FABRICATION AND PERFORMANCE OF LAMINAR SOIL BOX WITH RIGID SOIL BOX FOR LIQUEFACTION STUDY

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ABSTRACT: Occurrence of the liquefaction causes wide range of damages such as residential foundation damaged due to ground subsidence, lateral spreading, ground failures, and cracks on the road facilities. The better understanding about this phenomenon will aid delivering better mitigation strategies. This research describes the design and construction of the laminar soil box for studying the behavior of saturated soils especially the liquefaction phenomenon. To study the performance of laminar soil box it is filled with the potentially liquefied soil and results are compared with the rigid soil box in the form of accelerometer response, pore water pressure and the deformations.

Key Words: *laminar soil box, liquefaction, subsidence, rigid soil box*

INTRODUCTION

For the mitigation of geo-disaster hazards, it is necessary to have better understanding of the dynamic properties of the soil and their effects on liquefaction potential, wave amplification, soil-structure interaction response relevant to the field of geotechnical earthquake engineering. This field encompasses different testing methodologies on element, models and full scale structures. For understanding the soil behavior such as stress-strain relationships of liquefaction phenomenon, element testing are performed by means of triaxial tests, torsional shear tests and simple shear tests under the dynamic loads are extensively used. Element testing involves the appreciable boundary affects that may not depicts the actual field loading conditions due to the limitation of devices and size of the specimen. Scaled models either N-G or 1-G are the prime alternative to overcome these limitations. For instance, centrifugal testing is able to reproduce the same level of stress expected in the field. Similarly, in 1-G model testing the level of stress is relatively low in contrast to that expected in full scale structures. However, 1-G model testing has been widely used to study the behavior of soil under seismic loading. This study will focus on the (i) design and fabrication of the one-directional laminar box (ii) comparison of soil response, pore water pressure and deformation of rigid soil box with this newly fabricated laminar soil box.

BACKGROUND

A number of institutions are using the laminar soil containers to reproduce the true field conditions. Nine

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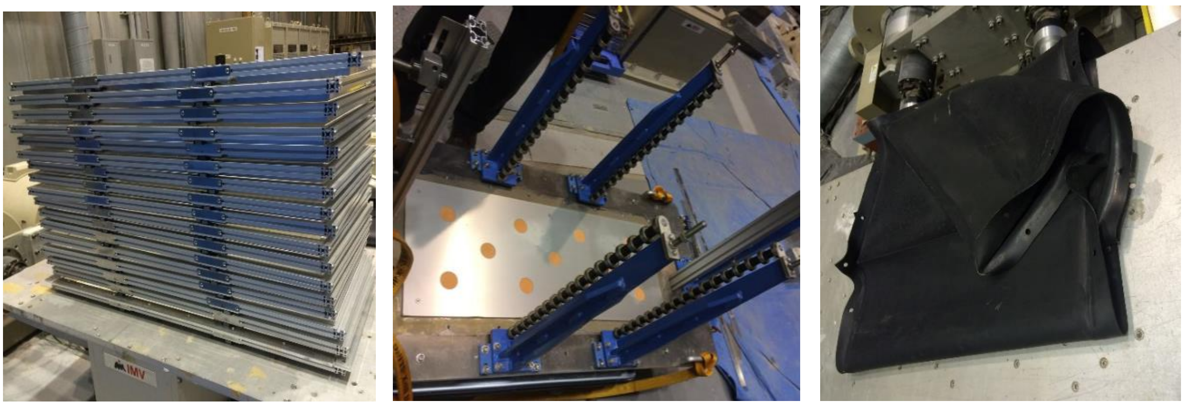
different types of laminar containers are reported here from literature used for 1-G and N-G centrifugal testing. These types cover the possible geometric shape, direction of operation and the size of laminar containers (Table 1). Prasad et al.,2004 and Gibson et al.,1997 described the one dimensional laminar soil container while the Meymand et al.,1998 and Ueng et al.,2006 reported the 2-dimentional laminar container for 1-g tests. Single axis flexible container can allow the laminae movement in one direction of horizontal plane. The other direction are stopped by installing the rigid guide walls or bearings. Double axis flexible soil container can allow the two directional movement of laminae in horizontal plane. Ueng et al., 2006 developed 2-directional flexible soil container with ribbed membrane hanging from top to bottom. Pamuk et al., 2007 Van et al. and Takahashi et al., 2001 developed the 1-directional rectangular flexible container for centrifugal model testing and Shan et al. developed the 2-dimentional polygonal flexible container for centrifugal testing.

