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Experimental Study On Monotonic Behavior of Babolsar Sand Under Isotropic And Anisotropic Consolidation Based On State Parameter

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ABSTRACT

In this study, drained and undrained triaxial tests under isotropic and anisotropic consolidation were conducted on the reconstituted samples of Babolsar sand, which underlies a densely populated, seismic region of the southern coast of Caspian Sea in Mazandaran, Iran. It is demonstrated that the sand can experience the whole possible states of liquefiable soil i.e. flow failure, limited flow, and dilation. The steady-state and flow liquefaction lines of this sand are presented and compared with some previously tested sands. It is shown that the initial stress anisotropy can affect the potential of volume change and pore pressure generation. The SSL line, however, remains identical for the isotropically and anisotropically consolidated specimens under drained and undrained conditions. The tests data are then analyzed in order to investigate the liquefaction susceptibility of this sand in terms of some parameters such as state parameter, relative state parameter index, and lateral earth pressure ratio at failure.

KEYWORDS

Monotonic Triaxial Test, Steady State, Isotropic and Anisotropic, State Parameter, Liquefaction.

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1- INTRODUCTION

Liquefaction occurrence near the ground surface commonly results in great deformations; thereby producing significant damage to the man-made or natural earth structures. Castro (1969) observed that cohesionless soils with different densities exhibit three basic phenomenological behaviours termed liquefaction, limited liquefaction, and dilation; when they undergo sufficient shear strains. The state in which the soil continually deforms under constant volume, shear, and confining stress has been defined as the steady state and the corresponding strength of soil is called the steady-state (SS), residual, or post-peak strength. Evaluation of steady-state strength of soils from static tests has been taken into consideration by many researchers (e.g., Castro, 1969; Della et al., 2011).

The current study presents results of the experimental investigation on the poorly graded coastal sand located at Babolsar region, Mazandaran province of Iran. Initial effective stress, shear stress, and relative density have been considered as state variables for evaluating the steady-state strength and liquefaction susceptibility of this sand. Several drained and undrained static triaxial tests under initial isotropic and anisotropic stress conditions were conducted. Subsequently, dilative and contractive behaviour of this sand is expressed in terms of some parameters like state parameter and excess pore pressure ratio at failure. The incremental rates of excess pore pressure (for undrained tests) and volume change (for drained tests) are shown to be different for the isotropically and anisotropically consolidated specimens.

2- THE EXPERIMENTAL PROGRAM

The triaxial experiments were performed on Babolsar sand, which underlies a densely populated, seismic region of the southern coast of Caspian Sea in Mazandaran, Iran. The reconstituted specimens of the sand were prepared using the bulk samples taken from the borrow pits on the beach. The sand is poorly graded and classified as SP according to Unified Soil Classification System (USCS).

3- PRELIMINARY RESULTS

Several drained and undrained tests under isotropic and anisotropic consolidations were conducted on Babolsar sand. The tests initial conditions are named as A to F series. A series: isotropically consolidated undrained (CIU-Test) triaxial tests, including 15 tests under initial mean effective stresses of 40 to 410 kPa and initial relative densities of 5 to 55%.

When undrained shearing begins, the specimens with contractive behaviour generate positive excess pore water pressure and shear resistance reaches a peak value that occurs at a relatively small strain and the specimens would then collapse. After peak point, excess pore water pressure increases dramatically and the stress path reaches the steady-state line with considerable strain softening. In these cases, the specimens have exhibited flow liquefaction behaviour in which the static shear stress required for equilibrium (peak point) are greater than the available shear strength in steady-state condition. Fig. 4c also illustrates effective stress paths of two specimens which anisotropically consolidated with α=0.2. For specimen C27 (relative density of 19.83%, initial effective confining pressure of 340 kPa, and α=0.2), the stress path initially shows contractive behaviour while larger strains causes an elbowing and the stress path switches to the dilative type of behaviour and moves along the steady-state line. This type of behaviour which contains the transition from contractive to dilative behaviour is called limited liquefaction. The third type of behaviour which is observed for C31 (see Figs. 4a to 4c) implies dilative behaviour throughout the shearing. The excess pore water pressure in this case is permanently negative.

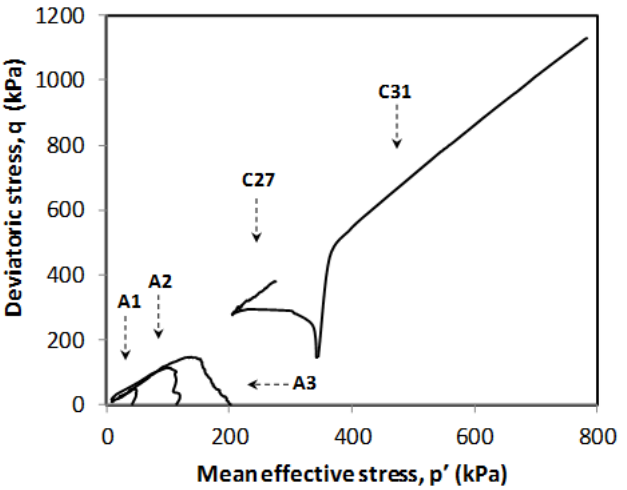

Figure 1: Effective stress paths

The preliminary results of the tests reveal that Babolsar sand can experience the whole possible undrained behaviours of typical sands i.e. flow liquefaction, limited liquefaction, and dilation.

