Effect of Polyester Fibers on Strength Properties of Clayey Soil of High Plastiicty

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Abstract— Construction of building and other civil engineering structures on available clayey soil is highly risky on geotechnical grounds due to poor strength properties of the clayey soil. There may be the need for soil treatment to improve the engineering properties of soil. In practice admixtures with fly ash, lime and geogrids are used frequently to stabilize soils and improve their strength properties. Polyester fibers have been extensively used in civil engineering applications for many years. These fibers are used in concrete as a three dimensional secondary reinforcement. The influence of randomly oriented polyester fiber on the engineering behaviour of soil has not been reported to the same extent. Ease of application and reduction in cost are making this treatment more popular. The purpose of this investigation is to identify and quantify the influence of fiber variables (content and length) on performance of fiber reinforced soil specimens. In this study polyester fibers were mixed with clayey soil in various proportions (0%,0.25% 0.50%, 0.75%, 1.00% and 1.50% by weight of dry clayey soil) to investigate the relative strength gained in terms of compaction, CBR, unconfined compression, shear parameters, and consolidation parameters etc. It was found that strength properties of clayey soil increases with the inclusion of fibers up to 0.50%.

Index Terms— Ground Improvement techniques, Polyester fibers, California bearing ratio, Unconfined compression value, Shear parameters, Conpression index.

1 INTRODUCTION

In Today's era, due to rapid growth in urbanization and mordernization leads to less amount of land is available for construction. The increasing value of land and the limited availability of sites for construction, construction of various structures these days, is being carried on land having weak or soft clayey soil. The stability of any structure depends on the properties of soil on which it it is to be built. If the soil is good at shallow depth below the ground surface, shallow foundation such as footings and rafts, are generally most economical. However, if the soil just below the ground surface is not good but a strong stratum exists at a great depth, deep foundations, such as piles, wells and caissons are required. Deep foundations are quite expensive and are cost effective only in where the structure to be supported is quite heavy and huge. Sometimes the soil conditions are very poor even at greater depth and it is not practical to construct even deep foundation.

Geotechnical engineers face various problems while designing the foundations on highly compressible clayey soil due to poor bearing capacity and excessive settelment. Most of the soil available are such that they have good compressive strength adequate shear strength but weak in tension/ poor tensile strength. To overcome the same, many researchers have concentrated their studies on soil improvement techniques by developing new such materials, through the elaboration of composites.

Improvement of certain desired properties of soil like compaction, CBR, unconfined compression, shear strength, swelling characteristics can be undertaken by a variety of soil improvement techniques. There are many soil improvement techniques either chemical or mechanical. They may be classified as ground reinforcement, ground improvement, and ground treatment. All these techniques require skilled manpower and equipment to ensure adequate performance.

Recently, soil reinforcement is an effective and reliable technique for improving strength and stability of soils. The concept of earth reinforcement is an ancient technique and demonstrated abundanty in nature by animals, birds and the action of tree roots. The nature is the best example of earth reinforcement. In nature, the roots of plant and trees hold the earth during heavy rain and cyclone. These reinforcement resists tensile stress developed within the soil mass thereby restricting shear failure. Reinforcement intracts with the soil through friction and adhesion.The inclusion of randomly distributed discrete fiber increases strength parameters of the soil same as in case of reinforced concrete construction.

The majority of currently published literature about randomly oriented fiber reinforcement deals with the reinforcement of cohessionless or granular soils. Most of these studies were conducted on soil samples in C.B.R., unconfined compression, triaxial and direct shear tests (Andersland and Khattak, 1979: Hoare 1979: Gray and Ohashi, 1983; Maher and Gray, 1990; Charan, 1985; Michalowski and Zhao, 1960; Michalowski and Cermak, 2003; Kaniraj and Havangi, 2001; Kaniraj and Gayatri, 2003; Gosavi et al., 2004, Yetimoglu et al., 2005). Only limited information has been reported on the use of randomly distributed discrete fibers for highly compressible clayey soil. Thus an experimental programme to study the effect of randomly distributed fibers on highly compressible clayey soil using compaction, CBR, unconfined compression, shear parameters, and consolidation parameters etc has been undertaken.