Table 1. Summary of available laminar shear container

Use	Shape	Dimensions(L x W x H) mm^3	Directions of operation	Reference
1-G	Rectangular	1000 x 500 x1000	1-directional	Prasad et al.,2004
1-G	Rectangular	900 x 350 x470	1-directional	Gibson et al.,1997
1-G	Rectangular	900 x450 x 807	2-directional	Turan et al.,2008
1-G	Rectangular	1888 x 1888 x 1520	2-directional	Ueng el al. ,2006
1-G	Circular	2130(D,H) x2280	2-directional	Meymand el al.,1998
N-G	Rectangular	710 x 355 x 355	1-directional	Pamuk et al. 2007
N-G	Rectangular	457 x 254x 254	1-directional	Van et al.,1994
N-G	Rectangular	450 x 200 x 325	1-directional	Takahashi et al.,2001
N-G	Polygon(12 sided)	500(D,H) x584	2-directional	Shen et al.,1998

FABRICATION OF LAMINAR BOX

The laminar soil box was developed in Institute of Industrial Science, The University of Tokyo .There are three main components of laminar soil box (i) a set of 17 laminae (ii) skeleton for laminae with bearings (iii) a rubber membrane of 2 mm thickness.



(a) (b) (c)

Figure 1. (a) Laminae (b) Skelton for laminae (c) 3 mm thick rubber membrane

A set of seventeen horizontal laminae(Fig 1a) are placed on each other in a skeleton(Fig 1b) supported by the linear bearings so that the linear movement will be allowed in one direction and the other direction movement is stopped by means of rigid anti shake bearings.

