Periodica Polytechnica
Civil Engineering

60(4), pp. 479–490, 2016
DOI: 10.3311/PPci.8010

RESEARCH ARTICLE

Black Cotton Soil Modification by the Application of Waste Materials

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Received 24-02-2015, revised 12-12-2015, accepted 20-01-2016

Abstract

The black cotton soil is a type of problematic expansive soil which causes many problems in the construction of structures founded on them. It is having a swelling and impervious nature with poor geotechnical subgrade characteristics. In this research an approach is made towards the way of improvement in the various geotechnical properties of black cotton soil such as index properties, swelling characteristics, consolidation characteristics, hydraulic conductivity characteristics and strength characteristics by blending it with waste materials such as river sand, fly ash and marble dust. Hence, from these approaches, the impacting effect of waste materials on the environment reduced due to optimum utilization of these waste materials in the improvement in various properties of black cotton soil.

Keywords

Black cotton soil · Soil modification · geotechnical properties

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1 Introduction

The disposal of waste materials is a big problem in the developing country like India. Due to lack of land required for disposal technique. The substitution of these waste materials in the form of stabilizing agent in the soil stabilization is a modern approach by which waste materials can be advantageously used. The idea behind the technique of soil stabilization used in this study is that the finer particles of soil are replaced with coarser particles of stabilizing material so that a composite having the interlocking between the particles forms resulting in a material with better geotechnical properties.

The black cotton soil used in this study is a highly plastic clayey soil having high swelling nature and is proved to be very problematic for the construction of various infrastructures like embankment, pavements, foundation, hydraulic barriers etc. The black cotton soils contain the Montmorillonite as a clay mineral, which causes the swelling nature in soil, due to water bond between the particles of soil. In India, the black cotton soil is available in about 20 - 25% land area, which includes major portion of Madhya Pradesh and Andhra Pradesh of India. The alternate swell and shrink in the black cotton soil, due to wet and dry season, causes the differential settlement in the structure founded on them. This results the structural damage of the structures in the form of micro cracks on its surfaces. Hausmann [28] revealed that the variation in the volume properties of expansive soil occurs due to variation in the seasonal moisture content. Gourley et al., [27] revealed that the black cotton soil causes the annual structural damage of about $1000 Millions in USA, £150 UK, and many billions pounds in worldwide. Murthy, [33] conducted the swell pressure test of black cotton soil and concluded the method of reducing the swell pressure of soil. Sherif M. ElKholy [25] revealed the effective use of coarse-grained soil (sand) in reduction of swelling characteristics of black cotton soil.

The production of solid waste such as marble dust, fly ash, stone dust, tiles and ceramic waste etc. is occurring at a great pace in our country due to rapid industrialization. The fly ash is a waste material which acts as a pollutant, which is produced after combustion of coal in the thermal power plants. As per

Tab. 1. Physical properties of black cotton soil, river sand, fly ash and marble dust

Properties	Black cotton soil	River sand	Fly ash	Marble dust
Specific gravity	2.29	2.640	1.980	2.62
Coefficient of uniformity, C_u	-	1.750	-	-
Coefficient of curvature, C_c	-	1.010	-	-
Liquid limit (%)	62.7	-	43.0	-
Plastic limit (%)	30.4	-	-	-
Plasticity index (%)	32.3	-	-	-
Shrinkage limit (%)	13			-
Maximum dry density (MDD), g/cm^3	1.53	1.60	1.17	1.63
Optimum moisture content (OMC), (%)	22.8	6.70	33.0	14.32
ASTM classification	CH	-	-	-
Differential free swell index (%)	58	-	-	-
Swell pressure (kPa)	78	-	-	-
Soaked CBR (%)	2.78	9.10	2.12	5.37
Coefficient of permeability (cm/s)	1.123×10^{-7}	2.84×10^{-3}	5.53×10^{-5}	3.24×10^{-4}

the Central Electricity Authority, New Delhi, fly ash is successfully applicable as the substitution of conventional construction materials. The fly ash imparts better geotechnical properties to the soil by using it in soil stabilization. Fly ash possesses pozzolanic nature so it is basically used in chemical stabilization technique. Cokca [22] revealed the positive influence of C class fly ash on geotechnical properties of expansive soil. Xing [42] concluded the beneficial impact of fly ash and lime on compaction, particle size and California bearing ratio characteristics of expansive soil. White [41] reported the effect of fly ash on various geotechnical properties i.e. plasticity, hydration, compaction and strength characteristics of expansive soil. Chauhan et al. [21] concluded that, influence of fly ash percentage mixed with silty sand is that it reduces the maximum dry density and increases the optimum moisture content. Brooks [16] reported the impact of Fly Ash and rice husk ash (RHA) on the various characteristics such as sub grade characteristics, swelling characteristics, unconfined compressive strength of expansive soil. Bose [15] reported that effect of fly ash on compaction characteristics of black cotton soil and concluded that maximum dry density increases up to 20% fly ash and then gradually deceases with increase in fly ash whereas it further increments reduces the optimum water content. A numerous researcher such as Metcalf [31], Brown [17], Phanikumar [34], Edil et al. [24], Ahmaruzzaman [2], Tastan et al. [37], Takhelmayum et al. [36] etc. worked in the field of the effective utilization of fly ash in soil stabilization technique to improve the geotechnical properties of soil.

Similarly, lots of researchers completed work in effective utilization of reactive properties formed by fly ash when blended with some cementing material, in a constructional engineering point of view, such as Wang [39], shows the structural effects of fly ash blended with cement based materials. They propose a numerical analysis to evaluate the fly ash effect on both dilution and chemical effects of cement and also this model is valid for fly ash-cement blends with lower the water-binder ratio and higher fly ash volume replacement, also Wang et.al [40], reported the numerical approach to analysis the compressive strength effect of high-volume fly ash (HVFA) concrete in which typically about 50-60% of fly ash as a total cementitious material. From his study, they concluded that the contribution of fly ash in HVFA concrete mixes prepared at a lower water to binder ratio was greater than those prepared at a higher water to binder ratio.

