Fibre-reinforced backfills for retaining structures

Remblaie renforcé par les fibres pour des structures de support

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ABSTRACT: The shear strength of inferior backfill materials can be considerably improved by mixing them randomly with fibres. The increase in shear strength decreases the active soil pressures and increases the passive soil pressures, eventually leading to economy in the design of retaining structures. In the present study, a backfill material such as fine sand is mixed with coir fibre at different fibre contents and aspect ratio of the fibre. Triaxial tests established the marked gain in shear strength resulting from fibre inclusions. A table-top retaining wall apparatus, capable of simulating six modes of wall movements, was fabricated and tests were conducted in it with the above backfill in which wall deformations and thrusts were measured and the rupture figures delineated under all the above modes. Analytical studies by the Finite Element Method confirmed the experimental findings. The studies establish the advantage of using fibre-reinforced backfills for retaining structures.

RÉSUMÉ: La résistance de cisaillement des materiaux de remblaie de qualité inférieure peut être augmenté d'une façon significative en les mélageant aléatoirement avec des fibres. Cette augmentation de la résistance au cisaillement diminue les presssions de sols actives at augmente la pression de sol passive, ainsi conduisant à une conception efficace des structures de support. Dans l'étude actuelle, le matériau de remblaie -le sable fin est mélangé avec des fibres de noix de coco. Différents taux de mélanges et des rapports de longueurs sur largueur de fibres ont été étudiés. Des essais triaxiaux ont montré une augmentation importante de la résitance de cisaillement résultant de l'apport des fibres.Un appareil de laboratoire a été conçu pour simuler le mouvement d'un mur selon six axes et des essais ont été conduits à l'aide de cet appareil sur le matériau étudié et les deformations et des forces sur le mur ont été mesurés selon les six axes et les figures de rupture ont été obtenues.Une analyse par élémnts finis a conforté des résultats expérimentaux. Cette étude confirme les avantages de l'utilisation des renforts de fibres pour les materiaux de remblaie pour des structures de support.

1 INTRODUCTION

Among the more recent soil retention techniques, the pride of place goes to 'reinforced earth' in which high-modulus metallic reinforcing strips are incorporated in the backfill soil with one end connected to a thin facing skin, and the other end left free. While these reinforcements are 'ideally inextensible', a technically feasible and economically viable alternative is to mix the backfill soil randomly with 'ideally extensible' materials such as fibres (Mc. Gown et al. 1978) which would serve as 'inclusions' contributing to increasing the shear strength of the medium. Such soil-fibre composites are called 'ply soils' (Ranjan & Charan 1998) in which strengthening occurs at the meso-scale characterised by isotropic behaviour and absence of potential planes of weakness as occurring in the case of reinforced earth.

Equally important as determinants of the pressure distribution on a retaining wall are the modes of wall movement, the possible relative movement between the wall and the backfill and the friction at the interface. Even though, earth pressure is a classi cal problem in geotechnical engineering, it is already known that

