3^{rd} *International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,*
28-30 June 2012, Near East University, Nicosia, North Cyprus

Experimental study on shear resistance of Babolsar sand under anisotropic consolidation

Yaser Jafarian
Department of Civil Engineering, Semnan University, Semnan, Iran

Ali Ghorbani
Faculty of Engineering, Guilan University, Rasht, Iran

Siavash Salamatpoor
International Branch, Guilan University, Rasht, Iran, SSalamatpoor@yahoo.com

KEYWORDS: Anisotropic, Triaxial test, Static liquefaction, CVR line

ABSTRACT: The southern bank of Caspian Sea is regularly visited by many tourists. Accordingly, many tall buildings and heavy structures are going to be constructed over this coastal area. The region is overlaid by poorly graded clean sand which is susceptible to liquefaction. Hence, undrained resistance of this sand can potentially be important for controlling stability of the structures. In this study, several undrained monotonic triaxial tests were conducted on reconstituted samples of this sand. The specimens were consolidated anisotropically to simulate initial shear stress which is mobilized due to surface constructions. Different states of soil behavior were obtained by applying different levels of initial relative density, shear stress, and effective stress. It is shown that this sand can experience the whole possible states of liquefiable soils i.e. fully liquefaction, limited liquefaction, and dilation behaviors. It is shown that different states of liquefaction susceptibility may happen due to changing initial shear stress. The outcome of this study is presented in terms of CVR or (critical void ratio) line which is a boundary between contractive and dilative behaviors. It is considered as a boundary between states in which a particular soil was or was not susceptible to liquefaction. It will be shown that the CVR line under anisotropic consolidation is different from that is produced from isotropic states.

1 INTRODUCTION

During earthquakes, ground oscillation may cause saturated cohesionless soils to lose their strength and behave like a liquid. This phenomenon is called soil liquefaction and will cause settlement or tilting of buildings and failure of earth dams and slopes. Increased accuracy in liquefaction potential assessment may lead either to lower construction costs or to safer design decision. Advanced study of soil liquefaction was triggered following the liquefaction-induced failures observed after the 1964 Niigata, Japan and Alaska earthquakes. Static liquefaction is commonly studied using triaxial apparatus to obtain a better understanding of the mechanism and parameters controlling the liquefaction occurrence. Testing on anisotropically consolidated samples might be useful to simulate soil behavior within the sloping ground or beneath the structures which tolerate high shear stresses.

Critical void ratio (CVR) line, which was discussed in several contexts such as Kramer (1996), defines the state of soils in terms of void ratio and effective confining pressure. The CVR line is used to display the boundary between contractive and dilative states. Also, the CVR line is considered as an indicator for flow liquefaction, while soils with initial states falling below the CVR line are considered nonsusceptible to liquefaction.

Castro (1969) performed several static tests on anisotropically consolidated specimens and distinguished three different types of behavior for sands, as shown in Figure 1. The figure shows A, B, and C states where indicate liquefaction, limited liquefaction, and dilation states, respectively. Bobei et al. (2009) studied behavior of anisotropically consolidated sand in undrained condition. Three tests were conducted under anisotropic condition, naming as F2, F4 and F5, with initial mean confining stress (P'_0) and void ratio (e_0) of 369 kPa, 0.744, 471 kPa, 0.689, 368 kPa, and 0.739, respectively. Their results show that F2 and F5 samples reached steady state line (SSL), but F4 sample never reached.

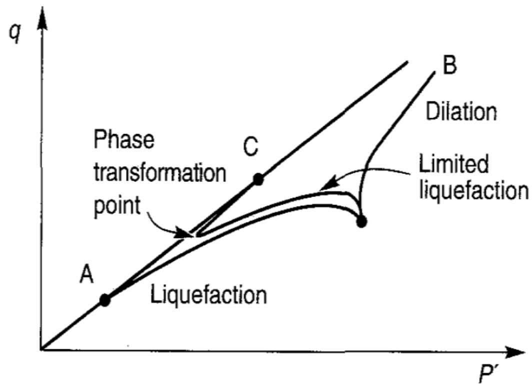

Figure 1. Liquefaction, limited liquefaction, and dilation in monotonic loading tests (after Castro 1996)

In this study, effective stress, shear stress, and relative density have been considered as state variables for predicting the static liquefaction behavior of the poorly graded clean sand located at Babolsar region, in Mazandaran province at Iran. Several undrained triaxial tests were conducted on isotropic and anisotropic specimens. Babolsar sand at different conditions demonstrates phenomenological behaviors of typical sands i.e. fully liquefaction, limited liquefaction, and dilation over a broad range of strain levels. The CVR line, which is a boundary between contractive and dilative behaviors, is shown for this sand to distinguish susceptible and nonsusceptible conditions.