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2 EXPERIMENTAL PROGRAMME

2.1 Soil Sample used

For the present study, Soil samples blackish in colour were collected from the Bhal Chandra Industry, Dabhoi, Baroda. All the preliminary tests as mentioned in Table 1 were conducted as per relevant Indian Standards. The engineering properties of soil are listed in Table 1.

2.2 Soil Reienforcement used

TABLE 1
ENGINEERING PROPERITIES OF SOIL SAMPLE USED

Properties	Values
Specific gravity	2.44
Gravel, %	1
Sand, %	8
Silt, %	66
Clay, %	25
Liquid limit, %	52.9
Plastic limit, %	27.5
Plasticity index, %	25.4
Shrinkage limit, %	23.5
IS classification	CH
Maximum dry density, gm/cc	1.65
Optimum moisture content, %	16.23

For the improvement of engineering properties of clayey soil polyester fibers are used as a reinforcement which is supplied by Reliance Industry Limited. The properties of fibers are listed as: type = Polyester, cut length = 12.1mm, cross section = triangular, diameter = 30 – 40 µm, tensile elongation = >100%, specific gravity = 1.34-1.39, tensile strength = 400 – 600 N/m². Due to triangular cross section fibers are better bonded with clay particle.

2.3 Compaction Test

Compaction tests were performed as per IS 2720 (Part 7) to determine moisture density relationships of highly compressible clay without fiber and then reinforced with fibers. Amount of fibers varies from 0 to 3%. The compaction curves obtained are shown in Fig. 1.

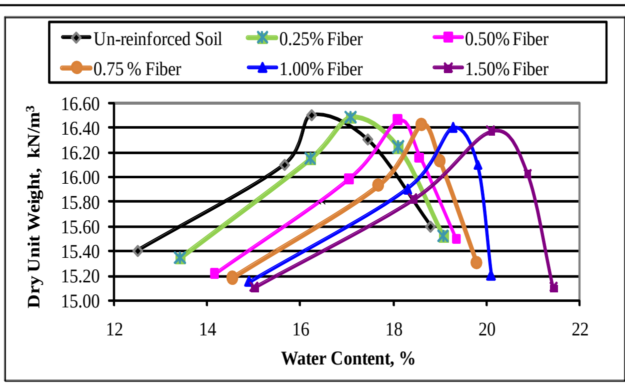


Fig. 1. Maximum dry unit weight and optimum moisture content of soil mixed with polyester fibers

The result of compaction tests shows that MDD of 1.65 gm/cc is independent of amount of fibers. Thus the effect of fiber inclusions on the MDD is negligible and OMC increases with increase in fiber content.

2.3 California Bearing Ratio Test

To study the effects of adding polyester fibers on the strength characteristics of highly compressible clay soil for sub grade CBR tests were conducted. The amount of fiber content were varies from 0 to 1.50% (by weight of dry soil). The Polyester fibers are mixed in dry soil by manually till it homogeneously mixed with soil. Both un-reinforced and fiber reinforced soil is compacted at same MDD and OMC for maintaining uniformity. The CBR tests were conducted inside a modified proctor mould at soaked state per ASTM D1883-92. The mould was a rigid metal cylinder with an inside diameter of 152mm and a height of 178 mm. A manual loading machine equipped with a movable base that travelled at a uniform rate of 1.27 mm/min and a calibrated load indicating device was used to force the penetration piston with a diameter of 50mm into the specimen. The loads were carefully recorded as a function of penetration up to a total penetration of 30mm to observe the post-failure behaviour as well. The Fig. 2 and Table 2 show the effect of inclusion of polyester fibers on the soaked CBR value of clayey soil.

