Available online at www.sciencedirect.com
ScienceDirect
Geotextiles and Geomembranes 26 (2008) 181–188
Geotextiles and Geomembranes
www.elsevier.com/locate/geotexmem

Technical Note

Numerical simulation of fiber-reinforced sand behavior

G.L. Sivakumar Babu*, A.K. Vasudevan, Sumanta Haldar

Department of Civil Engineering, Indian Institute of Science, Bangalore 560012, India

Received 28 January 2007; received in revised form 9 June 2007; accepted 13 June 2007
Available online 22 October 2007

Abstract

This paper reports the results of triaxial compression tests on sand reinforced with coir fibers and demonstrates that fibers are useful in increasing the shear strength of sand. An approach for considering the effect of random-oriented fibers in numerical analysis is proposed and the results of numerical simulations are reported. Numerical simulation results are compared with those obtained from laboratory triaxial compression tests. The mechanisms by which random fibers reinforce sand are explained in terms of microstructure that prevents the formation of distinct localized strain bands and increases pull-out resistance.

Keywords: Coir fiber; Random-reinforced sand; Shear behavior; Pull-out resistance

1. Introduction

Coir and other similar natural fibers have applications in filtration and drainage functions similar to polymeric geosynthetic materials. Coir fibers are also used as random reinforcement and coir fiber mixed soils are used in the construction of bunds and earth embankments. Coir, being biodegradable is considered environmental friendly and used in the construction of bunds for providing short-term stability. The suitability of natural materials such as coir and jute in applications for short duration of 2–3 years is established by various researchers and stress–strain behavior of soils at different confining pressures and fiber contents is examined (Rao et al., 2000; Rao and Balan, 2000; Lekha and Kavitha, 2006; Sivakumar Babu and Vasudevan, 2007). A few analytical approaches are available in literature to examine the degree of improvement with reference to synthetic fibers. Michalowski and Zhao (1996) developed a model based on homogenization technique to quantify the effect of fiber inclusion on the shear strength behavior of sand. Ranjan et al. (1996) and Zornberg (2002) proposed discrete models for soil and fiber and evaluated major principal stress at failure and equivalent cohesion/friction of the soil reinforced with fibers.

It is useful to examine the behavior of randomly reinforced fiber soil in terms of soil–fiber interaction using numerical analysis as the results capture the overall stress–strain response. However, results are not available in literature and hence an attempt is made in this direction. In this paper, an approach to consider random reinforcement in soils in numerical analysis is suggested and implemented to obtain the stress strain response of fiber-reinforced soil. The results of numerical analysis obtained using the finite difference code, Fast Lagrangian Analysis of Continua (FLAC^{3D}) are used to quantify the effects of fibers in soil. The following aspects are presented in this paper:

(a) experimental results on coir-reinforced sand,
(b) numerical analysis of coir-fiber-reinforced sand, and
(c) failure mechanisms due to the presence of coir fibers.

2. Literature review

Gray and Ohashi (1983) conducted a series of direct shear tests on dry sand reinforced with synthetic, natural and metallic fibers to evaluate the effect of parameters such

*Corresponding author. Tel.: +91 80 22933124; fax: +91 80 23600404.
E-mail address: gls@civil.iisc.ernet.in (G.L. Sivakumar Babu).

0266-1144/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.geotexmem.2007.06.004

as fiber orientation, fiber content, fiber area ratio and fiber stiffness. Maher and Gray (1990) conducted triaxial compression tests on sand reinforced with randomly distributed fibers and observed the influence of various fiber properties, soil properties and other test variables. Michalowski and Zhao (1996) presented experimental and analytical results based on homogenization technique to quantify the effect of fiber inclusion on strength of sand. Ranjan et al. (1996) conducted a series of triaxial compression tests on soil reinforced with randomly distributed fibers (both synthetic and natural) to study the influence of fiber characteristics (i.e., weight fraction, aspect ratio and surface friction), soil characteristics and confining stress on the shear strength of reinforced soil and presented a mathematical model based on regression analysis of test results. Rao and Balan (2000) reported results of triaxial compression tests on sand reinforced with coir fibers. Zornberg (2002) suggested another approach, which characterizes the fiber-reinforced soil as two-component material consisting of soil and fiber material. The methodology treats the fibers as discrete elements that contribute to stability by mobilizing tensile stresses along the shear plane. Michalowski and Coermark (2003) conducted drained triaxial compression tests on fiber-reinforced sand and developed a model for the prediction of failure stress in triaxial compression. According to this model, the failure envelope has two segments: a linear part associated with a fiber slip and a non-linear one related to yielding of the fiber material. The analysis indicates that the yielding of fibers occurs well beyond the stresses encountered in practice. The concept of macroscopic internal frictional angle was introduced to describe the failure criteria of fiber-reinforced sand. This angle includes the influence of both sand and fibers. Equivalent (or macroscopic) internal friction angle is given by

