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Experimental Setup for Sand Liquefaction Studies on Shaking Table

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ABSTRACT

This paper presents some important features in experimental setup for sand liquefaction studies on shaking table. The first part deals with the main aspects in the process of design, construction and installation of the laminar box in the Laboratory for Dynamics of Soil and Foundation at the Institute of Earthquake Engineering and Engineering Seismology in Skopje, Macedonia, whereas the second part involves characterization and definition of the dynamic parameters and liquefaction susceptibility of Skopje sand, which is planned to be used in the model testing, by a series of triaxial, cyclic tests, and dynamic simple shear test. The results from the so far performed research have provided encouraging and valuable basis for the second phase of the investigations – shaking table test on geo models. The comprehensive research program of the Skopje sand is expected to give beneficial and useful results in the soil liquefaction experimental research area.

Introduction

Model tests are essential when prototype behaviour is complex and difficult to be understood. In model testing, usually the boundary conditions of a prototype are reproduced in a small-scale model. If done properly, scaled model tests can be advantageous for seismic studies because of their ability to give economic and realistic information about ground amplification, change in pore water pressure, soil non-linearity, and occurrence of failure and soil structure interaction problems (Prasad et. al, 2004, Ueng et. al, 2010; Kokusho, 2003; Orense et al., 2003; Sesov, 2003; A.T. Carvalho et. al, 2010; Coelho, 2007; Taylor, 1994; Cubrinovski et. al, 2006; Towhata et. al, 2004 and others). The model tests can be divided into two categories, namely, those performed under gravitational field of earth (generally called shaking table tests or 1-g tests) and those performed under higher gravitational field (centrifuge tests or multi-g tests). Both shaking table and centrifuge model tests have certain advantages and limitations. Shaking table tests have the advantage of well controlled large amplitude, multi-axis input motions and easier experimental measurements and their use is justified if the purpose of the test is to validate the numerical model or to understand the basic failure mechanisms (Jafarzadeh, 2004). In the case of geotechnical structures, an additional issue is related to the presence of a container which will set the boundary conditions of the soil. Laminar box or shear box is widely used experimental tool for both mentioned categories.

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IZIIS investigated the key parameters and criteria, which laminar boxes as experimental tools have to satisfy in order to enable representative shaking table tests on large geo-models. The laminar box is designed and is installed in the laboratory for Dynamic Testing of Soils at the Institute of Earthquake Engineering and Engineering Seismology IZIIS in Skopje, Macedonia. The laminar box is planned to be used for experimental testing on fully saturated cohesionless soil in order to investigate the liquefaction phenomena and cyclic behavior of cohesionless soil in earthquake conditions. The comprehensive research program is ongoing and is expected to give beneficial and useful results into the soil liquefaction experimental research area. On the other hand, the sand which is planned to be used in the shaking table tests is representative for the alluvial deposits around the Vardar River and the performed investigations can be a good basis for further definition and higher awareness of the liquefaction hazard in the Republic of Macedonia.

Laminar Box – Design Issues

The ideal container is one that gives a seismic response of the soil model identical to that obtained in the prototype, i.e. the semi-infinite soil layer 1D response under vertically propagating shear waves. The boundary conditions created by the model container walls have to be considered carefully, otherwise the field conditions cannot be simulated properly. The presence of rigid and smooth end walls in the case of a ground model introduce three serious boundary effects compared with a semi-infinite soil layer in the prototype: deformation incompatibility, stress dissimilarity and input excitation pattern dissimilarity (A.T. Carvalho et al. 2010). For flexibility of the walls of the container, a laminar system is applied, since in this system, the shear stiffness of the walls is limited to the friction between the layers and the influence of the rubber membrane inside the box. So this kind, the so called laminar shear box, at the time of liquefaction, has the least undesirable effect in the real behavior of the model (Sesov, 2003).

