Influence of Waste Materials on Geotechnical Characteristics of Expansive Soil

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Abstract

Rapid growth of industrialization produces hazardous waste materials at a large extent. If there is any fault in the disposal process of the waste materials then they act as a pollutant and also affect the ecological system of the environment. It shows that there is urgent need for exploring the alternative of disposal of these materials. In current practice, these waste materials may be good alternative as construction materials. This paper shows the influence of waste materials such as Beas river sand, fly ash on compaction, and strength characteristics of black cotton soil. The utilization of these materials have measurable advantage on the economy as well as the strength, when used as construction materials in infrastructure projects like pavements, hydraulics structures, embankments, etc. and reduce the impact on the environment.

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Keywords: Expansive soil, Beas sand, Fly Ash, Compaction Characteristics and California Bearing Ratio.

1. Introduction:

The black cotton soil is an expansive soil. In India, it is found in major parts of Madhya Pradesh and Andhra Pradesh. The black cotton soil covers about 20-25 % land area of the country. Due to the cyclic swelling and shrinking behavior of black cotton soil, many problems are created during construction. Generally, when the moisture content comes in the contact with black cotton soil its causes swelling and when moisture content decreases shrinkage occurs in the soil. The estimated results shows that the black cotton soil causes the structural damage of about $1000 Millions in USA, £150 UK, and many billions pounds in worldwide annually (Gourley *et al.*,1993). The black cotton soil contains high percentage of montmorillonite mineral which imparts expansive nature to it. There are several methods for reducing the expansive nature of black cotton soil in which stabilization is predominately used. In some stabilization technique, the finer particles of black cotton soil are replaced with coarser particles of admixture like sand, foundry sand, etc, which creates the uniform gradation of particles in the soil, so that the composite mix contain both cohesion and friction as well as improved load carrying capacity when properly mixed, placed and compacted at site.

Generally, the soil having cracks or fractured surface, when it is dried, shows that it is expansive in nature. When the expansive soil comes in contact with water it become very sticky because of high montmorillonite content. Often, it appears in two types on dried conditions, either it appear as a "popcorn like texture" as shown in Fig. 1(a) or appear with lot of "cracks" on the its surface as shown in Fig. 1(b).

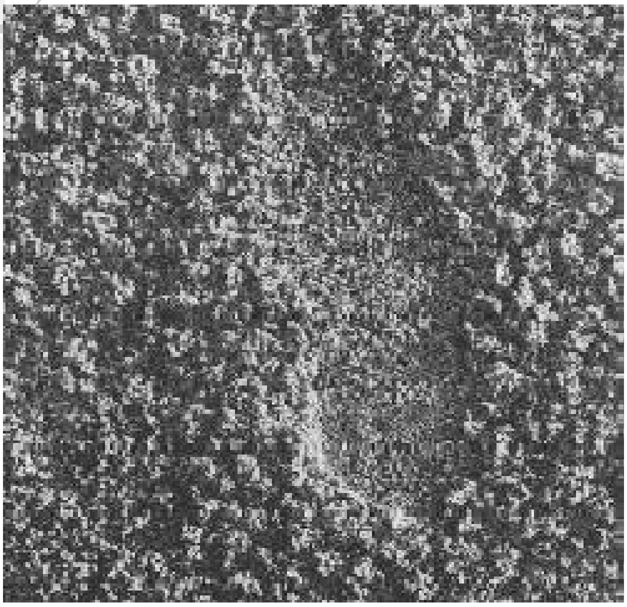

Fig.1 (a): Expansive soil with "popcorn" texture (http://www.surevoid.com).

Fly ash is one of the industrial residues generated in the combustion of coal. In the past, fly ash produced from coal combustion was simply dispersed into the atmosphere. This created environmental and health hazards. Worldwide, more than 65% of fly ash produced is disposed of in landfills. In India alone, fly ash landfills cover an area of 40,000 acres (160 km²). These sites are not lined and it leads to seepage of the harmful chemicals into the ground thereby contaminating groundwater and soil. It lowers soil fertility and contaminates surface and groundwater as it can leach into the subsoil. It also reduces the pH balance and potability of water.

Fig.1 (b): Expansive soil with cracks (http://www.surevoid.com).

