Stabilization of Black Cotton Soil using Calcium Carbide Residue

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Abstract. Wide variety of soils are available in the world out of which some are good in views of Construction Engineers and few are problematic due to their swelling and shrinkage properties, and Black Cotton Soil (BCS) is one of them. These properties can easily produce uplift movement and may lift the light-weight civil engineering structures and causing collapse, cracking and ultimately hazard to mankind. In such a case, there is an extreme need for soil stabilization and hence to find and introduce cheap and easily adoptable stabilizing agent. Calcium Carbide Residue (CCR) which is a by-product of acetylene gas manufacturing industry due to its alkaline properties can be effectively used as stabilizing material, reducing the environmental problem of its disposal is taken into the frame. This study depicts the use of CCR in stabilizing BCS. Introducing CCR in BCS can increase the strength and swell property of soil, for this CCR fixation point was determined by sequentially adding 1%-10% CCR to BCS and studying properties like P^H and consistency limits. Strength and swell pressure of BCS were checked with varying percentage of CCR. To study strength properties unconfined compression test is conducted and to examine swell properties a portable and in-house fabricated swell pressure measuring device was used. Maximum strength development in stabilized clay is found at 7% CCR cured for 28 days at standard temperature. It was further observed that addition of CCR to BCS resulted in increased strength of about 5 times than that of virgin BCS and it was observed that stabilization of soil with 7% CCR reduces its swell pressure by around 88%.

Keywords: Calcium Carbide Residue, stabilization, expansive soil.

1 Introduction

Increasing population in the world, especially developing nations has led to increasing demand for roadways, railways, housing facilities, and other infrastructures. Soil with higher stability is required to bear the weight of these structures [13]. Generally speaking, the stability of any construction-related structure directly or indirectly depends on soil stability. India is home to various geographical features such as rivers, mountains, valleys, tablelands, seashores, deserts, and flat terrains. Due to which a huge variety of soils like alluvial, red, mountain, black cotton and laterite soils are found in India. Basically mentioning black cotton soil, geographically black cotton soils are spread over 5.0 lakh sq. km [20](i.e. 16.6 percent of the total geographical area of the country).

The Black cotton soil is very hard when dry, but loses its strength when in wet condition. This property of black cotton soil is seen due to the presence of high clay mineral content of montmorellonite. Because of high swelling and shrinkage characteristics of Black cotton soil, these have been a challenge to the construction field. Special attention is gained by the development of cracks of varying depth in highways and other structures due to settlement, heavy depression, cracking and unevenness, and wetting and swelling characteristics of this soil type [14]. As such Black cotton soil has very low bearing capacity and high swelling and shrinkage characteristics.
Considering problems encountered in field of construction, many stabilization techniques have been used in past to improve their engineering properties such as Cement stabilization, chemical stabilization by using lime, cement etc., [15, 18, 19] mechanical stabilization by using rollers, rammers, vibrators, etc. [1]other deep foundation techniques may prove to be uneconomical because of the input required and procedures involved [17]. Hence many researchers have given their emphasis on study and utilization of industrial by-products for stabilizing such expansive soils, such as blast furnace slag, fly ash, stone dust, recycled materials to reduce their impact on the environment[3, 5, 21]. Utilization of industrial wastes in recent times have seen wide importance for stabilization like utilization of ground granulated blast furnace slag, cement wastes, bag gash ash, bassanite.[2, 3, 9, 12]. One of these stabilization techniques can include the utilization of Calcium carbide residue (CCR) an industrial by-product generated from acetylene gas manufacturing industries.

Now a day’s acetylene gas manufacturing industries are facing the problem of dumping this by-product (CCR) as shown in figure 2. So, the CCR is very cheaply available around these industries. CCR contains around 76% of lime hence it’s a good binding agent. Hence, it proves to be an economical source of stabilizing agent and incorporated in the present study. Acetylene gas is produced when calcium carbide reacts with water; which evolves acetylene gas, heat and hydrated lime slurry which is further dried in the beds and the calcium carbide residue is obtained which is highly basic in nature. Following reaction occurs when calcium carbide reacts with water[5, 7].

$$CaC2 + 2H2O = C2H2 + Ca(OH)2 \qquad (1)$$

This CCR is creating a dumping issue and thereby creating environmental hazards. Hence to treat expansive soils such as black cotton soil whose expansive properties are due to presence of clay mineral Montmorellonite, CCR as a stabilizing agent can prove to be an efficient technique[10, 11].

