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Experimental Investigation on the Effect of HDPE Fibres on the Subgrade Strength of Black Cotton Soil

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Abstract- **In India, Black cotton soil covers over one-fifth of the entire land area. These are mostly found in and around the Deccan plateau. The soils are characterized by high shrinkage and swelling characteristics. Foundations in such soils undergo alternate swelling and shrinkage upon wetting and drying, resulting in large scale formation of cracks. The shearing strength of the soils is extremely low. The soils are highly compressible and have very low bearing capacity. It is extremely difficult to work with such soils. This study demonstrates the potential of high density polyethylene strips (HDPE) as soil reinforcement for improving the subgrade strength of black cotton soil. HDPE strips of a particular aspect ratio were randomly mixed with the soil. A series of California Bearing Ratio (CBR) tests, Swell tests, Permeability tests, Proctor's Compaction tests and Triaxial compression tests were carried out on reinforced soil samples by varying the percentage of HDPE strips by weight. A comparison of both unreinforced and reinforced soil sample was carried out. It was observed that the friction angle and cohesion values increased with increasing percentages of HDPE, with 12% being the optimum percentage. At 12% HDPE the friction angle obtained was almost three times as that of unreinforced soil. At 12% HDPE the cohesion obtained was almost five times as that of unreinforced soil. In the case of swell index test, the optimum percentage of HDPE was observed to be 10%. At 10% HDPE, the free swell of the soil sample got reduced by about fifty times. It was observed that the coefficient of permeability decreased with increasing percentages of HDPE, with minimum value being at 12% HDPE. It was observed that the CBR value showed an increase with increasing percentages of HDPE. The optimum value was observed at 12% HDPE. An embankment model was created using Plaxis 2D software and the effect of vehicular load on the embankment strength was analysed. Class A loading was used. It was observed that the settlement obtained was very low.**

Keywords- Black Cotton Soil, California Bearing Ratio, Free Swell, High Density Polyethylene, Triaxial Compression, Permeability, Compaction and.

I. INTRODUCTION

The sub-grade layer of a pavement is, essentially, the underlying ground. Subgrade can be called as the Formation Level. At the subgrade level, the excavation stops and the construction begin. Hence, subgrade is the lowest layer of the pavement structure. The subgrade strength is an important factor deciding the strength and stability of overlying pavements. The CBR value of soil is an important index of the strength of soil and its suitability to be used as subgrade. Triaxial compression test gives an indication of the shear characteristics of the subgrade soil. The extent of swell undergone by soil is an important indication of its suitability to be used as subgrade material. Compaction test is used to determine the maximum dry density and optimum moisture content.

Black cotton soil covers about one-third of the Deccan Peninsula between latitudes 15 to 26° north and longitudes 73 to 83° east. These soils are also called Karail soil in the lower Gangetic basin in Uttar Pradesh and Bhal in Gujarat. It covers almost the whole of Maharashtra, southern regions of Gujarat, the western half of Madhya Pradesh, some areas of Andhra Pradesh, Karnataka and Tamil Nadu, the districts of Bundi and Tonk of Rajasthan and Bundelkhand division of UP. In Kerala, Black Cotton Soil is found in Chittor region of Palakkad district. These soils are derived from the Deccan basalt trap rocks and developed under semi-arid and sub-humid climatic conditions under grass vegetations. These are smectitic clay rich, self-mulching soils with swell-shrink properties. Black soil is characterized by a dark grey to black colour, high clay content, and neutral to slightly alkaline in reaction. Two kinds of parent rocks are involved in the formation of such soils viz., the Deccan and Rajmahal traps and Granite, gneisses and schists. Deccan and Rajmahal traps include volcanic rocks such as basalt and other basic metamorphic rocks whereas Granite, gneisses and schists indicates basic lime and soda lime feldspars. During the formation of black soils, the presence of high proportion of alkaline earth and impeded drainage conditions of the parent materials are of great importance. According to soil taxonomy, medium and deep black soils are grouped into Vertisols whereas shallow black soils are grouped into Entisols and Inceptisols. These soils have a very high coefficient of expansion and contraction involving churning. The process of churning leads to the development of wide and deep cracks. These soils have narrow workable moisture, low infiltration rate, poor drainage and moisture stress. It is poor in organic Carbon and has low Nitrogen, Phosphorous and Sulphur content.

