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Settlement Analysis of Cement and Residue from Spent Calcium Carbide Stabilized Cohesive Soil.

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Abstract
Foundation settlement is a difficult issue frequently experienced in structures; the whole structure may collapse if built on poor soil without proper site investigation. Therefore stabilization to improve the engineering properties of soft soil and reduction in construction constraints is necessary. Undisturbed soil samples obtained at depth of 1-2 metres were blended with Portland Limestone Cement (PLC) and Residue from Spent Calcium Carbide (RSCC) and later subjected to Consolidation test. The cohesive soil was mixed with 3%, 4%, 5% and 6% PLC content by weight of the soil and for every percentage of PLC content, 7%, 9%, 11%, 13% and 15% RSCC by weight of the soil was added. Results revealed that there were decrease in the compression index, coefficient of volume change and settlement of the stabilized soil due to the addition of PLC and RSCC. Furthermore, addition of more than 5% PLC and 15% RSCC resulted in an increase in compression index and coefficient of volume change while addition of more than 6% PLC and 11% RSCC caused increase in settlement. From the results, the most suitable mix proportion of PLC and RSCC for the stabilization of cohesive soils is 6% PLC and 11% RSCC to meet settlement criteria. In view of the experimental results, PLC and RSCC mixed together blends reasonably for the stabilization of cohesive soils.

Keywords: *Cohesive soils, Portland Limestone Cement, Residue from Spent Calcium Carbide, Settlement, Soil Stabilization.*

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I. Introduction

Settlement in saturated cohesive soil is characterized into: (1) Immediate settlement as the load is applied, (2) Consolidation settlement as excess pore pressures generated by loads are dissipated, and (3) secondary or creep settlement controlled by the soil's composition and structure.

The tendency of foundation constructed on saturated cohesive soils to deform over time is time dependant. In most cases, both immediate and consolidation settlements are evaluated to determine if the projected deformation is within the superstructure's tolerance limit (Akpila, 2013). When heavily stressed by structural loadings, foundation soil tends to deform more than the allowable limits. As a result of the soil's low bearing capacity, larger foundation sizes are required, which is uneconomical. The engineering properties of foundation soils determine the soil's resistance to deformation. In such cases, it is necessary to improve the foundation soil in order to address the allowable settlements by means of stabilization.

Low load bearing cohesive soils are evidently widespread in Rivers state, Nigeria and this has a significant impact on foundation deformation (settlement). Therefore stabilization to improve the engineering properties of soft soil and reduce construction constraints is necessary.

Portland Limestone Cement (PLC) has been successfully utilized to improve cohesive soils (Ho and Chan 2011; Cecchin et al. 2017; Fan et al. 2017; Bobet et al. 2011; Horpibulsuk et al. 2005, 2010, 2015b; Sukmak et al. 2015). However, its production technique has created a number of economic and environmental concerns that need to be addressed further. Significant CO_2 emissions from combustion and other associated industrial processes (Chang et al. 2015), particle air pollution and NOx (nitrogen oxide) emissions are among these problems (Rashid et al. 2017). As a result of the aforementioned issues, there is a growing interest in researching more environmentally friendly alternative additives that are also affordable to replace or partially replace PLC. This idea has led to the utilization of varieties of industrial waste materials and by-products such as gypsum, slags, fly ash, Residue from spent Calcium Carbide (RSCC), geopolymers etc. for clay stabilization (Yilmaz and Civelekoglu 2009).

Residue from Spent Calcium Carbide (RSCC) is a by-product of acetylene gas production process that contains a considerable amount of $Ca(OH)_2$, making it a potentially appealing alternative for usage as a stabilizing agent. Except for the inclusion of carbon, RSCC is chemically and mineralogically similar to hydrated lime (Suksiripattanapong et al. 2017).

Previous studies on the use of PLC and RSCC for the stabilization of cohesive soils have mostly focused on modifications with respect to road pavements. In addition, related studies on its use include strength characteristics of soils in terms of foundation of structures. However, there is a dearth of information on the deformation characteristics of using PLC and RSCC for stabilized cohesive soils. Therefore, the bridge between the present study and previous is in the use of RSCC and PLC as a blend for stabilization of cohesive soil with respect to deformation response to loading for the most suitable mix proportion of PLC and RSCC stabilized cohesive soil.