The CCR obtained is mixed with the soil in different percentage (2, 4, 6 & 8) with the soil samples collected from the field is mixed with the soil and maximum dry density and optimum moisture content are obtained. This optimum moisture content is used for preparing the unconfined compressive strength of samples. The test shows that 8% dose of CCR to soil gives 5 times increase in unconfined compressive strength. Effect of a varied percentage of CCR on density and swell pressure is also investigated and discussed in this paper.

2 Soil Sample

A natural disturbed soil sample was collected from the Nashik region in Maharashtra, India. The location is part of the area covered by the expansive soil commonalty known as black cotton soils of central India. The region is part of the Western Deccan Volcanic Province and is believed to be the youngest basalt rock of the Eocene age [8].

The natural water content of the soil was 34% while hygroscopic moisture was 8% to 9%. Figure 1 shows the grain size distribution of the soil sample collected. It composed of 8% sand, 44% silt and 48% clay. The specific gravity of soil was 2.68. The liquid and plastic limits were 64% and 24% respectively. According to the Unified Soil Classification System (USCS), the soil was classified as clay with high plasticity (CH). Free swell ratio (FSR) was determined by taking the ratio of equilibrium sediment volume of 10gm of oven-dried soil passing through 425 µm sieve in distilled water to that in kerosene [16]and found to be 1.55. Based on FSR soil was classified as Montmorillonitic with moderate expansivity. Table 1 shows the chemical composition of the soil sample. Presence of SiO_2, Al_2O_3, and Fe_2O_3 was high enough for the pozzolanic reaction.

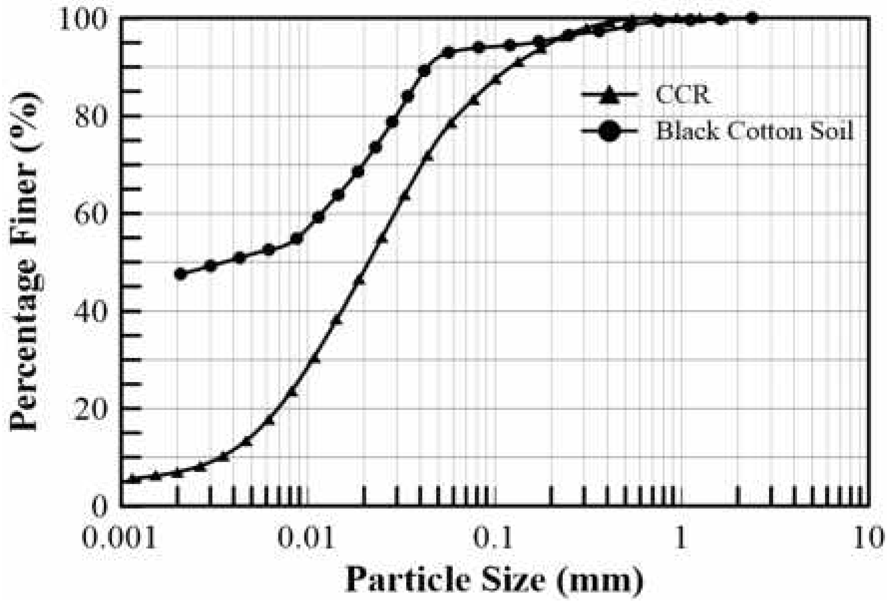

Fig. 1. The grain size distribution of silty clay and CCR

3 Calcium Carbide Residue

Calcium Carbide Residue (CCR), a grayish-white powder was obtained from Swastika Industrial Gas Manufacturing Pvt. Ltd. Nashik, India. CCR was collected from the disposal area in dry form as shown in figure 2 (b). The CCR was oven-dried at 105°C for 24 hours and ground in Los Angeles abrasion machine. The CCR was passed through 425 µm sieve for further use in experimentation. The specific gravity (Gs) of CCR was 2.30. Table 1 also shows the chemical composition of CCR. Presence of CaO content (90%) and other pozzolanic materials (SiO_2, Al_2O_3, and Fe_2O_3) indicate the suitability of CCR to produce cementitious material.