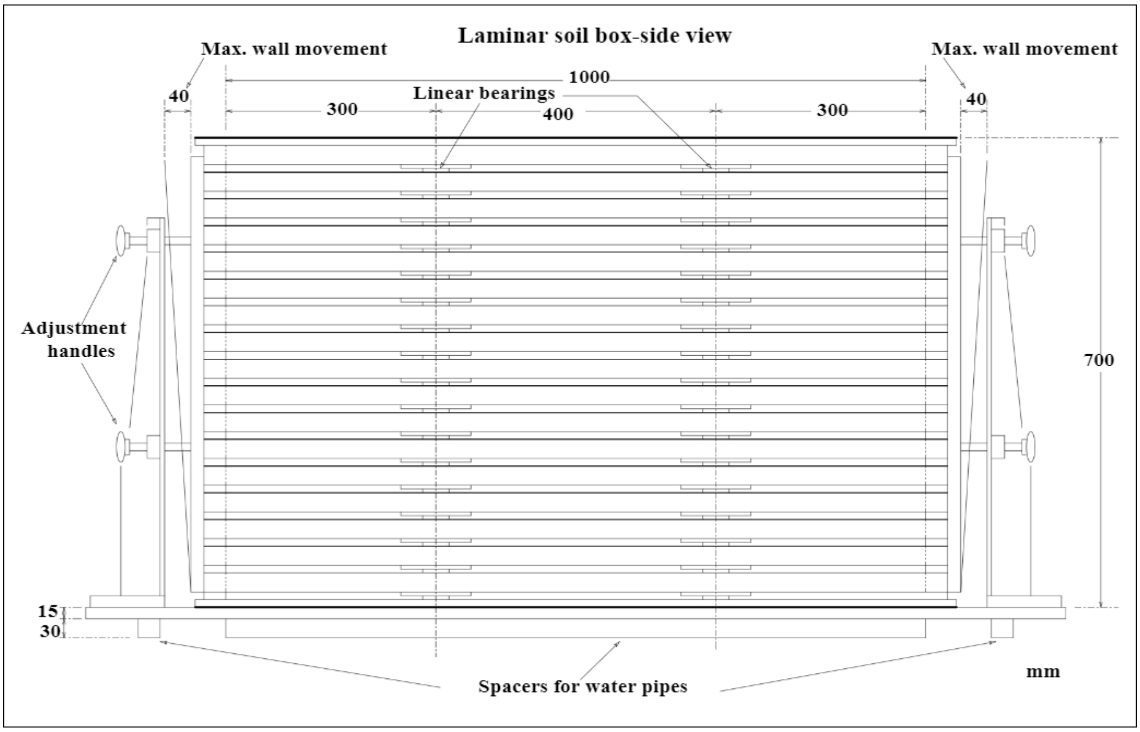


Figure 2a. Laminar soil box-side view

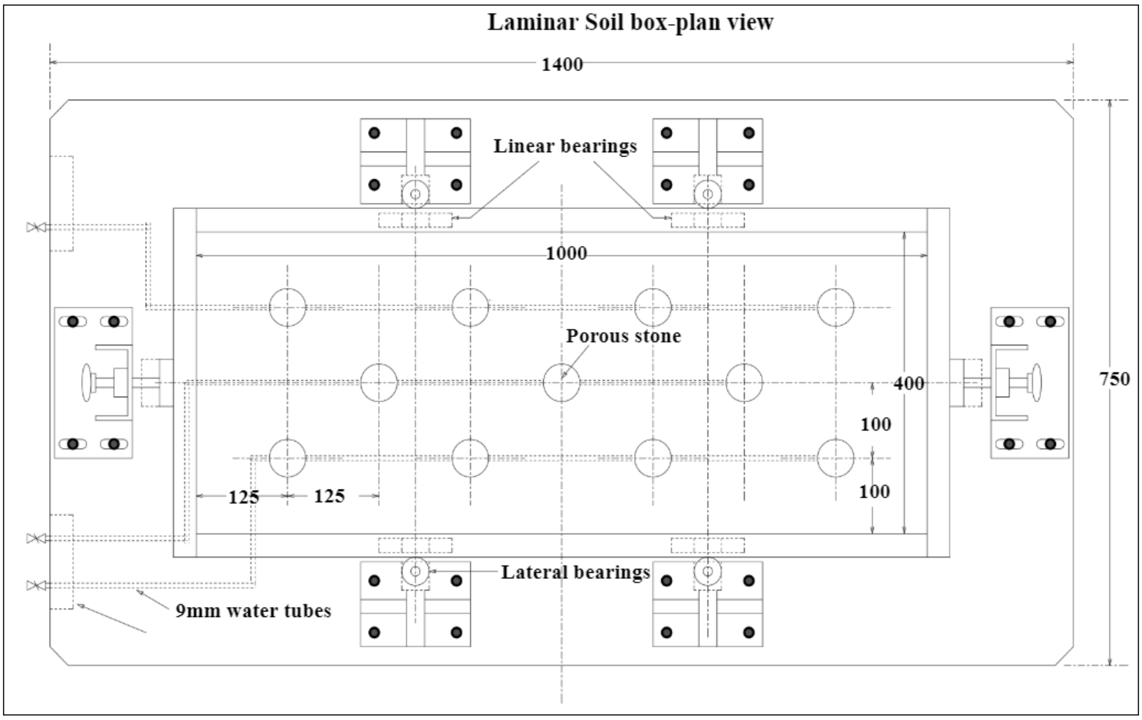
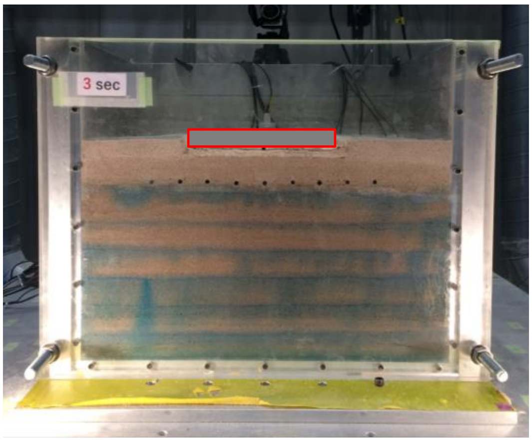


Figure 2b. Laminar soil box-plan view

One laminae consists of the hollow, high strength aluminum box sections bolted together to make the horizontal assembly having the plan dimensions 400mm x1000mm.Each laminae is guided by the 4 linear bearings that allows the movement of the laminae in one direction. A set of 17 laminae is assembled together to make the 700mm high,1000mm long and 400 mm wide soil container.
A 2mm water tight, flexible rubber membrane is attached inside the container (Fig 1c).Prior to place the soil in the container, a set of two box section on each of the shorter side is clamped properly to prevent the movement of the laminae during the sample preparation (Fig.2a) and removed before the application of shaking.11 porous stones are placed for injecting/extracting the water for saturation/desaturation (Fig.2b). A 15 mm solid steel base is attached to avoid the movement at soil-base plate interface.

