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Load Carrying Capacity of Circular Footing on Black Cotton Soil Reinforced with Fibre Mixed Soil-Cement Column

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Abstract*: The load carrying capacity (Q_a) of black cotton (BC) soil reinforced with single ordinary soil-cement column (OSC) or fibre mixed soil-cement column (FSC) is presented in this paper. Different quantities of cement or polypropylene fibres with cement (i.e., in case of FSC) were taken to construct OSC and FSC. The test on composite soil bed was conducted after the curing period of 28 days. The test results show that the Q_a of the composite soil bed reinforced with OSC containing 5% cement content (C_c) is 2.36 times the Q_a of untreated soil. Similar is the observation for the FSC reinforced BC soil test beds containing combination of F_c and C_c. The FSC reinforced soil bed improves Q_a more significantly than that by the OSC. At 1% F_c and 5% C_c the Q_a of the FSC reinforced BC soil is nearly the same to that of OSC reinforced soil with C_c of 15%. Thus, FSC reinforcement in BC soil provides an economical and environmentally viable solution for ground improvement than the conventional OSC.

***Keywords*: Black cotton soil, deep soil mixing, fibre mixed soil-cement column, polypropylene fibre.**

I. INTRODUCTION

The deep soil mixing (DSM) is widely used stabilisation technique to strengthen ground having deep deposits of the weak/soft soils. In this technique instead of excavating and mixing the additive to whole weak soil, the vertical columns of cement mixed soil are constructed in-situ up to the desired treatment depth. Inclusion of soil-cement columns in the soil reduces the compressibility, limits the settlement and increases the strength of the weak ground [1].

In DSM technique, a high-speed rotating shaft equipped with the mixing head (attached with cutting bit and injection nozzles) at the bottom, is advanced into the ground. During penetration, the cutting bit shears the soils, then the binder (in powdered or slurry form i.e., dry mixing or wet mixing) is pumped through the injection nozzle and mixes with the soil by radial mixing paddles to form soilcrete mortar.

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During the withdrawal stage of the rotating shaft to the surface; additional mixing of mortar is achieved. The mortar hardens during the hydration process and form a columnar structure that is stiffer and stronger than the virgin soil bed. Typically, cement is used in ordinary soil cement columns (OSC) as a binder, but other additives can also be used. For a specific field condition, the soil-cement columns are designed by adjusting any one or more variables like, diameter of columns, mixing type, treated area ratio (the ratio between the combined area of all columns to the total area of improved ground), type and quantity of binder [2]. Normally the columns diameter (d_{sc}) varies from 0.5 to 1.75 m, the centre to centre spacing (S_c) from 1.0 to 1.5 m (i.e., 2d_{sc} to 3d_{sc}), the length from 10 to 30 m and the area improvement ratio from 10 to 30% [7].

The DSM technique is successfully used worldwide: stabilisation of soil of the Bagna-Bangkapong highway in Thailand [8], support for spread footings of a five-level parking garage in Allentown, Pennsylvania [9], foundation support of cement dome, port of Stockton, California, USA [11], excavation support structure of the museum of fine arts, Boston [6], stabilisation of week soil of SR 83/US 331 corridor in Florida [15], are some of the examples. Use of DSM technique in weak soil improvement is not reported so far in India.

The construction of engineering structure on black cotton (BC) soil is a very challenging task. The presence of montmorillonite mineral in this soil causes it to absorb high amount of water during rainy season, resulting in to large volume change accompanied with the loss of strength. The DSM technique applies to a large range of soils such as clays, silty clays, silts, sandy silts, sands, peat and organic clays but not practically applicable in the ground where stiff or very dense soil or cobbles or boulders present [12]. BC soil retains high water during the rainy season and its moisture content could be close to its liquid limit value reducing its strength significantly. The ground improvement in such soils using this method needs to be explored as it may result in a technically viable and economical solution to tackle the problems associated with such soils.