2 SAMPLE PREPARATION AND TESTING PROCEDURE

Moist tamping has been adopted as a reasonable method for specimen preparation. Oven-dried sands were carefully mixed with 5% of distilled water and the wet samples were divided in five equal parts by weight. Each part was then carefully poured into the circular split-mould by a spoon and then leveled with a spatula. The rubber membrane having 0.3 mm thickness was kept in position by applying suction between the mould and the membrane. The top of any compacted layer was then scratched to promote the required friction between the layers. The procedure was repeated for each of the five layers. A low level of vacuum was applied to the specimen and then sample height and diameter were measured. The target height and diameter of samples were tried to be 100 mm and 50 mm, respectively. Figure 2 illustrates two stages of sample preparation. Subsequently, the cell was installed and water supply was opened to fill out the cell with water. The confining pressure around 10 kPa was applied while the vacuum was removed. The sample was blowing with carbon dioxide for easier saturation. Then, de-aired water was inserted under a prescribed back pressure to achieve the 95 percent or more saturation. After consolidation and recording the squeezed water, strain-controlled undrained loading was applied up to sample failure or reaching axial displacement to 35mm. For anisotropic tests, axial load was applied with a very low rate in drained condition.

Figure 2. Examples of a procedure and prepared triaxial sample

3 BASIC CHARACTERITICS OF BABOLSAR SAND

Relative density is an applicable parameter for sands that may control their stress-strain behaviour or can change their liquefaction susceptibility. Relative density is simply given by the following equation:

$$Dr = (e_{max} - e) / (e_{max} - e_{min})$$

where e_{max} is defined as the voids ratio achieved in quickly inverting a measuring cylinder containing the dry soil and e_{min} is that achieved under optimal vibration of dry soil without causing crushing. The e_{max} and e_{min} values of Babolsar sand, measured according to ASTM (D20-40), are 0.81 and 0.56, respectively. Babolsar sand is widely distributed in southern coast of Caspian Sea. This is poorly graded clean sand which is classified as SP according to unified soil classification system. Its grains size distribution curve is shown in Figure 3. Basic properties of this sand is summarized in Table 1.

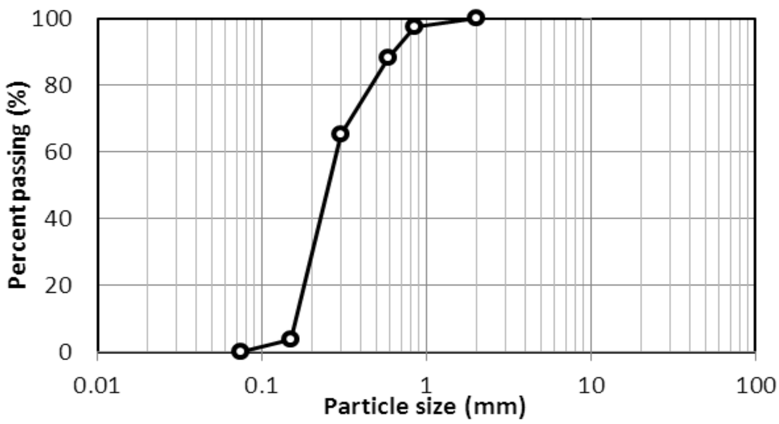

Figure 3. Grains size distribution curve for Babolsar sand

Table 1. Basic properties of Babolsar sand

	e_{max}	e_{min}	G_s	D_{50} (mm)	C_u
Babolsar sand	0.81	0.56	2.78	0.24	1.8

4 RESULTS

This paper presents results of an experimental program to investigate static liquefaction of Babolsar sand. The first part of the study deals with anisotropically consolidated specimens which were prepared with initial axial loading in drained condition. For this purpose, α was defined as the ratio of initial shear stress (initial axial stress divided by 2) to effective confining stress (σ_{3c}). Accordingly, α =0 denotes isotropically consolidated specimens. Triaxial tests with α =0.2 were conducted under two different effective stresses of 40 and 300 kPa and variable relative densities of 20%, 40% and 64%. For α =0.2 and σ_{3c} =40 kPa, the specimens sustained 3.2 kg shear load and for α =0.2 and σ_{3c} =300 kPa specimens undergo 24 kg shear load. After anisotropic consolidation, samples will be failed under axial strain-controlled loading. Results of the anisotropic consolidated tests are shown through Figures 4 to 9.

