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Unconfined Compressive Strength Behaviour of Fibre-Reinforced Lateritic Soil

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Abstract: **Several techniques are available for improving the strength of soils for using them as construction materials. Fibre-reinforced soil is one of the modern techniques in which fibres of desired type and quantity are added to the soil, mixed uniformly in random directions and then laid in position. It is different from reinforced earth, in which the reinforcement in the form of strips, rods and sheets is laid horizontally at specific intervals. In this study, a locally available lateritic soil is first reinforced with glass fibres of lengths ranging from 10 to 30 mm and contents ranging from 0.25% to 1.25% by dry weight of the soil and. Thereafter, compacted specimens of the soil mixes are subjected to unconfined compression tests so as to understand the strength behaviour.**

1. INTRODUCTION

Reinforcement of soils for increasing strength and stability is now widely used in practice. In the traditional methods, the reinforcing elements are mainly in the form of strips, rods and sheets. Fibre-reinforced soil is a relatively new development. The fibres used may be synthetic or natural. Synthetic fibres such as polypropylene, nylon, plastic, glass etc. are preferred because of their higher strength and greater resistance to biodegradation. Natural fibres such as jute, coir, bamboo etc. are biodegradable and environment friendly, and they are useful in applications such as for erosion control and embankment construction.

Randomly distributed fibres limit potential planes of weakness that can develop parallel to oriented reinforcement and thereby maintain strength isotropy. Therefore, it has become a focus of interest in recent years. Many investigators have studied the strength behaviour of fibre-reinforced soils through unconfined compressive strength tests, triaxial tests, CBR tests, direct shear tests, tensile and flexural strength tests.

The mechanics of fibre reinforcement in cohesionless soils was initially studied by [1]. Unconfined compression tests of fibre-reinforced cohesive soil have been reported by several investigators [2-10]. Results indicate that synthetic fibres increase the shear and compressive strength and ductility of the cohesive soils. Fibre-reinforced cohesive soils treated with lime, cement, fly ash, and chemical stabilizer was investigated with unconfined compression tests [11-15].

Prior to any field applications such as in road subgrade and foundation bed, it is necessary to carry out laboratory tests to arrive at optimum contents and lengths. This paper discusses the influence of glass fibre reinforcement on the unconfined strength behaviour of a lateritic soil.

2. MATERIALS AND METHODS

2.1 Materials

The lateritic soil used in this study was obtained from a nearby hill. The soil contains 25.2% sand, 54.4% silt and 20.4% clay fraction with 2.63 as its specific gravity. The plastic limit and liquid limit of the soil were 25% and 46%, 25.58 respectively. As per Indian Soil Classification System, it is classified as silt of intermediate plasticity (MI). The physical and mechanical properties of the glass fibres used are listed in Table 1.

Table 1. Physical and mechanical properties of fibres

Type	Synthetic glass fibre
Colour	White
Fibre lengths	10, 20 and 30 mm
Average diameter	0.15 mm
Fibre contents	0.25, 0.5, 0.75, 0.1 and 1.25% by dry weight of soil
Specific gravity	2.57
Tensile strength	1.53 GN/m^2
Modulus of elasticity	112.3 GN/m^3

2.2 Methods

First, standard proctor compaction test was conducted on the soil as per Indian Standards [16], and the maximum dry density (MDD) and optimum moisture content (OMC) were found as 16.8 kN/m^3 and 19.5%, respectively.

For unconfined compressive strength (UCS) tests, test specimens with fibres and of 38 mm diameter and 76 mm height were compacted at the soil's MDD and OMC. The compression tests were performed as per Indian Standards

[17]. For each combination of fibre content and length, three specimens were tested.

3. RESULTS AND DISCUSSION

The test results have been analyzed to delineate the effect of fibre content and fibre length on (a) load-deformation response, (b) unconfined compressive strength, (c) failure strain, (c) stiffness modulus, and (d) failure patterns.

3.1 Load-Deformation Response

3.1.1 Effect of Fibre Content

Figures 1 to 3 depict typical load-deformation response of fibre-reinforced soil for different fibre contents. For comparison, the plot for the unreinforced soil is also shown.

For short fibre (10 mm), the reinforced soil is found to strengthen for all fibre contents used in this study (Fig. 1). In case of 20 mm fibre, the peak strength improves significantly up to 1% content and thereafter it decreases drastically at 1.25% content (Fig. 2). In case of longer fibre (30 mm), the peak strength increases to a similar level only at both 0.75% and 1.0% contents, and then decreases thereafter at 1.25% content (Fig. 3).