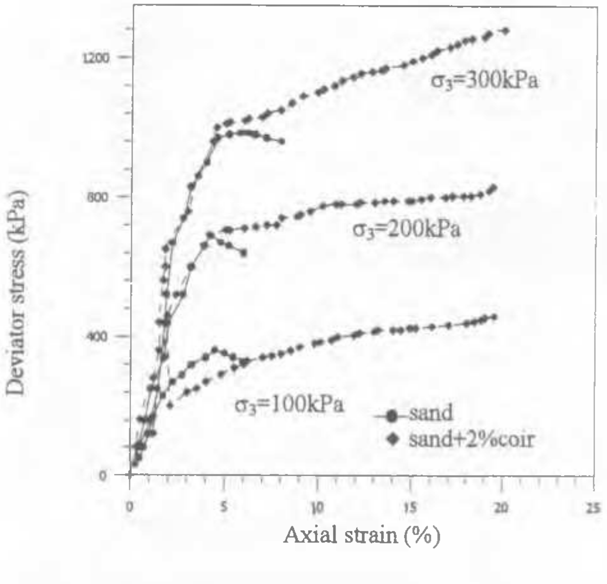


Figure 1. Triaxial test results

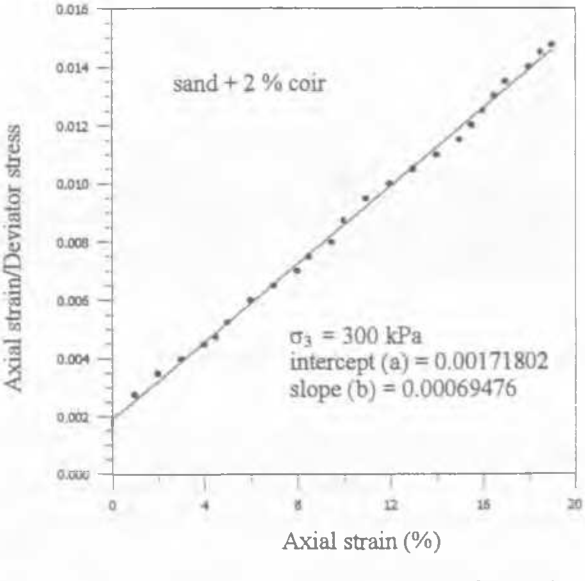
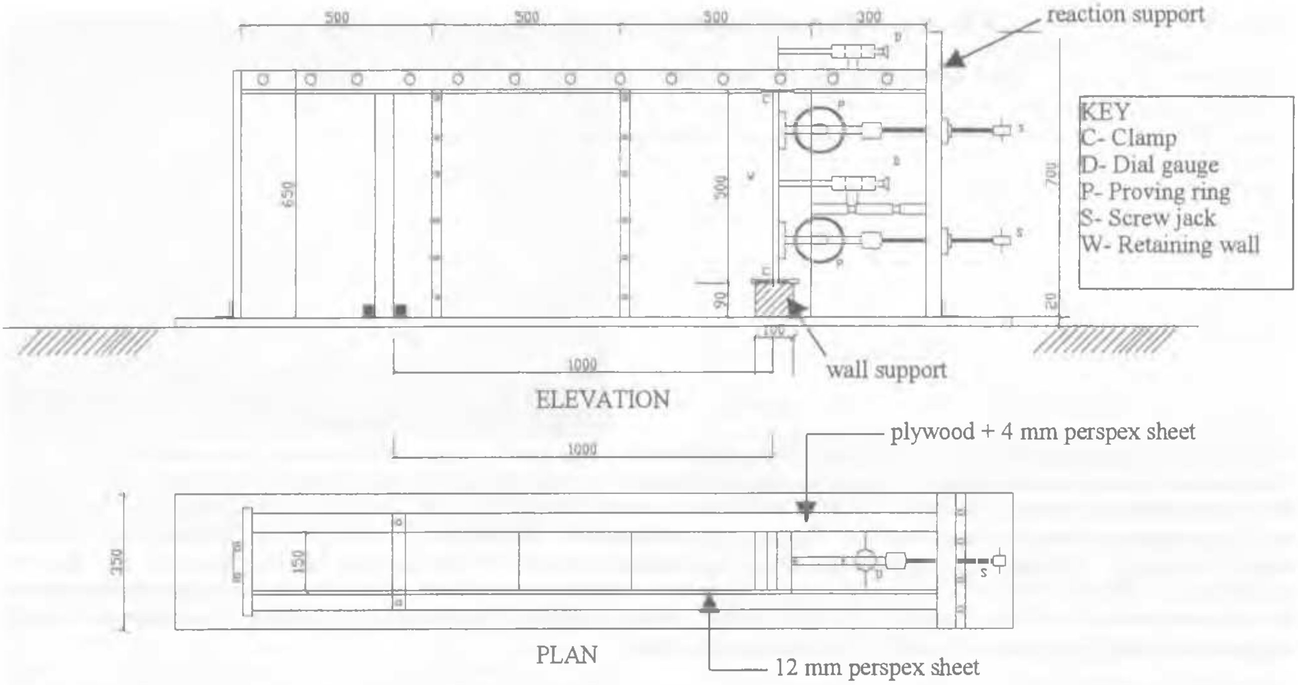