Marble is a preferable stone and used for decorative purpose in structures across the world. The marble dust is a by-product of marble produced after cutting and finishing of marble in marble industries. Marble dust is also a pollutant and causes many diseases. There are a number of a researcher who worked in the field of soil stabilization using marble dust as a stabilization agent. Kavas et al. [30], Baser [14], Demirel [23], Agrawal et al. [1], Chandra et al. [20], Sabat et al. [35], Viswakarma et al. [38], Gandhi [26] etc reported the utilization of the marble dust in soil stabilizing techniques which basically improves the geotechnical properties such as compaction characteristics, swelling characteristics, hydraulic conductivity, unconfined compressive strength characteristics and index properties of soil such as plastic limit, liquid limit, and shrinkage limit.

It is clear from the aforesaid literature review that till now either fly ash alone or fly ash lime combination or fly ash reinforced with any fiber has been used in soil stabilization process. Therefore, a new combination of river sand, fly ash and marble dust together has been used for the modification of black cotton soil in the present study.

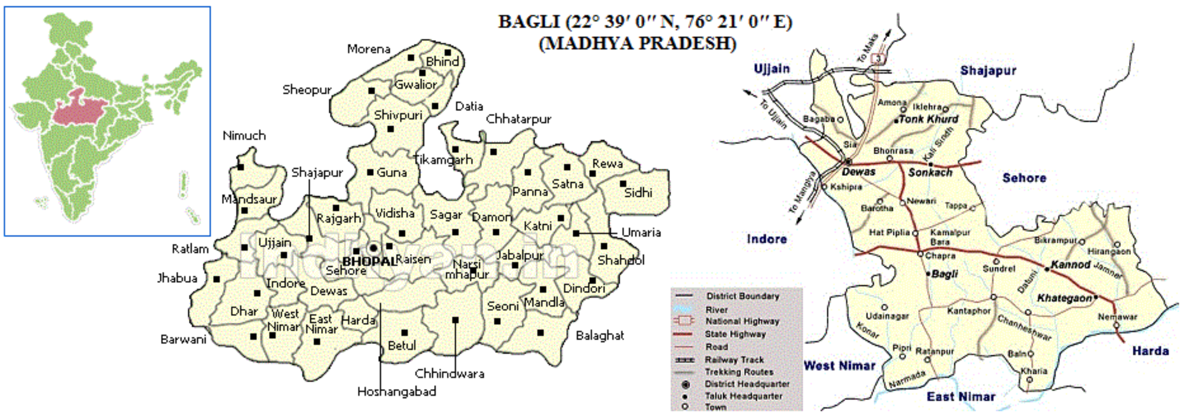

Fig. 1. Map shows the source of black cotton soil used

2 Materials

2.1 Black Cotton Soil:

Black cotton soil was collected from Bagli (22° 39′ 0″ N, 76° 21′ 0″ E), Madhya Pradesh, India (map shown in Fig. 1). As per ASTM D2487-11 [6], the black cotton soil used in this study was clay with high plasticity (CH).The physical properties of black cotton soil are given in Table 1.

2.2 River-sand:

The river sand used in this research work is obtained from Beas River which is uniformly graded. Basic physical properties of river sand are given in Table 1.

2.3 Fly ash:

Fly ash used in this study belongs to the F class category, which was collected from Ropar (HP, India) thermal power plant. Physical and chemical properties of class F fly ash used in this study are given in Table 1 and Table 2 respectively.

2.4 Marble Dust:

Marble dust used in this study was collected from local marble industry. The physical properties and chemical composition of marble dust used in this study is given in Table 1 and Table 3 respectively.

Tab. 2. Chemical properties of fly ash

Constituent	Percentage
Silica (SiO_2)	59.48
Alumina (Al_2O_3)	27.12
Iron oxide (Fe_2O_3)	7.34
Calcium oxide (CaO)	2.32
Magnesium Oxide (MgO)	0.56
Sulphur tri oxide (SO_3)	0.94
Loss of ignition	2.21
Soaked California bearing ratio (%)	2.12

3 Testing Methodology Adopted

The laboratory tests were conducted as per relevant standards into the following steps:

Tab. 3. Chemical composition of marble dust

Constituent	Percentage
SiO_2	0.54
Al_2O_3	0.44
Fe_2O_3	0.11
CaO	54.65
MgO	1.43
SO_3	0.16
Na_2O	0.05
K_2O	0.17
Loss of ignition	42.36

1 A series of standard proctor compaction test were conducted on black cotton soil (BCS) mixed with different percentages of river sand (SD) i.e. 10%, 20%, 30%, 40% & 50%. The purpose of mixing waste river sand in black cotton soil was to make the blending process easy and convenient and to satisfy the criteria of good soil for mix design also mixture behaves as a cohesive non-swelling soil (CNS) layer concept.

2 The unconfined compressive test (UCS) conducted for the above blending percentage of river sand with black cotton soil and on the basis of maximum UCS value, the optimum mix was chosen.

3 Further the above optimum BCS –SD mix obtained was blended with different percentages of fly ash (FA) i.e. 5%, 10%, 15% & 20%. For all these mixes, standard proctor tests were carried out followed by UCS test to obtain the most appropriate black cotton soil-river sand-fly ash mix.

4 By using this appropriate BCS-SD-FA mix as a reference mix, further modification was done by stabilizing this mix with marble dust (MD) waste in different percentage i.e. 8%, 12%, 16% and 20%, also, the standard compaction test and UCS test was conducted to obtained the final optimum mix of black cotton soil blended with river sand, fly ash and marble dust waste.

5 After finding the optimum mixes for all the combinations i.e. optimum mixes of BCS-SD, BCS-SD-FA, and BCS-SD-FA-MD on the basis of Compaction and UCS characteristics; all

the optimum mixes were tested for Index properties tests, California bearing ratio test, Swelling characteristics tests, Consolidation test and Hydraulic conductivity test to analysis the positive changes in geotechnical characteristics of black cotton soil on every modification.

4 Result and Discussions

4.1 Standard Compaction Test

The standard compaction test were conducted in laboratory for all composite materials blended with black cotton soil in accordance with ASTM D698-07e1 [4] with the help of this test the maximum dry density (MDD) and optimum water content (OMC) of all composites were found out and it was concluded (Table 4) that on addition of sand particles into soil, void spaces between the black cotton soil particles were occupied by the river sand particles and also the flocculate to disperse structure aggregation of the mix, the MDD goes increases with sand percentage, similarly, on increasing sand content the OMC of the BCS-SD mix decreases because the sand particles having coarse-grained texture, which having the small specific surface area and thus requires the lesser amount of water to lubricate the mix to obtained MDD. As no optimum mix could be decided on the basis of the results of the compaction tests, it was decided to conduct unconfined compressive strength tests for the BCS-SD mixes and it is concluded that due to dispersed structure aggregation the UCS values were increased up to 100-30 mix of BCS-SD (Table 5) and further addition of sand the UCS values goes decreases due to excessive addition of cohesion less particles into pure clay, hence, the 100-30 ratio mix was finalized as a reference optimum mix for further addition of fly ash.

