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MONOTONIC BEHAVIOUR OF SAND UNDER TORSIONAL LOADING WITH DIFFERENT CONFINE STRESS

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ABSTRACT: This study assessed the effects of anisotropy in sands with various confining stresses. The tests conducted in this research include 20 hollow cylinder torsion shear tests under torsional loading conducted on Tehran sand with high angularity. The confining stresses of the samples were 100, 200 and 400 kPa, and the effect of the inclination angle of the major principal stress to the vertical axes was also studied. In each confine stress three inclination angle 15, 30 and 60 degrees were applied. According to the results, an increase in the alpha will result in a more contractive behavior in the sands. The effect of anisotropy also becomes more obvious, as the confining stresses increases; however, it was found that the mechanical properties of sands changed markedly with confining stress. To explain the effect of particle shape on the mechanical behavior of sand, with its increase the soil sample behaved in an isotropic manner and the shear strength of the sample decreases.

Keywords: Sand, Strength, Anisotropy, Confining stress

1. INTRODUCTION

The stress-strain behavior of sands under monotonic loading has been the subject of various studies in the past [1-3]. Key parameters-such as density, grain size distribution, particle shape and mineralogy, a method of sample preparation, the direction of loading, and anisotropy that affect the behavior of a sand under monotonic loading have been presented widely [3-6].

In addition, Extensive studies have been focused on the effects of inherent and induced anisotropy on the behavior of clean sand [7-9].In some geotechnical problems, such as the bearing capacity of shallow foundations on a sand ground, the confining stress dependency of sand mechanical behavior plays an important role as a stress level effect.

In the geotechnical literature, a large number of intensive experimental studies have been devoted to the induced anisotropy of granular material. First, the conventional triaxial apparatus was largely used by Poorooshasb, et al. [10], Poorooshasb, et al. [11], Tatsuoka and Ishihara [12], Ishihara and Okada [13] and Vaid, et al. [14], among others, used to investigate the effects of stress-induced anisotropy on the subsequent drained and undrained behaviour of dense sand. One of the objectives was to recognize the yield surface within the light of the elastoplasticity framework. Therefore, in the following decades, with advances in measurements and control techniques, complex machines such as the true triaxial, by Arthur and Menzies [15]; hollow cylinder torsional shear (HCTS) by Hight, et al. [16]; Khayat, et al. [1]; and plane strain machines by Park, et al. [17], were used to further explore the role of induced anisotropy, principal stress rotation and intermediate principal stress.

The mechanical properties of sands change notably with a variation of the confining stress. Sugiura, et al. [18]were investigating confining stress dependency of mechanical properties of sands. From their test results, it was found that the mechanical properties of sands changed very markedly with confining stress, and the degree of confining stress dependency diverges with the primary properties.

In this paper, the effect of initial confining stress and effect of the inclination angle on sand behavior has investigated The tests was conducted on Tehran sand (TS), with high angular grains, The effective confining stress was performed in 100, 200 or 400 kPa. In addition, the effects of the inclination angle of the major stress were investigated.

2. EXPERIMENTAL PROCEDURE

2.1 Material Properties

The materials employed in this study was Tehran sand (TS) with angular grains, The grain size distribution curves for sand is given in Fig. (1), which indicates that influence of particle shape alone is isolated without introducing a possible additional variable in the form of grain size distribution.

Results of the XRD scans of sands indicate that quartz as the main phase is the dominant mineral (>75%)among analyzed sands. The minor amount contains Palygorskite and Kaolinite (<10%). The minor phases Kaolinite (Table.1).

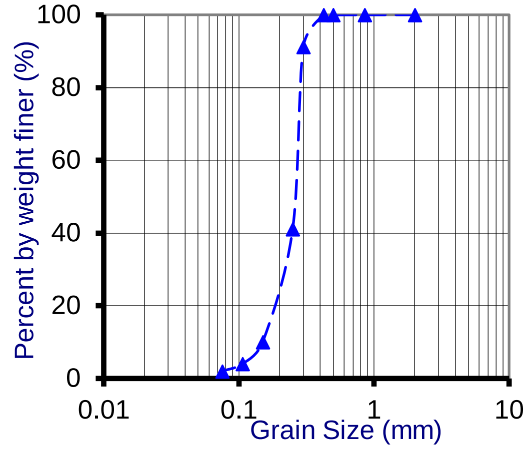

Fig.1 Grain size distribution curves of the Tehran sand.

