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Compressional behaviour of various size/shape sand–clay mixtures with different pore fluids

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ABSTRACT

Sand–clay mixtures can be considered as a composite matrix of coarser and finer particles. Nature of the interaction between coarser (sand) and finer (clay) particles can be demonstrated using intergranular void ratio (e_s), and transition fines content (FC_t). The common aspect of the intergranular void ratio equations is based on the determination of an empirical relationship between e_s and effective stresses (σ'), fines content (FC), and void ratio (e). However, there is a lack of theoretical basis for determining consistent e_s and FC_t values. This paper presents an investigation carried out to relate the various sizes (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 behaviour by determining e_s and FC_t values. Oedometer tests performed during this investigation indicate that the higher viscosity pore fluid in a specimen could cause a lower compressibility, and the sand with lower roundness (R) and sphericity (S) values exhibit higher FC_t and C_{c-s} values.

1. Introduction

Most of the experimental works concerning stress–strain properties of granular soils studied the response of clean sands. However, researchers indicate that soils with clay and/or silt behave differently from soils containing clean sands. Traditionally, void ratio (e) has been utilized as one of the most significant state variables to predict some engineering properties (liquefaction potential, compressibility, stress–strain behaviour) of soils. However, recently published papers have indicated that void ratio is a confusing parameter for characterizing the behaviour of a clayey or silty sand. Therefore, intergranular void ratio (e_s) can be used as an alternative parameter to express the behaviour of such composite soils. Intergranular void ratio concept was proposed by Mitchell (1976) to identify the inactive clay content in a soil matrix. Kenny (1977) observed that the residual strengths of composite soil matrix, which is composed of crushed quartz and various clay minerals, depend on the relative volumes of clay mineral and quartz minerals. Lupini et al. (1981) indicated that residual shear properties vary as the clay content increases. Troncoso and Verdugo (1985) obtained similar results on the tailing sand with fines tested in cyclic triaxial apparatuses. Kuerbis et al. (1988) employed intergranular void ratio to understand the undrained shear strength behaviour. They estimated intergranular void ratio using the following equation (Eq. (1)).

$$e_s = \frac{V_T G_S \rho_W - (M - M_{silt})}{(M - M_{silt})} \tag{1}$$

where, e_s is the intergranular void ratio. Researches related to the influence of fines on overall stress–strain behaviour (Thevanayagam and Mohan, 2000; Chu and Leong, 2002), liquefaction potential (Koester, 1994; Vaid, 1994; Yamamuro and Covert, 2001; Thevanayagam and Martin, 2002; Yamamuro and Wood, 2004), and compressional characteristics (Yamamuro et al., 1996; Kumar and Wood, 1999; Chuhan et al., 2003) of composite soil matrices have been recently accelerated. For instance, Salgado et al. (2000) reported that fines entirely control the soil behaviour in terms of shear strength and dilatancy, when the fines content is more than 20%. Vallejo and Mawby (2000) found that shear strength of the clay–sand mixtures is fully controlled by the sand below 25% of fines content. Georgiannou et al. (1990) described an experimental investigation of the stress–strain behaviour of clayey sands, and observed that the effective stress paths in triaxial tests were almost same for similar intergranular ratio values. They had proposed an intergranular void ratio equation, which was simplified by Thevanayagam (1998), as shown in Eq. (2).

$$e_s = \frac{e + f_c}{1 - f_c} \tag{2}$$

where, e is void ratio, f_c is fines content. Following the study by Pitman et al. (1994) showing that e_s estimates would be more reasonable when

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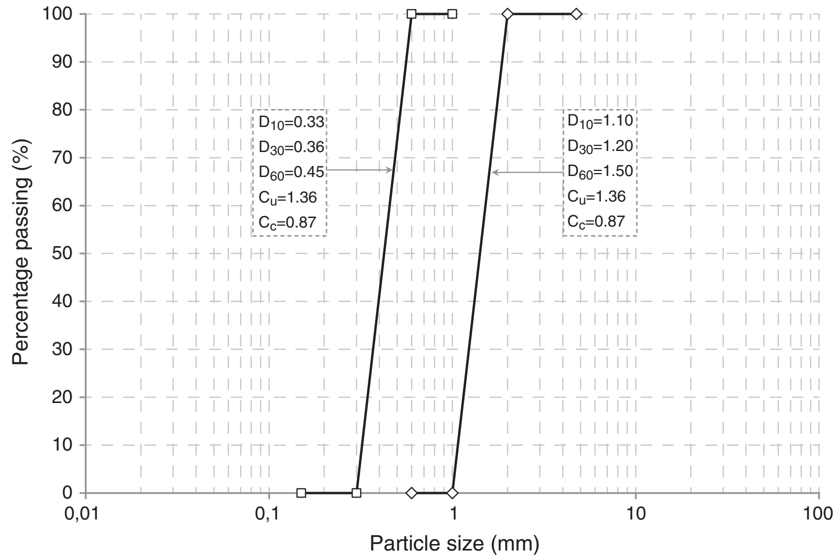