Mixing of cement with soil imparts stiffness and brittleness to the soil and leads to peak strength at low strain [13]. These problems can be resolved by mixing discrete polypropylene fibres with cemented-soil. Polypropylene fibres are petroleum by-product. Mixing of these fibres in soil-cement enhanced the shear strength, unconfined compressive strength (UCS), tensile strength, reduces the stiffness, lowers the post-peak strength loss and also reduce the brittleness of cemented soil [5]. The effect of mixing polypropylene fibre in cemented-black cotton soil is studied by [14]. They found that the UCS of polypropylene fibre mixed cemented-soil with 5% C_c and 1% F_c is equal to the UCS of cemented-soil with 12% cement alone at 28 days curing period; for same UCS of cemented-soil, addition of polypropylene fibre reduced the quantity of cement required. As the cement manufacturing plants emits CO_2, NO_x and particulate matter in the air that has an adverse impact on the environment, hence any effort to reduce the consumption of cement is a welcome step for sustainable development. Thus, use of polypropylene fibre mixed soil-cement column for soil reinforcement can be an economical and environmentally viable method than using ordinary soil cement column.

It therefore follows that DSM technique using OSC or FSC has great potential for application in stabilizing the deep deposits of BC soil. The BC possesses two major problems i) loss of strength and ii) excessive volume increase on wetting. In order to address the strength aspect, load test was planned in this research and the load carrying capacity (Q_a) of a model circular footing on test beds of BC soil containing OSC or FSC in the center was investigated. The moisture in the soil was kept high to simulate field moisture condition during rainy season. The details of the experimental work are discussed below.

II. EXPERIMENTAL NVESTIGATION

A. Materials Used

The materials used in this study are BC soil, ordinary Portland cement and polypropylene fibre. The BC soil used was collected from the college campus of Maulana Azad National Institute of Technology, Bhopal. The basic properties of the BC soil are listed in Table- I.

Table- I: Properties of soil

Properties	Value
Clay content Silt content Sand Content	74.6% 25.4% Nil
Specific gravity	2.74
Consistency limits Liquid limit Plastic limit Plasticity index	 55% 27% 28%
Differential free swell	55%
Modified proctor test Maximum Dry Density (KN/m^3) Optimum water content (%)	 15.40 24.50
IS soil classification [4]	CH

The cement used in the study is ordinary Portland cement of Grade 43 manufactured by JK Lakshmi Cement Limited. The physical properties of the cement are listed in Table- II.

Table- II: Physical Properties of the Cement (Source: Manufacturer datasheet)

Properties↓	Values →	Standard	Test Results
Fineness (m^2/kg)		≯225	279
Soundness Le Chatelier's Method (mm) max		≮10	1
Setting Time (minutes)	Initial	≯30	135
	Final	≮600	275
Compressive Strength (MPa)	3days	≯23	33
	7days	≯33	41
	28 days	≯43	50

The fibres used in the experiments are polypropylene fibres obtained from Reliance Industries Limited (Fig.1). The properties of polypropylene fibres are listed in Table- III.

Table- III: Properties of fibres (Source: Manufacturer datasheet)

Properties	**Value**
Length of fibre	6mm
Diameter of fibre	30µm
Specific surface	140m^2/kg
Unit weight	8.5kN/m^3
Tensile strength	270MPa
Young's modulus	3700MPa

Fig. 1.Fibres used in the study.

B. Methodology and Test Procedure

The soil collected from the field was cleaned and made free from foreign materials. It was then dried, pulverized and sieved through 75-micron sieve to remove the coarse fraction. The cement content (C_c) used in the study was selected as 5, 10 and 15% by dry weight of the soil. The common C_c range is between 4 and 18% for soil cement-column reinforced clays suggested in the literature [1], [14]. The polypropylene fibre content (F_c) chosen were 0.3, 0.6, and 1% by weight of the dry soil [14].

A cylindrical mould made up of brass having an internal diameter (d_m), 150 mm and height (h_m), 230 mm with wall thickness 5mm was taken to prepare the test bed. The BC soil was mixed with the 35% water content (by dry weight of the soil) with the help of mechanical mixer and allowed to rest in a sealed plastic bag overnight, so as to have uniform properties before filling it to the test mould. The mould was filled with the wet BC soil in three layers. Drainage was not allowed from the bottom of the mould by a rubber gasket fitted at the base. For installing the OSC or FSC in the soil, the procedure adopted by [10] was followed. It requires scooping the soil from the centre of the test mould and mixing with the desired amount of cement, or cement and fibres (i.e., in case of FSC). The paste was then poured in the hollow space in the mould in five layers and compacted. The test mould was kept in a humid chamber for curing. After the 28days of curing, load test was performed using a circular steel plate of diameter 125mm and thickness 12mm.

