



## STABILIZATION OF HIGHWAY EXPANSIVE SOILS WITH HIGH LOSS ON IGNITION CONTENT KILN DUST

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### ABSTRACT

*This study was carried out to evaluate the effect of high loss on ignition content cement kiln dust on the stabilization of highway expansive soils. Laboratory tests were performed on the natural and stabilized soil samples in accordance with BS 1377 (1990) and BS 1924 (1990), respectively. The preliminary investigation carried out on the expansive soil (also known as black cotton soil) found in Deba, Gombe State, Nigeria shows that it falls under Silt-Clay material of Group A-7-6 (16) using AASHTO classification and inorganic clay material CL according to Unified Soil Classification System (USCS). The maximum dry density (MDD) for British Standard Light (BSL) and British Standard Heavy (BSH) compactive efforts increased to peak values of 1.66 and 1.91 Mg/m<sup>3</sup> at 6% and 4% cement kiln dust (CKD) contents respectively. The MDD for West African Standard (WAS) compactive effort increased with higher CKD content. The Optimum Moisture Content (OMC) for BSL and BSH compactive efforts increased up to 6% CKD content then decreased with higher CKD content. For the WAS compactive effort, the OMC generally decreased with higher CKD content. The unsoaked California bearing ratio (CBR) values of 3, 5 and 7% for the natural soil compacted with BSL, WAS and BSH compactive efforts, respectively, increased to 7, 10 and 19% at 10% CKD content. The 24 hour soaked CBR values of the natural soil of 3% for BSL, 3% for WAS and 5% for BSH compactive energies, respectively increased to their peak values of 5%, 6% and 8% respectively at 10% CKD content*

*Keywords:* Modification, Cement Kiln Dust, Black Cotton Soil, California bearing ratio

### 1. INTRODUCTION

Geotechnically, soil improvement could either be by modification or stabilization, or both. Soil modification is the addition of a modifier (cement, lime, cement kiln dust, etc) to a problem soil to improve its index properties for better usefulness, while soil stabilization is the treatment of problem soils to improve their index properties and strength characteristics such that they permanently become suitable for construction and meet engineering design standards.

In all engineering design, the principal aim is to design against failure [1]. The need to reduce 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. For this is prodigy to a safe disposal of industrial and agricultural wastes that requires urgent and cost effective solutions to the devastating effect of these

materials on the environment and health hazards that they constitute.

Expansive soils are also referred to as “black cotton soil” in some parts of the world like Nigeria. They are so named because of their colour and suitability for growing cotton. Black cotton soils have colours ranging from light grey to dark grey and black [2]. Black cotton soils are confined to the semi-arid regions of tropical and temperate climatic zones and are abundant where the annual evaporation exceeds the precipitation [3, 4]. Black cotton soils occur in continuous stretches as superficial deposits and are typical of flat terrains with poor drainage. The absence of quartz in the clay mineralogy enhances the formation of fine-grained soil material, which is impermeable and waterlogged [5].

The mineralogy of this soil is dominated by the presence of montmorillonite which is characterized by large volume change from wet to dry seasons and vice

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versa. Deposits of black cotton soil, which occupy an estimated area of  $104 \times 10^3 \text{ km}^2$  in North-Eastern Nigeria, show a general pattern of cracks during the dry season of the year. Cracks measuring 70mm wide and over 1m deep have been observed and may extend up to 3m deep or more in case of high deposit [6].

Cement kiln dust (CKD) or cement by-pass dust (CBPD) is the fine grained, solid highly alkaline waste removed from cement kiln exhaust gas by air pollution control devices. A typical Portland cement is manufactured by feeding materials containing appropriate proportions of lime, silica, alumina and iron into the upper end of a kiln. The mix passes through the kiln at a rate controlled by the slope of the kiln and the speed at which the kiln rotates. Burning fuel is forced into the lower end of the kiln where it produces temperatures of 1400-1650°C, changing the raw mix to a cement clinker. During this operation a small percentage of the material in the form of dust (i.e. CKD) is collected. The physical and chemical properties of CKD can vary from plant-to-plant, depending on the raw materials used and type of collection process in the plant. However, the dust collected from the same kiln and producing the same cement type will typically have a relatively consistent composition.