Fly ash properties are somewhat unique as an engineering material. Engineering properties that will affect the use of fly ash in the form of admixture in embankment design, compaction characteristics, compressibility, shear strength, permeability and drainage characteristics and frost susceptibility. Soil stabilization involves addition of fly ash to improve the engineering performance of the soil. This is typically used for soft clayey sub-grade beneath a road that will experience repeated loading.

Sridharan *et al* (1985) studied the free swell index of Indian expansive soils. The change in the volume, due to seasonal moisture variation in black cotton soil is reported by (Hausmann, 1990). Ramana Murthy (1998) reported a study on swell pressure and the method of controlling swell of expansive soil. ElKholy (2008) reported that the effect of coarse-grained soil (sand) on the swelling characteristics of black cotton soil. The swelling nature of black cotton soil is reduced as increasing percentage of coarse-grained soil (sand). Choudhary *et al* (2011) reported the improvement in CBR values of expansive soil sub grade using geo synthetics.

Numerous researchers have worked on the stabilization of soil using fly ash. Cokca (2001) showed the effect of class C fly ash on the stabilization properties of an expansive soil. White (2005) showed the effect of fly ash on the compaction, hydration, plasticity, durability and compressive strength characteristics of black cotton soil. Bhuvaneshwari (2005) concluded that workability and maximum dry density was achieved at 25% of fly ash. Edil *et al* (2006) indicated the effectiveness of fly ashes for stabilization of fine grained soils. Chauhan *et al* (2008) observed that optimum moisture content increases and maximum dry density decreases with increased percentage of fly ash mixed with silty sand. Brooks (2009) showed the effect of fly ash and rice husk ash on the unconfined compressive strength ,California bearing ratio and swelling characteristics of black cotton soil and reported that the unconfined compressive strength increased about 97% and California bearing ratio increased about 47% on addition of fly ash at 0-25% and similarly the stress and strain increased about 106 % and 50 % respectively on addition of rice husk ash at 0-12%, hence 25% fly ash and 12% rice husk ash is recommended for improving strength of black cotton soil. Bose (2012) reported that maximum dry density increases up to 20 % fly ash mix, and then gradually decreases whereas the optimum moisture content decreased with increase in fly ash and also CBR values of clay-fly ash mixes tested under un-soaked conditions, shows peaks at 20% and 80% ash content.

However, limited information exists about the combined use of poorly graded sand and fly ash in black cotton soil stabilization. In this paper, sub-grade characteristics of black cotton soil blended with poorly graded river sand and fly ash in different proportions has been studied.

2. SCOPE AND OBJECTIVES:

In this study the engineering properties of black cotton soil with different proportions of sand and fly ash has been studied to bring out the possibility of usage of the above composite for the various construction purposes. The objectives of the study are:

1. Geotechnical properties of black cotton soil, Beas sand and fly ash were determined individually.
2. Beas river sand was mixed with black cotton soil in varying percentages and maximum dry density and optimum moisture content of the mix were determined.
3. Fly ash in percentages of 5%, 10%, 15% and 20% was mixed with optimum combinations of black cotton soil and Beas sand (70:30) and compaction and California bearing ratio (CBR) tests were conducted.
4. The CBR value of the most appropriate combination of fly ash and Beas sand has been determined at the optimum moisture content and maximum dry density.

3. Experimental Program

3.1 Materials:

The black cotton soil is obtained from Gupta Form House, Bagli District Dewas, Madhya Pradesh (INDIA). Sand used in this experimental investigation has been obtained from river Beas and fly ash is obtained from Ropar thermal power plant According to ASTM classification system (ASTM D2487-11), the black cotton soil was classified as clay with high plasticity (CH) and the properties of black cotton soil are given in Table 1. The fly ash was obtained as residue left after electronic precipitation of the burnt gases. The chemical composition of fly ash is given in Table 2 (ASTM D5239-2004).

