USE OF INDUSTRIAL WASTES AND ITS EFFECT ON THE PROPERTIES OF BLACK COTTON SOIL

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Abstract: *A problem that continually faces an engineer is that dealing with procedure and technique by which otherwise unsuitable subgrades may be improved by means of stabilization. In many instances, subgrade soils which are unsatisfactory in their natural state can be modified by means of adding admixtures or quantities of aggregate or by proper compaction and thus made suitable for highway subgrade construction. Utilization of industrial wastes such as fly ash, Phosphogypsum, rice husk ash etc., in soil stabilization is cost effective, reduces disposal problems and environment friendly. The main aim of the present study is to assess the usefulness industrial waste as a soil admixture and to improve the properties of soil. The present study aims at the stabilization of black cotton soil using two industrial waste that is Phosphogypsum and fly ash. Black cotton soil was treated with varying percentages of Phosphogypsum (2%, 4%, 6% and 8%) and with the combination of Phosphogypsum and fly ash.*

The treated soil was tested in terms of its engineering and strength properties such as Plasticity characteristics, Compaction characteristics and California bearing ratio (CBR). Both Phosphogypsum and fly ash were found to increase the plastic limit, dry density, CBR and decrease index properties such as liquid limit, plasticity index, thus enhancing the strength parameters of black cotton soil.

Keywords: Phosphogypsum, fly ash, black cotton soil, Atterberg limits, compaction, CBR

1. INTRODUCTION

Soil stabilization is a method used to improve soil strength, bearing capacity and durability under adverse moisture and stress conditions. It refers particularly to the mixing of the parent soil with other soil, fly ash, cement, lime, bituminous products, silicates and various other chemicals and natural or synthetic, organic and inorganic materials. The recent trends on soil stabilization have evolved innovative techniques of utilizing local available environmental and industrial waste material for the modification and stabilization of deficient soil. In the process of soil stabilization and modification emphasis is given for maximum utilization of local material so that cost of construction may be minimized to the maximum extent. At the same time safe disposal of agricultural and domestic wastes become challenging task for engineers. Hence an attempt has been made by researchers to use agricultural and domestic wastes/industrial wastes as soil stabilizers. Soil stabilization can be classified broadly into mechanical stabilization and Chemical stabilization.

1.1 Principle of stabilization

The basic principles in soil stabilization are as follows

- Evaluating the properties of given soil.
- Deciding the method of supplementing the lacking property by the effective and economical method of stabilization.
- Designing the stabilized soil mix for intended stability and durability values.
- Considering the construction procedure by adequately compacting the stabilized layers.

1.2 Black cotton soil

Black cotton soil is the name given to Indian expansive soil. Expansive soils subjected to volume change when it comes in contact with water. It expands during rainy season due to presence of water and shrinks during summer season. Expansive soils owe their characteristics to the presence of swelling clay minerals. Black cotton soils are highly clayey soils which are greyish to blackish in colour found in several states in India. Black cotton soils are formed from basalt or trap and contain the clay mineral called 'Montmorillonite', which is the reason for the excessive swelling and shrinkage characteristics of soil. Expansive soil deposits occur in the arid and semi-arid regions of the world. In India, Expansive soils cover nearly 20% of the landmass and include almost the entire Deccan plateau, Western Madhya Pradesh, parts of Gujarat, Andhra Pradesh, Uttar Pradesh, Karnataka, and Maharashtra. The black cotton soil used in the present study was collected from Raichur district of Karnataka, India

2. Phosphogypsum

Phosphogypsum (PG) is a waste by-product from the processing of phosphate rock by wet acid method in fertilizer production. In India, about 6 MT of waste gypsum such a Phosphogypsum, Fluro gypsum etc., are being generated annually therefore it is necessary to set a secondary industry and recycling these wastes into useful material. About twelve fertilizer plants in the country produce nearly 4 to 5 million tons of Phosphogypsum as a by-product. While some quantities are utilized for production of ammonium sulphate and few other uses, there are accumulated stocks of more than 10 million metric tons of Phosphogypsum at various plant sites. The Phosphogypsum used in this study is collected from chemical fertilizer industry, Thoothukudi, Tamilnadu. It's a grey coloured, fine-grained material.

