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Evaluating undrained behavior of Babolsar sand using strain-controlled triaxial tests

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ABSTRACT: When the strain level is large enough, soil samples under shearing tend to be in a state of continuous deformation under constant shear and normal stresses. There exists a correlation between the void ratio and mean effective principal stress, which is referred to as the ultimate steady state line (USSL). Soil behavior can be achieved by expressing the state of effective confining stress and defining the location of this point relative to the steady state line. Therefore, one can say that sand behavior not only is dependent to relative density but also a description of stress state has to be defined. Babolsar sand is a poorly graded clean sand which is widely distributed in a main part of Caspian Sea beach in Iran. The current study tries to investigate behavior of this sand under different conditions such as confining effective stress and relative density using undrained monotonic triaxial compression tests. Investigation is carried out on the steady state or residual strength of this sand by strain-controlled tests. As expected, the analyzed results show that the sand behavior varies from dilative to contractive state while initial isotropic effective stress increases. Therefore, confining effective stress level will directly affect the overall behavior of sand. The observed behavior obtained from the conducted tests is then compared with some previously tested sands including Yamuna, Ganga, and Toyoura.

1 INTRODUCTION

Void ratio has been used as a state variable for predicting the static liquefaction, also known as pre-failure instability of sand using the steady state (SS) line framework. Soil behavior can be expressed by determination of the current proximity of soil state relative to steady state line, at the same effective confining stress. Typically, static liquefaction is studied using a triaxial apparatus to obtain a better understanding of the mechanism and parameters controlling this type of soil response. Numerous studies (e.g., Poulos et al. 1985, Been & Jefferies 1985, Vaid et al. 1990, Lade 1992, Ishihara 1993, Yamamuro & Lade 1997, Alarcon-Guzman et al. 1988, Wanatowski & Chu 2007, Bobei & Lo 2001), have concluded that the initial state expressed in terms of both initial void ratio, e_0, and initial effective mean stress, p'_0, significantly affect the undrained soil response. Hence, different combinations of e_0 and p'_0 can potentially obtain the whole possible phenomenological behaviors of undrained responses: flow liquefaction, limited flow liquefaction, and dilation. These behaviors are schematically illustrated in Figure 1, where the values of both deviatoric and effective stresses are normalized by p'_0. Flow behavior occurs when the initial state, defined by (p'_0, e_0), falls above the steady-state line. Limited flow behavior is expected to occur when the initial state is in the proximity of the SS line (i.e., slightly above or below). Dilative behavior is observed for the initial state located below the SS line. Although liquefaction phenomenon is commonly referred to a cyclically-induced failure, the term static liquefaction is also used to describe flow and limited flow responses in which soil stiffness declines significantly. In the case of limited flow, there is a temporary state of minimum deviatoric strength wherein strain softening switches to strain hardening, introduced as quasi-steady state (QSS) by Alarcon-Guzman et al. (1988).

In this study, triaxial samples were prepared with various initial relative density and effective confining stress to be subjected to undrained loading. The analyzed results show that sand behavior varies from dilative to contractive state provided initial isotropic effective stress would increase. Thus, the level of confining effective stress will directly affect the overall behavior of sand. Undrained behavior of the tested sand is compared with those observed for some previously studied sands having similar grains distribution curve.

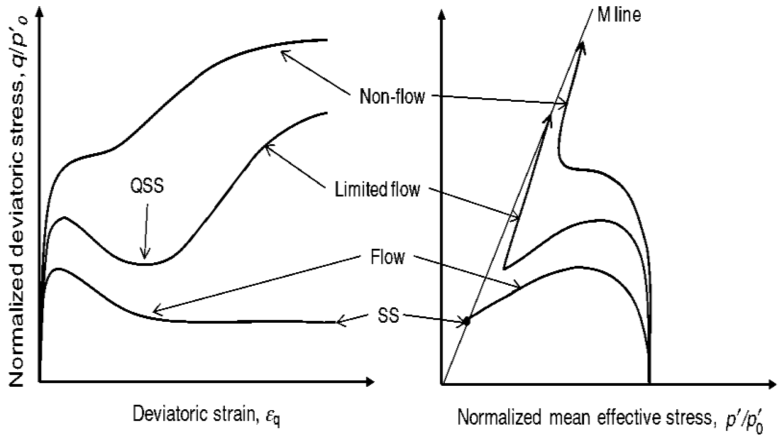

Figure 1. Undrained behaviours of sand (after Rahman 2008)

