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SYNOPSIS: A new laminar box constructed with aluminum frames of 24mm wide and 10mm thick for model shaking tests on liquefaction phenomenon of soft saturated sandy soil in centrifugal gravity field was manufactured. The box was designed to develop shear distortion in the soil unimpeded by a rigid-type container. Liquefaction tests were performed on horizontally laid soft saturated sand and obtained the same results as Tokimatsu and Yoshimi 1983.

INTRODUCTION

Recent Japan promotes some big construction projects in waterfront area such as Tokyo Port which has experiences of damages induced by great earthquake and liquefaction. In order to study liquefaction problems an apparatus for model shaking test in centrifugal condition is in great demand. A laminar box apparatus for shaking tests on liquefaction with hydraulic exciter used in centrifugal gravity field studied by Hushmand et al. 1988 and obtained good results. In this paper, authors described an apparatus which had a laminar box and a gearwheel-lever type exciter used in centrifugal field and tests on simulating a liquefaction phenomenon of prototype sandy ground.

TEST APPARATUS

Geotechnical Centrifuge

The equipment, the Chuoh University 3.05m radius centrifuge (Fujii et al. 1988), was used for tests on the performance of a newly developed shaking container and on liquefaction behavior of soft sandy ground.

Shaking Apparatus

Figure 1 shows a shaking system employed. The system consisted of a laminar box, a pair of L-shaped leaf springs, a torque motor, a gearwheel, a lever, an accumulator, an electromagnetic valve and a base plate. The L-shaped leaf springs were tightly bolted to the base plate and the container (the laminar box). The container was supported by eight vibration isolated rubber blocks. Figure 2 shows mechanism of shaking lever. Electrical signals from operation control box passed through slip rings and a relay box caused the electromagnetic valve open, high oil pressure in the accumulator released and rotation of the torque motor started. The rotation of the motor caused rotation of the gearwheel and a cog of the gearwheel hitted a metal tip downward which was bolted at an end of the lever. Up and down movement of the hitted tip of an end of the lever was converted to horizontal movement of the other end of the lever by pin support (Figure 3).

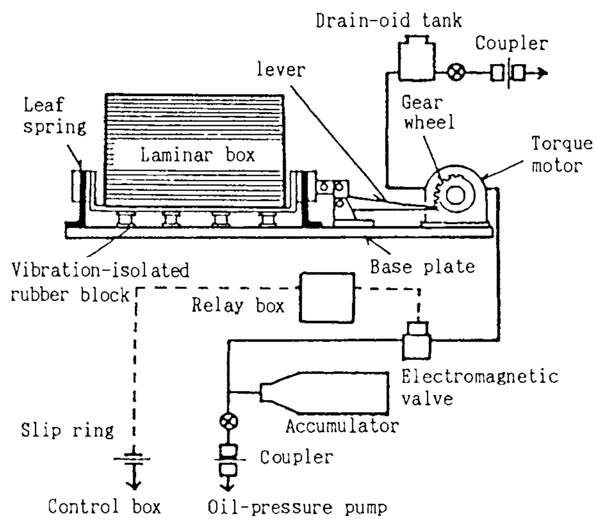

Fig.1 Shaking apparatus and laminar box

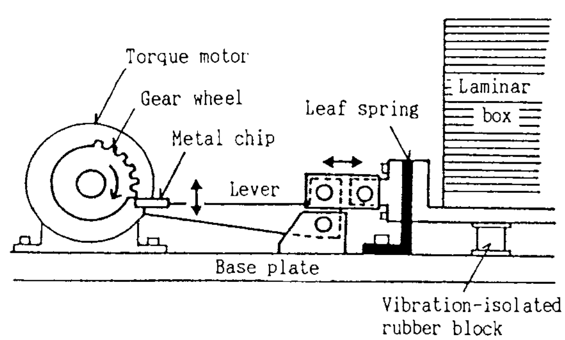

Fig.2 Schematic illustration of shaking system

The horizontal movement of the lever end caused deflection of the leaf springs and horizontal displacement of the laminar box. The deflection of the springs resulted in free vibration of the leaf spring and forced vibration of the laminar box until the next cog's hitting to the tip.