Black cotton soil is characterized by having a very high degree of Swelling. They also have a significantly low value of shear strength. Owing to their high sensitivity to moisture variation, an alternate wetting and drying of such soils results in large scale settlement and formation of cracks. Hence, a subgrade layer of Black Cotton Soil is prone to failure, especially in tropical climate like that in Kerala. High Density Polyethylene strips offer a very efficient method for improving the swelling characteristics and overall properties of such soils.

G Venkatappa Rao and R.K.Dutta (2001), conducted an experimental study to assess the overall influence of sand-waste plastic mixtures on the bearing capacity improvement of granular trench. Study concluded that sand-waste plastic mixtures improved the bearing capacity of granular trench and consequently the bearing capacity ratio. *Khaled Sobhan et al* (2002) conducted an experimental study to evaluate the split tensile load-deformation strength and toughness properties of a granular soil chemically stabilized with cement and fly ash, and mechanically reinforced with recycled HDPE strips obtained from milk and water containers. Study showed that recycled HDPE strips used at an appropriate length and amount can develop a sufficient bond with the soil-cement fly ash matrix, and thus delay the propagation of tensile cracks and that increasing the amount of supplementary cementitious materials by adding fly ash has a beneficial effect on both strength and toughness of the composite studied in this research. *Khaled Sobhan et al* (2002), conducted an experimental study to evaluate the fatigue behaviour of an alternative pavement foundation material containing cement stabilized reclaimed crushed aggregate, Class C fly ash, and waste-plastic strip [High density polyethylene] HDPE Reinforcement. A comparison with similar unreinforced specimens demonstrated that the use of shredded HDPE strips did not provide meaningful improvement of fatigue behaviour. *Achmad Fauzi, et al* (2012), showed that the engineering properties of Kuantan Clayey soil can be improved by adding crushed mineral water plastic bottle (HDPE) and crushed glass as stabilizers. A general trend of increasing CBR values with increasing HDPE and Glass content was observed in the study. The gain in CBR values depended on the amount of stabilizer and water content in the mixture. *Priti Mishra et al*(2013), used Steel slag, a by-product of steel making, in combination with HDPE strips as reinforcement for pavement subgrade material. Study showed that polythene fibres are more efficient when WRP was subjected to tension rather than compression. Vertical displacement was significantly higher than in the fibre reinforced specimens than the unreinforced specimens. *Achmad Fauzi et al* (2015), evaluated the engineering properties on utilizing waste plastic High Density Polyethylene (HDPE) and waste crushed glass as additive on subgrade improvement. The CBR values were increased when content of waste HDPE and Glass increased. C, ϕ Values were decreased and increased respectively when content of waste HDPE and Glass were increased. Utilization of waste HDPE and Glass eliminated the need for expensive borrow material and promoted cost saving through decreasing of pavement thickness, solving disposal problems.

II. EXPERIMENTAL PROGRAM

A. Soil

Black Cotton Soil was collected from Eruthempathy, Chittor from Palakkad district of Kerala. About 25 kg of disturbed soil sample and 8 kg of undisturbed soil sample was collected, labelled properly and stored in the laboratory. Soil samples were air dried before using them for laboratory tests. Physical properties of the soil were determined as per IS Specifications.

Figure 1: Black Cotton Soil

B. Reinforcing material

High Density Polyethylene strips used for the study were purchased in the form of sheets from a wholesale plastic supplying firm at Kottayam. The sheets were 0.1mm thick. HDPE sheets were cut into 4mm X 5mm strips. The density specified by manufacturers was 0.95 g/cm^3. Five different proportions of HDPE, ranging from 4% to 14% by dry weight of soil were used for the study.

