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SOME IMPORTANT ASPECTS IN EXPERIMENTAL SETUP FOR LIQUEFACTION STUDIES ON SHAKING TABLE TESTS

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ABSTRACT

Shaking table tests for investigating the liquefaction phenomena are planned to be performed on a recently designed laminar box in the Laboratory for dynamics of soil and foundation at the Institute of Earthquake Engineering and Engineering Seismology in Skopje, Macedonia.

The first part of the paper deals with the important aspects in the process of design, construction and installation of the laminar box whereas the second part involves the characterization and definition of the dynamic parameters and liquefaction susceptibility of the Skopje sand by series of triaxial, cyclic tests, and dynamic simple shear tests, which is planned to be used in the model testing.

The comprehensive research program of the Skopje sand is expected to give beneficial and useful results into the soil liquefaction experimental research area.

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 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

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(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.

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 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 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 good basis for further definition and higher awareness of the liquefaction hazard in Republic of Macedonia.

DESIGN PROCESS OF THE LAMINAR BOX IN IZIIS

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 in 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 rubber membrane inside the box. So this kind, so called laminar shear box; at the time of liquefaction, has the least undesirable effect in the real behavior of the model (Sesov, 2003).

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

- Layers and the membrane inside should have 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.

- Height of each layer is small which 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

All the construction activities are carried out at IZIIS only some necessary specific parts for the project are purchased from specialized companies. Figure 2 presents some parts of the construction and installation process of the laminar box.

Figure 2 The construction process of the laminar box

CHARACTERIZATION OF REPRESENTATIVE SAND TYPE BY DYNAMIC TRIAXIAL TESTS – SKOPJE SAND

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 at Skopje valley. The shape of the sand particles is well rounded and homogeneous as it can be seen in Figure 3. 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) for high susceptible sands to liquefaction (Cvetanovska J. et al. (2013)). The physical properties of Skopje sand are given in Table 1.

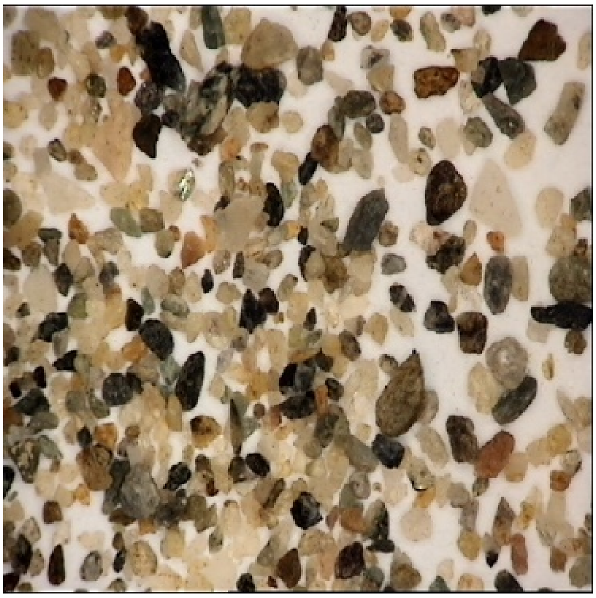

Figure 3 Particle shape of Skopje sand [zoom 40x]

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

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
- 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 %.

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. Figure 4 present the results from two selected triaxial tests with the same CSR of 0.2 but different densities of 30 % and 50 %. The presented graphs clearly show the liquefaction development of the Skopje sand given by the axial strain development and accumulation of excess pore pressure.

Since this is new type of sand, that was not investigated before, the liquefaction curves of Skopje sand for the different densities are given in Figure 5, compared with the liquefaction curve of standard Toyoura sand (Tatsuoka et al., 1986). Results presented in this figure clearly notified the liquefaction susceptibility of the Skopje sand.