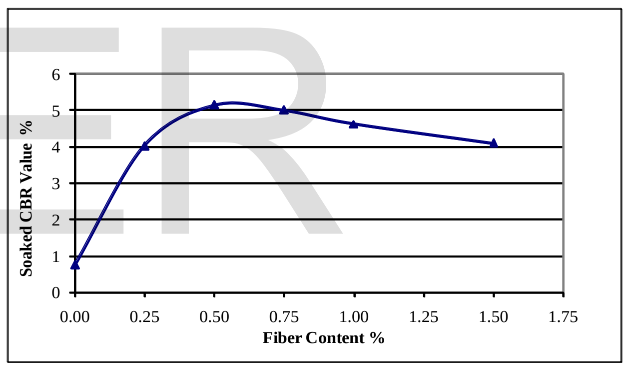


Fig. 2. Effect of inclusion of polyester fibers on soaked CBR value of soil

The soaked CBR value for un-reinforced soil is found to be 0.75%. With the inclusion of 0.25% fibers, it was observed that there is a sharp increase in CBR value. The soaked CBR value increases with the inclusion of fiber content up to 0.50% and with further inclusion of fibers beyond 0.50% decrease in soaked CBR value was observed. Also the soaked CBR value

TABLE 2
SOAKED CBR VALUE OF SOIL MIXED VARRIOUS % OF POLYETSTE FIBERS

Type of Soil	Soaked CBR Value, %
Un-reinforced Soil	0.75
Soil + 0.25% fibers	4.02
Soil + 0.50% fibers	5.15
Soil + 0.75% fibers	5.00
Soil + 1.00% fibers	4.62
Soil + 1.50% fibers	4.10

further increases with increase in fiber length.

2.3 Unconfined Compression Strength Test

The unconfined compression test was carried out as per IS: 2720 (Part 10) 1991. The unconfined compressive strength is defined as load per unit area at which an unconfined cylindrical specimen of soil will fail in the axial compression test. All specimens tested in this investigation were 38 mm diameter and 76 mm high. To prepare the specimens, moist soil was compacted into three equal layers. Before compacting the soil in the mould, inside of the mould was coated with lubricant in order to lessen the chance of fracturing of specimens during removal. Compacting effort was applied until each portion of the soil filled the mould to reach the desired fraction of height of the untrimmed sample. Between the compaction of layers, the surfaces of the compacted layers were scoured to provide a reasonable bond between the layers. After removal of each sample from the mould, was immediately trimmed to the desired height. Any polyester fibers sticking out at the top and bottom of the samples were trimmed with scissor. The specimen shall be compressed until failure surfaces have definitely developed, or the stress-strain curve is well past its peak, or until an axial strain of 20 percent is reached.

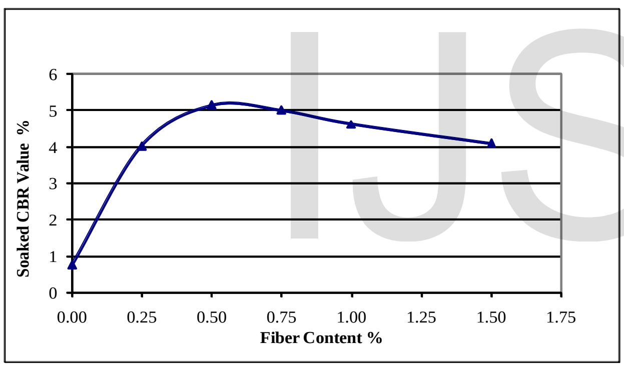


Fig. 3. Effect of inclusion of polyester fibers UCS value of soil

The result of unconfined compressive strength shows that the UCS value of soil increases with the inclusion of polyester fiber up to 0.50%. It becomes maximum at 0.50% fiber content for both fiber lengths. Then it decreases with further inclusion of fibers beyond 0.50%.

TABLE 3
UNCONFINED COMPRESSIVE STRENGTH OF SOIL MIXED VARRIOUS % OF POLYETSTE FIBERS

Type of Soil	Unconfined Compressive Strength, kN/m²
Un-reinforced Soil	263
Soil + 0.25% fibers	412
Soil + 0.50% fibers	594
Soil + 0.75% fibers	564
Soil + 1.00% fibers	510
Soil + 1.50% fibers	486