II. Materials And Methods

2.1 Materials

The clayey soil samples used were collected from Amalem community in Abua, Rivers State, Nigeria. The Portland Limestone Cement was acquired from roadside building material vendors in Mile 3 market Diobu Port Harcourt's. The Residue from Spent Calcium Carbide was obtained from various auto mechanic workshops in Port Harcourt.

2.2 Methods

The remolded soil samples were taken at a depth of 1.0m to 2.0m below ground level. These samples were subsequently sent to a Geotechnical and Chemical Engineering Laboratory for tests. The RSCC was oven-dried for 24 hours at 100°C before being ground in a Los Angeles abrasion machine. A 425-μm sieve was used to filter larger particles from the RSCC. Every laboratory tests and data analysis followed American Society for Testing and Materials (ASTM) and British Standard (BS) guidelines for soil testing. The moisture content, specific gravity, particle size distribution, Atterberg limit and UCS of the cohesive soil (clay) were all examined first. The specific gravity, as well as physical and chemical parameters, of the PLC and RSCC, were assessed. Various percentages of cement content (3% - 6 %) were employed, and each percentage of cement content was combined with 7%, 9%, 11%, 13%, and 15% RSCC content, respectively.

Consolidation Test for PLC and RSCC Modified Soil was also carried out. The soil sample was mixed with PLC (3% - 6%) and for each percentage of the soil cement mixture, 7%, 9%, 11%, 13% and 15% RSCC was added. The bulk density of the soil, as well as its initial moisture content, was determined first. After cleaning and weighing the specimen ring, the sample was placed in the consolidation ring. A 12mm thick porous plate was put at the bottom of the consolidation pot. The top of the specimen was then covered with a porous plate 18mm thick, and the screws were tightened to secure the consolidation ring in place. Furthermore, the oedometer was set in the consolidation machine at the same time as the loading arm was leveled and the dial gauge was adjusted to zero. The stop clock was started simultaneously as the 2.27kg load was applied, and the consolidation pot was immediately filled with water to completely saturate the sample. At intervals of 10, 15, 30 seconds, 10, 15, 30 minutes, 1, 2, 4, 8, 20, and 24 hours, dial gauge readings were taken. The weights were then increased to 4.54kg, 9.07kg, and 18.14kg, respectively. As before, the dial gauge readings were taken. The sample was unloaded after the final loading and the final dial reading was recorded. After draining the water from the pot, the sample was taken from the ring and the moisture content was determined.

Table 1 shows that 40 samples (2 per percentage) of PLC and RSCC of varying mix proportions were prepared for consolidation test.

Table 1: Number of PLC and RSCC Stabilized Soil Samples for consolidation test

PLC (%)	RSCC (%)	NO OF SAMPLES	TOTAL NO OF SAMPLES
3	7, 9, 11, 13 and 15	2	10
4	7, 9, 11, 13 and 15	2	10
5	7, 9, 11, 13 and 15	2	10
6	7, 9, 11, 13 and 15	2	10
TOTAL SAMPLES			**40**

After the test, the following calculation procedures to obtain the consolidation properties is shown using equations (2.0) – (2.7).

- Height of Solids (H_s) is calculated from;

$$H_s = \frac{M_d}{G_s A \rho_w} \tag{2.0}$$

Where;

M_d= dry mass of soil specimen
A = cross sectional area of the specimen
G_s = specific gravity of soil solids
$\boldsymbol{\rho}_w$ = density of water.

