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STUDIES ON EXPERIMENTAL TECHNIQUE OF SHAKING TABLE TEST FOR GEOTECHNICAL PROBLEMS

Takashi MATSUDA and Yozo GOTO

Technical Research Institute , Ohbayashi Corporation, Tokyo, Japan

SUMMARY

This paper refers to a manufacturing method to reproduce saturated sandy ground in the first. Experimental results of liquefaction of the ground model obtaind by this method are presented. Then, a method to accurately estimate the dependency on confining pressure and shear strain of dynamic properties of soil by solving the equation of motion of the ground model taking spring constants as unknowns is presented. Finally, the authors describe an experimental attempt which could increase the confining pressure in the ground model using vacuum pumping.

INTRODUCTION

The shaking table test is one of the key methods to reproduce dynamic behaviors in the analysis of dynamic problems involved in ground or soil-structure interaction. The purpose of the present study is to enhance experimental precision and to expand the scopes of applicability of shaking table test concerning such geotechnical problems.

A shearing stack container whose wall is movable in response to the inner soil behavior has been found suitable to hold the ground model in limited space of location such as on the shaking table[1)]. Beside, a ground model using actual soil is usually utilized to take into consideration the nonlinearity of soil which depends on confining pressure and shear strain. Along with these, we have developed a large-sized shearing stack container having 2m height to enable modelling of deep layer locations of proto-ground, as shown in Photo1, and we have made following studies.

METHOD OF MANUFACTURING SATURARED SANDY GROUND

We herein propose a new method of manufacturing ground models with a good reproductivity in particular applicable to either saturated or partially saturated sandy ground.

This method is briefly outlined as follows: ① charge the sand into the container and simultaneously inject pressurized water from the bottom of the shearing stack container, ② subject it to vibrations by the shaking table in order to exhaust air bubbles, ③ stop the injection of water and drain the surplus so that grains precipitate and deposit. With this method air bubbles can be almost completely exhausted and grains settle down uniformly. Therefore, a high degree of saturation and reproductivity can be expected.

The experiment of liquefaction was conducted on a ground model manufactured in the present method taking table acceleration as a parameter. The relative density of the ground model made of actual soil was 31% on average as shown in Table 1. Table 2 shows maximum acceleration in experimental cases. It should be noted that a virgin ground manufactured by the aforesaid method was used for each experiment.

Records of acceleration and excess pore water pressure in case S4 are shown in Fig.2. Fig.3 shows the distribution of maximum excess pore water pressure in each case. It is found that ①as the input amplitude of acceleration increases, liquefaction zone tends to enlarge at the bottom, and ②the distribution of pore water pressure under an earthquake wave with an A_{max}:maximum acceleration (measured at the bottom of the container) and the one under 10 sine waves with an $0.6\times A_{max}$ amplitude are almost equal.

DYNAMIC PROPERTIES OF DRY GROUND MODEL

Dynamic properties of a ground model to be used in a quantitative study of shaking table test results are often estimated by soil element test in laboratory. However, it is hardly possible to carry out the soil test with accuracy in laboratory under the extremely low confining pressure. Thus, we have estimated the shear modulus and the damping factor under the actual confining pressure of the deposit by using the Dynamic Back Analysis based on the results of shaking table test.

The Dynamic Back Analysis will be introduced as follows: accelerometers are burried in the ground on the same cross sectional plane in the vertical direction and a numerical model is made using lumped mass corresponding to the above locations (Fig.4). The dynamic equation of the model is given in equation (1), where Gothic print denotes the complex with respect to the phase angle. The relative displacement terms [D] and the inertia force $\{M\times Y''\}$ are calculated by observed acceleration Y" from the resonant tests; consequently spring K can be obtained. Where H_j is the depth of j^{th} layer, then shear modulus G, damping factor h are calculated from equation(2), and shear strain γ_j from equation(3). By varying amplitude or frequency during resonant tests, we can estimate not only the relation between shear modulus and shear strain but a lso the relation between damping factor and shear strain.

