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The effect of fines plasticity on monotonic undrained shear strength and liquefaction resistance of sands

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ABSTRACT

The paper presents results of an investigation into the effects of fines plasticity on the undrained monotonic and cyclic response of sands. Monotonic and cyclic triaxial tests on mixtures of sand with 5% and 15% fines content were performed. Non-plastic and plastic fines of varying plasticity were used. At a given fines content, confining effective stress and void ratio, the results show that the undrained shear strength and cyclic resistance decrease with increasing plasticity index of fines up to a threshold value. Above this threshold value, the undrained shear strength and cyclic resistance increase with increasing plasticity index of fines. This pattern of behaviour was also reflected in the excess pore water pressure rise during both monotonic and cyclic loading. The mechanism controlling the behaviour of sands with fines and the implications of the test results to the engineering practice are finally discussed.

1. Introduction

Liquefaction of sandy soils under both static and cyclic loading conditions is considered one of the major causes of damage to earth structures and foundations. Up to date, a great research effort has been devoted to improve the knowledge concerning the liquefaction characteristics of natural soil deposits and the ability to predict the nature and the extent of liquefaction phenomenon. Most of the research effort has been focused on the behaviour of clean sands and sands containing non-plastic (NP) fines ([17,33,40,41,45,47,30]) mainly due to the fact that sands with plastic fines are considered to present lower liquefaction potential [16].

Numerous case histories, however, concerning failures due to earthquake-induced liquefaction are correlated with the presence of sands containing plastic fines. Kishida [19] reported that soils with 10% clay content liquefied during Mino-Owar, Tohankai, and Fukui earthquakes, in Japan. Chang [8] summarised liquefaction ground failures caused by the 1976 Tangshan Earthquake in China and concluded that sands containing plastic fines are not immune to liquefaction. Youd et al. [44] reported that silty sands containing as much as 10% clay liquefied at the Kornbloom site in the Imperial Valley, during the 1981 Imperial Valley earthquake in USA. Miura et al. [24] also reported the liquefaction of sands with up to 48% fines and 18% clay fraction during the 1993 Hokkaido Nansai-Oki earthquake.

Moreover, existing semi-empirical SPT and CPT based procedures for the assessment of the undrained residual strength [36,38] and liquefaction resistance ([26]; Eurocode [9]) of sands consider only the presence of NP fines, implying that sands with plastic fines would be unlikely to liquefy, despite the extensive opposite field evidence mentioned above.

Thus, the aim of the work presented in this paper is the investigation of the influence of fines plasticity on the undrained monotonic and cyclic behaviour of sands containing fines. For this purpose, undrained monotonic and cyclic triaxial tests were performed on mixtures of sand with 5% and 15% fines content. The results of the tests are presented and discussed. Finally, the practical implications of the tests results for the evaluation of the undrained shear strength and cyclic resistance of sands with fines are discussed.

2. Background

It is well known that fabric, density, and stress state are the dominant parameters influencing the mechanical behaviour of granular soils [22]. Numerous studies have reported that the behaviour of granular soils is greatly influenced by the specimen preparation technique due to the fact that different specimen

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Table 1
Physical properties of materials used.

Soil	Specific Gravity G_s	Max. Void ratio e_{max}	Min. Void ratio e_{min}	Mean Diameter D_{50} (mm)	Coefficient of Uniformity C_u	5 μm < % < 75 μm	% < 5 μm	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI (%)
Sand (S)*	2.649	0.841	0.582	0.30	1.3	–	–	–	–	NP
Assyros Silt*	2.663	1.663	0.658	0.02	7.5	88	12	–	–	NP
Speswhite Kaolin	2.610	–	–	–	–	10	90	65	30	35

* [29]

