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AN EXPERIMENTAL STUDY ON DAMPING CHARACTERISTICS OF SOIL DEPOSITS

- SHAKING TABLE TEST USING LARGE FLEXIBLE SHEAR VESSEL -

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SUMMARY

Presented in this paper is dynamic damping characteristics of soil deposits. Shaking table tests were conducted on a model sand deposit encased in a large flexible shear vessel. The model soil deposit was sinusoidally shaken at low acceleration to obtain the damping characteristics in the low strain level. Input acceleration was increased up to 10~200Gal in case of seismic excitation. Acceleration was measured at several depths of the soil deposit and at the shaking table. Transfer characteristics were analysed using observed records to obtain the damping factor of each layer of the model and modal damping factors of the model. Decrease of modal damping factors in higher mode was reconfirmed by this shaking table test.

INTRODUCTION

In recent years, modal damping factors of soil deposits were revealed to have the tendency to decrease in higher modes, which was pointed out from the analysis of the observed earthquake records at some existing sites. Authors explained this phenomena by adopting Maxwell visco-elastic model for soil deposits. In order to check this phenomena and applicability of Maxwell visco-elastic model, shaking table tests were conducted on model sand deposit. The obtained results are reported in this paper.

EXPERIMENTAL METHODS

The sand soil model was formed with the flexible shear vessel shown in Fig.1. This vessel is 1.4m in diameter and 1.8m in height, which was made as large as possible to simulate the field soil. The side surface of the vessel is composed of multi-layered tension rings made of steel plate and a rubber membrane in order that the boundary condition of the soil model is close to that of the field soil. The uppermost ring of the vessel is supported by ball bearings on four rigid columns to suspend the steel plate tension rings, thus preventing the model soil from deforming in flexure.

The vessel was filled with the dry sand (Toyoura standard sand), with the accelerometers and velocitymeters laid at the specified position of the model as shown in Fig.2.

Experimental program is shown in Table 1. Seismic exploration was carried out before and after the sinusoidal and seismic excitation, to check the compaction of the sand through vibration. Input acceleration level of sinusoidal excitation was set as small as 5Gal, 8Gal and 12Gal so that the stiffness of the sand soil model was not reduced. Excitation frequency was in the range from 5Hz to 60Hz covering resonant frequencies from the 1st to the 3rd. After sinusoidal excitations seismic excitations were carried out. EL CENTRO 1940 NS was used for the input seismic wave. Five input levels of seismic motion were chosen ranging from small acceleration level of 10Gal to large acceleration level of 200Gal. Time mesh of seismic wave was decided according to the scale law shown in Table 2.

In the sinusoidal and seismic excitation, accelerations were measured on the surface and underground of the soil model as well as on the shaking table by accelerometers shown in Fig.2. In the seismic exploration the velocities were measured at five points in the soil model by velocitymeters.

EXPERIMENTAL RESULTS

Shear Wave Velocities The shear wave velocities obtained by the seismic exploration are shown in Fig.3. The values ranged from 90m/sec to 170m/sec, getting larger in the deeper layer. It can be recognized from Fig.3 that the compaction of soil model is not caused by the sinusoidal and seismic excitation.

Modal Damping Factors By Half Power Method Modal damping factors were obtained from the results of sinusoidal excitation by applying half power method to the transfer function from the shaking table to the ground surface. The relationship of modal damping factors and resonant frequencies is shown in Fig.4. The modal damping factors are 0.04~0.07 for the 1st mode, 0.02~0.04 for the second mode and 0.01~0.03 for the 3rd mode. They decrease in higher order modes. There is little difference between the damping factors obtained by the first excitation and those by the second excitation.

Comparison of Shear Wave Velocities and Material Damping Factors Obtained by Two Method Shear wave velocities and material damping factors are obtained by two methods from the results of sinusoidal excitation. The first method is based on the shear stress(τ)-strain(γ) relationship of each layer as shown in Fig.5. Shear stress can be derived from the acceleration of each layer as the cumulative inertia force divided by the area of soil column. Shear strain can be obtained as the relative displacement divided by the thickness of the corresponding layer. The displacement of each point is calculated by double-integrating the acceleration. Equivalent damping factor(h), equivalent shear modulus (G) and the shear wave velocity (Vs) are obtained by next formula from τ-γ curve, where notation is the same as in Fig.5.

