (CV) (m^2/sec)	$5.82x10^{-8}$	$1.60x10^{-7}$	$1.21x10^{-7}$	$2.6x10^{-7}$	$3.6x10^{-7}$	$3.475x10^{-7}$	$2.61x10^{-7}$	$3.66x10^{-7}$
COEFFICIENT OF VOLUME COMPRESSIBILITY (MV) (M^2/MN)	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
0-100 KN/M^2	0	0.01	$9.995x10^{-3}$	0.049	0.013	0	0	0
100-200 KN/M^2	0	0.04	0.095	0.016	0.013	0.036	0.019	0
200-400 KN/M^2	$3.39x10^{-3}$	0.06	0.063	0.036	0.041	0.034	0.031	$7.76x10^{-3}$
400-800 KN/M^2	$5.08x10^{-3}$	0.03	0.024	0.028	0.013	0.018	0.019	$4.98x10^{-3}$
800-1600 KN/M^2	0.01	0.02	0.025	0.015	0.019	0.014	0.013	0.010
1600-3200 KN/M^2	7.70	0.02	0.015	0.099	0.011	0.009	0.009	$8.55x10^{-3}$
OEDOMETER SETTLEMENT (SOED) (mm)	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
0-100 KN/M^2	0	0.025	0.020	0.093	0.025	0	0	0
100-200 KN/M^2	0	0.087	0.190	0.033	0.025	0.072	0.037	0

200-400 KN/M^2	0.014	0.250	0.252	0.143	0.163	0.135	0.124	0.030
400-800 KN/M^2	0.041	0.253	0.194	0.221	0.101	0.146	0.150	0.040
800-1600 KN/M^2	0.163	0.346	0.403	0.280	0.300	0.231	0.213	0.016
1600-3200 KN/M^2	0.246	0.496	0.485	0.317	0.335	0.287	0.292	0.274
COEFFICENT OF PERMEABILITY (K) (m/s)	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
0-100 KN/M^2	0	1.95x10^{-11}	1.19x10^{-11}	1.88x10^{-10}	3.21x10^{-11}	0	0	0
100-200 KN/M^2	0	6.84x10^{-11}	1.13x10^{-11}	6.28x10^{-11}	3.21x10^{-11}	4.87x10^{-11}	1.23x10^{-11}	0
200-400 KN/M^2	1.93x10^{-12}	9.82x10^{-11}	7.49x10^{-11}	1.36x10^{-10}	1.04x10^{-10}	7.95x10^{-10}	1.16x10^{-10}	2.79x10^{-11}
400-800 KN/M^2	2.90x10^{-12}	4.97x10^{-11}	2.88x10^{-11}	1.06x10^{-10}	3.24x10^{-10}	4.87x10^{-10}	6.14x10^{-10}	1.79x10^{-11}
800-1600 KN/M^2	5.81x10^{-12}	3.40x10^{-11}	2.99x10^{-11}	6.68x10^{-11}	4.88x10^{-11}	3.33x10^{-11}	4.77x10^{-11}	3.63x10^{-11}
1600-3200 KN/M^2	4.40x10^{-12}	2.43x10^{-11}	1.80x10^{-11}	3.79x10^{-11}	2.69x10^{-11}	2.31x10^{-11}	3.07x10^{-11}	3.07x10^{-11}

Table 10: Results of consolidation parameters and settlement potentials for lateritic soil from 0% to 30% cement substitutions