At 1.25% fibre content for longer fibres (20 and 30 mm), a more ductile response is observed with no clear peak. It is also seen that the fibre-reinforced soil exhibits smaller loss of post-peak strength, and the loss still becomes less pronounced for higher fibre content. Thus, the results indicate that the optimum fibre content depends on the fibre length.

Overall, it is noted that as the fibre dose increases, the behaviour of soil progressively changes to that of a ductile one. This is because with increase in fibre content, the surface area of fibres increases considerably which provides more surface for soil-fibre interaction.

Energy absorption capacity can be computed from the area under the stress-strain curve up to 20% strain, and it indicates the resistance to indentation of the fibre-reinforced soil. An increase in either failure strain or peak strength or both leads to an increase in absorbed energy.

With all specimens compacted at the same dry unit weight (i.e. at MDD), an increase in fibre content results in a significant increase in absorbed energy. This is consistent with the results reported by [3] and [10].

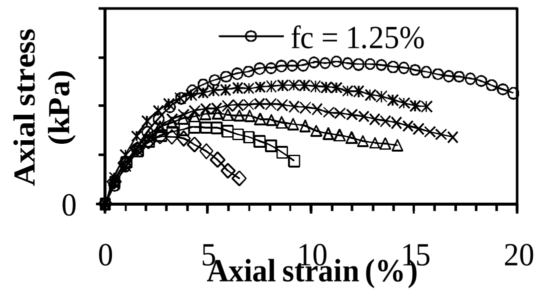


Figure 1. Effect of fibre content (L = 10 mm) on stress-strain response

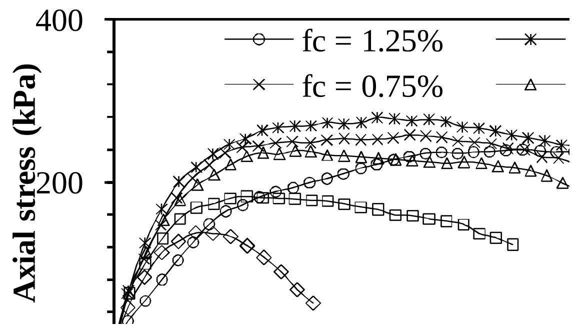


Figure 2. Effect of fibre content (L = 20 mm) on stress-strain response

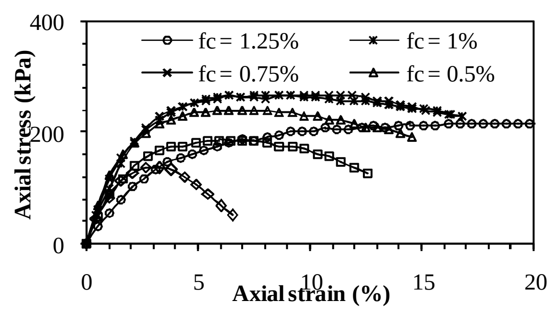


Figure 3. Effect of fibre content (L = 30 mm) on stress-strain response

3.1.2 Effect of Fibre Length

Load-deformation plots showing the effect of fibre length are in Figures 4 to 8. For fibre contents up to 0.75%, it is observed that the strength has improved considerably with fibre length up to 20 mm length and thereafter it increases only marginally with 30 mm long fibres (Figs. 4 to 6). However, at fibre content of 1%, the strength with 30 mm long fibres is lower than that with 20 mm long fibres (Fig. 7). At a higher fibre content of 1.25%, the strength is the maximum with 10 mm long fibres (Fig. 8). Thus, the results indicate that the optimum fibre length depends on the fibre content.