$$h=\frac{1}{4\pi}\frac{\Delta W}{W}, \qquad G=\frac{\tau a}{\gamma a}, \qquad Vs=\sqrt{\frac{G}{\rho}}$$

The second method is a strip-layer method. This method is to obtain the physical properties of each layer, identifying them layer by layer by stripping off the uppermost layer whose properties are identified. The shear wave velocity and material damping factor of top layer are obtained from the predominant frequency and amplification ratio of the top layer. Fig.6 shows the results of the two methods. Shear wave velocities are 20~50m/sec at upper layers, 50~70m/sec at middle layers and 70~200m/sec at lower layers. At middle layers shear wave velocities by τ-γ curves are similar to that by stripping method. At upper and lower layers difference can be seen. As these values are about half that of seismic exploration results shown in Fig.3, it might be possible that the stiffness of each layer of soil model is reduced in case of sinusoidal excitation. The material damping factors by two method are 0.05~0.1 except at the bottom layer, and there is a little difference between both values.

Simulation of the Transfer Function by Optimization Method Based on the idea of the equivalent linearization, the optimization of Maxwell visco-elastic wave reflection model was applied to the transfer function of seismic excitation. As the result of optimization shear wave velocities and material damping factors are obtained. Optimized Maxwell type material damping factors for the 1st frequency are shown in Fig.7. The material damping factors are scattering from 0.1 to 0.35 from the surface to the bottom. These are roughly regarded as constant from the surface to the bottom in each acceleration level. These increase as the acceleration level becomes higher. Fig.8 shows the transfer functions by the experiment and optimization. As a whole, experimental transfer function could be roughly simulated by Maxwell visco-elastic wave reflection model, though there is a little difference between both transfer function.

Modal Damping Factors by Spectrum Fitting Method Using optimized shear wave velocities the soil model was substituted to a lumped mass model, and modal damping factors from the 1st to the 3rd mode were obtained by spectrum fitting method concerning the seismic excitation. The relationship of modal damping factors and predominant frequencies is shown in Fig.9. Modal damping factors from 10Gal excitation to 100Gal excitation are 0.06~0.11 in the 1st mode, 0.02~0.07 in the 2nd mode and 0.0~0.05 in the 3rd mode. They decrease as the modal number is higher. In case of 200 Gal excitation the modal damping factors are 0.22 in the 1st mode, 0.12 in the 2nd mode and 0.03 in the 3rd mode, emphatically decreasing as the modal number is higher. In Fig.10 transferfunctions by the experiment and the spectrumfitting are shown for the case of 10Gal excitation and 200Gal excitation. In the sharpness and amplitude of predominant peaks the simulated transfer function approximates the experimental one.

CONCLUSION

Following results were extracted.

(1) Decrease of modal damping factors in higher modes was reconfirmed by this shaking table test. The phenomenon was observed both in the response curves by sinusoidal excitation and in transfer function between the ground surface and underground by seismic excitation. This decreasing tendency was emphasized in high acceleration excitation.

(2) The transfer characteristics of the soil model deposit could be simulated by Maxwell visco-elastic wave reflection model.

REFERENCE

1. KITAZAWA, K., KAWAMURA, S., and OSAWA, U.,"A Study On Dynamic Characteristics Of Damping Of Soil Deposits —Shaking Table Test Using Large Flexible Shear Vessel—" Proceedings Of The Seventh JAPAN Earthquake Engineering Symposium, 223-228, (1986)