Figure 2. Hyperbolic fitting of stress–strain data – Transformed plot



All dimensions in mm

Figure 3. Table-top retaining wall apparatus

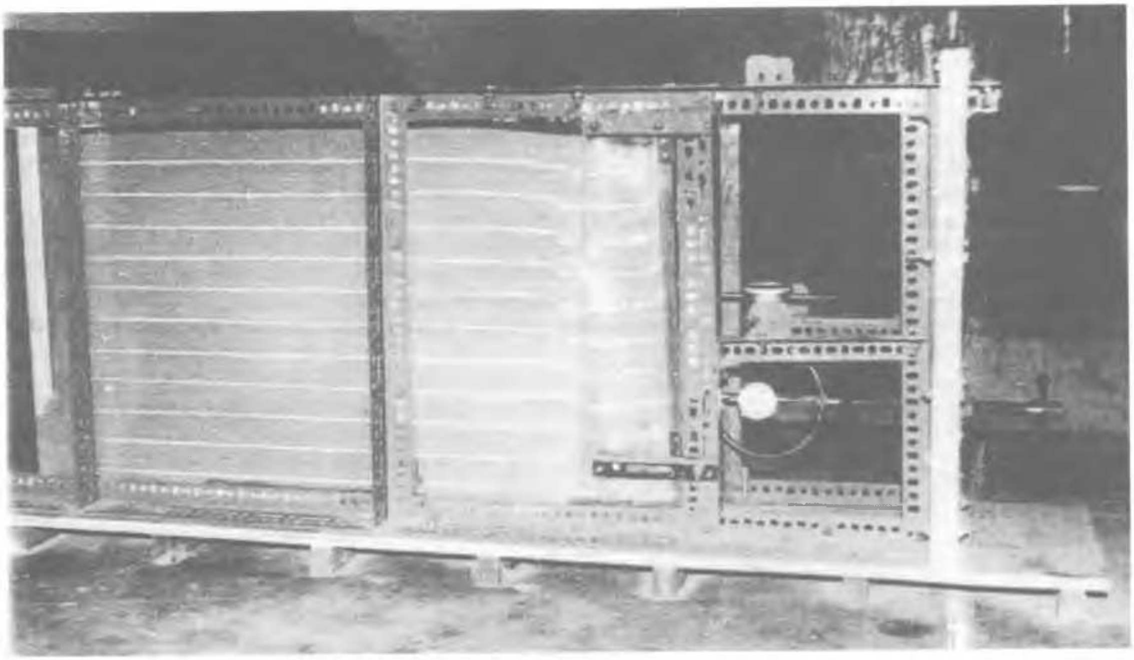


Figure 4. Rupture figure seen through the flume wall

classical theories such as by Coulomb and Rankine do not give an accurate pictutre of the pressure distribution and the location of the resultant thrust. As a result predictions made by the conventional methods of analysis based on them are prone to error.

2 SCOPE

Fine sand as backfill material in the free state and with coir fibre as inclusion randomly mixed in it were tested in a retaining wall apparatus designed to simulate six modes of wall movements involving the active and passive states. Experimentation of this kind are specifically meant to yield detailed information on stress and deformation leading to a better understanding of the behaviour of the backfill material that can result in new design algorithms for use in the future. (James 1971) This is particularly so when the same is coupled with modern methods of analysis such as by the Finite Element Method, which can verify such results, as attempted in the present case. The study has proved to be a rewarding and valuable exercise, shedding light on the extent to which the actual behaviour differs from the predictions of classical earth pressure theories. (Sridhar Reddy 2000)

3 TRIAXIAL TESTS ON REINFORCED SAND

After several trials, the following material combination to serve as backfill was selected for the present study.

Base: Fine sand: Unit weight - 16 kN/m^3, Density index - 65%, Average grain size - 0.25 mm
Fibre: Coir (natural fibre derived from coconut husk): Average dia 0.3 mm, Length-to-diameter ratio – 50, Fibre content – 2 %

Triaxial tests were conducted with and without the inclusion at three values of confining pressures. The results are shown in Fig. 1. Unlike the unreinforced sand which showed a definite peak, the reinforced sand showed a continuous increase of stress with strain. Failure was recognised as the stress corresponding to the peak value in the case of the former, and 15 % axial strain, in the latter. The angle of internal friction (ϕ) so obtained was found to increase from 37° to 42° from the unreinforced to the reinforced case. In addition the reinforced case showed a 'pseudo cohesion' of 20 kPa. In order to determine the initial tangent modulus (E_i) for subsequent analysis, the stress-strain data were fitted hyperbolically (Duncan & Chang 1970, Kurian 1992). The corresponding transformed plot is showed in Fig. 2 from which E_i is obtained as 1/a.