Figure-1: Phophogypusm

3. Fly ash

Fly ash is a by-product of coal fired electric power generation facilities; it has little cementitious properties compared to lime and cement. Fly ashes are readily available, cheaper and environmentally friendly. There are two main classes of fly ashes; class C and class F. Class C fly ash are produced from burning sub bituminous coal, it has little cementing properties because of high content of free CaO. Class C from lignite has the highest CaO (>30%) resulting in self-cementing characteristics. Class F fly ash are produced by burning anthracite and bituminous coal, it has low self-cementing properties due to limited amount of free CaO. The fly ash used in this study is collected from Raichur thermal power plant, Karnataka and is classified as class C fly ash in accordance with the ASTM standards. The specific gravity (G) of the fly ash was found to be 2.1, the maximum dry density was 15.19 KN/m3 and the optimum moisture content was found to be 17%.

Figure-2: Fly ash

4. Objective of the present study

- To study the properties of black cotton soil.
- To study the effect of varying percentages of Phosphogypsum (2%, 4%, 6% and 8%) on the strength and plasticity characteristics of black cotton soil.
- To find out the optimum percentage of Phosphogypsum with the addition of flyash to achieve maximum strength of soil.

5. LITERATURE REVIEW

Jijo James et al (2014), in this study, the effectiveness of PG in stabilizing an expansive soil has been investigated. From the tests performed on the expansive soil amended with varying percentage of PG, the conclusion can be drawn as, addition of PG to expansive soil resulted in decrease in liquid limit, increase in plastic limit and hence reduced plasticity of the soil, which implies improved plasticity characteristics of the soil. PG reduced the FSI and increased the shrinkage limit of the soil indicating an improvement in swell-shrink characteristics. PG amendment of expansive soil changed its classification from CH to ML. PG amended soil resulted in better UCC strength of the soil comparable to some of the other industrial waste materials, thereby enhancing the strength characteristics of the soil. Test results reveal that 40% PG is optimal in enhancing the index properties as well as the strength of the expansive soil.

Raviteja.A et al (2015), in this work, an attempt was made to utilize an abundantly available powder like Phosphogypsum, industrial residue resulting from the production of phosphoric acid used in many agricultural fertilizers, along with lime to improve the properties of black cotton soil. The combined effects of lime and Phosphogypsum on compaction characteristics, Atterberg limits, unconfined compressive strength, California bearing ratio (CBR) of an expansive soil are discussed in this study. From the test results it can be concluded that, the UCS and CBR of lime treated BC soil improved substantially with increasing percentages of lime content. Also, the UCS and CBR of natural soil enhanced 10 - 12 times after lime stabilization. The natural BC soil stabilized with lime and phosphogypsum mix also resulted 13-15 times strength enhancement in both UCS and CBR. From the experimental investigations, it was found that soil treated with the mix containing lime and Phosphogypsum (4:4) has better strength characteristics and can be used for stabilization of Black cotton soils for pavement subgrades.

6. EXPERIMENTAL INVESTIGATION

6.1 General

In the present study, the various experimental work that has been carried out are wet sieve analysis, hydrometer analysis, Atterberg limit tests (liquid limit and plastic limit), maximum dry density by heavy compaction method, California bearing ratio and unconfined compression test (UCC) for untreated black cotton soil.

Then the black cotton soil is treated with varying percentages of Phosphogypsum 2%, 4%, 6% and 8% by dry weight of soil and tests like Atterberg limit tests (liquid limit and plastic limit), maximum dry density by heavy compaction method and California bearing ratio (CBR) are conducted. Further, the soil is treated with varying percentages of Phosphogypsum i.e. 2%, 4%, 6% and 8% with the optimum percentage of fly ash i.e. 5% and the above tests are conducted.

