EVALUATION OF VARIOUS PARAMETERS ON RESPONSE ANALYSIS OF EARTHQUAKE MOTIONS INCLUDING SOIL-BUILDING SYSTEM

by

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SYNOPSIS

The influences of the five dimensionless parameters on the interaction effects were quantitatively examined using the soil-building interaction model. In order to evaluate these parameters, an earthquake observation system for an existing simple model of building and its surrounding subsoil has been carried out. Some observational data have been recorded and analyzed with aid of the results of some auxiliary experimental and analytical studies. It is pointed out from the results that the shear wave velocity in soil layers plays an important role in determining the suitable model of soil-building system.

INTRODUCTION

It has been widely recognized that soil-building interaction is one of the most important problems in the field of earthquake engineering. As the various factors related to interaction effects are involved as a whole in the earthquake response of buildings, it is necessary to evaluate separately each of model constants used in the earthquake response analysis. In order to know how much each of parameters contributes to interaction effects, the analytical interaction model was rearranged and reexamined based on the dynamic compliance theory. From the evaluation of these parameters, the earthquake observation for selected sites and buildings should be made in order to verify the validity of modeling and to evaluate its parameters. The purpose of this study is to clarify the interaction effects on the earthquake response of buildings, and to use the results for improvement of the dynamic design method of buildings through the analytical and observational investigations.

THEORETICAL BACKGROUND OF INTERACTION MODEL

Parameters Related to Interaction Effects - In order to know how much each of parameters contributes to interaction effects, the analytical simple model resting on a half-space elastic medium was selected taking account of dynamic compliance theory established by Bycroft[1]. This model has three degrees of freedom which are known as swaying, rocking and relative displacement of model.

According to the equation of motion, displacements are expressed in terms of the steady-state input wave Ug at ground surface and the corresponding magnification factor as follows[2][3]; $U_Y = Y \cdot Ug$, $Ux = X \cdot Ug$, $U_B = Z \cdot Ug$, where Y, X, Z are complex magnification factors for rocking, swaying and relative displacement, respectively. Five dimensionless parameters which

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are considered to be suitable to examine the interaction effects, are as follows; mass ratio ($\alpha = M_0/M_1$), structural damping ratio (h), building shape ratio (H/R), rigidity ratio ($a = \omega_0 R / V_s$) and effective mass ratio ($\beta = M / \rho R^2 H$), where Mo, Ml=top and bottom mass of model, H=height of model, R=radius of the base, ω_0 =undamped natural frequency of the model, Vs=shear wave velocity of soil, ρ =mass density of soil.

Characteristics of Various Parameters - To investigate the effect of the above parameters, the maximum magnification factors (M.M.F.) were calculated under the condition that one parameter was variable on another parameters being constant. Representative results are as follows; (1) The building shape ratio (H/R) has much influence on rocking motion (Y). Influence of (H/R) to (Y) increases 40% as (H/R) increases 20%. Another M.M.F.(X) increases linearly and M.M.F.(Z) decreases with (H/R). So it is pointed out that M.M.F.(T) is affected by (Z) in the range of (H/R)<1.5, (X, Y) in the range of (H/R)>1.5 and Minimum of M.M.F.(T) is taken place at (H/R)≒1.5 (Fig. 1). (2) Maximum of M.M.F.(Y,X) are taken place in the range of (a)=0.4-0.8 with (H/R) but M.M.F.(Z,T) decrease exponentially as parameter (a) increases. However it is pointed out that parameter (a) is extremely affected by shear wave velocity (Fig. 2).

From the evaluation of these parameters, it is proposed for the earthquake observation system that experimental interaction model should be established at site which the M.M.F.(X,Y) appears as much as possible and are not affected by parameters (a) and (H/R) with coincidence between natural frequency of the interaction system and the predominant one of soil layers.

OUTLINE OF THE SUBSOIL AND TEST MODEL

Subsoil - The Fuchinobe district, Kanagawa Prefecture, near the Tokyo Japan, was selected as an earthquake observation site. The subsoil in the site consists of a few layers. They are the Kwanto loam layer, the clayey gravel and fine sand, which are distributed and cover with range in this district. The soil profile, the penetration test results (N-values) and the results of seismic prospecting test by the well shooting method are shown in Fig. 3. The densities and poisson's ratio of various soil layers are also shown in the same figure.