Figure 2: HDPE Strips

C. Testing program

Both unreinforced soil and reinforced soil were tested according to Indian Standards. The engineering properties and strength tests such as Sieve Analysis, Atterberg Limit, Specific Gravity, Particle Size Analysis, Standard and Modified Proctor Tests, Unconfined Compressive Strength Test, Triaxial Compression Test and California Bearing Ratio Test were conducted on unreinforced soil sample.

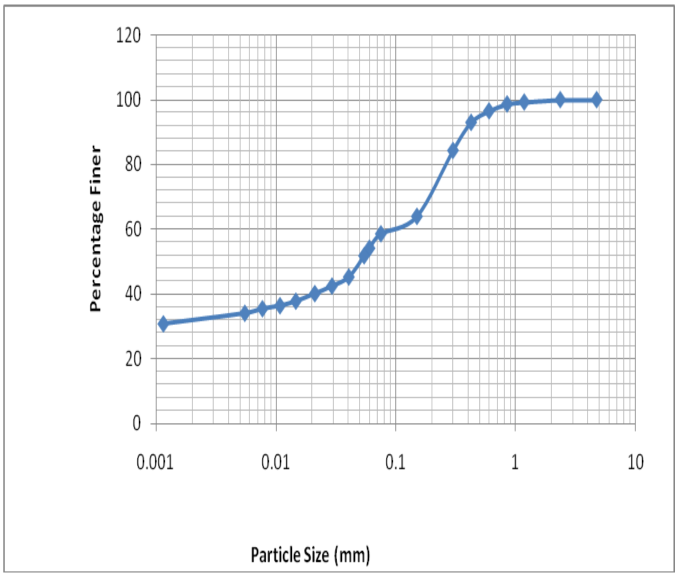

Figure 3: Particle Size Distribution Curve

D. Testing procedure

i. Engineering property tests and strength tests were conducted on raw black cotton soil and the corresponding properties were determined.

ii. Soil sample was then mixed with varying percentages of HDPE fibres, ranging from 4% to 14%.

iii. Tests like Free swell index test, California Bearing Ratio test, Triaxial compression test, Permeability test, Proctor's Compaction test etc., were conducted for all the soil samples.

iv. Laboratory tests conducted on Black Cotton Soil

- California Bearing Ratio Test [IS : 2720 (Part XVI) - 1987]
- Standard Proctor Test [IS : 2720 (Part VII)-1980]
- Modified Proctor Test [IS : 2720 (Part VIII)-l983]
- Atterberg Limits [IS : 2720 (Part V)-l985]
- California Bearing Ratio Test [IS : 2720 (Part XVI) - 1987]
- Unconfined Compressive Strength Test [IS : 2720 (Part X)- 1991]
- Triaxial Compression Test [IS : 2720 (Part XII) - 1984]
- Swell Test [IS : 2720 (Part XVI) - 1987]
- Grain Size Distribution [IS : 2720 (Part 4) - 1985]
- Permeability Test [IS:2720 (Part XVII)-1986]

II. RESULTS AND DISCUSSIONS

A. Properties of raw black cotton soil

Index and engineering properties of raw black cotton soil were determined in the laboratory as per Indian Standards and the results are tabulated in Table 1.

Table 1: Properties of Raw Black Cotton Soil

Properties of Soil		Values
Natural Moisture Content (%)		8.63
Specific Gravity		2.63
Liquid Limit (%)		58
Plastic Limit (%)		11.53
Plasticity Index		46.47
Shrinkage Limit (%)		16.25
Volumetric Shrinkage (%)		46.9
Classification (ISC System)		CH
Standard Proctor Test	Optimum Moisture Content (%)	18.5
	Maximum Dry Density (g/cm^3)	1.825
Modified Proctor Test	Optimum Moisture Content (%)	6.25
	Maximum Dry Density (g/cm3)	2.18
Unconfined Compressive Strength (kN/m^2)		22.465
Cohesion, c (kN/m^2)		11.23
CBR Value (Soaked) (%)		4.464
Free Swell Index (%)		160
Angle of internal friction		6^{0}25′43.49″