Table –1: Physical properties of Black Cotton soil

Soil type	Black cotton soil
Particle Size Distribution	
Gravel, %	0
Sand, %	20.96
Silt, %	32.24
Clay, %	46.80
Atterberg's Limits	
Liquid limit, %	71.30
Plastic Limit, %	31.72
Plasticity Index, %	39.58
Standard compaction results	
Maximum Dry Density, KN/m³	15.50
Optimum moisture content, %	25.40
Heavy compaction CBR	
Unsoaked CBR, %	6.07
Soaked CBR, %	1.40
Unconfined Compressive Strength, KN/m²	202.0

6.2 PROPERTIES OF PHOSPHOGYPSUM TREATED BLACK COTTON SOIL

Table-2: Results of Atterberg limits on black cotton soil treated with varying percentage of Phosphogypsum

Phosphogypsum dosage, Percentage by weight of dry soil	Liquid limit %	Plastic limit %	Plasticity index %
0	71.3	31.72	39.58
2	68.0	32.56	35.44
4	66.2	33.97	32.23
6	65.1	35.64	29.46
8	62.8	37.18	25.62

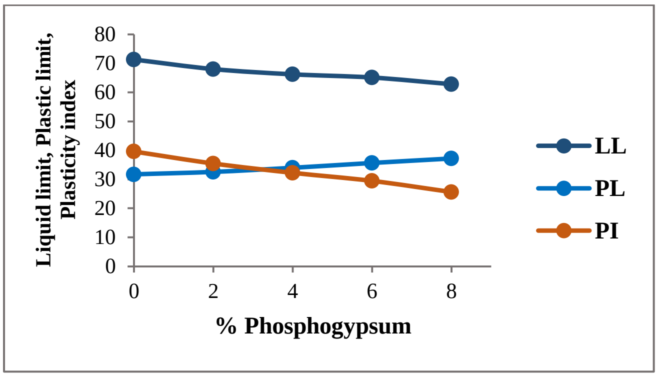

Chart-1: Variation of the Atterberg limits with varying percentage of Phosphogypsum

Table-3: Variation in OMC and MDD of Black Cotton Soil with Varying Percentages of Phosphogypsum

Mixture	OMC (%)	MDD (KN/m³)
BC only	25.40	15.50
BC + 2% PG	24.50	16.18
BC + 4% PG	22.36	16.57
BC + 6% PG	20.87	16.76
BC + 8% PG	23.38	16.28

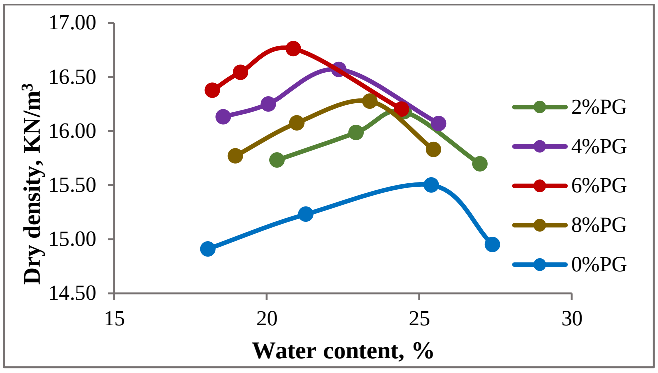

Chart-2: Compaction curve of Black cotton soil treated with varying percentage of Phosphogypsum

Table-4: CBR test results of Black cotton soil treated with varying % of Phosphogypsum

Mixture	CBR % (Unsoaked)	CBR % (soaked)
BC only	6.07	1.40
BC + 2%PG	7.71	2.34
BC + 4%PG	8.41	3.04
BC + 6%PG	9.81	3.50
BC + 8%PG	7.94	2.34

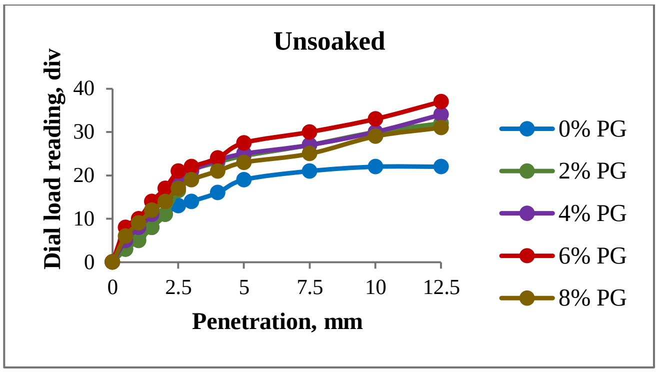

Chart-3: Load – penetration curve of Unsoaked CBR test on black cotton soil treated with varying % of PG

