International Journal of Solids and Structures 51 (2014) 1103–1114

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Non-coaxiality of strain increment and stress directions in cross-anisotropic sand

Nina M. Rodriguez [a], Poul V. Lade [b,*]

[a] Department of the Navy, Naval Sea Systems Command 05C, Washington Navy Yard, Washington, DC 20376, USA
[b] Department of Civil Engineering, The Catholic University of America, Washington, DC 20064, USA

ARTICLE INFO

Article history:
Received 4 June 2013
Received in revised form 25 November 2013
Available online 16 December 2013

Keywords:
Cross-anisotropy
Non-coaxiality
Sand
Three-dimensional
Torsion shear

ABSTRACT

An experimental program was carried out in a recently developed torsion shear apparatus to study the non-coaxiality of strain increment and stress directions in cross-anisotropic deposits of Fine Nevada sand. Forty-four drained torsion shear tests were performed at constant mean confining stress, σ_m, constant intermediate principal stress ratios, as indicated by $b = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$, and constant principal stress directions, α. The experiments were performed on large hollow cylinder specimens deposited by dry pluviation and tested in an automated torsion shear apparatus. The specimens had height of 40 cm, and average diameter of 20 cm, and wall thickness of 2 cm. The stress–strain behavior of Fine Nevada sand is presented for discrete combinations of constant principal stress direction, α, and intermediate principal stress. The effects of these two variables on the non-coaxiality are presented. The experiments show that the directions of the strain increments do not in general coincide with the directions of stresses, and there is a switch from one to the other side between the two quantities.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

The issue of the direction of the major principal strain increment relative to the direction of the major principal stress has interest for modeling of these quantities using elasticity and plasticity theories. For cross-anisotropic materials these directions are not expected to coincide. A detailed experimental investigation was performed for cross-anisotropic sand deposits in a hollow cylinder torsion shear apparatus. The notation for the physical quantities used here is given in Table 1. A series of torsion shear experiments was performed on large hollow cylinder specimens of Fine Nevada sand with constant principal stress directions relative to vertical, α, varying between 0° and 90° and with the intermediate principal stress, σ_2, varying from σ_3 to σ_1 as indicated by $b = (\sigma_2 - \sigma_3)/(\sigma_1 - \sigma_3)$. The Fine Nevada sand was deposited by dry pluviation, thus producing a sand fabric with horizontal bedding planes and cross-anisotropic characteristics. The various stress conditions were achieved by varying the pressures inside and outside the hollow cylinder specimen relative to the shear stress and the vertical deviator stress according to a pre-calculated pattern. All stresses and all strains were determined from careful measurements so that analysis of the soil behavior could be made reliably. The soil behavior was determined for a pattern of combinations of α varying with increments of 22.5° from 0° to 90° and b varying with increments of 0.25 from 0.0 to 1.0. Thus, 25 test locations were established, but many tests were repeated to study the consistency of the results. The measured stress–strain behavior is presented for 15 tests in which the major principal stress was not aligned with or perpendicular to the bedding planes. The results show that strain increment directions are generally not coinciding with the major principal stress directions. When the major principal stress forms angles greater than approximately 45° with the bedding planes, the major principal strain increment directions are closer to the bedding plane direction. However, a switch occurs such that when the major principal stress direction forms more shallow angles below 45° with the bedding planes, the direction of the major principal strain increment is steeper than the direction of the major principal stress. All tests except those with $b = 0.0$ resulted in shear bands, after which strains are not uniform anymore.

2. Previous studies

A significant aspect of soil behavior, which may be modeled by hardening plasticity theory, is that relating to coincidence in physical space of principal strain increments with principal stresses and the influence of anisotropy on this behavior. The stress–strain behavior of sands measured in torsion shear tests has previously been analyzed in terms of the directions of major principal strain increment and major principal stress during

* Corresponding author. Tel.: +1 202 319 6942; fax: +1 202 319 6677.
E-mail addresses: nina.m.rodriguez1@navy.mil (N.M. Rodriguez), Lade@cua.edu (P.V. Lade).

0020-7683/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijsolstr.2013.12.003

Table 1
Notation for physical quantities.

Symbol	Physical quantity
b	$=(\sigma_2-\sigma_3)/(\sigma_1-\sigma_3)$ = relative magnitude of the intermediate principal stress
D_{50}	Mean diameter of sand grains
e	Void ratio
F_v	Vertical load on hollow cylinder specimen
h	Height of hollow cylinder specimen
LVDT	Linear variable differential transducer
p_0, p_i	Outside and inside pressures on hollow cylinder specimen
R	σ_1/σ_3
R_0, R_i	Outside and inside radii of hollow cylinder specimen
T	Torque applied to hollow cylinder specimen
α	Inclination of major principal stress to vertical
β_R	Non-uniformity index = $(R_{max}-R_{min})/R_{avg}$
$\gamma_{z\theta}$	$=2\cdot\varepsilon_{z\theta}$ = engineering shear strain
Δ	$=(\xi-\alpha)$ = angle between directions of major principal strain increment and major principal stress
ΔI_{vol}	Volume change of inner cell
ΔV	Volume change of specimen
$\Delta\theta$	Twist angle of hollow cylinder specimen
ε_z, ε_θ, ε_r	Vertical, tangential and radial normal strains
ε_1	Major principal strain
$\varepsilon_{z\theta}$	Shear strain
ξ	Inclination of major principal strain increment to vertical
σ_v, σ_θ, σ_r	Effective vertical, tangential, and radial stresses on hollow cylinder specimen
σ_1, σ_2, σ_3	Effective major, intermediate, and minor principal stresses
σ_m	Effective mean normal stress
$\tau_{z\theta}$	Torsional shear stress