2 SOIL TESTED

Babolsar sand is a poorly graded clean sand which is widely distributed within a main part of Caspian Sea beach in Iran. The grains size distribution curve of this sand is shown in Figure 2. The sand is classified as SP according to Unified Soil Classification System (USCS). Index properties of this sand were determined in laboratory. Also, a comparison between the basic properties and gradation curves of Ganga, Toyoura, Yamuna, and Babolsar sands is presented in Table 1 and Figure 2. It shows that, except for Yamuna and Babolsar sands, Ganga and Toyoura sands have very similar gradation curves. However, their grains size distribution curves are similar in shape. Results of the current study are to be compared with the results obtained for these sands in the previous studies (Ishihara 1993, Datta 2005, Basudhar 2008).

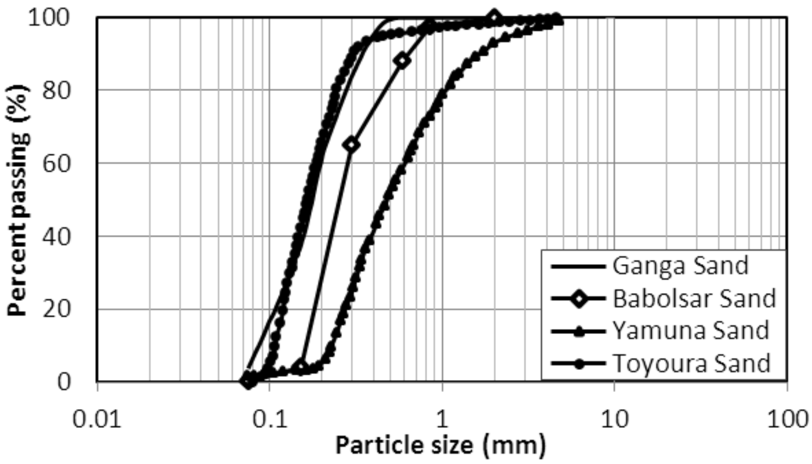

Figure 2. Comparing grains size distribution of four sands

Table 1. Comparison of e_{max}, e_{min}, G_s, D_{50}, C_u for four sands

Sand	e_{max}	e_{min}	G_s	D_{50} (mm)	C_u
Babolsar	0.81	0.56	2.78	0.24	1.8
Yamuna	0.91	0.57	2.66	0.48	2.60
Ganga	0.97	0.64	2.67	0.16	2.30
Toyoura	0.977	0.597	2.65	0.17	1.7

3 TRIAXIAL TESTING PROCEDURE

A series of triaxial tests were conducted on the saturated samples of Babolsar sand. The experimental program includes conventional undrained triaxial tests in various initial mean stress and relative density. All samples were remoulded by moist tamping method with the target relative densities ranging between 5% to 55%. Samples were setup by a split mould on the bottom pedestal and applying a small vacuum pressure to hold the membrane within the mould. The sand was placed in layers to achieve the desired sample density uniformly. Then, a vacuum pressure of 10-15 kPa was transferred to the sample through the drainage link to maintain its shape while the mould was removed. The top and bottom caps were placed and sealed with o-rings. All samples are approximately 50 mm in diameter and 100 mm in height and so had a length to diameter ratio of 2. When the cell was filled with water, the partial vacuum was removed, and confining pressure of about 10-15 kPa was applied. Sample saturation was done by blowing the specimens with carbon dioxide before adding de-aired water. A minimum B-value of 0.95 was obtained for all specimens, ensuring full saturation. After saturation, the specimens were isotropically consolidated. The monotonic triaxial tests were strain-controlled and the rate of applied strain was about 1 mm/min. The samples were sheared until the axial strain reaches 25% in which the sample loses its uniformity and fails. Examples of a ready-to-test specimen and a deformed sample at the end of testing are shown in Figure 3.