The major parameters that determine CKD characteristics are the raw feed material, type of kiln operation, dust collection systems, and fuel type. Since the properties of CKD can be significantly affected by the design, operation and materials used in a cement kiln, the chemical and physical characteristics of CKD must be evaluated on an individual plant basis [7].

CKD containing high CaO content and low loss on ignition (LOI) performs best for most applications [8]. High LOI dusts contain a higher percentage of bound water within its chemical structure and less CaO is available to react. The high LOI can also interfere with the hydration process. Several processing factors influence the chemical and physical properties of CKD. Because plant operations differ considerably with respect to raw feed, type of operation, dust collection facility, and type of fuel used, CKD from each plant can vary markedly in chemical, mineralogical and physical composition. Therefore it is important to thoroughly test CKD upon high or low loss of ignition content for any proposed application for soil modifications or stabilization prior to use [8].

Bhatty and Todres [9], reviewed some existing literatures and summarized them as follows:

- CKD with high free lime ( $\approx 15\%$ ) and low alkalies ( $< 4\%$  water soluble  $\text{K}_2\text{O}=\text{Na}_2\text{O}$  or  $< 3\%$   $\text{Na}_2\text{O}$  equivalent) resulted in improved compressive strengths for clay soils.
- CKDs with low free lime ( $< 8\%$ ) and high alkali CKD ( $> 7\%$  water soluble  $\text{K}_2\text{O}=\text{Na}_2\text{O}$  or  $> 3\%$   $\text{Na}_2\text{O}$  equivalent) adversely affected the unconfined compressive strength.
- High loss on ignition (LOI) indicates that the CKD is high in slow-reacting calcium carbonate and low in reactive free lime. A high LOI was not defined numerically, however a CKD with a LOI of 28% was described as high.
- Higher concentrations of alkalies in CKDs can counter stabilization reactions because of ionic interference.
- CKD with low LOI ( $< 9\%$ ) and moderate alkalies ( $> 3\%$   $\text{Na}_2\text{O}$ ) reduced the PI and improved the unconfined compressive strength.
- CKDs with moderate free lime and low alkalies were shown to improve plastic indices, reduce swelling, and improve strength and durability.

## 2. MATERIALS AND METHODS

### 2.1 Materials

The disturbed black cotton soil samples used for this study were collected in March, 2012 at Deba (Latitude  $10^{\circ}13'N$  and longitude  $11^{\circ}23'E$ ), Gombe State, Nigeria. The Cement Kiln Dust (CKD) was obtained from Sokoto Cement Factory, Sokoto, the capital of Sokoto State of Nigeria directly from the factory's kiln dust collection cylinder. The characterization of the CKD by determining its chemical composition was conducted by method of Energy Dispersive X-Ray Fluorescence at the Nigerian Geological Survey Agency, Barnawa-Kaduna. The loss on ignition content of the CKD used in this study was characterized as high (39.28%) considering the literature review of Bhatty and Todres [9].

Laboratory tests were performed on the natural soil samples in accordance with BS 1377 [10] and on the cement kiln dust treated black cotton soil in accordance with BS 1924 [11]. These tests include, particle size distribution, Atterberg limits, compaction characteristics and California bearing ratio tests.

### 2.2 Methods

#### 2.2.1 Particle Size Distribution

The particle size analysis test was carried out in accordance with BS 1377; 1990 Part 2. Wet sieving was conducted by measuring 200g of the soil sample

and soaking it for 24 hours. The sample was then washed through BS No 200 sieve. The particles retained were then dried in the oven for 24 hours and a dry sieving was carried out on the dried sample, while hydrometer sedimentation test was carried out on the portion passing BS No 200 sieve to obtain the particle size distribution.

### 2.2.2 Atterberg limits

The test includes the determination of the liquid limits, plastic limits and the plasticity index of the natural and CKD-stabilized soils. They were conducted in accordance with Test 3 of the BS 1377 (1990) Part 2.

### 2.2.3 Compaction test

The compaction tests were carried out on the natural soil and the stabilized soils with 0, 2, 4, 6, 8 and 10% of CKD; using the British Standard light (BSL), West African Standard (WAS) and the British Standard heavy (BSH) energies, in accordance with the Nigerian General Specifications [12].