As fly ash content increase MDD of BCS-SD blended with fly ash decreases while OMC increases. The variation in MDD has occurred due to the reason that the fly ash having the lesser specific gravity as the BCS-SD composite. This is mainly attributed to flocculated structures aggregation formed by the addition of fly ash having low specific gravity and similarly, the variation in OMC has occurred due to fly ash having the large specific surface area so required more water for sufficient lubrication of the composite for achieving the MDD. As disused above, for obtaining the reference optimum mix, the UCS tests were conducted with different percentage of fly ash and it was revealed from result tabulated in Table 5, that the UCS values slightly decrease after addition of fly ash up to 15 percentage and further increment in fly ash content, UCS values goes effectively decreases so that finalized the 100-30-15 ratio for BCS-SD-FA optimum reference mix for further addition of marble dust. As marble dust content increase, MDD of BCS-SD-FA blended with Marble dust increases while OMC decreases. The variation in MDD occurred due to the reason that the marble dust having the greater specific gravity as the BCS-SD-FA composite. This is mainly attributed to dispersed structures aggregation formed by the addition of marble dust and similarly, the variation in OMC occurred due to marble dust having the lesser specific surface area so required less water for sufficient lubrication of the composite for achieving the MDD. For obtaining the final optimum mix, the UCS tests were conducted with different percentage of marble dust and it was revealed from result tabulated in Table 5, that the UCS values increase up to 12% addition of marble dust and further increment in marble dust content, UCS values goes decreases so that finalized the 100-30-15-12 ratio for BCS-SD-FA-MD final optimum mix for all laboratory test conducted. The variation in the maximum dry density and optimum water content of optimum mixes of all Compositions are shown by Fig. 2. The maximum dry density and optimum water content for all composites are given in Table 4.

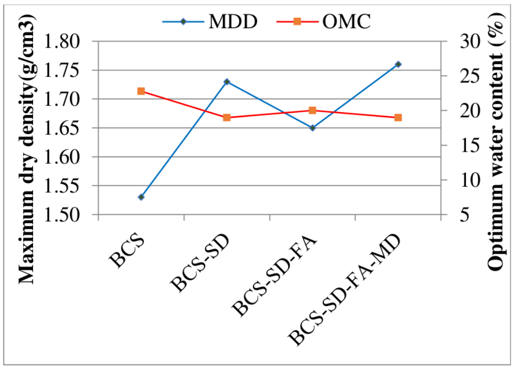

Fig. 2. Variations in maximum dry density and optimum water content for all optimum mixes blended with soil

4.2 Unconfined Compressive Strength Test Results:

As per ASTM D2166-13, unconfined compressive strength test for all composites were conducted in the laboratory using a strain rate of 1.2 mm/min. As discussed in above section, with the help of UCS test, optimum mixes for all composites were obtained which is tabulated in Table 5. Unconfined compressive strength of black cotton soil used in this study was 138.01 kPa. Due to the addition of sand percentage in the soil, dispersed structure aggregation occurs up to 100-30 ratio of BCS- SD mix, so as resulted UCS values increased from 138.01 kPa to 327.07 kPa and then the further addition of sand particle, which means cohesion less particles, the UCS values suddenly decreased. Similarly, addition of fly ash in 100-30 reference optimum mix of BCS-SD, the UCS values slightly decreased up to 15% of fly ash i.e. from 327.07 kPa to 291.62 kPa, which is basically decreased due to flocculated aggregation formed also the further addition of fly ash the UCS values goes suddenly decreases up to 248.58 kPa so that the 100-30-15 ratio of BCS-SD-FA mix were finalized as a reference mix of marble dust. Similarly, addition of marble dust in 100-30-15 reference optimum mix of BCS-SD-FA, the UCS values increased up to 12% of marble dust i.e. from 248.58 kPa to 286.13 kPa, which is basically increased due to the formation of calcium silicate hydrated [C-S-H] reaction in presence of calcium content in marble dust which also attribute to dispersed aggregation, but further addition of marble dust the UCS values was decreased up to 252.46 kPa, so that the 100-30-15-12 ratio of the BCS-

SD-FA-MD mix were finalized as a reference mix of marble dust. Hence, it was revealed from the UCS results, that the UCS values of final optimum mix increased from 138.01 kPa to 286.13 kPa i.e. increased up to 107.32%. The stress-strain behaviors of all optimum composites are shown in Fig. 3. The variation observed in the values of unconfined compressive strength for different optimum mixes are shown in Fig. 4. And it is also cleared from Table 5, that for all the composition mixes, the value of unconfined compressive strength is greater than that of the pure black cotton soil.

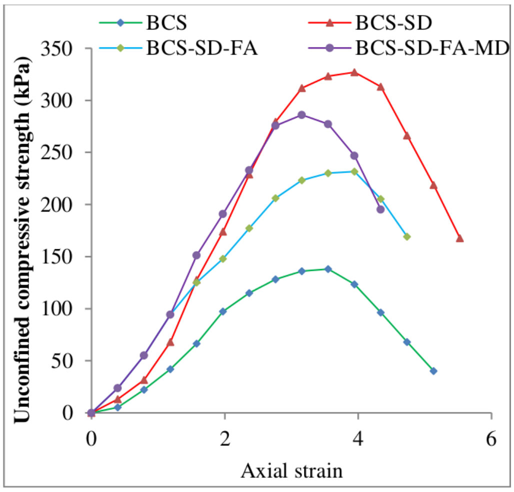

Fig. 3. Unconfined compressive strength for optimum mixes blended with black cotton soil

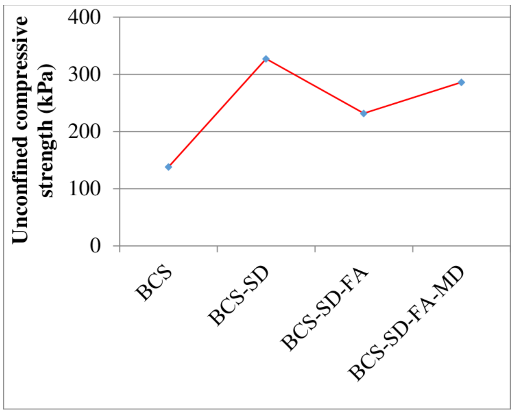

Fig. 4. Variations in unconfined compressive strength values for all optimum mixes blended with black cotton soil

The Fig. 5 clearly shows the black cotton soil failure pattern achieved with a straight orientation which indicate that black cotton soil categorized in purely cohesive soil with a lack in friction. Then after addition of river sand in the black cotton soil, the mix contains both friction and cohesion which clearly indicated by failure pattern inclined at 45^0 to horizontal. As fly ash blended in sand stabilized black cotton soil the failure pattern changed in complex nature which indicates the cohesion in the mix is more than friction but after addition of marble dust the final mix passage a good friction as well as cohesion.

