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SYSTEM FOR 1-G MODEL TESTING OF SAND

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Abstract

Liquefaction is a complex phenomenon during earthquakes and is associated with large deformation, pore pressure generation and loss of effective stress. Experimental methods complemented by numerical verification is appropriate tool for investigation of the dynamic behaviour of soil. In this paper, comprehensive experimental program, on new type of sand was performed to upgrade the understanding of the dynamic behaviour of cohesionless soil.

The performed research at first, 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, and second, involves characterization and definition of the dynamic parameters and liquefaction susceptibility of Skopje sand, which is used in the model testing, by an element testing program sustained of series of triaxial, cyclic tests, and dynamic simple shear test.

Detailed investigations were performed to define 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. Model tests in the designed laminar box were performed on shaking table, which are not presented in this paper. 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.

Keywords: liquefaction, laminarbox, shaking table, element tests

1. Introduction

Model tests are essential when the prototype behaviour is complex and difficult to understand. 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 handy information about ground amplification, change in pore water pressure, soil non-linearity, and occurrence of failure and soil structure interaction problems [1], [2], [3], [4], [5], [6], [7] and others. The model tests can be divided into two categories, namely, those performed under gravitational field (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, [8]. 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.
The study 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 of soils and foundations at the Institute for 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 behaviour 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 good basis for further definition and higher awareness of the liquefaction hazard in Republic of Macedonia.

2. Design process of the laminar box

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

The designed container consists of the following main components:
(a) Aluminum layers and ball bearings;
(b) Base plate with the saturation and drainage system in the floor;
(c) Steel frame to ensure the 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

The ideal container is the one that gives a seismic response of the soil model identical to that obtained in the case of 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 ground model introduce three serious boundary effects compared with a semi-infinite soil layer in a prototype: deformation incompatibility, stress dissimilarity and input excitation pattern dissimilarity, [4]. Bhattacharya [9] provides a review and discussion about all six different types of model container designs:

- Rigid container;
- Rigid container with flexible boundaries;
- Rigid container with hinged end-walls;
- Equivalent shear beam container;
- Laminar container;
- Active boundaries container.

Based on his review, it is realized that none of the six types of containers are suitable for all types of modelling applications. It is important to choose particular types of container depending on the analysed problem.

For the simulation of horizontal ground infinity the best solution is to applied laminar system of rings where the shear stiffness of the walls is limited to the friction between the layers and the stiffness of rubber membrane installed for water tightness. Such system of laminar rings similar to simple shear apparatus has the least undesirable effects simulating the dynamic soil behaviour, [5].

Design process followed the basic following criteria:

- Layers and the membrane should have minimum resistance to horizontal deformation of the soil model during shaking.
- Each laminar ring should have mass much smaller than the representative built in soil material
- It retains water and air without leakage.
- Allows vertical settlement of soil.
- Height of each layer is small enough which enables the smooth horizontal soil deformation along the container's walls increased the flexibility for the deformation of 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 shear stress on the interface between soil and vertical wall equal to that on the horizontal plane.
- It provides good contact between the bearings and 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.
- To provide stiff connection to the shaking table

The container consists of the following main components:

(a) Aluminium layers and ball bearings;
(b) Base plate with saturation and drainage system in the floor;
(c) Steel frame used to hold the laminar layers;
(d) Internal membrane used as a cut-off and keeping the moving bearings away from dust.

3. Experimental program

The selected Skopje sand, which is used for the shaking table tests, is natural alluvial sand from the river terraces of Vardar at Skopje valley. The shape of the sand particles is well rounded and homogeneous as it can be seen in Figure 2, left. 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 compared with other standard sands for investigating the liquefaction phenomena and it fits very well into the boundaries given by Terzaghi et al. (1996) [10] for high susceptible sands to liquefaction, [11], (Figure 2 on the right). The physical properties of Skopje sand are given in Table 1.