The present laminar box (Figure 1) is designed according the following criteria:

- The layers and the membrane inside should have a minimum stiffness to horizontal shear;
- The laminar box should have mass much smaller than the soil material which is built inside it;
- It retains water and air without leakage;
- It offers little resistance to vertical settlement of soil;
- The height of each layer is small which increases the flexibility for the deformation of the soil inside;
- It is fairly large to better simulate field behaviour;
- It possesses capability to increase confining pressure;
- It maintains its horizontal cross section during shaking;
- It develops a shear stress on the interface between the soil and the vertical wall equal to that on the horizontal plane;
- It provides good contact between the bearings and the groove;

- It allows free movement of soil along the transverse cross section;
- It possesses provision for instrumentation;
- It is strong and stable against all the dynamic forces and moments;
- Its connection to the shaking table is stiff.

Dimensions: 2m * 1m * 1.5m
Material of the sliding laminar rings – aluminium
Material of the frame and base plate – steel
Number of rings: 16
Weight of each ring ~36kg
Total weight of the empty container: 1553 kg

The designed container consists from the following main components:

(a) Aluminum layers and ball bearings;

(b) Base plate with saturation and drainage system in the floor;

(c) Steel frame to ensure sliding of the laminar rings in one direction;

(d) Internal membrane used as a cut-off and keeping the moving bearings away from dust.

Figure 1. The laminar box designed and constructed in IZIIS

Skopje Sand Properties

The selected Skopje sand, which is planned to be used for the shaking table tests, is natural alluvial sand from the river terraces of Vardar in Skopje valley. The shape of the sand particles is well rounded and homogeneous (Figure 2). From the detailed silicate analysis, it is obtained that the sand is mostly consisted by silica oxides (around 78 %). The grain size distribution curve of the sand (ISO/TS 17892-4:2004) is shown in Figure 2 together with other standard sands for investigating the liquefaction phenomena and it very well fits into the boundaries given by Terzaghi et al. (1996) for high susceptibility sands to liquefaction. The physical properties of Skopje sand are given in Table 1.

Table 1. Skopje sand physical properties.

e_{min}	e_{max}	Gs [kN/m^3]	D_{50} [mm]	Cu	Cc
0.88	0.51	2.615	0.16	1.8	0.8

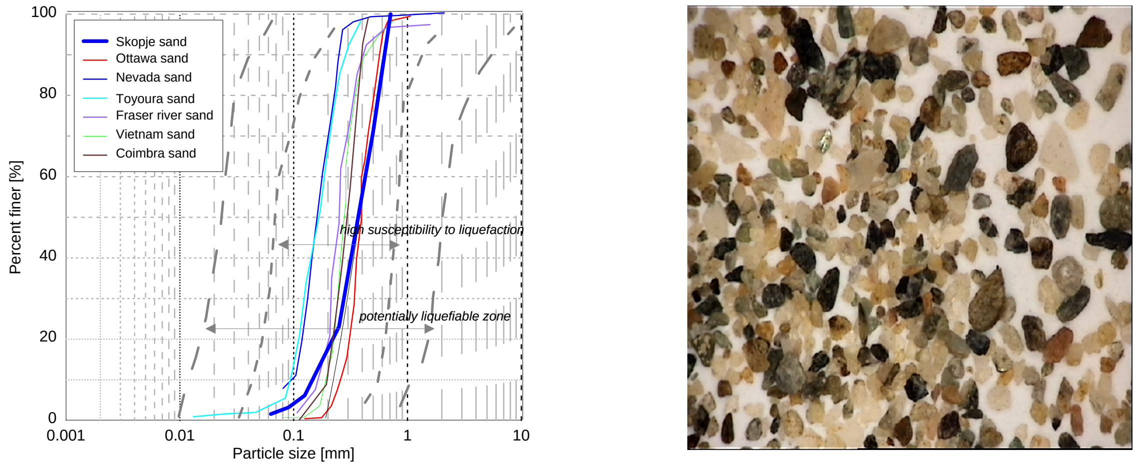

Figure 2. Particle shape of Skopje sand [zoom 40x] (left) and grain size distribution of Skopje sand (right)

Selected Results from Element Testing

Cyclic Simple Shear Tests

Two series of 7 cyclic simple shear series on soil sample with relative density of Dr=50% and vertical stress of 97 kPa were performed. Dynamic excitation was applied in the form of short series of cyclic simple shear loads with frequency of 0.1 Hz by controlling the shear strains (strain control). The excitation was applied step-by-step, with variation of the maximum amplitude of shear strains.

