Particuology 23 (2015) 82–89

Contents lists available at ScienceDirect

Particuology

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

Using a modified direct shear apparatus to explore gap and size effects on shear resistance of coarse-grained soil

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ARTICLE INFO

Article history:
Received 21 June 2014
Received in revised form 15 October 2014
Accepted 7 November 2014
Available online 20 April 2015

Keywords:
Direct shear apparatus
Gap effect
Size effect
Shear resistance
Coarse-grained soil

ABSTRACT

This work used a modified direct shear apparatus, created newly by the authors, to explore effects of the gap between shear box halves and specimen size on the shear resistance of coarse-grained soil. The shear boxes of this apparatus were assembled from a series of steel structures capable of superimposition and nesting. Such characteristics facilitated variation of specimen size in both diameter and height. The new device can also maintain a constant gap during shearing. We performed a series of gap-effect and size-effect tests for two uniformly graded, coarse-grained soil samples. The test results showed that both the gap space and specimen size had significant influences on shear resistance of the coarse-grained soil. Further, analysis of variations in shear strength indices led to a reasonable gap dimension and specimen size of the two soil samples.

Introduction

Coarse-grained soil is well known for its excellent resistance against shear and has been widely used in geotechnical engineering projects (Terzaghi, Peck, & Mesri, 1996, chap. 17) such as foundations, earth-filled dams, embankments, and breakwaters. Also, shear resistance of this soil is often described by direct use of the Mohr–Coulomb (MC) parameters, internal friction angle φ and cohesion c. These two parameters can be determined from a direct shear test (DST) or triaxial compression test. In this study, however, only the DST was used to investigate shear strength of coarse-grained soil, owing to its simplicity, convenience, and reduced test duration (Zhou, Shen, Helenbrook, & Zhang, 2009).

It has been widely reported that the shear strength of soil depends upon many factors, e.g., soil type (Bareither, Edil, Benson, & Mickelson, 2008; Cerato & Lutenegger, 2006; Chen & Wan, 2004), compactness (Igwe, Fukuoka, & Sassa, 2012; Vallejo & Mawby, 2000), grain composition (Adunoye, 2014; Cabalar, Dulundu, & Tuncay, 2013; Hamidi, Azini, & Masoudi, 2012; Simoni & Houlsby, 2006; Vallejo, 2001), particle shape (Cho, Dodds, & Santamarina, 2006; Hubler, Athanasopoulos-Zekkos, Ohm, & Hryciw, 2014; Le Pen, Powrie, Zervos, Ahmed, & Aingaran, 2013; Shin & Santamarina, 2013; Uday, Padmakumar, & Singh, 2013), rock type of particle (Bareither et al., 2008; Xu, Xu, & Hu, 2011), environmental conditions (stress state, water content variation, disturbance magnitude, and seepage state; e.g., Caruso & Tarantino, 2004; Ke & Takahashi, 2012; Kokusho, Hara, & Hiraoka, 2004; Lehane & Liu, 2013), and even the test method (Amšiejus, Dirgėlienė, Norkus, & Skuodis, 2014; Bagherzadeh-Khalkhali & Mirghasemi, 2009; Cabalar et al., 2013; Vithana, Nakamura, Gibo, Yoshinaga, & Kimura, 2012). Regarding the DST however, the gap between shear box halves and specimen size, which can be summarized as the scale effect (Cerato & Lutenegger, 2006; Moayed & Alizadeh, 2011; Orlando & Shen, 2012; Palmeira & Milligan, 1989; Rechenmacher, 2006; Wu, Matsushima, & Tatsuoka, 2008; Zhou et al., 2009), may be two important factors affecting shear strength of a specific coarse-grained soil sample. Parsons (1936) reported the scale dependence of the internal friction angle of a cohesionless soil sample, observing that the larger the direct shear box, the smaller the internal friction angle.

A consistent opinion currently accepted in the field of geotechnical engineering is that shear strength of coarse-grained soil basically stems from resistance against sliding between particles and particle rolling. Nevertheless, when shearing a coarse-grained soil specimen along a specified shear band in a direct shear apparatus (DSA), sliding between particles and particle rolling depend upon specimen size and gap dimension. If diameter D and height H of the specimen, or the gap T between the shear box halves

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http://dx.doi.org/10.1016/j.partic.2014.11.013

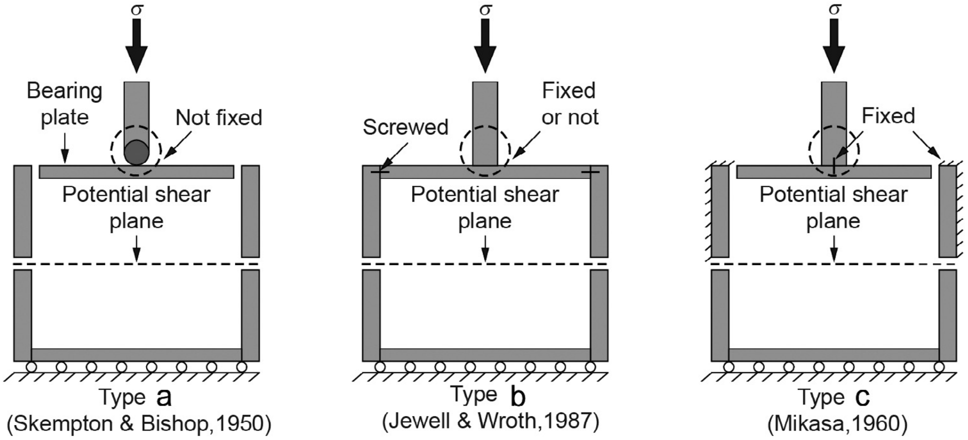

Fig. 1. Three types of direct shear apparatus (DSA).