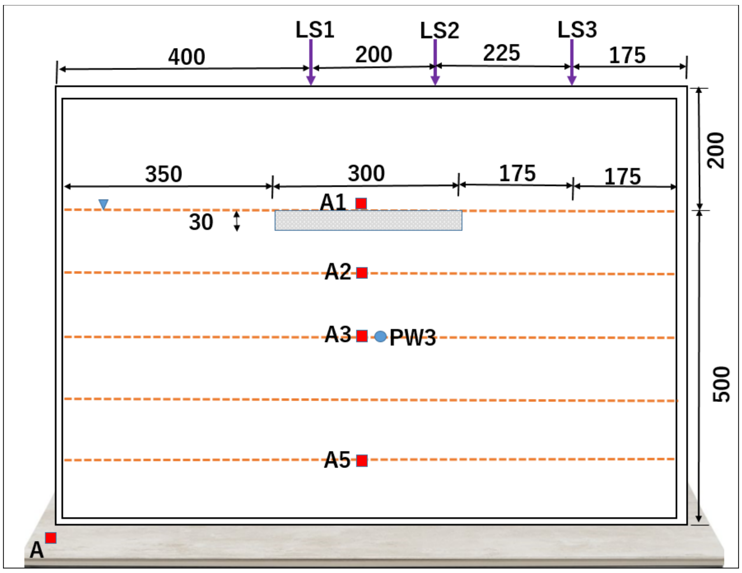
TEST METHODOLOGY

Two tests were performed 1) Case1: shaking table test with the rectangular rigid soil box 2) Case 2: shaking table test with the rectangular laminar soil box. These two cases are performed at scale down factor that is equal to 20.



(a)

(b)



(c)

