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Physical modeling and 1-G testing using the new type of a laminar container

La modélisation physique et les tests 1-G utilisant le nouveau type de conteneur laminaire

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ABSTRACT: The research study dealt with the main aspects of the process of design, construction and installation of a laminar box and the liquefaction susceptibility of Skopje sand, along with 1-G model testing. A middle size laminar box was constructed at the Laboratory for Dynamics of Soils and Foundation at IZIIS, Skopje, During the design process, particular attention was paid to satisfying the key aspects related to the laminar container in order to enable representative physical modelling of large geo-models. Special type of aluminum alloy profile, light and rigid at the same time, was used to construct the laminar rings and small industrial type of bearings were chosen for the contact between the laminar rings. These bearings enable perfect rolling of the rings, reducing the friction to almost zero. The bottom of the container consists of perforated steel plates with a system of small pipes for saturation of the soil model. The interior side of the container walls was wrapped with a flexible thin membrane to prevent penetrating of soil particles and water into the bearing system. Such design details produced unique conditions for physical modeling and shaking table testing of the geo-models. The laminar container was mounted on the 5x5 shaking table and a series of dynamic tests were conducted to evaluate the liquefaction potential of the Skopje sand. The results show that the response of the soil model in the laminar container is of a shear beam type, with intensive liquefaction manifestation under higher levels of shaking.

RÉSUMÉ: Les etudes de recherche ont porté sur les principaux aspects du processus de conception, de construction et d'installation d'une boîte laminaire et de la sensibilité à la liquéfaction du sable de Skopje, ainsi que sur des essais sur modèle 1-G. Un boîtier laminaire de taille moyenne a été construit au laboratoire sur la dynamique des sols et des fondations à IZIIS, Skopje. Au cours du processus de conception, un soin particulier a été apporté à la satisfaction des aspects essentiels liés au conteneur laminaire afin de permettre la modélisation physique de larges géomodèles. Un type spécial de profil en alliage d'aluminium, à la fois léger et rigide, a été utilisé pour la construction des anneaux laminaires et de petits roulements de type industriel ont été choisis pour le contact entre les anneaux laminaires. Ces roulements permettent un roulement parfait des anneaux, réduisant le frottement à presque zéro. Le fond du conteneur est constitué de plaques d'acier perforées avec un système de petits tuyaux pour saturer le modèle de sol. L'intérieur des parois du conteneur a été enveloppé d'une fine membrane flexible pour empêcher la pénétration de particules de sol et d'eau dans le système de roulement. Ces détails de conception ont créé des conditions uniques pour la modélisation physique et les tests sur table à

secousses des géomodèles. Le conteneur laminaire a été monté sur la table à secousses 5x5 et une série d'essais dynamiques a été réalisée pour évaluer le potentiel de liquéfaction du sable de Skopje. Les résultats montrent que la réponse du modèle de sol dans le conteneur laminaire est du type à faisceau de cisaillement, avec une manifestation de liquéfaction intensive sous des niveaux plus élevés d'agitation.

Keywords: laminar box; physical modelling; shaking table; liquefaction; sand.

Mots-clés: boîte laminaire; modélisation physique; table à secousses; liquéfaction; le sable.

1 INTRODUCTION

Model tests are essential when the prototype behavior 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 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 (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, stable experimental measurements and scaling aspects. 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 ground. Laminar container or shear box is widely used experimental tool for either shaking table or centrifuge testing.

This paper presents the results from investigation on the key parameters, which laminar box as experimental tool has to satisfy in order to enable representative shaking table tests on large geomodels. 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, (http://www.iziis.edu.mk/?page_id=119). The laminar box was used for shaking table tests on fully saturated cohesionless soil in order to investigate the liquefaction phenomena in earthquake prone regions. The sand which was used for the shaking table tests was taken from the alluvial deposits around the Vardar River. The results from shaking table tests verified the laminar box's response and proven the usefulness of its application for investigations of complex geotechnical earthquake problems. The performed investigations rise up researchers' awareness on the liquefaction hazard in Republic of Macedonia.

2 DESIGN CRITERIA FOR THE LAMINAR BOX

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 the container's wall a laminar system is introduced, 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. This so called laminar shear box; during the shaking has the least undesirable effect in the real behavior of the model (Sesov, 2003).

Figure 1. The new constructed laminar box at IZIIS

The geotechnical model cannot be directly mounted on shaking table due to the requirements of confinement. An ideal container should be large, flexible, massless and transparent. However, it is impossible to provide all the essential features. During the last decade many laminar boxes are being developed to suit field conditions better.