Fig. 1. Particle size distributions for the sands used during the experimental study.

the f_c is relatively low to the void space between the sand particles, Thevanayagam et al. (2002) suggested the use of a 'b' parameter at higher fines content relative to the void space (Eq. (3)).

$$e_s = \frac{e + (1-b) f_c}{1-(1-b) f_c} \quad (3)$$

where, 'b' represents the content of fines that is active in force structure. Thevanayagam (2001) proposed that 'b' depends on $C_{uc}C_{uf}^2/R_d$ [C_{uc} is the uniformity coefficient of coarser sandy materials, C_{uf} is the uniformity coefficient of finer nonplastic grains, and R_d is D_{50}/d_{50} (D = size of coarser sand, d = size of finer grains)]. Ni et al. (2004) proposed that 'b' depends on D_{10}/d_{50}. Yang et al (2006) proposed that 'b' is not a constant value for the sand they tested. Recently, Rahman and Lo (2008) suggested an empirical equation for 'b' depending on the basic characteristics from binary concept developed by McGeary (1961).

The influence of fines content on liquefaction potential (Lade et al., 1998; Naeini and Baziar, 2004) has been studied in the last two decades. The purpose of such investigations was mainly to quantify the effects of nonplastic fines on liquefaction potential of soils. Efforts have been made to develop correlations of the influence of fines on resistance to liquefaction potential and post-liquefaction strength. For example, Chang (1990) prepared by mixing a medium sand with a silt at different silt contents, and showed that at the same void ratio, cyclic strength of silty sand decreases with an increase in fines content. Whereas, the trend reverses and the strength increases with a much further increase in silt content. Xenaki and Athanasopoulos (2003) observed that for fines content from 0 to 44%, the liquefaction resistance of the soil with constant global void ratio decreases compared to that of the clean sand. However this trend is reversed for values of fines content more than 44%. Whereas, the liquefaction resistance of the mixtures varied monotonically when the intergranular void ratios were kept constant, and the values of fines content were increased. Thevanayagam (2007) demonstrated that, at the same void ratio, liquefaction resistance of sand with silt decreases with an increase in fines content (f_c) up to a threshold value (FC_t). Beyond this FC_t, interfines contacts become significant as the intercoarse contacts diminish, and the liquefaction resistance starts to be fully controlled by interfine contents only. The transition fines content (FC_t) range is around 20–30% for non-plastic fines (Koester, 1994; Polito and Martin, 2001), and less than 20% for plastic fines (Georgiannou et al., 1991). Influence of fines on the compression characteristics of composite soil matrix has also been studied by experimental researches. Yin (1999) stated the limitations of obtaining correlations of consolidation parameters (C_c, C_r, C_α) with fines (i.e., clay) content for reconstituted soil deposits. It was also demonstrated that internal angle of friction decreases with an increase in clay content for the reconstituted soils. Martins et al. (2001) studied on some aspects of the compressibility of a clayey sand. They observed that the fines in a composite soil matrix avoids a unique compression line. Consequently, they pointed out the requirement of a new framework for such soil which does not behave in a harmony with general compression behaviour in the literature. Monkul and Ozden (2007) employed a series of oedometer tests on reconstituted kaolinite–sand mixtures indicating that percentage of fines and stress conditions influence the compression characteristics. Performed direct shear tests by the researchers revealed that there is a close relationship between transition fines content and shear strength, which is harmonic with the oedometer test results. Cabalar (2010) investigated the transition fines content and intergranular void ratio on the response of micaceous soils in oedometer, triaxial, and resonant testing equipments. The effect of fine platy particles has been a very significant increase in void ratio, coupled with reduced strength, shear modulus, and increased compressibility, damping ratio values. In other researches, tests have been conducted on materials composed of platy fines within coarse bulky materials. Such as, Vermeulen (2001) observed that a 'clay-like' high volumetric compressional behaviour under oedometric and isotropic loading as the fines content increased. Clayton et al. (2004), and Theron (2004) have obtained similar results using mixtures of mica and bulky sand particles. It is seen that further investigations on the particle shape characteristics of composite soil matrix are required in order to gain insight regarding their effects on intergranular void ratio and transition fines content characteristics.

It has been long understood that particle shape characteristics have a significant effect on the engineering properties of soil matrix (Terzaghi, 1925; Gilboy, 1928; Lees, 1964, Olson and Mesri, 1970;

Table 1
Some properties of the sands used during the experimental study.

Sand	Size (mm)	e_{max}	e_{min}	G_s	C_u	C_c	ϕ (°)	R	S
TS	0.3–0.6	0.97	0.68	2.65	1.36	0.87	36°	0.43	0.67
	1.0–2.0	0.99	0.59	2.65	1.36	0.87	40°	0.43	0.67
CSS	0.3–0.6	1.0	0.65	2.68	1.36	0.87	36°	0.16	0.55
	1.0–2.0	1.1	0.57	2.68	1.36	0.87	48°	0.16	0.55

TS: Trakya Sand, CSS: Crushed Stone Sand, R: Roundness, S: Sphericity.