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Comparison of cyclic simple shear and triaxial tests on natural sand

Comparaison d'essais cycliques simples en cisaillement et triaxiaux sur sable naturel

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ABSTRACT: The determination of strain-dependent dynamic properties is crucial for the seismic performance of a certain soil. The cyclic triaxial tests are widely used to find out the dynamic properties of soils due to simplicity and the cycle simple shear stress simulate well the earthquake conditions. However, the stress conditions are not the same in both apparatus. Extensive experimental research program on element tests have been performed on natural sand from the Vardar river terraces in the city of Skopje. In this paper, the results of liuefaction potential obtained from the dynamic simple shear tests are compared with the results of cyclic triaxial tests. Strain-controlled dynamic simple shear tests with constant volume approach were carried out for low level of relative density (30-35%). The samples were prepared with air pluviation technique and were subjected to cyclic loading with a frequency of 1.0 Hz. The cyclic triaxial tests were performed according to the ASTM standard D 5311-92 for similar relative density (35-40%). All the samples were prepared by wet tamping technique, were tested under effective stresses of 100kPa and the applied cyclic loading frequency was 0.5 Hz with sinusoidal loading function. Valuable comments on the compared results are given which are good basis for further research aspects on the investigated sand.

RÉSUMÉ: La détermination des propriétés dynamiques dépendantes de la déformation est cruciale pour la performance sismique d'un sol donné. Les tests triaxiaux cycliques sont largement utilisés pour déterminer les propriétés dynamiques des sols à cause de leur simplicité. Le cycle de contrainte de cisaillement simple simule les conditions sismiques. Cependant, les conditions de stress ne sont pas les mêmes dans les deux appareils. Un vaste programme de recherche expérimentale sur les tests d'éléments a été réalisé sur du sable naturel provenant des terrasses de la rivière Vardar dans la ville de Skopje. Dans cet article, les résultats du potentiel de liquéfaction obtenus à partir des tests de cisaillement simple cycliques sont comparés aux résultats des tests triaxiaux cycliques. Des essais de cisaillement simple dynamique contrôlés par contrainte avec une approche à volume constant ont été effectués pour une faible densité (30 à 35%). Les échantillons ont été préparés avec la technique de pluviation dans l'air et ont été soumis à un chargement cyclique à une fréquence de 1,0 Hz. Les essais triaxiaux cycliques ont été réalisés conformément à la norme ASTM D 5311-92 pour une densité relative similaire (35-40%). Tous les échantillons ont été préparés par une technique de bourrage humide. Les échantillons ont été testés sous des contraintes effectives de 100 kPa et la fréquence de chargement cyclique appliquée était de 0,5 Hz avec une fonction de chargement sinusoïdal. Les commentaires sur les résultats comparés était trés favorables, et constituent une bonne base pour des recherches supplémentaires sur le sable étudié.

Keywords: cyclic simple shear; cyclic triaxial; liquefaction; constant volume approach; sand.

1 INTRODUCTION

Recent earthquakes, for example, the 2010 Christchurch earthquake in New Zealand, showed that many of the damages and economic losses were related to geotechnical problems and soil liquefaction (Cubrinovski et al. 2011). The high losses incurred due to destructive earthquakes promoted the need for assessment and better understanding of the soil behavior under cyclic loading. This requires improved investigation techniques and sophisticated and advanced experimental tests to define soil behaviour.

Eventhough the cyclic simple shear is a more realistic representation of sand behaviour under earthquake loading, results obtained under triaxila conditions are frequently used to obtain equivalent cyclic simple shear response (Vaid et al. (1996)). The main uncertainty in the cyclic simple shear tests is that the horizontal stresses are not measured nor could be controlled independently of the vertical stress (Silver et al., (1980)). There is a difference in the stress state in the direct simple shear stress which is anisotrpoic (σ'_{vc}, $K_0*\sigma'_{vc}$, where K_0 is the coefficient of earth pressure at rest) as opposed to an isotropic stress state ($\sigma'_{1c}= \sigma'_{2c}=\sigma'_{3c}$) in triaxial stress condition In this study, an effort is made to compare and give comments on cyclic tests of Skopje sand in direct simple shear test device and dynamic triaxial test device, both performed at the Laboratory for soil Dynamics and geotechnical engineering in IZIIS, Skopje, Macedonia, taking into account the differencies associated to the stress conditions in both appratus.

The investigated sand is natural representative sand from the city of Skopje, (Cvetanovska et al., (2013)) from the Vardar river terraces. In specific stress conditions, the natural alluvial sand is assumed to be associated with liquefaction occurrence and development of large deformations during an earthquake.