- Voids ratio (e) is calculated from;

$$e_0 = \frac{H - H_s}{H_s} \quad (2.1)$$

Where;

H = final specimen height

- Compression Index $C_{c.}$: To determine the compression index, plot of voids ratio e versus log$\boldsymbol{\sigma}$' is made. The initial compression curve would be found to be a straight line and the slope of this line would give the compression index $C_{c.}$

Mathematically; $$C_c = \frac{e_0 - e_1}{\log(\frac{p_1}{p_0})} \quad (2.2)$$

Where;

e_0= initial void ratio
e_1= final void ratio
p_0= initial pressure
p_1= final pressure

- Coefficient of Compressibility a_v is calculated as follows:

$$a_v = \frac{0.435\,C_c}{\sigma'} \quad (2.3)$$

Where;

a_v = Coefficient of compressibility
$\boldsymbol{\sigma}$' = Average pressure for the increment

- Coefficient of Volume Change m_v is calculated as follows:

$$m_v = -\frac{a_v}{1+e_0} \quad (2.4)$$

$$or \quad m_v = \frac{1}{1+e_0}\, x\, \frac{e_0 - e_1}{p_1 - p_0} \quad (2.5)$$

- Consolidation Settlement is calculated as follows:

$$\rho_f = m_v H \boldsymbol{\Delta}\sigma' \quad (2.6)$$

or $$\rho_f = \frac{e_0 - e_1}{1+e_0}\, x \text{ H} \quad (2.7)$$

III. Results And Discussion

3.1 Properties of the Cohesive Soil

The properties of Amalem cohesive soil is shown in Table 2, which helps in the identification and classification of the soil for general engineering purposes. The physical and chemical properties of PLC and RSCC are shown in Table 3.

Table 2: Properties of Amalem Cohesive Soil

PROPERTY	VALUE
Moisture content (%)	23.65
Bulk density kN/m^3	20.59
Specific gravity	2.4
Liquid Limit (%)	33.2
Plastic Limit (%)	9.36
Plasticity index (%)	23.84
Coefficient of Volume Change (m^2/kN)	0.00343
Compression Index	0.301
Settlement (mm)	146
Unified soil classification system (USCS)	CL
AASHTO classification	A-6

Table 3: Physical and Chemical Properties of PLC and RSCC

PROPERTY	PLC	RSCC
Ph	11	12.20
CaO (%)	64	61.41
SiO_2 (%)	20.40	2.69
Al_2O_3 (%)	5.75	1.78

Fe_2O_3 (%)	2.50	0.17
MgO (%)	1.94	0.80
SO_3 (%)	2.75	0.36
LOI (%)	1.20	32.51

3.2 Coefficient of Volume Change of PLC and RSCC Modified Cohesive Soil

Table 4 shows the coefficient of volume change, Compressibility Index and Settlement for unmodified and modified soil samples results obtained from consolidation tests on different mixtures of PLC (3% - 6%) and RSCC (7% - 15%) stabilized cohesive soil and with the use of Equations (2.0) to (2.7).

Table 4: Coefficient of volume change, m_v, Compressibility Index, c_c and Settlement, ρ_f Values for Unmodified and Modified Soil Samples

PLC Content (%)	RSCC Content (%)	m_v (m^2/kN)	c_c	ρ_f (mm)
0	0	0.00343	0.301	146
	7	0.00193	0.170	118
	9	0.00166	0.144	105
3	11	0.00124	0.109	104
	13	0.00097	0.086	103
	15	0.00079	0.071	102
	7	0.00056	0.050	100
	9	0.00040	0.036	99
4	11	0.00027	0.024	98
	13	0.00024	0.021	84
	15	0.00021	0.019	75
	7	0.00021	0.018	66
	9	0.00019	0.016	61
5	11	0.00016	0.013	51
	13	0.00014	0.011	40
	15	0.00011	0.008	30
	7	0.00016	0.013	28
	9	0.00022	0.017	25
6	11	0.00027	0.020	21
	13	0.00049	0.036	23
	15	0.00076	0.056	26

Figure 1 and 2 shows the behavior of the cohesive soil for each percentage of PLC and its varied RSCC content.