Table1 Results of semi-quantitative bulk XRD analysis.

Sample No	Main Phase	Minor phase	Trace Phase
Tehran	quartz	Kaolinite	-

In addition one of the important factors in experiments on the sands under high pressure is particle's fracture. If the particles of the sands are broken, under load, the grain size distribution of the sand is changed. Hence, to the assessment of the particle fracture, two direct shear tests with 64 kg load (equal 900 kPa) were performed for each type of the sands. The weight of the sands was passed through the sieve No.40 & 100 which measured before and after the test. Results indicated that only one percent of the sand was fractured during the test, which can be neglected. The physical characteristics of studied sand were measured (Coefficient of curvature and uniformity respectively 1.22 and 1.69)

2.2 Maximum and Minimum Void Ratios of Sand

Kandasami and Murthy [19] based on their experimental results, indicated that the influence of sand mechanical response is a function of the deviatoric stress, relative density and confining stress. Some researcher has extensively described the non-coaxial behavior of sand under various stress paths through a series of HCTS tests [1, 16, 19]. The non-coaxial behavior was found to depend on the type of sand, relative density of the sample and on the direction of stress increment, and was also found to decrease with increasing strains[20].

An effective factor in the general behavior of saturated sands in monotonic loading is soil relative density $\left(D_r = \left(e_{\max} - e\right)/\left(e_{\max} - e_{\min}\right)\right)$, which is a factor that indications the sample's specifications at the end of consolidation stage. The samples prepared at low densities display contractive behaviors in the drained tests; this behavior causes excess pore water pressure in undrained tests, which decreases the effective confined stress. The change of stress-strain from the softening to hardening states is related mostly to the relative density, which is observed and reported by several researchers such as Bishop [21], Castro [22], Castro, et al. [23]and Seed and Idriss [24].

2.3 Testing Apparatus and Method

To investigation, the inherent anisotropy, a hollow cylinder torsional shear (HCTS) device is used. For a better investigation of the post-peak response, the device can perform tests with both stress and strain controls. A closed loop control is applied to the machine to handle any type of desired stress history including major principal stress rotation and intermediary stress ratio. Four electrical/pneumatic [E/P] transducers are used to control the pressure of the inner and outer cell pressures in addition to the torsion and axial load pneumatic actuators. The use of an alternative DC motor for torsional strain control test enables the study of the post-peak behavior. In the case of our tests, the motor is utilized because strain control is essential to study the softening response. The motor speed in all of the tests remains constant and equal to one degree per min. Eleven transducers are adjusted to measure the different factors constantly: three water pressure sensors, two for the inner and outer cell pressures and one for the pore pressure; one vertical dislocation sensor to measure axial strain and one rotation angle sensor to measure torsional strain; two differential pressure sensors; two axial and torsional stress sensors; and finally, two limit switch sensors are set up. A computer program is utilized to control all of the test procedures by means of a PID control algorithm. A data logging device is the last part of the control system. The sample dimensions were 16 cm in height, 5 cm in inner diameter and 8 cm in outer diameter.

The maximum inclination of the principal stress (α^{o}), initial confining stress and particle shape are considered the critical parameters in this research. The intermediate stress parameter (b)is constant (= 0.5), for avoid or more variable parameters in tests.