A. Standard Proctor Test [IS : 2720 (Part VII)-1980]

Soil samples were air dried and pulverized and those passing through IS 20 mm sieve were used for the test. Light compaction test was conducted on unreinforced soil and in six samples of reinforced soil with 4%, 6%, 8%, 10%, 12% and 14% of HDPE respectively. The results so obtained are shown in Table 2. The water content vs. dry density curves for all the samples are shown in Figure 4.

Unreinforced Black Cotton soil showed optimum moisture content of 18.5% and a maximum dry density of 1.825 g/cm^3. It was observed that addition of HDPE strips increased the maximum dry density, with the optimum value being at 10% HDPE. Optimum moisture content was observed to be decreasing with increasing percentages of HDPE with the optimum value being at 10% HDPE.

Table 2: Proctor Compaction Test Results

Percentage HDPE added (%)	Optimum Moisture Content (%)	Maximum dry density (g/cm^3)
Unreinforced Soil	18.5	1.825
4	16.46	1.839
6	12.465	1.842
8	11.39	1.855
10	10.51	1.860
12	12.8	1.639
14	17.13	1.5574

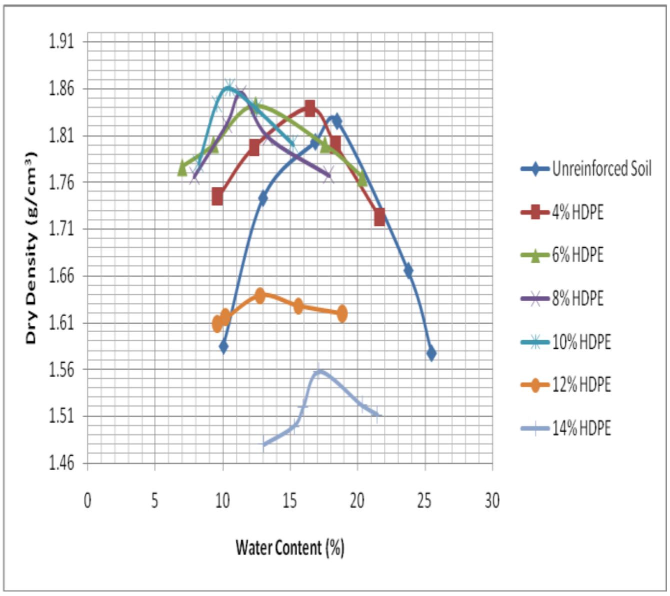

Figure 4: Water content vs. Dry density curves for Proctor's Compaction Test

B. Triaxial Compression Test [IS : 2720 (Part XII) - 1984]

Triaxial test is used to determine the unconsolidated, undrained, compressive strength of cylindrical specimens of cohesive soils in undisturbed as well as remoulded condition, using a strain controlled application of the axial compression-test load where the specimen is subjected to a confining fluid pressure in a triaxial chamber. The method measures the total stresses applied to the specimen.

Soil samples were air dried and pulverized used for the test. Triaxial Compression Tests were conducted on unreinforced soil and in six samples of reinforced soil with 4%, 6%, 8%, 10%, 12% and 14% of HDPE respectively. The obtained results are shown in Table 3. Unreinforced soil sample showed an internal friction angle of 6.43^o and a cohesion value of $3kN/m^2$. For reinforced soil, the internal friction angle and cohesion increased with increasing percentage of HDPE. The optimum value was observed at 12% HDPE.