PARAMETERS	**CONTROL (0% CEMENT)**	**10% CEMENT**		**20% CEMENT**		**30% CEMENT**	
SOAKED HOUR	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
PRECONSOLIDATION PRESSURE (PC) (KN/M^2)	110	300	1030	2000	2750	1350.50	1370.50
COMPRESSION INDEX (CC)	0.063	0.062	0.052	0.038	0.022	0.329	0.251
COEFFICIENT OF CONSOLIDATION (CV) (m^2/sec)	3.17x10^{-7}	5.78x10^{-7}	1.88x10^{-7}	2.65x10^{-7}	4.59x10^{-7}	5.41x10^{-7}	4.76x10^{-7}
COEFFICIENT OF VOLUME COMPRESSIBILITY (MV) (M^2/MN)	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
0-100 KN/M^2	0.025	0.042	0	0	0	0	0
100-200 KN/M^2	0.091	0.014	7.08x10^{-3}	0	0	5.73x10^{-3}	0
200-400 KN/M^2	0.106	0.045	0.011	6.94x10^{-3}	7.22x10^{-3}	0.123	3.56x10^{-3}
400-800 KN/M^2	0.017	0.018	5.32x10^{-3}	5.21x10^{-3}	0.014	0.088	5.34x10^{-3}
800-1600 KN/M^2	0.102	8.88x10^{-3}	8.00x10^{-6}	2.61x10^{-3}	3.63x10^{-3}	0.087	3.57x10^{-3}
1600-3200 KN/M^2	0.016	4.47x10^{-3}	5.82x10^{-6}	2.18x10^{-3}	3.19x10^{-3}	0.029	3.13x10^{-3}
OEDOMETER SETTLEMENT (SOED) (mm)	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
0-100 KN/M^2	0.050	0.084	0	0	0	0	0
100-200 KN/M^2	0.181	0.028	0.014	0	0	0.011	0
200-400 KN/M^2	0.434	0.182	0.043	0.028	0.029	0.986	0.014

400-800 KN/M²	0.135	0.141	0.042	0.042	0.116	0.705	0.042
800-1600 KN/M²	1.634	0.142	0.128	0.042	0.058	1.389	0.057
1600-3200 KN/M²	0.512	0.143	0.186	0.070	0.102	1.244	0.100
COEFFICENT OF PERMEABILITY (K) (m/s)	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*	*1-HR*	*24-HR*
0-100 KN/M²	$7.74x10^{-11}$	$2.39x10^{-10}$	0	0	0	0	0
100-200 KN/M²	$3.03x10^{-11}$	$7.94x10^{-11}$	$1.31x10^{-11}$	0	0	$3.00x10^{-11}$	0
200-400 KN/M²	$3.39x10^{-11}$	$2.58x10^{-11}$	$1.96x10^{-11}$	$1.80x10^{-11}$	$3.25x10^{-11}$	$6.54x10^{-10}$	$1.66x10^{-11}$
400-800 KN/M²	$5.26x10^{-11}$	$9.98x10^{-11}$	$9.72x10^{-12}$	$1.35x10^{-11}$	$6.51x10^{-11}$	$4.68x10^{-10}$	$2.49x10^{-11}$
800-1600 KN/M²	$3.17x10^{-11}$	$5.04x10^{-11}$	$1.48x10^{-11}$	$6.79x10^{-12}$	$1.64x10^{-11}$	$4.61x10^{-10}$	$1.67x10^{-11}$
1600-3200 KN/M²	$4.98x10^{-11}$	$2.54x10^{-11}$	$1.07x10^{-11}$	$5.67x10^{-12}$	$1.44x10^{-11}$	$2.06x10^{-10}$	$1.46x10^{-11}$