$$\{K\} = [D]^{-1}\{M\times Y''\} \qquad \text{----------- (1)}$$

$$K_j\times H_j = G_j = |G_j|\{1-2h_j^2+2ih_j\sqrt{1-h_j^2}\} \qquad \text{----------- (2)}$$

$$\gamma_j = |Y_j - Y_{j-1}| / H_j \qquad \text{----------- (3)}$$

where:

$$\{K\}^T = \{K_n, K_{n-1}, \dots, K_1\}$$

$$\{M\cdot Y''\}^T = \{M_n Y_n'', M_{n-1}Y_{n-1}'', \dots, M_1 Y_n''\}$$

$$[D] = \begin{bmatrix} Y_n - Y_{n-1}, & 0 & \dots & ,\dots, & 0 \\ Y_{n-1}-Y_n, & Y_{n-1}-Y_{n-2}, & 0 & ,\dots, & 0 \\ 0 & , Y_{n-2}-Y_{n-1} & , Y_{n-1}-Y_{n-2} & ,\dots, & 0 \\ & \dots & & & \\ 0 & 0 & 0 & \dots & , Y_1 - Y_0 \end{bmatrix}$$

As an example of applying for the Dynamic Back Analysis, we performed the experiment utilized dry sand. The physical properties of used sand are given in Table 1. Seven accelerometers were installed at regular intervals of depth as shown in Fig.1. It can be found that predominant frequensy is 13.1Hz estimated by the Fourier spectrum of the microtremor at the ground surface, as shown in Fig.5. The results of resonant test in which the amplitude of shaking table varies from 20 to 200 gal are shown in Fig.6. The results of the Dynamic Back Analysis concerning the third layer at the same center of the depth are given in Fig.7 as an example. It is found that the shear modulus ratio G/Go tends to decrease with the increase of the shear strain γ and the damping factor h appears to increase conversely [2)3)].

Earthquake response analysis was performed concerning shaking table tests using earthquake waves. The experiment employed El Centro wave scaling down the time scale to 1/5 of the actual earthquake records. Earthquake response analysis was carried out based on Multiple Reflection Theory of S-Wave while evaluation the nonlinearity in the Equivalent Linear Method. Fig.8 shows the transfer function between the bottom and the surface of the model ground. It can be said that the predominant frequency is coincident despite the difference in the maximum amplification.

ADDITIONAL CONFINING PRESSURE USING VACUUM PUMPING

The shear modulus is sometimes increased by applying a surcharge load on the surface of the ground model, taking advantage of the dependency on confining pressure of the actual soil. We sealed tightly the model including the superstructure with thin rubber membrane and inner air pressure was reduced by vacuum pumping. The pressure difference between the atmospheric pressure and the inner soil of the model was created in an attempt to simulate this surcharge load P.

We applied the preset method to dry sandy ground and concrete block that was settled on the ground surface. Fig.9 shows the profile and the dimensions of the model and the locations of measurement gauges. The value of the surcharge load was confirmed to be created up to a maximum of $P=7t/m^2$. In the case of ground model, the relation between the shear modulus of the ground G that is calculated by equation(4) using the predominant frequency and overburden σ at the center of the ground model is shown in Fig.10. The relation between maximum shear modulus Go and overburden σ given in equation (5) is estimated from this figure. The black marks in Fig.5 show the relation between G/Go - γ and h- γ, which were obtained by the Dynamic Back Analysis with a surcharge load $P=7t/m^2$.

$$G = \rho(Vs)^2 = \rho(4Hf)^2 \qquad \text{----------} \ (4)$$

$$G_0 = 1600\sigma^{0.4} \quad \text{in } (t/m^2) \qquad \text{----------} \ (5)$$

where, ρ :Mass
Vs :Velocity of S wave
H :Thickness of the ground
f : Predominant frequency

In the case of soil-block interaction model, the resonant curves at the top of the concrete block as well as at the ground surface are shown in Fig.11. It is obvious that the resonant frequency becomes higher as the shear modulus increases following the increase of the surcharge load P. It should also be noted that the resonant characteristics of ground and the one of the rocking mode of the concrete block are transposed, which indicates that the shear modulus does not separately affect the ground or the structure but exert effect on them as a soil-structure interaction system.

