Stress-Strain Characteristics of Polypropylene Fibre Reinforced Soil

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***Abstract* - The study provides an approach for the use of polypropylene fibre as reinforcement material in clayey soil, which can be used for ground improvement. Fibre is being added to the soil in four different percentages of fibre content, i.e. 0.25, 0.50, 0.75 and 1.0% by weight of raw soil. The change in properties like optimum moisture content, maximum dry density and unconfined compressive strength has been recorded. Through the results obtained, it was observed that on addition of polypropylene fibre the optimum moisture content of soil increased while maximum dry density decreased and UCC strength increased. A series of triaxial tests at different confining pressures were performed to determine stress-strain response of the soil. The results show a significant improvement in the failure deviator stress on the addition of fibre.**

Keywords— Fibre reinforcement; cohesive soil; polypropylene fibre; stress strain behaviour; triaxial test

I. INTRODUCTION

With urbanization and modernisation at its peak, less amount of land is available for construction. Owing to this, structures these days are being designed on land having weak or soft soil. Stability of any structure depends on the properties of soil. Most of the soils available are such that they have good compressive strength and adequate shear strength but are weak in tension or have poor tensile strength. Using land having soft soil for construction necessitates various ground improvement or soil stabilization techniques. Earth reinforcement is an effective and reliable technique for increasing the strength and stability of soils. The concept and principle was first developed by Henri Vidal in 1969 by which he demonstrated that the introduction of reinforcing elements in a soil mass increases the shear resistance of the medium.

Reinforced soil is a construction material that consists of soil fill strengthened by a variety of tensile inclusions ranging from low-modulus, polymeric materials to relatively stiff, high-strength metallic inclusions. These tensile inclusions come in many forms ranging from strips and grids to discrete fibres and woven and non-woven fabrics. Reinforcement can vary greatly; either in form (strips, sheets, grids, bars, or fibres), texture (rough or smooth), and relative stiffness (high such as steel or low such as polymeric fabrics). Earth reinforcement has become routine in geotechnical engineering to enhance the bearing capacity of geostructures such as airfields, foundations, embankments, and pavement roads built on soft soils, and to stabilize engineered soil slopes and loosely filled retaining walls. Fibre reinforced soil exhibits greater extensibility and small losses of post peak strength i.e., greater ductility in the composite material as compared to unreinforced soil or soil reinforced with high modulus inclusions.

A number of factors such as the fibre characteristics (content, length, thickness, modulus, tensile strength, and failure strain) and the soil characteristics (grain size distribution and mean particle size) influence the behaviour of the soil–fibre composite. Randomly distributed fibre reinforcement technique has successfully been used in a variety of applications such as slope stabilization, road subgrade and sub base etc. This is a relatively simple technique for ground improvement and has tremendous potential as a cost effective solution to many geotechnical problems. One of the main advantages of randomly distributed fibres is the maintenance of strength isotropy and absence of potential failure plane that can develop parallel to oriented reinforcement. The soil and reinforcing element will interact by means of frictional resistance. Appropriate selection of the type and location of the reinforcement material is necessary in order to achieve optimum improvement. Using fibres ranging from steel bars, polypropylene, polyester, glass fibres, and biodegradable fibres such as coir and jute, has been proven to be particularly effective for soil reinforcement.

Due to access of cheap polypropylene fibre material, short discrete polypropylene fibre is employed to prepare the fibre reinforced soil samples in this investigation. A series of tests were carried out to analyze the variation of engineering properties of soil reinforced by polypropylene fibre and some significant findings are presented here. Polypropylene fibre is the most widely used inclusion in the laboratory testing of soil reinforcement. Polypropylene fibre has the following unique advantages: (i) it is of high intensity; (ii) like lime and cement, it can be dispersed easily into soil and the reinforced soil samples take on isotropic strength characteristics; and (iii) the presence of short discrete polypropylene fibre in soil can prevent the occurrence of potential weak structural planes which usually form due to the laying direction of geotextile and laying distance of geogrid.