### 2.2.4 California bearing ratio test

The strength characteristic test performed in this study is the California bearing ratio (CBR) test. It was carried out in accordance with the Nigerian General Specification [12] which specified that specimen be cured in the dry for six days and then soaked for 24 hours before testing.

## 3. RESULTS AND DISCUSSION

### 3.1 Chemical Composition of Cement Kiln Dust

The result of the chemical composition test is shown in Table 1.

### 3.2 Soil Identification

The results of the identification test conducted on the natural soil are summarized in Table 2.

### 3.3 Particle Size Distribution

The particle size analysis from hydrometer sedimentation test for black cotton soil – cement kiln dust mixtures are shown in Figure 1. On a general note, a nominal increase in the percentage fines was observed with increasing cement kiln dust content. This was as a result of the soil particles being replaced by the finer CKD particles, hence the increased finer particles.

Table 1: Chemical Composition of Cement Kiln Dust

| Oxide                          | Percentage of oxide in CKD |
|--------------------------------|----------------------------|
| CaO                            | 44.28                      |
| SiO <sub>2</sub>               | 7.24                       |
| Al <sub>2</sub> O <sub>3</sub> | 1.90                       |
| Fe <sub>2</sub> O <sub>3</sub> | 4.47                       |
| MgO                            | 0.82                       |
| MnO                            | 0.11                       |
| In <sub>2</sub> O <sub>3</sub> | 0.66                       |
| BaO                            | 0.11                       |
| SO <sub>3</sub>                | 0.13                       |
| Lu <sub>2</sub> O <sub>3</sub> | 0.05                       |
| LOI(1000°C)                    | 39.28                      |
| CdO                            | 1.3                        |
| Re <sub>2</sub> O <sub>7</sub> | 0.21                       |

Table 2: Properties of the Natural Black Cotton Soil

| Property  | Quantity             |
|---|----------------------|
| Percentage passing BS No 200 sieve                | 73.6                 |
| Natural Moisture Content, %                       | 21.0                 |
| Liquid Limit, %                                   | 48.2                 |
| Plastic Limit, %                                  | 27.2                 |
| Plasticity Index, %                               | 21.0                 |
| Linear Shrinkage, %                               | 16.9                 |
| Free Swell, %                                     | 80.0                 |
| Specific Gravity                                  | 2.33                 |
| AASHTO Classification                             | A-7-6 (16)           |
| USCS  | CL                   |
| NBRRI Classification                              | High swell potential |
| <i>Maximum Dry Density, Mg/m<sup>3</sup></i>      |                      |
| British Standard light                            | 1.63                 |
| West African Standard                             | 1.72                 |
| British Standard heavy                            | 1.82                 |
| <i>Optimum Moisture Content, %</i>                |                      |
| British Standard light                            | 18.0                 |
| West African Standard                             | 17.9                 |
| British Standard heavy                            | 14.6                 |
| <i>California Bearing Ratio (24hr soaking), %</i> |                      |
| British Standard light                            | 3                    |
| West African Standard                             | 3                    |
| British Standard heavy                            | 5                    |
| Colour  | Greyish black        |
| Dominant clay mineral                             | Montmorillonite      |

### 3.3 Effect of CKD on Atterberg Limits

The variation of liquid limit of black cotton soil with cement kiln dust content is shown in Fig. 2. The introduction of cement kiln dust into the soil first

caused an increase in the Atterberg limits to a peak value at 2% CKD treatment in the case of the liquid limit and 4% CKD treatment for plastic limit and linear Shrinkage and thereafter decreased. The increase can be attributed to addition of CKD which introduced more pozzolanic substance into the specimen that required more water for hydration to be completed. The subsequence decrease can be associated with the agglomeration and flocculation of the clay particles which is as a result of exchange ions at the surface of the clay particles. The trend observed in liquid and plastic limits is in agreement with Ramzi et al. [13]. There was a general decrease in the plasticity index value from a value of 21.0% for the natural soil to a least value of 12.8% at 6% CKD treatment. [14] and [15] reported that the reduction

in plasticity index with chemical treatment could be attributed to the depressed double layer thickness due to cation exchange by potassium, calcium and ferric ions. A nominal increment was observed at 8 and 10% CKD contents.