Shear stress versus shear strain relationships for each selected soil material was derived from the performed tests. The characteristic results for G/Gmax and damping D curves for different level of shear strain are presented in Figure 3.

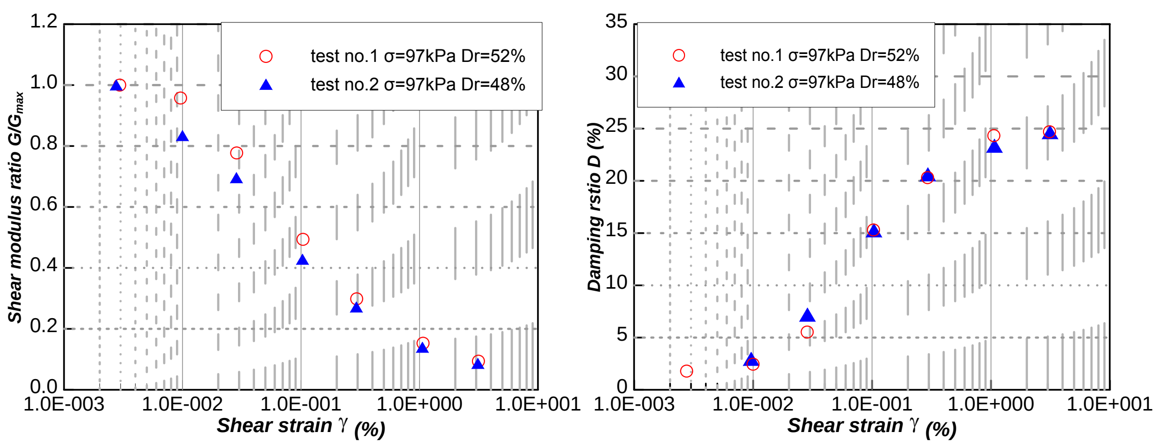

Figure 3.G/Gmax and damping D curves depending on shear strain levels [%]

Triaxial Monotonic Compression Tests in Drained Conditions

The drained behavior of Skopje sand was investigated under monotonic triaxial compression. A series of monotonic tests were performed with the same loading rate of 0.2 mm/min, for different relative densities Dr of the samples (30 %, 50% and 70%), and for various levels of consolidation pressure (50 kPa, 100kPa, 200kPa and 400kPa). The wet tamping method was used as sample preparation method. The stress strain behavior versus axial strain for the sample with Dr=50% under different consolidation pressure is presented in Figure 4. It was compared to the monotonic behavior of the Toyoura sand investigated in the laboratory for Soil Dynamics in IZIIS Skopje (Edip, 2013). From the presented graphs, it can be noted that the Skopje sand has a slightly higher strength values than the Toyoura sand, as shown by the laboratory investigation of the liquefaction phenomena.

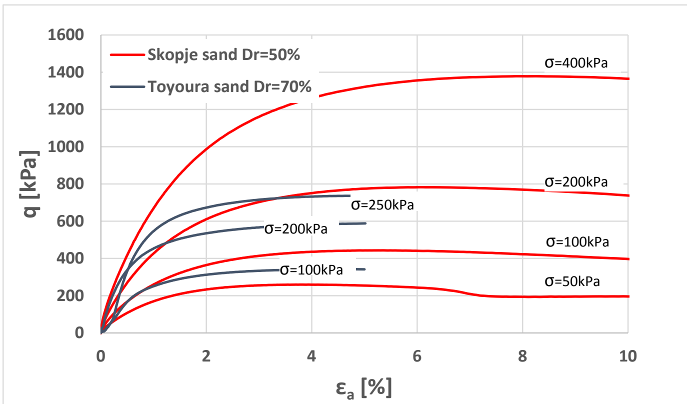

Figure 4.Stress-strain behavior under monotonic compression in drained conditions for Dr=50% compared to the Toyoura sand (Dr=70%).

