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Strength anisotropy of fibre reinforced sands under generalised loading conditions using the Hollow Cylinder Torsional Apparatus

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ABSTRACT: The results from an experimental campaign which aimed investigate the behaviour of fibre reinforced sand in the multiaxial stress space are shown in the present paper. Using the Hollow Cylinder Torsional Apparatus (HCTA), fibre reinforced samples have been subjected to probing stress paths with different orientation of principal stresses. The observed behaviour was found to be highly anisotropic and strength envelope in the multiaxial stress space will be for the first time provided for this type of material.

KEYWORDS: Hollow Cylinder Torsional Apparatus, Hostun sand, Fibre Reinforced sand, Anisotropy, Fibre

1 INTRODUCTION

Mixing sands with random discrete flexible fibres increases their strength and influences their deformation characteristics (Gray and Ohashi, 1983; Michałowski and Cermák, 2003; Diambra A, 2010 among others). Recent experimental studies on fibre reinforced soils have demonstrated that the reinforcing effect may be highly anisotropic as a result of the preferential horizontal bedding induced by the mixing and compaction processes employed (Diambra et al. 2007 and Ibraim et al. 2012).

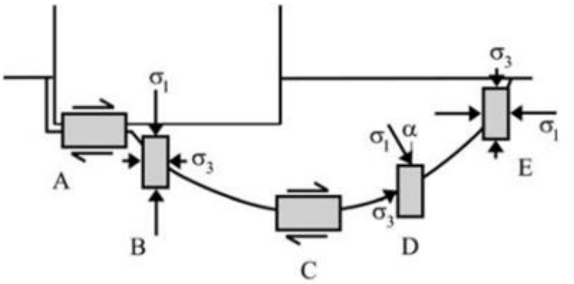

Figure 1 Stress conditions along a potential failure surface.

Considering that the rotation of the principal stress axis almost invariably occurs within a soil mass (for example, see Figure 1), this aspect is of foremost importance for the perspective field application of the fibre reinforcing technique. Thus the present study aims to extend the previous experimental work by investigating the anisotropic behaviour of fibre reinforced sands in the generalised multiaxial stress space using the Hollow Cylinder Torsional Apparatus.

2 MATERIALS AND APPARATUS

2.1 Fibres

For the whole campaign of tests, crimped polypropylene fibres (LoksandTM) have been used as a reinforcing material. These fibres present a circular cross section of 0.1mm diameter and they are 17.5 mm long. This length was selected to have a reasonable fibre to wall thickness ratio while maintaining an easily detectable fibre contribution. A study on the effect of fibre length in triaxial samples was performed by Mandolini (2012), results ensured that 17.5 mm long fibres provide a measurable strength increase.

2.2 Hostun sand

Hostun sand is European standard sand for this laboratory campaign with a high siliceous amount (SiO_2>98%). Its grain shape varies from angular to sub-angular. Its physical properties are as follows: mean grain size D_{50}=0.32 mm, coefficient of uniformity Cu=1.70, coefficient of gradation Cg=1.1, specific gravity Gs=2.65 and minimum and maximum void ratios, respectively e_{min}= 0.62 and e_{max}= 1.00.

2.3 Hollow Cylinder Torsional Apparatus

Traditionally, experimental investigations on fibre reinforced sands have been carried out on conventional triaxial apparatus and direct shear. HCTA provides a greater freedom to explore general variations of stresses and strains. Soil samples tested in the HCTA have a typical hollow cylindrical shape (as shown in Figure 2a) and the apparatus has the capability to control axial load (W), torque load (T) and internal and external pressure (P_i and P_o) independently.

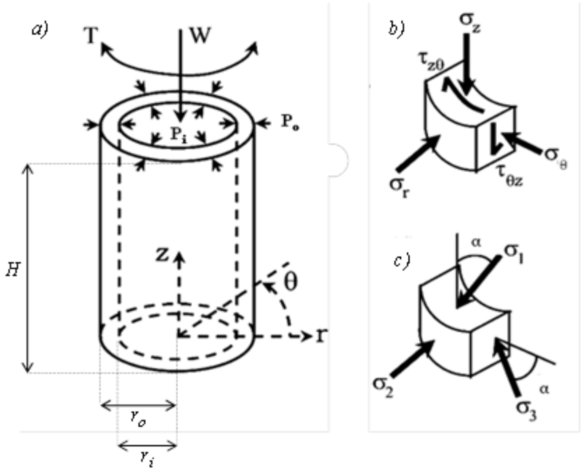

Figure 2 Stress state in hollow cylinder torsional sample. (a) Surface loads, (b) stress components, (c) main principal stresses;

3 EXPERIMENTAL TESTING

3.1 Sample preparation

The Bristol HCTA enables the testing of specimens with the following nominal dimensions: height (H) of 200mm, outer radius (r_o) of 50mm and inner radius (r_i) of 30mm (Figure 2a).