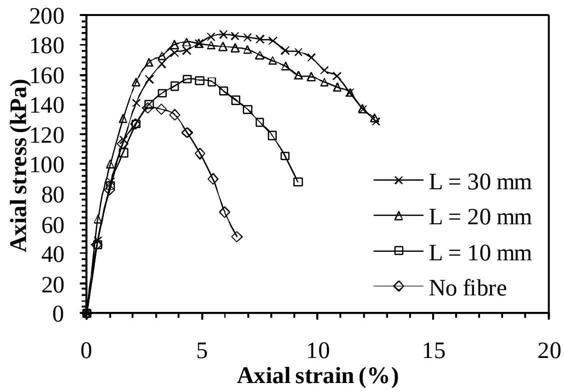


Figure 4. Effect of fibre length (f_c = 0.25%) on stress-strain response

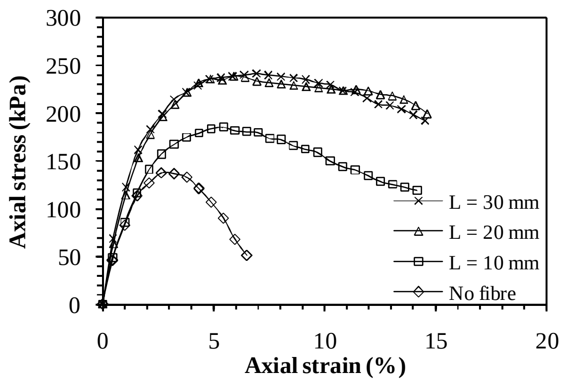


Figure 5. Effect of fibre length (f_c = 0.50%) on stress-strain response

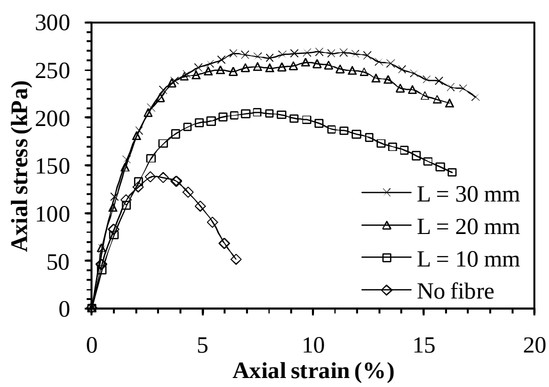


Figure 6. Effect of fibre length (f_c = 0.75%) on stress-strain response

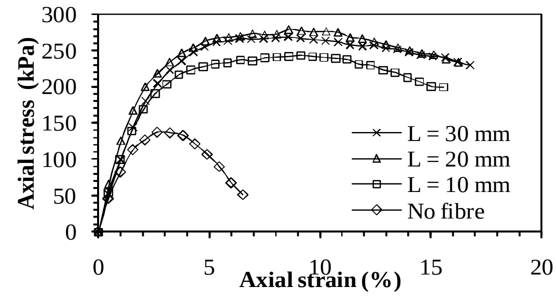


Figure 7. Effect of fibre length (f_c = 1%) on stress-strain response

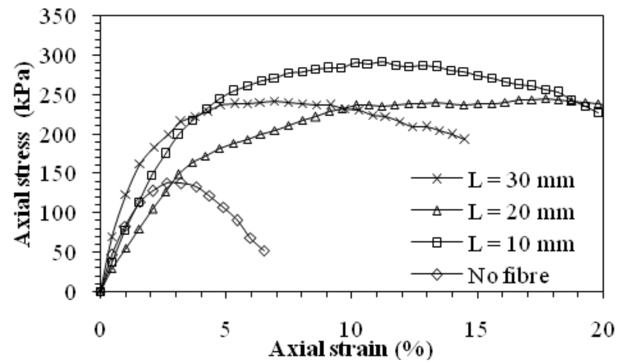


Figure 8. Effect of fibre length (f_c = 1.25%) on stress-strain response

3.2 Effect on Unconfined Compressive Strength

Figures 9 and 10 present the percentage improvement in unconfined compressive strength of fibre-reinforced soil compared to that of unreinforced soil. It can be clearly observed that the UCS of the soil improves noticeably with fibre addition. The maximum improvement is found for 1% fibre content at all fibre lengths except for 10 mm fibre which has the maximum strength for 1.25% fibre content (Fig. 9). It is also noted that for all fibre contents between 0.5% and 1%, the increase in UCS is the maximum for 20 mm fibre (Fig. 10).