Table 1 Skopje sand physical properties

e_{min} (Mimimum void ratio)	e_{max} (Maximum void ratio)	Gs [kN/m^3] (Specific gravity)	D_{50} [mm] (Median particle size diameter)	Cu (Uniformity coefficient)	Cc (Coefficient of curvature)	φ_c [°] (Critical friction angle)
0.95	0.51	2.615	0.26	1.8	0.8	28.5

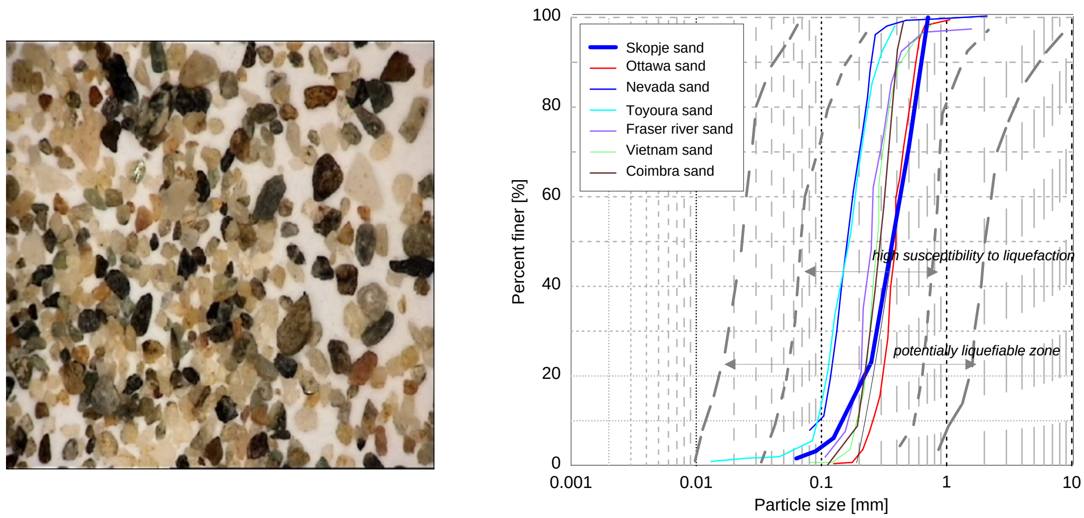

Figure 3 Particle shape and grain size distribution curve of Skopje sand [zoom 40x]

The main aspect of this study is to investigate the liquefaction susceptibility for the new type of sand in order to verify the applicability for the planned model shaking table tests. For that purpose the following test program has been set up and is still ongoing:

- Series of cyclic simple shear tests to define the dynamic properties of the soils, shear modulus and damping.
- Series of triaxial monotonic tests in undrained conditions
- Series of triaxial load controlled cyclic tests according to the ASTM standard D 5311-92 for different densities, 30% and 50%. As sample preparation method the wet tamping method was used. The applied cyclic loading frequency is 0.5 Hz. The liquefaction initiation is defined on the basis of the number of cycles required to reach a limiting double amplitude strain of 5 %.

Cyclic simple shear tests

Cyclic shear tests under constant vertical load with control of shear strains were performed in order to obtain information regarding the dynamic properties of Skopje sand. The defined dynamic characteristics will suit for further analysis and comparison to the planned shaking table investigation of the soil properties in liquefaction conditions.

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 performed tests. Characteristic results for G/Gmax and damping D curves for different level of shear strain are presented in Figure 3.