CONCLUSION

The experimental and analytical technique of shaking table test using the large-sized shearing stack container are presented. According to our studies, the followings are pointed out:

(1) Using pressurized water, reproducible saturated sandy ground can be made with a high degree of saturation in a brief time.

(2) It is found that the Dynamic Back Analysis is effective for either quantitative analysis or numerical analysis.

(3) It became possible to manufacture the ground model with the realistic dynamic property of soil by controlling the surcharge load even if the model is provided with a superstructure.

REFERENCES

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2. Iwasaki, Tatsuoka, Takagi : Dynamic deformation characteristics of sand in the wide strain area, PRI Report 1080, 1976 (in Japanese)
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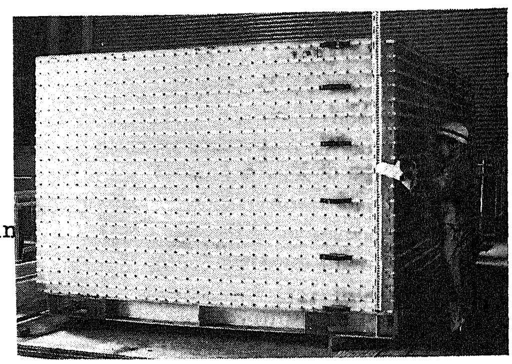

Photo 1
Large-Sized Shearing Stack Container

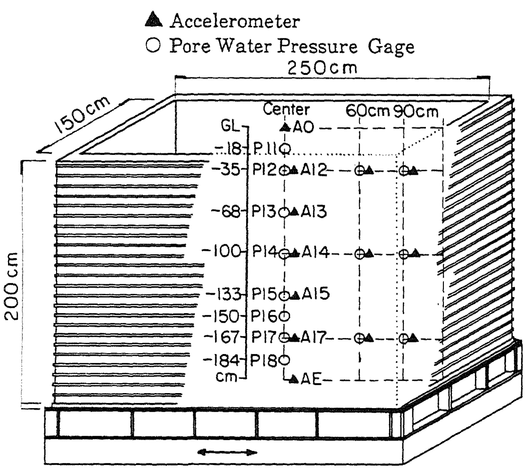

Fig.1 Shearing Stack Container and Measuring Points

Table 1 Physcal Properties of Sand

Soils (Common)	Effective grain size(D_{10})	0.16mm
	Specific gravity (U_c)	2.75
	Max void ratio (e_{max})	1.011
	Min void ratio (e_{min})	0.615
Dry ground	Unit weight (γ_d)	1.63 t/m³
	Relative density (Dr)	98%
	Shear modulus (G_0)	2050t/m²
Saturated ground	Unit weight (γ_d)	1.88 t/m³
	Relative density (Dr)	31%

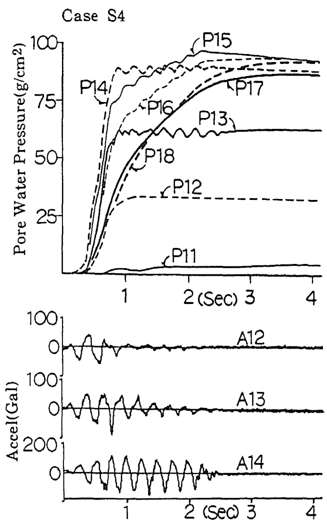

Fig.2 Pore Water Pressure and Acceleration Records

Table 2 Test Conditions

	Sine Wave(4Hz) 10waves							El Centro 1940NS time scale1/2				
Case	S1	S2	S3	S4	S5	S6	S7	F1	F2	F3	F4	F5
Max accel. (gal)	20	27	57	80	112	164	207	24	40	61	93	131