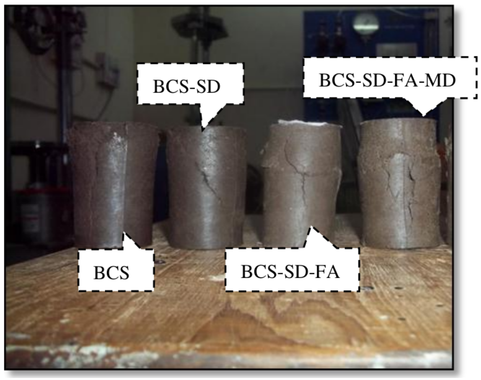

Fig. 5. Variations in failure Pattern achieved in UCS test for all optimum mixes blended with black cotton

4.3 Index Properties Tests

The index properties i.e. consistency limits, specific gravity and particle size distribution tests were conducted as per relevant ASTM standards. Table 6 shows the values of various index properties for all optimum compositions

4.3.1 Consistency Limits

As per ASTM D4318-10 [7] standard, the consistency limits test was conducted in Laboratory which shows that liquid limit, plastic limit and plasticity index decreases whereas the shrinkage limit increases on every addition of waste material in the black cotton soil. The variations were obtained due to changing of soil texture from fine-grained to increasingly granular nature of BCS-SD-FA-MD mix. The variation in the Consistency limits i.e. liquid limit, plastic limit, shrinkage limit and plasticity index of all composites are shown by Fig. 6.

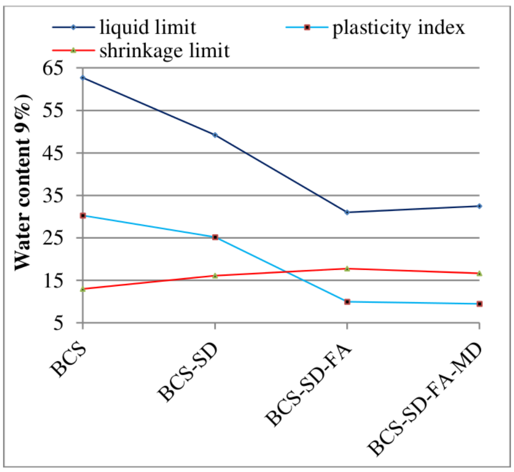

Fig. 6. Variations in consistency limits for all optimum mixes blended with black cotton soil

4.3.2 Specific Gravity Test

As per ASTM D854-10 [5] the specific gravity test for all optimum composites were conducted in laboratory. The change in the specific gravity was obtained due to addition of heavier as well as lighter material in black cotton soil. The variation in the specific gravity for all optimum compositions is shown by Fig. 7.

Tab. 4. Compaction parameters for all the composite mix

Composites	Proportions (%)	Maximum dry density (g/cm3)	Optimum water content (%)
Black cotton soil	100	1.53	22.8
Black cotton soil: river sand	100 - 10	1.59	21.29
	100 - 20	1.651	20.48
	100 - 30	1.73	19
	100 - 40	1.75	17.33
	100 - 50	1.784	16.07
Black cotton soil: river sand: fly ash	100 - 30 - 5	1.691	19.5
	100 - 30 - 10	1.668	19.8
	100 - 30 - 15	1.65	20
	100 - 30 - 20	1.604	19.75
Black cotton soil: river sand: fly ash: marble dust	100 - 30 - 15 - 8	1.73	19.6
	100 - 30 - 15 - 12	1.76	19
	100 - 30 - 15 - 16	1.74	19.3
	100 - 30 - 15 - 20	1.71	18.8

Tab. 5. UCS values for all composite mixes

Compositions	Proportions	UCS (kPa)
Black cotton soil	100	138.01
Black cotton soil: river sand	100 - 10	187.42
	100 - 20	291.63
	100 - 30	327.07
	100 - 40	309.81
	100 - 50	283.19
Black cotton soil: river sand: fly ash	100 - 30 - 5	298.39
	100 - 30 - 10	295.76
	100 - 30 - 15	291.62
	100 - 30 - 20	248.58
Black cotton soil: river sand: fly ash: marble dust	100 - 30 - 15 - 8	273.18
	100 - 30 - 15 - 12	286.13
	100 - 30 - 15 - 16	264.32
	100 - 30 - 15 - 20	252.46

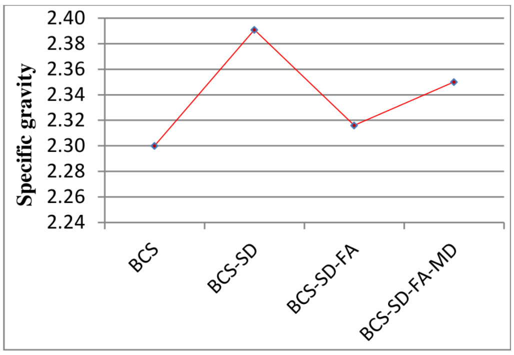

Fig. 7. Variations in Specific gravity for all optimum mixes blended with black cotton soil

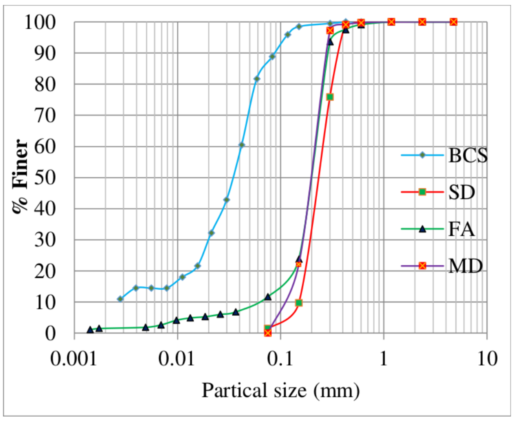

Fig. 8. Particle size distribution curve for black cotton soil, river sand, fly ash, marble dust

4.4 Particle Size Distribution Test

As per ASTM D6913-04 [9] and ASTM D422-63 [3] Particle size distribution and hydrometer test were conducted. The particle size distribution curves of black cotton soil, river sand, fly ash and marble dust are shown in Fig. 8. It is revealed from the figure that black cotton soil and fly ash belongs to the well graded category while river sand and marble dust falls under uniform graded category.

