Soils and Foundations 2015;55(1):213–219

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Soils and Foundations

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Determination of the transitional fines content of sand-non plastic fines mixtures

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Received 7 December 2013; received in revised form 12 September 2014; accepted 21 October 2014
Available online 24 December 2014

Abstract

The transitional fines content is the boundary between fines-dominated and sand-dominated behaviour. Experimental and calculation methods for the determination of the transitional fines content of sand-non plastic fines mixtures are summarized based on former studies. Different methods have been applied to data from several published sources in order to make a comparison. The results indicate that the calculation methods, which use the property indices of the sand and fines, may not always predict the value of the transitional fines content observed in laboratory tests. These differences and their possible causes are discussed. The relative size of the fines and sand particles has been considered as a parameter which influences the value of the transitional fines content. The analysis indicates that when the ratio of large to small grain diameter is large enough, the value of the transitional fines content remains within a relatively small range.

Keywords: Sand; Non-plastic fines; Transitional fines content; Critical state soil mechanics; Property index

1. Introduction

The occurrence of silty sand around the world has led to much research on the influence of fines on sand behaviour; for example, Georgiannou et al. (1990), Lade et al. (1998) and Thevanayagam (2000) tested different combinations of sand and non-plastic fines, while more recently Carrera et al. (2011) examined the effect of the fines content on the behaviour of mine tailings, Dash et al. (2010) studied the liquefaction potential of a silty sand from a seismic region and Ke and Takahashi (2012) studied the internal erosion of a silty sand. In the case of mixtures of sand and non-plastic fines, simple categories of behaviour can be identified based on the fines content. At low fines contents, the soil behaviour is mainly controlled by the host sand ("sand-dominated"), but when the fines content exceeds a certain value, the behaviour is mainly controlled by the fines ("fines-dominated"). Thevanayagam and Mohan (2000) proposed that at low fines contents, the sand particles are in contact with each other and form the major skeleton of the soil, while the fines fill the voids between the sand particles and only make a secondary contribution to the overall soil behaviour. In this case, the fines can be ignored in the force chain and the soil state should depend on the stress and the intergranular void ratio, e_s, defined as

$$e_s = \frac{V_v + V_f}{V_s} \tag{1}$$

where V_v, V_f and V_s are the volumes of the voids, fines and sand particles, respectively. Eq. (1) can be rewritten in terms of the specific gravities of the soils, the fines content and the overall void ratio as follows:

$$e_s = \frac{e(G_f - G_f f_c + G_s f_c) + G_s f_c}{G_f(1 - f_c)} \tag{2}$$

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Peer review under responsibility of The Japanese Geotechnical Society.

http://dx.doi.org/10.1016/j.sandf.2014.12.017
0038-0806/

where e is the global void ratio of the soil, f_c is the fines content (as a decimal), and G_s and G_f are the specific gravities of the sand and the fines, respectively. At high fines contents, the sand particles may only make a secondary contribution to the soil behaviour. In this case, the sand may be ignored in the force chain and the soil state should depend on the stress and the interfines void ratio, e_f, defined as

$$e_f = \frac{V_v}{V_f} \tag{3}$$

Eq. (3) can be rewritten as

$$e_f = \frac{e(G_f - G_f f_c + G_s f_c)}{G_s f_c} \tag{4}$$

If the sand and the fines originate from the same parent rock, and have a similar composition, we can ignore the difference between G_s and G_f, so that Eqs. (2) and (4) can be simplified to (Thevanayagam and Mohan (2000))

$$e_s = \frac{e + f_c}{1 - f_c} \tag{5}$$

$$e_f = \frac{e}{f_c} \tag{6}$$

The boundary between low fines content and high fines content is the transitional fines content, FC_t. It should represent a changing point in the behaviour of the soil. In the following, different methods to determine the transitional fines content, which are based on experimental data and theoretical considerations, are applied to published data and compared. The existence of a unique FC_t is discussed.