Table 1. The chemical property of silty clay and CCR

Chemical Composition (%)	Black Cotton Soil	CCR
SiO_2	48.50	4.6
TiO_2	1.48	0.009
Al_2O_3	20.46	0.49
Fe_2O_3	15.73	0.10
MnO	0.14	0.002
MgO	4.38	0.22
CaO	9.60	90
Na_2O	1.54	0.06
K_2O	3.29	0.002

(a) (b)

Fig. 2. Disposal of Calcium Carbide Residue: (a) slurry form; (b) dry form

4 Properties of Stabilized Clay

4.1 Optimum Percentage of CCR

Two independent methods proposed by Eades and Grim (1966)[4]and Horpibulsuk et al. (2012)[6]were used to obtain an optimum dose of CCR. The first method is suggested for lime stabilization, in which a minimum pH value of 12.4 is necessary to initiate the pozzolanic reaction. The pH values measured for soil sample for the various percentage of CCR is shown in figure 3. As the CCR content increases, the pH of stabilized clay significantly increases. However, when CCR content is greater than 7% the pH was observed to be 12.4 and change in pH is minimal. This point thus can be chosen as an optimum percentage of CCR. Figure 4 shows the change in consistency indices of stabilized clay. Liquid limit (LL) was observed to be increased in proportion with increase CCR content. However, the plastic limit (PL) was observed to decrease the resulting decrease in plasticity index (PI). The decrease in PI was minimal after 7% CCR content. These observations are in line with the observation made by Horpibulsuk et al. (2012)[6]. Based on the above two independent methods 7% CCR content was chosen as the optimum percentage for stabilization of soil.