The maximum acceleration of the container vibration was depended upon thickness of the metal tip at the lever-end. The frequency of the vibration was controlled by natural frequency of the leaf springs. Number of the gear cog determined duration time of the excitation and the gearwheel had six cogs because of being close to duration time of an prototype earthquake. The shaking system was put on the platform of the centrifuge so as to have vertical shaking direction.

Laminar Box Container

Outline of the laminar box is shown in Figure 3.

Rectangular frames of the laminar box, inside dimensions were 352mm and 352mm, were made by aluminum with width of 24mm and thickness of 10mm and the 22 frame stacks had the height of 220mm. Surfaces of the frames were grinded by sandpaper (Japan Industrial Standard, R6253, #1500) and oiled (silicone oil) so as to reduce friction resistance between them. In order to measure the static friction coefficient, an experiment on the friction between the frames was performed and resulted in the coefficient of 0.18. An disposable neoprene rubber bag was put in the box.

Preliminary Tests

Preliminary tests were performed on the performance of the laminar box, as shown in Figure 3. Saturated sand ground (Relative density was nearly 60%) was modeled in the box by tap water and Toyoura sand (Figure 8) and shaking tests were performed on the model under 100g (g: gravity acceleration).

Accelerometers at the side of the frames CH1-CH5, CH10 and CH11, and in the sand CH6-CH9 were respectively positioned at the same depth below the ground surface.

Figure 4 shows acceleration history of CH1, that of the bottom plate of the box. There can be seen sharp-peaked, high amplitude waves which were generated by hitting the metal tip of the lever by the six cogs of the gearwheel, as mentioned above. The sinusoidal-like waves between the sharp waves are free vibration of the springs and the box. The maximum prototype values of the sharp acceleration waves and the free vibration waves were about 400 gal and 60 gal respectively.

Figure 5 shows acceleration histories of CH8 embedded in the sand model, and CH4 positioned at the side of the frame at the same depth as CH8. The both waves are very similar with their phase and amplitude each other. Respect with other acceleration histories, the same relation could be observed; CH2 and CH6, CH3 and CH7 and CH5 and CH9.

Figure 6 shows acceleration histories of CH3 and CH10, the accelerometers positioned in the plane normal to exciting direction at the same frame. Both waves are very similar to each other with their phases and amplitude. Respect with histories of CH4 and CH11, the same relation could be obtained. These show that the laminar box had no rotation in the horizontal plane.

These tests would result in the good performance of the laminar box in shaking tests under centrifugal field.