Test Model - According to the theoretical background of interaction analysis, the simple model was constructed on a relatively simple natural soil layer. The reinforced concrete mat foundation and upper model structure are 4.0m x 4.0m with slab of 1.0m thickness in plan. The four steel pipes (4-216 x 6) are used as column having same rigidity in both directions. The plan and elevation is shown in Fig. 4.

DYNAMIC CHARACTERISTICS OF THE SIMPLE MODEL AND SUBSOIL

The forced vibration tests using a vibrator on the foundation or the top of the model were made to know the dynamic characteristics of the model on the natural soil layers and of the wave propagation.

Soil-Foundation (S.F.) System - The results are shown in Fig. 5 indicating the resonance curve and mode shape in NS component. Judging from these curves, the fundamental natural frequency of S.F. System is 13.5cps and the natural frequency for tortional mode is 18cps.

Soil-Foundation Building (S.F.B) System - The results generated by vibrator on the foundation are shown in Fig. 6. The fundamental natural frequency of S.F.B. system is 3.41cps. It should be noted that vibration due to the relative displacement is predominant.

EARTHQUAKE OBSERVATION

System - The location of seismometers on the model and underground is shown in Fig. 7. The purposes of observation are to learn (1) the modification of ground motions in accordance with depth of soil (2) the effects of the model on the natural soil with distance from the model and the variation of this effects, and (3) the characteristics of boundary conditions between model and subsoil as interaction effects.

The pendulum of the seismomenters is heavily damped (h≒10), and the output voltage having the natural frequency of 3.5cps is proportional to the acceleration. The sensitivity and range of instruments are 6.5 to 500mm/gal and constant in the range 0.3 to 30cps, respectively.

Observational Data and Analysis - Seismograms of 10 earthquake (Intensity I-IV in JMA scale) have been recorded during Apr. 1975 - Jun. 1976. Illustrative wave forms in the S.F. and S.F.B systems, which data are listed in Table 1, are shown in Fig. 8.

The characteristics of the underground was determined from the observational data of the earthquake by taking the fourier spectral ratio (Fig. 10) between the ground surface (-0.5Y15) and the underground layers (-15Y15) using the fourier spectra shown in Fig. 9 in NS component. The results are listed in Table 2 with the values obtained analytically using S-wave velocity by Haskell's method and the result of microtremor.

The characteristics of the interaction effect and the model were also determined from the observational data of the earthquake in the similar way mentioned above. Figs.11 and 12 show the fourier spectral ratio between the foundation (FCY) and the ground surface (-0.5Y15) in S.F. and S.F.B. system, and the spectral ratio of the top and bottom of the model records shown in Fig. 9, respectively. In Fig. 12, the spectral ratio between the top of the model and the ground surface is also shown. These results are shown in Table 2 together with those obtained by vibration test and model analysis.

ESTIMATION OF VARIOUS FACTORS

The damping and stiffness of soil layer are the most influencial factors in the analytical model using compliance theory. To compare the observed natural frequency and the amplitude in S.F. system with the computed ones, three kinds of shear wave velocities (Vs) were used. These are (1) 140m/sec, (2) 167.5m/sec (2b), (3) 220m/sec (3b), where value of (1) is Vs modified from dispersion curve of surface wave and values of (2) and (3) are averaged ones with consideration of soil depth equal to 2b and 3b, b means a half width of the foundation. In this analytical model, it is assumed that these shear wave velocities are continued to infinite as a half-space elastic medium.

The resonance curves computed with the analytical S.F. system are shown in Fig. 13. It can be seen by comparing Fig. 5 with Fig. 13 that the natural frequency of S.F. system having 167.5m/sec of shear wave velocity coincides well with one analyzed from the vibration test. However disagreement is seen in the amplitude characteristics (Table 2). These tendencies are similar to S.F.B. system. On the other hand, in order to obtain the suitable M.M.F. under earthquake motions, the randomness effect of earthquake input wave was introduced from response spectra. The modified M.M.F. values in S.F. and S.F.B systems on amplitude characteristics agree fairly well with observed data after considering the difference between the analytical model and experiments (Table 2).