These dimensions respect the recommended dimensions suggested by Sayão and Vaid (1991), in order to minimise the sample curvature and restraint effect which may lead to stress and strain non-uniformities. To obtain an acceptably uniform distribution of fibres and fulfil the repeatability requirements a new sample fabrication was developed. Fibre reinforced sands were prepared in five different layers, deposited into the mould (appositely designed for this experimental campaign) and then vibrated to reach the desired density.

3.2 Testing programme

A total of 24 drained tests have been performed on both unreinforced and reinforced (wf =0.5%) specimens, imposing probing stress paths with different values of the orientation of the major principal stress direction α (see Fig.2c for its definition). Tests were carried out imposing rotation α of *0°*, *15°*, *30°*, *45°*, *60°* and *90°*. The nominal void ratio used was 0.94.The tests have been performed using the same value of internal and external confining cell pressure kept constant during the test. Two different confining pressures of 100kPa and 200kPa have been used.

4 RESULTS AND DISCUSSION

A typical comparison between reinforced and unreinforced failure envelopes at a fixed deviatoric strain (ε_q=10%) is presented in the normalised shear stress-deviatoric stress plane only for the confining pressure of 100 kPa (Figure 3).

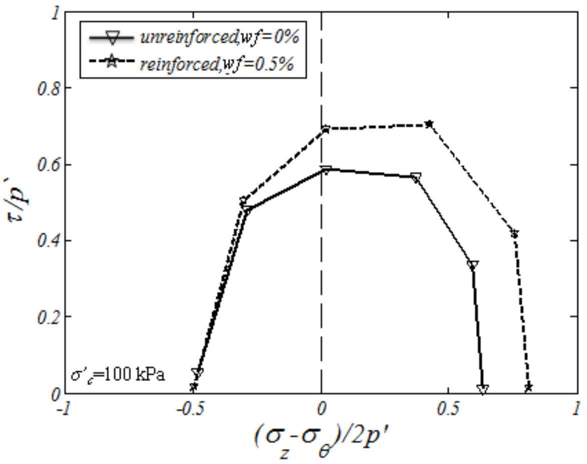

Figure 3 Rosette, for unreinforced (solid line) and reinforced samples (dotted line), plotted considering the stress state at ε_q=10% for samples under 100kPa.

The difference between the unreinforced failure envelope (solid line) and the reinforced one (dotted line) in Figure 3 represents the fibre strengthening effect. The reinforcement contribution is noticeable for lower rotation of the principal stress axis, such as α=0°, 15° and 30° (Figure 3) but becomes progressively closer towards the pure extension case (α=90°). The anisotropic strength of fibre reinforced specimen is related to the fibre orientation with to tensile strain direction. In triaxial compression (α=0°), the fibres, which are expected to be mostly horizontally oriented, lie in the same direction as tensile strain thus may mobilise consistent tensile stress. By increasing α, the tensile strain direction gradually rotates towards the vertical and thus the stretched amount of fibre is expected to decrease.
This outcome is even more evident in the following plot which collects the gain in friction angles ($\Delta\varphi'_{10}$) due to the addition of fibres:

$$\boldsymbol{\Delta\varphi'_{10} = \varphi'_{10r} - \varphi'_{10u}} \qquad (1)$$

where φ'_{10r} and φ'_{10u} are the friction angles for a reinforced and the correspondent unreinforced specimen at ε_q=10%.
The outcomes show a well-established benefit in using fibre as reinforcement, especially for the smaller value of α. In terms of friction angle it corresponds to an average increase from 17% to 25% for tests at α up to 30° (Figure 4). Strengthening effect drops between α=45° and 60°.

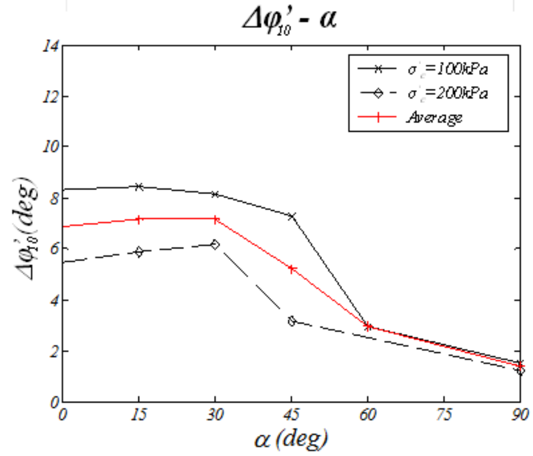

Figure 4 Variation of the friction angle (at ε_q=10%) between reinforced and unreinforced samples for different α angles.

5 CONCLUSIONS

In this research has been investigated the anisotropy of the fibre contribution effect under generalised loading condition.
The fibre contribution is highly dependent on the inclination of the major principal stress direction. Since the moist tamping method leads to a preferred sub-horizontal orientation of fibres, they result more effective when oriented along the direction of the tensile strains. A remarkable strengthening effect arises for loading direction α from 0° to 45°, while for further rotation (α=60° and 90°) the improvement gradually disappears. This point indeed concerns a potential field application where variation of the principal stress axis direction inevitably occurs along a failure surface (Figure 1).

6 ACKNOWLEDGEMENT

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