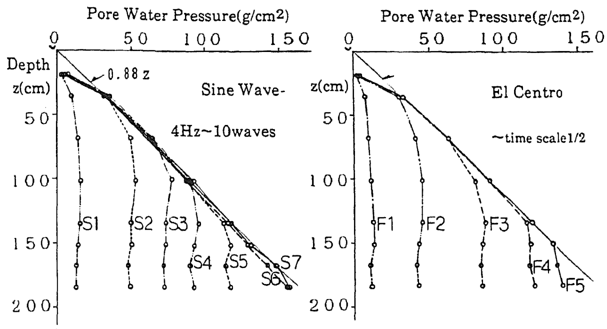

Fig.3 Maximum Pore Water Pressure Distributions

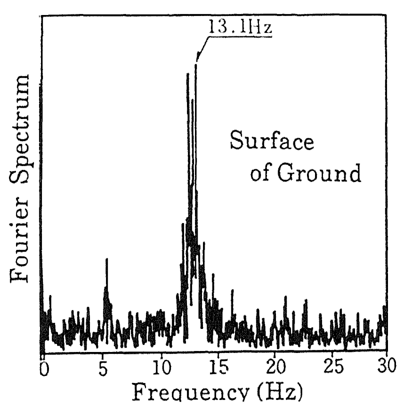

Fig.4 Fourier Spectrum of the Microtremor

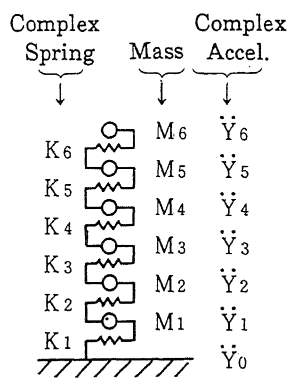

Fig.5 Lumped Mass Model for Dynamic Back Analysis

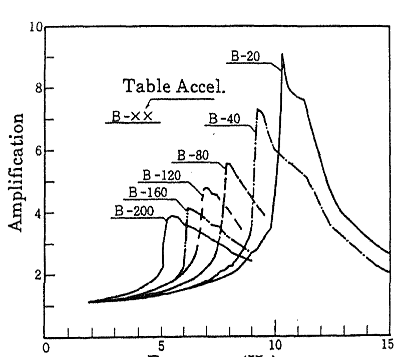

Fig.6 Resonant Curves (at A0)