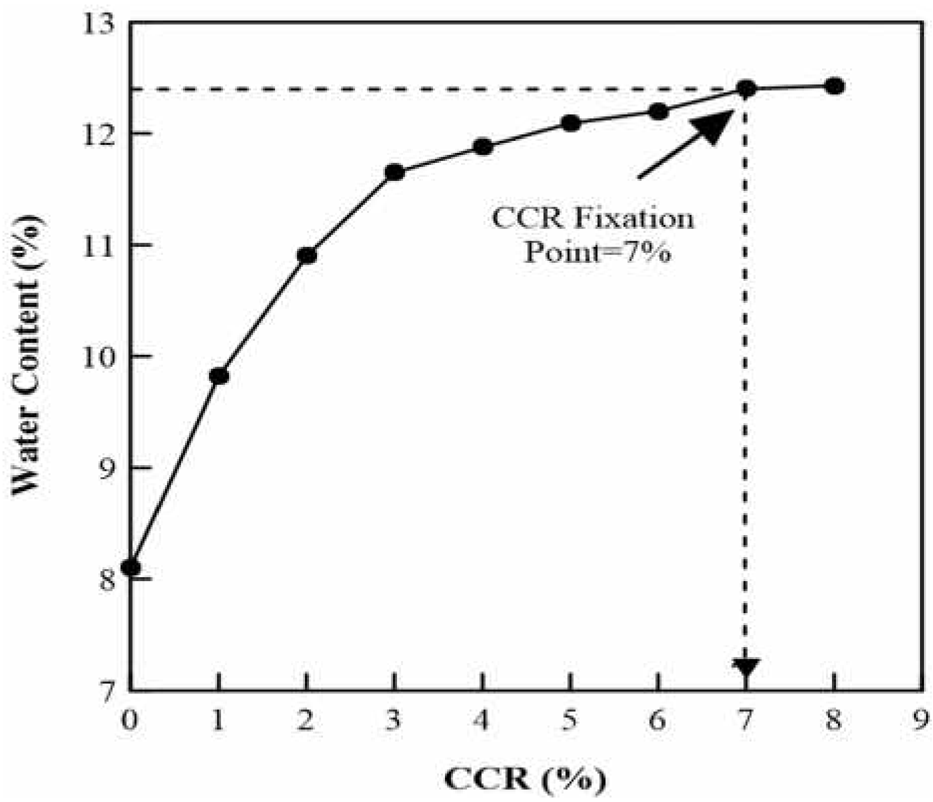

Fig. 3.pH of CCR stabilized soil

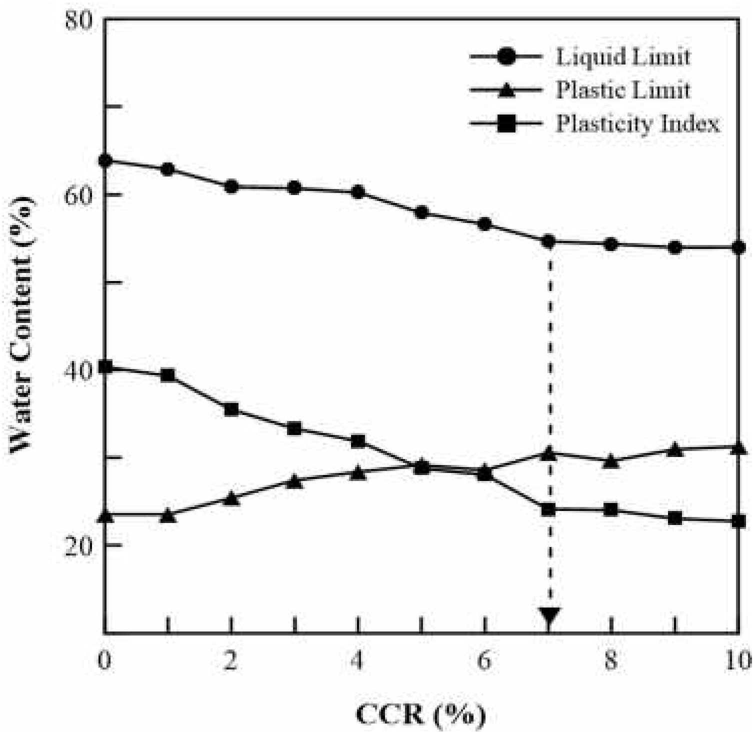

Fig. 4. CCR fixation point

4.2 Compaction Characteristics

The clay sample was sieved through 20mm sieve and air-dried for compaction test. Compaction was carried out using standard Proctor test. The compact effort for the test consists of the energy derived from a 2.5 kg rammer falling through 30 cm onto three layers of soil, each receiving 25 blows. Compaction characteristics i.e. optimum moisture content (OMC) and maximum dry unit weight (γ_{dry}) for clay stabilized with 7% CCR were 28% and 14.4 kN/m^3. Having obtained compaction characteristics the air-dried clay sample was mixed with various content of CCR (0-8%). Figure 5 shows the compaction curves obtained from standard compaction test on clay and CCR stabilized clay. The OMC was found to be increased by 3% and γ_{dry} was decreased by 6.5% at an optimum percentage of CCR. Lower specific gravity and affinity of CCR towards water reduce the γ_{dry}.

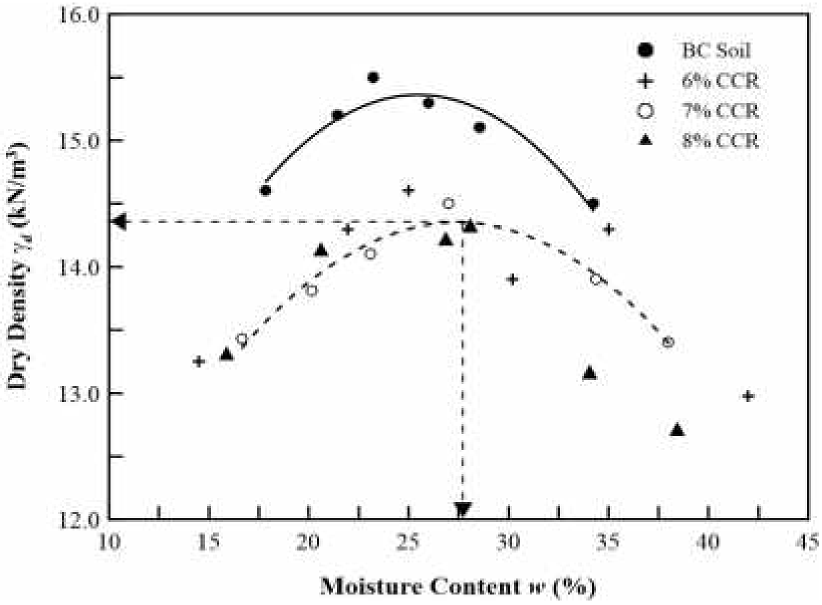

Fig. 5. Relation of OMC & MDD with respect to the addition of different % of CCR.