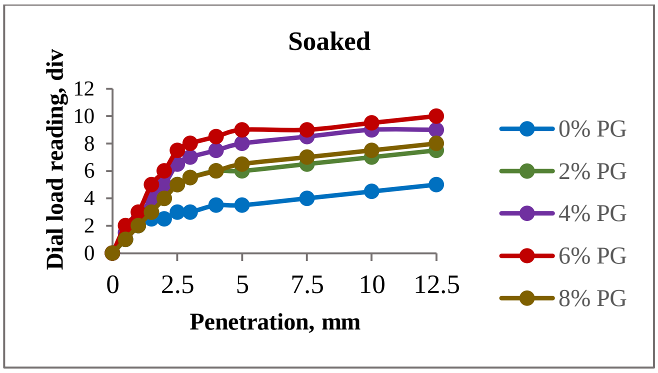

Chart-4: Load – penetration curve of soaked CBR test on black cotton soil treated with varying % of PG

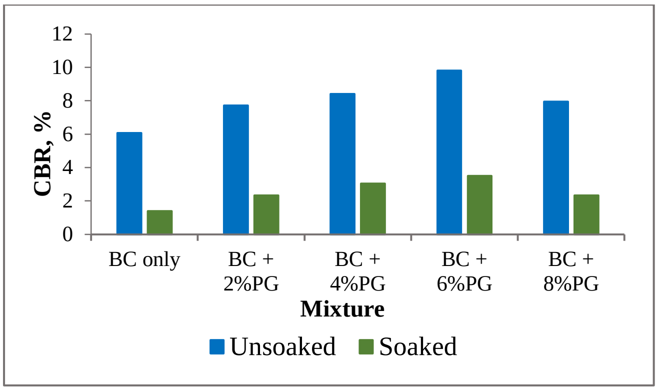

Chart-5: Comparison of CBR value for black cotton soil treated with varying percentages of phosphogypsum

6.3 TESTS ON SOILS TREATED WITH FLYASH AND PHOSPHOGYPSUM

Table-5: Results of Atterberg limits of black cotton soil treated with 5% of fly ash and with varying percentages of Phosphogypsum

Mixture	Liquid limit %	Plastic limit %	Plasticity index %
BC	71.30	31.72	39.58
BCS + 5%FA + 2%PG	64.70	34.27	30.43
BCS + 5%FA + 4%PG	63.20	36.44	26.76
BCS + 5%FA + 6%PG	59.66	38.28	21.38
BCS + 5%FA + 8%PG	57.44	40.37	17.07

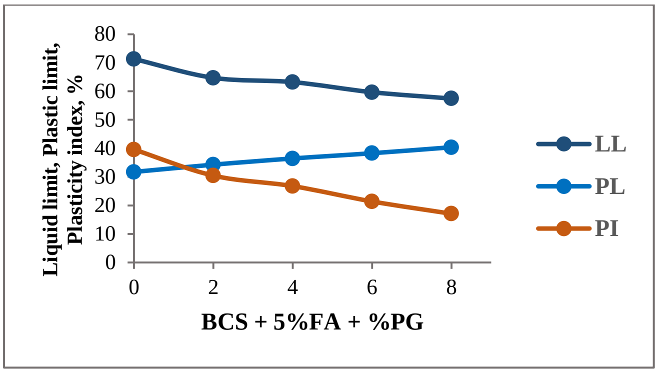

Chart-6: Results of Atterberg limits of BCS treated with 5% of fly ash and with varying of PG

Table-6: Variation in OMC and MDD of Black Cotton Soil with optimum percentage of fly ash (5%) and with varying percentages of Phosphogypsum

Mixture	OMC (%)	MDD (KN/m³)
BC	25.40	15.50
BC + 5% FA +2% PG	21.63	16.57
BC + 5% FA +4% PG	22.25	16.96
BC + 5% FA +6% PG	23.34	17.34
BC + 5% FA +8% PG	20.99	16.66

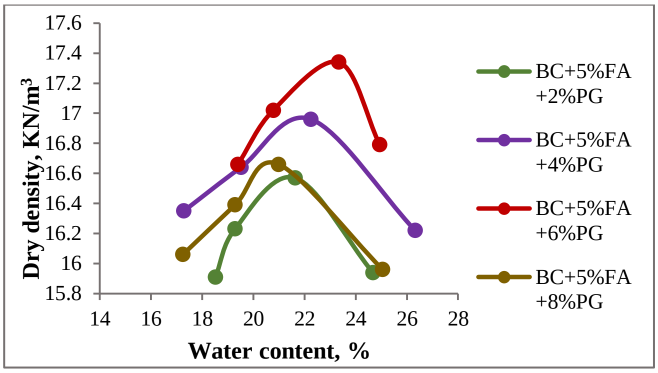

Chart-7: Compaction curve of Black cotton soil treated with 5% FA and with varying % of PG