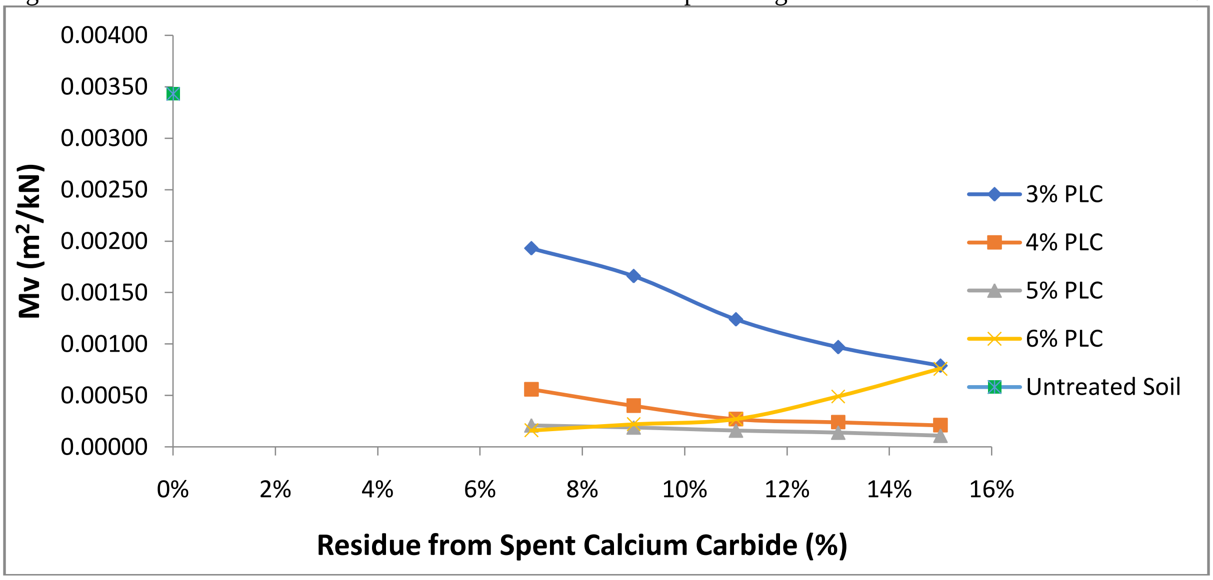

Figure 1: Coefficient of Volume Change, m_v of PLC and RSCC Modified Cohesive Soil