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Table 1: Physical properties of black cotton soil, sand and fly ash

Property	Black Cotton Soil	Sand	Fly Ash
Specific gravity	2.30	2.635	1.966
Maximum dry density, g/cc	1.515	1.592	1.164
Optimum moisture content, %	22.03	7.0	32.0
Activity	2.73	-	-
Differential free swell index, %	58.86	-	-
Liquid limit, %	62.5	-	40.0
Plastic limit, %	32.5	-	-
Plasticity index, %	30.0	-	-
Uniformity coefficient, Cu	-	1.73	-
Coefficient of curvature, Cc	-	1.02	-
Soaked CBR, %	2.69	9.09	1.94

Table 2: Chemical composition of fly ash

Chemical Composition	Proportion (%)
Silica (SiO_2)	55.69
Alumina (Al_2O_3)	26.33
Calcium oxide (Cao)	3.43
Iron oxide (Fe_2O_3)	6.90
Potassium Oxide (K_2O)	0.98
Sulphur (SO_3)	0.45
Magnesium Oxide (Mgo)	0.62
Loss on ignition	5.60

3.2 Method of Testing:

The laboratory tests were conducted in accordance with ASTM standards. The specific gravity tests, consistency limit tests and the standard Proctor tests were conducted in accordance with ASTM D854-10, ASTM D4318-10 and ASTM D698-07e1 respectively. The physical properties of black cotton soil, sand and fly ash are presented in Table 1.

The hydrometer analysis tests were conducted as per ASTM D422-63. The particle size distribution of black cotton soil, sand and fly ash tested as per ASTM D6913-04 (2009) are given in Fig.2. The sizes of the compaction molds used were of 101 mm diameter and 125 mm height. Compaction tests were conducted on black cotton soil with varying percentages of sand from 10% to 50% and optimum mixes were obtained. After obtaining optimum mix proportion varying percentages of fly ash is added with black cotton soil-sand mix from 5 to 20% in increments of 5%. The California bearing ratio tests were performed in laboratory in accordance with ASTM D1883-05. The sizes of samples were of 150 mm diameter and 125 mm height. Soaked CBR tests were conducted in standard mold for samples compacted statically at maximum dry MDD and OMC. Surcharge weight of 50N was used during the testing. A metal penetration plunger of diameter 50 mm and 100 mm long was used to penetrate the samples at the rate of 1.25 mm/minute using computerized CBR testing machine.

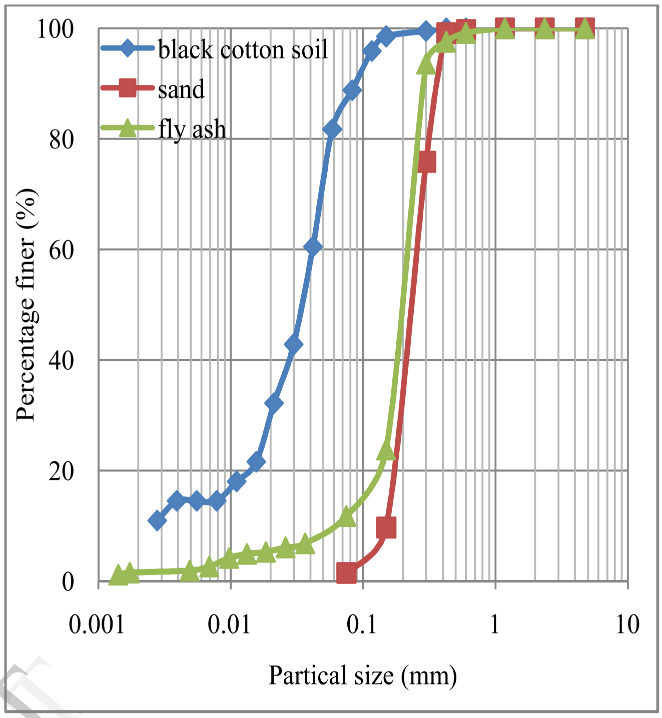

Fig. 2: Particle size distribution of black cotton soil, sand and fly ash

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4. Results and Discussions

4.1. Compaction Tests:

The water content-dry density curves of black cotton soil mixed with sand content varying from 10% to 50% are shown in Fig. 3. It is observed that maximum dry density (MDD) of the black cotton soil-sand composite increases with the increase in sand content up to 50%. This occurs due to the reason that the void spaces between the sand particles are occupied by the black cotton soil particles.