**3.4 Effect of CKD on Compaction Characteristics**

**3.4.1 Maximum Dry Density**

The variation of maximum dry density (MDD) of black cotton soil with cement kiln dust contents for the three compactive efforts are shown in Fig. 3.

For British Standard light (BSL) and British Standard Heavy (BSH) compactions, the MDD increased from 1.63 and 1.82Mg/m<sup>3</sup> for the natural soil to 1.66 and 1.91Mg/m<sup>3</sup> at 4 and 6% CKD contents respectively.

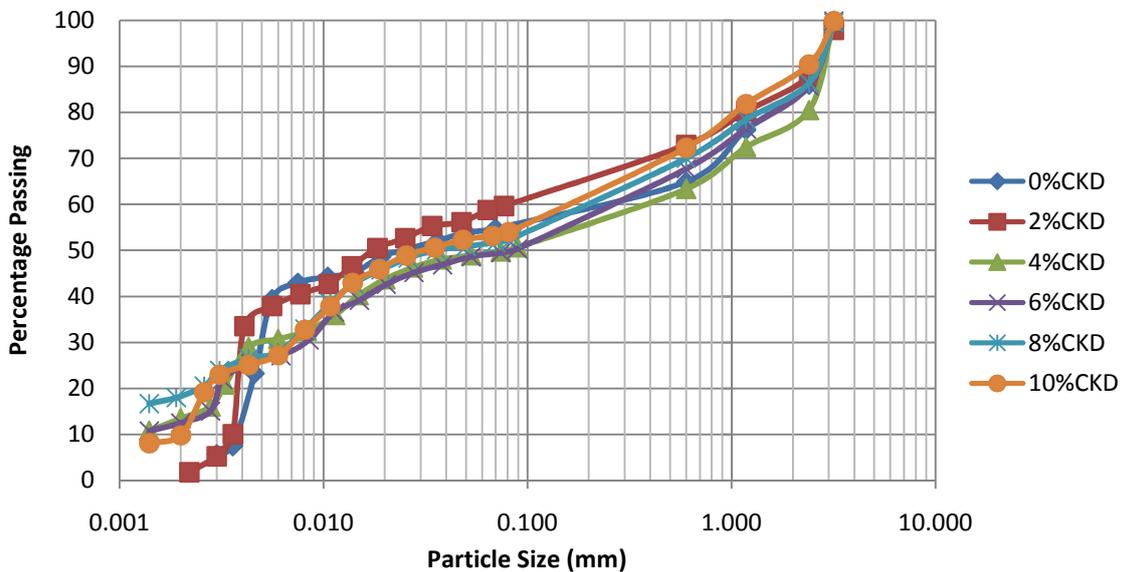


Figure 1: Particle Size Distribution curves of combined Dry and Hydrometer Sedimentation Tests of Black Cotton Soil-Cement Kiln Dust Mixtures