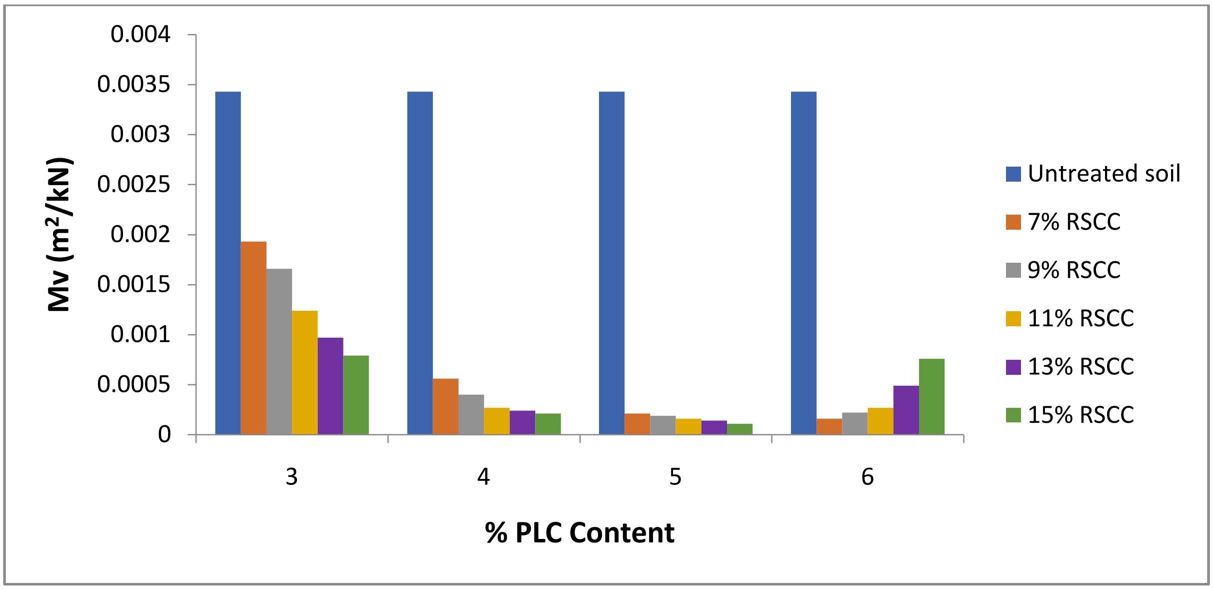

Figure 2: Bar Chart Showing m_v of PLC and RSCC Modified Cohesive Soil

From the results presented in Figure 1 and 2, the coefficient of volume change reduced as the PLC and RSCC content increased. This means that addition of RSCC to the cohesive soil improved the Coefficient of Volume Change. In any case, addition of over 5% PLC and 15% RSCC caused an increase in the Coefficient of volume change. This is due to increasing PLC and RSCC content forming a gel-like material that made the soil structure more porous, counteracting the strength obtained by cementation and thus reduced the bond between the cohesive soil and the modifiers.

3.3 Compression Index of PLC and RSCC Modified Cohesive Soil

Figure 3 and 4 shows the cohesive soil's behavior for each percentage of PLC and its varied RSCC content.