2.1 Experimental Program

For sample preparation, the proper amount of sand is deposited into a split mold through a funnel with a long tube after a molding vacuum of 5 kPa is applied to the sample and the split mold is removed. Then the cell parts are assembled. Carbon dioxide

(CO_2) and de-aired water are passed through the sample in their saturated states. The circulating time for the CO_2 that is used in the tests conducted by Zlatovic and Ishihara [25] was 30 min for clean sand. This method is applied in the present study. After circulation of the CO_2, the de-aired water enters from the bottom similar to the CO_2, in the opposite direction of gravity and seeps into all of the voids in the sample. The saturation procedure continues as the confining stress increased, and the pore water pressure is measured in several steps. If the B-value exceeded 0.95, then the sample is supposed to be wholly saturated. At this time, the saturation stage is completed and the sample should be consolidated. Since all of the tests conducted in this research are of the Consolidated Undrained (CU) type, all drainage valves should be opened during consolidation and connected to the system. The amount of water discharged from the sample during consolidation can be measured by reading the burette numbers at the beginning and end of this stage. After consolidation, the shear stage starts with one degree per minute, which is the lowest speed can be applied to the system. During the shearing step, the pore pressure is almost uniform.

3. RESULTS

The stress-strain behavior of sands under monotonic loading has been the subject of various studies in the past. Key parameters-such as density, grain size distribution, particle shape and mineralogy, a method of sample preparation, the direction of loading, and shearing mode which can affect the behavior of a sand under monotonic loading have been investigated and reported widely [4, 26].

The main goal of this research is to study the effect of confining stress upon anisotropy features as well as various inclination angle (α^{o}) on the sand's behaviors. To avoid of another variable parameters effect on tests, the intermediate stress parameter is constant (b = 0.5). In the laboratory, the protocol for reconstitution of a sand sample generates an inherently anisotropic fabric structure due to the orientation and morphology of the particles [27]. As a result of different inherent anisotropy of investigated sands, reaching the same void ratio in the similar preparation method of samples is difficult. In equal confining stress, we reach similar relative density in sample sands. For this reason, ASTM 4253 and ASTM 4254[28] (ASTM, 2006b)are used to measure the minimum void ratio (e_{min}) (densest state) and maximum void ratio (e_{max}) (loosest state) respectively.

Test results of stress-strain and effective stress path curves are presented in Figs (2-4). According to these curves, the behavior of the sample are similar to those of dense sands based on the classification of undrained sand behavior in most conducted tests, which the results are in good agreement with Yoshimine, et al. [8].The results also indicate that the samples strength decrease with increasing α^{o}.

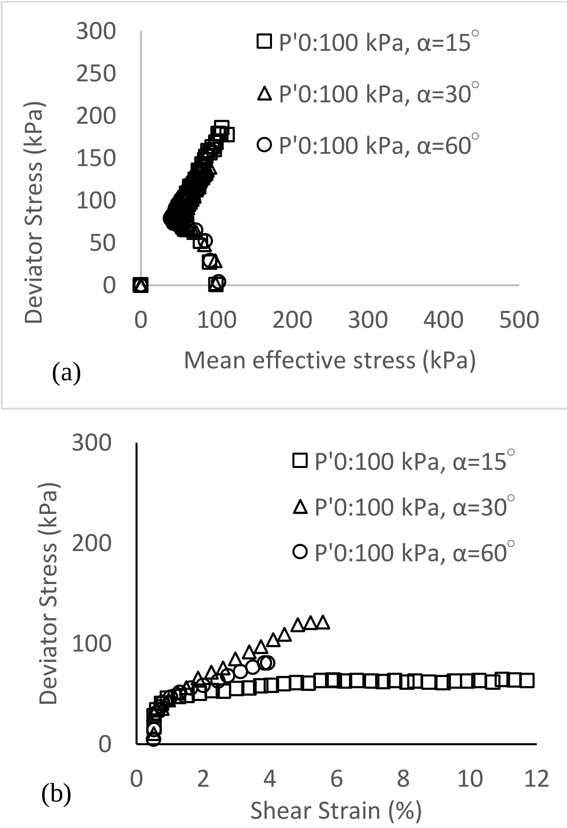

Fig. 2 (a) Stress path and (b) stress-strain curves in Tehran sand subjected to an initial effective stress of 100 kPa.