Table 3: Triaxial Compression Test Results

Percentage of HDPE added (%)	Angle of internal friction (^{0})	Cohesion (kN/m^2)
Unreinforced Soil	6.42875	3
4	7.22875	4.5
6	8.90875	6
8	9.462328	8
10	14.91827	12
12	16.3932	14
14	12.78911	10

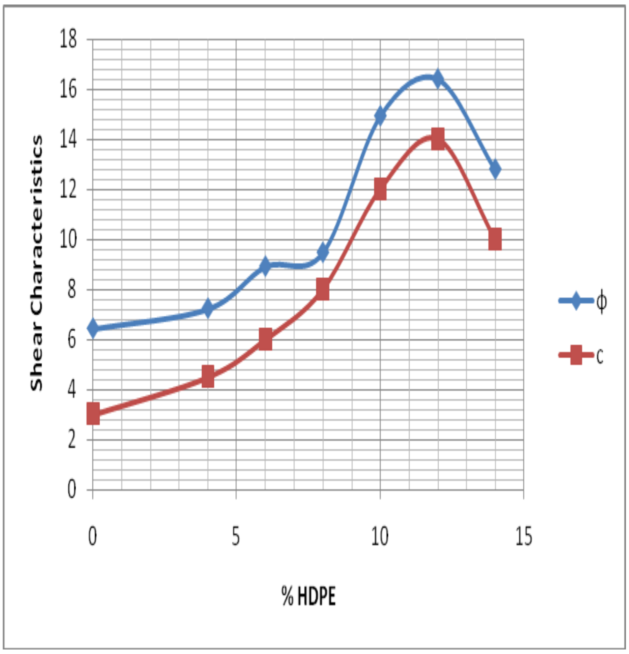

Figure 5: Variation of Shear Characteristics with Percentage of HDPE Added

C. Falling head Permeability test[IS:2720 (Part XVII)-1986]

A 2.5 kg soil sample was taken from a thoroughly mixed oven-dried material passing through 9.5 mm IS sieve, for the test. The moisture content of the sample was predetermined. Falling head permeability tests were conducted on unreinforced soil and in six samples of reinforced soil with 4%, 6%, 8%, 10%, 12% and 14% of HDPE respectively. The obtained results are shown in Table 4. For reinforced soil, the coefficient of permeability decreased with increasing percentage of HDPE. The minimum value was observed at 12% HDPE. . The obtained results are shown in Table 4.

Table 4: Permeability Test Results

% HDPE added	k (mm/s)
Unreinforced soil	8.97E-04
4	6.13703E-05
6	2.78877E-05
8	7.13E-06
10	8.64E-06
12	5.61E-07
14	7.63E-06

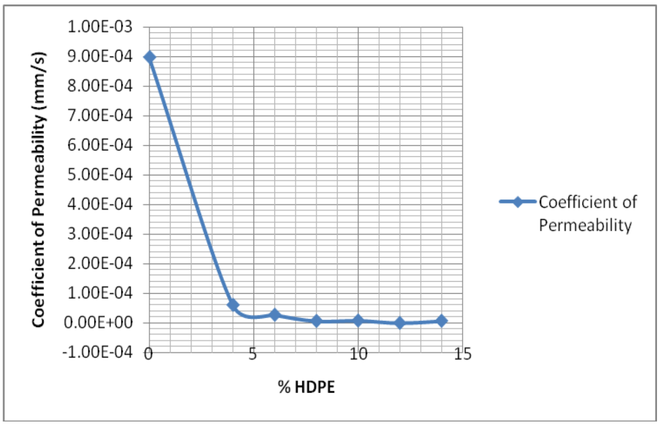

Figure 6: Variation of Coefficient of Permeability with Percentage of HDPE Added

D. Swell Test [IS : 2720 (Part XVI) - 1987]

A 5kg soil sample was taken from a thoroughly mixed oven-dried material passing through 19 mm IS sieve, for the test. Swell test was conducted on unreinforced soil and in six samples of reinforced soil with 4%, 6%, 8%, 10%, 12% and 14% of HDPE respectively. The obtained results are shown in Table 5. For reinforced soil, the swell values decreased with increasing percentage of HDPE. The minimum value was observed at 10% HDPE.