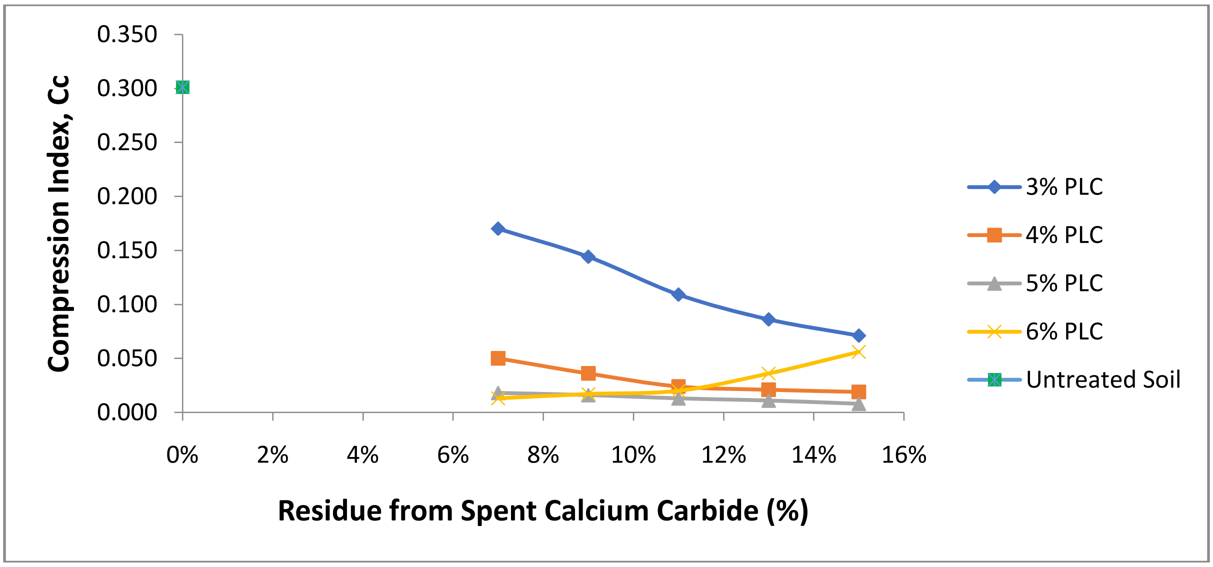

Figure 3: Compression Index, C_c of PLC and RSCC Modified Cohesive Soil

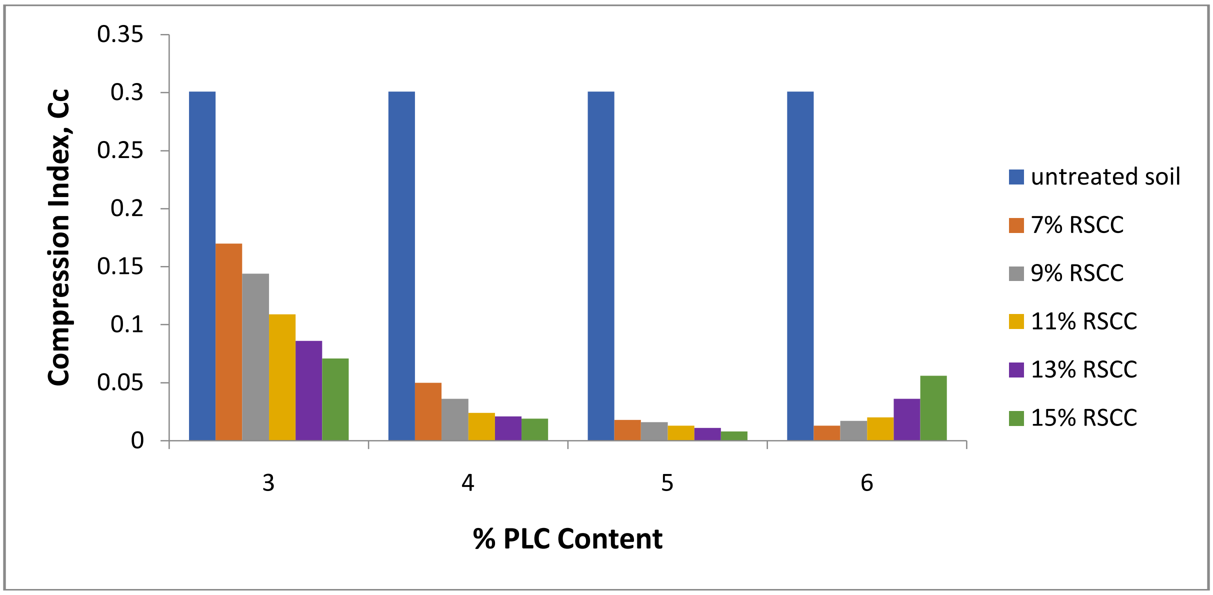

Figure 4: Bar Chart Showing C_c of PLC and RSCC Modified Cohesive Soil

The result revealed that the Compression index followed the same trends as that of coefficient of volume change, decreasing as the PLC and RSCC content increased. This means that adding RSCC to the cohesive soil improved the compression index. However, the addition of more than 5% PLC and 15% RSCC resulted in the increase in the Compression Index and this is as a result of the same reason as that of the coefficient of volume change.

3.4 Settlement of PLC and RSCC Modified Cohesive Soil

Figure 5 and 6 shows the cohesive soil's behavior for each percentage of PLC and its varied RSCC content.