2.4 Triaxial Test

A series of unconsolidated undrained triaxial compression tests were carried out as per IS: 2720 (Part 11) 1993 to determine the effect of fiber on shear strength characteristics of soil. The tests were conducted with sample size of 38 mm diameter X 76 mm height on the un-reinforced and fiber reinforced soil with various amount of 12 mm length polyester fibers. The fibers were mixed thoroughly by hand using rubber gloves in to dry soil to achieve a fairly uniform mix. The sample was prepared at maximum dry unit weight and OMC for all the tests in triaxial split mould in three equal layers. Each layer of the mix was compacted to achieve required density throughout the depth of the sample. All the tests were done at an axial strain rate of 1.25 mm/min. The test was continued until the maximum value of stress has been passed or until an axial strain of 20% has been reached. A total of 15 triaxial tests were conducted to study the influence of fiber content, confining pressure on the strength of fiber reinforced Soil. Three tests were conducted on un-reinforced clayey Soil A and remaining twelve tests were conducted on clayey Soil A mixed with 0.25 %, 0.50 %, 1.00 % & 1.50 % fiber content at confining pressure (CP) of 50 kN/m², 100 kN/m² & 150 kN/m².

Fig. 4 to Fig. 6 represent axial strain Vs deviator stress for un-reinforced and fiber reinforced soil with fiber content 0.25 % to 1.50 % for cell pressure (CP) of 50 kN/m², 100 kN/m² & 150 kN/m² respectively. The Figures show that peak shear stress increases with the increase in fiber content up to 0.50 %. At 1.00 % fiber content, the peak shear stress decreases.

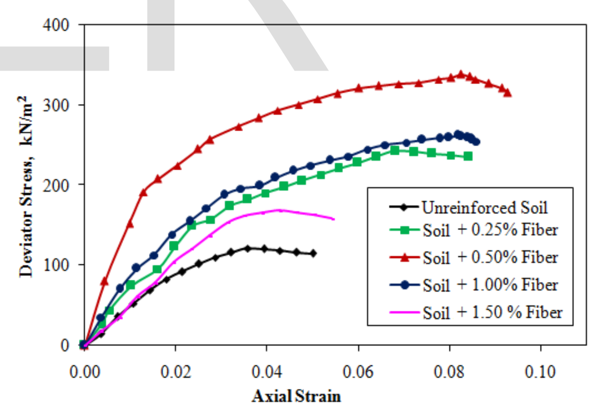
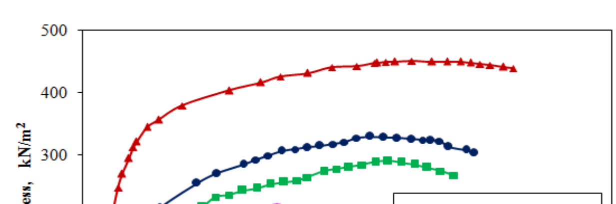


Fig. 4. Variation of stress strain with fiber content for cell pressure of 50 kPa

The c and φ values obtained from the mohr circles using triaxial test results are presented in Table 4.The c and φ values for un-reinforced soil found to be 59 kN/m² and 5.50⁰ respectively. There is slight increase in c value with increase in fiber content, but φ value remarkably increase with increase in fiber content up to 0.50 %, then at 1.00 % both c and φ value decreases.



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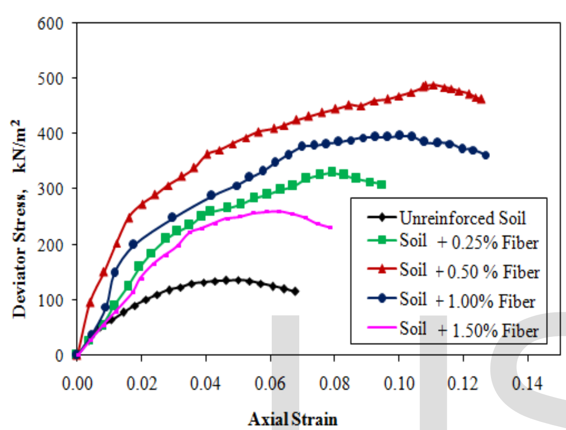