II. MATERIALS

The soil (naturally occurring kaolin clay) was collected from Thonakkal region, obtained through quarrying from English India Clays Ltd. The physical properties of the soils are presented in Table1.

TABLE 1. PHYSICAL PROPERTIES OF SOIL

Property	Value obtained
Natural water content (%)	22.5
Liquid limit (%)	48.2
Plastic limit (%)	26.3
Shrinkage limit (%)	19.4
Plasticity index (%)	21.9
Specific gravity	2.1
Optimum moisture content (%)	25
Maximum dry density (kN/m^3)	14.5
Percentage sand (%)	21.5
Percentage silt (%)	20.5
Percentage clay (%)	58
Unified Soil Classification	CI

The particle size distribution curve of the soil is shown in Fig 1.

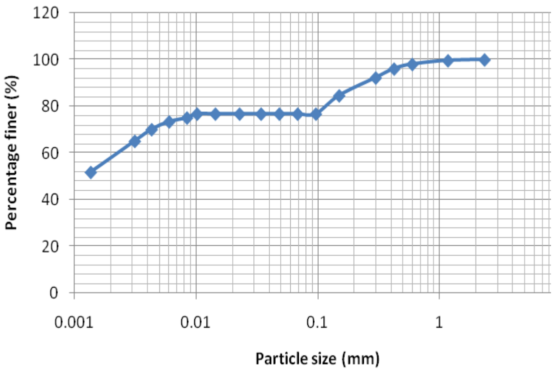

Fig.1. Particle size distribution curve

The polypropylene fibre obtained in the market is manufactured by Reliance Industries Ltd. The product specifications provided by the company are given in Table 2.

III. SPECIMEN PREPARATION AND TESTING PROCEDURE

The test to determine the optimum moisture content (OMC) and maximum dry density (MDD) of unreinforced and fibre reinforced (0.25%, 0.5%, 0.75% and 1% polypropylene fibre) soils were done using light compaction according to IS 2720 (Part 7)-1980.

Unconfined compression tests were carried out on cylindrical specimens of 38mm diameter and 76mm height. Each specimen used in the unconfined compression test was compacted at OMC and MDD based on IS 2720 (Part 10)-1991. The UCC tests were conducted for different percentage of polypropylene fibre (0%, 0.25%, 0.5%, 0.75% and 1.0%).

Triaxial tests under unconsolidated-undrained (UU) conditions were carried out on samples for different percentage of polypropylene fibre (0%, 0.25%, 0.5%, 0.75% and 1.0%) that were formed at the state of MDD and OMC in a mould with a length of 100 mm and an inner diameter of 50 mm. The soil samples were extracted from the moulds after compaction. The testing procedure was in accordance with IS2720 (Part11)-1993. The cell pressures applied were 50, 100 and 150 kPa. The specimens were sheared at a rate of 1.25mm/min.

TABLE 2. PROPERTIES OF POLYPROPYLENE FIBRE

Property	Description
Product name	Recron® 3s Polypropylene Short-cut Fibre
Manufacturer	Reliance Industries Ltd., Navi Mumbai - 400 701
Appearance	Form: Short-cut staple fibre
Colour	Raw-white, white
Odour	Odourless
Relative density	0.89 – 0.94 g/cm³
Length	12mm
Tensile strength	4000-6000 kg/cm²
Melting point	160ºC

IV. RESULTS AND DISCUSSION

The results obtained from the conduct of the various tests are discussed below.

A. COMPACTION TEST

The MDD and OMC of unreinforced and polypropylene fibre reinforced soil is obtained through standard proctor method. The compaction curves are shown in Fig 2.