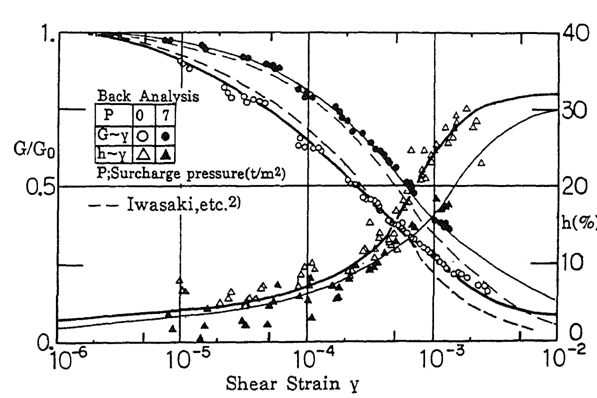

Fig.7 $G/G_0 \sim \gamma$ Relation and $h \sim \gamma$ Relation

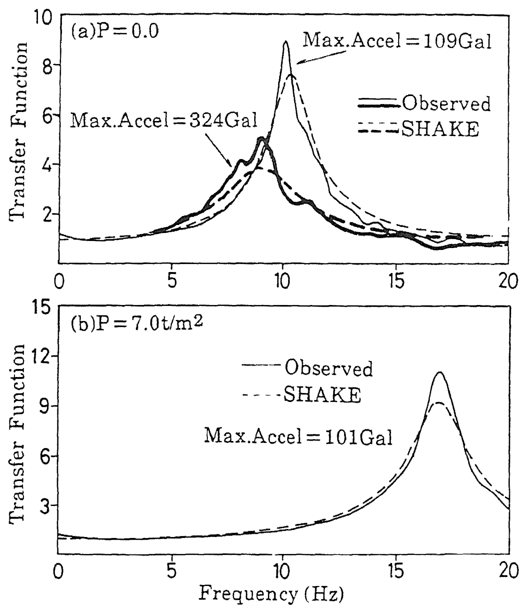

Fig.8 Transfer Function (A0/table)

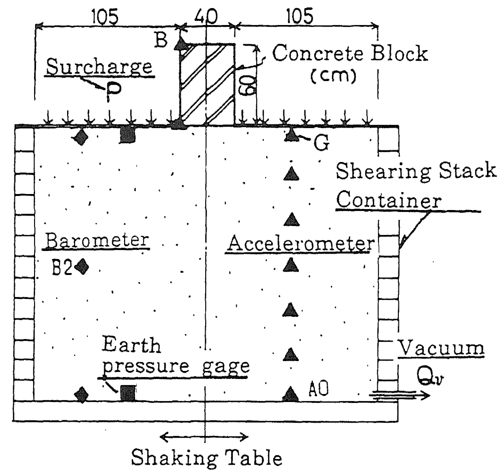

Fig.9 Cross Section of Soil and Concrete Block Model

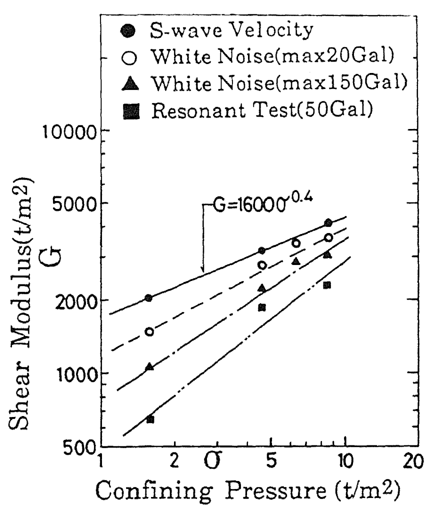

Fig.10 Comparison of G versus Confining Pressure σ

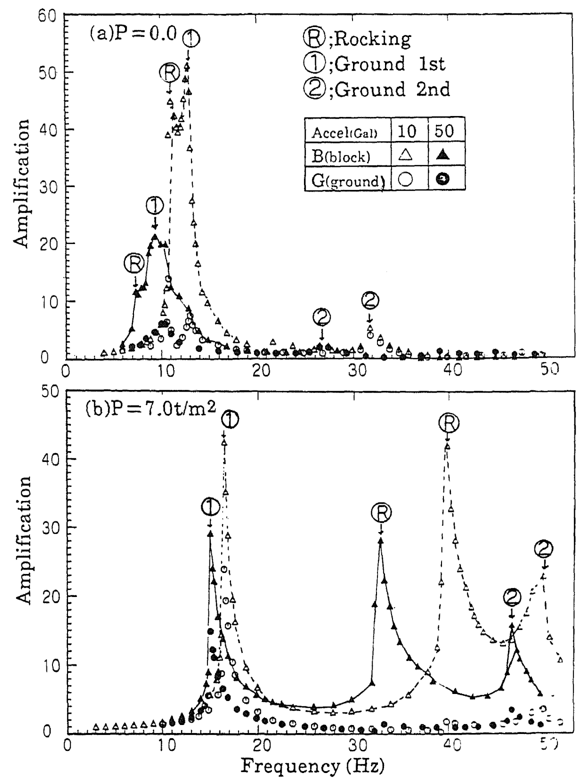

Fig.11 Comparison of Resonant Curves (Block Model)