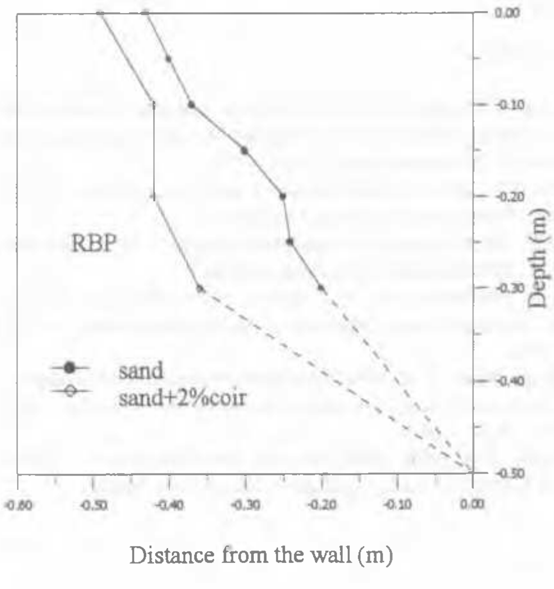


Figure 5. Rupture figures traced from break in colour bands from the flume

4 TESTS IN THE RETAINING WALL APPARATUS

The table-top retaining wall apparatus (Fig. 3) fabricated for this study was a narrow flume with internal dimensions of 1000 mm (length), 150 mm (width) and 600 mm (height). The height of the retaining wall, which was rigid, was 500 mm. Screw jacks helped to simulate uniform translation, rotation about the bottom, and rotation about the top, for the wall, either away from the backfill (active) or towards the backfill (passive), giving rise to six modes of wall deformations in all. (While translations were effected by working the two screw jacks simultaneously, rotations were produced by one jack only depending upon which end is hinged.) These have been designated as: TA, RBA, RTA, TP, RBP and RTP, respectively. (It is known that while RBA is relevant for the stem of cantilever retaining walls, the ruling mode is RTA in the case of supporting system for cuts, Kurian 1994.) The inside of the flume was lined with smooth perspex sheets to simulate two dimensional behaviour as closely as possible. The retaining wall which was rigid was also lined with perspex to create a smooth interface with the backfill. The backfill material was deposited by the sand-raining technique. Horizontal coloured bands incorporated on the backfill face helped the delineation of the rupture figures (Fig. 4). In the tests the screw jacks were turned in the appropriate direction to specified values of thrust measured by the proving rings installed in their line and the corresponding deformations of the wall were obtained from dial guages, as seen in the figure.

Fig. 5 shows typical rupture figures traced from the break in the coloured bands. The increase in ϕ with reinforcement is well reflected in these rupture figures.

5 FINITE ELEMENT ANALYSIS OF TEST CASES

The test cases were subjected to two-dimensional nonlinear plane-strain analysis by the Finite Element Method using the GEOFEM – M package. In the analysis, while the wall was assumed to behave as linearly elastic, the backfill was assumed to be a linearly elastic-perfectly plastic material with a Mohr-Coulomb yield surface. The interface elements were also bilinear. A very high normal stiffness of 10^6 MPa/m was assigned to the interface to maintain perfect contact between the wall face and the backfill. Initial shear stiffness of 230 MPa/m was assigned to the interface elements. When the shear strength of the interface was exceeded, the shear stiffness was assigned a small value of 0.01 MPa/m, while maintaining the high normal stiffness.

Fig. 6 shows the lateral earth pressure and the corresponding earth pressure coefficients with depth obtained in the analysis for the TA mode. Moments of the thrust about the base, obtained from proving ring readings in the test and nodal reactions in the analysis, have been compared, of which Fig. 7 is a typical result. Fig. 8 is a typical mesh deformation diagram.

6 CONCLUSIONS

The major conclusions obtained from the present studies are:

1. There is a significant increase in peak stress and stiffness with the inclusion of fibre in the backfill.

2. The addition of fibre results in a significant increase in ϕ and E_I.

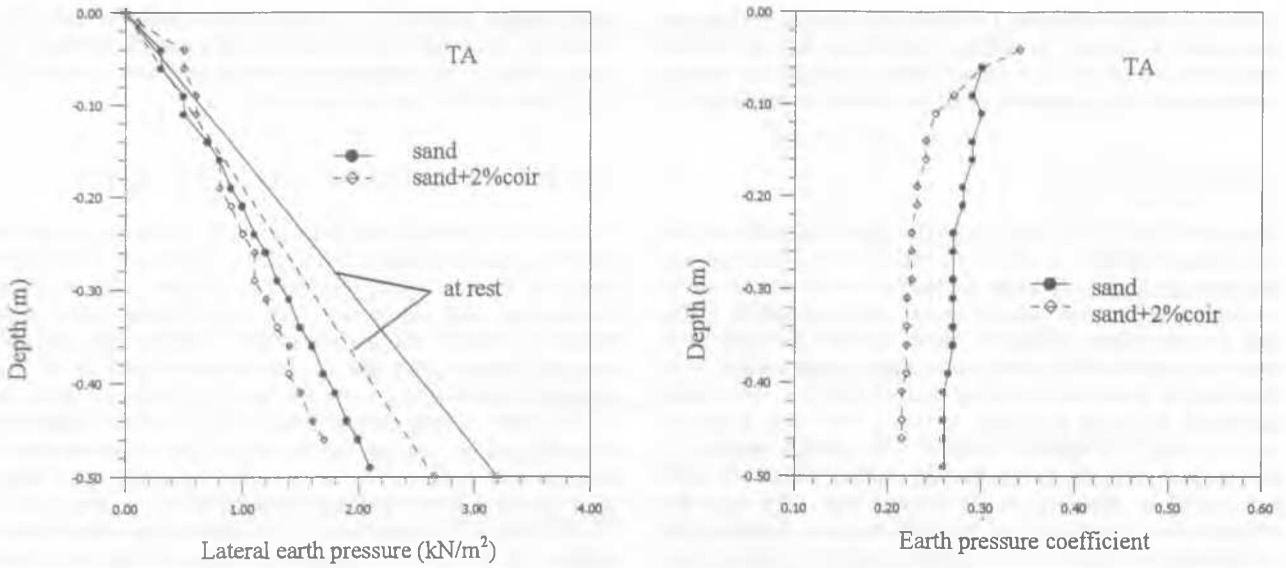


Figure 6. Lateral earth pressures and earth pressure coefficients with depth

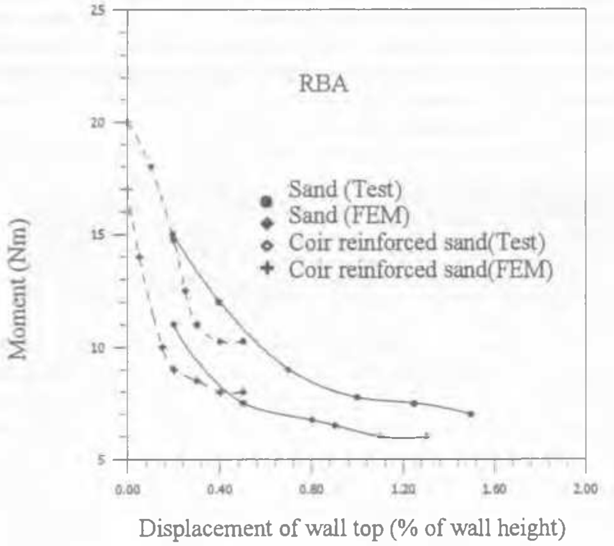


Figure 7. Comparison of moments of thrust from test and analysis

3. The 2% fibre content used in the present study has been found to be effective in reducing the active earth pressure by about 25 % and increasing the passive earth pressure by about 35%.

4. When compared to classical theories, there is a significant difference in the lateral earth pressure distribution and the point of application of the resultant thrust, which must duly accounted for in the design.

The aspect of cost vs. benefit is an inherent consideration in all soil improvement methods including the present case involving the backfill for a retaining wall. In this instance, the saving in wall design should more than offset the cost of fibre addition if the scheme is to be economically viable. To this must be added the need for the inclusion to be made as durable as the wall.

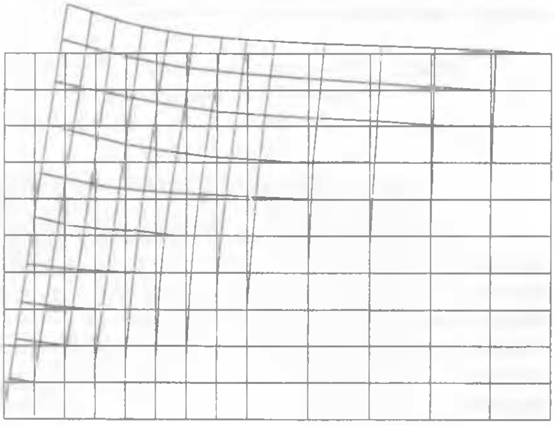


Figure 8. RBP with sand – Mesh deformation

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