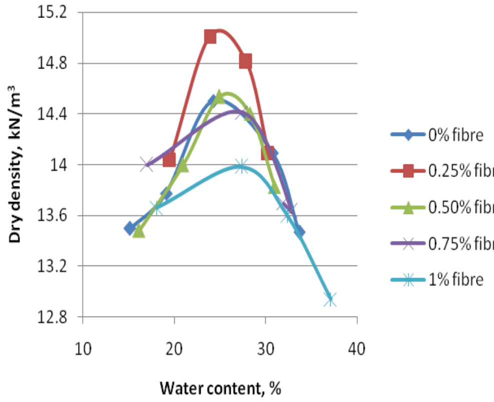

Fig. 2. Standard compaction curves

The variation of MDD and OMC with different fibre additions are presented in Fig 3 and Fig 4 respectively.

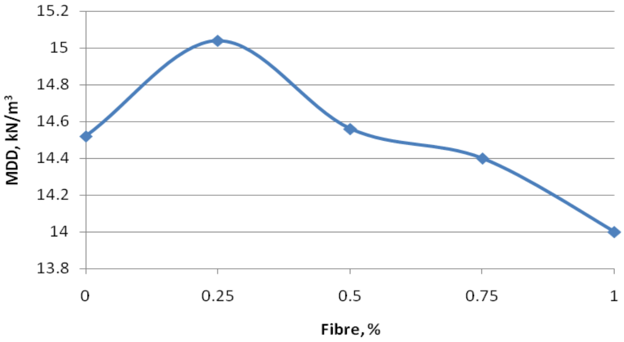

Fig.3. Variation of MDD with increase in polypropylene fibre content

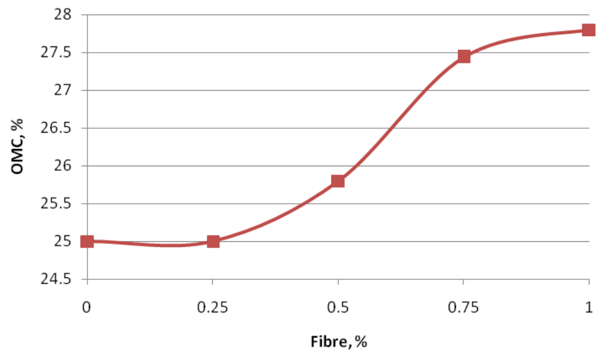

Fig..4. Variation of OMC with increase in polypropylene fibre content

An increase in fibre content from 0 to 0.25% increases the MDD. Further addition of fibre causes a reduction in dry density. This behaviour can be attributed to the reduction of average unit weight of solids in the mixture of soil and fibre.

B. UNCONFINED COMPRESSIVE STRENGTH

Unconfined compressive strength of the soil samples with different percentages of polypropylene fibre were calculated from the loads at failure. There was a 50% increase in strength on addition of 0.25% fibre and maximum strength was seen on addition of 0.75% fibre. At higher fibre content the UCS decreases compared to its maximum value. This is due to the fact that with higher fibre content, the quantity of soil matrix available for holding the fibre is insufficient to develop an effective bond between fibres and soil, causing balling of fibres and poor mixing. The variation of UCS with different percentage addition of polypropylene fibre is given in Fig 5.

C. Triaxial Test: Unconsolidated Undrained (UU) Test

A number of stress-strain curves were plotted from the test results of triaxial compression test performed on the soil and soil reinforced with various fibre contents.

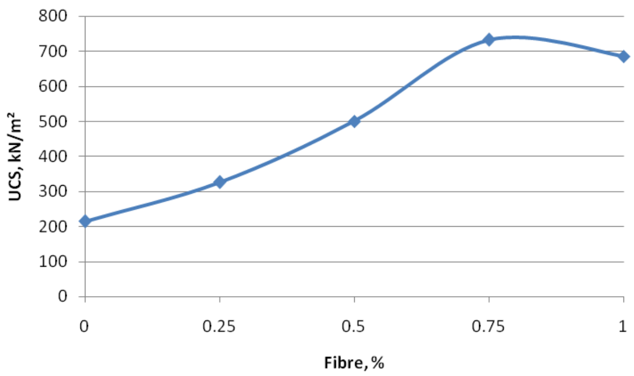

Fig..5. Effect of fibre content on UCS of fibre-reinforced soil

The plot of stress-strain curves for confining pressures of 50kPa, 100 kPa and 150 kPa are shown in Figs 6, 7 and 8.

