STABILIZATION OF SOFT SOIL USING CEMENT KILN DUST

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1. INTRODUCTION

Bearing capacity of soil played a major role in decision making on site selection for geotechnical projects. Once the bearing capacity of the soil was poor, the following were options:

- Change the design to suit site condition.
- Remove and replace the in situ soil.
- Abandon the site.

Abandoned sites due to undesirable soil bearing capacities dramatically increased, and the outcome of this was the scarcity of land and increased demand for natural resources. Affected areas include those which were susceptible to liquefaction and those covered with soft clay and organic soils. Other areas were those in a landslide and contaminated land. However, in most geotechnical projects, it is not possible to obtain a construction site that will meet the design requirements without ground modification. The current practice is to modify the engineering properties of the native problematic soils to meet the design specifications. Now a day, soils such as, soft clays and organic soils can be improved to the civil engineering requirements. Keeping in this mind, it has been planned to study the soil characteristics with the soil stabilization method which is one of the several methods of soil improvement. Soil stabilization aims at improving soil strength and increasing resistance to softening by water through bonding the soil particles together, water proofing the particles or combination of the two. Stabilizing agents such as lime, fly ash, rice husk ash, blast furnace slag, cement kiln dust etc. are the various waste products. The use of various waste products in civil engineering construction has gained considerable attention in view of economy & eco-friendly. Also increasing cost of waste disposal and environmental degradation are the main concerns due to these waste products. To protect the environment from degradation due to these waste products, the utilization of waste is the major task for the civil engineers. Keeping these objectives in mind this this project is taken for the utilization of Cement kiln Dust as stabilizing agents to enhance the engineering properties of soil.

2. LITERATURE REVIEW

In the field of geotechnical engineering in general and soil stabilization in particular, the parent soils are practically categorized under either cohesion less soils (i.e., sandy and larger particle-sized soils) or cohesive soils (i.e., primarily clay and silt). Since the soil stabilization mechanism of fine-grained soils requires calcium (in the form of lime) as the major stabilizing agent, it is possible that some CKDs, especially those high in free lime, would similarly be useful in stabilizing clay soils. In the case of sandy soils, which are commonly selected in the pavement layers, the usage of CKD may provide cementitious materials when it is mixed with water in a way similar to the mechanism by which Portland cements provide their binding characteristics. Any potential application of CKD, including sand and clay stabilization, is governed by the physical and chemical composition of the dust. In practical terms, the dusts vary markedly from plant to plant in chemical, mineralogical, and physical composition, depending upon the feed raw materials, type of kiln operation, dust collection facility, and the fuel used [Klemm, 1980]. Nicholson presented a number of patents [1977, 1982] for a series of investigations on CKD and fly ash mixtures for producing subbase materials with different aggregates. CKD was used up to 16% by weight of the mixture, producing a durable mass by reacting with water at ambient temperatures. Collins and Emery [1983] demonstrated the effectiveness of substituting CKD for lime in a number of lime-fly ash-sandy aggregate systems for subbase construction. The results indicated that the majority of the CKD-treated fly ash and aggregate mixtures resulted in materials which were comparable in strength, durability, dimensional stability, and other engineering properties, to those of the conventional lime-fly ash-aggregate mixtures. Miller, et al. [1980] have also reported the use of CKD and fly ash as the cementitious ingredients in developing pozzolanic bases that demonstrated comparable properties to those of a stabilized base. It was pointed out, however, that the use of any particular CKD-fly ash combination would require an appraisal of the chemical and strength test data to establish optimum properties for a suitable mix design. Napeierala [1983] examined the possibility of using CKD in stabilizing sandy soils for pavement subgrade applications. It was reported that an addition of 15% CKD having 5.9% free CaO and MgO, and 0.97% total alkalies (K2O + Na2O) ensured a compressive strength of 360 psi (2.5 MPa), which is a standard practice in Poland for the subgrade within 14 days of the treatment. Baghdadi and Rahman [1990] studied the effects of CKD on stabilizing siliceous dune sand in highway construction. It was deduced that a mix proportion of 30% CKD and 70% sand gave peak performance for application as base materials. In a somewhat similar study conducted later, Baghdadi et al. [1995] reported that the use of CKD between 12 and 50% was satisfactory to stabilize dune sand. For light applications, 12 to 30% CKD was found sufficient, and for heavily-loaded applications, about 50% CKD gave satisfactory stabilization. A number of CKDs and clay-type soils were used by McCoy and Kriner [1971] to study the soil stabilization. SoilCKD mixes containing 3, 8, and 10% of CKD were tested for various engineering properties, such as the unconfined compressive strength, moisture-density relationship, liquid limits (LL), plastic limit (PL), plasticity index (PI), and shrinkage limit. The study found that the use of CKD was potentially promising in stabilizing soils for subbase applications. Bhatty et al. [1996] reported that CKD with high free lime (26.6%) and moderate alkalies (□ 4.6%, expressed as Na2O equivalent) produced mixtures with compressive strengths comparable to those obtained with cement and lime. CKDs having low free lime (0.5%) and low alkalies (2.2% Na2O equivalent) gave lower strengths. In general, CKDs with high free lime and moderate alkalies gave enhanced stabilization in terms of improved compressive strengths and reduced plasticity. It might also be pointed out that higher alkalies in CKDs can counter the stabilization reactions because of the ionic interference. Baghdadi [1990] reported the usage of CKD for stabilizing pure kaolinite and a 50:50 kaolinite-bentonite clay mixtures. Pure bentonite clay was highly plastic (PI □ 520), whereas the kaolinite was less plastic (PI □ 9). The 50:50 kaolinite-bentonite clay mixtures gave a PI of 150. A study on the use of CKD in clay stabilization was also reported by Zaman et al. [1992] and Sayah [1993]. They established potentially useful correlations among the engineering properties of the clays and their stabilized counterparts. However, their investigations were based on only one CKD and primarily one clay soil, a dark grey "fat" clay, although, at times, some selected tests were also carried out on other potentially expansive clays. The primary clay used in the investigations belonged to the CH group [Spangler and Handy, 1992]. The clay-CKD mixtures containing 5% to 40% CKD by weight were cured for up to 56 days. The results showed that, with the exception of the dry densities, the engineering properties of the CKD-clay mixtures were comparable to those of fly ash-soil and cement-soil mixtures. According to Southgate and Mahboub [1994], the CBR test also positively correlates with the modulus of elasticity and strength of the stabilized soils.