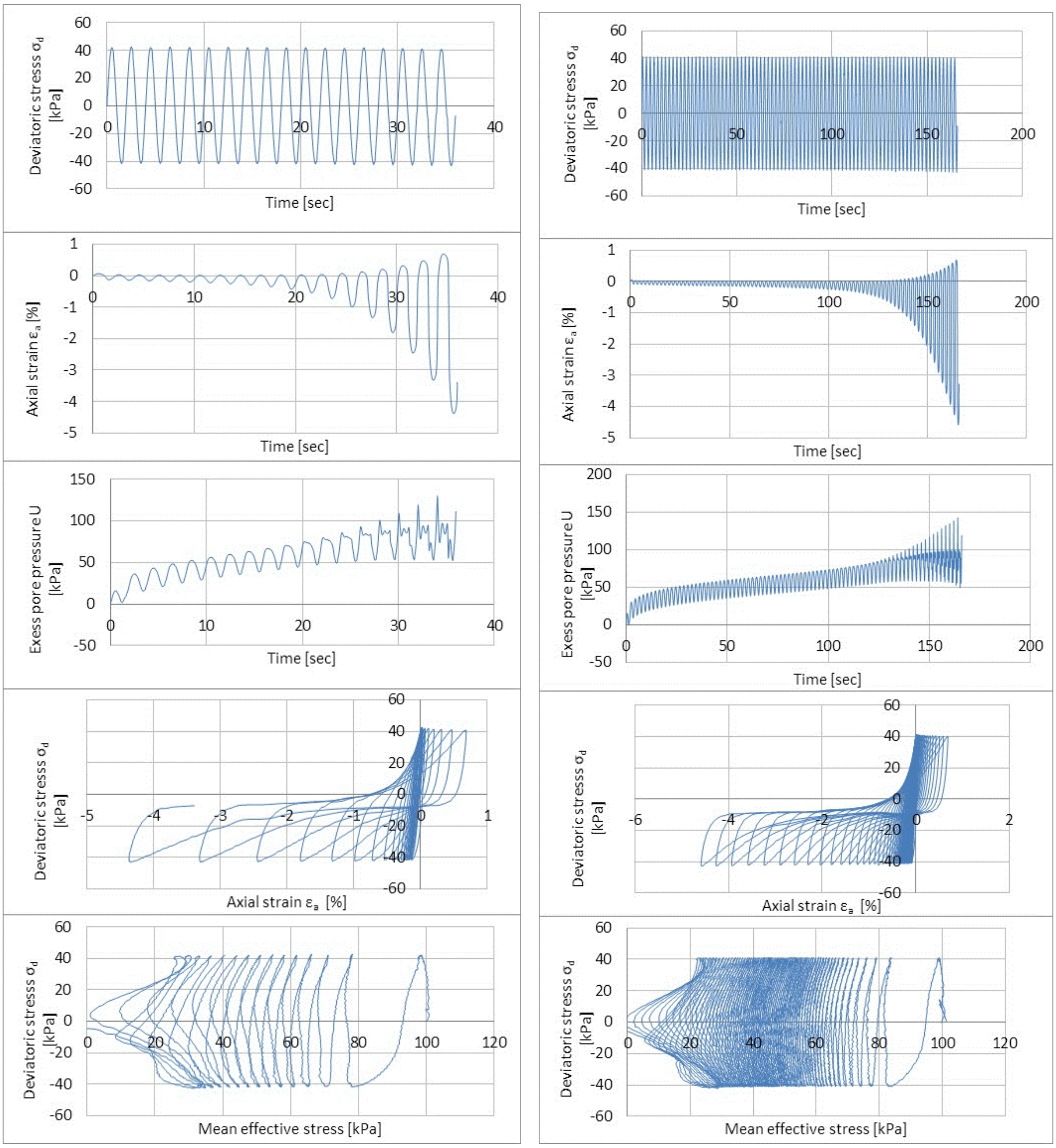

Figure 4 Test results for Dr=30% (left) and for Dr=50% (right)

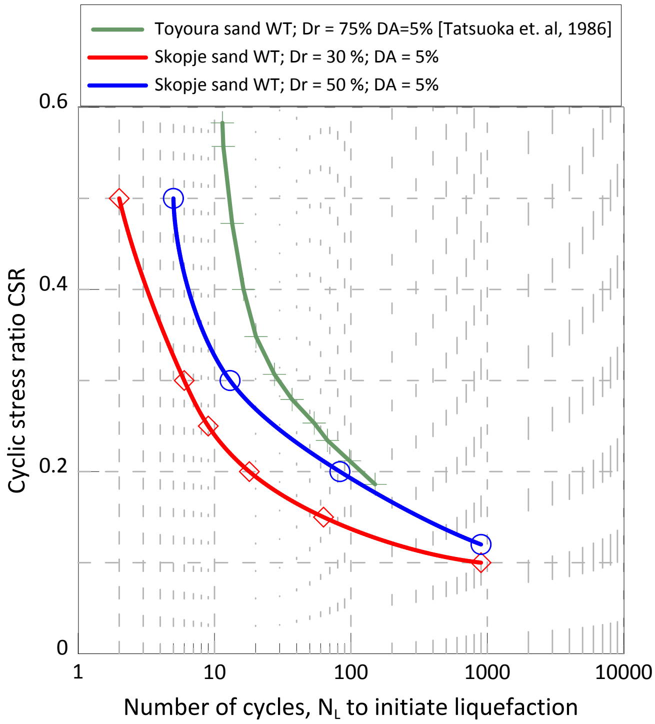

Figure 5. CSR vs. Number of Cycles to initiate liquefaction

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 on the liquefaction phenomena and cyclic behaviour of cohesionless soil. Use of laminar box will improve the efficiency of testing and simulating the real ground conditions. Amplification, liquefaction and cyclic mobility phenomenon, excess pore water pressure generation and dissipation rates can be performed using such facilities.