4.5 Swelling Pressure Test

As per ASTM D4546-08 [13] and IS 2911 [18], the constant volume swell pressure test on all optimum composites were conducted in the laboratory. The results indicate that the swell pressure of black cotton soil is 78 kPa. After the optimum addition of sand in black cotton soil i.e. 100-30 of BCS-SD mix

Tab. 6. Index properties for all the optimum composite mix

Composites	Liquid limit (%)	Plastic limit (%)	Shrinkage limit (%)	Plasticity index (%)	Specific gravity
Black cotton soil	62.7	32.4	13	30.3	2.3
Black cotton soil: river sand	49.21	24	16.13	25.21	2.391
Black cotton soil: river sand: fly ash	31	21	17.79	10	2.316
Black cotton soil: river sand: fly ash: marble dust	32.5	23	16.68	9.5	2.35

the swelling pressure suddenly decreased from 78 kPa to 23 kPa which is basically because development of dispersed aggregation opposes the formation of diffused double layer in black cotton soil or in other word reduction in formation of hydrogen bond in Montmorillonite content exist in soil. A further optimum addition of fly ash causes a reduction in exchangeable cation concentration which also reduces the swelling pressure up to 12 kPa, similarly addition of marble dust creates C-S-H reaction which further reduces the swelling pressure up to 9 kPa.

After soil stabilization with optimum quantities of waste materials, the swell pressure values decreases up to 9 kPa i.e. it reduced by 88.46%. The variation in the swell pressure of all optimum mixes as shown by Fig. 9.

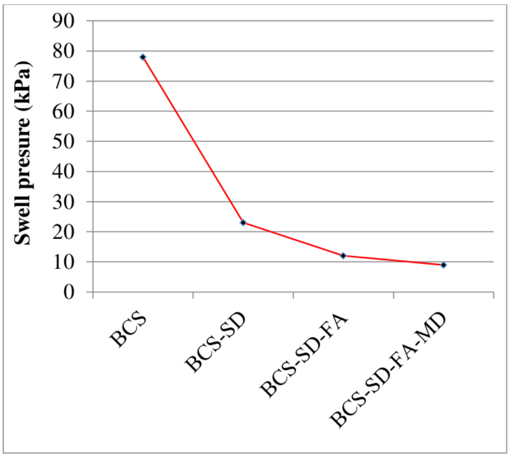

Fig. 9. Variations in swell pressure for optimum mixes blended with black cotton soil

4.6 Differential Free Swell Index Test

As per IS 2911 Part 3 [19], the differential free swell index test for all the optimum composites were conducted in the laboratory. The results show that the differential free swell index of black cotton soil is 58%. After soil stabilization, the differential free swell index value for the final optimum mix reduced to a value of 18% i.e. it reduces by 68.96%. This variation revealed due to alteration in the minerals concentration as discussed in above section. The variation in the differential free swell index of all optimum mixes is shown by Fig. 10.

Also, as per Indian standard, the degree of the expansiveness of black cotton soil is very high. But after soil stabilization, the degree of the expansiveness of final composite i.e. Black cotton soil: river sand: fly ash: marble dust obtained by this study decreased appreciably and it belongs to a low category as shown in Table 7.

Tab. 7. As per IS 2911 Part 3 [19], degree of expansiveness and differential free swell index

Degree of expansiveness	Differential free swell index (%)
Low	Less than 20
Medium	20 - 35
High	35 - 50
Very high	Greater then 50

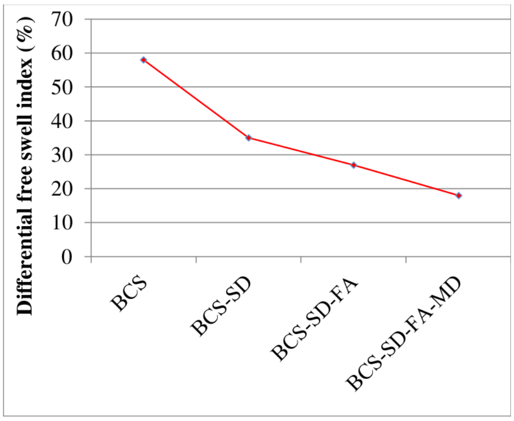

Fig. 10. Variations in differential free swell index for optimum mixes blended with black cotton soil

4.7 One Dimensional Consolidation Test

As per ASTM D2435- 11 [10], the one-dimensional consolidation test for all optimum composites were conducted in the laboratory. Table 8 shows the consolidation parameter for all optimum compositions corresponding loading applied in fixed ring consolidometer for all optimum compositions.

From the Table 8 and Fig. 11 and 12 it is cleared that Compression index and Swelling index were significantly reduced after blending of sand-fly ash-marble dust mix in black cotton soil, this happened because the waste mix attributed to the increasingly granular nature of the black cotton soil resulting in higher porosity and permeability so the stabilized soil acts as a less compressible and swelling soil, which also confirm a valid reason for an increase in the coefficient of consolidation (cv).

The increment in the coefficient of consolidation (c_v) shows the reduction in time for completion of primary consolidation. Similarly the coefficient of volume compressibility and swelling index (m_v) reduces for the composite optimum mixes obtained by blending black cotton soil with waste materials.