Table 5: Swell Test Results

% HDPE	SWELL (mm)	SWELL (%)
0	26	20.47
4	23	18.11
6	18	14.17
8	9.6	7.559
10	0.5	0.394
12	3	2.362
14	10.2	8.032

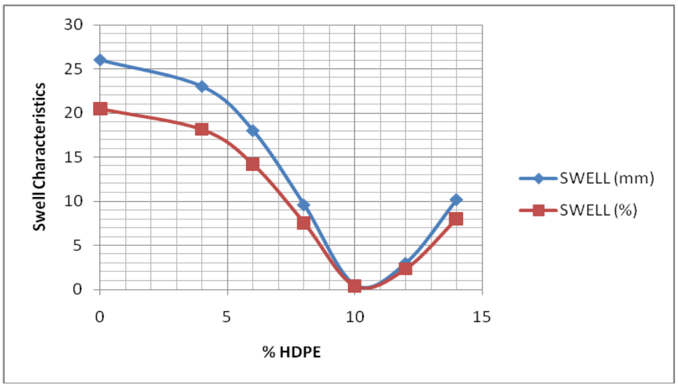

Figure 6: Variation of Swell Characteristics with Percentage of HDPE Added

E. California bearing ratio test [IS : 2720 (Part 16) - 1987]

California bearing Ratio (CBR) is the ratio expressed in percentage of force per unit area required to penetrate a soil mass with a circular plunger of 50mm diameter at the rate of 1.25 mm/min to that required for corresponding penetration in a standard material. The ratio is usually determined for penetration of 2.5 mm and 5.0 mm.

Soil samples were air dried and pulverised and those passing through IS 4.75 mm sieve were used for the test. Soaked CBR test was conducted on unreinforced soil and in six samples of reinforced soil with 4%, 6%, 8%, 10%, 12% and 14% of HDPE respectively. The results so obtained are shown in Table 6. It was observed that in all the test cases, the higher CBR value was observed at 5mm penetration. These tests were hence repeated and the CBR values were determined. In the latter case too, higher CBR value was observed for 5mm penetration. Hence these values were taken as the CBR values for corresponding soil samples.

Table 6: California Bearing Ratio Test Results

Percentage HDPE added (%)	CBR at 2.5mm penetration	CBR at 5mm penetration
0	4.18	5.577
4	4.464	5.952
6	6.84	10.04
8	9.5	13.94
10	12.65	21.83
12	17.86	23.81
14	14.88	22.32

The load vs. penetration curves for all the samples are shown in Figure 7. Unreinforced Black Cotton soil showed significantly low CBR value at 2.5 mm and 5 mm penetrations. It was observed that addition of HDPE strips increased the CBR value. CBR values kept on increasing with increasing percentages of HDPE with the optimum value being at 12% HDPE. The optimum CBR value was about four times of that corresponding to unreinforced soil.

