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Strength of various sands in triaxial and cyclic direct shear tests

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ABSTRACT

This paper presents the result of an extensive series of experimental investigation carried out in triaxial and cyclic direct shear tests on sands having various properties, which were obtained from different locations in Turkey and in Northern Cyprus. In order to investigate the link between strength and physical properties (i.e., shape) of the sand particles, three series of triaxial tests (Consolidated-Drained, CD; Consolidated-Undrained, CU; and Unconsolidated-Undrained, UU) for each were performed under three different confining pressure values (450 kPa, 500 kPa, and 550 kPa) with a back pressure of 400 kPa. The cyclic shear behaviour of the sands was tested by considering the normal stresses of 50 kPa, 100 kPa, and 150 kPa. Experimental results in both triaxial and cyclic direct shear tests showed a relation between the physical properties of the sands and the behaviour of them under monotonic and cyclic loading. The given pictures show the physical differences/similarities among the sands used during the investigation. The goal of the presented experimental investigation is to have an understanding of the behaviour due to shape characteristics (i.e., roundness, sphericity) of these four types of sands (Narli, Birecik, Trakya, and Crushed Stone), which are widely used in earthwork projects in certain parts of Turkey and Northern Cyprus.

1. Introduction

Stress–strain response of soils under monotonic and cyclic loading is necessary for analyzing and designing of civil engineering geosystems. Monotonic and cyclic loadings will induce transient and permanent deformations in soils. The deformations could damage the structures located on these soil layers (Basheer, 2002; Shahnazari et al., 2010). Civil engineering works in Gaziantep city in Turkey and its vicinity have been significantly increasing over the last decade, as Gaziantep is a city growing very fast. The sands obtained from its vicinity have been widely used for geotechnical engineering works in/around the city. For this reason, investigations of the behaviour of the 'Birecik' and 'Narli' sands have received attention in this study. 'Trakya' sand, which is commonly used in the experimental works, was supplied by Set/Italcementi Group, Turkey, confirming to TS EN 196-1. It was obtained from the Thrace Region in North-west of Turkey. 'Crushed stone' sand used in this investigation is widely consumed in civil engineering works, in particular earthworks, in Northern Cyprus. Fig. 1 shows the location of the sampling areas.

Shape characteristics of these four sands' (Birecik, Narli, Trakya, Crushed Stone) grains, which were each artificially graded to a narrow size range to provide uniform specimens for visual classification purposes, could affect some significant properties of the soil, such as; density, porosity, permeability, compressibility, shear strength (Terzaghi, 1925; Gilboy, 1928; Lees, 1964; Olson and Mesri, 1970; Abbiredd and Clayton, 2009; Clayton et al., 2009). Terzaghi is one of the first engineers to make an investigation to understand the shape characteristics using a flat-grained constituent (i.e., mica) (Terzaghi, 1925). Terzaghi (1925) postulated that the compressibility of cohesionless material is governed by the grain size, uniformity, volume of voids and mica content. The observations, made by Gilboy (1928), that any system of analysis or classification of soil which neglects the presence and effect of the shape will be incomplete and erroneous. Because of the importance of particle shape and its role in the behaviour of sands for practicing engineers and researchers in helping to estimate soil behaviour, numerous researches have been carried out. Holubec and D'Appolonia (1973) showed that the results of dynamic penetration tests in sands depend on particle shape. Confort (1973), Holtz and Kovacks (1981) demonstrated how particle shape impacts the internal fiction angle (φ). Cedergen (1989) pointed out that particle shape affects the permeability. Particles shape also plays a significant role in liquefaction potential (Kramer, 1996). The three recent investigations (Vermeulen, 2001; Clayton et al., 2004; Theron, 2004) into the behaviour of gold mine tailings have also pointed to the importance of the influence of particle shape on the behaviour (i.e., strength, compressibility) of geomaterials using experimental data in triaxial testing. Wadell (1932), Krumbein (1941), Powers (1953), Holubec and D'Appolonia (1973), Youd (1973), and Cho et al. (2006), have introduced detailed explanations of particle shape. Two independent

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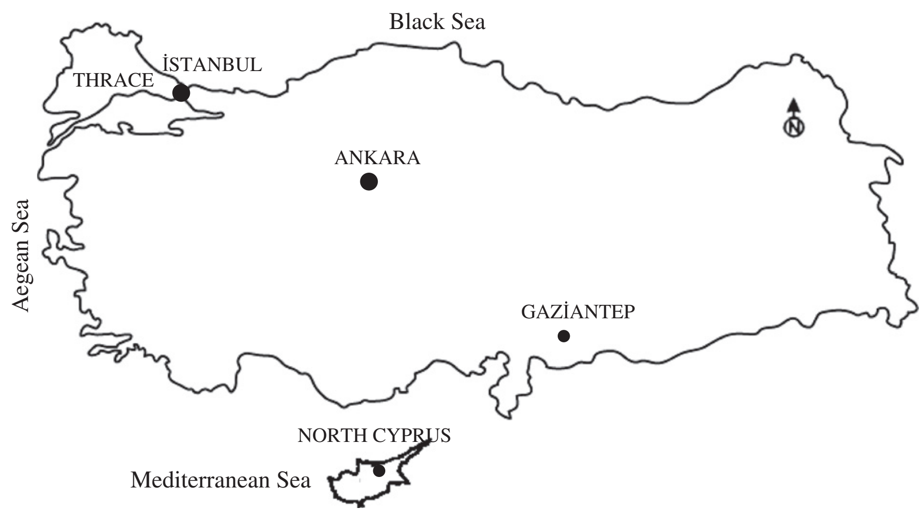