The variation of maximum dry density of various black cotton soil-sand mixes is shown in Fig. 4. It is observed that maximum dry density of black cotton soil-sand composite approximate linearly increases with increase in sand content up to 50%. On linear regression model, the relationships between the percentage of sand and maximum dry density of the black cotton soil; in which maximum dry density is represented by 'γ_{dmax}' and percentage of sand is represented by 's'; is given by:

$$\gamma_{dmax} = 0.0054s + 1.5349$$
$$R^2 = 0.961$$

The variation of optimum moisture content (OMC) with addition of sand to black cotton soil is shown in Fig. 5. The OMC decrease linearly as the percentage of sand increases.

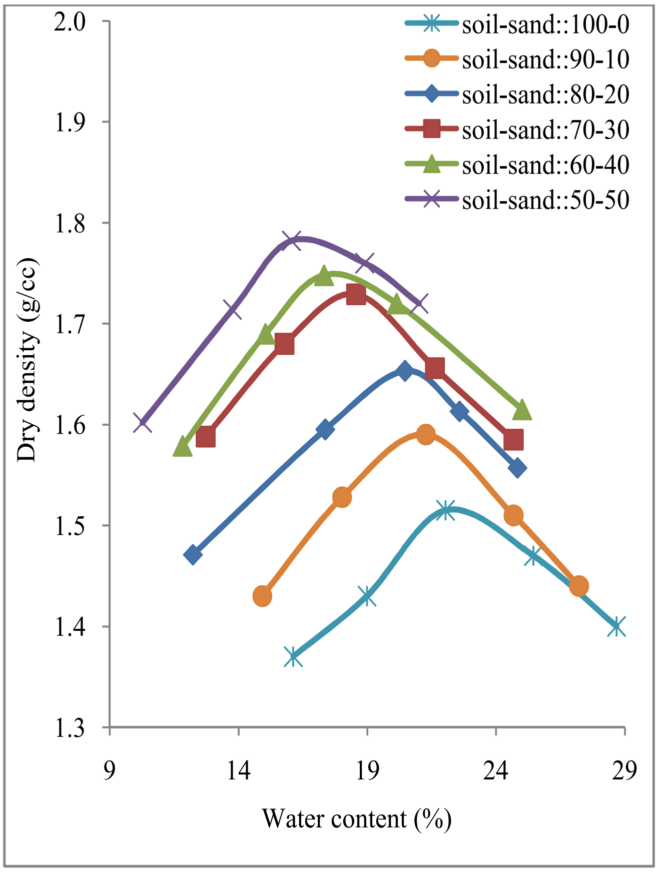

Fig. 3: Compaction characteristics of black cotton soil-sand mixes

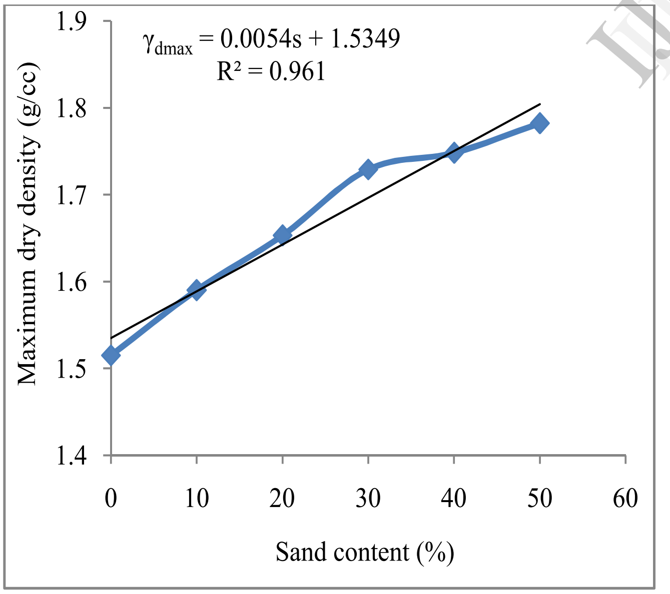

Fig. 4: Variation of maximum dry density of black cotton soil-sand mixes

On linear regression model, the relationships between the percentage of sand and optimum moisture content of the black cotton soil; in which optimum moisture content is represented by 'OMC' and percentage of sand is represented by 's'; is given by:

$$OMC = -0.1265s + 22.463$$
$$R^2 = 0.9856$$

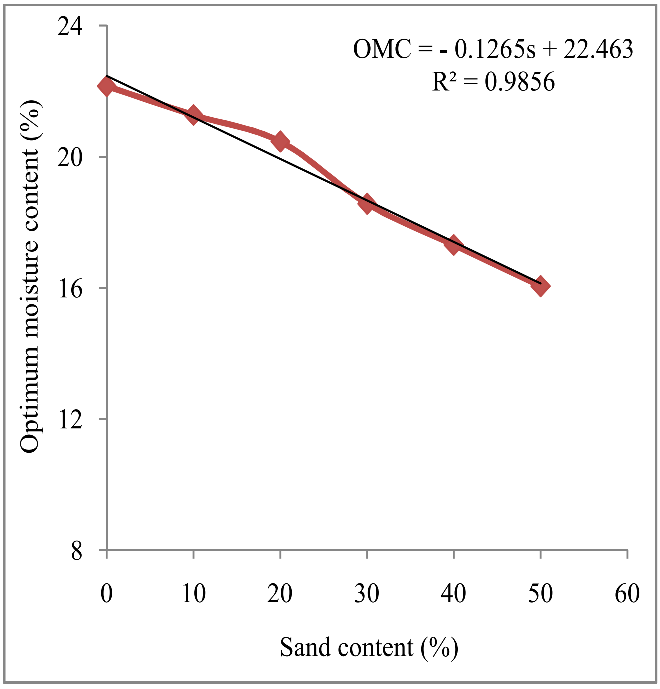

Fig. 5: Variation of optimum moisture content of black cotton soil-sand mixes

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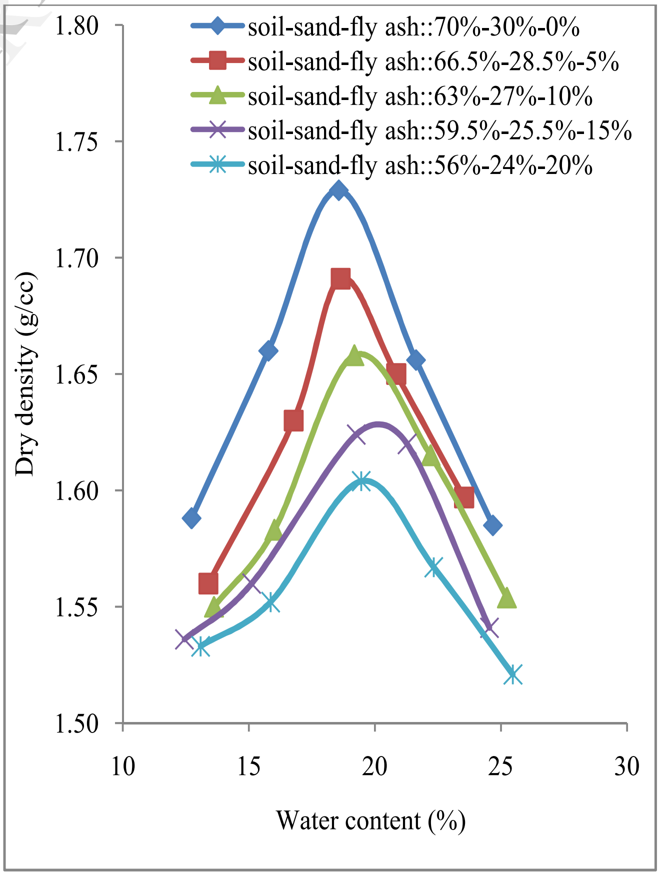

Fig. 6: Compaction characteristics of black cotton soil-sand-fly ash mix

The water content-dry density curves of the black cotton soil-sand (70:30) composite with fly ash content varying from 5% to 20% is shown in Fig. 6. The maximum dry density achieved after the addition of fly ash is lesser compared with black cotton soil-sand mix. This is due to the reason that the black cotton soil particles can fill most of the voids in the sand when mixed in the ratio of 70:30 (black cotton soil:sand). Further, it is observed that as the fly ash content increases, the maximum dry density decreases but the optimum moisture content increases.

