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Influence of Grain Size Distribution on Critical State of Granular Materials

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Summary. This paper aims to investigate the influence of grain size distribution (GSD) on the critical state of Hostun sand. Drained triaxial tests were conducted on saturated specimens with different GSD ($C_u=1.4, 5, 10, 20$) under different confining pressures (100, 200, 400 kPa). The experimental results highlight that the critical state of the tested sand predominantly depends on its GSD.

Keywords: grain size distribution, critical state, triaxial tests.

1 Introduction

Since the pioneering work of Roscoe and Schofield (1958), the critical state concept has been developed and largely regarded as a fundamental framework for the development of constitutive models for soils. Based on this concept, lots of studies have been conducted on crushable soils (see for example Daouadji and Hicher, 1997), which have shown that the GSD of the soil changes during its lifetime by crushing of particles, leading to an increase of the coefficient of uniformity C_u . These changes influence the basic constitutive properties of the material, in particular the properties such as the critical state which is dependent on the particle size distribution at a given point of the loading history. As the fine content increases and the soil becomes better graded, it has been experimentally shown that the critical state line moves downwards (Biarez and Hicher 1994). Based on these new findings, some new models for crushable soils have been developed (Daouadji et al. 2001). Also, by means of discrete element method (DEM), Wood and Maeda (2007) showed the dependence of the critical state of granular materials on their initial GSD. However, so far, no detailed experimental data confirm these findings obtained by DEM.

This study aims to investigate the influence of initial particle GSD of a granular material on its mechanical behavior in terms of critical state and stress-strain relationship. A series of drained triaxial tests were performed on specimens of Hostun sand. Due to the high strength of Hostun sand particles, grain breakage may be considered as being negligible during shearing under testing loading conditions, permitting to maintain the same GSD all along the mechanical loading.

2 Testing Program

Samples with different GSD, corresponding to different coefficients of uniformity C_u (d_{60}/d_{10}) varying from 1.4 to 20, with identical mean grain size d_{50} , were tested (Fig.1a). Three effective confining pressures (CP = 100kPa, 200kPa, 400kPa) were applied. All specimens were prepared by the moist tamping method (Ishihara 1993) in order to obtain very loose specimens.

Fig. 1. (a) Particle size distribution; (b) GSD ($C_u=1.4$ CP=400 kPa) before and after test

In order to confirm the assumption of no particle breakage occurring during testing, grain size distributions were systematically measured at the end of each test. As an example, the grain size distribution of one specimen ($C_u = 1.4$ and confining pressure = 400 kPa), most prone to grain breakage among all the tested specimens, before and after the test is presented (Fig.1b). It shows that no global grain occurred; only a small amount of fines was produced by attrition.

3 Results and Discussions

Responses of specimens with different initial void ratios under triaxial compression at the same confining pressure are shown in Fig.2. It can be observed that the two specimens have the same tendency of contracting until the critical state is reached. However, the denser specimen appears less contractive. Although the initial void ratios are different, both specimens reach the same ultimate strength, corresponding to a same final void ratio at critical state.

The comparison of the critical state lines (CSL) obtained for different C_u (1.4, 5, 10 and 20) in the $p'-q$ plane is presented in Fig.3a. It can be concluded that the tested specimens exhibit a unique critical stress ratio ($M = q/p'$) upon compression regardless of GSD, except for the case of $C_u = 20$ which shows a slight deviation with higher maximum stress ratio. The uniqueness of the critical stress ratio confirms that the shear resistance is not influenced by the change in GSD (Bandini and Coop, 2011). The differences obtained for C_u equals 20, may be due to the heterogeneity of the specimens during preparation, resulting in higher void ratio in the upper part of the sample due to some segregation of the finer part.

Fig. 2. Mechanical response of specimen with different e_0

The CSL in the e - $\log p'$ plane for specimens with different C_u is presented in Fig.3b. It can be found that the location of the CSL varies with the change of C_u . The higher the C_u value, the lower the location of the CSL. In other words, a well graded material has a smaller void ratio at critical state than a badly graded one.

Fig. 3. (a)Critical state lines in p' - q space; (b) Critical state lines in e - $\log p'$ space

4 Conclusions

Although the factors influencing the critical state of soils have been widely investigated by means of numerical and experimental approaches, there is still a lack of detailed experimental data addressing the influence of the grain size distribution (GSD) on the critical state of sandy soils. Therefore, the objective of this

experimental study was to investigate the influence of initial GSD on the mechanical properties of non-crushable soils. A series of conventional consolidated-drained triaxial compression tests were carried out on loose saturated Hostun sand specimens with different coefficients of uniformities C_u (1.4-20). This sand could be regarded as non-crushable under loading conditions used in this study. The experimental results highlight that the critical state of the tested specimens are significantly affected by the changes in GSD. A higher value of C_u leads to a lower location of the critical state line (CSL) in the e - $\log p'$ plane while the CSL in the p' - q plane appears unique regardless of the value of C_u . In other words, the GSD affects the void ratio at critical state but not the ultimate shear strength or friction angle at critical state.

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