CKD sharply reduced the swell potential of the clay which was expansive in nature. The swelling of the raw clay, as determined by the ASTM D 4546 procedure, dropped from over 9% to 0% when treated with 25% CKD. Meanwhile, the swell potential measured as a part of the CBR tests, dropped from nearly 9% to 0.5%. Modifications of the swelling behavior in clay properties are important when considered for pavement applications, as reduced volumetric changes imply more stable behavior in the subbase or elsewhere in the pavement structure. Voids in the CKD-stabilized clay samples, measured optically, decreased with CKD additions. The raw clay soil had 7% void space whereas the samples with 25% CKD gave a void space between 1 and 2.3% [Sayah, 1993]. This may explain the strength gain as a consequence of decrease in voids. This phenomenon does not appear to be time dependent; it rather appears to be CKD-dosage dependent. The decrease in voids may result from a combination of processes occurring simultaneously, i.e., the hydration products developing early on, and the placement of CKD particles filling the voids to modify the morphology of the stabilized mass. Additional characterizations (scanning electron microscopy tests for example) of the CKD-treated clay samples would, however, be required to verify this point [Sayah, 1993]. CKD also increased the permeability of cohesive weathered shales giving increased coefficients of permeability from 3 x 10-8 to 1 x 10-5 cm/sec. The permeability of silty fine sand, however, somewhat decreased from 3 x 10-3 to 1 x 10-4 cm/sec when treated with 20% CKD. It might be important that if the CKD-soil mixtures were cured for longer periods, say 14 days, their permeability could decrease even further because of the growing reaction products and reduced connected voids [Todres et al., 1992]. XRD (x-ray diffraction) and SEM (scanning electron microscopy) investigations conducted on the CKD-stabilized clays showed the presence of hydration products and a subsequent decrease in void space, which resulted in increased strength and a reduction in the plasticity indices with curing times. This appears to be in line with an earlier hypothesis that CKD mechanistically functions similarly to cement [Laguros and Davidson, 1963] in stabilizing soils as it forms hydration products in the system and reduces the total porosity to promote compaction. Azad (2000) found that an increases in the unconfined compressive strength (UCS) of soil occurred with the addition of CKD. Furthermore, the increases in UCS were inversely proportional to the plasticity index (PI) of the untreated soil. Significant PI reductions occurred with CKD treatment, particularly for high PI soils. Mohamed (2002) evaluated the potential use of cement-kiln dust (CKD) for enhancing the mechanical as well as the hydraulic properties of soils in arid lands. Various tests were conducted to determine the different physical properties of the stabilized matrix and the optimum mixture that produces maximum internal energy and minimum hydraulic conductivity was selected. The analysis showed that 6% by weight of CKD is the optimum mix design, which increases the shear strength and decreases the hydraulic conductivity to less than 10 super(-9) m/s. Therefore, the treated soil could be used as a soil-based barrier layer for containment of hazardous waste, [Mohamed 2002]. In other words, the available free lime, soluble alkalies, and fineness of CKD influence the stabilization of soil, whether the underlying stabilization process is primarily pozzolanic, or ion-exchange, or a combination of both.