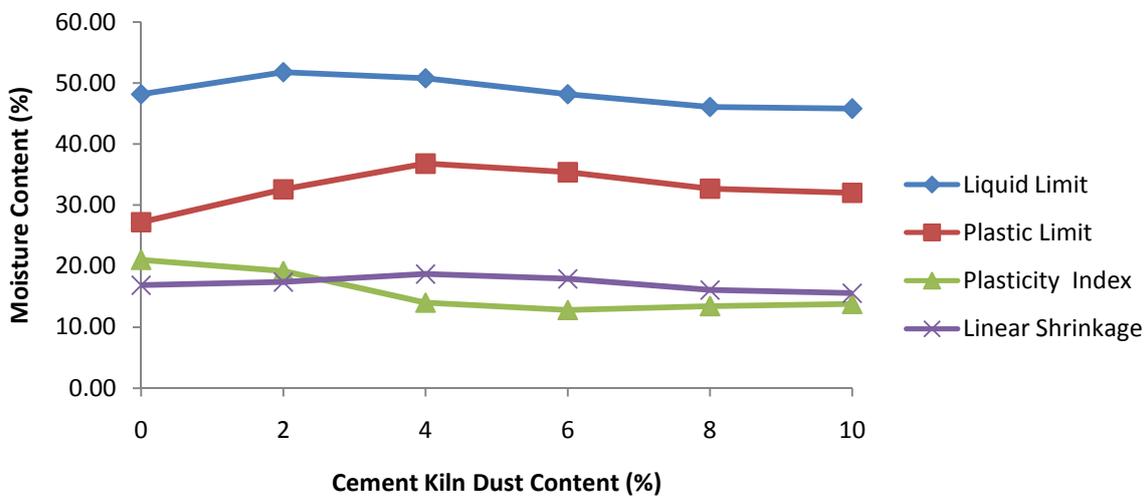


Figure 2: Variation of Atterberg Limits of Black Cotton Soil with Cement Kiln Dust Content

This increase in dry density with addition of CKD may be due to cation exchange reactions. It could also be due to CKD occupying the void within the soil matrix and in addition, the flocculation and agglomeration of the clay particle due to exchange of ions [1, 16, 17,]. The subsequent reduction in MDD may be probably due to the fact that for any soil/admixture, there is always a water content to produce maximum strength [18]. This trend is in agreement with Ola [19], Lees et al. [20] and Iorliam et al. [21]. The result of the West African Standard (WAS) compaction is in conformity with the trend of decreasing OMC with increasing MDD.

three compactive efforts is shown in Fig.4. For BSL and BSH compactions, the OMC increased from values of 18.0% and 14.6% for the natural soil to peak values of 19.7% and 15.8% both at 6%CKD contents.

This trend is in conformity with results reported by Ola [22], Gidigasu [23] and Osinubi [18]. An explanation that was offered for this trend is that there was increasing desire for water which commensurates with the higher amount of the additives because more water was required for the dissociation of admixtures with Ca<sup>2+</sup> and OH<sup>-</sup> ions to supply more Ca<sup>2+</sup> for the cation exchange reaction. The subsequent decrease in OMC with increase in CKD content might be due to cation exchange reaction that caused the flocculation of clay particles.

**3.4.2 Optimum Moisture Content**

The variation of optimum moisture content of black cotton soil with cement kiln dust contents for the

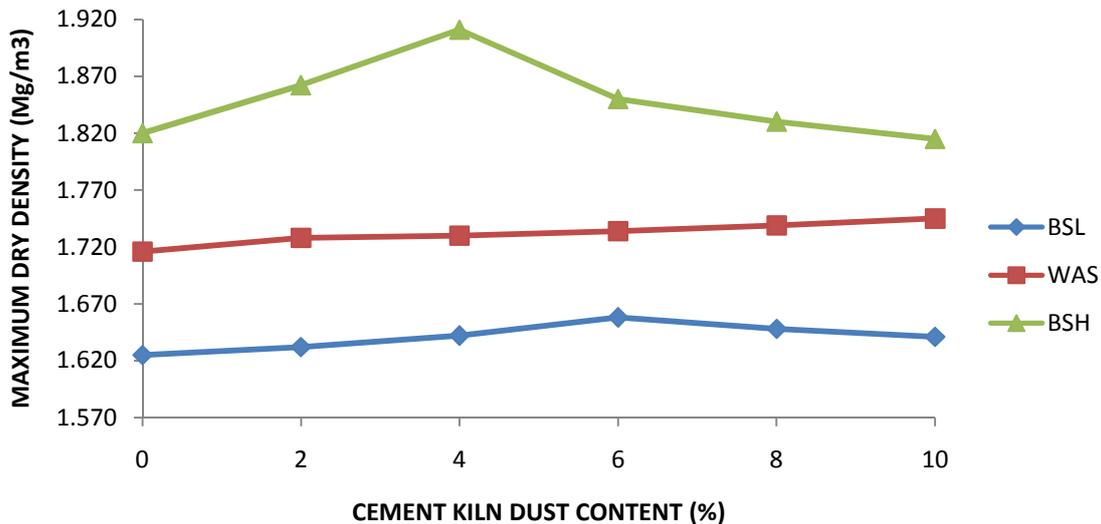


Figure 3: Variation of Maximum Dry Density of Black Cotton Soil with Cement Kiln Dust Content