3.1 The Effect of Inclination Angle (α°) on the Sand's Behaviours

In Figs (2-4), the strength of samples in phase transformation point is reduced as α^{o} increases in, which indicates that the soil becomes softer. This behavior has been confirmed and described by Yoshimine and Ishihara [29] for Toyoura sand and by Khayat, et al. [1] for a Firoozkuh sand-silt mixture.

The changes in the strength and deformation as a consequence of principal stress inclination can be construed as a continuum level indicator of the fabric anisotropy in sands [20, 30]. During shearing, sand particles continuously rearrange and adjust themselves in an ensemble by sliding and rolling so as to form an optimal and unique anisotropic fabric-structure [31] in relation to the loading conditions.

A slow monotonic shearing process is used in experiments to reach the final state, which also shows the coincident orientation of the stress and strain increments. While this does not present a detailed mapping of the network of contact vectors, experiments of this study utilized the principal stress inclination (α) as an ensemble measure of sands.

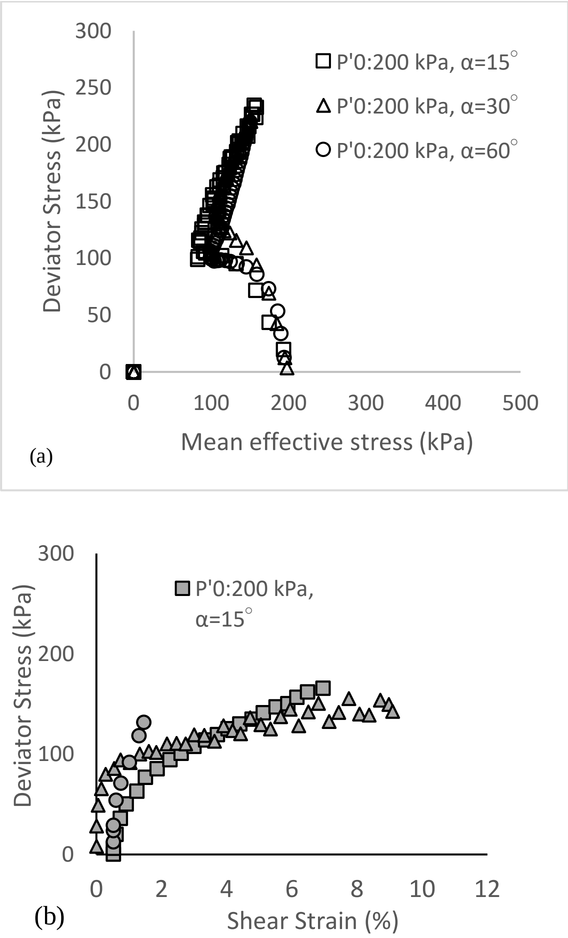

Fig.3 (a) Stress path and (b) stress-strain curves in Tehran sand subjected to an initial effective stress of 200.

In summary, it is especially interesting to study the effects of fabric on very angular particles, such as the ones used in this testing program. Angular sands have a propensity for orienting themselves in a plane normal to the direction of deposition under gravity and exhibit significant interlocking. The inherent anisotropy is especially predominant in very angular sands[32]. Research hitherto reported on various sands such as rounded sands (Ottawa sand—by Dakoulas and Sun [33], subrounded sands like Nevada sand [30], angular sands by Kandasami and Murthy [19], have significantly enhanced our understanding of sand behavior. The samples with a different roundness ratio generate different fabric-structures.