Fig. 1. Locations of sampling areas.

properties are typically employed to describe the shape of a soil particle: (i) Roundness is a measure of the extent to which the edges and corners of a particle has been rounded (ii) Sphericity (form) described the overall shape of a particle, it is a measure of the extent to which a particle approaches a sphere in shape. Wadell (1932) proposed a simplified sphericity (S) parameter, ($D_{max\text{-}insc}/D_{min\text{-}circ}$), where $D_{max-min}$ is the diameter of a maximum inscribed circle and $D_{min\text{-}circ}$ is the diameter of a minimum sphere circumscribing a gravel particle. Wadell (1932) defined roundness (R) as $D_{i\text{-}ave}/D_{max\text{-}insc}$, where $D_{i\text{-}ave}$ is the average diameter of the inscribed circle for each corner of the particle. Figs. 2–4 describe R, S and a chart for comparison between them to determine particle shape (Krumbein, 1941; Powers, 1953).

The principles of soil strength are given in many soil mechanics texts, including Holtz and Kovacks (1981), Lambe and Whitman (1969), Terzaghi et al. (1996), and Germaine and Germaine (2009). 'Triaxial' testing is a common method to measure the strength of geomaterials ranging from clay to rock. In a triaxial testing, it is possible to have some material properties (stress–strain and strength) of the specimen tested. These properties could be employed in modeling to estimate how the geomaterial will behave in some engineering applications (Cabalar et al., 2009, 2010; Edincliler et al., 2010). Appropriate residual strength parameters, which can be obtained from 'cyclic direct shear' tests, have a great importance for landslides triggering and post-landslide stability (Skempton, 1985; Masafumi, 2000; Meehan et al., 2010; Stark and Hussain, 2010), as well as both seismic and post-seismic slope analyses in an earthquake event (Olson and Stark, 2002; Idriss and Boulanger, 2007). Determination of the residual strength parameters of soils in cyclic direct shear test has a great

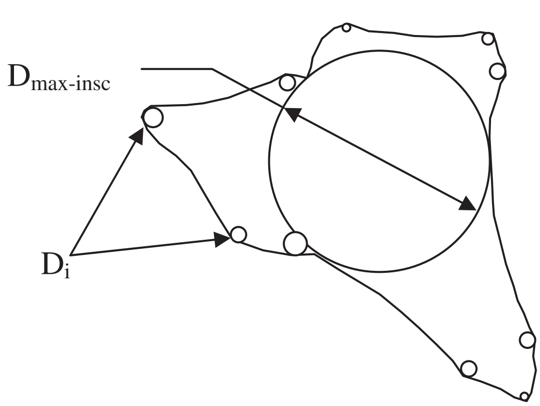

Fig. 2. Graphical representation of roundness R (redrawn from Muszynski and Stanley, 2012).

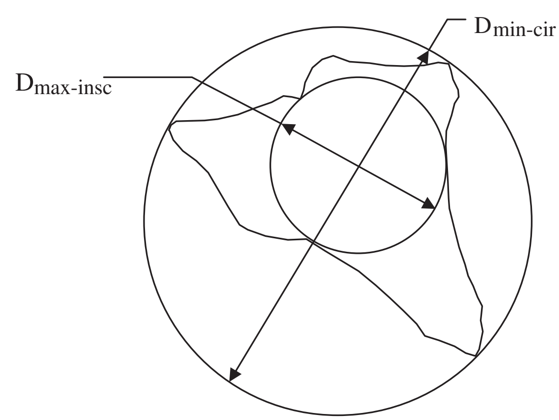

Fig. 3. Graphical representation of sphericity S (redrawn from Muszynski and Stanley, 2012).

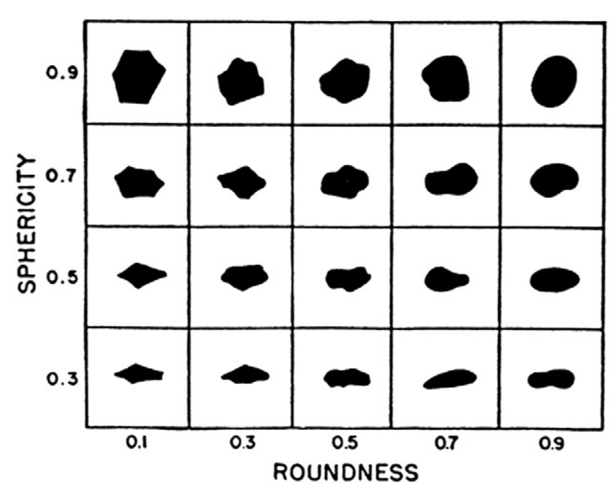

Fig. 4. Comparison chart (Santamarina and Cho, 2004).