rotation of principal stress axes in physical space (e.g. Lade 1975, 1976; Hight et al., 1983; Ishihara and Towhata, 1983; Tatsuoka et al., 1986; Symes et al., 1984, 1988; Pradhan et al., 1988; Vaid et al., 1990; Vaid and Sayao, 1995; Saada et al., 1999; Zdravkovic and Jardine, 2000; Sivathayalan and Vaid, 2002; Chaudhary and Kuwano, 2003; Yang et al., 2007; Lade et al., 2008, 2009). Similar testing and analyses have also been performed on clay (e.g. Broms and Casbarian, 1965; Saada and Baah, 1967; Hicher and Lade, 1987; Saada et al., 1994; Frydman et al., 1995; Hong and Lade, 1989a and b; Lade and Kirkgard, 2000; Nishimura et al., 2007). Lade et al., (2009) showed that modeling the observed behavior by an isotropic, plastic hardening soil implies that the two sets of directions coincide during stress rotation, but loading along the principal axes of an anisotropic material will also result in coincidence of principal stress axes with principal strain increment axes. The influence of cross-anisotropy, as is most often found in naturally deposited soils, may not be present in slope talus, sand dunes, or for fluvial or marine sands that have been mobile. However, the effect of cross-anisotropy on the soil behavior has drawn most attention and has been at the root of the use of torsion shear tests with stress rotation in many studies exemplified by those listed above.

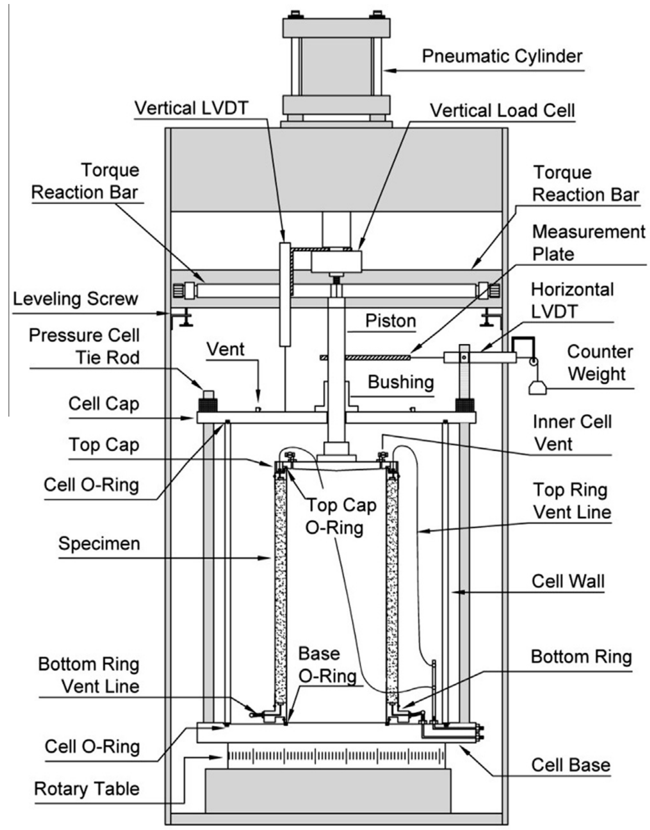

Fig. 1. Schematic drawing of torsion shear apparatus.

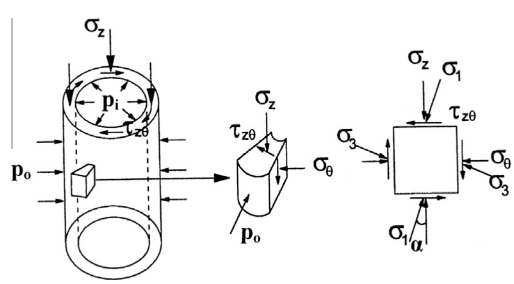

Fig. 2. Stress state in wall of hollow cylinder specimen during torsion shear test.

3. Torsion shear tests on hollow cylinder specimens

Torsion shear tests performed on hollow cylinder specimens are conducted in an apparatus as shown in Fig. 1. These tests are suitable for investigating the effects of principal stress directions on the behavior of soil, because in these tests the bedding planes remain horizontal and the principal stresses can be rotated relative to the bedding planes. In addition, there are only minor effects of imposed non-uniform stress conditions if the specimen is sufficiently tall (Lade, 1981). The state of stress in the hollow cylinder specimen is shown in Fig. 2. In these experiments the direction of the major principal stress may be changed relative to the cross-anisotropic deposit created by dry pluviation. This allows studying the direction of major principal strain increment relative to the direction of the major principal stress in cross-anisotropic sand deposits. The strength results of such torsion shear tests on dense, Fine Nevada sand were presented by Lade et al. (2013), and the non-coaxiality of strain increment and stress directions are presented and analyzed here.

3.1. Sand tested

All torsion shear tests were performed on Fine Nevada sand, which is composed of subangular to subrounded grains consisting mainly of quartz (98%). The properties of this sand are as follows: Mean diameter, D_{50} = 0.23 mm; coefficient of uniformity, 2.08; coefficient of curvature, 1.05; specific gravity, 2.65; maximum void ratio, 0.771; and minimum void ratio, 0.507.

3.2. Preparation of hollow cylinder specimens

The boundaries of the hollow cylinder specimen consisted of custom molded inner and outer latex rubber membranes attached to stainless steel end rings. Hollow cylinder specimens with hori-

Download English Version:

https://daneshyari.com/en/article/277488

Download Persian Version:

https://daneshyari.com/article/277488

Daneshyari.com