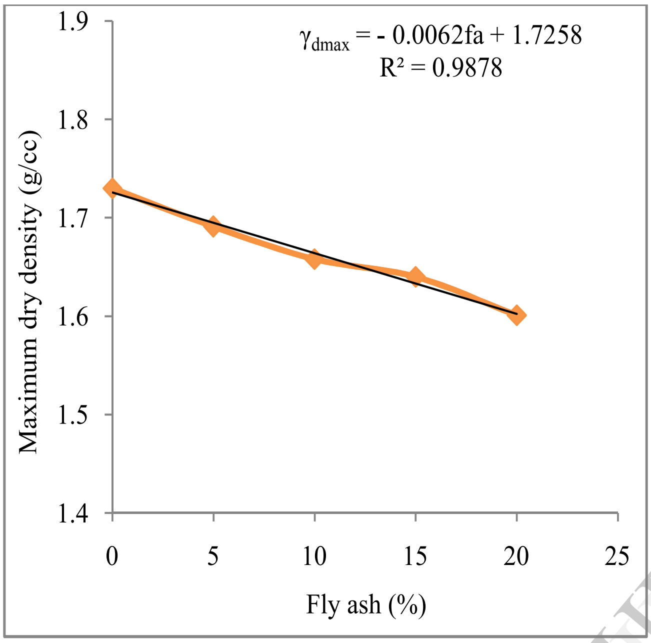

Fig. 7: Variation of maximum dry density of black cotton soil-sand composite with addition of fly ash

Figure 7 shows the variation of maximum dry density with addition of fly ash content. The value of maximum dry density of black cotton soil-sand mix decreases due to addition of fly ash which is a light weight material as compared to black cotton soil and sand. This is mainly attributed to flocculated structures formed by addition of fly ash having low specific gravity.

On linear regression model, the relationships between the percentage of fly ash and maximum dry density of the black cotton soil- sand mixture (70:30); in which maximum dry density is represented by 'γ_{dmax}' and percentage of fly ash is represented by 'fa'; is given by:

$$\gamma_{dmax} = -0.0062fa + 1.7258$$
$$R^2 = 0.9878$$

Figure 8 shows the variation of optimum moisture content with addition of fly ash to the black cotton soil-sand mix. The value of OMC increased with the addition of fly ash. On linear regression model, the relationships between the percentage of fly ash and optimum moisture content of the black cotton soil-sand (70:30); in which optimum moisture content is represented by 'OMC' and percentage of fly ash is represented by 'fa'; is given by:

$$OMC = 0.0438fa + 18.618$$
$$R^2 = 0.9584$$

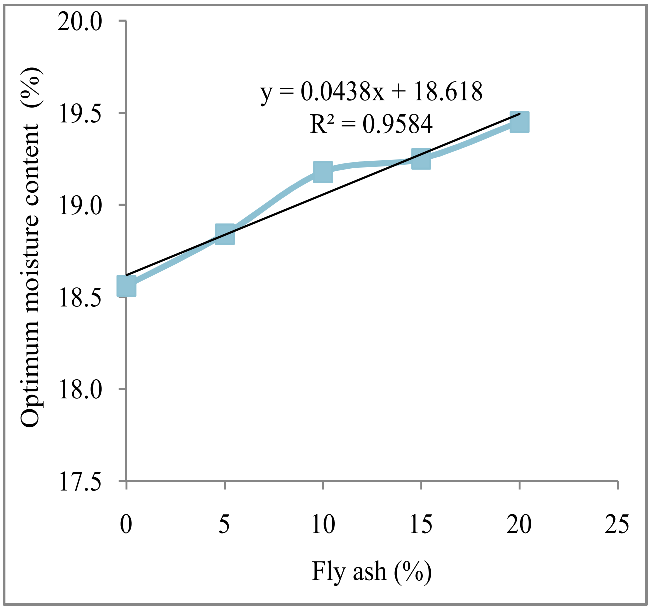

Fig. 8: Variation of optimum moisture content of black cotton soil- sand composite with addition of fly ash

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4.2. California Bearing Ratio Tests

The results of California bearing ratio (CBR) tests on black cotton soil treated with sand and fly ash are shown in figure 8. It is observed that soaked CBR value of black cotton soil increased with addition of sand and fly ash. The value of CBR increases from 2.69% for un-stabilized soil to 5.97% for soil stabilized with sand and fly ash. The improvement in CBR value may be attributed to better compaction and packing of the mix particles with addition of sand and fly ash.