The designed laminar box is going to be used in order to investigate the liquefaction phenomena and cyclic response of cohesionless soils. It represents useful tool for future experimental investigation of different kind of phenomena from the area of earthquake geotechnical engineering. We strongly believe that this new design of Laminar Container will overcome a lot of shortcomings that previous types of laminar box or shear box exhibits such as boundary conditions, saturation of sand etc. The results from the planned investigations will have big influence in the European region for the development of the geotechnical earthquake engineering.

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 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.

REFERENCES

Alper Turan, Sean D. Hinchberger, et al., Design and commissioning of a laminar soil container for use on small shaking tables, *Soil Dynamics and Earthquake Engineering* **29**: (2009) 404-414.

Carvalho A. T., Bilé Serra J., et al. Design of experimental setup for 1 g seismic load tests on anchored retaining walls. *Physical Modelling in Geotechnics* – Springman, Laue & Seward (eds) L. © 2010 Taylor & Francis Group, ISBN 978-0-415-59288-8.

Cvetanovska J. et al. (2012) Important Aspects In Design Of Laminar Soil Container For 1-G Shaking Table Tests, 22nd European Young Geotechnical Engineers Conference, Gothenburg, Sweden, 26-29th August, 2012.

Cvetanovska J. et al. (2013) Sand characterization for experimental studies on liquefaction phenomena. . ICEGE Conference, from case history to practice in honour of prof. Kenji Ishihara, Istanbul 2013

Coelho P. In situ densification as a liquefaction resistance measure for bridge foundations. PhD thesis (2007), Churchill College, Cambridge

Cubrinovski M., T. K. a. K. I. (2006). "Interpretation from large-scale shake table tests on piles undergoing lateral spreading in liquefied soils." Soil Dynamics and Earthquake Engineering 26: 275-286

Iai S. Similitude for shaking table tests on soil-structure-fluid model in 1g gravitational field. *(1989) Soils and Foundations **29**(*1): 105-118.

Jafarzadeh F. Design and evaluation concepts of laminar shear box for 1g shaking table tests. *13th world conference on earthquake engineering (2004)Paper No. 1391*. Vancouver, B.C., Canada.

Kokusho, T. (2003). "Current state of research on flow failure considering void redistribution in liquefied deposits." Soil Dynamics and Earthquake Engineering 23(7): 585-603.

Orense, R. P., Morimoto, I., Yamamoto, Y., Yumiyama, T. Yamamoto, H. and Sugawara, K., Study on wall-type gravel drains as liquefaction countermeasure for underground structures. Soil Dyn. Earthquake Eng., 2003, 23, 19–39.

Prasad S. K., I. Towhata I., G. P. Chandradhara and P. Nanjundaswamy. Shaking table tests in earthquake geotechnical engineering. *Current science, special section: geotechnics and earthquake hazards* (2004) **87**(10)

Sesov V. Dynamic behavior of potentially nonstable layers and application of a model for decreasing the seismic risk of liquefaction occurrence. PhD Thesis (2003). University Ss. Cyril and Methodius-Skopje, Macedonia

Tatsuoka et al. (1986). “Cyclic undrained riaxial and torsional shear strength of sands for different sample preparation methods” Soils and Foundations Vol.26 No.3 23-41

Taylor C.A., Dar A.R., Crew A.J.,(1994), “Shaking table modelling of seismic geotechnical problems”, Proceeding of the 10th European Conference on Earthquake Engineering , Balkema, 1995: 441-446.

Towhata, I. (2004). Development of Geotechnical Earthquake Engineering in Japan. 6th Int. Conf. Soil Mech. Geotech. Eng. Osaka, Japan. 1: 251-291

Terzaghi, K.; Peck, R. and Mesri, G. (1996).”Soil mechanics in Engineering Practise”. 3ª ed., New York, John Wiley & Sons Inc, USA.

Ueng, T. S. (2010). "Shaking Table Tests for Studies of Soil Liquefaction and Soil-Pile Interaction." Geotechnical Engineering Journal of the SEAGS &AGSSEA 41(1).