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PREPARATION OF A LARGE MAILIAO SILTY SAND SPECIMEN FOR SHAKING TABLE TEST

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ABSTRACT

Sample preparation method of the Mailiao silty sand specimen in a large scale laminar shear box (1.880 m × 1.880 m ×1.520 m) was evaluated for the study of the behavior of saturated silty sand in shaking table tests. Mailiao silty sand, a typical soil of the reclaimed lands in the western coastal area in Taiwan, was used in this study. The silty sand specimen inside the shear box was prepared by the staged sedimentation method from a specially made pluviation device. The uniformity, density and saturation of the sand were checked by the thin-walled tube sampling and P-wave velocity measurements. The results showed that uniformity and saturation of the specimen were satisfactory by the preparation method used in this study. A series of shaking table tests with various acceleration amplitudes, frequencies, durations, and shaking directions were performed on the saturated Mailiao silty sand inside the large laminar shear box at National Center for Research on Earthquake Engineering (NCREE). Pore water pressures and accelerations within the soil, and displacements, accelerations and velocities of the frames of various depths were measured during tests under both one- and two-dimensional shaking. It is found that the behavior of the silty sand under shaking, including pore water pressure generation and dissipation, surface settlement, and liquefaction, is quite different from that of the clean sand.

Keywords: Silty sand, Sample preparation method, Shaking table test, Liquefaction, Pore water pressure

INTRODUCTION

In the past, the studies on the undrained stress-strain behavior and seismic behavior of clean sand have been tested in the laboratory. However, natural sandy soils usually contain some amount of fines and have different mechanical behaviors from clean sand. At present, most studies on the seismic behaviors of silty sand, such as strain-stress relationship and liquefaction, are tested in the laboratory by using triaxial compression apparatus, simple shear devices, and torsional shear apparatus under regular or irregular dynamic loads (e.g., Yamauro & Lade, 1997; Thevanayagam et al., 2000; Amini & Oi, 2000; Huang et al., 2005). The stress conditions and deformations in the soil elements in these types of tests are significantly affected by the boundary condition, and the loading conditions are generally not the true field situations due to the limitations of the loading devices and the size of the specimens. A large-scale laminar biaxial shear box on the 5 m × 5 m shaking table at the National Center for Research on Earthquake Engineering (NCREE) in Taiwan has thus been developed to test a large soil specimen under one- and two-dimensional (multidirectional) earthquake shakings. The related studies on sample preparation of large sand specimen with a certain amount of fines are very limited (e.g., Ko, 2003; Huang et al., 2005). Thus, the main objective in this study is to develop a

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suitable way for preparing a large specimen of Mailiao silty sand in the large scale biaxial laminar shear box for the study of liquefaction and soil-structure interaction in a level ground.

BIAXIAL LAMINAR SHEAR BOX

Figure 1 shows schematically the biaxial laminar shear box which is composed of 15 layers of sliding frames. Each layer consists of two nested frames, an inner frame (1880 mm × 1880 mm) and an outer frame (1940 mm × 2340 mm). Both frames are made of a special aluminum alloy with 30 mm in thickness and 80 mm in height, except the uppermost layer that has a height of 100 mm. These 15 layers of frames are separately supported on the surrounding stacked rigid steel walls with a gap of 20 mm between adjacent layers. A 2-mm thick silicone membrane was placed inside the box to provide a watertight shear box to contain the saturated sand. Thus, a sand specimen of 1880 mm × 1880 mm × 1520 mm can be placed inside the inner frames.

Linear guideways consisting of sliding rails and bearing blocks are used to allow an almost frictionless horizontal movement without vertical motions. Each outer frame is supported by the sliding rails built on two opposite sides of the outer rigid walls. The bearing blocks on the outer frame allow its movement in the X direction with minimal friction. Similarly, sliding rails are also provided for each outer frame to support the inner frame of the same layer such that the inner frame can move in the Y direction with respect to the outer frame. With these 15 nested layers of inner and outer frames supported independently on the rigid walls, the soil at each depth can move in a multidirectional fashion in the horizontal plane without torsion in response to the wave actions induced by the shaking table.

Details of the design, manufacturing, sample preparation and tests of the performance of the laminar shear box can be found in (Ueng et al., 2006 a).