Tab. 8. Consolidation compression and swelling index (corresponding to linear slope of e-log p curve) for all optimum composite mix

Composites	Compression index(c_c) Corresponding to 400 - 800 kPa loading	Swelling index (c_s) Corresponding to 50 - 5 kPa loading
Black cotton soil	0.3986	0.071
Black cotton soil: river sand	0.277	0.0652
Black cotton soil: river sand: fly ash	0.1361	0.015
Black cotton soil: river sand: fly ash: marble dust	0.182706	0.00209

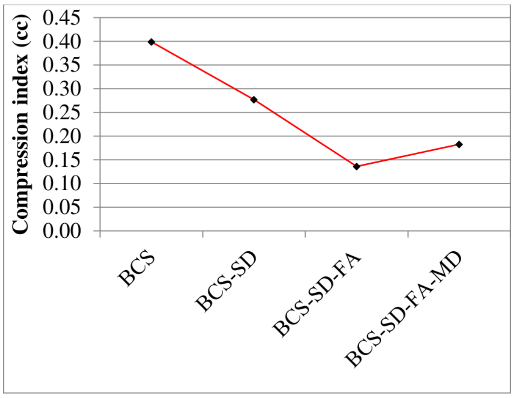

Fig. 11. Variations in compression index (c_c) for optimum mixes blended with black cotton

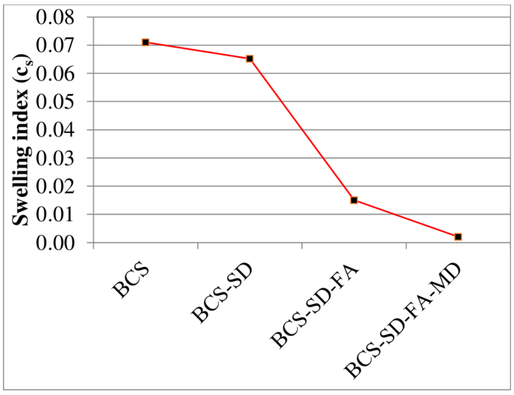

Fig. 12. Variations in swelling index (C_s) for optimum mixes blended with black cotton

The variation in the consolidation parameter i.e. compression index (c_c), swelling index (c_s), coefficient of consolidation (c_v), coefficient of volume compressibility (m_v) and e-log p curves for all optimum mixes are shown by Fig. 11, 12, 13, 14 and 15 respectively.

4.8 Permeability Test

As per ASTM D5084-03 [12] falling head permeability test for all optimum composites were conducted in the laboratory. Due to the addition of coarser particles in the black cotton soil, the optimum mix attributes the granular nature that's by the porosity and hydraulic conductivity increases. The variations in the permeability of all optimum mixes are shown by Fig. 16.

The results show the permeability value of black cotton soil was $1.12*10^{-07}$ (cm/sec). After soil stabilization, the final optimum mix obtained by blending of waste materials

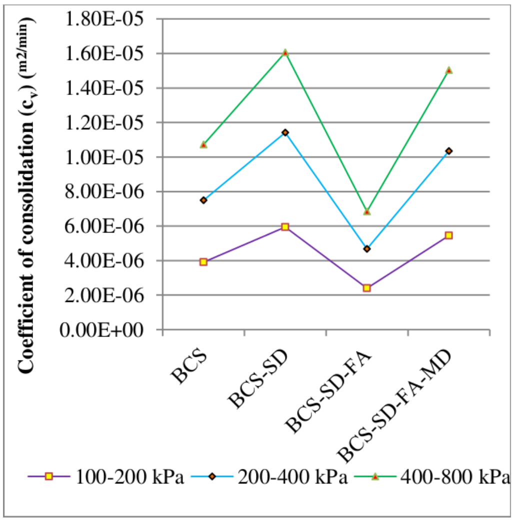

Fig. 13. Variations in Coefficient of consolidation (C_v) for optimum mixes blended with black cotton soil

in the black cotton soil possesses higher permeability value i.e.$1.32*10^{-05}$(cm/sec).

4.9 California Bearing Ratio Test

As per ASTM D1883-05 [11], California bearing ratio test for all optimum composites were conducted in the laboratory. The result shows the soaked and unsoaked CBR values of black cotton soil is 2.78% and 7.38% .The CBR values increases with addition of waste material mix due to the aggregation of soil texture to granular from fine grained so that the base exchange aggregation and dispersed aggregation effects attributes the final optimum mix into an interlocked granular mix so that, after the soil stabilization, the final optimum mix obtained by blending of waste materials in the black cotton soil possess soaked and unsoaked CBR values equal to 8.04% and 14.75% respectively i.e. they increased by 189.20% and 99.86% respectively. The variation in the CBR values of all optimum mixes is shown by Fig. 17.

4.10 X-Ray Diffraction Analysis Results:

The XRD test of black cotton soil and final optimum composite i.e. black cotton soil-waste sand-fly ash-marble dust were conducted in material and science departmental laboratory of national institute of Hamirpur, Himachal Pradesh. Fig. 18 & 19 shows the XRD graphs of black cotton soil and final optimum composites respectively.

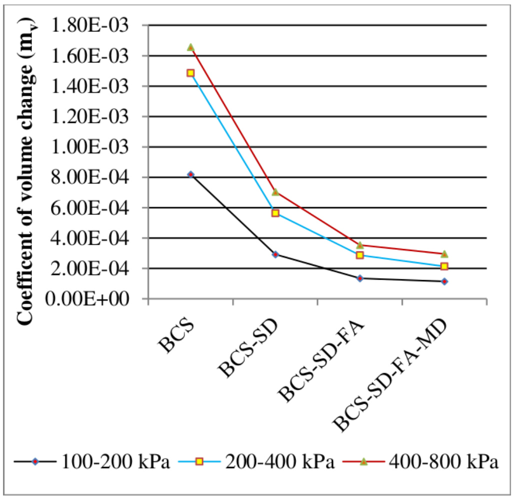

Fig. 14. Variations in Coefficient of volume compressibility (mv) for optimum mixes blended