4.3 Unconfined compression strength

An unconfined compression strength test was conducted on clay and stabilized clay with CCR. Specimens were prepared by mixing the desired proportions of distilled water, soil, and CCR. Percentages of CCR ranged from 0 to 8% by weight of dry soil. The soil-CCR mixtures were prepared by first thoroughly mixing dry predetermined quantities. The required amount of water determined from the compaction curve was later added to the dry mix and compacted at the energy levels of the standard Proctor. Specimens were cured for 7, 14, and 28 days.

Specimen were tested for the unconfined compression test and the failure pattern of the sample was studied as shown in figure 7. Test carried out on the pure black cotton soil at the 0 curing days is represented by the continuous line in figure 7 (a), (b), and (c), and it gave the maximum strength of 369.58kPa. Further, samples prepared with the addition of CCR and tested at the age of 7, 14, and 28 days indicated the increasing trend in the strength. Strength increment noted for the 7% addition of CCR, for 7, 14 and 28 was 1350.36, 1385.57, and 1660.95 kPa. 8% addition of CCR gives lower initial strength when the samples were cured for 7 days, but it gives higher ultimate strength with the further curing as indicated in figure 6. This increase in strength was due to the increase in the cementitious product in soil despite its lower dry unit weight[6, 21]. The effect of the addition of CCR on strength was observed to be maximum between 4 to 6% as shown in figure 6. Addition of CCR below 4% and above 6% the effect in strength gain is insignificant.