Triaxial Load Control Cyclic Tests

The cyclic tests were performed according to the ASTM standard D 5311-92 for different densities, 30% 50% and 70%. The wet tamping (WT) method was used as a sample preparation method. The applied cyclic loading frequency was 0.5 Hz. During the element tests, emphasis was given on the relative density Dr of the soil samples since it is one of the key parameters in the shaking table test modelling. The liquefaction initiation is defined on the basis of the number of cycles required to reach double amplitude (DA) strain of 5 %. Since this is a new type of sand, no previous results were available. The liquefaction curves of the Skopje sand for different densities are given in Figure 5, compared with the liquefaction curve of the standard Toyoura sand given by Tatsuoka et al., 1986).

Figure 6 presents selected triaxial tests with CSR of 0.2 for sand Dr of 30 % and 50%, respectively. The presented graphs emphasize the soil liquefaction development in the Skopje sand caused by axial strain development and accumulation of excess pore pressure. The results presented in this figure clearly show the liquefaction susceptibility of the Skopje sand.

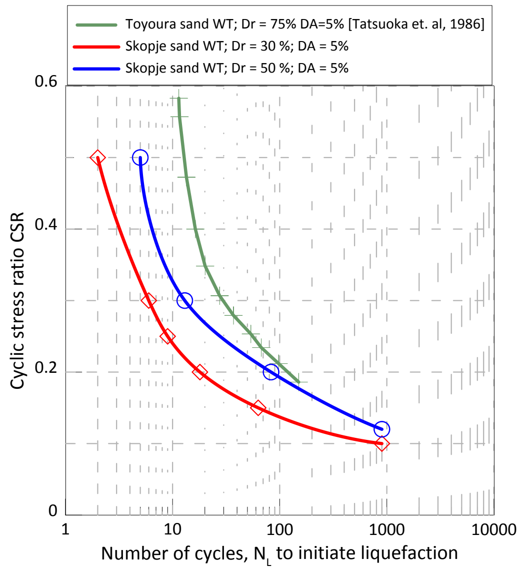

Figure 5.CSR vs. Number of cycles to initiate liquefaction

Conclusions

Model testing under 1-G environment in earthquake geotechnical engineering has become an integral part of research. The laminar box is a part of investigation study of liquefaction phenomena and cyclic behaviour of cohesionless soil. The use of laminar box will improve the efficiency of testing and simulating real ground conditions. Amplification, liquefaction and cyclic mobility phenomenon, excess pore water pressure generation and dissipation rates can be simulated by using such facilities.

The designed laminar box is going to be used for investigation of the liquefaction phenomena and cyclic response of cohesionless soils. It represents a useful tool for future experimental investigation of different kinds of phenomena in the area of earthquake geotechnical engineering. We strongly believe that this new design of a laminar container will overcome a lot of shortcomings exhibited by the previous types of laminar boxes or shear boxes such as boundary conditions, saturation of sand, etc. The results from the planned investigations will contribute a lot to the development of the geotechnical earthquake engineering in Europe.

The element testing program of the newly introduced Skopje sand is still ongoing and final assessment on whether this sand will be used for the model tests will be made after performing the complete testing program. The results from the so far performed element tests show suitable behavior of the Skopje sand as a new type of sand used in liquefaction studies. Finally, it can be pointed out that the Skopje sand could be used for investigating the liquefaction phenomena by shaking table model tests on a laminar box.

The comprehensive research program of the Skopje sand is expected to give beneficial and useful results in the soil liquefaction experimental research area. This sand is representative for the alluvial deposits around the Vardar River and the performed investigations can be a good basis for further definition and higher awareness of the liquefaction hazard in the Republic of Macedonia.