3. OBJECTIVE

The main objective of this project is to increase the strength and stability and enhance the feasibility of soil and to reduce the construction cost by making best use of cement kiln dust.

The following objectives which can be put forth as follows:

1. Efficient use of CKD for stabilization of clayey soil
2. Increase parameters of soil like strength using cement kiln waste in various proportions.

4. EXPERIMENTAL WORKMATERIALS

Soil: The soil is collected from BIT campus, Sindri, Dhanbad (INDIA). According to Unified Soil Classificationsystem, the soil was classified as clayey sand with low plasticity and the properties of soil are given in Table 4.1.

Table 4.1: Properties of Soil Sample

S. No.	Parameters	Values
1.	Specific Gravity	2.65
2.	Optimum Moisture Content	14.10 %
3.	Maximum Dry Density	1.77 g/cc
4.	Liquid Limit	38.00 %
5.	Plastic Limit	18.97 %
6.	Plasticity Index	19.03 %
7.	Category of Soil	
	As per USC System (fines fraction)	Cu = 8.771 Cc = 0.740 Poorly graded sandy soil
	As per USC System (A-line chart)	Clayey Sand (SC) Low Plasticity (CL)

Cement Kiln Dust: As the name implies, Cement kiln dust is fine powder-like by-product of Portland cement production. They are collected from the stacks of high-temperature rotary kilns by the federally mandated dust collection systems (e.g., cyclones, electrostatic precipitators, and/or bag houses). Large quantities of cement kiln dust are produced during the manufacture of cement clinker by the dry process. Several 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. The dust from each plant can vary markedly in chemical, mineralogical and physical composition. The research described in this project work was conducted exclusively with pre-calcinerCKD from Kalyanpur Cements Ltd. Banjari(INDIA) and all results and conclusions of the report are intended to referto CKD from kalyanpur Cements Ltd. Banjari (INDIA).

CKD consists primarily of calcium carbonate and silicon dioxide which is similar to the cement kiln raw feed, but the amount of alkalis, chloride and sulphate is usually considerably higher in the dust. CKD from three different types of operations: longwet. Long-dry, and alkali by-pass with precalciner were characterized for chemical and physical traits by Todres et al. (1992). CKD generated from long-wet and long-dry kilns is composed of partially calcined kiln feed fines enriched with alkali sulphates and chlorides. The dust collected from the alkali by-pass of precalciner kilns tend to be coarser, more calcined, and also concentrated with alkali volatiles. However, the alkali by-pass process contains the highest amount by weight of calcium oxide and lowest loss on ignition (LOI), both of which are key components in many beneficial applications of CKD. Table1 provides the composition breakdown for the three different types of operation and includes a typical chemical composition for Type I Portland cement for comparison.

Table 4.2: Typical Chemical Composition of Cement Kiln Dust

(Source: Kalyanpur Cement Ltd. Banjari, INDIA)

Oxide	CaO	Al_2O_3	SiO_2	Fe_2O_3	Mn_2O_3	Na_2O	K_2O	Loss of Ignition
Concentration (%)	50.81	4.71	17.18	1.92	0.002	0.001	1.35	24.03

5. METHODS

To study about soil stabilization, soil is mixed with CKD and their engineering properties were determined. Laboratory tests have been planned in such a way that it takes into account all the related aspects, such as related percentages of CKD are mixed at calculated OMC and dry weight of soil. Following laboratory tests have been conducted as per IS-2720-(1985) (Reaffirmed 1995):