Fig. 6. Variation of stress strain with fiber content for cell pressure of

2.5 Consolidation Test

The consolidation test was carried out as per IS: 2720 (Part 15) 1986 on un-reinforced and fiber reinforced Soil A reinforced with 12 mm length polyester fibers in order to determine the settlement characteristics of soil. The samples are prepared in the consolidation ring of 60 mm diameter and thickness of 20 mm by remolding the soil at maximum dry unit weight and optimum moisture content. The edge is trimmed carefully so that the sample flushes at the top and bottom edges of the ring. The bottom porous stone is centered on the base of the consolidation cell. The specimen is placed centrally between the bottom porous stone and the upper porous stone. A filter paper is provided between the specimen and porous stones. The consolidometer is placed in position in the loading device and suitably adjusted. Dial gauge is clamped into position for recording the relative movement between the base of the cell and the loading cap. A seating pressure of 5 kPa is applied to the specimen. The cell is kept filled with water. After 24 hrs, the test is continued using a loading sequence on the soil specimen of 10, 20, 40, 80, 160, 320, 640 and 800 kPa. For each loading increment, readings of the dial gauge is taken using time sequence 0, 0.25, 1.00, 2.25, 4, 6.25, 9, 16, 25, 36, 49 … up to 24 hrs. From 800 kPa the specimens were unloaded gradually. From the observations of all incremental pressure, void ratio Vs log (pressure) curve is obtained. The slope of the straight line portion shows compression index Cc. The results of consolidation test were presented in terms of void ratio Vs effective pressure and compression index C_c. At 10 kPa pressure, the soil was found to be swelling, and subsequently there is compression of samples as higher stresses were applied. The Fig. 7 and Fig. 8 show the semi log plot of effective pressure v/s void ratio for un-reinforced soil and fiber reinforced soil having 0.50% fiber content.

TABLE 4
EFFECT OF FIBER CONTETN ON C AND Φ VALUE OF SOIL

Type of Soil	Cohesion, kN/m²	Angle of internal friction Φ, degree
Un-reinforced Soil	59	5.50⁰
Soil + 0.25% fibers	70	18.65⁰
Soil + 0.50% fibers	76	26.58⁰
Soil + 1.00% fibers	64	23.65⁰
Soil + 1.50% fibers	62	13.69⁰

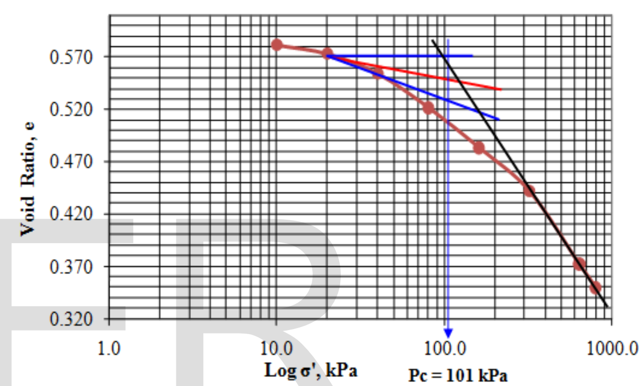

Fig. 7. Semi log plot of pressure Vs void ratio for un-reinfoced soil

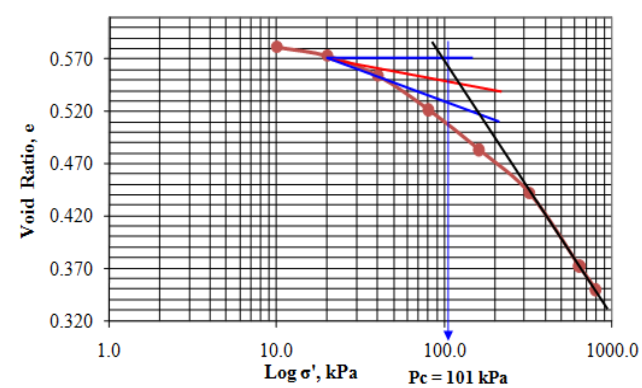

Fig. 8. Semi log plot of pressure Vs void ratio for soil mixed with 0.50% poltester fibers

The compression index C_c obtained for un-reinforced soil is 0.237. The compression index C_c found for fiber reinforced soil is listed in Table 5 and Fig 9. The compression index C_c value decreases with the inclusion of fibers up to 0.50 % and then with further inclusion of fibers beyond 0.50 % there is increase

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in compression index C_c.