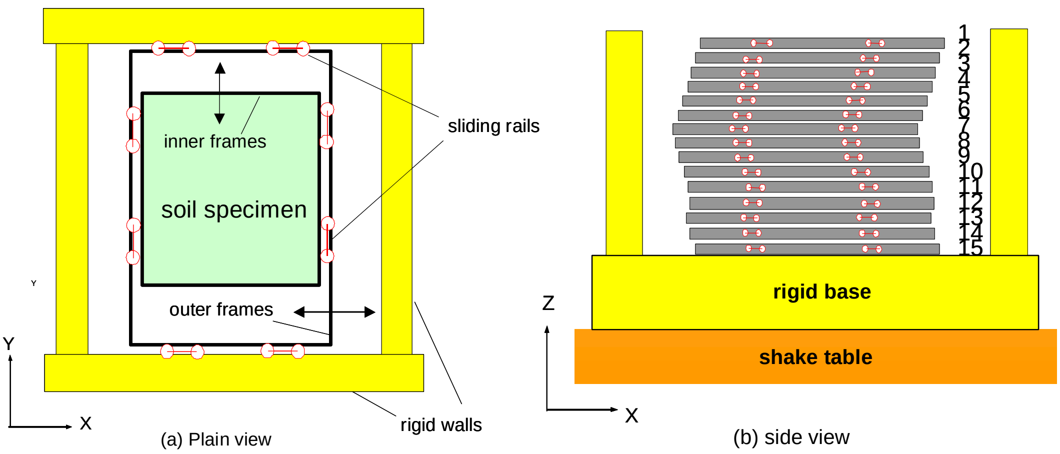


Figure 1. Schematic drawings of the biaxial laminar shear box

SAMPLE PREPARATION

Properties of Mailiao silty sand

Mailiao silty sand, a typical soil of the western coastal area in Taiwan, was used in this study. The grain shape of the Mailiao silty sand is mainly sub-angular and flaky. The sand is more compressible and less dilatable than silica sand. The basic properties are given in Table 1. The maximum and minimum void ratio of this sand are 0.586 and 1.162, respectively, according to ASTM D4253 Method 1B (wet method) and ASTM D4254 Method C. The fines content was obtained according to ASTM1140 because of the crumbly characteristic of Mailiao silty sand. The representative grain size distribution of the sand is also shown in Figure 2.

Table 1. Properties of Mialiao sand

G_s	D_{50} (mm)	C_u	e_{max}	e_{min}	FC (%)
2.71	0.20	2.66	1.162	0.586	6.49

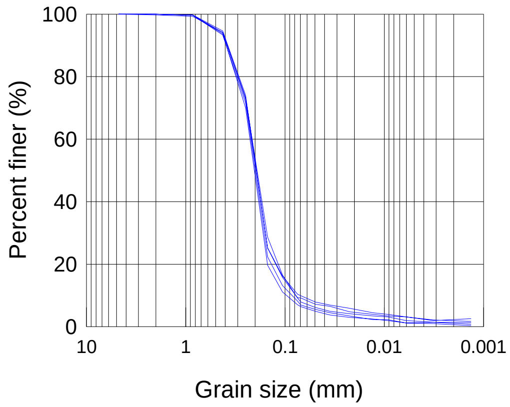


Figure 2. Grain size distribution of Mailiao silty sand

Preparation of a large silty sand specimen

Sample preparation methods, such as dry deposition method, moist tamping method and sedimentation method, are commonly used to prepare the reconstituted samples (Ishihara, 1993). Preparation methods for a large saturation specimen of clean sand, such as sedimentation method, to control the uniformity and saturation of the specimen have been reported by many researchers (e.g., Chang, 2002; Ueng et al., 2003). However, very little information is available for preparing large saturated specimens of silty sand to obtain the desired uniformity and density. In order to evaluate the preparation method for a large saturated specimen using the moist Mailiao silty sand in the laminar box, a series of experiments in a smaller glass container (500 mm × 230 mm × 350 mm) were conducted using various preparation methods, including wet sedimentation method using dry and moist sand, staged sedimentation method and pre-mixture filled method. It was found that the staged sedimentation method is the best among these methods tested in the small glass container (Tsou, 2006). Except a top thin layer of sand with a higher fines content there is no significant difference of fines content at other depths of sand specimen. Thus, the staged sedimentation method was adopted in this study.

A special pluviator with inside dimensions of 1600 mm × 1600 mm × 600 mm was designed for preparing the Mailiao silty sand specimen inside the large shear box. The pluviator, as shown in Figure 3 and 4, is composed of:

- A container houses the needed volume of sand (about 1.0Mg in mass at each stage) to fill the shear box. The bottom of the container is consisted of eight vanes with dimensions of 1600 mm × 200 mm, which can support the mass of the sand and rotate to open smoothly when the hooks are released.
- Two transmission shafts consisted of two rods and sixteen hooks to control the vanes to open simultaneously to dump sand into the shear box.