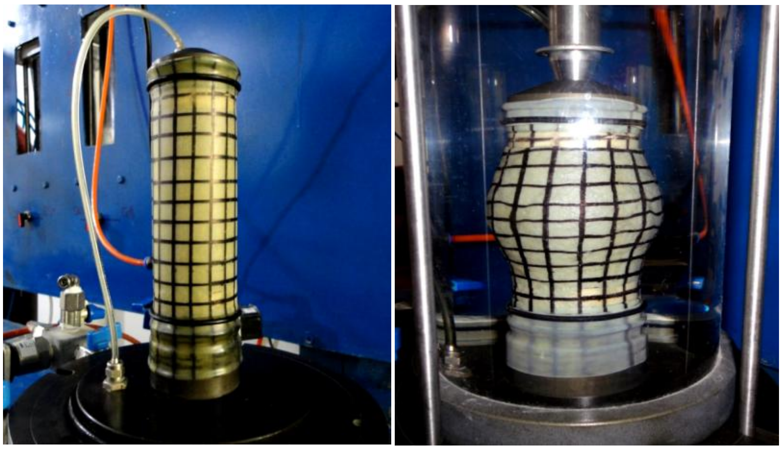

Figure 3. Examples of a prepared triaxial sample prior to testing and a deformed specimen after testing

4 TEST RESULTS

Strain-controlled undrained tests were conducted on the samples with three levels of relative density subjected to different consolidation pressures. The curves representing excess pore water pressure and deviatoric stress against axial strain and stress path behaviors are presented in Figures 4, 5, 6.

Figure 5 shows stress-strain behavior of samples prepared at three different relative densities that were initially subjected to the same consolidation pressure of 40 kPa. At loose state, once the peak stress is attained, significant strain softening occurs and soil reaches its steady state. For the sand with medium relative density, there is no a drop of shear stress and a quasi steady state seems to be reached. Thereafter, the sample tolerates more stress till the ultimate steady state is reached at large strains. At dense state, considerable decline in shear stress is observed till the ultimate steady state is reached. It is seen that as density increases steady state is obtained at a larger strain level. Also, Figure 6 demonstrates that for different relative density the effective stress paths introduce a state envelope.

Figures 7, 8 and 9 depict that samples with same consolidation stresses (σ'=300 kPa), when tested under different relative density, tend to converge to same strength at large strain level. Figure 8 show that deviatoric stress reaches a peak of about 1200 kPa at an axial strain of 8%. At this point, rapid increase in pore water pressure occurs due to the collapse of grains structure, accompanied by degradation of shearing resistance. Therefore, it can be observed that in the dense specimens, unlike the loose specimens, negative pore water pressure develops. Also in Figure 9 the position of the ultimate steady state line is unique with respect to the initial mean stresses but the positions of the quasi steady state line for different initial stresses are different.

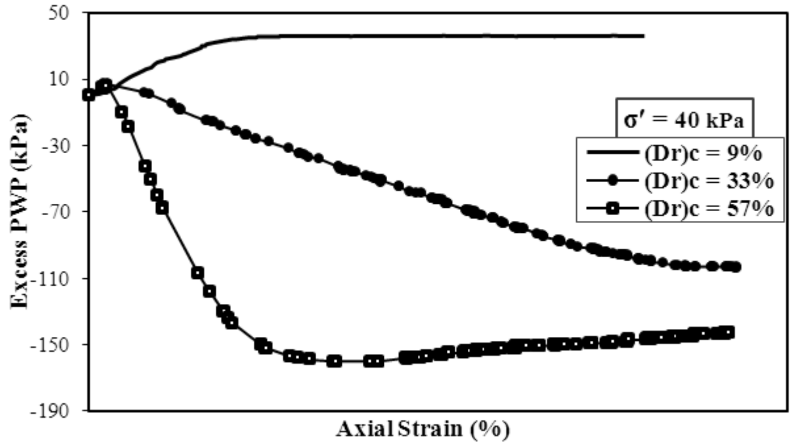

Figure 4. Excess pore water pressure versus axial strain at different relative densities and low effective confining pressure