The new laminar box constructed in IZIIS and described in this paper (Figure 1) is designed according the following criteria:

- The laminar box should have mass much smaller than the soil material which is built inside it
- It retains liquid / water, 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 behavior.
- 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.
- It allows free movement of soil along the transverse cross section.
- It allows space for instrumentation.
- It is strong and stable against all the dynamic forces and moments.
- To provide fixed and stable connection to the shaking table

3 COMPONENTS OF THE LAMINAR CONTAINER

The dimensions of the laminar container are 2.0 x 1.0 m at base and 1.5m in height. The total weight of empty container is 1553 kg and consists of the following main components:

(a) 16 Aluminum layers/rings and ball bearing system;

(b) Steel base plate with the saturation and drainage system;

(c) Rigid steel frame which enables the integrity of laminar layers;

(d) Flexible rubber based membrane which covers the internal area of conatiner's walls.

3.1 The layers and the mechanism of motion

Each layer is a rectangular ring which is composed of hollow aluminum 40×80 mm profiles. The whole system is composed of 16 layers-rings. In order to minimize the friction between the layers, transfer bearing system have been used so that the motion in the horizontal plane is possible. This system is designed in a way that it can be simply as possible and without any additional devices to provide maximum sliding of rings with minimum friction. This act as a column between the lower and upper hollow aluminum sections and prevents the surface from being deformed, by the point contact stress between the bearing and the surface of the aluminum profile. In order to make the distribution uniform, rotating ball bearing are used in each layer and the gap between the 2 adjacent layers is 3 mm. The weight of each ring is 36 kg.

3.2 The steel frame

The steel frame is used to attach the whole container to the shaking table and to provide the necessary integrity of the components of the laminar container. At the upper side, non-moving guides are installed for connection to the highest laminar layer. The guides should prevent vertical moving of the laminar layer. The steel frame allows installation of measuring devices for the acquisition system. Stoppers are constructed serving to fix the frame during preparation of the installation of the sand into the container, also rubber dampers are installed to limit and control eventually large translational movements of the laminar rings during the shaking.

3.3 Base plate, saturation and drainage system

The lowest laminar layer has been fixed on a steel U18 profiles which are fixed on a steel base with 2.7 × 1.7 × 0.015 m in dimensions. In order to allow saturation of the soil model, the base has been designed with double bottom plates (one is perforated) and system of small pipes. In this way, not only saturation and drainage of the samples is facilitated but also improves the contact between the soil and the steel plate of the container which makes better shear stress transition.

For hydraulic cut-off system and the protection of the ball bearings, the inside of the container is covered by a 1.2 mm rubber based membrane.

3.4 Sieve for installing the sand

The method for pouring the sand in the laminar box should: 1) be able to produce loose to dense sand beds in the unit weight range expected within an in-situ soil deposit; 2) the sand bed must have a uniform void ratio throughout; 3) the samples should be well mixed without particle segregation, regardless of particle gradation or fines content; 4) sample preparation method should simulate the mode of soil deposition commonly found in the soil deposit being modeled (Gade et. al, 2013).

One of the most widely used method for preparation of sand models is dry pluviation method where dry sand is either “rained” over the surface of the model, or poured close to the surface, creating a dry soil profile (Stringer et. al, 2013).

Dry pluviator devices can be split into three categories, based on the area over which sand is rained and the required number of axes of movement relative to the model: point pluviators, curtain pluviators and carpet pluviators. With point pluviators, the sand ‘rains’ from a relatively small opening which is moved along 3 axes to cover the complete model area and maintain a constant falling height. Curtain pluviators are designed to pluviate a complete line of sand across the surface of the model and as such they must be moved laterally across the model along one axis, as well as vertically. Finally, carpet pluviators drop sand across the full surface area of the model, requiring only vertical movement of the equipment. For the purpose of so called carpet pluviator technique of installing the sand in the laminar box,

sieve is constructed. Based on previous studies and tests, the sieve is made from wooden frame and steel plate perforated with holes of 10 mm. Calibration tests of installing the sand into the laminar box verified that the designed sieve is suitable for installation of the sand.

4 1-G TESTS ON LIQUEFACTION OF SAND

A series of tests on the shaking table at IZIIS were performed on homogenous sand model installed in the laminar box. The test was performed to a full scale, simulating a homogenous sand model with a height of 1.3 meters. No similitude laws were applied. The sand material used for the shaking table test was Skopje sand (Bojadjieva, 2015), Figure 2. The main objectives of the performed tests (Table 2) were the following:

- To verify the performance of laminar box and to confirm the design concepts;
- To simulate soil liquefaction and monitor the physical measurements such as accelerations, displacements and pore pressure development.