$$\bar{\phi} = 2\tan^{-1}\sqrt{\frac{\rho\eta M\,\tan\phi_{\mathrm{w}} + 6K_\rho}{6-\rho\eta M\,\tan\phi_{\mathrm{w}}}} - \frac{\pi}{2}, \tag{1}$$

where $M = k_{\mathrm{p}}\sin\theta_{\mathrm{o}}$, $K_\rho = \tan^2(45+\phi/2)$, $\theta_{\mathrm{o}} = \tan^{-1}\sqrt{k_{\mathrm{p}}/2}$, η is the aspect ratio, ϕ_{w} is the sand/fiber interface friction angle and ρ is the volumetric fiber content (fiber concentration).

3. Experimental results on coir-reinforced sand

In the present study, dry sand finer than 425 μm and coir fibers of 15 mm length (f_l) and 0.25 mm average diameter (f_d) were used for all the experiments. All the tests were conducted on soil samples of 38 mm diameter and 76 mm height. Initially, the required weights of sand and fibers (for each fiber content) were mixed thoroughly in dry condition and divided into three equal portions. Each of the three parts of the mix was transferred to a mold having a rubber membrane inside using a funnel. The height of fall of the coir-fiber-mixed sand from the funnel end was kept constant to maintain uniform density. Care was taken to produce even distribution of fibers during mixing and filling. The fibers were observed to be randomly distributed in the specimen and estimated to create a condition of isotropy in the sample.

The triaxial compression tests were carried out in a triaxial cell using standard loading frame as per the Bureau of Indian Standards. The tests were conducted at two confining pressures (100 and 150 kPa) for various fiber contents (0%, 0.5%, 1.0% and 1.5% by dry weight of sand). The density of soil specimens in all the experiments was kept at a constant value of 14.8 kN/m^3. Load was applied at a controlled strain rate of 1.58% per minute and measured with a proving ring of 5 kN capacity. The axial deformation was measured with a dial gauge. Deviator load was applied till the specimen failed or upto a strain of 10% whichever was earlier. The results of the triaxial tests are presented in Figs. 1 (a) and (b). It can be noted that stress–stain response is improved considerably by the addition of coir fibers. The properties of sand and fibers used in the experiments are presented in Tables 1 and 2, respectively.

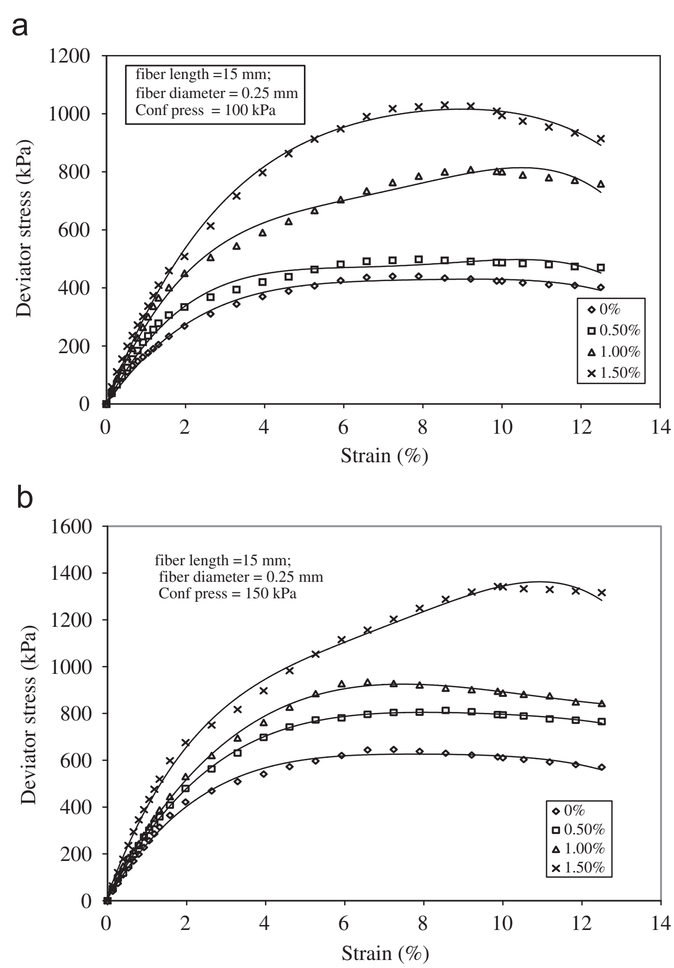

Fig. 1. Stress vs. strain curves for various fiber contents (laboratory experiments).