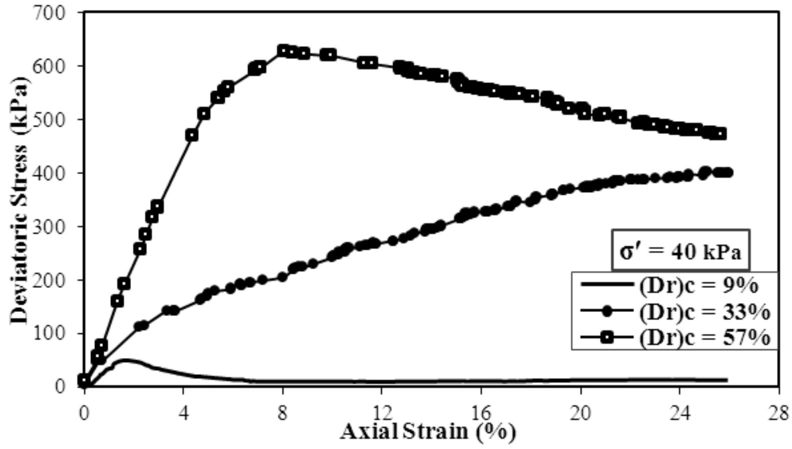

Figure 5. Stress-strain behavior at different relative densities and low effective confining pressure

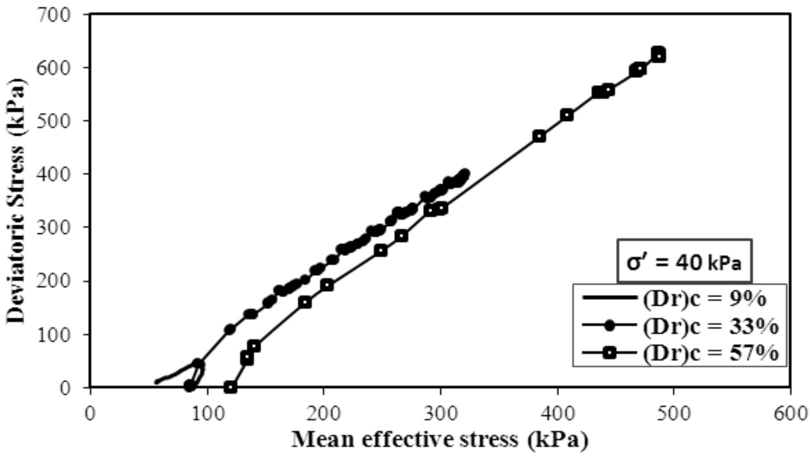

Figure 6. Effective stress path at different relative densities and low effective confining pressure

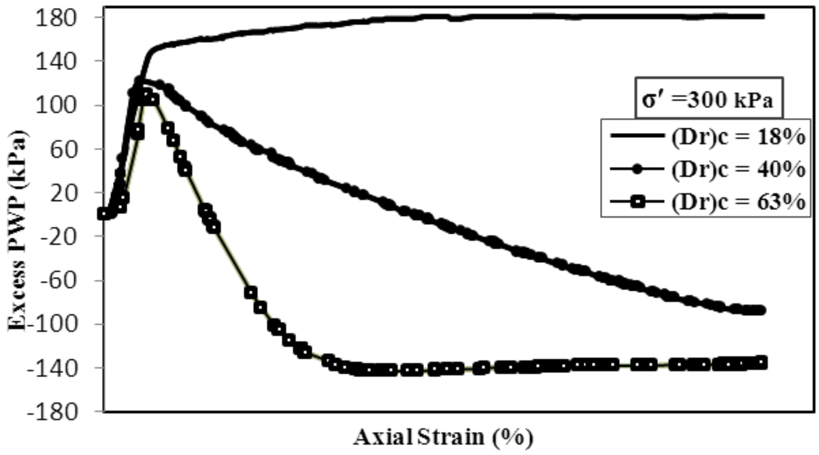

Figure 7. Excess pore water pressure versus axial strain at different relative densities and high effective confining pressure

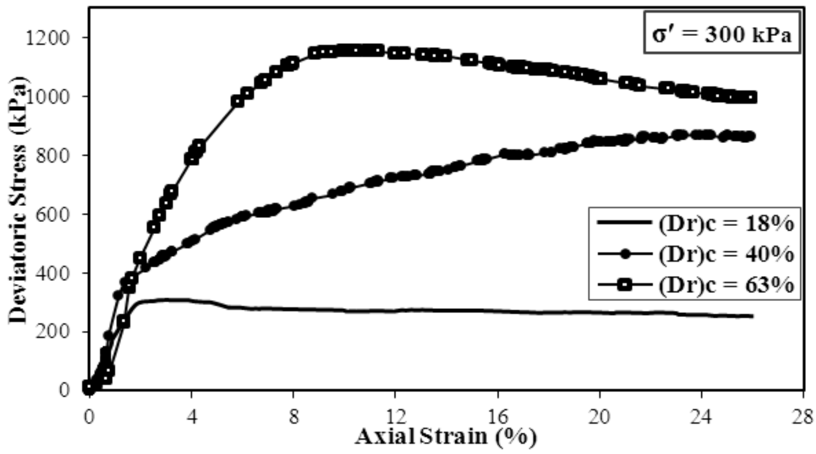

Figure 8. Stress-strain behaviour at different relative densities and high effective confining pressure