2. Determination of FC_t using experimental data

Data available in the literature were used to analyse the influence of the fines content on the behaviour of sand-non plastic fines mixtures. Details of the sands and the fines are summarized in Table 1 with references. Several studies have indicated the existence of a transitional fines content at which the maximum and the minimum void ratios, e_{max} and e_{min}, show a trough (Fig. 1). Lade et al. (1998) proposed the explanation that at low fines contents, the fines fill the voids between the sand particles without breaking the sand particle contacts, causing a reduction in the void ratio. With an increase in the fines content, the voids are progressively filled with fines until they are fully filled. At this point, the void ratio reaches its lowest point and the fines content is equal to the transitional fines content. As the fines content increases further, the sand particles start to separate and the void ratio increases. The transitional fines content determined from the e_{max} curve, however, is not always the same as that determined from the e_{min} curve; and therefore, these curves may only give an indication of the possible range in which the true value for FC_t may exist.

Physicists have been working on similar problems trying to estimate the minimum void ratio of granular assemblies in terms of the packing density and the solid volume fraction. Experimental data show that a maximum solid volume fraction of 0.64 is typically achieved with hard same-sized spherical balls, such as ball bearings (e.g., Scott and Kilgour, 1969). A higher volume fraction of 0.70 can be reached if small crystal-like clusters of spheres are cyclically sheared (Radin, 2008). This value is close to the theoretical densest possible packing of same-sized spherical balls that can be calculated as a volume fraction of $(\pi/\sqrt{18}) \approx 0.74$. In two-component size mixtures of broken solids, the intergranular void ratio is not affected if the ratio of large to small diameters, R, is more than about 100 (Furnas, 1931). For ratios $R = 10$–15 (i.e., for the magnitude of the mixtures used in this paper), the change in minimum void content should be about 75% of the change that would occur with infinitely small fine particles. The data shown in Fig. 1 suggest a smaller reduction in e_{min} of 30–50% compared with pure sand. This may be due to the different shapes of particles tested, but the lack of quantifiable information on the grain shapes makes it difficult to ascertain.

Table 1
Characteristics of sands and fines used in the analysis, with references.

Reference	Sand					Fines					R*
	Origin	e_{max}	e_{min}	d_{50} (mm)	G_s	Origin	e_{max}	e_{min}	d_{50} (mm)	G_s	
Dash et al. (2010)	Clean Ahmedabad sand	0.68	0.42	0.375	2.65	Non-plastic quarry dust around Bangalore	1.632	0.652	0.037	2.67	10
Carrera et al. (2011)	Sand from Stava tailings	1.068	0.615	0.21	2.721	Fines from Stava tailings	–	–	0.025	2.828	8.4
Thevanayagam et al. (2002)	F55 Foundry sand	0.8	0.608	0.25	–	Non-plastic crushed silica fines	2.1	0.627	0.01	–	25
Yang et al. (2006)	Hokksund sand	0.949	0.572	0.44	2.712	Chengbei non-plastic silt	1.413	0.731	0.032	2.739	14
Polito and Martin (2001)	Monterey no. 0/30 sand	0.821	0.631	0.43	–	Fine-grained portion of Yatesville silty sand	1.723	0.727	0.03	–	14
Papadopoulou and Tika (2008)	Clean sand M31 from Assyros in Greece	0.841	0.582	0.30	2.649	Non-plastic silt from Assyros in Greece	1.663	0.658	0.02	2.663	15
Xenaki and Athanasopoulos (2003)	Sxinias-Marathon sand	1.04	0.66	0.12	–	Sxinias-Marathon fines	1.71	0.66	0.02	–	6
Cabalar (2010)	Leighton Buzzard sand	0.79	0.52	0.90	2.65	Mica	3	2.2	0.13	2.90	7

R* ratio of large (coarse) particle diameter to small (fines) particle diameter.