Soil Compaction Test (Light Compaction Test) as per IS-2720 (Part VII)

Atterberg's Limit Test (Liquid limit & Plastic Limit) as per IS-2720(Part V)

Unconfined Compression Test as per IS-2720 (Part X)

CBR Test as per IS-2720 (Part 16),and

Permeability Test (Falling head method)

6. RESULT AND DISCUSSION

Following laboratory test results are obtained for different percentages of CKD (0 % to 30 %) when mixed with dryweight of Soil is given in table 6.1

Table 6.1: Laboratory Test Results

CKD (%)	OMC (%)	MDD (g/cc)	W_L (%)	W_P (%)	I_P (%)	UCS (kg/cm^2)	Soaked CBR (%)	Unsoaked CBR (%)	Permeability (k) (cm/ sec)
0	14.10	1.77	38.00	18.97	19.03	0.949	2.64	3.40	2.661×10^{-5}
5	14.40	1.75	37.80	19.99	17.81	1.073	3.85	3.96	2.275×10^{-5}
10	14.80	1.72	36.75	22.02	14.73	1.441	4.30	4.29	1.785×10^{-5}
15	15.20	1.70	35.25	22.60	12.65	1.816	5.02	4.98	1.644×10^{-5}
20	15.50	1.69	35.02	24.36	10.66	2.383	5.54	5.27	1.392×10^{-5}
25	15.90	1.67	34.78	25.73	9.05	2.629	6.02	5.85	5.825×10^{-6}
30	16.30	1.65	33.50	26.00	7.50	2.833	6.74	6.35	2.565×10^{-6}

Compaction Test Result:

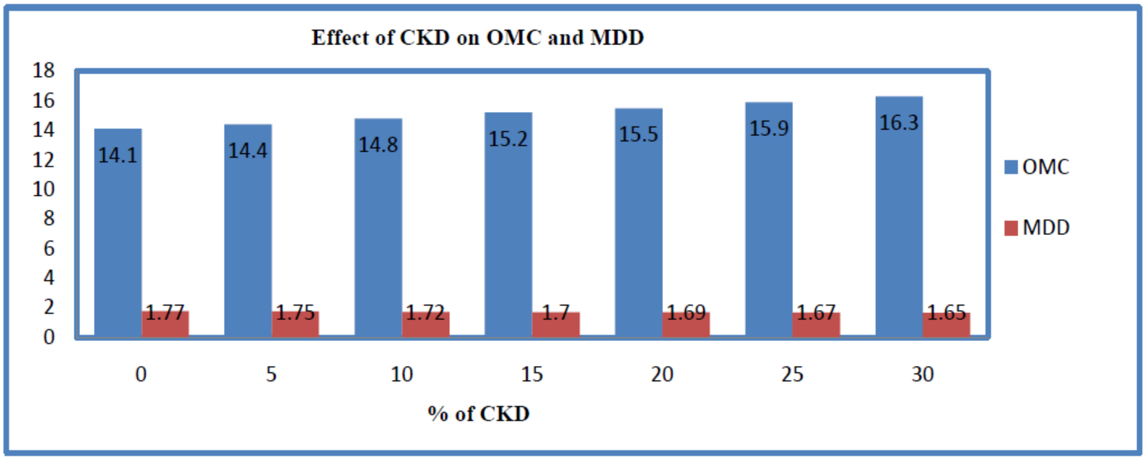

Fig. 6.1: OMC and MDD at varying percentages of CKD

As per above Fig. 6.1, OMC is increasing but MDD is decreasing gradually as finer particles of CKD are increasing. When CKD is used as soil stabilizing additive, Soil particles become large-sized clusters, resulting in texture change. This flocculation-agglomeration process results in flock formation. The enlarged particle size causes the void ratio to increase. This increase in void ratio reflects the decrease in MDD and increase of moisture content for the Soil-CKDmixture.