The moist Mailiao silty sand with a mass of 1.0 Mg and an average water content of 7.22% were dumped down into the laminar box filled with water to a pre-calculated depth at first. After an interval of about 30 minutes for the major sedimentation, the laminar box was filled with water slowly to the calculated depth based on the measurements of water level and elevation of the sand specimen after the first step. The two steps above were so-called one stage in the staged sedimentation method. It took seven stages to complete a Mailiao silty sand specimen of about 1.350 m in height. The saturation of the specimen prepared by this method was verified by measuring P-wave velocity across the specimen horizontally at different depths. A small steel ball hit the sand specimen at the 20-mm gaps between the frames and the arrival times of the P-wave were measured using the accelerometers close to the hitting point and across the specimen. Figure 5 shows the results of P-wave velocity measurements at two vertical sections of the sand specimen. It can be seen that the sand was well saturated with the P-wave velocities between 1450 m/s and 1566 m/s at various depths including the water above the sand surface. In order to directly measure the density, fines content and uniformity of the large sand specimen, short thin-walled tube samples (≈ 150 mm in length and 73 mm in diameter) were taken at various locations and depths inside the shear box. These thin-walled tubes were pushed into the sand at various elevations during the excavation of the sand from the shear box, and the samples were taken by carefully removing the surrounding soil. Figure 5 shows the dry densities and fines contents of the sand specimen at different depths immediately after specimen preparation. The results indicated that the sample was well-saturated and the uniformity of density and fines content of the sample was acceptable.

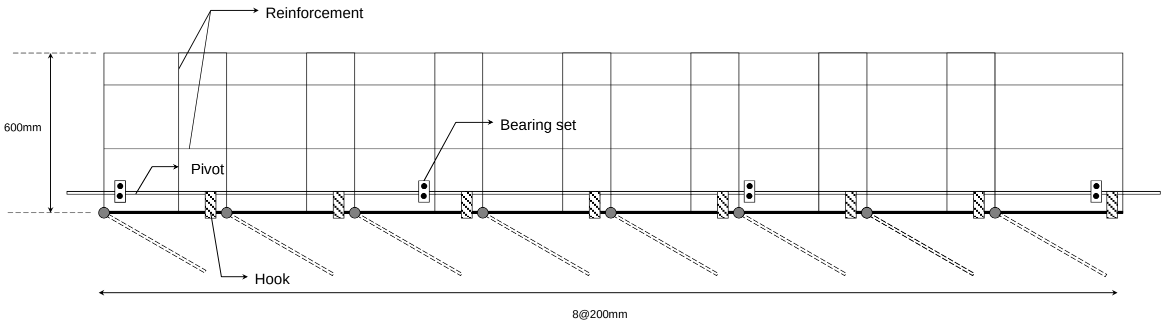


Figure 3. Schematic drawing of the pluviator

Figure 4. The picture of the pluviator

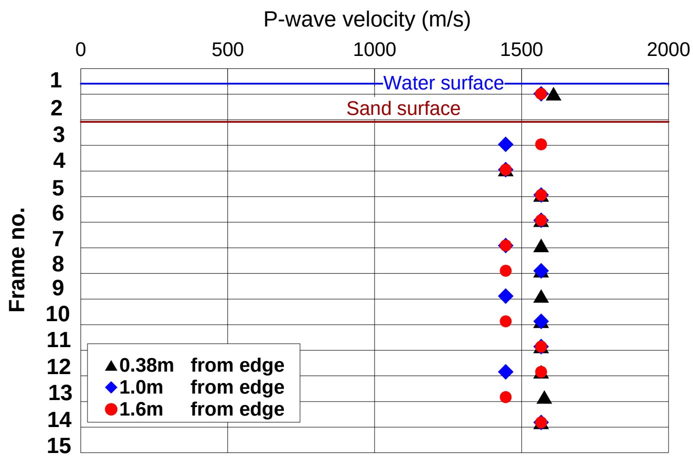
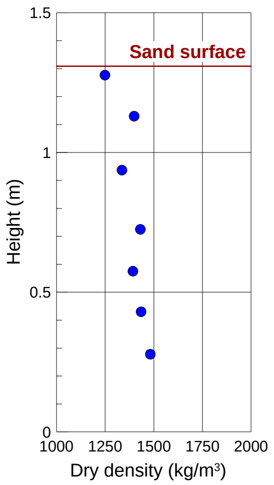
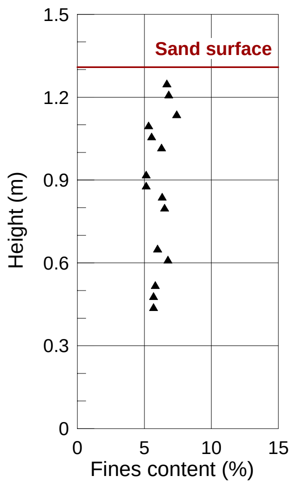