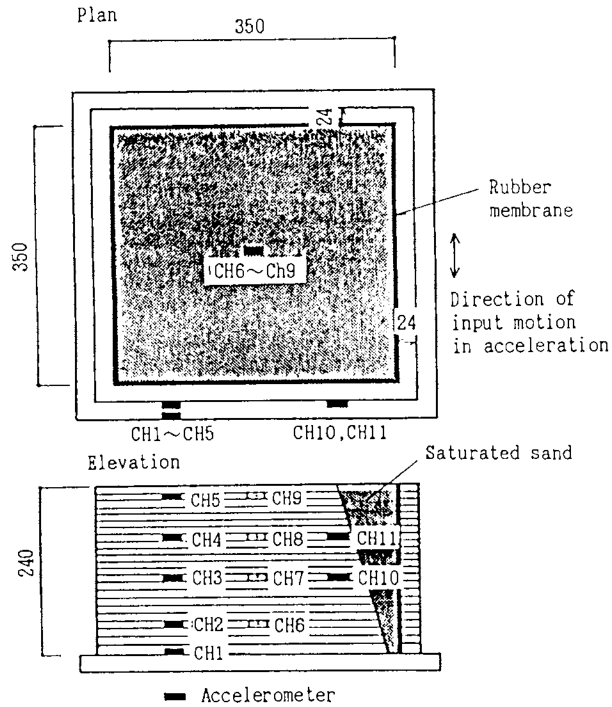

Fig.3 Laminar box and model ground

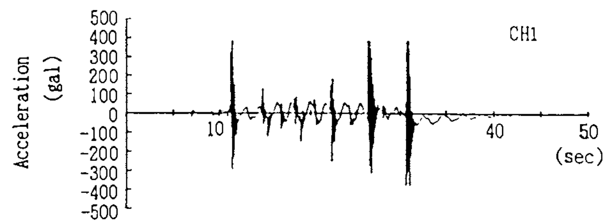

Fig.4 Acceleration history of base motion at location CH1

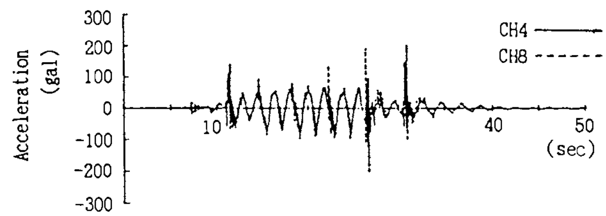

Fig.5 Acceleration histories of CH8 embeded in the sand model and CH4 positioned at the side of the frame at the same depth as CH8

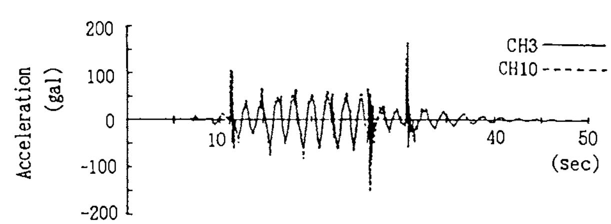

Fig.6 Acceleration histories of CH3 and CH10 positioned at the same frame

LIQUEFACTION TESTS

Testing Model

Figure 7 shows a model of liquefiable ground put in the laminar box. The bottom soil layer was 10cm thick stiff soil made of fine aggregate of concrete material ($e_{max}=0.853$, $e_{min}=0.481$; e = void ratio) which was divided in three layers and compacted by a vibrator in order to obtain a no-liquefiable bearing stratum.

Glycerin solution with a viscosity 100 times of tap water and a density of $1.22 gf/cm^3$ at 22°C as a pore fluid was used to obtain a comparable time scale between the model and a prototype in seepage characteristics. The bottom soil layer was saturated with the solution. Loose sand layer of 10cm thick was placed on the bottom layer using Toyoura sand with grain-size curve shown in Figure 8. Adjusting the relative density of the loose sand layer was done at every 2cm of 10cm thick. The sand of weight of 2cm thick was rained into the glycerin solution of 2cm deep. Accelerometers and porewater pressure gauges were placed as shown in Figure 7.

Shaking tests were performed under 100g.

Test Results

Figure 9 shows the relation between excessive porewater pressure ratio $\Delta u/\sigma_0'$ (Δu is excessive porewater pressure and σ_0' is effective vertical stress at the porewater pressure gauge) and depth of the loose sandy layer. σ_0' was determined by static porewater pressure measured under 100g