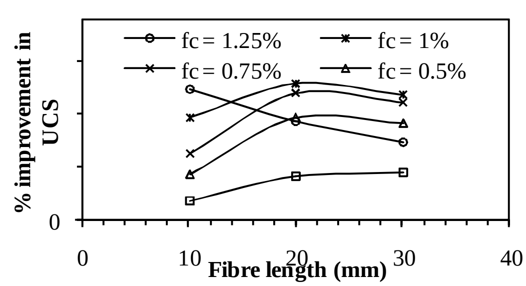


Figure 9. Effect of fibre content on UCS

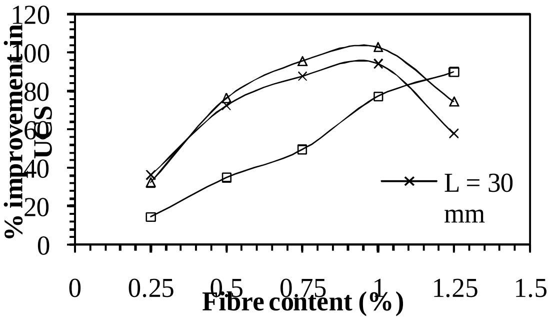


Figure 10. Effect of fibre length on UCS

3.3 Effect on Failure Strain

Strain ratio is the ratio of strain corresponding to the UCS for reinforced soil to that for unreinforced soil. Figures 11 and 12 depict the effect of fibre reinforcement on failure strain. The strain ratio of reinforced soil has improved for all fibre contents. The increase is greater for higher fibre doses showing very good improvement in ductility.

The improvement in strength and failure strain can be explained in the way that the fibres restrict the movement of soil. As the fibre content increases, the no. of fibres crossing the failure plane increases and the resistance towards the deformation of soil along the failure plane increases which ultimately enhance the failure strain (Fig. 11).

Also during shearing, the load from the soil particles is transferred to the fibres which ultimately generate tensile stress in the fibres. Longer fibres resist the movement of soil particles more effectively by interlocking and intertwining with them (Fig. 12). Overall, fibre inclusion improves the strength and deformation response considerably.

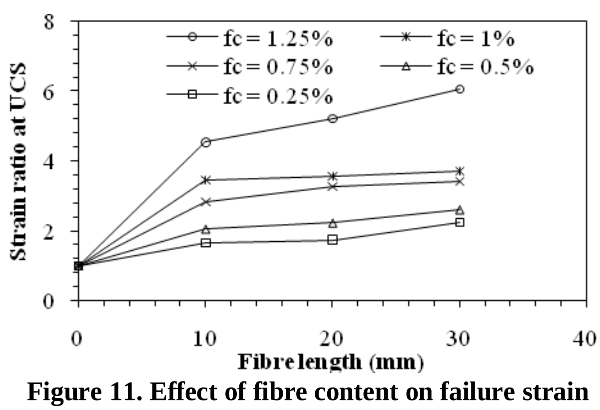


Figure 11. Effect of fibre content on failure strain

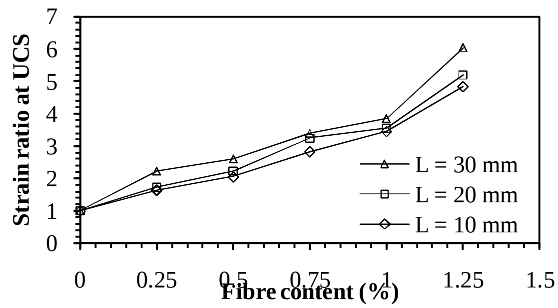


Figure 12. Effect of fibre length on failure strain

3.4 Effect on Stiffness Modulus

Stiffness modulus at any particular strain can be obtained by dividing the axial stress at that strain with the corresponding strain. The influence of fibre reinforcement on the stiffness modulus at 2% strain is presented in Figures 13 and 14.

It is noted that the stiffness modulus improves considerably for 0.5-1.0% fibre contents (Fig. 13) and for 20-30 mm fibre lengths (Fig. 14). For 10 mm fibre length, the variation of stiffness modulus with fibre content is marginal. However, for the maximum fibre content of 1.25%, there is a large reduction in stiffness modulus leading to greater ductile behaviour and this can also be noticed from the stress-strain plots (Figs. 1 to 3).

3.5 Failure Patterns

Figures 15 and 16 show typical failure patterns of the fibre-reinforced soil specimens prepared with different fibre contents and lengths. The unreinforced soil exhibits brittle behaviour and the failure is triggered by the formation of a noticeable single large tension crack which extends from top to bottom (Fig. 15a).

With addition of fibres up to 0.5% content, multiple and smaller tension cracks develop during loading till failure condition (Figs. 15b, 15c & 15d). As tension cracks start to develop during loading, the fibres within the soil resist the development of this crack by bridging them effectively which results in higher failure strain (Figure 16).