Table-7: CBR test results on black cotton soil specimens treated with optimum percentage of fly ash and with varying percentages of Phosphogypsum

Mixture	CBR % (Unsoaked)	CBR % (soaked)
BC	6.07	1.40
BC + 2%PG + 5%FA	7.94	2.57
BC + 4%PG + 5%FA	8.88	3.50
BC + 6%PG + 5%FA	10.28	5.14
BC + 8%PG + 5%FA	8.41	3.04

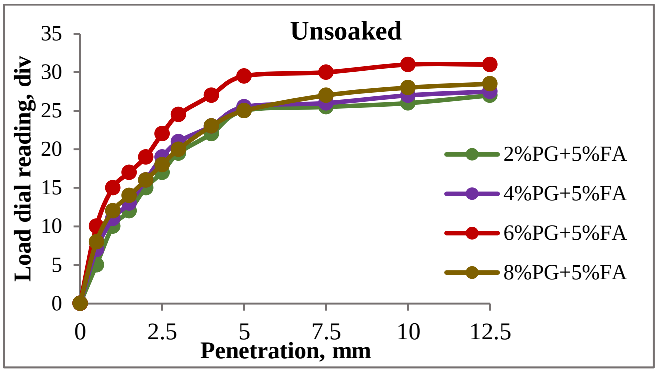

Chart-8: Load – penetration curve of Unsoaked CBR test on black cotton soil treated with 5% of flash and with varying percentage of Phosphogypsum

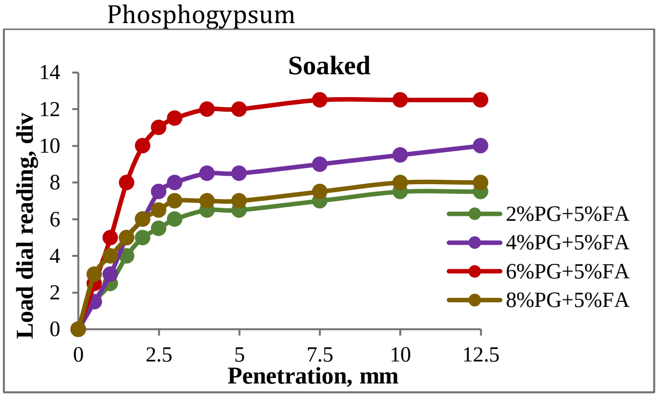

Chart-9: Load – penetration curve of soaked CBR test on black cotton soil treated with 5% of fly ash and with varying percentage of

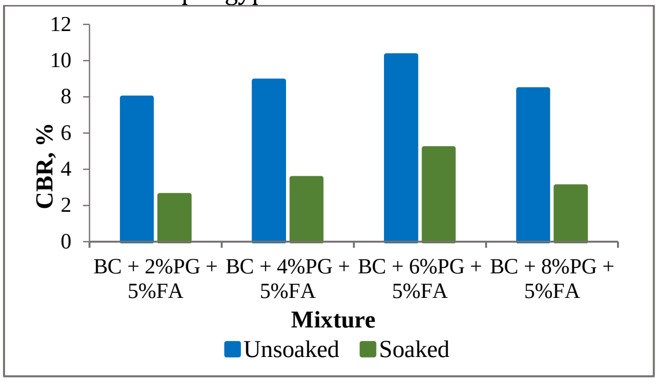

Chart-10: Variation of CBR values of black cotton soil treated with 5%FA and varying percentage of phosphogypsum

7.DISCUSSIONS

Basic plasticity and strength characteristics of Black cotton soil

1. The liquid limit, plastic limit and plasticity index of untreated black cotton soil is 71.30%, 31.72% and 39.58% respectively.,
2. The maximum dry density and optimum moisture content of untreated black cotton soil 15.50 KN/m^3 and 25.40% respectively.,
3. The Unsoaked and soaked CBR value of untreated black cotton soil is 6.07% and 1.40% respectively.,
4. The compressive strength of untreated black cotton soil is 202 KN/m^2.