2 EXPERIMENTAL PROGRAM

The cyclic behavior of natural sand is investigated through the dynamic simple shear tests are compared with the results of cyclic triaxial tests. Strain-controlled dynamic simple shear tests with constant volume approach were carried out for low level of relative density (30-35%). The samples were prepared with air pluviation with funnel technique and were subjected to cyclic loading with a frequency of 1.0 Hz. The cyclic triaxial tests were performed according to the ASTM standard D 5311-92 for similar relative density (35-40%). All the samples were prepared by wet tamping technique and the applied cyclic loading frequency was 0.5 Hz with sinusoidal loading function.

2.1 Skopje sand properties

Skopje sand is representative natural sand from the river terraces of the Vardar River, which flows through Skopje city. The shape of the sand particles is subangular and homogeneous as it can be seen from the grain size distribution in Figure 1. From the detailed silicate analysis, it is obtained that the sand mostly consists of silica oxides. The physical properties of Skopje sand are given in Table 1.

Table 1. Physical properties of Skopje sand

e_{min}	e_{max}	Gs [kN/m^3]	D_{50} [mm]	φ [°]
0.95	0.51	2.615	0.26	28.5

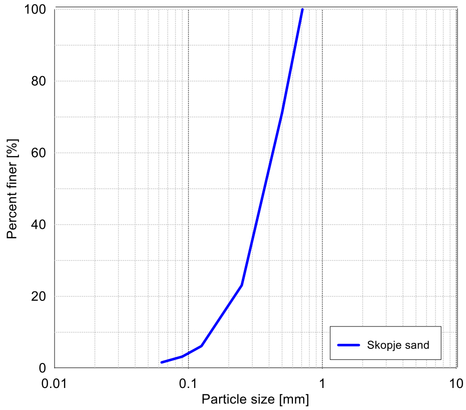

Figure 1. Grain size distribution of Skopje sand

2.2 Cyclic direct simple shear tests

The equipment used for the tests is Dynamic Simple Shear Device, produced by Dames and Moore, London, UK (Dames and Moore, (1981)). This device is used for testing of two cylindrical models restrained rigidly in vertical direction by three loading plates, while in radial direction, with a series of PTFE coated steel rings. The dynamic excitation in the form of shear strains is applied in horizontal direction through a central loading plate placed between the two models. Since the upper and lower loading plates are fixed in horizontal direction, loss due to friction is reduced, increasing thus the accuracy. Significant is also the reduction of the moving mass, providing thus better control of the applied cyclic function. The equipment consists of four principal components: Testing device, Hydraulic pump, Digital control and response recording unit - PC controlled. Several design features contribute to performance of the apparatus: a dual-sample concept which eliminates the frictional problems associated with bearing supported loading platens, dynamic loading system, custom designed for small displacement and high force applications uses a novel system of roiling diaphragms and flexural supports to achieve smooth high load performance and the control system which optimize dynamic range both in measurements and control of force and displacement (Sesov et al., (2012)).A scheme presentation is provided in Figure 2.

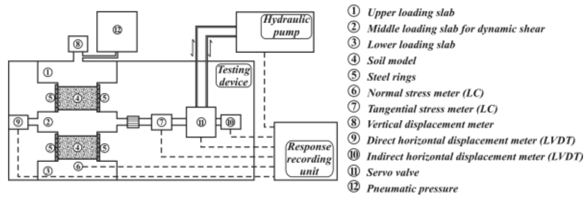

Figure 2. Schematic view of direct simple shear apparatus

The main characteristic of the performed cyclic tests is that a soil specimen is sheared at a constant volume (Talaganov, (1986)). This created the conditions for increase in pore-pressure. A cyclic excitation with controlled shear strain amplitude is applied and shear stress is recorded. In liquefaction considerations this procedure is defined as strain approach. It is characteristic that by application of the cyclic excitation the pore-pressure increases, as well as τ–γ transformation, occurs which affects all the other results. The scheme of the concept is shown in Figure 3.

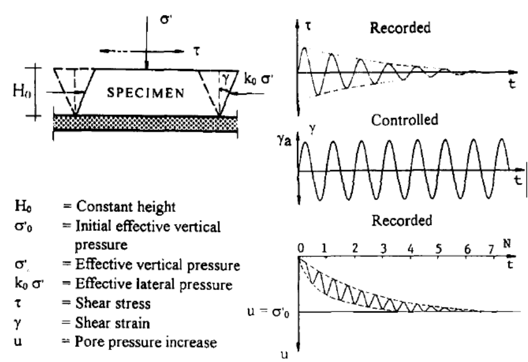

Figure 3. A scheme of constant volume test (Talaganov, (1996)).