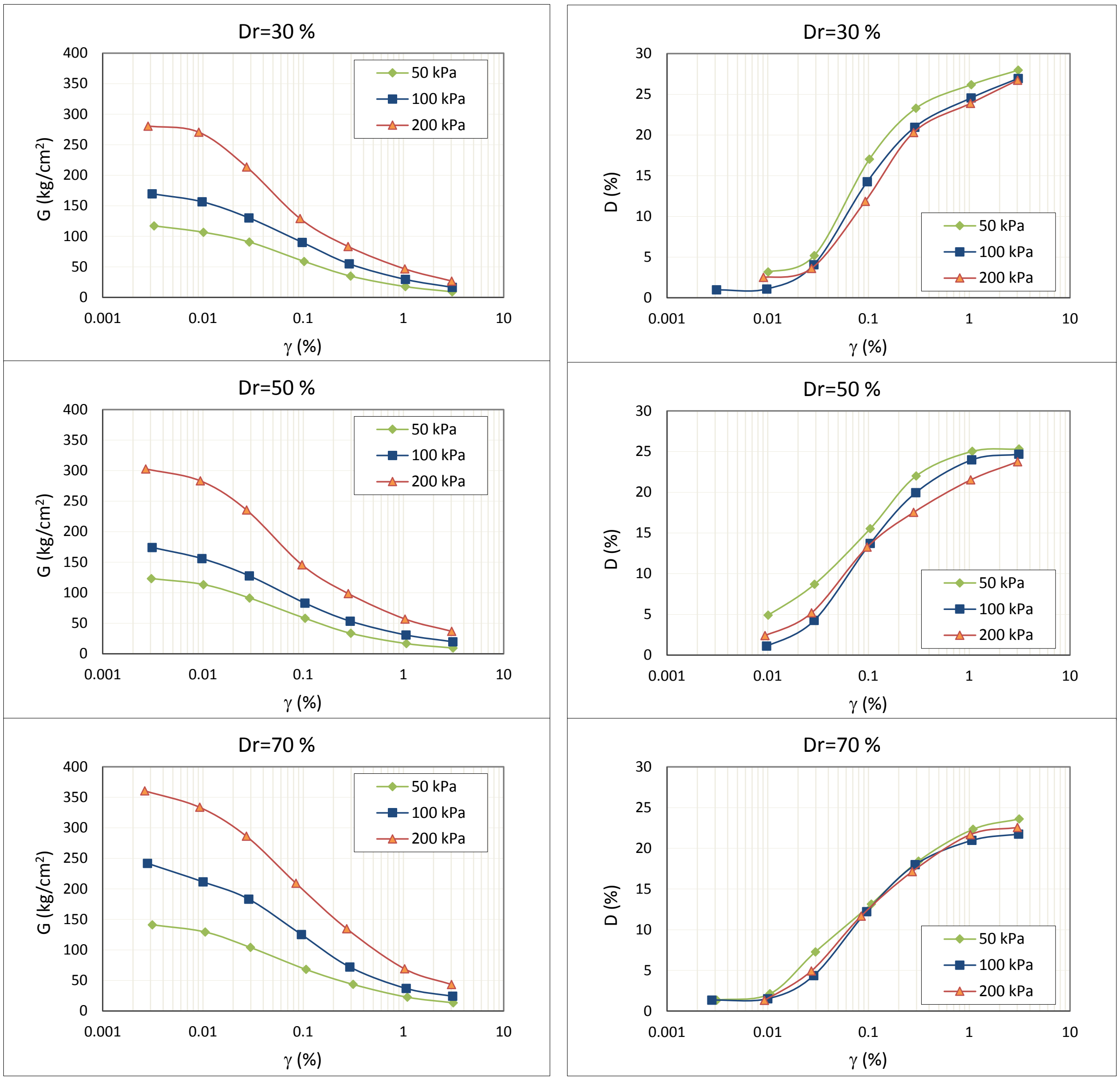

Figure 3. G/Gmax and damping D curves depending on shear strain levels [%] for different effective stresses

Triaxial monotonic compression tests in undrained conditions

A series of monotonic tests with the same loading rate of 0.2 mm/min were performed for different densities of samples (40 %, 55% and 75%) and for various levels of consolidation pressure (50 kPa, 100kPa, 200kPa and 400kPa. As sample preparation method the wet tamping method was used. Loose samples with density of 40 %, with different effective stresses, show contractive behavior and positive value of the pore pressure. This is also shown on the stress path graph in the p-q state, where the contractive loop can be easily observed.