Plasticity and strength characteristics of Black cotton soil treated with varying percentage of Phosphogypsum

1. The liquid limit of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% are 68%, 66.2%, 65.1% and 62.8% respectively.
2. The plastic limit of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% are 32.56%, 33.97%, 35.64% and 37.18% respectively.
3. The plasticity index of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% are 35.44%, 32.23%, 29.46% and 25.62% respectively.
4. The optimum moisture content of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% are 24.5%, 22.36%, 20.87% and 23.38% respectively.
5. The maximum dry density of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% as additive are 16.18 KN/m^3, 16.57 KN/m^3, 16.76 KN/m^3 and 16.28 KN/m^{3}respectively
6. The Unsoaked CBR value of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% for heavy compaction is 7.71%, 8.41%, 9.81% and 7.94% respectively.
7. The soaked CBR value of black cotton soil treated with Phosphogypsum 2%, 4%, 6% and 8% for heavy compaction is 2.34%, 3.04%, 3.50% and 2.34% respectively.

Plasticity and strength characteristics of Black cotton soil treated with optimum percentage of fly ash (5%) and with varying percentage of Phosphogypsum

1. The liquid limit of Phosphogypsum treated black cotton soil with optimum content of fly ash are 64.7%, 63.2%, 59.66% and 57.44% for 2%, 4%, 6% and 8% respectively.
2. The plastic limit of Phosphogypsum treated black cotton soil with optimum content of fly ash are 34.27%, 36.44%, 38.28% and 40.37% for 2%, 4%, 6% and 8% respectively.
3. The plasticity index of Phosphogypsum treated black cotton soil with optimum content of fly ash are 30.43%, 26.76%, 21.38% and 17.07% for 2%, 4%, 6% and 8% respectively.
4. The optimum moisture content of Phosphogypsum treated black cotton soil with optimum content of fly ash are 21.63%, 22.25%, 23.34% and 20.99% for 2%, 4%, 6% and 8% respectively.
5. The maximum dry density of Phosphogypsum treated black cotton soil with optimum content of fly ash are 16.57 KN/m^3, 16.96 KN/m^3, 17.34 KN/m^{3}and 16.66 KN/m^3 for 2%, 4%, 6% and 8% respectively
6. The Unsoaked CBR value of Phosphogypsum treated black cotton soil with optimum content of fly ash for heavy compaction are 7.94%, 8.88%, 10.28% and 8.41% for 2%, 4%, 6% and 8% respectively.
7. The soaked CBR value of Phosphogypsum treated black cotton soil with optimum content of flyash for heavy compaction are 2.57%, 3.50%, 5.14% and 3.04% for 2%, 4%, 6% and 8% respectively.

8. Conclusions

1. Based on grain size analysis and plasticity characteristics black cotton soil falls under A-7-5(20) group as per HRB classification system and CH (High compressibility clay) group as per IS classification system.
2. The black cotton soil stabilized with Phosphogypsum (2%, 4%, 6% and 8%) resulted in decrease in liquid limit, increase in plastic limit and hence reduced plasticity of the soil. Which indicates improved plasticity characteristics of the soil. Similar observation has been observed when black cotton soil treated with optimum percentage of fly ash (5%) and with varying percentages of Phosphogypsum (2%, 4%, 6% and 8%).
3. The black cotton soil stabilized with Phosphogypsum (2%, 4%, 6% and 8%) resulted in increase in MDD and decrease in OMC, it indicates the better binding of the soil particles with the presence of Phosphogypsum.
4. The Phosphogypsum treated black cotton soil stabilized with fly ash resulted in increase in both MDD and OMC, the increase in OMC is attributed to the increase in the amount of water required for pozzolanic reactions to take place with the addition of fly ash.
5. Black cotton soil stabilized with optimum fly ash (5%) and Phosphogypsum (6%) yield substantial

strength in terms of CBR when compared to black cotton soil stabilized with optimum fly ash (5%) and Phosphogypsum (2%, 4% and 8%)

6. Based on the laboratory studies carried out, it can be concluded that the black cotton soil stabilized with optimum content of Phosphogypsum (6%) and fly ash (5%) is superior and performing better than black cotton soil alone.

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