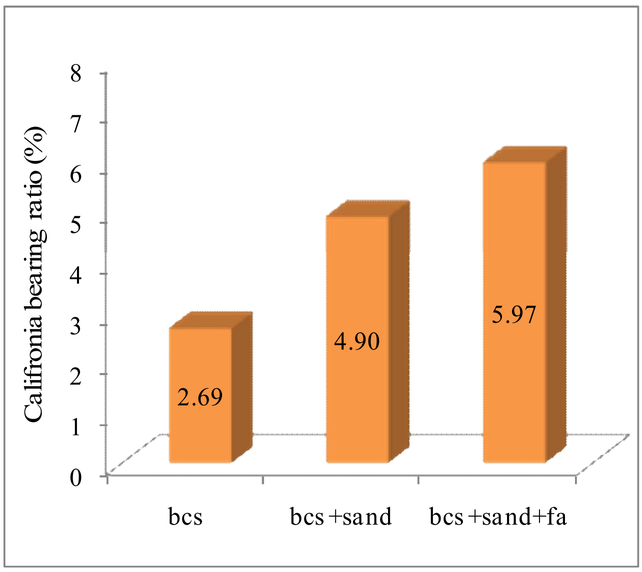

Fig. 9: Variation of soaked CBR value for optimum mixes

The California bearing ratio provides a basis of designing the sub-grades of flexible pavements. Usually, a value of CBR more than 5.0 to 5.5 is considered to be satisfactory for the design of flexible pavements with traffic intensity of 1 to 10 million standard axles (msa). Thus, the black cotton soil can be stabilized with sand and fly ash for the construction of sub-grades.

5. Conclusions:

Black cotton soil creates many problems when come in the contact of water. Fly ash is a waste material produced by the burning of coal in thermal plants and has low specific gravity and high CBR value. The addition of Beas river sand and fly ash with black cotton soil, improves the properties of the composite thus formed, and allows its application in the construction of roads leading to a safe disposal of fly ash. Based upon the above study the following conclusions can be drawn:

1. The black cotton soil is can be stabilized with addition of sand because the finer particles of black cotton soil are replaced with coarser particles of sand.
2. The optimum value of maximum dry density is achieved for black cotton soil-sand mix of 70:30 followed by other proportions (Fig. 3). On further increasing the percentage of sand in the composite, amount of sand required increases and composite becomes uneconomical.
3. The maximum dry density of black cotton soil-sand mix increased with the addition of sand (Fig. 4).
4. The optimum moisture content of black cotton soil-sand mix decreased with the addition of sand (Fig. 5), thus greatly decreasing the tendency of the composite to swell and shrink. This occurs due to lower quantity of water required to lubricate the sand particles which are coarser compared with soil particles.
5. There is significant increase in the CBR value with addition of sand to black cotton soil. The composite of 70% black cotton soil + 30% sand gives a CBR value closer to that generally used.
6. The optimum moisture content of black cotton soil-sand-fly ash mix increased with the addition of fly ash (Fig.8). This occurs due to the fact that the optimum moisture content of fly ash is higher (since the fly ash particles are much finer and rounded in shape) as compared to that of black cotton soil and sand (Table 1).
7. The addition of fly ash causes decrease in maximum dry density and an increase in optimum moisture content but there was an increase in the CBR value and the composite was found to be more stable. The CBR value of black cotton soil improved significantly i.e. from 2.69% to 5.97% with addition of sand and fly ash (Fig. 9).
8. Based upon the test results, it can be concluded that 15% of fly ash may be added when 63% black cotton soil + 27% sand composite. On further increasing the percentage of fly ash, the maximum dry density decreases significantly, hence, higher percentage of fly ash should not be used. Thus, sand-fly ash stabilized black cotton soil can be used for the construction of sub-grades.

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