The second part of the study treats isotropically consolidated tests under effective confining stress of 40 and 300 kPa for variable relative densities of 9%, 33%, and 57%. Results of this part are shown through Figures 10 to 12. It is necessary to explain that all relative densities for both isotropically and anisotropically condition at the beginning of the tests were 5%, 30% and 55%.

From the results, it can be seen that specimens of loose clean Babolsar sand exhibit contractive behavior and lead to continuous increase in excess pore water pressure and decrease in the effective stress. Therefore, the deviatoric stress reaches its peak value and subsequently drops until the specimen fails. The dense specimens exhibit dilatant behavior after the initial contraction. Hence, because of negative pore water pressure, the effective stress increases after temporary instability.

The results of anisotropic tests under σ_{3c} =40 kPa with different relative densities of 9%, 34%, and 57% are shown in Figures 4, 5, and 6. The variations of excess pore water pressure and deviatoric stress versus axial strain are shown in Figures 4 and 5, respectively. As shown in Figure 6, all stress paths follow dilation state.

Anisotropic tests under σ_{3c} =300 kPa with different relative densities of 20%, 40%, and 64% are shown through Figures 7, 8, and 9. As shown in Figure 9, for the specimens having relative densities of 20% and 40%, the stress paths mimic limited liquefaction state and excess pore water pressure has positive quantity in the low to moderate strains. For the relative density of 64% (dense sand), the specimen experiences dilation state because of negative excess pore water pressure.

Three isotropically consolidated tests under σ_{3c} =300 kPa with different relative densities of 18%, 40%, and 63% were conducted and their results are shown through Figures 10, 11, 12. Fully liquefaction under σ_{3c} =300 kPa and $(D_r)_c$ =18% happened and two other tests have resulted in limited liquefaction state, as shown in Figure 10 and 12. Hence, Babolsar clean sand experiences all three possible states i.e. fully liquefaction, limited liquefaction, and dilation under different conditions.

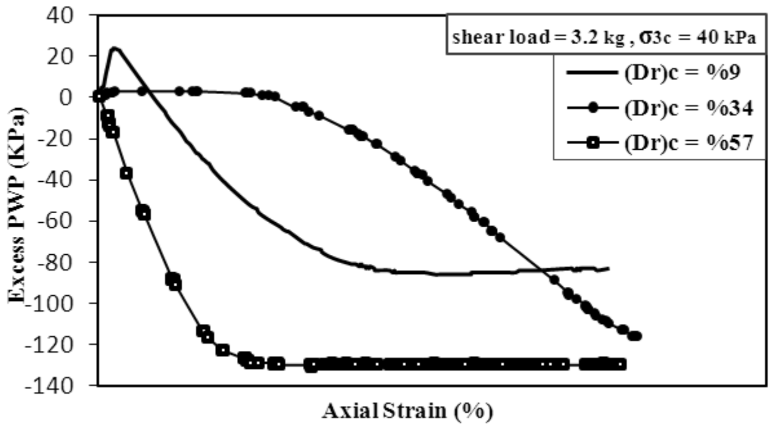

Figure 4. Excess pore water pressure versus axial strain at different relative densities and small shear load in anisotropic stress condition

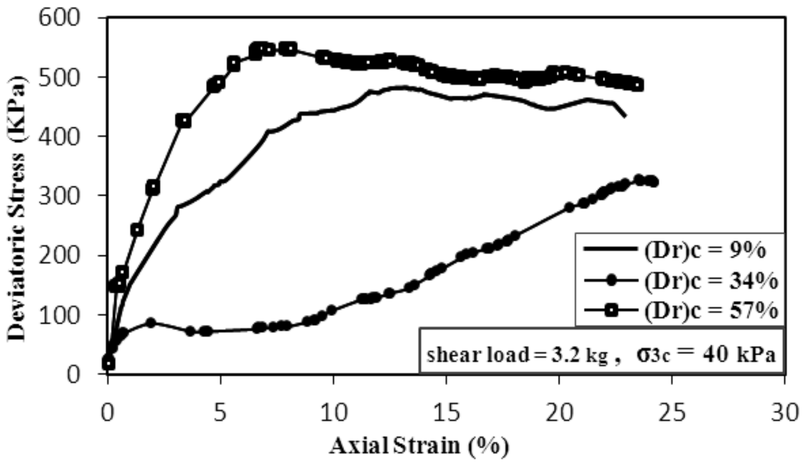

Figure 5. Stress-strain behavior at different relative densities and small shear load in anisotropic stress condition