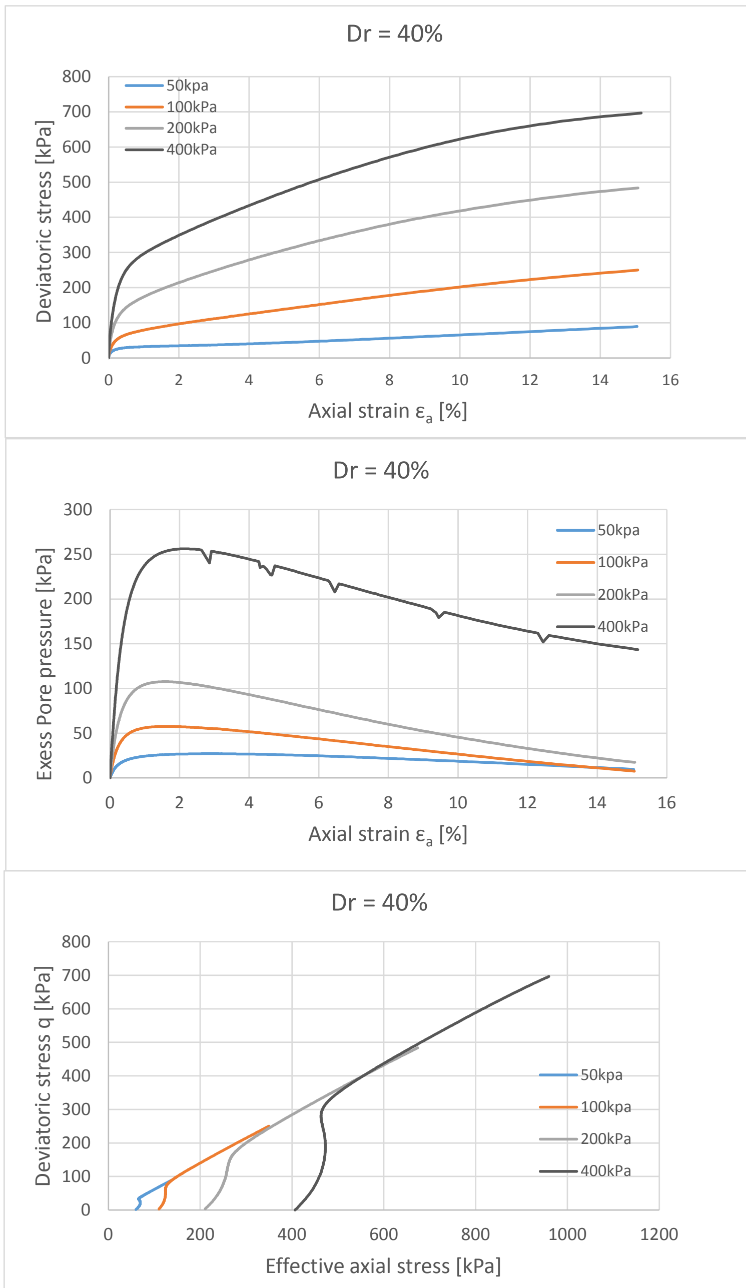

Figure 4. Results from monotonic compression undrained tests, (deviatoric stress vs axial strain, volume change vs axial strain and stress path) for the Dr=40% and different values of effective stresses for Skopje sand

Triaxial load control cyclic tests

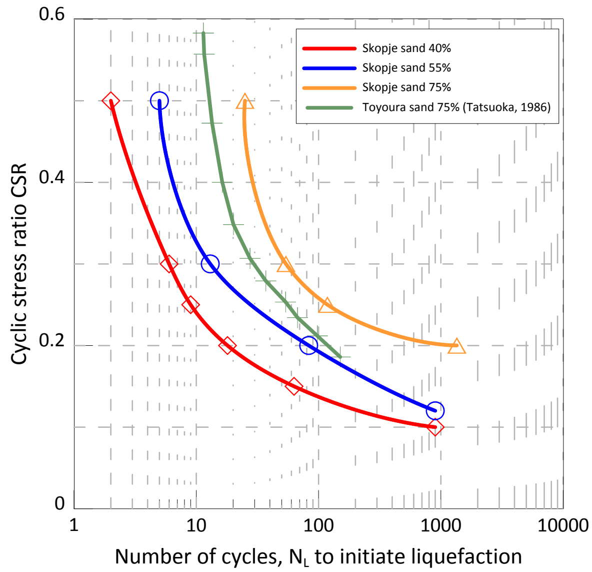

Figure 5. CSR vs. Number of Cycles to initiate liquefaction

The cyclic tests were performed according to the ASTM standard D 5311-92 for different densities, 40% 55% and 75%. As sample preparation method the wet tamping (WT) method was used. The applied cyclic loading frequency is 0.5 Hz, and the effective stress is 100 kPa. 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 new type of sand, no previous results were available, the liquefaction curves of Skopje sand for the different densities are given in Figure 4, compared with the liquefaction curve of standard Toyoura sand given by Tatsuoka et al., 1986, [12], . Results presented in this figure clearly notified the liquefaction susceptibility of the Skopje sand.
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 modeling.

4. Conclusions

Strong efforts have been made at Laboratory for Dynamics of soils and foundations at IZIIS, Skopje to design and installed medium size laminar container for research studies in the field of earthquake geotechnical engineering. Particular attention have been made towards boundary conditions that new laminar container should satisfied. The unique design of laminar rings and system of rollers overcome some of the shortcomings experienced at previous laminar containers. Experimental program has been defined to obtained necessary data for dynamic properties and liquefaction susceptibility of new type of sand.
The element testing program of the newly introduced Skopje sand is comprehensive and the results from the so far performed element tests show suitable behaviour of the Skopje sand as a new type of sand used in liquefaction studies. Finally, it can be pointed out that the Skopje sand is appropriate for investigating the liquefaction phenomena on shaking table model tests on laminar box. The comprehensive research program of the Skopje sand is expected to give beneficial and useful results into the soil liquefaction experimental research area. This sand is representative for the alluvial deposits around the Vardar River and the performed investigations can be good basis for further definition and higher awareness of the liquefaction hazard in Republic of Macedonia.

5. Copyrights

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