Liquid Limit & Plastic Limit Test Result:

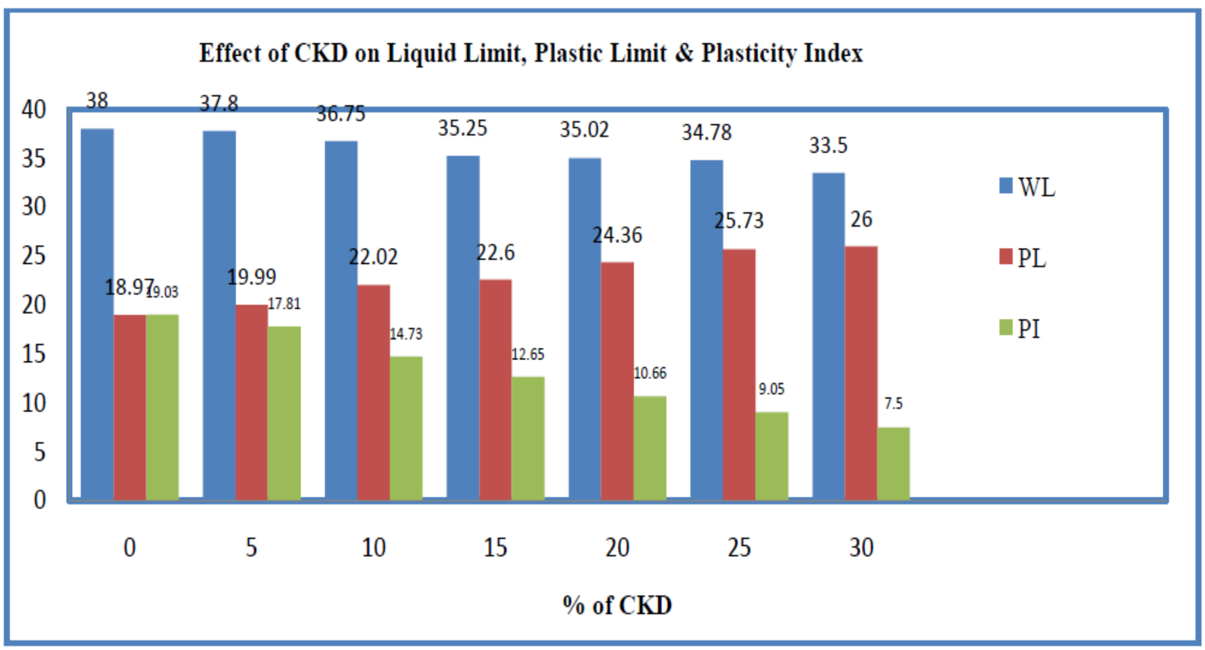

Fig. 6.2: Liquid Limit, Plastic Limit & Plasticity Index at varying Percentages of CKD

LIQUID LIMIT TEST RESULTS:				
DETERMINATION NUMBER	1	2	3	4
WT. OF CONTAINER(W1)	25	25	25	25
WT. OF CONTAINER+WET SOIL(W2)	52	69	64	52
WT. OF CONTAINER+DRY SOIL(W3)	48	61	56	46
WEIGHT OF WATER(Ww)=W2-W3	4	8	8	6
WEIGHT OF DRY SOIL(Ws)=W3-W1	23	36	37	21
MOISTURE CONTENT(%) W.C=Ww/Ws	17.14%	22.20%	25.80%	28.50%
NUMBER OF BLOWS	156	77	72	54

PLASTIC LIMIT TEST RESULTS:			
CONTAINER NUMBER	1	2	3
WT. OF CONTAINER(W1)	26	27	26
WT. OF CONTAINER+WET SAMPLE(W2)	29	29	29
WT. OF CONTAINER+DRY SAMPLE(W3)	28	30	28
WEIGHT OF DRY SAMPLE(Ws)=W3-W1	2	3	2
WEIGHT OF WATER IN THE SOIL(Ww)=W3-W2	1	1	1
MOISTURE CONTENT(%) W.C= $\frac{W3-W2}{W3-W1}*100$	50%	33.30%	50%

Atterberg's limit indices variation with CKD content is shown in figure 4.2. Liquid limit and Plastic limit increased with CKD content, while the Plasticity index decreased with CKD content. This is due to the presence of Ca2+, Si2+, andAl3+cations with increased CKD usage they react with soil particles. This reduction in the plasticity may be attributed to the chemical and cementation effect on structural composition of the soil. Since the modification of soil particles leading to increase the effective particle size (resulting from inter-particle cementation), consequently the amount of moisture that attracted to these particles decreased. The increase in Plastic limit may be attributed to the quantity of water used should be just sufficient to satisfy hydration requirements of the CKD and to make the mixture workable**.**

Unconfined Compression Test Result:

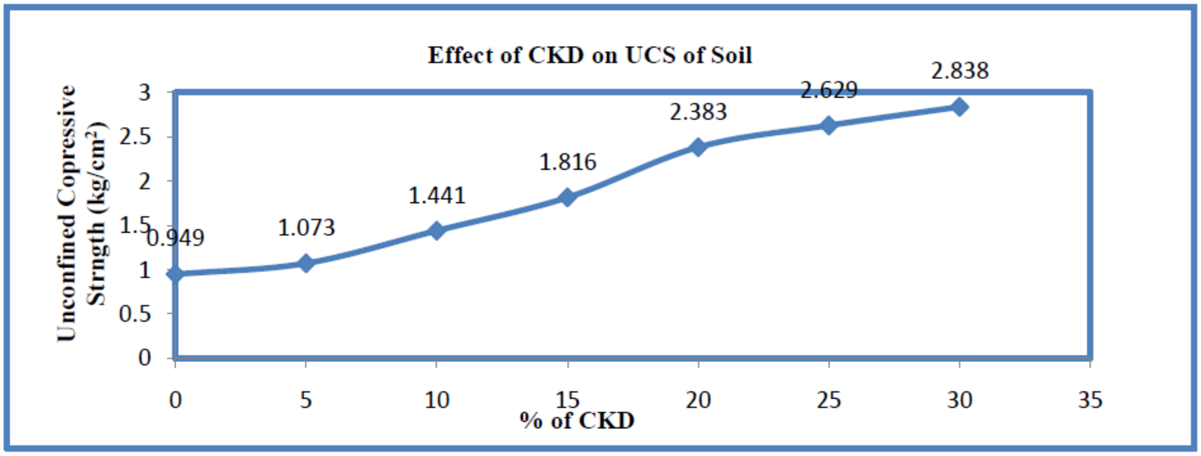

Fig. 6.3: UCS of Soil at varying Percentages of CKD

From above fig. 6.3, it can be seen that the Unconfined Compressive Strength of the Soil sample have increased as the percentage of CKD increases. The Unconfined Compressive Strength at 30% addition of CKD to the soil is 2.833 kg/cm^2. As compared to the untreated soil (at 0% CKD), the percentage increase at 30% addition of CKD to the soil is about 198.52%. This is due to the fact that addition of CKD make available additional amount of Silica and lime than that of present in natural soil only.

CBR Test Result:

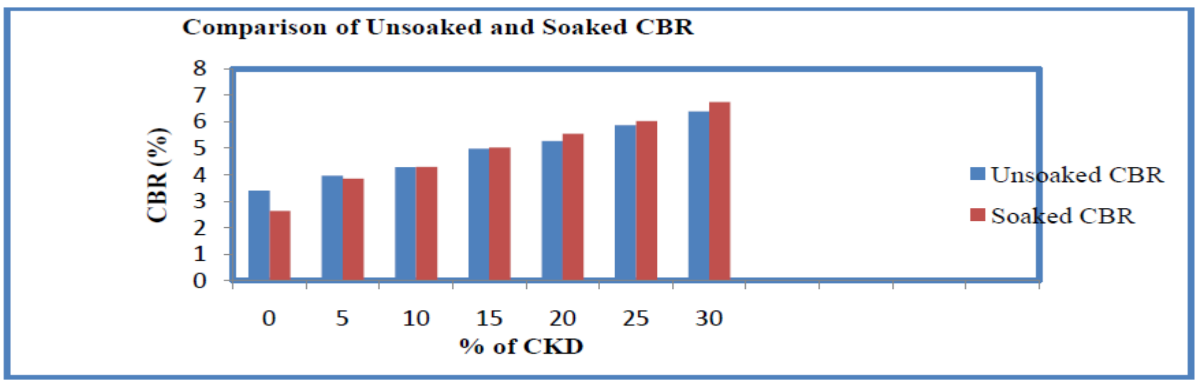

Fig. 6.4: Unsoaked& Soaked CBR Variation of Soil-CKD Mix.

Here, as per above fig. 6.4, Soaked CBR value is greater than Unsoaked CBR value at 10% addition of CKD and onward.