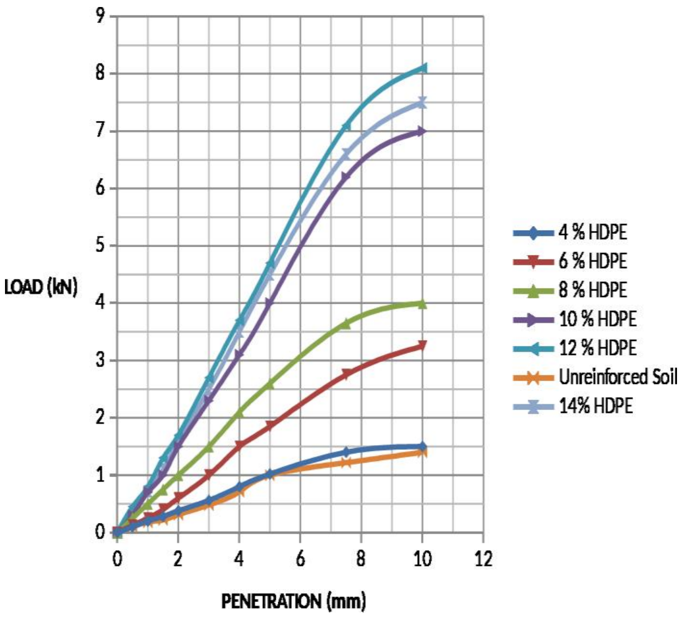

Figure 7: Load vs. Penetration Curves for CBR Tests

F. Analysis of embankment model Using PLAXIS 2D Software

PLAXIS 2D is a finite element package used for the two dimensional analysis of deformation and stability in geotechnical engineering. With PLAXIS 2D the geometry of the model can be defined in soil mode as well as structures mode and after that, independent solid models can be intersected and meshed. The staged construction mode allows for simulation of construction and excavation processes by activating and deactivating soil clusters and structural objects. The calculation kernel enables a realistic simulation of the non linear, time dependent and anisotropic behaviour of soils and/or rock. As soil is a multi phase material, special procedures are provided for calculations dealing with hydrostatic and non hydrostatic pore pressures in the soil. The output consists of a full suite of visualization tools to check the details of the 2D underground soil-structure model.

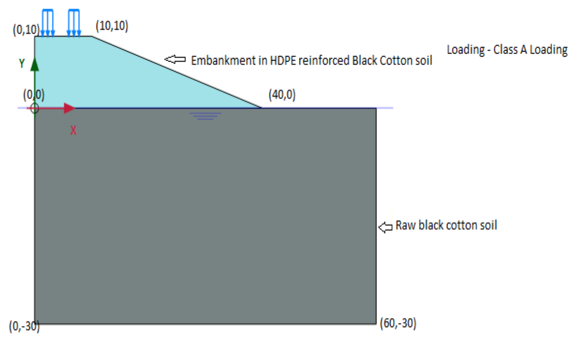

Fig 8: Embankment model created using Plaxis 2D software

An embankment of trapezoidal shape, with base length of 80m and height of 10m was provided over the deposit of black cotton soil. The embankment was made of reinforced soil with 12% HDPE fibres. Since the model is symmetric about vertical axis, only one half of the model was analyzed. Class A loading was used for vehicular loads. Four line loads of 2042.5 kg magnitude (i.e., in total 8170 kg) was taken as the load acting on the embankments. Soil model is shown in Figure 8.