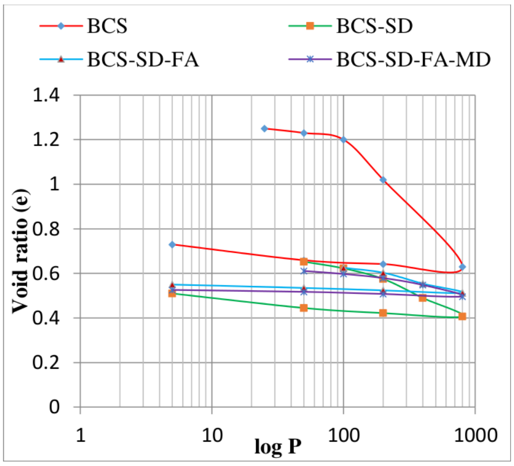

Fig. 15. E-log p curves for optimum mixes blended with soil

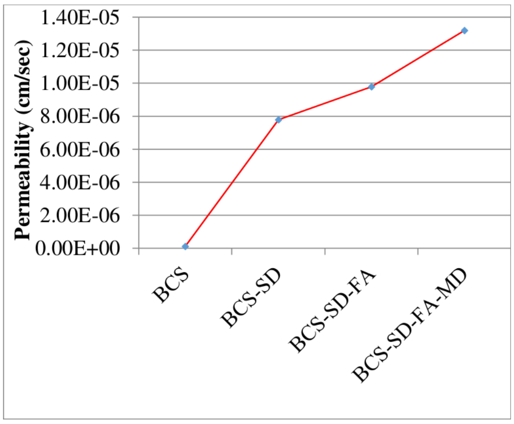

Fig. 16. Variations in permeability for optimum mixes blended with black cotton soil

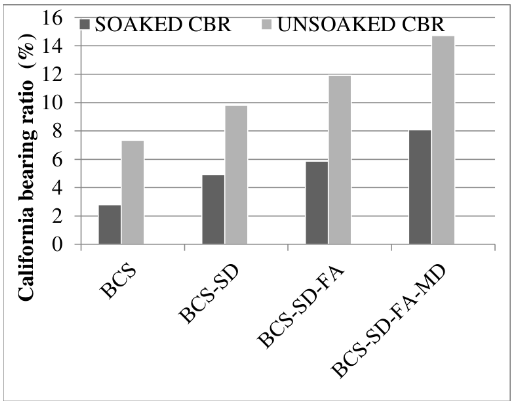

Fig. 17. Variations in soaked and unsoaked CBR values for optimum mixes blended with black cotton

5 Practical applications

5.1 Design of Flexible Pavement

According to Indian Road Congress (IRC): 37-2001 (Guidelines for the design of Flexible Pavements) [29], a flexible pavement has to be designed for cumulative traffic of 1, 5 and 10 msa (million standard axles) with reference to CBR values of black cotton, soil stabilized with the optimum percentage of waste materials respectively. (Table 9) Generally, the soaked CBR value greater than 5.50% is preferred for sub-grade of flexible pavements having lighter traffic intensity. The soaked CBR value of unstabilized black cotton soil is 2.78% and the soaked CBR values of stabilized soil with waste optimum mixes i.e. BCS-SD, BCS-SD-FA, BCS-SD-FA-MD are 4.92%,5.87%, and 8.07% respectively, which have been considered for the design purpose..

From the Fig. 20, it is clear that the pavement thickness with respect to cumulative traffic (msa), reduces significantly, with stabilization of black cotton soil in the influence of waste materials and also a reduction in pavement thickness, directly influences the cost of construction of flexible pavement.

Thus, the stabilization of locally available soil utilizing industrial and construction waste materials along with the natural poorly graded river sand provides improved compaction and strength characteristics and reduces the cost of construction substantially

5.2 Material requirements for sub-grade and embankment design as per Ministry of Road Transport and Highways (MORTH) specification

According to the MORTH specifications [32], the requirement for the materials used as a filler material will have plasticity index (PI) less than 45% and maximum dry density requirements are given in Table 10

The results of geotechnical properties of black cotton soil reveled that it has plasticity index less than 45%, low dry density and swelling in nature that the soil not satisfied the MORTH specifications (2001) criteria for use as an embankment and sub-grade material. But after soil stabilization with waste materials the geotechnical properties of soil improved i.e. MDD of composite optimum mix (BCS-SD-FA-MD) increases from 1.52 g/cm^3 to 1.76 g/cm^3 (17.6 kN/m^3) and also the black cotton soil changes its nature from swelling to non-swelling which shows that the composite stabilized soil satisfied the MORTH specification requirements for sub-grade and embankment materials.

Tab. 9. Pavement thickness consideration as per guide lines of IRC: 37-2001

CBR (%)	Overall Pavement Thickness (mm)					
	Cumulative Traffic (msa)					
	1	**5**	**10**	**50**	**100**	**150**
2	660	795	850	925	955	975
3	550	690	760	830	860	890
4	480	620	700	780	800	820
5	430	580	660	730	750	770
6	390	535	615	675	700	720
7	375	505	580	650	675	695
8	375	475	550	610	640	660
9	375	475	540	605	635	655
10	375	475	540	600	630	650

Tab. 10. Maximum Dry Density Requirements for Sub-Grade and Embankment Materials

Type of work	Maximum laboratory dry unit weight when tested as per IS:2720 (Part 8)
Embankments up to 3 meters height not subjected to extensive flooding.	Not less than 15.2 KN/m³
Embankments exceeding 3 meters height or embankments of any height subject to long periods of inundation	Not less than 16.0 KN/m³
Sub-grade and earthen shoulders/verges/backfill	Not less than 17.5 KN/m³

