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SHAKING TABLE TESTS ON THE ADAPTABILITY OF LIQUEFACTION SENSORS

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Introduction

Liquefaction sensors have been developed to detect the occurrence and extent of liquefaction during earthquakes. Two types of sensors have been produced: the open–type sensor, which is based on the measurement of the rise of water level inside the hollow pipe, and the close–type sensor, which detects the variation of the water level inside a hollow pipe with a closed upper end by measuring changes in the air pressure. The development and mechanisms of these sensors are explained in past publications (see References). To study the validity of these sensors, shaking table tests which include the effects of different overburden pressures were performed.

Material, Equipment and Testing Procedure

The soil employed in the experiment consists of fine sand (from Yamaguchi Prefecture) mixed with silt (from Chiba Prefecture) to obtain a silty sand having F_c=20% and D_r=40% to simulate the soil condition in the field. In order to approximate the actual overburden pressure in–situ, the test box shown in Fig. 1(a) is used where additional overburden pressure, P_o, can be applied on top of the box. P_o's corresponding to 0.0, 0.1 and 0.2 kgf/cm^2 are employed in the experiment.

The saturated model ground is prepared by water pluviation technique. When the level of the sand reaches the top of the test box, the cover is placed, after which the prescribed overburden pressure is applied. When equilibrium is obtained, the sensor is attached and the box is shaken at a certain acceleration level and time duration until liquefaction occurs.

A total of 13 tests (5 for close–type and 8 for open–type sensors) were performed involving various P_o's, acceleration levels, duration of shaking, fine contents and sensor pipe diameters. For Cases C–1 ~ C–5 (close–type) and O–1 ~ O–5 (open–type), the model ground consists of silty sand, while clean sand is used for Cases O–6 ~ O–7. The prototype sensor with an inside diameter of 3.3cm is employed in all tests, except for Case O–8 where a 1cmϕ–pipe is employed. The locations of the pore pressure transducers and accelerometers are shown in Fig. 1(b).

Test Results and Discussions

Close–Type Sensor: The relation between the maximum pore pressure reading (Δu_{max}) monitored by the transducers at the level of the strainer and the water level registered in the close–type sensor is shown in Fig.2. In the figure, ΔH_{liq} refers to the water level in the sensor when the transducers registered their maximum readings, while ΔH_{max} denotes the maximum water level. Note that ΔH_{liq} and ΔH_{max} are almost equal to Δu_{max}, indicating that the close–type sensor can detect liquefaction quite accurately. It should be mentioned that the time lag between the occurrence of ΔH_{liq} and ΔH_{max} is about 0 ~ 8sec. This finding is supplemented by Fig. 3, which plots the development (at every 1–sec interval) of pore pressure (Δu) with the increase in water level (ΔH) for various P_o's. The relation is more or less a straight line, indicating simultaneous increase of Δu and ΔH.

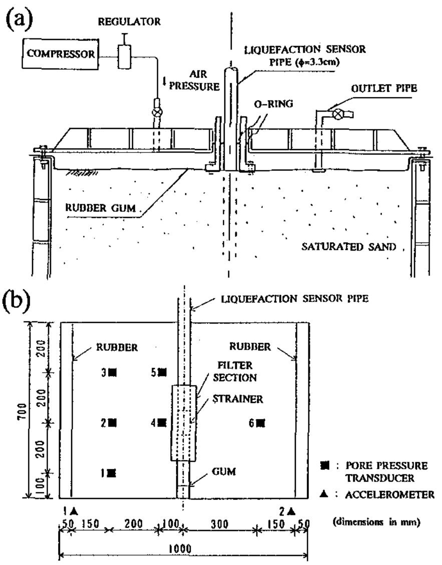

Figure 1: (a) Application of overburden pressure; (b) Experimental set–up and location of transducers