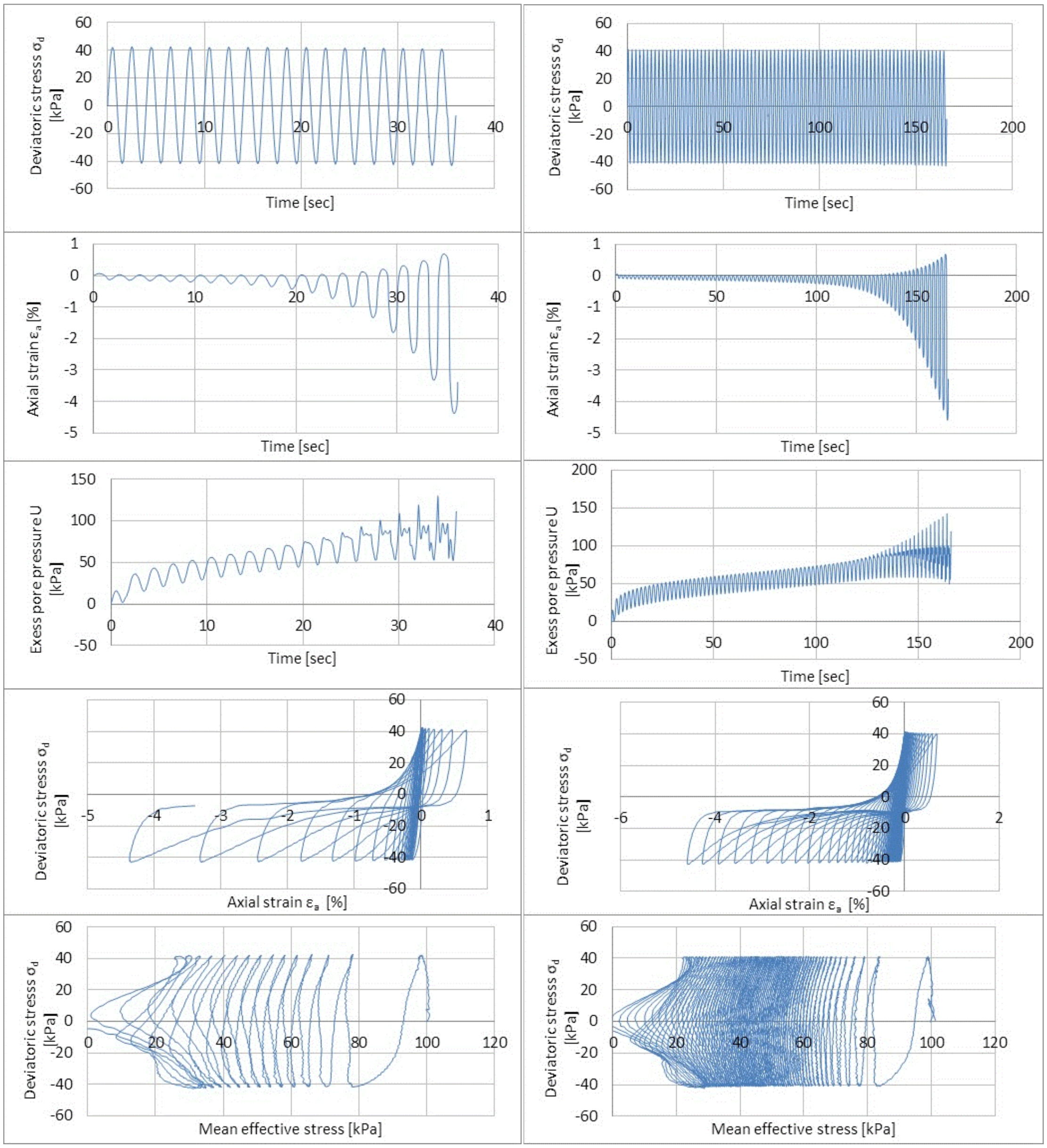

Figure 6.CSR vs. Number of cycles to initiate liquefaction for Dr of 30% (left) and 50% (right)

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