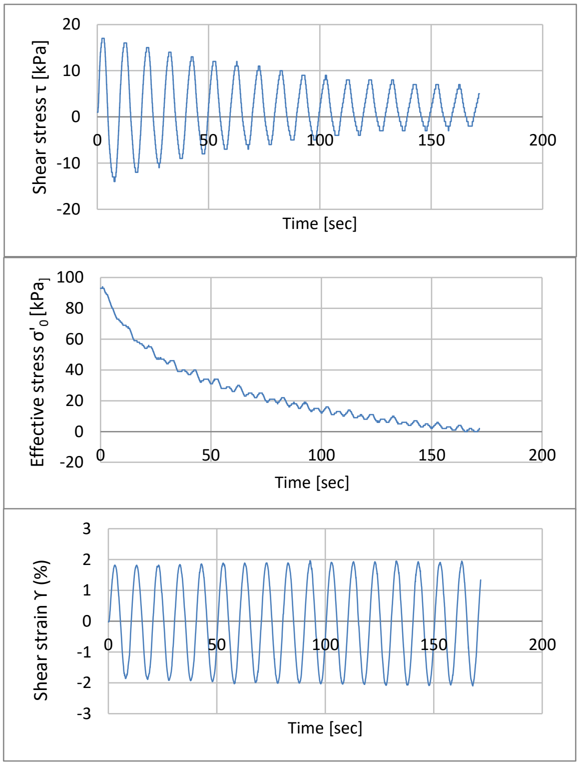

Figure 4. Results from direct simple shear test with 0.18 % strain

A specific test procedure using dry sand samples in constant volume conditions was applied in the presented investigations. As a result of cyclic shearing in constant volume conditions a decrease in initial pressure σ'_0 of the samples takes place. This pressure decrease was taken to be equal to the pore-pressure increase in saturated samples.

Tests were carried out as strain controlled with application of selected values of shear strain amplitudes at an interval of 0.1 up to 1%. The stress-strain relationships are recorded during the tests as well as the decrease of initial pressure σ'_0 which is taken as equivalent to the pore-pressure u increase. As a result of σ'_0 decrease, a permanent transformation of τ–γ is recorded.

Five sand samples to define the liquefaction curve, were prepared by air pluviation technique and tested as dry disturbed samples (fractions with d<2 mm were tested), i.e. as reconstituted samples with a relative density from 30-35% (Kitanovski, (2018)). The sand samples a reconstituted with cylindrical shape of a diameter of 6.1cm while the height ranges from 1.3 to 1.5cm, restrained in vertical direction, placed between three loading plates. The samples were exposed to consolidation of vertical load of ~100kPa and the applied frequency was 0.1 Hz. Figure 4 shows a typical test result for sand with *Dr* = 33 % and cyclic shear strain amplitude γ=0.18%.

2.3 Cyclic triaxial tests

The performed dynamic triaxial tests were performed according to the ASTM standard D 5311-92 for relative densities from 35- 40% on the dynamic triaxial apparatus in IZIIS (Figure 5). As sample preparation method, the wet tamping (WT) method was used. The sample dimensions are diameter 70mm and height of 138-140mm. More detailed information regarding the experimental program and results can be found in Bojadjieva (2015). Two main variables were analyzed, the relative density and the cyclic stress ratio. The applied cyclic loading frequency was 0.5 Hz and the loading function was sinusoidal. The liquefaction initiation was defined on the basis of the number of cycles required to reach a double amplitude (DA) of axial strain of 5 %. The results presented in this study clearly show the liquefaction potential of the Skopje sand.

Figure 5. Dynamic triaxial apparatus

Figure 6 presents the results from the performed triaxial tests for CSR=0.25 considering different relative densities of 40 %, 55 % and 75%. The presented graphs clearly show the liquefaction development in the Skopje sand by axial strain development and accumulation of excess pore pressure. The obtained graphs emphasise the soil liquefaction development of the Skopje sand initiated by axial strain development and accumulation of excess pore pressure.

It can be noted that failure in all the cases of loose and dense samples is governed by cumulative development of axial strain rather than pore pressure generation. It seems that the sand demonstrates a "cyclic mobility" behavior. For the same cyclic stress ratio, the number of cycles to reach liquefaction increases as the soil density increases.