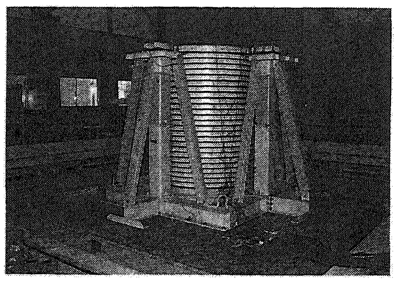


Fig.1 Flexible Shear Vessel

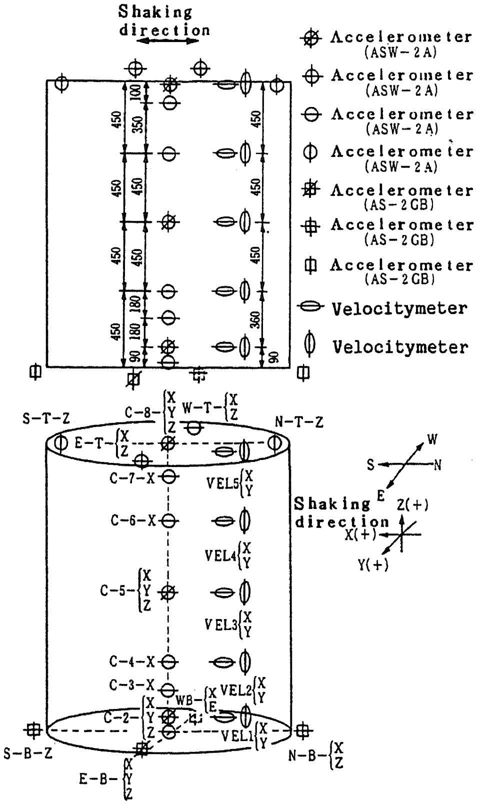


Fig.2 Position of Accelerometers and Velocitymeters

Table 1 Experimental Program

Contents	Acc. Level	№1	№2
Sinusoidal Motion	5Gal	○	○
	8Gal	○	○
	12Gal	○	○
Seismic Motion (EL-CENTRO 1940 NS)	10Gal	Δt = 0.00625sec	
	20Gal	〃	
	50Gal	〃	
	100Gal	〃	
	200Gal	〃	
Seismic Exploration	Before and After Each Motion		

Table 2 Scale Law

	Prototype	Model	Scale Factor
Vs Value	210 m/sec	70 m/sec	$(\frac{1}{3})$
Depth	16 m	1.8 m	$(\frac{1}{9})$
Time Mesh	0.02 sec	0.00625 sec	Nearly $(\frac{1}{3})$

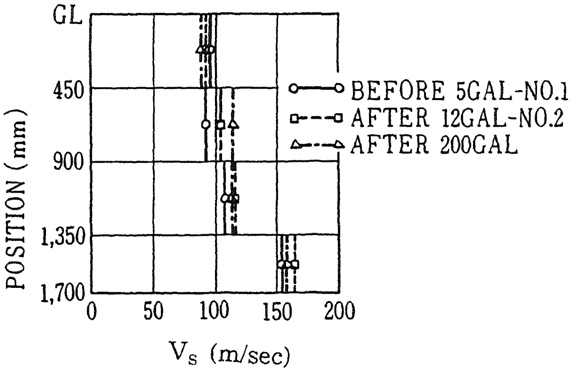


Fig.3 Shear Wave Velocity
by Seismic Exploration

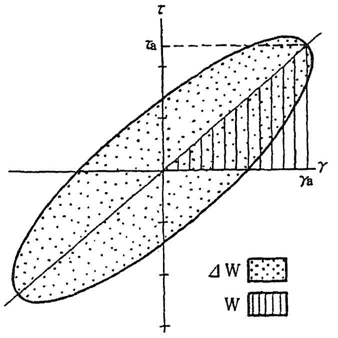


Fig.5 τ~γCurve

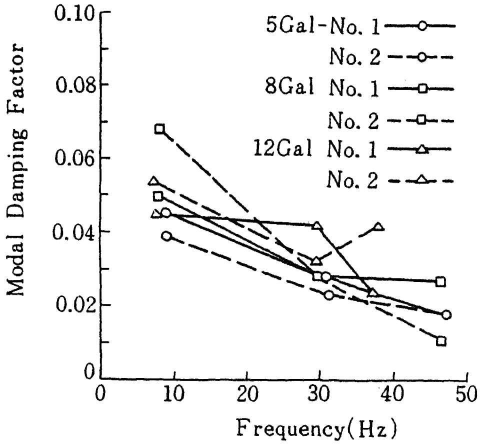


Fig.4 Relationship of Modal
Damping Factors and
Resonant Frequencies
by Sinusoidal Excitation

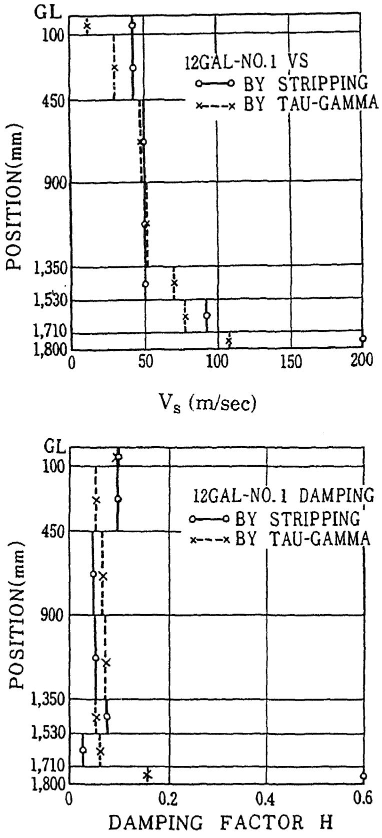


Fig.6 Shear Wave Velocities and
Material Damping Factors by
τ~γ Curve and by Strip-layer
Method