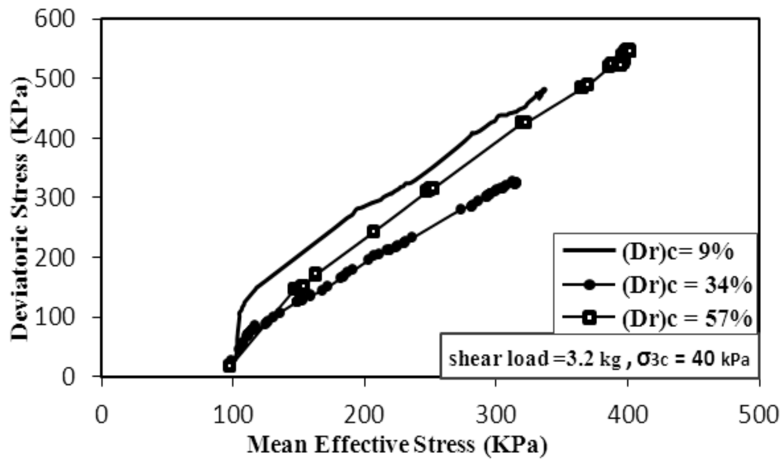

Figure 6. Effective stress path at different relative densities and small shear load in anisotropic stress condition

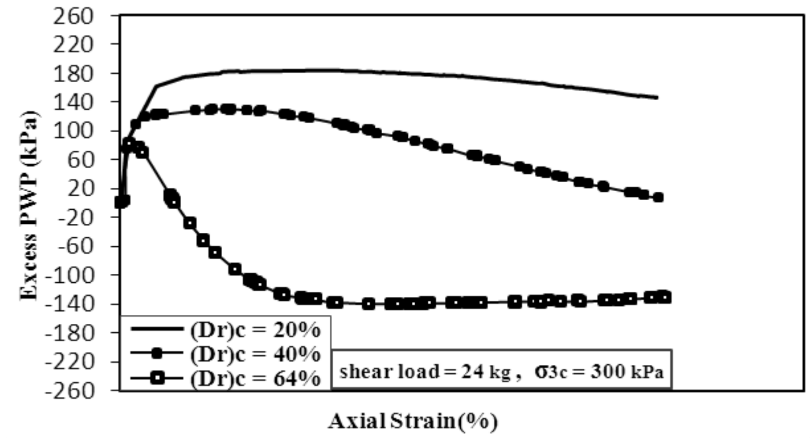

Figure 7. Excess pore water pressure versus axial strain at different relative densities and high shear load in anisotropic stress condition

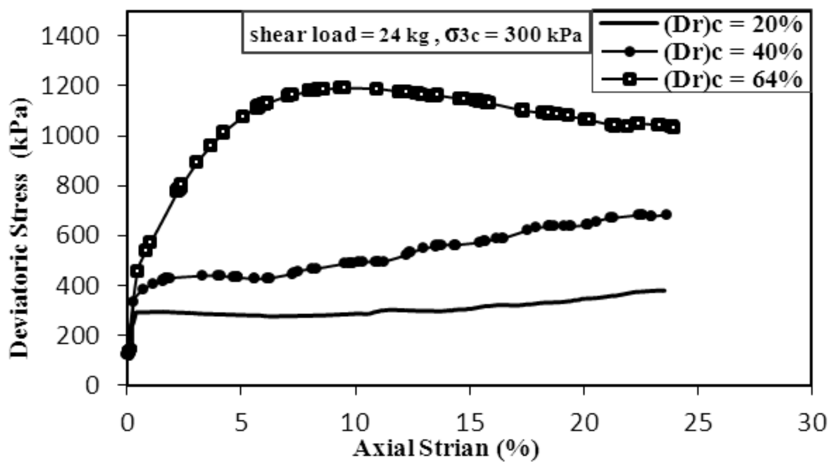

Figure 8. Stress-strain behavior at different relative densities and high shear load in anisotropic stress condition