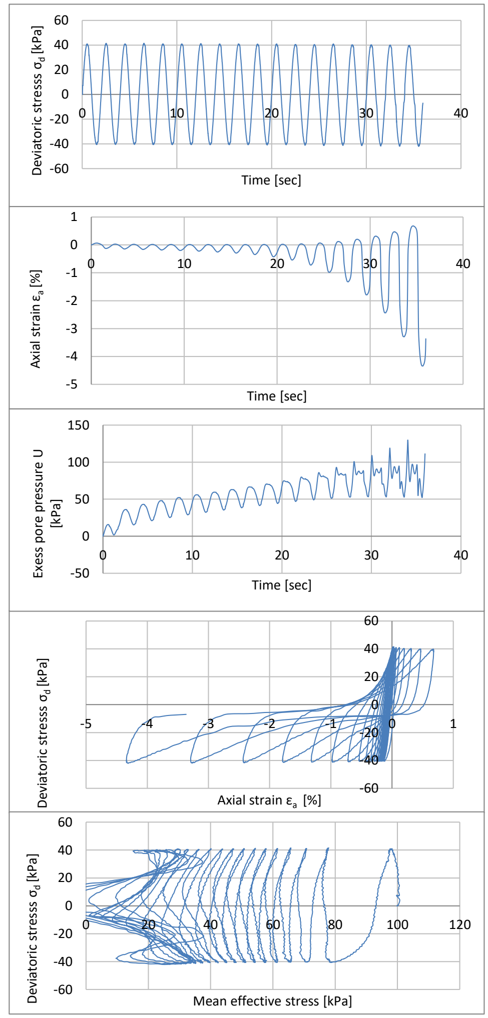

Figure 6. Results from triaxial cyclic test on Skopje sand for Dr = 40%, CSR=0.20

3 COMPARISON OF RESULTS AND COMMENTS

Figure 7 represents the liquefaction curve versus number of cycles to initiate liquefaction. For the simple shear tests the cyclic strength ratio is represented as Rτ (eq.1):

$$R_\tau = \frac{\tau}{\sigma'_{vc}} \quad (1)$$

Where,

σ'_{vc} is the initial vertical consolidation stress and τ is the maximum single amplitude horizontal shear stress.

For the triaxial tests the Cyclic strength ratio is represented as CSR (eq.2):

$$CSR = \frac{\sigma_d}{2\sigma'_{vc}} \qquad (2)$$

Where,

σ_d is the maximum single amplitude axial stress,

σ'_{vc} is the effective isotropic consolidation stress.

The element testing, more specific the performed cyclic tests are a good basis for understanding better the cyclic behavior of the Skopje sand and the density correlation with the liquefaction potential. The results presented in this study clearly show the liquefaction susceptibility of the Skopje sand. The obtained graph emphasise the soil liquefaction development of the Skopje sand initiated by axial strain development and accumulation of excess pore pressure in the triaxial stress conditions and the decrease of the effective and shear stresses in the simple shear stress conditions.

It can be noted that despite the difference in the stress conditions in both apparatus, the liquefaction curves of the natural sand are similar and give good foundation as basis for further research and comparison of other effects on sands and parameters obtained in the tests.

It is also to be underlined that there is difference in the preparation method in both apparatus, wet tamping method for the triaxial tests and dry deposition method for the simple shear test.

It is known that different methods of reconstituting samples produce samples of different structure and behavioral characteristics, (Tatsuoka, 1986). Thus, it is important to be able to reproduce the same density and soil fabric of specimens according to the purpose of the research. Yet, in this paper the number of results to compare the preparation methods were limited, so conclusion can not be derived concerning this issue.

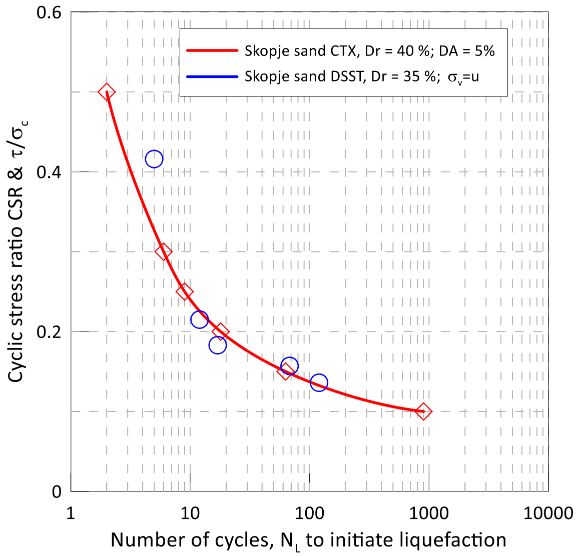

Figure 7 Results from triaxial cyclic test on Skopje sand for Dr = 40%, CSR=0.20

4 CONCLUSIONS

Extensive experimental research program on element tests have been performed on natural sand from the Vardar river terraces in the city of Skopje. In this paper, the results of liuefaction potential obtained from the dynamic simple shear tests are compared with the results of cyclic triaxial tests. The obtained graph emphasise the soil liquefaction development of the Skopje sand initiated by axial strain development and accumulation of excess pore pressure in the triaxial stress conditions and the decrease of the effective and shear stresses in the simple shear stress conditions. It can be noted that despite the difference in the stress conditions in both apparatus, the liquefaction curves of the natural sand are similar. The results can be good foundation for further research and definition of correlation coefficients between cyclic simple shear tests and cyclic triaxial tests which can be useful for analyzing laboratory element tests on sands.

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