TABLE 5
EFFECT OF FIBER CONTETN ON COMPRESSION INDEX CC OF SOIL

Type of Soil	Compression Index, Cc

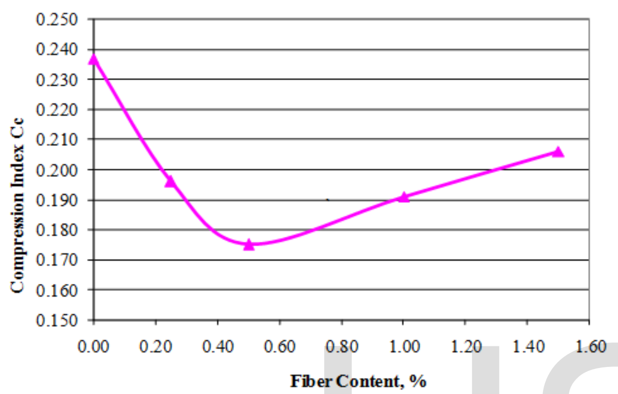

Fig. 9. Effect of inclusion of polyester fibers compression index, Cc value of soil

The swelling behavior is evaluated in consolidation test in terms of swell index = $(\Delta h / h_i) * 100$. Where (Δh) is increase in height of compacted specimen after 24 hours under 10 kPa pressure, and h_i is initial height of the specimen.

3 CORRELATION FOR STRENGTH PROPERTIES OF FIBER REINFORCED SOIL

By curve fitting method, the following equations of the

TABLE 6
% SWELL REDUCTION OF SOIL REINFORCED WITH VARIOUS AMOUNT OF POLYESTER FIBERS

Type of Soil	% Swell after 24 Hours	% Reduction in Swell
Un-reinforced Soil	7.0	--
Soil + 0.25% fibers	4.5	35.7
Soil + 0.50% fibers	4.2	40.0
Soil + 1.00% fibers	5.0	28.6
Soil + 1.50% fibers	5.2	25.7

strength properties of fiber reinforced clayey soil are derived, in terms of fiber content. The coefficient of correlation for equations 1, 2, 3, 4 and 5 are 0.999, 0.976, 1, 1, and 1 respectively. There is good correlation obtained between fiber content and various strength properties.

$$(CBR)_f, \% = -3.493 (f)^4 - 16.96 (f)^3 - 29.05 (f)^2 + 19.44 (f) + CBR \quad \text{....1}$$

$$(UCS)_f, kPa = 1008 (f)^4 - 2463 (f)^3 + 1187 (f)^2 + 507.3 (f) + UCS \quad \text{....2}$$

$$(C)_f, kPa = 60.8 (f)^4 - 130.4 (f)^3 + 31.2 (f)^2 + 43.4 (f) + C \quad \text{....3}$$

$$(\varphi)_f, degree = 24.78 (f)^4 - 51.72 (f)^3 - 13.80 (f)^2 + 58.89 (f) + \varphi \quad \text{....4}$$

$$(C_c)_f = -0.08 (f)^4 + 0.134 (f)^3 + 0.094 (f)^2 - 0.194 (f) + C_c \quad \text{....5}$$

Where, f is the fiber content varies from 0 to 1.50%. In the above equations $(CBR)_f$, $(UCS)_f$, $(C)_f$, $(\varphi)_f$, $(C_c)_f$ are the strength properties of fiber reinforced soil and CBR, UCS, C, φ, C_c are the strength properties of un-reinforced reinforced Soil A.

4 CONCLUSIONS

Following conclusions are drawn from the above study.

- Experimental result on compaction test of shows that there is a slight decrease in maximum dry unit weight and increase in optimum moisture content with increase in polyester fiber content. The decrease in density is may be due to the result of the fiber filaments are having less specific weight in comparison with the soil grains and the fibers prevent the soil particles approaching each other. The increase in moisture content is may be due to the result of the fibers having a greater water absorption capacity than the surrounding soil.
- Improvement in strength properties of clayey soil like compaction, CBR, unconfined compression, shear strength, swelling characteristics were obtained by the inclusion of polyester fibers. The increase in strength was observed with the inclusion of fibers up to 0.50% and beyond that it decreases. The maximum strength gain was observed at 0.50% fiber content.
- With increase in fiber content, there is an increase in homogeneous and isotropic properties of soil medium and soil becomes more uniform. Beyond 0.50% fiber content, with further inclusion of fibers the strength properties of fiber reinforced clayey soil decreases; this due to the mixing of fibers beyond 0.50% fiber content becomes difficult.

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