(or combinations thereof) are too small, a portion of rock particles within the specified shear band will have crush and fracture failures during shearing. The occurrence of such failures causes overestimation of actual shear resistance of the coarse-grained soil. For this reason, ASTM D3080/D3080M-11 (2012) suggests: “the minimum specimen diameter for circular specimens, or width for square specimens, shall be 50 mm, or not less than ten times the maximum particle size; the minimum initial specimen thickness shall be 13 mm, but not less than six times the maximum particle size; the minimum specimen diameter to thickness or width to thickness ratio shall be 2:1″. This standard also mentions that “the shear box is fitted with gap screws, which create the gap between the top and bottom halves of the shear box prior to shear. Presently there is insufficient information available for specifying the gap dimension based on particle size distribution”.

As shown in Fig. 1, there are three types of DSA (Jewell & Wroth, 1987; Mikasa, 1960; Shibuya, Mitachi, & Tamate, 1997; Skempton & Bishop, 1950). Conventional DSAs, particularly those made for testing coarse-grained soil, are generally suited to the laboratory DST because of heavy weight and large bulk. The shear box halves of these apparatuses, circular or square cross section, often have fixed diameter (or width) and height. Accordingly, specimen size must fit with a specific shear box and cannot be varied according to gradation distributions and particle sizes of soil samples. In addition, the gap space cannot be held constant during shearing by some DSAs.

The modified DSA in this work solves the aforementioned problems. This apparatus enables variation of the direct shear box dimension in both diameter and height, and can maintain a constant gap during shearing. DSTs with different specimen sizes or shear band thicknesses can be carried out using a suite of DSAs. These DSAs are suitable for the in situ DST and laboratory test, but this study only addresses the latter. We used the new device for exploring the influences of gap dimension and specimen size on shear resistance of the coarse-grained soil. Only two uniformly graded, coarse-grained soil samples, with grain sizes being 2–5 and 5–10 mm, were selected to test the gap and size effects in the DSTs.

Experimental

Direct shear apparatus

The DSA presented in Fig. 2 is structurally similar to Type (a) in Fig. 1. A slight difference is a thrust force acting on the upper shear box half of this DSA according to specifications of patents issued to Fu and Zheng (2013, 2014). The shear box halves initially connected with alignment screws were placed between an upper reaction force plate and lower base plate, as shown in Fig. 2. The two plates were connected by six steel pillars. The position of the reaction force plate can be adjusted by top nuts nested on the six steel pillars to accommodate shear box and vertical jack. The lower shear box half is rigidly fixed to the base plate. The reaction force plate and two steel pillars on the right side of Fig. 2 apply the vertical and horizontal reaction forces, respectively, for the normal and shear stresses during shearing. A circular groove was milled at the top of the bearing plate so that the piston of the vertical jack could be extended into this groove. There were two rows of equal-diameter steel balls connecting two small square steel plates between the vertical jack and reaction force plate. The two rows of steel balls moved parallel to the shear direction and were put into V-shaped roll grooves milled near the front and back sides of the two small steel plates. A circular groove was also milled at the bottom of the lower small steel plate to make the top of the vertical jack nested within this groove. The inner shape of the shear box was circular, but the outer shape was square. Both shear box halves were assembled from a series of steel structures capable of superimposition and nesting to enable variation of specimen size in both diameter *D* and height *H*. Accordingly, different combinations of *D* and *H* could be implemented in the DST.

The steel structure assemblies are illustrated in Fig. 3. Each layer was 2.5 cm thick. Maximum layer number was four for the upper or lower shear box half. *H* values could be 5, 10, 15, or 20 cm after assembling. Fig. 3(a) shows superimposition modes for the

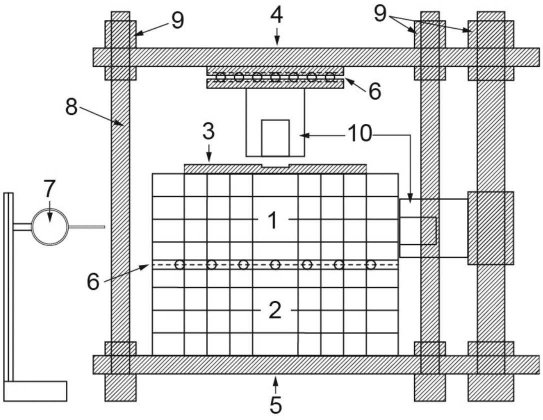

Fig. 2. Sketch of the modified DSA. 1: upper shear box half; 2: lower shear box half; 3: bearing plate; 4: reaction force plate; 5: base plate; 6: roll groove; 7: dial gauge; 8: connection pillar; 9: nut; 10: jack.