3.2 Effect of Initial Effective Confining Stress on the Behaviour of Sand

As showed in Figs. (5), with increasing the confining stress these phenomena is more obvious in the investigated sand. In other hand confining stress has a significant effect on the strength behavior of granular materials. Alim, et al. [34], also indicated that confining stress has a significant effect on the strength behavior of granular materials

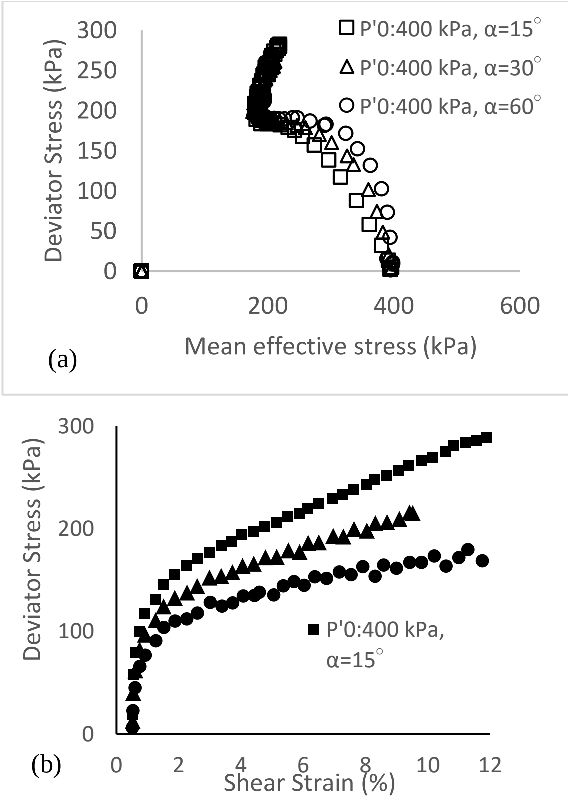

Fig.4 (a) Stress path and (b) stress-strain curves in Tehran sand subjected to an initial effective stress of 400 kPa.

. Vaid and Negussey [35] showed that, at equal relative densities, angular sand was more resistant to liquefaction at lower confining pressures, however, less resistant to higher confining stress than rounded sands. Alim, et al. [34]was defined the average number of contacts per particle, and called it, the coordination number of the particle. The average coordination number of the assembly is defined as the ratio of the total number of contact points within the assembly volume to the total number of particles in the assembly.

4. CONCLUSIONS

In this study, the following parameters were controlled:

1) The grain-size distribution curves of the investigated sands were close to each other.
2) The sampling stages for studied sand were similar.
3) The comparison samples were consolidated under similar confining stresses (100, 200

and 400 (kPa)).

4) With applying same initial confining stress the relative density of studied will be close to each other.

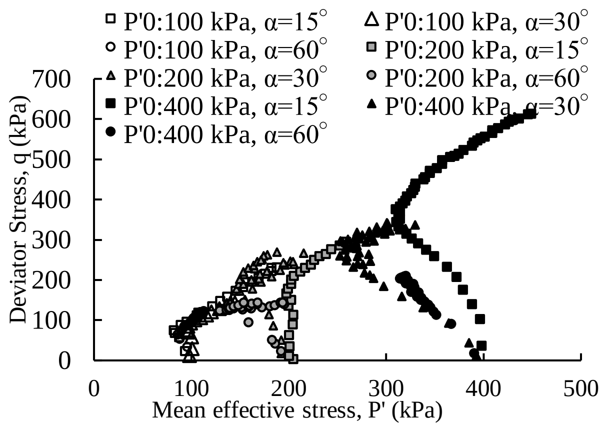

Fig. 5. (a) Stress path and (b) stress-strain curves in Tehran sand

Among the parameters which have an effect on sand behaviors the grading curve, sampling stages, relative density, tried to be identical, and results indicated the variation of roundness ratio (r_r) and confining stress.

The results can be summarized as follow:

1) With increasing confining stress, anisotropy behavior became remarkable, so the effect of shape more pronounced.

2) For each sand at constant mean effective stress, the decrease in the final state friction angle was a direct consequence of the decrease in final state shear strength under various inclination angles (α^{o}).

Finally, these experimental results indicated that sands with more angularity, not only cause increasing the shear strength but also cause increasing the anisotropy. This behavior has been more pronounced with increasing confining stress. The anisotropic behavior of sand was a function of the stress ratio, relative density, initial confining stress and particle shape ratios, which could affect the behavior of sand samples.

5. ACKNOWLEDGEMENTS

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