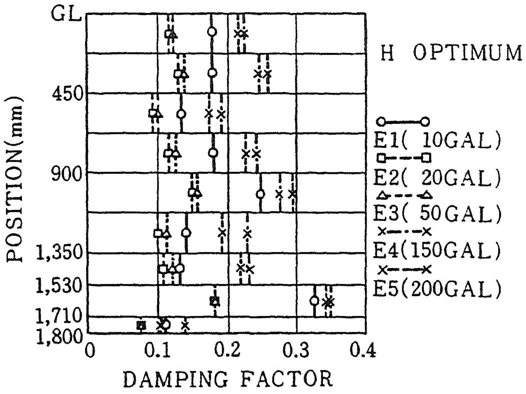
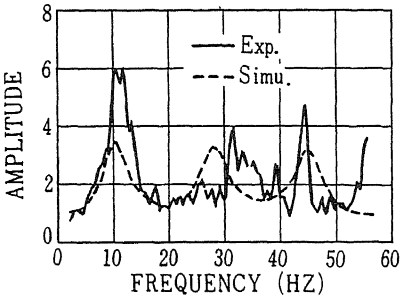
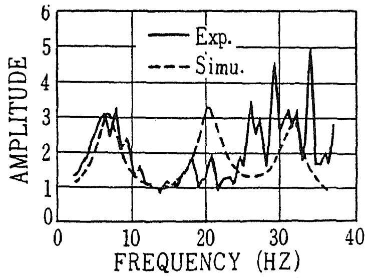


Fig.7 Material Damping Factors by Optimum Method of Wave Reflection Model (Damping Factors of Maxwell Type for the 1st Frequency)



(a) 10Gal Motion



(b) 200Gal Motion

Fig.8 Transfer Functions of Experiment and Simulation by Wave Reflection Model

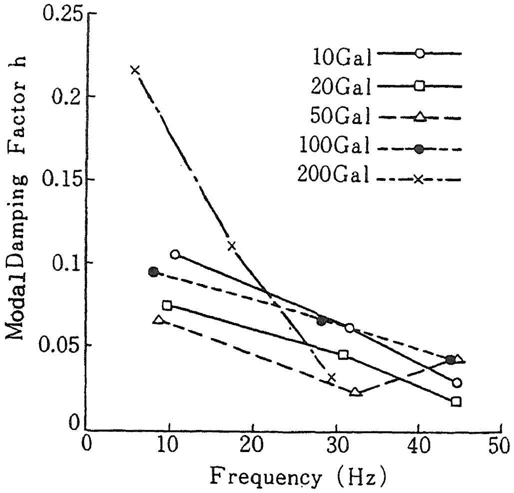
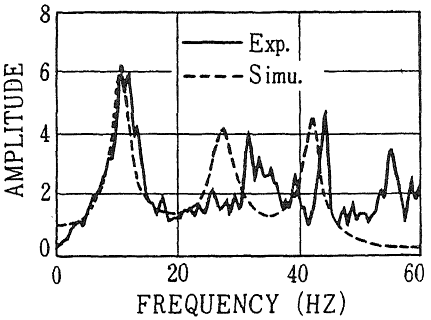
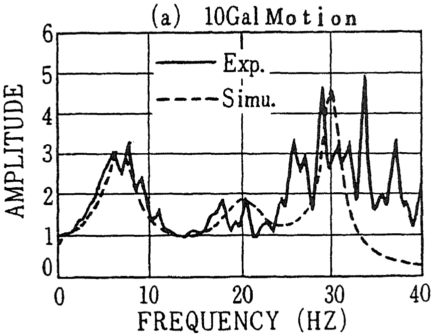


Fig.9 Relationship of Modal Damping Factors and Resonant Frequencies by Seismic Excitation



(a) 10Gal Motion



(b) 200Gal Motion

Fig.10 Transfer Functions of Experiment and Simulation by Lumped Mass Model