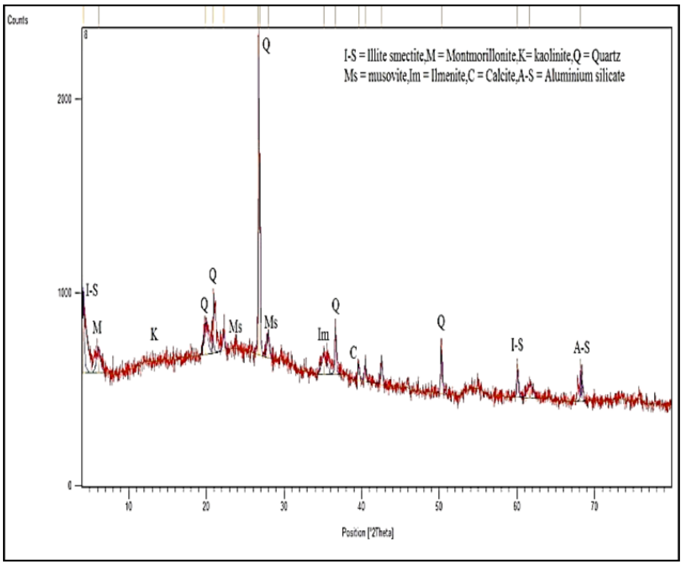

Fig. 18. XRD graph for black cotton soil

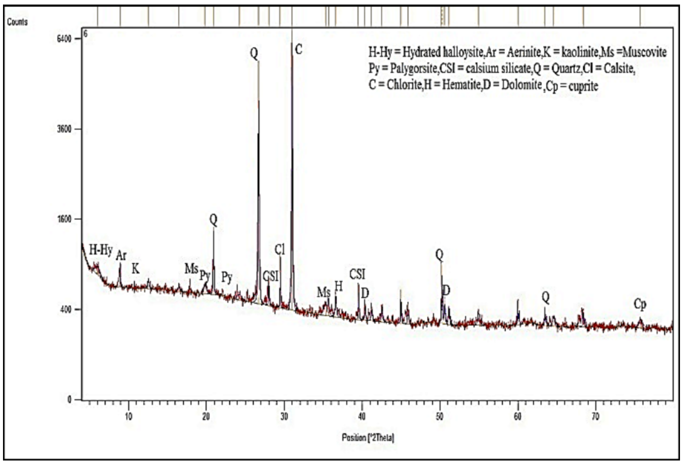

Fig. 19. XRD graph for final optimum composition for black cotton soil blended with waste materials
I-S=Illite-Smectite, M=Montmorillonite, K=Kaolinite, Q=Quitz, C=calcite, Ms=Muscovite, Py=palygorsite, Im=Ilmenite, H-Hy=hydrated-hallosite, Cl=chlorite, CS=calcium-silicate, D=dolomite, Cp=cuprite, A-S=Alumunium Silicate, H=hematite

6 Conclusions

When the black cotton soil comes in contact of water, it causes structure damage and also creates many problems. The replacement of finer particle of black cotton soil with coarser particle of waste materials used alter the gradation of it and the composite acts as a well graded material. Further the addition of these hazardous waste materials i.e. fly ash and marble dust in the river sand stabilized black cotton soil improved the various geotechnical properties of black cotton soil. Also, the final composite allows its application in many construction fields beneficially and also leads to a safe and effective disposal technique of waste materials. Based upon the above study the following conclusions can be drawn:

- The black cotton soil can be well stabilized with river sand, fly ash and marble dust as black cotton soil converts to a well graded material on their addition.
- As per Unconfined Compression Strength test results, the optimum mix selected by this study is BCS-SD-FA-MD::100-30-15-12 (Table 4 and Table 5).
- The standard compaction parameters i.e. maximum dry density of black cotton soil increases from 1.53 g/cm^3 to

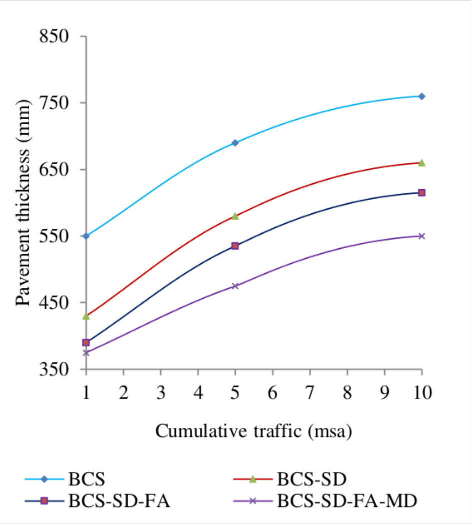

Fig. 20. Variations in pavement thickness corresponding with cumulative traffic (msa)

1.76 g/cm^3 for the final optimum composite whereas the optimum water content of black cotton soil decreases from 22.8% to 19% for the final optimum composite.(Fig. 2)

- The result of UCS test shows that, after stabilization of soil, unconfined compressive strength values of black cotton soil increases from to 138.01 kPa to 286.13 kPa i.e. increased up to 107.32%. (Fig. 3 - 5)
- The index properties i.e. liquid limit and plastic limit of soil blended with waste materials reduces from 62.7 and 32.4% to 32.5 and 23% respectively whereas the shrinkage limit reduces from 13 to 16.68% (Table 6).The result of index properties shows that the black cotton soil changes from clay of high compressibility nature to clay of low compressibility. (The variation in index properties is shown in Fig. 6).
- The variation in swell pressure test of black cotton soil blended with waste material shows the swell pressure of black cotton soil as 78 kPa while addition of waste materials it significantly reduces it to 9 kPa. It shows that the black cotton soil changed its swelling nature after stabilizing with waste materials into non swelling nature.(Fig. 9)
- The result of differential free swelling index test of black cotton soil blended with waste material shows that the differential swelling index of black cotton soil is 58% while addition of waste materials significantly reduces it to 18%. (Fig. 10) Also as per IS 2911 Part 3-1980, after stabilization of black cotton soil with waste materials the degree of expansiveness changes from very high to low. (Table 7).
- The consolidation test results show that the values of coefficient of consolidation (c_v) increases as the black cotton soil is blended with waste materials to form the composite optimum mix. The increment in the coefficient of consolidation (c_v) shows the reduction in time for the completion of primary consolidation. Similarly the coefficient of volume compressibility and swelling index of black cotton soil reduces with addition of waste materials. (Fig. 11 - 15)
- The permeability of black cotton soil blended with waste materials increases with the addition of waste materials because the fine particles of black cotton soil get replaced by the coarser particles of waste materials. The results of permeability test shows that the permeability value of black cotton soil is $1.12*10^{-07}$ (cm/sec) but after soil stabilization, for the final optimum mix the permeability value increased up to $1.32*10^{-05}$ (cm/sec) .(Fig. 16)
- The result of CBR test shows that the soaked and un-soaked CBR values of black cotton soil increases to 189.20% and 99.86% respectively. (Fig. 17)
- The mineralogical composition of black cotton soil and the final optimum mix were determined with the help of XRD techniques, which shows that the black cotton soil having the Montmorillonite as a clay mineral which passage a swelling nature in soil but after stabilization the final optimum mix have not contain these mineral and having calcium minerals in large quantity so that by they form a calcium silicate hydrated structure and passage greater strength and lack in swelling nature. (Figs. 18 - 19)
- The final optimum mix of waste materials blended with black cotton soil is an improved construction material in the construction of flexible pavement design.
- From the practical point of view, the stabilized black cotton soil has been successfully used as an embankment and subgrade material in flexible pavement design with cost effectiveness.
- Thus, the stabilization of locally available problematic soil with utilizing industrial and construction waste materials along with the natural poorly graded river sand provides improved compaction and strength characteristics and reduces the cost of construction substantially. The degradation caused to the environment due to use of these waste materials can also be controlled to some extent.

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