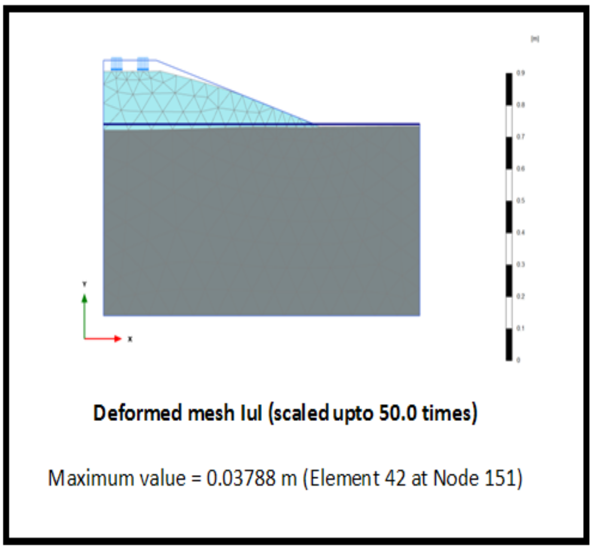

Fig 9: Deformed mesh

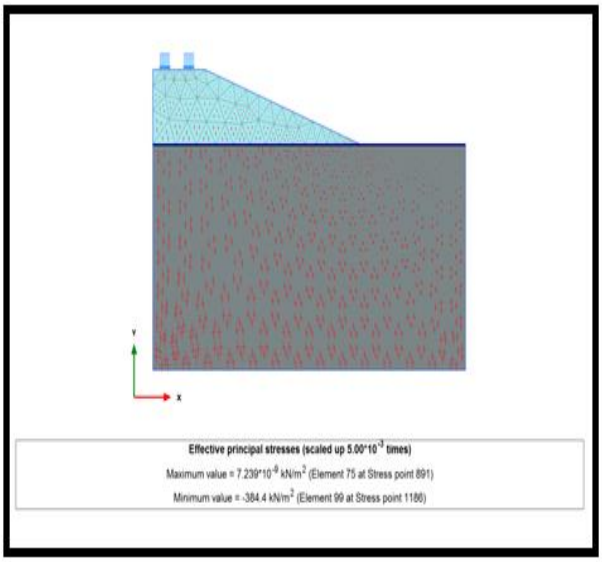

Fig 10: Effective Principal Stresses

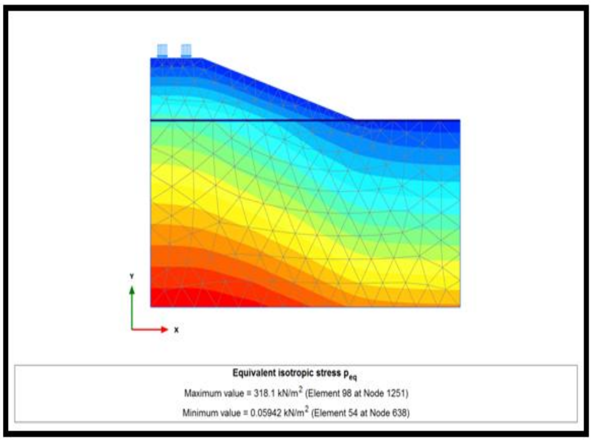

Fig 11: Equivalent isotropic stress

Figure 9 shows the deformed mesh. Maximum deformation was obtained as 0.03788 m. It was obtained at 42nd element at Node 151. Effective principal stress distribution is shown in Figure 10. Maximum Effective Principal Stresses was obtained at element 75 at stress point 891 and it was $7.239x10^{-9}$ kN/m^2. The distribution of Equivalent isotropic stress is shown in figure 11. Maximum Equivalent isotropic stress was obtained at element 98 at node 1251.

IV. CONCLUSION

A number of strength tests and engineering properties tests were conducted on Black Cotton Soil collected from Chittor region of Palakkad district, Kerala. After the analysis of test results, the following conclusions are drawn.

i. Maximum dry density of the soil sample increased with increasing percentages of HDPE strips, optimum value being that at 10% HDPE.
ii. The Optimum moisture content decreased with increasing percentages of HDPE. The optimum value was obtained at 10% HDPE. At 10% HDPE, the Optimum moisture content obtained was about three-fifth as that of unreinforced soil.
iii. Angle of internal friction showed an increase with increasing percentages of HDPE. The optimum value was observed at 12% HDPE. At 12% HDPE, the internal friction angle obtained was about three times as that of unreinforced soil.
iv. The Cohesion value showed an increase with increasing percentages of HDPE. The optimum value was observed at 12% HDPE. At 12% HDPE, the shrinkage ratio obtained was almost five of that of unreinforced soil.
v. Coefficient of permeability decreased with increasing percentages of HDPE. The optimum value was obtained at 12% HDPE.
vi. Swelling of the soil sample decreased with increasing percentages of HDPE. The optimum value was

obtained at 10% HDPE. The swell obtained for unreinforced soil was about fifty two times as that obtained at 10% HDPE.

vii. An embankment model with 12% HDPE reinforcement was created using PLAXIS 2D software and the maximum values of deformation, effective principal stress and equivalent isotropic stress were determined.

viii. Reinforcement using HDPE strips proves to be an efficient method for improving the engineering properties of Black cotton soil.

V. SCOPE FOR FUTURE WORK

i. Study can be conducted to determine the effect of durability of HDPE fibres on its efficiency to be used as a reinforcing material.

ii. Study can be conducted by varying the aspect ratios of HDPE strips and finding out their effects on different engineering and index properties of subgrade material.

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