Figure 3. (a) Rigid soil box (b) Laminar soil box (c) Sensors location

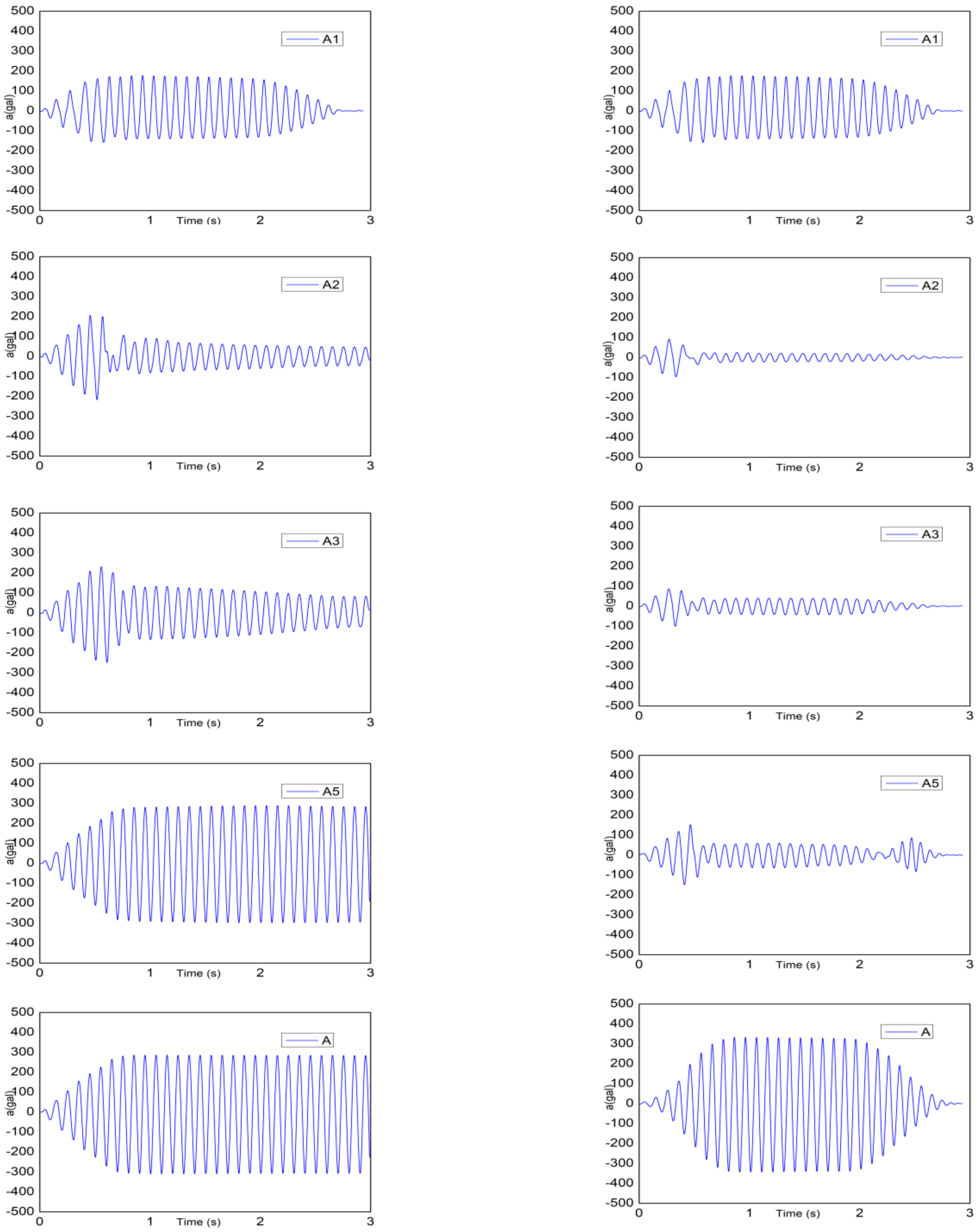
A rectangular prismatic steel box (67cm-length x 47cm-wide x 50cm-high) is used as rigid soil box for the case 1(Fig.3a).Front side of the rigid box is made up of transparent glass to observe the displacement and deformation of the soil during and after the shaking. A flexible soil container of size((100cm-length x 40cm-wide x 70cm-high) was used for the case2(Fig.3b).In both the cases, firstly the soil box is filled with the water upto 10cm.Then the dry Silica sand 5(Gs=2.638, γ_{max}=15.493kN/m^3, γ_{min}=12.748kN/m^3, D_{50}=0.64mm) is dropped from 60cm height above the water surface by means of hopper so that the 2.5cm depth of the container was filled with soil. The water is again to raised to 10cm and the same steps is repeated. A pavement road bed made up silica sand 5, Kaolin clay and Ordinary Portland cement (8:2:1) are placed over the sand deposit. The unit weight of the pavement model for both the cases is 21kN/m^3.

Accelerometers (A1, A2, A3, A5, A), pore water pressure meter (PWP3) embedded in the soil deposit to monitor the behavior of the model (Fig.3c). Laser sensors (LS1, LS2, and LS3) are mounted to record the deformation at the three locations. A sinusoidal base loading of f=10Hz, t=9s, cycles=90 and amplitude of 300 gal was applied for the Case1. For the case 2 same sinusoidal wave with duration of 3 second is considered. In both the cases the sinusoidal wave increase progressively to the 300 gal amplitude. Accelerometer responses, pore water pressure and settlements for the first 3s are compared for both the cases. The obtained accelerometers was corrected by linear base corrections and them filtered by the Butterworth filter between the frequency of 3Hz and 25Hz by keeping the actual nature of the response unchanged. Baseline correction was done by the SeismoSignal through least-square fit method (regression analysis) with the polynomial curve that best fits the time acceleration values. Filtering helps to remove the unwanted frequency components from the signal to smoothen the data.

RESULTS AND DISCUSSIONS

The results are compared in form of acceleration response, pore water pressure and deformations. Initially when the pore water build up is very small, the response acceleration at all the locations is almost the same as that of input acceleration A. At this stage the model is behaving like a rigid body reflects that the frequency of the input shaking is far less than the fundamental frequency of the model. As therefore water pressure starts increasing with the seismic shaking, both the acceleration amplitude and its waveform is changed. The variation of the waveform is highly dependent on the input seismic loading and the location where it is recorded. Usually the soil at the lesser depth are more prone to the liquefaction as compare to the deeper one because of the less vertical stresses. Amplification of soil response was not observed for both the cases. The response of the pavement (A1) is higher for the case 1(PGA=267gal) as compare to the case 2(PGA=191gal).The sudden drop of the acceleration response represents the decreases in the stiffness hence onset of the liquefaction. The soil at the A2 locations shows sudden drop after 6 cycles (PGA=223gal) recorded in rigid soil box (Fig 4a). While on the other hand the waveform at A2 location show the evidence of liquefaction after three cycles (PGA=98gal) at A2 location (Fig.4b). The same behavior were found at the location A3.Acceleration response at A5 location did not show any liquefaction signs for the rigid soil container case while showing the drop of acceleration response for laminar soil box. It may be concluded from the accelerometer response that the liquefaction onset was observed earlier and at lesser input shaking in the laminar soil box than the rigid soil box.

