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Technical note

Drained responses of granular soil sheared under inclined principal stress axes: Impact of sample preparation

Yuanqiang Cai[a,b], Xuewei Song[b], Qi Sun[c,*], Quanyang Dong[c,*], Jun Wang[c]

[a] College of Civil Engineering and Architecture, Zhejiang University of Technology, Hangzhou 310000, PR China
[b] Department of Civil and Environment Engineering, Shenzhen Graduate School,Harbin Institute of Technology, Shenzhen 518055, PR China
[c] College of Civil Engineering and Architecture, The Key Laboratory of Engineering and Technology for Soft Soil Foundation and Tideland Reclamation of Zhejiang Province, Wenzhou University, Higher Education Zone, Chashan Town, Ouhai District, Wenzhou 325035, PR China

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ABSTRACT

Previous studies have found that the sample preparation method and the resulting sand fabric have significant effect on sand behavior. In the present study, sand specimens were prepared in the laboratory by dry deposition (DD) method and moist tamping (MT) method to create two distinct initial fabrics of sand. Drained hollow cylinder tests were carried out on these specimens under fixed but inclined principal stress axes. Test results show that the major principal stress direction has greater influence on the development of both deviatoric and volumetric strains for DD samples than for MT. DD samples tend to have a higher stress ratio R corresponding to the characteristic state point than MT series. Moreover, the shear strength of DD samples is higher than MT, but significantly influenced by the major principal stress direction. DD samples show stronger non-coaxiality than MT samples under low stress ratio ($R \le 0.1$).

1. Introduction

It is well recognized that the granular soils properties are affected by many factors, such as stress condition, void ratio, particle size and shape, type of pore fluid, saturation, and gradation (Santamarina and Cho 2004; Yang 2005; Clayton et al. 2009; Gu 2012; Cabalar and Hasan 2013; Cabalar and Mustafa 2015; Dong et al. 2016; Sun et al. 2017; Cai et al. 2017). In general, laboratory tests on granular soils are performed on reconstituted specimens as it is difficult to obtain in-situ undisturbed specimens due to the lack of cohesion. Various sample preparation methods have been developed based on the moisture condition of the soil (e.g., dry, moist, or wet), the method of soil placement (e.g., pluviation, spooning, or flowing), and medium through which the soil is placed (e.g., air or water). Previous laboratory observations have found that sand specimens prepared by different reconstitution methods to the same relative density may display quite different responses to applied loading under otherwise similar conditions (Mulilis et al. 1977; Miura and Toki 1983; De Alba et al. 1984; Tatsuoka et al. 1986; Ibrahim and Kagawa 1991; Yamashita and Toki 1993; Rashidian et al. 1995; Vaid et al. 1999; Ishibashi and Capar 2003; Yang et al. 2008; Gu 2012; Sze and Yang 2014). The differences are thought to be linked to the different initial fabrics of the specimens formed by different methods, which can be defined as the spatial arrangement of sand particles and associated voids (Oda and Iwashita 1999).

Among them, Mulilis et al. (1977) performed cyclic triaxial tests under undrained condition and showed that sand specimens prepared by air pluvation exhibited a much lower liquefaction resistance than their counterparts formed by moist tamping, implying the initial fabric formed by sample preparation method was another influential factor that is significantly governing the liquefaction resistance to cyclic loadings except for the density and confining pressure. Yang et al. (2008) investigated the undrained responses of sand specimens prepared by dry deposition (DD) and moist tamping (MT) methods under monotonic triaxial compression condition and indicated that the specimen prepared by MT exhibited an obviously dilative response while their counterparts prepared by DD showed greatly contractive response. Sze and Yang (2014) performed undrained cyclic loading tests on sand specimens prepared by DD and MT methods and found that the soil fabric formed by DD could lead to unique failure modes different from those of MT samples in certain situations. Through experimental tests under small strain level (i.e., < 0.001%), De Alba et al. (1984) found that the maximum shear modulus G_{max}, calculated by the shear wave velocity measured by bender elements, of specimens prepared by moist tamping was greatly larger than their counterparts formed by dry pluvation to the same void ratio and confining pressure. Gu (2012) pointed out that the G_{max} values of the specimens prepared by moist tamping

* Corresponding authors.
E-mail addresses: caiyq@zju.edu.cn (Y. Cai), sunqi_131@163.com (Q. Sun), dongqy@zju.edu.cn (Q. Dong), wangjunx9s@zju.edu.cn (J. Wang).