CONCLUDING REMARKS

According to theoretical background, analysis was made for the dynamic characteristics of simple model and subsoil layers. The observational data of earthquake motions on the model and in the underground have been accumulated and analyzed. The results can be summerized as follows; Good agreement was seen in the natural frequency between the analytical simple model and experiments such as the forced and free vibration tests, the microtremor measurement, earthquake observation. However there was certain amount of disagreement on amplitude characteristics between them. It seems that one of the main reason for the disagreement is due to the effect of energy consumption produced by the reflection and refraction of propagating waves at the boundary of soil layers. It is pointed out that the determination of shear wave velocity in soil layers is an important factor, especially just under building. After getting enough earthquake data, it is expected to clarify the interaction effects for the improvement of the theory as simple as possible.

ACKNOWLEDGEMENT

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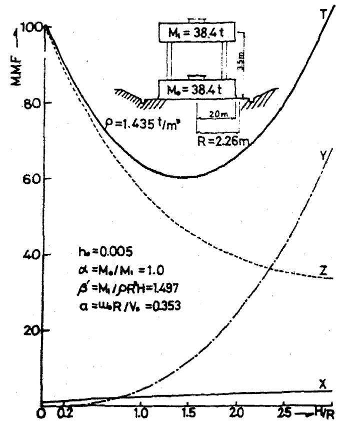

Fig. 1 Maximum Magnification Factor

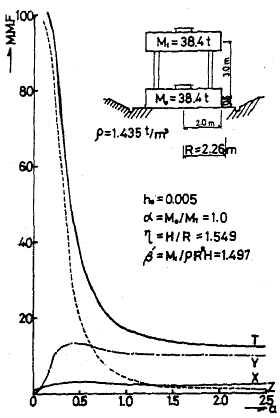

Fig. 2 Maximum Magnification factor.

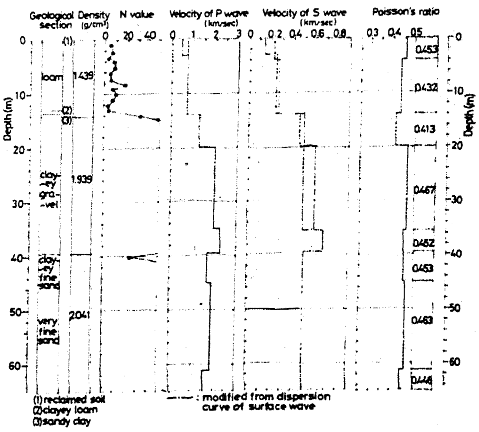

Fig. 3 Soil Profile and Underground Structure.

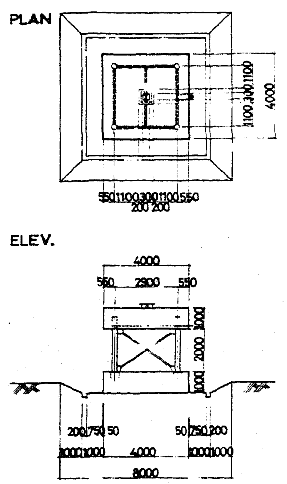

Fig. 4 Plan and Elevation.

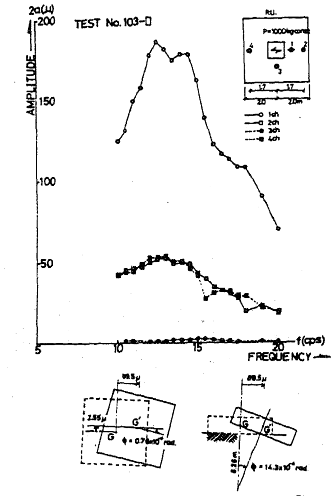

Fig. 5 Resonance Curve and Mode Shape.