The pore water pressure at the location PWP3 is recorded by means of pressure meter for both the cases. The pore water pressure begins to increase as the shaking starts. The pore water pressure ratio (u /σ'v) assists to understand that how the initial vertical stresses are diminishing due to input seismic loading. The pore water pressure ratio equals to 1 means that all the vertical stresses are lost and soil is liquefied. The pore water pressure development starts earlier in case 2 .Although the rate of pore water pressure build up is same for both the cases. The pore water pressure ratio reaches to reference stress level earlier in the laminar soil box case (Fig.5a).



(a) (b)

Figure 4. (a)Case 1: rigid soil box soil response (b) Case 2: laminar soil box soil response

Three laser sensors (LS1, LS2, and LS3) are used to measure co seismic and post seismic settlements of the pavement roadbed model and soil. The average settlement measured by the LS1 and LS2 shows that settlement observed in the laminar soil box is more than the rigid soil box. Further, the settlement in the laminar soil box starts earlier with the higher rate and the rate is decreasing with time, while in rigid soil box case rate of settlements remains same(Fig 5b).

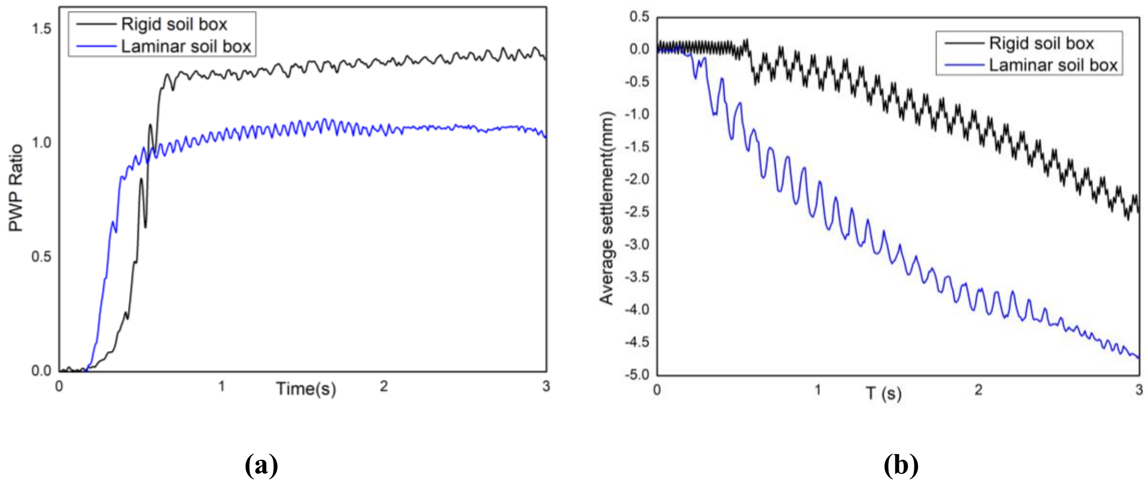


Figure 5. (a) PWP ratio time history (b) Average settlement time history

CONCLUSION

Liquefaction can cause the serious damage to all types of facilities. The better understanding of liquefaction phenomenon can help to mitigate the liquefaction induced disasters. The scaled model at the laboratory can give the better understanding of this phenomenon. The flexible soil container was developed with 2mm internal rubber membrane thickness. To determine the effectiveness, the results of newly developed soil container was compared with the corresponding results of the rigid soil box in the form of accelerometer response, pore water pressure and deformation. The results represents that the response of soil in the laminar soil box is very less and soil observe the less cycles to liquefy. The pore water pressure development starts well before than that observed in the rigid soil box. The settlements observed by laser sensors showing that the observed settlements are higher in case of laminar soil box that starts with the higher rate and the rate is decreasing with time.

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