This increasement may be attributed to the chemical and cementation effect (the Oxides amount in the CKD is about2/3rd of Oxide amounts found in Portland cement) on structural composition of the soil. Presence of Ca2+, Si2+, andAl3+cations in CKD, it react with water and resulting in the formation of Calcium-Silicate-hydrates (CSH) andCalcium-Aluminate- hydrates (CAH). CSH and CAH are cementation products similar to those formed in Portland cement. Time duration and sufficient water favours these reactions.

Permeability Test Result:

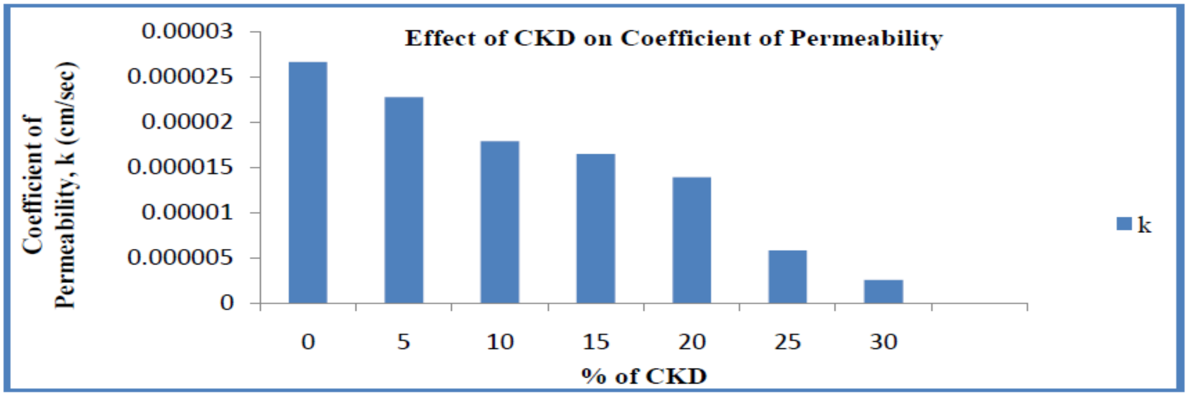

Fig. 6.5: Coefficient of Permeability with varying Percentages of CKD

From above fig. 6.5, it can be seen that the Permeability of the Soil Sample have decreased as the percentage of CKDincreased. The Coefficient of Permeability at 30 % addition of CKD to the soil is 2.565x10-6cm/sec. As compared tothe Untreated Soil (at 0 % CKD), the percentage decrease at 30 % addition of CKD to the soil is 90.36 %. This is due tothe increase in finer material as percentages of CKD increase in the Soil-CKD mixture. Permeability decreases evenfurther because of the growing reaction products (CHS & CAH) and reduction in connected voids.

Fig. 6.6 Sieve Analysis

Fig. 6.7 Liquid Limit

Fig. 6.8 Plastic Limit

7. CONCLUSION

Based on the obtained results and discussion thereof following conclusions can be made:

- The compaction characteristics of soils vary significantly with CKD content. The optimum moisture content increases and maximum dry density decreases with increased CKD content.
- As compared to untreated soil, the percentage increase in OMC at 30% addition of CKD to the soil is15.60%,and percentage decrease in MDD is 7.27%.
- Liquid limit decreases and Plastic limit of soil increases as the percentage of CKD increases. The Plasticityindex of soil reduces with increased CKD content. Reduction in Plasticity index is 60.58%. Hence the soil samples become less plastic and compressible.
- With increases of CKD percentage compressive strength of soil increases. Percentage increase in compressive strength of soil is 203.79%.
- CBR value for soaked and unsoaked condition increases with increases in percentage of CKD. Percentageincrease in CBR value for soaked and unsoaked is156.06% and 86.76% respectively.

CBR values of soil are indicator of sub-grade soil strength and are often used for design of flexible pavement. The CBR value of CKD treated soil is 6.76% which can be used for the designing of flexible pavement for light and medium traffic

- Coefficient of permeability i.e., Hydraulic conductivity of soil reduces with increased CKD percentages.

Percentage reduction in Permeability of soil is 90.36%; hence stabilized soil may be used for the impervious core in embankment and, the treated soil could be used as a soil-based barrier layer for containment of hazardous waste. This project work concluded that CKD is potentially useful in stabilizing of soil. However, the stabilizing effect is primarily a function of the chemical composition, fineness, and addition level of the CKD as well as the type of parents oil. CKD is an effective soil stabilization agent, based on the results observed and described in this thesis. It is recommended that it can be considered for use in the stabilization of soil.

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