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were about 17–21% higher than those prepared by air pluvation in bender elements tests, while around 7% higher in resonant column tests and torsional shear tests. However, most of the previous studies on the impact of sample preparation tended to concentrate on the cases where the major principal stress direction was coaxial with vertical or horizontal directions, e.g., triaxial compression or extension states. Little research has been performed under inclined major principal stress directions.

With the development of the hollow cylinder apparatus since the 1980s, the stress paths involving various major principal stress directions can be realized in laboratory tests as it can independently control four degrees of load components. Using the hollow cylinder apparatus, many researchers (Miura et al. 1986; Symes et al. 1988; Gutierrez et al. 1991; Nakata et al. 1998; Tong et al. 2008; Wu et al. 2017; Cai et al. 2017; Guo et al. 2018; Cai et al. 2018) investigated the properties of soils under inclined principal stress directions. Among them, Miura et al. (1986) found that the deformation behavior and shear strength under drained condition were influenced by the direction of principal stress axes. Nakata et al. (1998) conducted a series of undrained tests on sand specimens with different relative densities, indicating that the range of deviatoric strain during the strain softening phase increased with increasing angle of principal stress direction and the steady state was dependent on the principal stress angle. The aforementioned studies implied that the difference existing due to the effect of inherent anisotropic of the specimen prepared in the studies. However, the sand properties of various initial fabrics under inclined principal stress directions have not been investigated properly. Such investigation is needed because it can provide useful insights into the effect of soil fabric formed by sample preparation methods and is also of value to the development of constitutive models for the fabric effect.

This paper presents an experimental study aimed at investigating the impact of sample preparation on the drained responses of saturated sand sheared under inclined principal stress axes using hollow cylinder apparatus. Dry deposition and moist tamping were used in this study to prepare specimens with distinct fabrics, which are two commonly used methods for laboratory preparation of sand specimens (Ishihara 1993). As evidenced by the microscopic measurements of Yang et al. (2008), the particles of sand specimens prepared by dry deposition have an optimum arrangement direction while by moist tamping randomly arrange, leading to a higher degree of initial fabric anisotropy of dry deposition sample than moist tamping sample. Generally, the dry deposition method is considered suitable for simulating the natural deposition process, whereas the moist tamping method can model the soil fabric of rolled construction fills and has the advantage of preventing segregation of well-graded materials (Kuerbis and Vaid 1988). In this paper, the drained responses of sand specimens formed by two methods are discussed, including the strain, shear strength, and non-coaxiality.