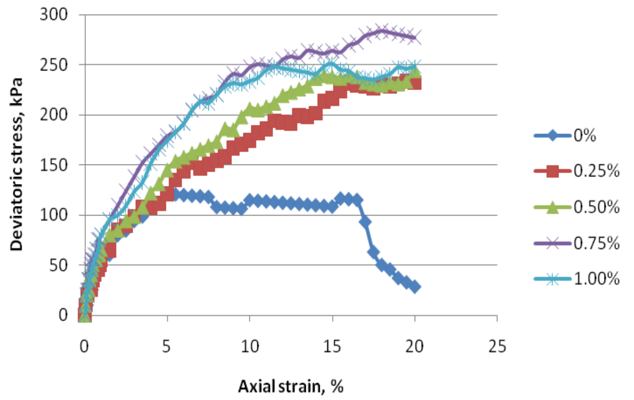

Fig .6. Stress-strain curves of reinforced soil for 50 kPa confining pressure

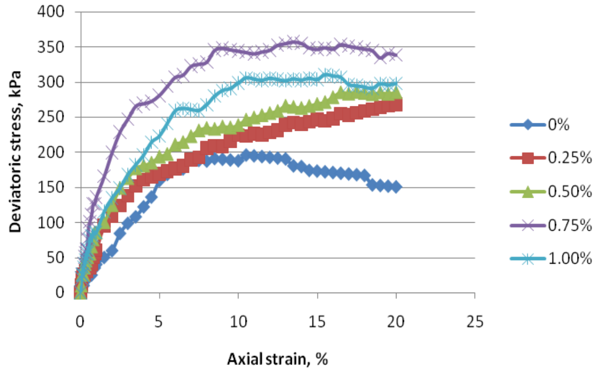

Fig .7. Stress-strain curves of reinforced soil for 100 kPa confining pressure

Under higher confining pressures soil samples are more confined and more resistant to deformation which results into higher deviator stress at failure. Increasing fibre content leads to increasing strain at failure and, consequently, to more ductile behaviour. The inclusion of fibres in the soil decreases the brittleness and improves the ductility behaviour. The deviator stress increases with increase in fibre content. This continues up to 0.75% fibre content beyond which the deviator stress decreases.

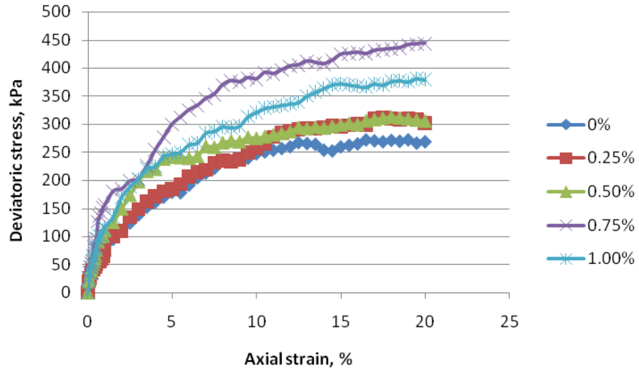

Fig .8. Stress-strain curves of reinforced soil for 150 kPa confining pressure

V. CONCLUSION

From the study conducted, it can be concluded that there is significant increase in the mechanical properties of fibre reinforced soil. The compaction characteristics indicate a

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reduction in maximum dry density and increase in optimum moisture content on fibre addition. The UCC strength improved 3.4 times that of unreinforced soil. The peak UCC value is obtained at 0.75% polypropylene fibre reinforced soil. Stress–strain behaviour of soil is improved by incorporating polypropylene fibres in the soil, deviator stress at failure can increase up to 2 times over plain soil by fibre inclusion.

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