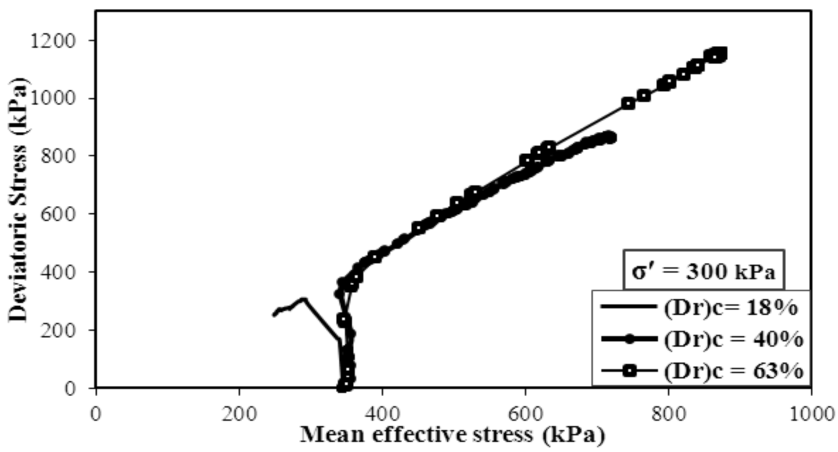

Figure 9. Effective stress path at different relative densities and high effective confining pressure

5 COMPARISON

The test data of Babolsar clean sand is compared with the experimental results obtained for Ganga, Yamuna and Toyoura sands. A comparison of grains size distribution and index properties were presented in Figure 2 and Table 1. Also, stress-strain behavior at different void ratio for a particular confining stress presented in Figure 10 indicates that these sands show different stress-strain characteristics.

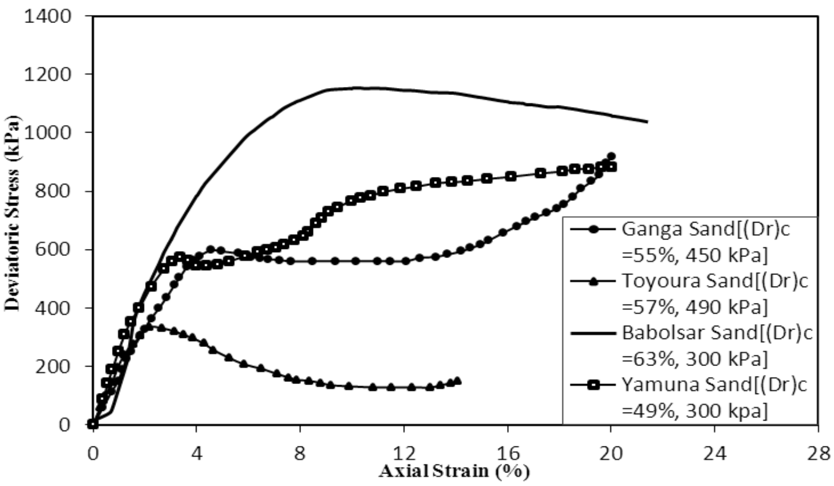

Figure 10. Comparison of stress-strain behavior at different relative densities

6 CONCLUSIONS

There exists a correlation for sands between the void ratio and mean effective principal stress, which is referred to as the ultimate steady state line. The current study investigates undrained behavior of Babolsar sand which is widely deposited in southern coast of Caspian Sea. Thus, several strain-controlled triaxial tests were conducted on the reconstituted specimens of this sand. The experiments were scheduled in order to account for various combinations of relative density and effective stress. The analyzed results show that sand behavior varies from dilation to contractive state due to increasing initial isotropic effective stress. It has been shown that level of confining effective stress will directly affect the overall behavior of sand.

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