Figure 5. P-wave velocities of sand specimen after preparation



(a) Density



(b) Fines content

Figure 6. Density and fines content of Mailiao silty sand after preparation

SHAKING TABLE TESTS

Transducers for displacement and acceleration measurements were placed at various locations and depths on the outside rigid walls, the outer frames for X-direction motions, and the inner frames for Y-direction motions. In addition, mini-piezometers and mini-accelerometers were installed inside the box for pore water pressure and acceleration measurements at different locations and depths before placing the sand into the shear box. Two settlement plates were also installed to measure the surface settlements during shaking tests. The height of the sand surface was also measured manually after each shaking test so that the settlement of the sand specimen can be calculated. Figure 7 shows Mailiao silty sand specimen on the shaking table.

A series of shaking table tests have been conducted on Mailiao silty sand specimen in the biaxial laminar shear box at NCREE in May 2006. Various one- and multi-directional input motions were imposed by the shaking table. The input motions included sinusoidal (1Hz, 2Hz, 4Hz and 8Hz) accelerations, with amplitudes (A_{max}) from 0.03g to 0.2g in X and/or Y directions. In the two-dimensional (multidirectional) shaking, there is a 90° phase difference between the input acceleration in X and Y directions, i.e., a circular or ellipse motion was applied. The acceleration time history recorded at She-Tou seismograph station in Chi-Chi Earthquake were also imposed in X and Y directions.

Figure 7. Mailiao silty sand specimen in the shear box on the shaking table

PRELIMINARY SHAKING TEST RESULTS

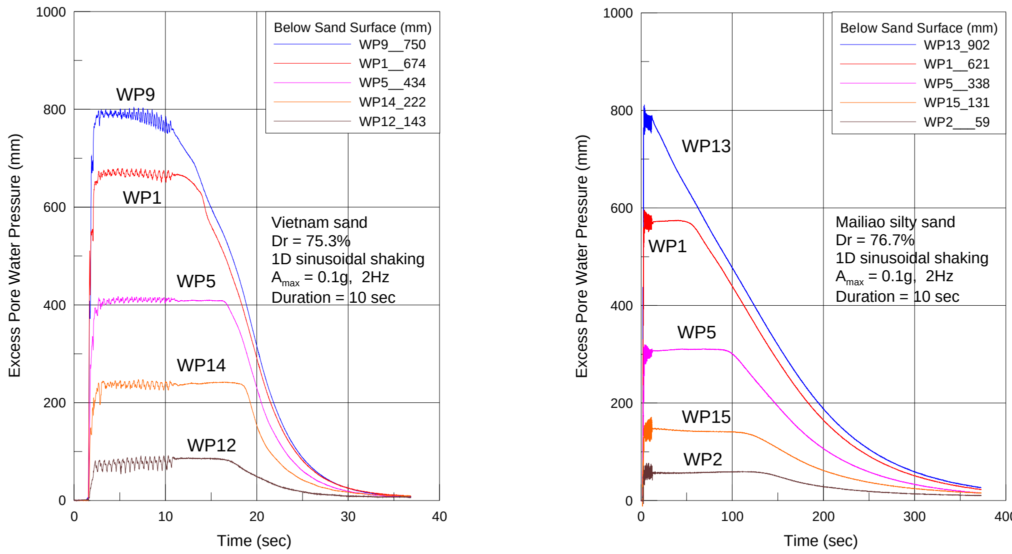
Liquefaction phenomenon

Sand boil is a well-known feature on the ground surface after liquefaction owing to the expelled water carrying sand particles with it to the surface through volcano-like vents. It is rarely seen in the uniform saturated specimen of clean sand under any kind of shakings due to its high permeability. Figure 8 shows that sand boils occurred on the surface of the Mailiao silty sand specimen after liquefaction. The thin layer of sand with a high fines content on the top of the sand specimen might be one of the reasons for this phenomenon.

