Effect of Soil Characteristics on Shear Strength of Sands

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Abstract. The paper presents the results of a laboratory investigation into the influence of (a) mineral composition and angularity of sand grains and (b) fines type and content on the strength parameters of sandy soils tested at various densities and normal stresses in a direct shear apparatus under drained conditions.

Keywords: Shear strength · Critical state · Dilatancy · Sands · Fines Relative density

1 Introduction

The shear strength of sand is usually characterized by the peak friction angle, φ'_{max}, and the critical state friction angle, φ'_{crit}. The latter is considered when the sand is shearing at constant volume conditions and is generally lower than the former, especially in the case of high relative density, D_r. Bolton (1986) investigated the effect of D_r on the dilatancy related component of strength, φ'_{max} - φ'_{crit}, of clean sands and suggested simple correlations for the estimation of the friction angles. The purpose of the work presented in this paper is to clarify the effect of sand grains characteristics and fines type and content as well as relative density on the shear strength parameters of sands by means of direct shear tests, which were carried out in the Laboratory of Geotechnical Engineering of University of Thessaly.

2 Tested Soils and Testing Procedure

The tested soils fall into three groups: clean sands of similar grading (group 1), sands containing non-plastic fines (group 2) and sands containing plastic fines (group 3). Sands A and B are comprised totally of quartz whereas sand C is comprised of 77% quartz and 23% feldspar. Only sand B consists of angular grains. Both group 2 and group 3 were prepared by mixing the same clean sand A with a non-plastic sandy silt with D_{50} = 0.04 mm and Cu = 6 (group 2), or kaolin with PI = 18% (group 3). Table 1 summarizes the physical properties of the tested soils.

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Table 1. Physical properties of tested soils

Group	Tested soil	FC (%)	CF (%)	Cu	D_{50} (mm)	D_{max} (mm)	e_{min}	e_{max}	G_s	USCS
(1)	A	–	–	1.8	0.35	0.85	0.645	0.907	2.659	SP
	B	–	–	1.8	0.38	0.50	0.600	0.994	2.659	SP
	C	–	–	1.3	0.21	0.35	0.617	0.988	2.650	SP
(2)	A-S-1	8	2	2.5	0.32	0.85	0.606	0.879	2.657	SP-SM
	A-S-2	17	2	9.1	0.31	0.85	0.414	0.687	2.653	SM
(3)	A-K-1	11	4	7.3	0.31	0.85	0.568	0.820	2.657	SP-SM
	A-K-2	18	8	11.4	0.30	0.85	0.412	0.664	2.652	SC-SM

FC: Fines content < 75 μm CF: Clay fraction < 2 μm Cu: Coefficient of uniformity.

The specimens had dimensions of D = 62.5 mm and H = 25 mm, and were prepared at optimum moisture content directly into the shear box using the undercompaction method (Ladd 1978). Specimens of uniform structure at various densities were prepared from each soil and tested in the direct shear apparatus at a range of normal stresses σ'_v = 50–400 kPa under drained conditions according to ASTM D3080 (2011). The strength parameters at both peak and critical state were determined in order to evaluate the dilatancy of the tested sands.

3 Results

Due to the space restriction, the results only at σ'_v = 100 kPa are presented in Figs. 1, 2 and 3 for soil groups 1, 2 and 3 respectively. The results show the variation of peak angle, φ'_{max}, and critical angle, φ'_{crit}, of soil resistance as well as the dilatancy related component of strength, φ'_{max} - φ'_{crit}, with relative density, D_r. The values of φ′ were determined based on the results for the whole range of the applied σ'_v (50–400 kPa) using the Mohr – Coulomb criterion. The linear correlations between the above parameters are also given. For soil group 3 (sands with plastic fines) the variation of cohesion, c′, and shear stress, τ, with relative density, D_r, is also presented.

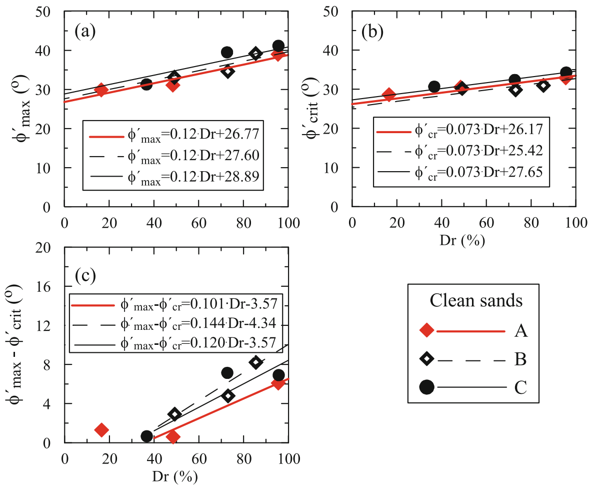

Fig. 1. Variation of (a) peak friction angle, φ'_{max}, (b) critical friction angle, φ'_{crit}, and (c) φ'_{max} - φ'_{crit} with relative density, D_r, for soil group (1) at $\sigma'_v = 100$ kPa (Apostolaki 2016).