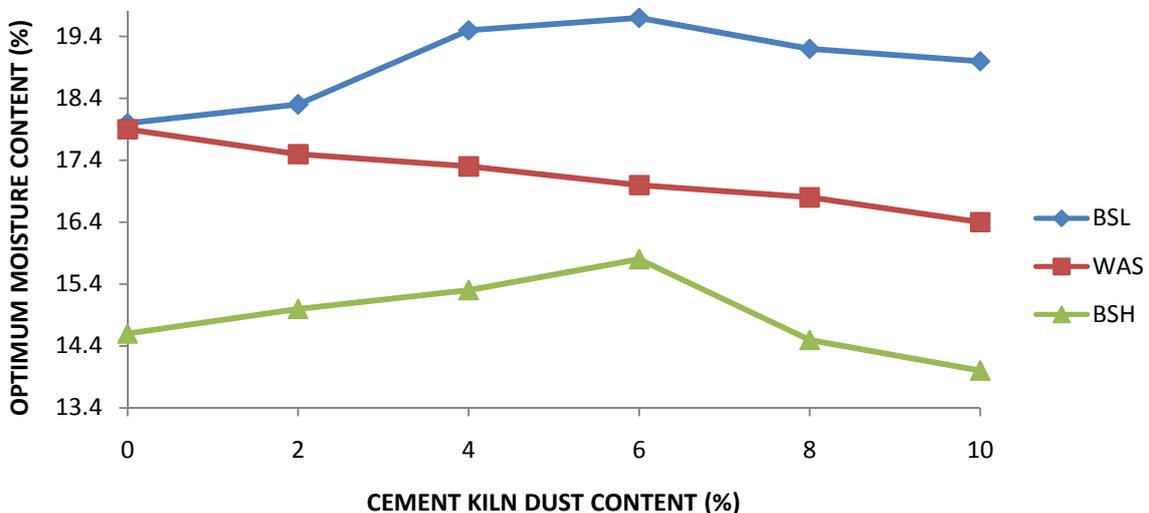


Figure 4: Variation of Optimum Moisture Content of Black Cotton Soil with Cement Kiln Dust

### 3.5 California Bearing Ratio

#### 3.5.1 Unsoaked CBR

The variation of the unsoaked CBR values with cement kiln dust content for the three energy levels used for compaction is given in Figure 5. A general increase in CBR values with CKD content was observed. This increase could be due to the presence of adequate amounts of calcium required for the formation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), which are the major compounds responsible for strength gain. The soil-CKD mixtures failed to meet the minimum CBR value of 30% specified by (BS 1990) for materials suitable for use as base course material when determined at MDD and OMC.

The highest unsoaked CBR value of 18.82% was observed at 10% CKD content using the BSH compactive effort. This is close to the findings of Gidigas and Dogbey (1980) [24], which stated that minimum CBR value of 20-30% is required for sub-bases when compacted at OMC.

#### 3.5.2 Soaked CBR

The variations of soaked CBR (24 hours soaking) of natural and CKD-stabilized soil using BSL, WAS and BSH compactive efforts are shown in Figure 6. It was observed that the CBR values, both unsoaked and

soaked, increased with higher CKD contents and higher compactive effort.

### 4. CONCLUSION

From the results of the study conducted, the following conclusions can be drawn.

- ❖ The black cotton soil is classified as A-7-6 (16) using the AASHTO classification system and CL using the USCS. This makes it geotechnically a problem soil.
- ❖ A high lost on ignition (LOI) content cement kiln dust (CKD) has no significant effect on the particle sizes of black cotton soil.
- ❖ The effect of high LOI content CKD on the Atterberg limits is most significant (for soil modification) at 10% or more.
- ❖ Generally, the chemical, mineralogical and physical composition of CKD should be thoroughly evaluated on an individual plant basis because several processing factors influence them.
- ❖ Cement kiln dust with high Loss on Ignition and alkali contents should be avoided in use for expansive soil modifications due to its low CBR values.