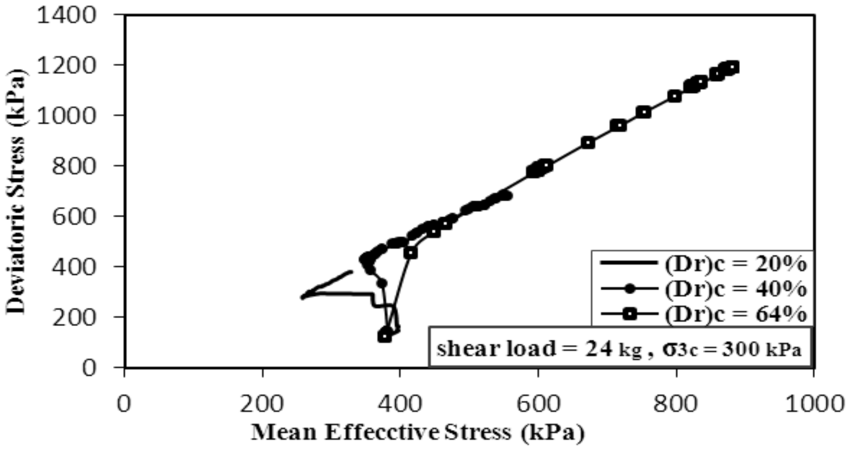

Figure 9. Effective stress path at different relative densities and high shear load in anisotropic stress condition

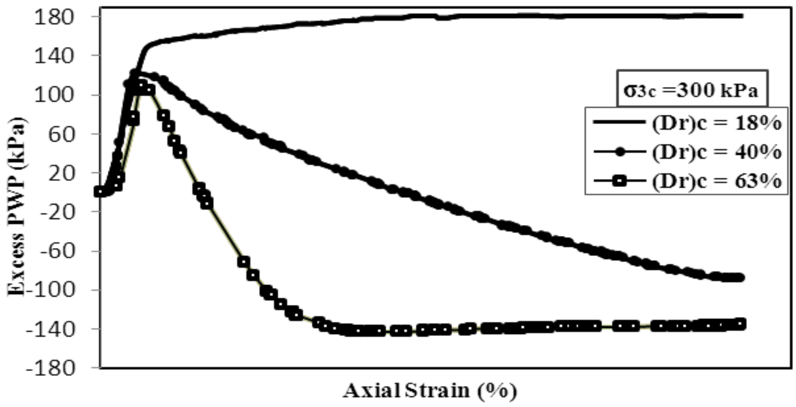

Figure 10. Excess pore water pressure versus axial strain at different relative densities and high effective confining pressure in isotropic stress condition

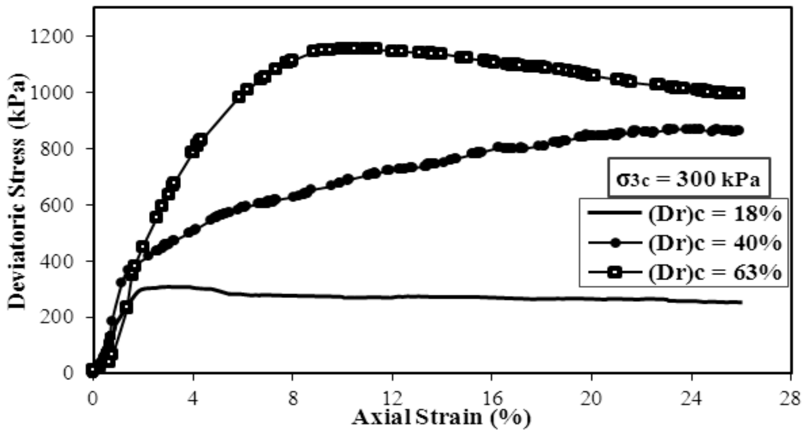

Figure 11. Stress-strain behavior at different relative densities and high effective confining pressure in isotropic stress condition

