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Fall cone tests on clay–sand mixtures

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ABSTRACT

Fall cone tests were performed on clay–sand mixtures to investigate the variation of liquid limit with sand content and the link between undrained shear strength and water content for various sand contents in the mixtures. Five different particle gradations (4.75–0.075 mm, 4.75–2.0 mm, 1.18–0.6 mm, 0.6–0.075 mm, and 0.425–0.3 mm) of sands having distinct shapes (rounded and angular) were added to a low plasticity clay with mixture ratios of 0%, 10%, 20%, 30%, 40%, and 50%. Data of the clay–sand mixtures showed that the depth of cone penetration against water content relationship is about linear. The liquid limit estimates of the mixtures were measured to be slightly affected by the gradation and shape of the grains in the range of sand contents employed. The obtained results indicated a decrease of undrained shear strength with an increase in the amount of sand. The use of rounded sands in a clay matrix leads to the development of higher undrained shear strength values, on which gradation of the sands has no effect.

1. Introduction

Laboratory studies and field observations indicate that cohesive soils may contain granular geomaterials (cohesionless) with different shape and size properties. The cohesionless geomaterials should be expected to affect the properties of cohesive soils. The use of fall cone test to estimate the liquid limit of soils has been widely studied (Terzaghi, 1927; Hansbo, 1957; Houlsby, 1982; Wood, 1982, 1985; Leroueil and Le Bihan, 1996; Feng, 2000). Previous researches of index properties of clay–sand mixtures have usually stated that the liquid limit decreases linearly with the clay content (Seed et al., 1964; Nagaraj et al., 1987; Tan et al., 1994). The fall cone test is thought to be a reliable method to estimate the liquid limit, and is standardized in many countries. The fall cone test was originally developed for the determination of shear strength of cohesive soils in Scandinavia (Wood, 1985; Koumoto and Houlsby, 2001). Since the penetration by fall cone is controlled by the strength of the cohesive soil, the testing provides a measurement of strength, and an indication of the soil compressibility (Kumar and Wood, 1999). Hansbo (1957) proposed that a cone of mass m will penetrate into a clay of undrained shear strength s_u a distance d given by the following equation (Eq. (1)):

$$s_u = k\frac{mg}{d^2} \tag{1}$$

where, g is the gravitational acceleration, and k is a constant, which changes based on the angle of the cone and is found to be 0.85 for the 30° British cone (Wood, 1985). Thus, the experimental results can be converted to relations between the undrained shear strength and water content of the clay–sand mixtures.

It has been long understood that grain size and shape characteristics have a significant effect on the engineering properties of soil matrix (Terzaghi, 1925; Gilboy, 1928; Lees, 1964; Olson and Mesri, 1970; Abbireddy et al., 2009; Clayton et al., 2009; Cabalar et al., 2013; Cabalar and Hasan, 2013). Terzaghi is one of the first engineers to make an investigation to understand the shape characteristics by using flat-grained particles (Terzaghi, 1925), who postulated that sand compressibility is governed by its grain size, shape, 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. Numerous research were carried out, due to the importance of grain shape and its role in the behavior of sands for practicing engineers and researchers in helping to estimate soil behavior. For example, Holubec and D'appolonia (1973) showed that the results of dynamic penetration tests in sands depend on grain shape; Cornforth (1973) demonstrated how grain shape impacts the internal fiction angle (φ); Cedergren (1989) pointed out that grain shape affects the permeability. Further, grain shape plays a significant role in liquefaction potential as discussed by Kramer (1996). Wadell (1932), Krumbein (1941), Powers (1953), Holubec and D'appolonia (1973), Youd (1973), and Cho et al. (2006) have introduced detailed explanations of grain shape. Two independent properties are typically employed to describe the shape of a soil grain: roundness and sphericity. Roundness (R) is a

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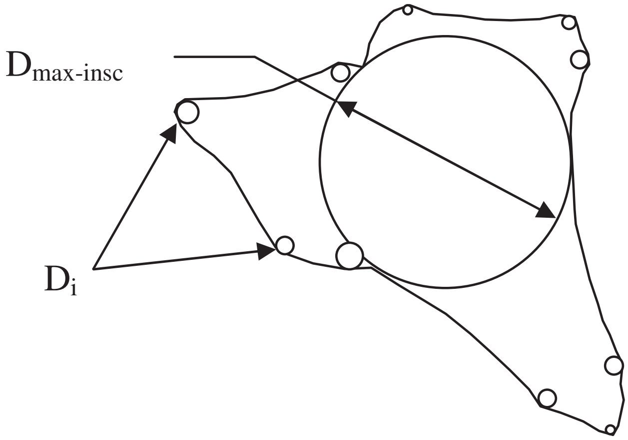

Fig. 1. Graphical representation of roundness, R.
Redrawn from Muszynski and Vitton, 2012).

measure of the extent to which the edges and corners of a grain has been rounded; while sphericity (S) describes the overall shape of a grain. It is a measure of the extent to which a grain approaches a sphere in shape. Wadell (1932) proposed a simplified sphericity (S) parameter, ($D_{max-insc}$ / $D_{min-circ}$), where $D_{max-min}$ is the diameter of a maximum inscribed circle and $D_{min-circ}$ is the diameter of a minimum sphere circumscribing a sand grain. Wadell (1932) defined roundness (R) as D_{i-ave} / $D_{max-insc}$, where D_{i-ave} is the average diameter of the corners of the grain. Figs. 1–3 describe R, S and a chart for comparison between them to determine grain shape (Krumbein, 1941; Powers, 1953).