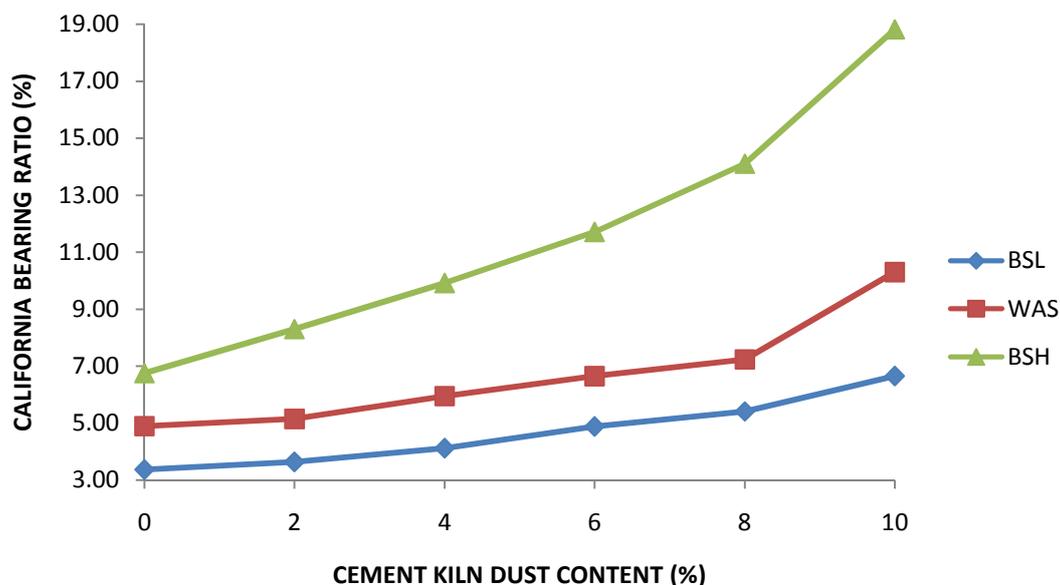


Figure 5: Variation of Unsoaked California Bearing Ratio of Black Cotton Soil with Cement Kiln Dust Content

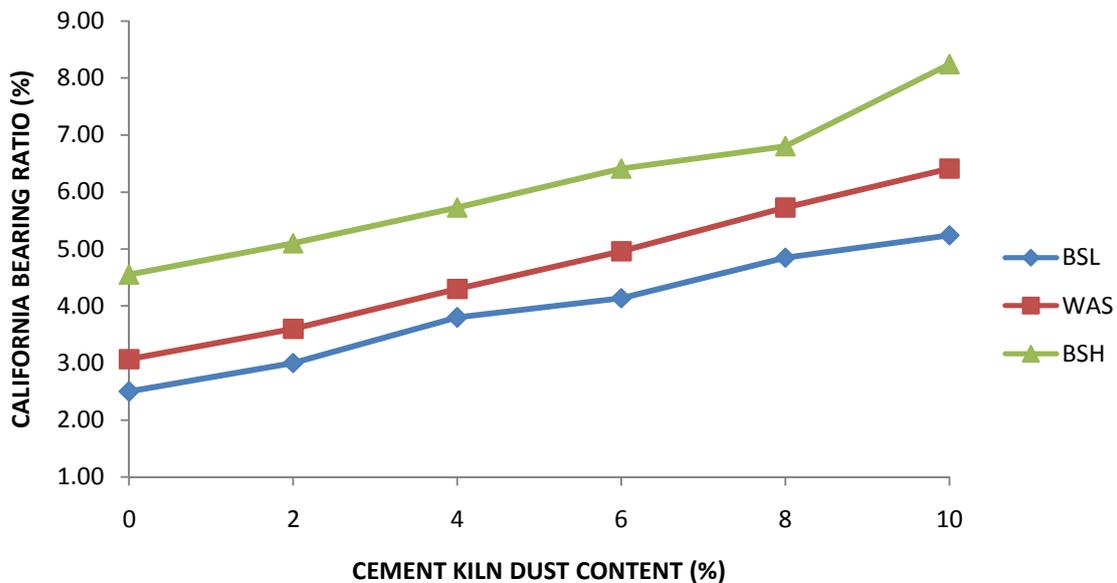


Figure 6: Variation of Soaked California Bearing Ratio of Black Cotton Soil with Cement Kiln Dust Content

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