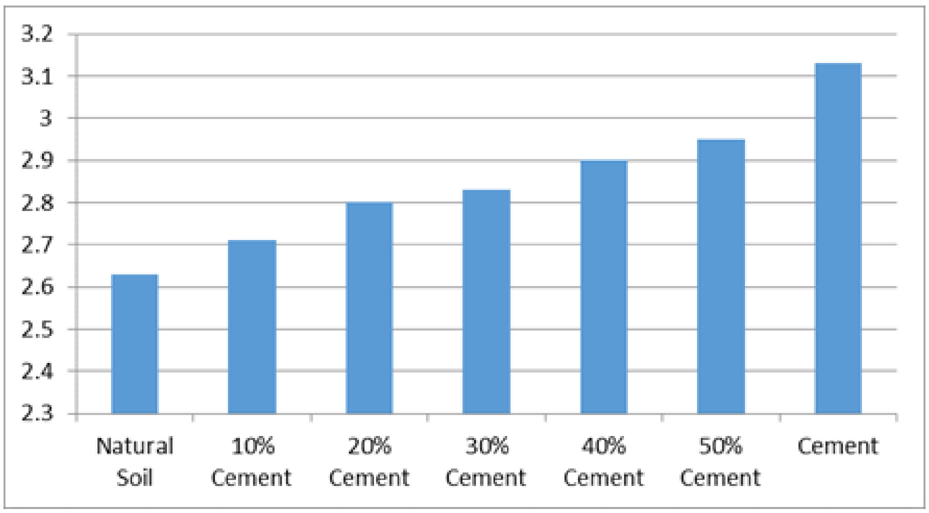

Figure 11: Results of Specific Gravity Test for Black cotton soil

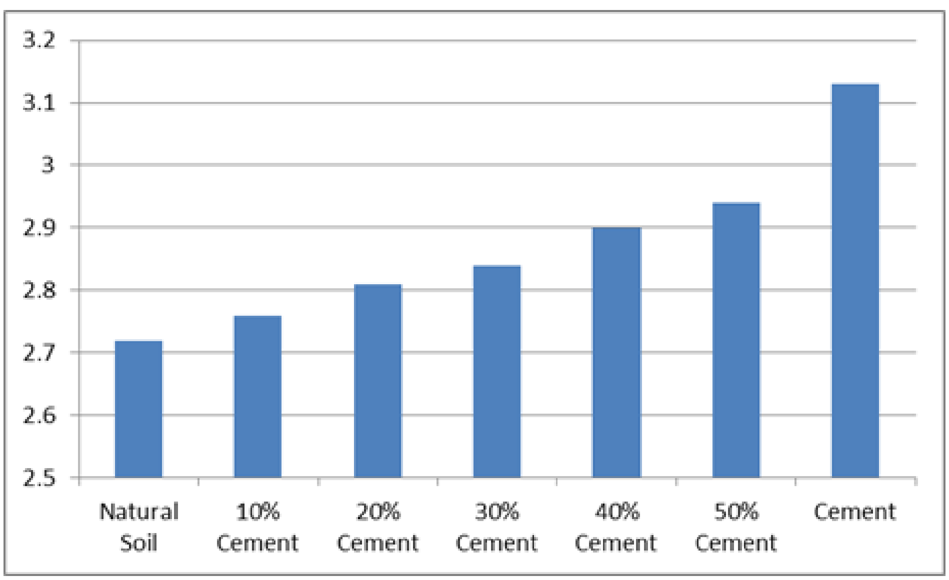

Figure 12: Specific gravity result for lateritic soil

Tables 9 and 10 compares the results of consolidation parameters and settlement potentials for black cotton and lateritic soils when at virgin soil and when mixed with cement in proportion of 10, 20, 30% substitutions. It is observed that the effect of cement on the soil is more. There are slight changes in the soil after the addition of cement. Table 4 compares the results of consolidation parameters when at virgin soil and when mixed with cement in proportion of 10, 20, and 30%. It is observed that the effect of cement on the soil is more. Increase in cement content after 1 hour soak is more stable compared to 24 hours soaked and the value went on adding to 30% of cement. For 1-hour soaked samples, black cotton and lateritic soils shows high resistant to load application due to the absence of moisture (water content) in the soil particles compared to 24-hour soaked having high presence of moisture (water content) Compression on application of pressure loads and expansion characteristics after gradual removal of pressure loads in the dial gauge readings also shows similar characteristics. Pre-consolidation pressure, Pc, and compression index, Cc in black cotton soil reduces as the percentage cement substitutions increases while coefficient of consolidation increases as the percentage cement substitutions. In the case of lateritic soil, it shows stability on the application cement stabilization.

Conclusion

In this study, the impact of underground accidental explosions occurring below the ground surface and directly above buried pipes This study has presented the results of various coefficient of consolidation of eggshell powder stabilized sedimentary formation from oedometer test. Eggshell powder was substituted in the lateritic soil (sedimentary formation) in range of 0% to 50% with 0% serving as control experiment for both the 1-hour soaked and 24-hour-soaked samples**.** The result implies that the optimum substitution level of eggshell powder is at 10% for the one hour soaked and 20% for the 24hour soaked sample. Finally, from the results, coefficient of consolidation reduces as the percentage eggshell powder substitution increases.

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