2. Experimental program

2.1. Test apparatus

The hollow cylinder apparatus (HCA) manufactured by GDS Corporation was used in this study. The HCA can realize many complex stress paths such as inclined principal stress directions, continuous principal stress rotation, and for the analysis of intermediate principal stress. A schematic diagram of the apparatus is illustrated in Fig. 1. The HCA system has the following components: axial and rotational controllers; outer cell, inner cell, and back pressure controllers. The axial load and torque are applied by the axial and rotational controllers, respectively, and are measured by a combined load and torque transducer mounted on the top of the cell. The outer cell, inner cell, and back pressure controllers are used to independently control the outer cell pressure, inner cell pressure, and back pressure through de-aired water, respectively. Fig. 2 shows the typical stress and strain state in the hollow cylindrical specimen. The HCA can independently control the vertical load (W), the torque (M_T), the inner cell pressure (p_i), and the outer cell pressure (p_o). Consequently, the vertical stress (σ_z), the radial stress (σ_r), the circumferential stress (σ_θ), and the torsional shear stress ($\tau_{z\theta}$), can be generated in the hollow cylindrical specimen. Accordingly, the four strain components, i.e., the vertical strain, the radial strain, the circumferential strain, and the shear strain, are denoted as ε_z, ε_r, ε_θ, and $\gamma_{z\theta}$, respectively. The principal stresses can also be employed to describe the stress state of the testing sample, i.e., the major principal stress (σ_1), the intermediate principal stress (σ_2), the minor principal stress (σ_3), and the rotational angle of the major principal stress to the vertical (α). More detailed description of the apparatus and stress and strain state is available in Cai et al. (2015).

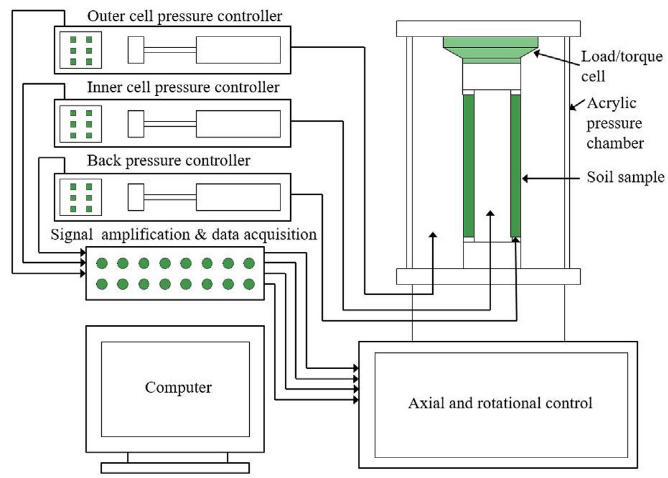

Fig. 1. Schematic diagram of HCA.

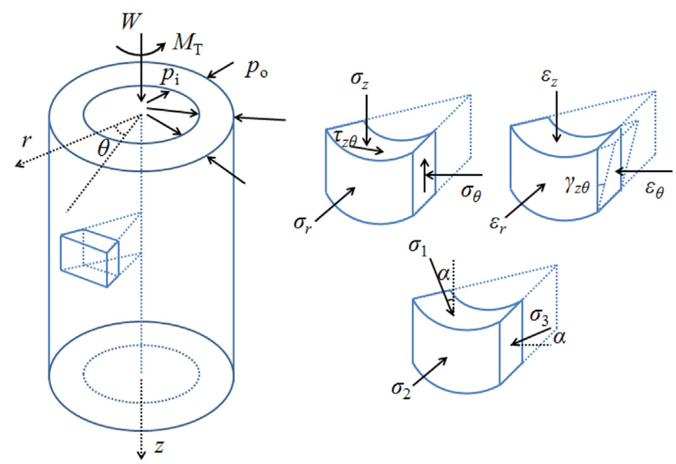

Fig. 2. Stress and strain state in the hollow cylindrical specimen.

2.2. Test material and specimen preparation

Toyoura sand, widely used standard sand, was utilized in this study. It is kind of uniform, fine sand consisting of subrounded to subangular particles and mainly composed of quartz (90%), feldspar and chert (Gutierrez et al. 1991; Yang 2005). The roundness R and sphericity S of Toyoura sand are respectively 0.61 and 0.395 (Yang 2005). Table 1 summarizes its physical properties.

All the hollow cylindrical specimens had an internal radius of 30 mm, an external radius of 50 mm, and a height of 200 mm. Both dry deposition (DD) and moist tamping (MT) methods were used to prepare specimens having distinct initial fabrics (Yang 2005; Sze and Yang 2014). In DD method, oven-dried sand was weighed according to the desired relative density and then filled into the mould in ten layers