Open–Type Sensor: From Fig. 4, it can be seen that in cases involving silty sand(Cases 1–5), the values of ΔH_{max} are generally slightly smaller than those of Δu_{max}, while in cases where clean sand is used (Cases 6–7), the two values are almost equal. This implies that the permeability of the ground affects the flow of water into the pipe. This finding is substantiated by the plots of the development (at 1–sec interval) of Δu and ΔH for various P_o's, shown in Fig. 5, which depict a slow rate of increase of ΔH. It is noted from the figure that when Δu is maintained at a high level as a result of liquefaction, ΔH continues to increase, indicating a time lag between the occurrence of ΔH_{liq} and ΔH_{max}. In general, this time lag is between 16 ~ 91min for Cases 1–5, and 0.4 ~ 2min for Cases 6–7. The effect of F_c is illustrated in Fig. 6 (time pitch at 1–sec interval), where it is seen that in the ground containing clean sand, ΔH increases almost simultaneously with Δu, while for silty sand, the rate of increase of ΔH is much smaller. Finally, the effect of pipe diameter is shown in Fig. 7 (time pitch for ϕ=1cm is 10sec). Note that when the pipe diameter is reduced, the rate of increase in ΔH approaches that of Δu. This is because when the diameter is large, sufficient amount of water is required to raise the elevation of water inside the pipe. In addition, the size of the container and the magnitude of P_o also affect the response.

Conclusions

A series of small–scale shaking table tests have been performed to investigate the effectiveness of the liquefaction sensor as a method of measuring the excess pore water pressure generated by earthquake. Based on the test results, the close–type sensor can detect the onset of liquefaction with high degree of accuracy, while the open–type sensor is quite slow as it is affected by the soil permeability and size of container.

References

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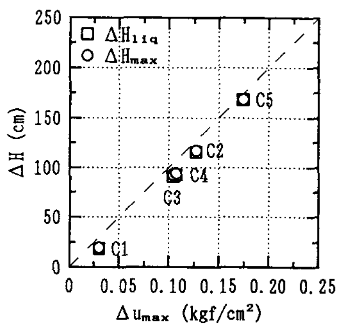

Figure 2: Relation between Δu_{max} and ΔH (close type)

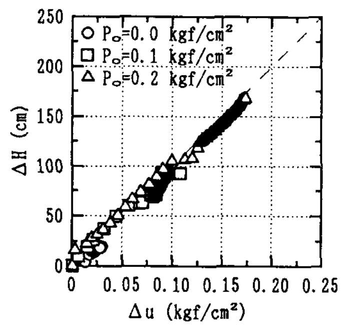

Figure 3: Effect of overburden pressure, P_o (close–type)

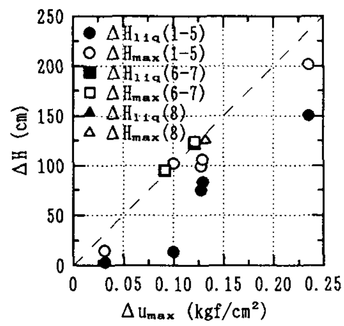

Figure 4: Relation between Δu_{max} and ΔH (open type)

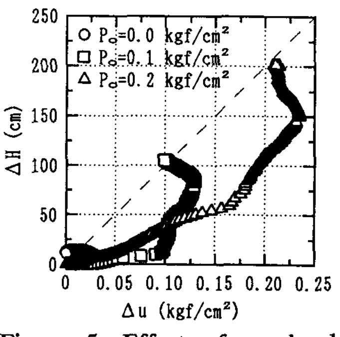

Figure 5: Effect of overburden pressure, P_o (open–type)

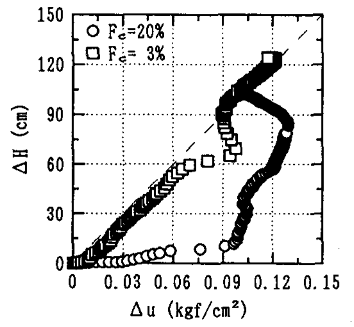

Figure 6: Effect of Fine Contents, F_c (open–type)

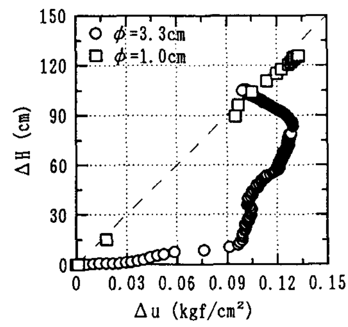

Figure 7: Effect of pipe diameter, ϕ (open–type)