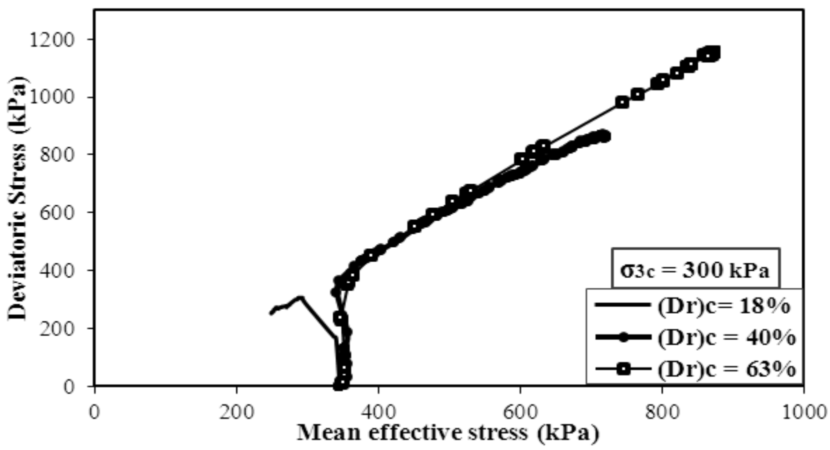

Figure 12. Effective stress path at different relative densities and high effective confining pressure in isotropic stress condition

The CVR (critical void ratio) line which is a boundary between contractive and dilative behaviors is shown for this sand in Figure 13 wherein e values (after consolidation void ratio) were plotted versus logσ_{3c}. CVR line is suggested to be a useful tool to distinguish states of susceptible and nonsusceptible liquefaction. The figure indicates that CVR lines are not identical for anisotropic consolidation undrained (ACU) and isotropic consolidation undrained (ICU) conditions. Accordingly, anisotropic condition obtains more inclined CVR line than the isotropic condition. Since the region above the CVR lines is associated with susceptible condition, thus, it can be concluded that anisotropically consolidated specimens are less prone to liquefaction failure compared with the isotropic ones in the same initial conditions. It is necessary noting that this finding is definitely limited to Babolsar sand under the scheduled experimental conditions.

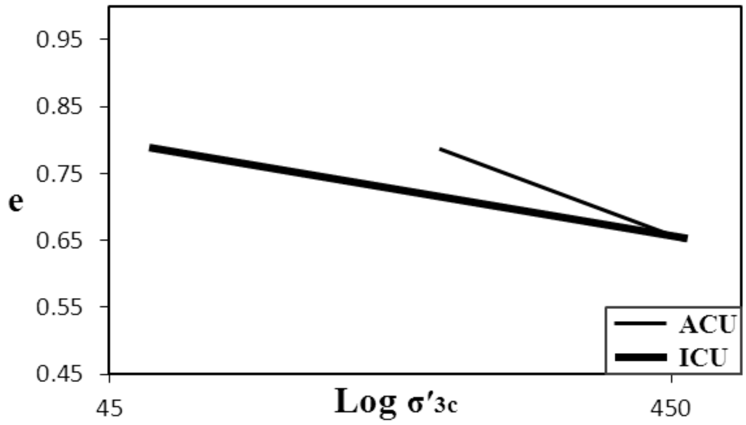

Figure 13. CVR lines at Anisotropic (ACU) and Isotropic (ICU) conditions with different relative densities for Babosar clean sand

5 CONCLUSIONS

This experimental study includes undrained triaxial tests on isotropically and anisotropically consolidated specmines of Babolsar clean sand. Three levels of relative densities with initial effective confining stresses of 40 and 300 kPa were specified in the experimental program.
The results show that this sand can experience the whole possible states of liquefable soils i.e. Fully liquefaction, limited liquefaction, and dilation behaviors. Also, the outcome of this study has been presented in terms of CVR or (ciritical void ratio) line which is a boundary between contractive and dilative behaviors. It is considered as a boundary between states in which a particular soil is or is not susceptible to liquefaction. The results show that CVR line under anisotropic consolidation has different trend from that is producted from isotropic states. It has been shown that Babolsar sand is more susceptible to liquefaction type of failure under isotropic condition.

ACKNOWLEDGEMENTS

The authors sincerely appreciate Armoon Geotechnics Co. for providing triaxial apprataus and other laboratory equipments to conduct this study. Also, the last author especially thanks his brother, Sina Salamatpoor, for his wholeheartedly assistance.

REFRENCES

Bobei, D. C., and Wanatowski, D. (2009). ” Modified state parameter for characterizing static liquefaction of sand with fines.” Canadian Geotechnical Journal, 46: PP. 281–295.

Castro, G. (1969). “Liquefaction of sands” Harvard Soil Mechanics series 87, Harvard University, Cambridge, Massachusets.

Kramer, L. (1996). “Geotechnical Earthquake Engineering.” , Prentice-Hall, Inc 653 P