Figure 8. Sand boils on the sand surface of the specimen

Pore water pressure changes, surface settlement and volumetric strain

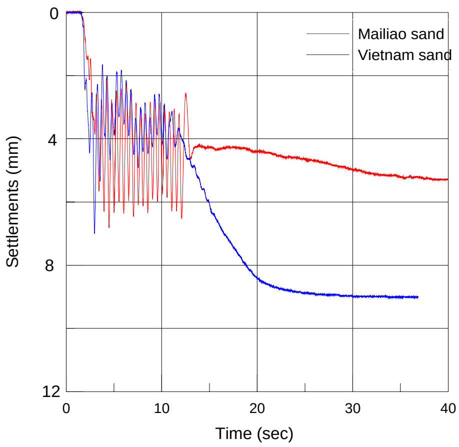
A comparison of pore water pressure changes at five different depths in the specimen of Vietnam silica sand and Mailiao silty sand during one-dimensional sinusoidal shaking with an amplitude of A_{max} = 0.1g is shown in Figure 9. It is found that the excess pore water pressure in Mailiao silty sand takes a longer time to dissipate than that in Vietnam sand due to the lower permeability of Mailiao silty sand. Figures 10 shows the measured surface settlements of Vietnam silica sand and Mailiao silty sand specimens during the same shaking test. It can be seen that the rate of the settlement after shaking is related to the rate of excess pore water pressure dissipation.



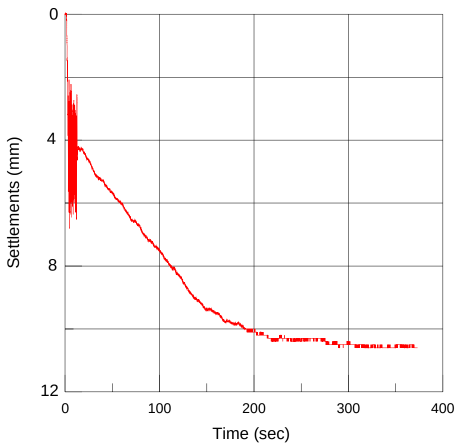
(a) Vietnam sand (clean sand)

(b) Mailiao silty sand

Figure 9. Water pressure changes during 1D shaking



(a) Settlement vs. time



(b) Settlement time history of Mailiao sand

Figure 10. Surface settlement of sand specimen during 1D shaking

The depth of the liquefied sand is determined based on the measurements of mini-piezometers and accelerometers on the inner frames (Ueng et al., 2006 b). With consideration of depth of the liquefied sand, the volumetric strain induced by liquefaction is 0.83% for Vietnam sand and 1.28% for Mailiao silty sand, respectively. The greater volumetric strain of Mailiao silty sand is probably due to its higher compressibility. Soil samples were taken using short thin-walled tubes at different locations and depths after completion of the shaking table tests. It is found that the density of the Mailiao silty sand in the shear box decreases slightly with depth after this series of shaking tests, as shown in Figure 11.

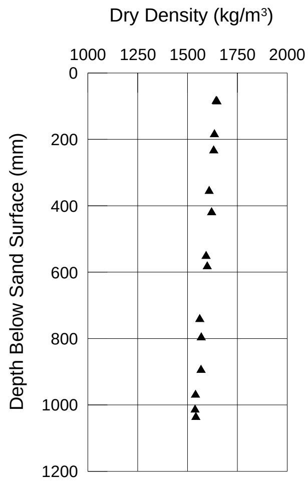


Figure 11. Dry densities after shaking test, May 2006

CONCLUSIONS

A large laminar shear box with a specimen size of 1880 mm × 1880 mm × 1520 mm at NCREE was used to study the dynamic response of sand specimen with fines. A special pluviator was also designed to prepare the Mailiao silty sand specimen by staged sedimentation method. The uniformity, density, fines content and saturation were checked by directly sampling and P-wave velocity measurements. The performance of the sample preparation method on the Mailiao silty sand in the large shear box was found satisfactory. A series of one- and multi-directional shaking table tests were performed on saturated Mailiao silty sand in the shear box. The preliminary results show that the relatively low permeability layer of the Mailiao silty sand resulted in longer duration of dissipation of generated pore water pressure and surface settlement compared with those of the clean Vietnam silica sand. The sand boils were observed when there was liquefaction of the Mailiao silty sand. Further analyses of the test results and more shaking table test are under way.

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