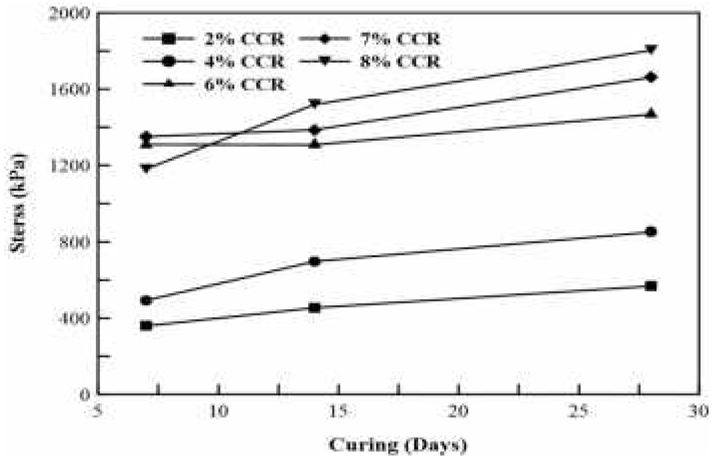

Fig. 6. Effect of addition of CCR on UCS after curing

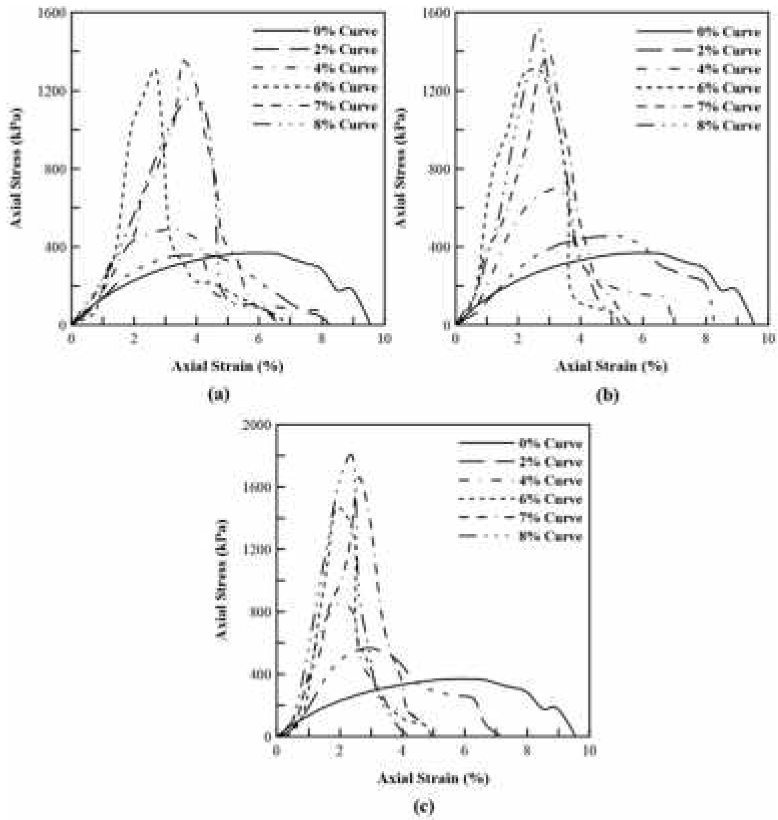

Fig. 7.A stress-strain pattern of the UCS samples during testing, cured for the period of (a) 7 Days (b) 14 Days, and (c) 28 Days

4.4 Swelling pressure of Black Cotton soil

Black cotton soil undergoes a high degree of volumetric change due to the presence of the montmorellonite clay mineral during wetting and drying process [10]. The volumetric change reflects the swelling in the soil and such soils are also referred to as expansive soils. Light structures constructed on such soils suffer more damage due to swelling [10]. Hence, the phenomenon of swelling is a key factor to be studied.

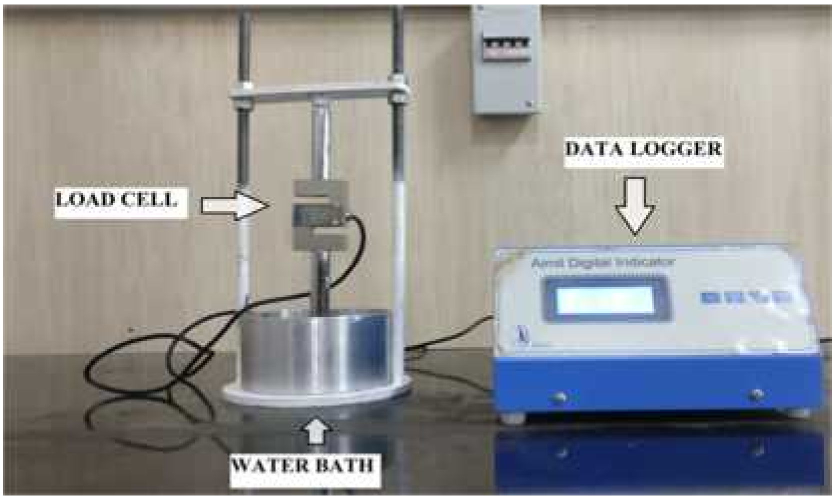

Fig. 8. Swell pressure measuring apparatus

In the present study swelling potential of the soil was determined from the direct method. Indirect method swell force is indicated directly and its test setup is shown in figure 8. This method is also known as constant volume swell test [10]. The testing assembly includes a mainframe, adapter, load cell, loading pad, and water bath for placing the oedometer mold with a soil sample. Porous stones were placed on the top and bottom side of the soil sample for a continuous supply of moisture. A seating load of 10 N was transferred from the loading cap with steel ball arrangement for maintaining a uniform contact between the loading cap and porous stone. Purpose of the loading cap is the uniform transfer of the load over the surface area. Water was filled in the water bath to initiate the test and water level was maintained constant throughout the test. At a suitable interval of time, swelling force reading was noted. The test was terminated after swell force reading becomes constant. After deducting the seating load from the constant swelling force, swell pressure was determined.