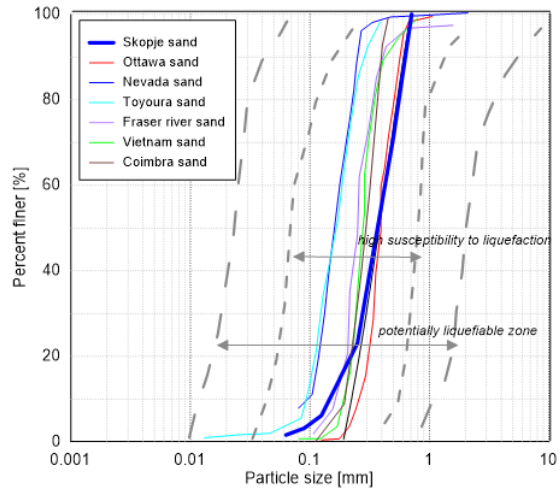

Figure 2 Skopje sand – grain size distribution along the distributions for other types of sands

Table 1. Description of the shaking table tests

Test	f [Hz]	a [g]	T [sec]
T_01	2	0.05	12
T_02	2	0.10	12
T_03	2	0.20	12

Results of the test are obtained from the several types of installed transducers: accelerometers (ACC), LVDTs and pore water pressure transducers (PWP). The instrumentation scheme is given in Figure 3.

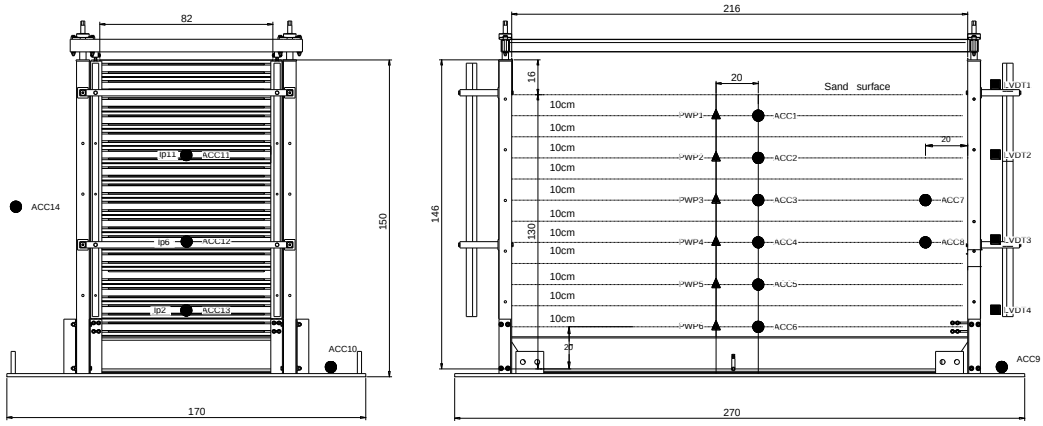

Figure 3 Instrumentation for the shaking table tests

The recorded data obtained from the installed devices exhibit reliable and stable measurements which is very important issue during the shaking table testing in order to capture the actual response of the soil model and laminar box.

The results show that the input acceleration matches exactly the acceleration measured at the base plate of the laminar box. Thus, the design concept that the laminar box should provide fixed connection to the shaking table is fulfilled, no relative movement laminar box and shaking table is allowed. Based on the comparison of acceleration time histories in both directions, it can be concluded that the design concept focused on one-dimensional vibration of the laminar box is also satisfied.

Based on the comparison of the recorded acceleration response in the middle of the sand layer ACC04 and the one close to laminar box's wall ACC08 at the same depth of -70cm (Figure 4), it can be observed very good agreement until the initiation of liquefaction, t=8.10 sec. This confirms that the boundary effects have no significant impact on soil response.

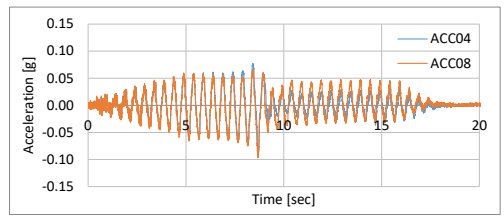

Figure 4 Recorded soil acceleration responses at the middle and close to wall, a_{input} = 0.05g