4- LIQUEFACTION SUSCEPTIBILITY

In this study, three indices including state parameter (ψ), relative state parameter index (ξ_R), and lateral earth pressure ratio at failure (k_f) are considered to recognize liquefaction susceptibility of the studied sand.

4- 1- STATE PARAMETER (ψ)

For the isotropically consolidated drained (CID) and undrained (CIU) tests (A and B series), the values of ϕ' were calculated as the friction angle at failure and the

values of ϕ'_{ss} were estimated when stress path reached the steady-state line. As shown in Fig. 8, the values of $\phi'-\phi'_{ss}$ were found to be between 0 and 12 degrees ($0<\phi'-\phi'_{ss}<12^{\circ}$) for A and B series. The figure also shows the upper and lower bounds reported by Been and Jefferies (1985) for six different clean and silty sands. Although majority of the tests data specify the $\phi'-\phi'_{ss}$ values less than 5 degrees and fall within the Been and Jefferies (1985)'s range, it is seen that three liquefied samples have obtained out of range results. As indicated by Been and Jefferies (1985), this is due to the inaccuracies associated with the determination of ϕ' from the results of the liquefied samples.

4- 2- RELATIVE STATE PARAMETER INDEX (ξ_R)

From the curve fitting of the results for isotropically drained (CID) and undrained (CIU) tests, Q has been found to be 8.28 for Babolsar sand while ξ_R varies between 0.25 to -0.35. Accordingly, relative density and mean effective confining stress were between 8.48 to 65% and 40 to 410kPa, respectively

4- 3- LATERAL EARTH PRESSURE RATIO AT FAILURE (K_F)

k_f has been defined as the ratio of initial effective confining stress to effective axial stress at failure $k_f = \sigma'_{3c}/\sigma'_{1f}$. Fig. 10 demonstrates values of k_f ratio versus the friction angle at failure (ϕ') for CID and CIU tests. It could be shown that the k_f-ϕ' data for these samples are located between two descending dash lines. The liquefied samples have maximum k_f ratios and minimum ϕ' values compared with the rest of tests data. Larger values of k_f ratio for the liquefied samples might be associated with the decrease of axial stress at failure for these samples.

5- THE EFFECT OF ANISOTROPIC LOAD

Experimental results of the current study reveals that isotropically and anisotropically compressed samples approach toward an identical steady-state line.

For Babolsar sand under isotropic and anisotropic consolidation (series B, E, and F) shows the values of with positive - $\delta\varepsilon_v/\delta\varepsilon_a$ demonstrate dilative behaviour at failure moment and vice versa. For Babolsar clean sand under undrained shearing, the rates of pore pressure versus p'_u/p'_f for CIU and CAU conditions are shown. Positive sign of $(\delta u/p'_f)/\delta\varepsilon_s$ denotes on contractive behaviour and vice versa. Similar to the drained tests, it is observed that the isotropic samples specify positive and zero $(\delta u/p'_f)/\delta\varepsilon_s$ values while majority of anisotropic data points obtain negative and zero values.

6- SUMMARY AND CONCLUSION

This paper presents results of an experimental study including drained and undrained static triaxial tests on isotropically and anisotropically consolidated specimens of Babolsar clean sand which underlies a vast region in the southern coast of Caspian Sea. The conclusions can be summarized as follow:

(1) In the undrained triaxial test under monotonic loading, Babolsar sand can experience the whole possible behaviours of liquefiable soils i.e. flow failure, limited liquefaction, and dilation.

(2) Babolsar sand with the initial state located in the upper region of this line is prone for flow type of failure. As expected, the decreasing trend of the SSL in e-logp′ plane confirms that sand behaviour varies from dilation to contractive state due to the increase in initial isotropic effective stress at the constant relative density. In fact, dilatancy is suppressed with increasing initial effective confining pressure.

(3) For undrained tests of the current study, it was observed that the isotropic samples specify positive and zero $(\delta u/p'_f)/\delta\varepsilon_s$ values while majority of anisotropic data points obtain negative and zero values.

(4) According to the results obtained from the present study on Babolsar sand, the existence of initial shear load which is related to anisotropically stress conditions, there is the possibility that sand behavior change from contractive state into an dilative state, so that by making a comparison between two samples with the same relative density, the isotropic and liquefied sample A1 (contractive) is seen under initial shear load 0.4 and shear strength of the sample D32 experiences an increase up to 96.75, compared to the sample A1.

7- REFERENCES

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