Specimen preparation for swell pressure measurement.
In the present study swelling of the soil was examined by preparing the indistinguishable soil samples from the soil passing through the 425 microns IS sieve. From the MDD and OMC test results, soil, CCR, and water required for filling the oedometer mold were calculated. Distilled water was used in the present study for avoiding any

further chemical reactions. For achieving the uniform mix, measured quantities of soil and CCR were mixed in the dry state and later step by step water were added. With the help of a spatula, the soil was mixed in the crucible. The soil was compacted in the oedometer mold on the wet side of the OMC (i.e. OMC+5%) to avoid any possible losses during mold preparation. After uniform mixing, the mixture was sealed for 24 hours in a crucible for uniform distribution of moisture [11]. For achieving the compaction characteristics mixture obtained after 24 hours was statically compacted in the mold in two layers [10]. Using wooden mallet and spacer block, each layer was compacted 25 times in the 75 mm diameter mold. Before placing the sample in the swelling pressure meter, the upper layer of the compacted soil sample was leveled with a steel spatula for providing a proper base to the porous stone. Test was conducted on the pthe uthe re Bthe C the soil and with addition of 2, 4, 6, 7, and 8% CCR. For each mix proportion, three samples were prepared and their average indicates one data point in the graphical representation.

Results of swell pressure.

The swell pressure values of CCR stabilized soil with 7% CCR (optimum dosage) and with variation in its content can be observed in figure 9. Swell pressure for pure black cotton soil was observed to be 82.2 kPa whereas for CCR stabilized soil at 7% CCR was 9.7 kPa. Thus it can be said that stabilization of soil with 7% CCR reduces its swell pressure by 88 % of its initial value. Hence CCR stabilized soil reduces the uplift pressure exerted by the soil on the loading cap. Mixing CCR with soil significantly reduces the swelling potential of soil, and this reduction in swell is due to the bonding of the clay particles due to cementitious material [5]. With the increase in CCR content reduction in swelling pressure was noted as indicated in figure 8. Addition of CCR beyond fixation point reduces the vertical swell unsubstantially. But, the effect is more substantial when the addition of CCR is below 4%.

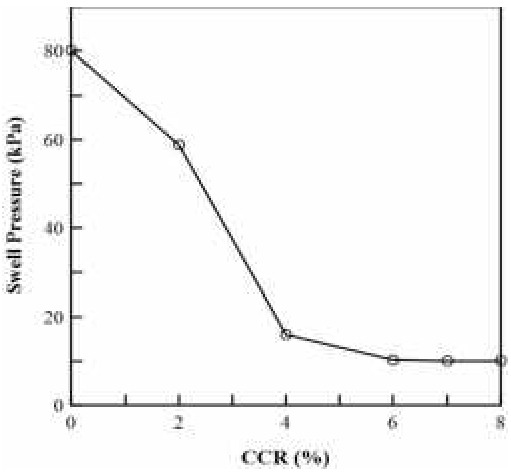

Fig. 9. Variation in swelling pressure with the addition of CCR

5 Conclusion

Engineering properties of soil stabilized with CCR, a sustainable stabilizing agent which is a by-product of acetylene gas manufacturing plants has been studied. The index and Engineering properties refer to pH, Atterberg's limit, compaction curves, UCS tests, and swelling pressure characteristics. The following conclusions can be drawn.

1. Calcium Carbide Residue an industrial by-product is found to be a suitable soil stabilizing agent because of its high $Ca(OH)_2$ content of about 76%.
2. On the basis of pH test and Plasticity index, the optimum dosage of CCR is found to be 7% by weight for black cotton soil stabilized with CCR for Nashik region.
3. CCR is highly alkaline (pH ranging around 12.5), the pH value of stabilized soil increases with increase in CCR content.
4. As the CCR content in the soil increases, this decrease in Plasticity Index occurs due to the flocculation of clay particles, due to adsorption of Ca^{+2} ions from the cation exchange process. However, when the CCR content is greater than 7%, the change in the Plasticity Index is minimal i.e. there is minimal absorption of Ca^{+2} ions.
5. While conducting the proctor test it was observed that the OMC tends to increase with an increase in CCR content whereas the MDD decreases with increase in CCR content. The reduction in MDD is due to the lower specific gravity of CCR and an immediate formation of cementitious products.
6. Unconfined Compression Test with varying CCR content and for different curing days it was observed that UCS of the sample increases with increase in CCR content. Moreover, UCS also increases with increase in the duration of curing. For 7% CCR and 28 days curing the strength observed is 4.49 times the unconfined compressive strength of black cotton soil.
7. Swelling behavior of the black cotton soil reduces considerably with the increase in CCR content. With the addition of 7% CCR, 87.5% reduction in swell pressure was observed when compared with the swell pressure in black cotton soil.

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