Typical observations of the compressional behavior of various size/shape sand–clay mixtures were presented by Cabalar and Hasan (2013). They made an investigation carried out to relate the various size fractions (0.3 mm–0.6 mm; 1.0 mm–2.0 mm) and shapes (R = 0.43, S = 0.67; R = 0.16, S = 0.55) of sands with clay in different viscosity pore fluids (0.94 mm^2/s; 10.65 mm^2/s) to compressional behavior. They concluded that oedometer testing results were significantly affected by the amount of clay and size/shape properties of the sand grains. This linkage has been explored further in the present work using the liquid limit results that have been obtained from the fall cone tests, and the undrained shear strength estimates.

2. Experimental study

2.1. Materials

Two sands were used in the tests to form clay–sand mixtures, a Narli Sand (NS) and a Crushed Stone Sand (CSS). The sands used were

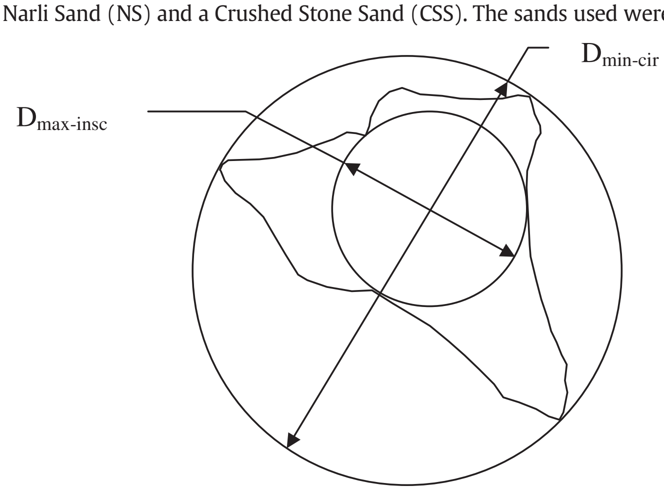

Fig. 2. Graphical representation of sphericity, S.
Redrawn from Muszynski and Vitton, 2012).

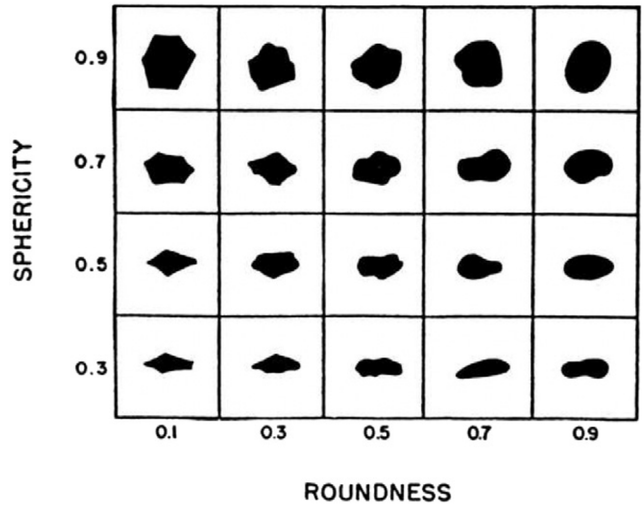

Fig. 3. Comparison chart.
Krumbein, 1941.

classified according to the Unified Soil Classification System (USCS). The clay–sand mixtures were tested with distilled water as a pore fluid and a low to high plasticity clay.

Narli Sand (NS) was collected from the Aksu River bank in and around Narli in Kahramanmaras, Turkey. The Aksu River starts in northwest of Kahramanmaras City, which lies in southern Turkey (37°36′N; 36°55′E) and bounded by hills or mountains on all sides. A commercially

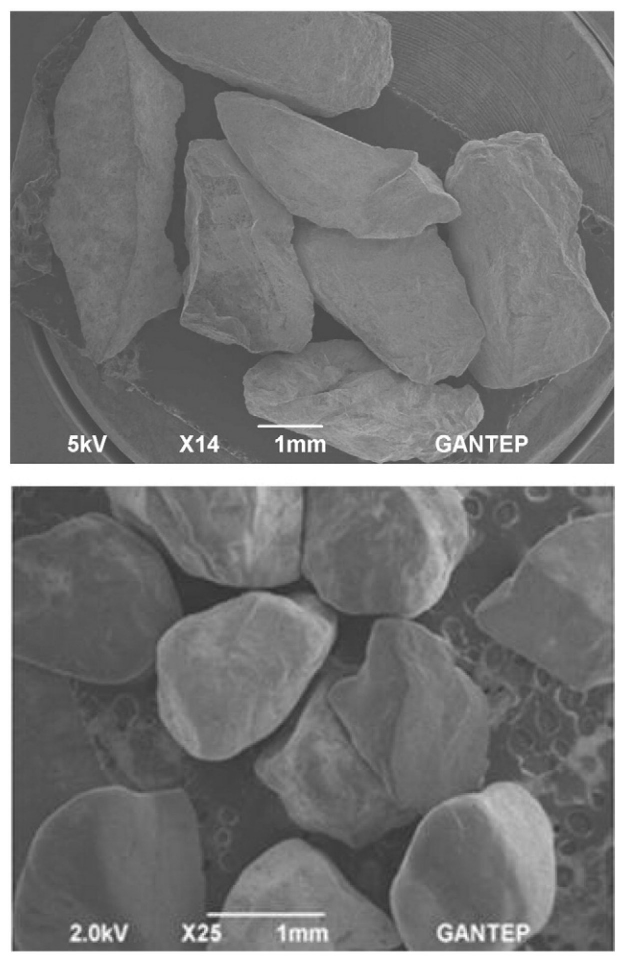

Fig. 4. SEM pictures of the (top) CSS and (bottom) NS used during the experimental study.