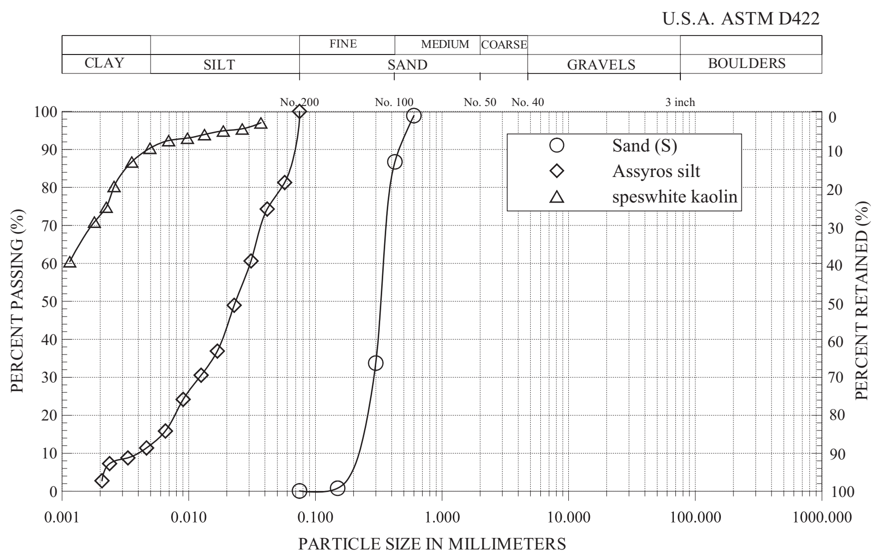

Fig. 1. Grain size distributions of sand (S), Assyros silt, and speswhite kaolin, used in the tests.

Table 2
Physical properties of tested mixtures.

Mixture	Fines content f_c (%)	Fines Plasticity Index PI (%)	Fines Liquid Limit LL (%)	Fines Plastic Limit PL (%)	Specific Gravity G_s	Max. Void ratio e_{max}	Min. Void ratio e_{min}	Mean Diameter D_{50} (mm)	Coefficient of Uniformity C_u	Fines composition (%)		Silt content 5 μm < % < 75 μm	Clay content % < 5 μm
										Assyros silt	Speswhite kaolin		
SF5 (NP)*	5	NP	–	–	2.650	0.762	0.544	0.30	1.6	5	0	4.4	0.6
SF5 (PI=6)	5	6	28	21	2.649	0.728	0.461	0.30	1.6	4.6	0.4	4.1	0.9
SF5 (PI=12)	5	12	30	18	2.649	0.797	0.554	0.30	1.6	3.85	1.15	3.5	1.5
SF15 (NP)*	15	NP	–	–	2.651	0.750	0.380	0.30	8.8	15	0	13.2	1.8
SF15 (PI=12)	15	12	30	18	2.649	0.808	0.506	0.30	10	11.55	3.45	10.5	4.5
SF15 (PI=22)	15	22	41	19	2.647	0.872	0.496	0.30	18.8	6.9	8.1	6.9	8.1
SF15 (PI=30)	15	30	56	26	2.645	1.120	0.648	0.30	136.4	2.55	12.45	3.5	11.5
SF15 (PI=35)	15	35	65	30	2.643	1.215	0.695	0.30	187.5	0	15	1.5	13.5

* [29]

preparation techniques result in different fabrics [25,39]. In specimens, prepared by air or water pluviation, particles are allowed to fall freely and the inclination of the forces normal to the tangential planes at their contact points is close to the vertical direction; whereas elongated particles are preferentially oriented in the horizontal direction with their long axes [27]. On the other hand, specimens formed by moist tamping have more isotropic initial fabric regarding the distribution of the preferred orientation of particle's long axes [43]. None of the specimen preparation techniques can reproduce the natural soil fabric in all circumstances. Water-pluviation is considered to better simulate sand fabric of alluvial and hydraulic deposits, whereas moist tamping may better represent sand fabric when sand is dumped as a fill material.

Density can be expressed through the following parameters: (a) void ratio, e, (b) relative density, D_r (%), and (c) intergranular void ratio, e_g. The intergranular void ratio expresses the relative contribution of sand fraction on the behaviour of the mixture and is given by the following equation [23]:

$$e_g = \frac{V_{FINES} + V_V}{V_{SAND}} = \frac{f_c + w \cdot (G_{SF}/S_r)}{(1 - f_c) \cdot (G_{SF}/G_{SG})} \qquad (1)$$

where V_{FINES} is the volume of the fines (silt and clay) particles, V_V is the volume of the voids, V_{SAND} is the volume of the sand grains, f_c is the fines content, w is the water content of the specimen, G_{SF} is the specific gravity of fines particles and G_{SG} is the specific gravity of the sand grains. For saturated specimens ($S_r = 100\%$) and considering that $G_{SF} \approx G_{SG}$, the intergranular void ratio of the