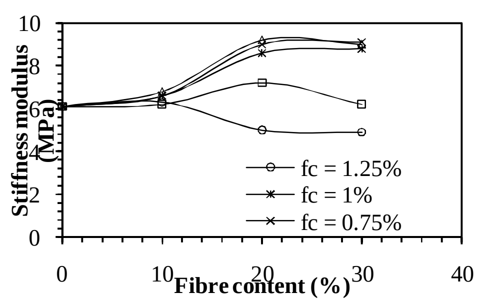


Figure 13. Effect of fibre content on stiffness modulus

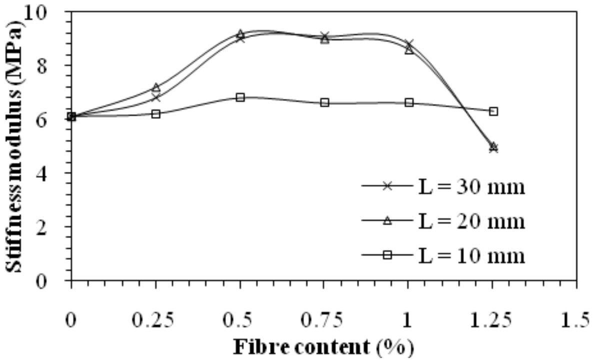
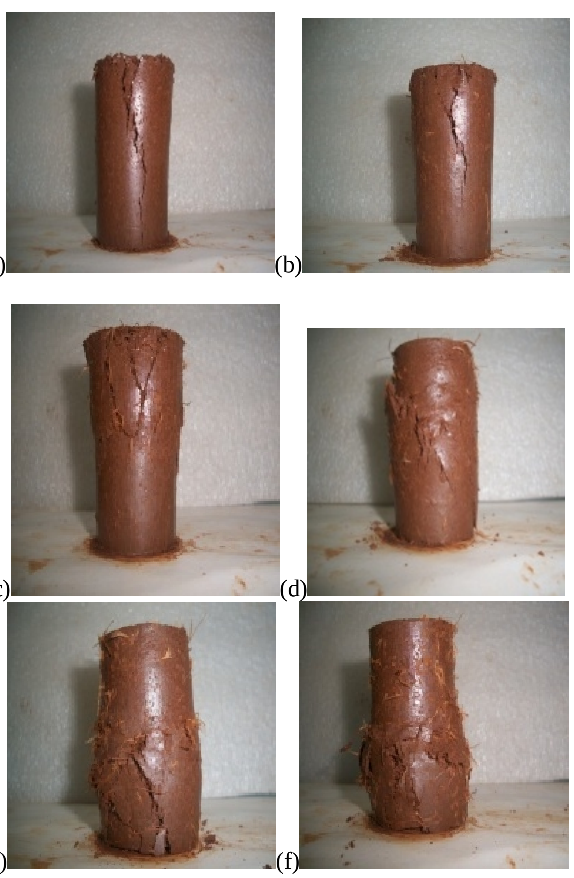


Figure 14. Effect of fibre length on stiffness modulus

At higher fibre contents of 1% and 1.25%, no obvious single dominated failure plane is found (Figs. 15e & 15f). The gradual increase in axial strain during compression leads to network of tiny cracks that form progressive failure zones with a barrelled failure shape of the specimen. In specimens with higher fibre content, the fibres can confine the soil particles and increase the global stability of the soil mass. In this way, fibre-reinforcement has changed the brittle nature of soil to ductile, and the ductility is found to improve with fibre content.



(a) (b) (c) (d) (e) (f)

Figure 15. Failure patterns at different doses of fibres: (a) unreinforced; (b) 0.25%, 10 mm; (c) 0.5%, 20 mm; (d) 0.5%, 30 mm; (e) 1%, 20 mm; (f) 1.25%, 30 mm

Figure 16. Bridging effect of fibre-reinforcement (0.5%, 20 mm)

4. CONCLUSIONS

1. The experimental study has provided a good insight of the unconfined strength characteristics of glass fibre-reinforced lateritic soil. The following conclusions have been made based on the results:

2. The UCS value of fibre-reinforced soil has significantly improved and the optimum fibre content depends on the fibre length.

3. For 10 mm fibre, the strength of soil is improved for all the fibre contents used.

4. For 20 mm fibre, the optimum content is found to be 1%, whereas in case of 30 mm fibre it is found to be 0.75%.

5. The optimum fibre length is 20 mm for fibre contents up to 1%, whereas it is 10 mm at 1.25% content.

6. The strain corresponding to peak UCS increases considerably with fibre reinforcement and it further increases with fibre content and length.

7. The stiffness modulus at 2% axial strain increases with fibre content up to 0.5%, remains almost the same up to 1% fibre content and then decreases at 1.25% content.

8. The failure patterns indicate that the fibres within the soil resist the development of tension cracks by bridging them effectively, which results in higher failure strain and overall ductility.

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