Thus, area improvement ratio, i.e., The ratio of the area of OSC or FSC to the area of soil loaded by the circular footing, of 16% was obtained. For modelling rough footing, about 3mm thick layer of well graded sand was placed under the test plate (Fig.2).

The test was conducted in a conventional loading machine using motorised strain control mechanism at strain rate of 0.5 mm/min, till the specimen failed. The soil resistance was noted through a calibrated proving ring. The summary of test conducted is given in Table- IV.

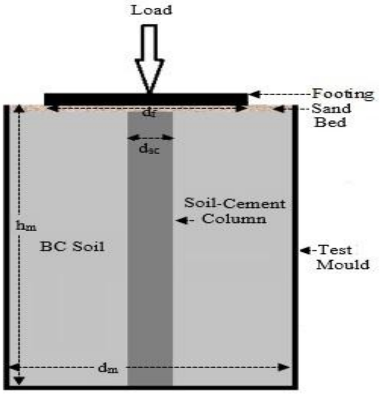

Fig. 2.Test Setup.

Table- IV: Summary of Tests Conducted.

Test Description	Test Variables		Number of Test Mould Prepared
	Cement Content (C_c)	*Fibre Content (F_c)*	
Untreated Soil bed	-	-	1
Soil bed reinforced with OSC	5,10 and 15%	-	3
Soil bed reinforced with FSC	5,10 and 15%	0.3,0.6 and 1%	9
Total Number of Test Mould Prepared			13

III. RESULT AND DISCUSSION

The results of the load test are presented in the form of pressure-settlement curve. The peak pressure in these curves is defined as the load carrying capacity of the ground and is denoted by Q_a.

A. Effect of OSC Reinforcement in BC Soil

Fig.3 shows the pressure-settlement curve for untreated soil and composite soil bed reinforced with OSC. The Qa of the untreated BC soil is observed 62.84kPa. The Qa of composite soil bed reinforced with OSC containing 5, 10 and 15% Cc is observed 148.10, 204.74 and 242.18kPa.

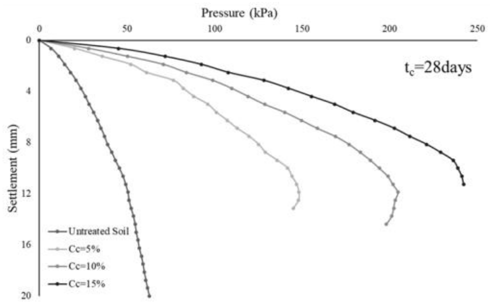

Fig. 3.Pressure-settlement curve of untreated soil and composite soil with OSC containing 5, 10 and 15% C_c.

The probable reason is: when dry cement is mixed with the soil, it reacts with the water present in it and a chemical process starts. Consequently, Calcium-Silicate-Hydrate (C-S-H) gel is formed. This C-S-H gel binds the soil particles together, filling voids and *becoming* stronger and denser with time [3]. The *higher* the cement content in OSC, the more the Qa observed for composite soil bed.

B. Effect of FSC Reinforcement in BC soil

The pressure-settlement curve for composite soil bed reinforced with FSC is shown in Fig.4. The Q_a of composite soil bed reinforced with FSC containing 5% C_c is observed 180.87, 229.02 and 244.20kPa at 0.3, 0.6 & 1% F_c respectively (Fig.4a) i.e., 2.87, 3.65 & 3.98 times the Q_a of untreated soil and 1.22, 1.55 & 1.65 times the Q_a composite soil bed reinforced with OSC for the same C_c. A similar trend is observed for 10 and 15% cement mixed black cotton soil (Fig.4b and 4c). When the polypropylene fibre admixed cemented-soil is loaded, the polypropylene fibres restrict tension cracks in the soil and limits the deformation and also exhibits the ductile behavior that improves the strength of cemented soil [5]. Consequently, the higher Q_a is observed in composite soil with FSC. The efficiency of polypropylene fibre mixed cemented-soil with high C_c is much greater than cemented-soil with low C_c. Increasing the C_c will improve the mobilized cohesion around polypropylene fibre surface and the soil particles, enhances the polypropylene fibres effectiveness and improves the soil strength. The maximum Q_a for composite soil bed of BC soil reinforced with FSC containing 1% F_c and 15% C_c is observed 353.01 kPa.