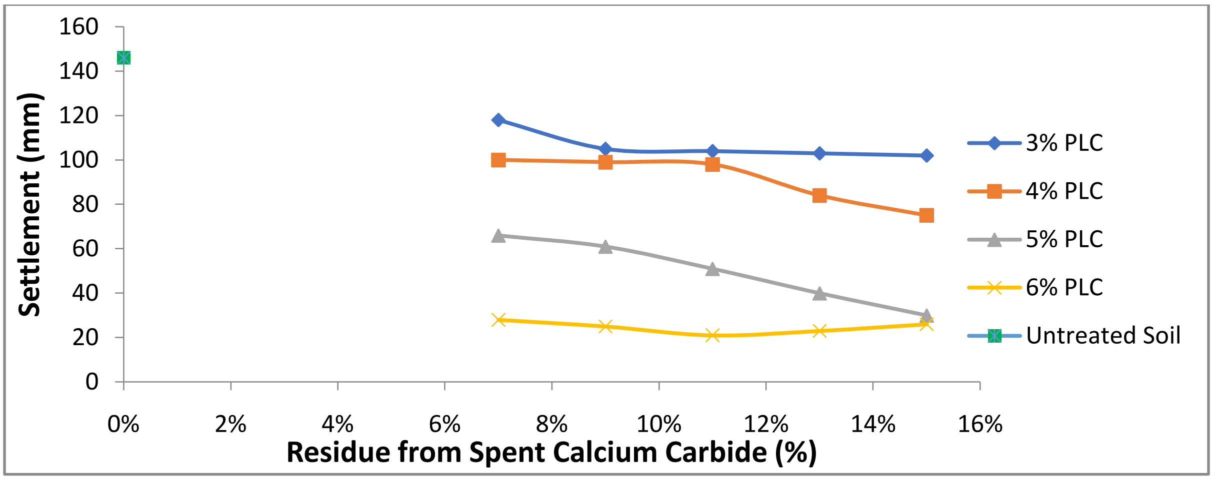

Figure 5: Settlement of PLC and RSCC Modified Cohesive Soil

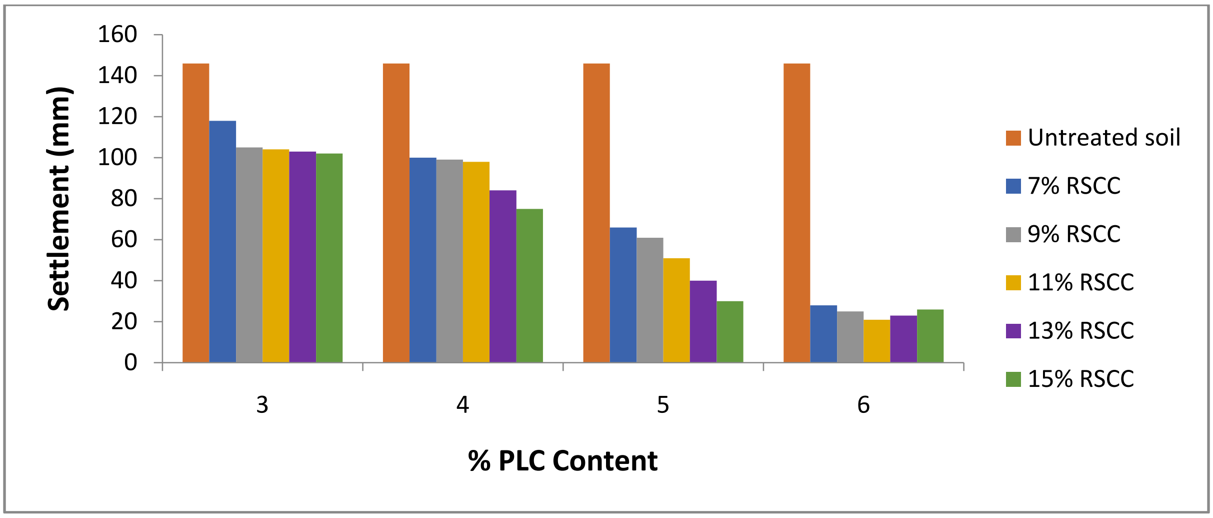

Figure 6: Bar Chart Showing Settlement of PLC and RSCC Modified Cohesive Soil

The results obtained showed that the natural (untreated) soil settlement is 146mm, indicating that the soil did not satisfy the maximum total allowable settlement criteria for cohesive soils as prescribed in IS- 1080 (1986). The blended proportion of PLC and RSCC result showed that the settlement of the soil decreased as the PLC and RSCC content increased. This suggests that the addition of PLC and RSCC improved the cohesive soil's settlement. However, the most suitable blend was recorded at settlement of 21mm that is at 6% PLC and 11% RSCC which gave about 85.62% improvement from the natural (untreated) settlement of the soil. Furthermore, addition of more than 6% PLC and 11% RSCC to the soil resulted in an increase in soil settlement and this is because of the same reason stated in the coefficient of volume change. However, the settlement values from 100mm below as shown in Table 4 meets the maximum allowable for shallow foundations and is in accordance with the IS- 1080 (1986) standard.

IV. Conclusion

From the results of the investigation carried out, the following conclusions can be drawn:

i. The modified cohesive soil in terms of Coefficient of volume change, Compression index and Settlement performed better than the unmodified soil sample.
ii. The most suitable mix proportion of PLC and RSCC with cohesive soils in relation to Coefficient of volume change, Compression index and Settlement is 6% PLC and 11% RSCC.

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