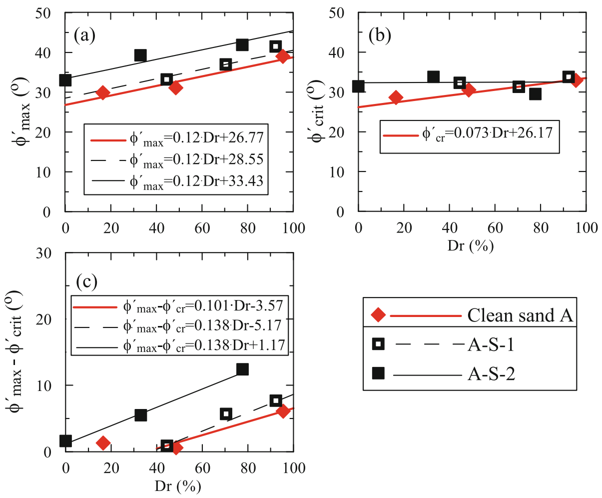

Fig. 2. Effect of non-plastic fines on the variation of (a) peak friction angle, φ'_{max}, (b) critical friction angle, φ'_{crit}, and (c) φ'_{max} - φ'_{crit} with relative density, D_r, for soil group (2) at $\sigma'_v = 100$ kPa (Tyri 2016).

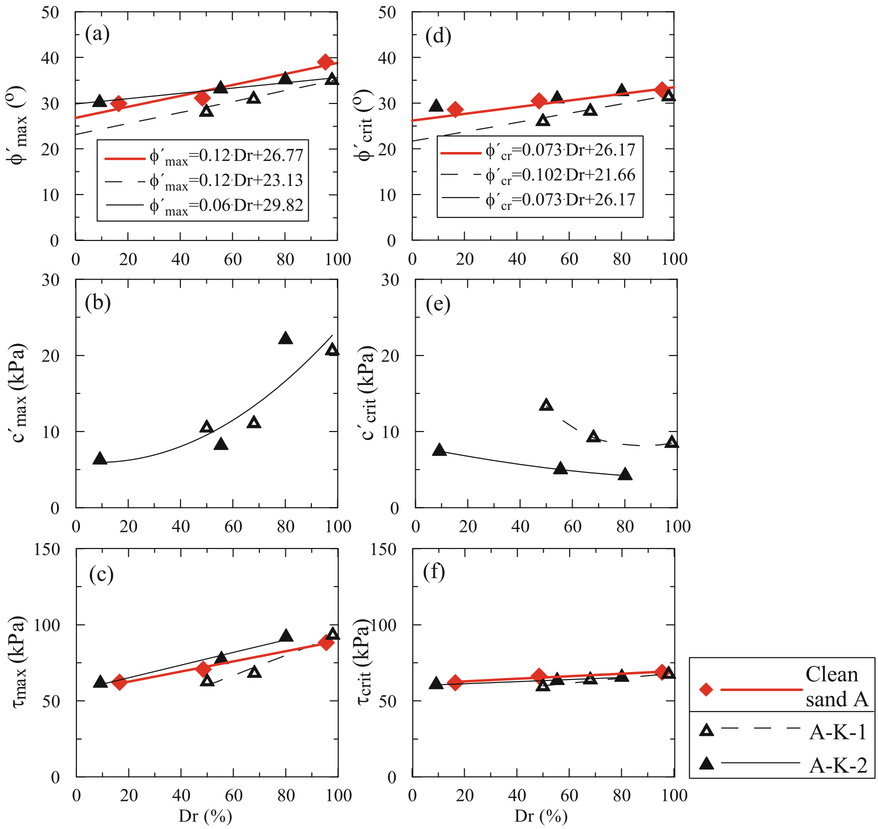

Fig. 3. Effect of plastic fines on the variation of (a) peak friction angle, φ'_{max}, (b) peak cohesion, c'_{max}, (c) peak shear strength, τ_{max}, (d) critical friction angle, φ'_{crit}, (e) critical cohesion, c'_{crit}, and (f) critical shear strength, τ_{crit}, with relative density, D_r, for soil group (3) at $\sigma'_v = 100$ kPa (Koulaouzidou 2016).

4 Conclusions

The following conclusions can be drawn from the results presented herein:

(a) Simple correlations between D_r and φ'_{max}, φ'_{crit} and φ'_{max} - φ'_{crit} are supported for the tested soils, showing the increase of φ′ values with the increasing D_r, especially in the case of φ'_{max} - φ'_{crit}.

(b) The differences among the φ′ values of the tested clean sands at the same level of D_r are small due to their similar gradings and may be attributed to the effect of grain angularity and soil mineralogy, e.g. the higher values are pertaining to sand containing portions of feldspar or angular grains.

(c) For the mixtures of sand with non-plastic fines, an increase of φ′ values is observed with the increase of FC and D_r, except for φ'_{crit} value which remains constant.

(d) For the mixtures of sand with plastic fines, a development of cohesion, c′, which depends on D_r, is observed in both peak and critical states but in an opposite way, whereas φ′ values increase with increasing D_r. The effect of FC on strength components, c′ and φ′, is not clear.

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