IV. CONCLUSIONS

A series of laboratory test were conducted to investigate the load carrying capacity of composite soil beds of BC soil reinforced with ordinary soil cement column (OSC) and the fibre mixed soil-cement column (FSC). On the basis of test results following conclusions are drawn:

1. The inclusion of OSC improves the strength of composite soil bed. The Q_a of composite soil bed reinforced with OSC containing 5% C_c is 2.36 times to that of untreated soil. By increasing the C_c to 10 and 15%, the Q_a further improves to 3.26 and 3.85 times respectively.
2. The Q_a of composite soil bed reinforced with FSC containing 5% C_c and 0.3, 0.6 and 1% F_c is 1.22, 1.55 & 1.65 times the Q_a for OSC reinforced soil containing the same C_c. A similar trend was observed for higher cement mixed FSC reinforced soil.
3. At 1% F_c and 5% C_c the Q_a of the FSC reinforced BC soil is nearly the same to that of OSC reinforced BC soil with C_c of 15%. Thus, 10% cement was replaced by mixing 1% fibre.
4. The study suggests that the load bearing capacity of deep deposits of soft BC soil could be improved with OSC or FSC. FSC provides an economically and environmentally viable solution than OSC.

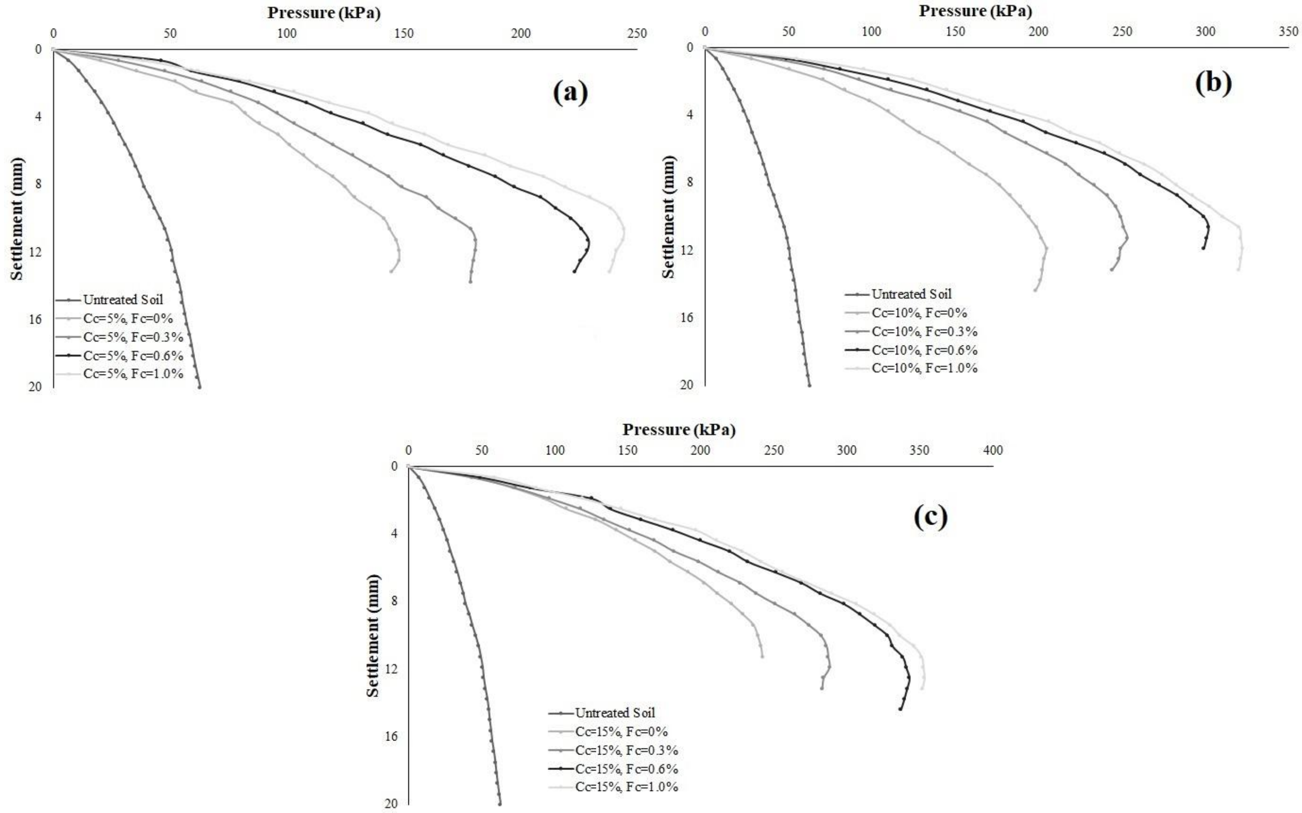

Fig. 4.Pressure-settlement curve of composite soil bed reinforcement with FSC containing 0,0.3,0.6 and 1% F_c: C_c (a) 5%, (b) 10%, (c) 15%.

REFERENCES

1. A. Dehghanbanadaki, K. Ahmad, N. Ali, M. Khari, P. Alimohammadi, and N. Latifi, “Stabilization of soft soils with deep mixed soil columns - general perspective.” Electron. J. Geotech. Eng., vol. 18, 2013, pp. 295–306.
2. A. Probaha, S. Shibuya, and T. Kishida, *State of the art in deep mixing technology. Part III: geomaterial characterization, Ground Improvement*. Thomas Telford Ltd., Japan, 2000, pp. 91-110.
3. A. Sreekrishnavilasam, S. Rahardja, R. Kmetz, and M. Santagata, “Soil treatment using fresh and landfilled cement kiln dust.” Constr. Build. Mater., vol. 21(2), 2007, pp. 318-327.
4. Bureau of Indian Standards (BIS), “Classification and Identification of Soils for General Engineering Purposes” IS 1498, New Delhi, 1970.