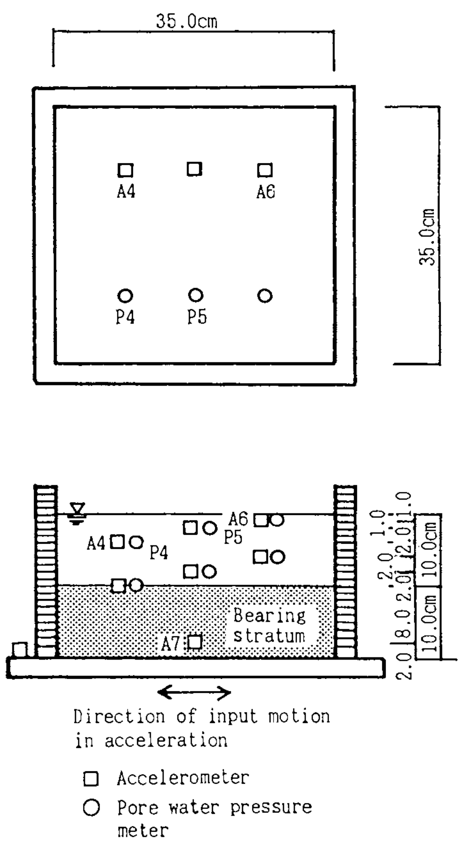

Fig.7 Ground model of liquefaction test

contrifugal acceleration. $\Delta u/\sigma_0'$ increased as the depth decreased. In the Test 5 $\Delta u/\sigma_0'$ reached 1.0 and the surface area liquefied. Figure 10 shows histories of the accelerations (A4, A6, A7) and the excessive porewater pressures (P4, P5) of the Test 5. History of the acceleration A6 embedded in the liquefied area mentioned above shows that amplitude of the waves after liquefaction becomes smaller than that before liquefaction. Wave of P5 placed in the liquefied area approaches to the maximum immediately after the first shaking wave. Value of P4 embedded in the no-liquefied area, in contrast, raises more gradually than P5.

Table 1 Density of upper sand layer

Test No.	Void ratio	Relative density (%)	Symbol
1	0.728	64	○
2	0.689	75	●
3	0.767	52	□
4	0.767	52	■
5	0.767	52	△
6	0.728	64	▲
7	0.767	52	◇

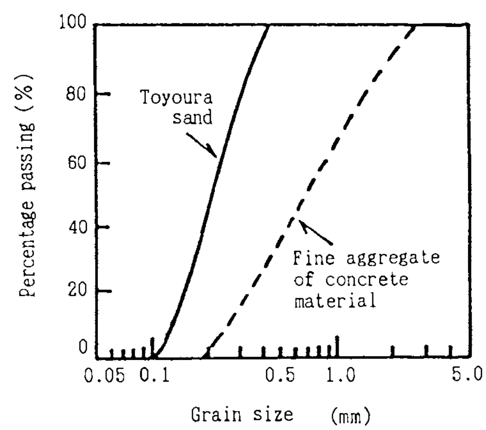

Fig.8 Grain size distribution

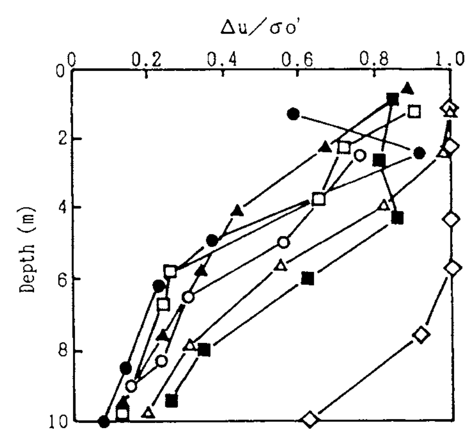

Fig.9 Relationship between maximum excessive porewater pressure ratio $\Delta u/\sigma o'$ and depth