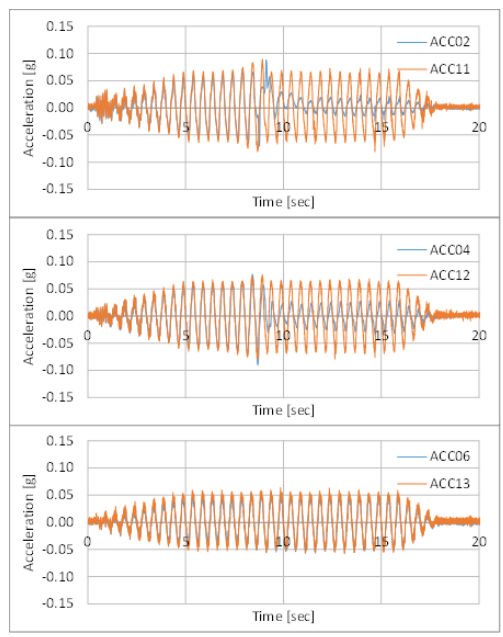

Figure 5 Recorded accelerations, at soil layer and steel frame, a_{input} = 0.05g

Figure 5 presents the results of acceleration recordings at the frame *(ACC11, ACC12, ACC13)* and at soil layers *(ACC02, ACC04, ACC06)*, from which can be concluded that the laminar box follows the soil response. Bearing system works fine, allowing 'zero' friction, soil movement is product only by soil response.

The soil liquefaction at each shaking table test was defined based on the recorded pore water pressures, accelerations and displacements. Liquefaction was observed within a certain depth instead of the whole model. The measurements from the transducers show that the liquefaction at each test occurs more or less at the same time along the model's depth. The number of cycles required to cause liquefaction increase with the increase of the relative density. It is worth mentioning that besides the recordings from measuring devices, manifestation of soil liquefaction like sand boils have been observed during the shaking.

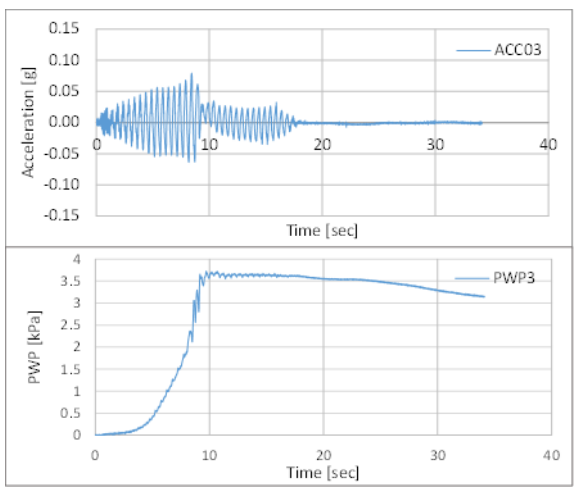

Figure 6 Soil liquefaction – acceleration and excess PWP time histories, at depth -50cm, a_{input} = 0.05g

Figure 6 shows typical results of liquefaction occurrence during the shaking. At the beginning of the test till t=0.80 s there is accumulation of pore water pressure but acceleration response of soil layer is stable, soil behaves like solid material. After t=0.80 s pore water pressure reaches the level of vertical stresses, effective stresses drops to almost zero and the soil loses its shear strength. Consequently drops of acceleration response can be observed and period of vibration elongates. This is characteristic response of fully saturated sandy soils.

Obtained results from shaking table tests for acceleration, pore water pressures development and soil displacements have shown that laminar box provides very good conditions for laboratory investigation of complex geotechnical problems in 1-G environment.

5 CONCLUSIONS

Model 1-G testing has become one of the essential method for investigation of complex earthquake geotechnical problems. Such testing requires special devices and equipment which are necessary to be well integrated in single system to have satisfactory results. Vigilant design procedure for new laminar shear container have been presented in this paper. Newly constructed laminar container at IZIIS satisfies most of the theoretical requirements for perfectly laminar shear containers.

The verification on laminar box's performance was done by series of shaking table tests on saturated sandy model. The main test objective was to investigate liquefaction potential of Skopje sand in 1-G field. The laminar box exhibited behavior as it was expected and the results confirmed that the design criteria were fulfilled Response of the soil layers during the shaking was similar to shear beam behavior. The sand used for the shaking table tests is representative for the alluvial deposits around the Vardar River. The results from tests are filling some of the gaps and unknowns which are currently present regarding the liquefaction potential of river terraces in Balkan regions

The 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, drainage, instrumentation.

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7 REFERENCES

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

Bojadjieva J. (2015). Dynamic Behavior Of Saturated Cohesionless Soils Based On Element And 1-G Experiments, PhD Thesis, Ss. Cyril and Methodius: Institute of Earthquake Engineering and Engineering Seismology.

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.

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

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.

A.T. Carvalho, J. Bilé Serra, 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.

V. Sesov. 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.

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

Stringer, M. E., L. Pedersen, et al. (2013). Design and use of a rotating spiral pluviator for creating large sand models. ICPMG2014 Physical Modelling in Geotechnics, CRC Press: 253-258.

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).