5. C. Tang, B. Shi, W. Gao, F. Chen, and Y. Cai, “Strength and mechanical behavior of short polypropylene fiber reinforced and cement stabilized clayey soil.” Geotext. Geomembr., vol. 25(3), 2007, pp. 194-202.
6. D. Weatherby, and D. Zywicki, “Deep soil mixed wall and jet grouting for an excavation retention system at the museum of fine arts Boston.” Proc. 4th Int. Conf. Grouting and Deep Mixing, New Orleans, Louisiana, 2012, pp. 379-388.
7. D.A. Bruce, “Practitioner’s guide to the deep mixing method.” Proc. Inst. Civ. Eng. Ground Improv., vol. 5(3), 2001, pp. 95–100.
8. D.T. Bergado, T. Ruenkrairergsa, Y. Taesiri, and A.S. Balasubramaniam, “Deep soil mixing used to reduce embankment settlement.” Proc. Inst. Civ. Eng. Ground Improv., vol. 3(4), 1999, pp. 145-162.
9. J. Cavey, L.F. Johnsen, and J. DiStas, “Deep soil mixing for foundation support of a parking garage.” Proc. GeoSupport Conf., Orlando, Florida, 2004, pp. 955-964.
10. J. Chai, and S. Pongsivasathit, “A method for predicting consolidation settlements of floating column improved clayey subsoil.” Frontiers Architecture Civ. Eng China. vol. 4(2), 2010, pp. 241-251.
11. L. Shao, and K. Ivanetich, “Heavy structures supported by soil-cement columns.” Proc. GeoShanghai Int. Conf.: Ground Improvement and Geosynthetics, Shanghai, 2010, pp. 125-130.
12. M.E.C. Bruce, R.R. Berg, J.G. Collin, G.M. Filz, M. Terashi, D.S. Yang, and S. Geotechnica, “Deep mixing for embankment and foundation support.” Federal Highway Administration design manual, No. FHWA-HRT-13-046, 2013, U.S.
13. M.J. Khattak, and M. Alrashidi, “Durability and mechanistic characteristics of fiber reinforced soil-cement mixtures.” Int. J. of Pavement Eng., vol. 7, 2006, pp. 53-62.
14. R. Gupta, P.K. Jain, and R. Kumar, “Effect of polypropylene fibre and curing period on unconfined compressive strength of cemented-black cotton soil.” Int. J. Eng. and Advanced Tech. (IJEAT), vol. 9(1). 2019. To be published.
15. W. Schmutzler, G. Mullins, and M. Bertoni, “Soil mixing for the SR-83 project in Florida.” Proc. 5th Int. Conf. Grouting, 2017, pp. 434-444.

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