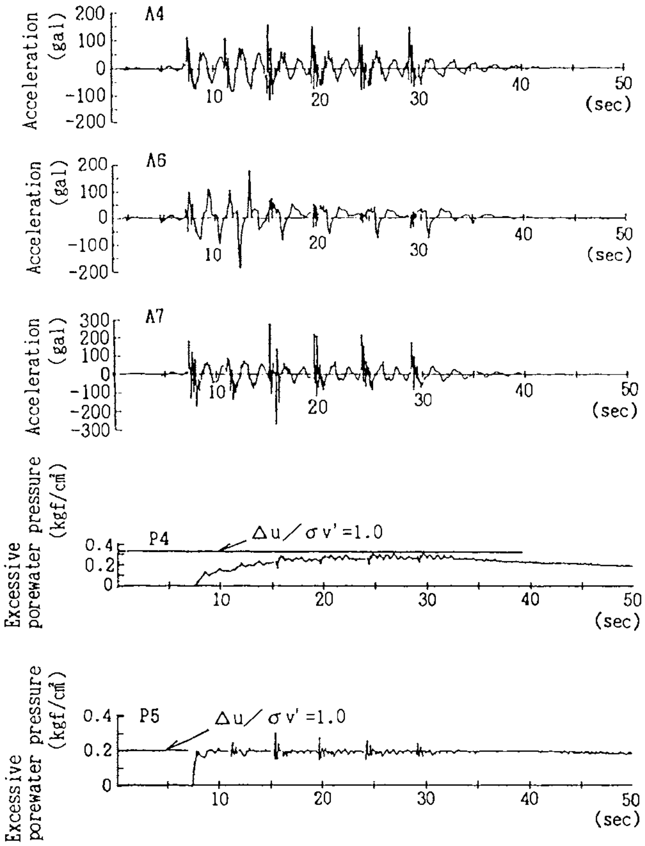

Fig.10 Histories of accelerations (A4,A6,A7) and excessive porewater pressures (P4,P5) of Test 5

Tokimatsu and Yoshimi 1983 said that the curve in Figure 11 represented the boundary between liquefaction and no-liquefaction condition, based on the laboratory tests on the insite freezing method and the field data on the liquefaction.

The test data in τ_d/σ_0' were plotted in Figure 11 which is the τ_d/σ_0'—Na relationship with 5% shear strain proposed by Tokimatsu and Yoshimi 1983; τ_d/σ_0' is dynamic shear stress ratio of saturated sand, and Na is the adjusted Standard Penetration Test value. In calculation of τ_d/σ_0', the maximum values of the embedded accelerometers were used (sharp-peaked waves are not used) as α_{max} and 0.65 was used as γ_n value. STP N value to calculate the adjusted Na value was estimated depending upon Mayerhof 1957 using the relative density in Table 1. The adjustment was done depending upon contents of fine grain soil (Tokimatsu and Yoshimi 1983) and effective overburden stress (S.S.C. Liao, et al. 1986). In Figure 11, authors' test results could be divided into two groups. The symbol ○ represented the data having 0.8—1.0 of $\Delta u/\sigma_0'$ and the symbol ● was those less than 0.8; Δu is excessive pore pressure and σ_0' is initial effective vertical stress. If the $\Delta u/\sigma_0'$ value of 0.8 could be supposed to be correspondent to "The Moderate Liquefaction" by Tokimatsu and Yoshimi 1983 authors' tests obtained the same results as those of Tokimatsu and Yoshimi 1983. It may be apparent from Figure 11 that the laminar box could simulate the prototype ground liquefaction behavior.

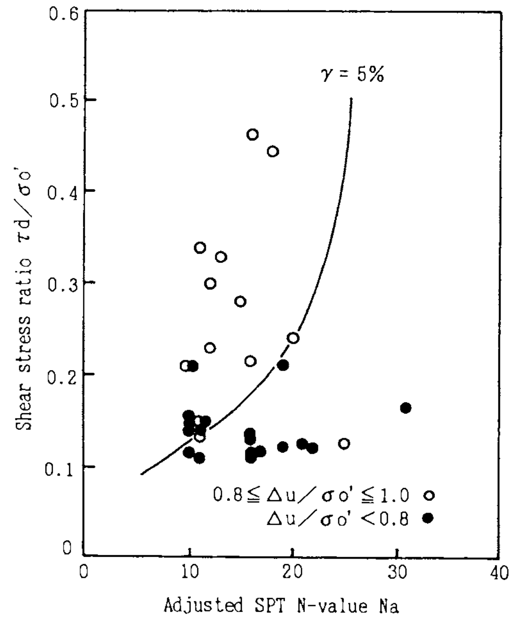

Fig.11 Relationship between shear stress ratio $\tau d/\sigma o'$ and adjusted SPT N-value Na

CONCLUSIONS

The laminar box was used for shaking tests under 100g of the centrifugal field. The tests were performed to simulate the liquefaction judgment curve proposed by Tokimatsu and Yoshimi 1983 and obtained good results, therefore the laminar box-shaking test could be suit for representing the prototype ground behavior at earthquake.

ACKNOWLEDGMENTS

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