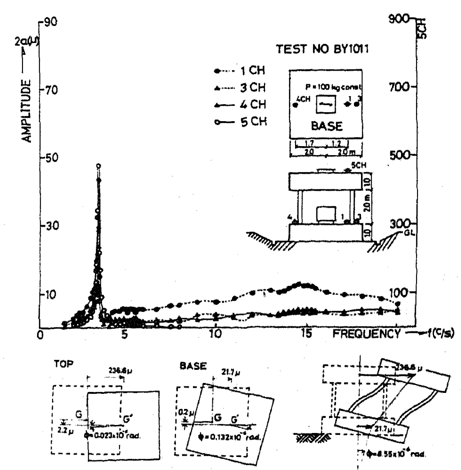

Fig. 6 Resonance Curve and Mode Shape.

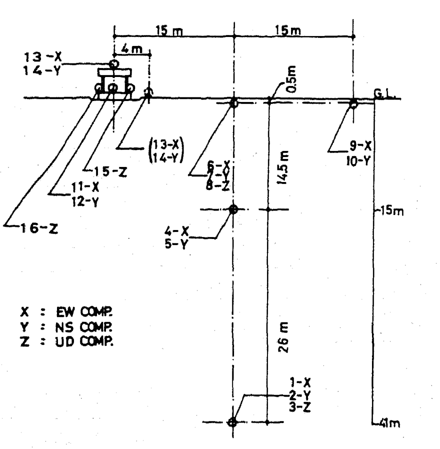

Fig. 7 Location of Seismometers.

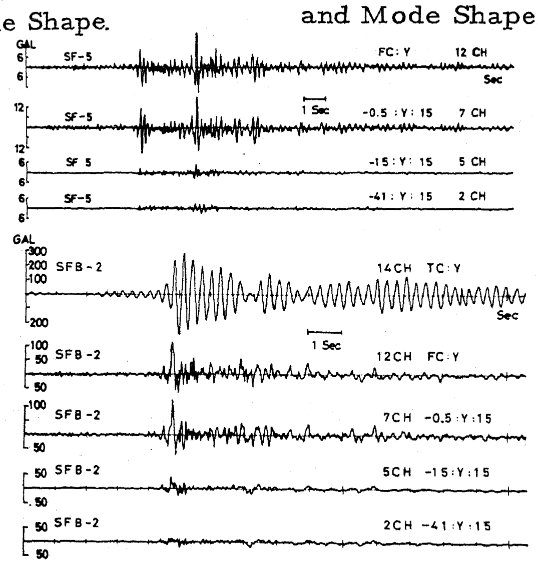

Fig. 8 Records of Acceleration.

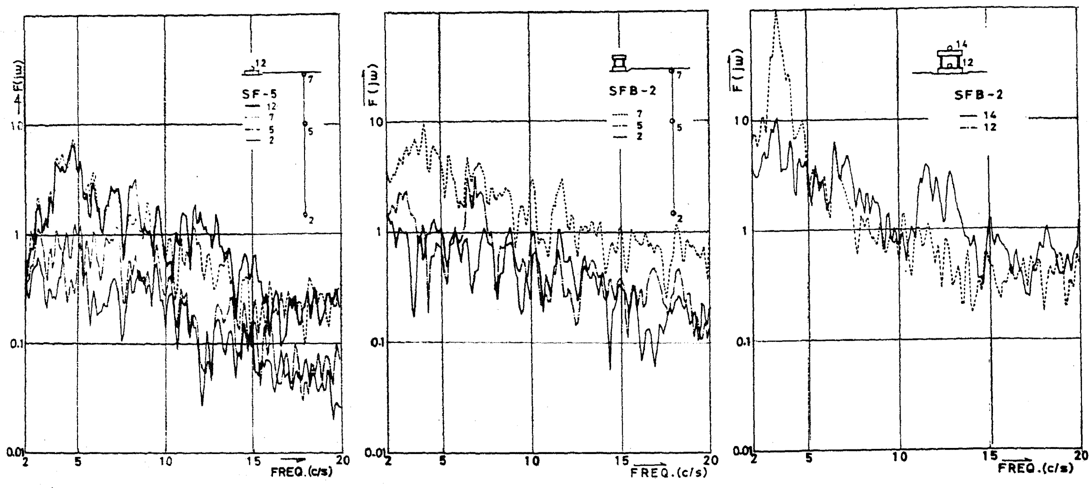

Fig. 9 Fourier Spectra.

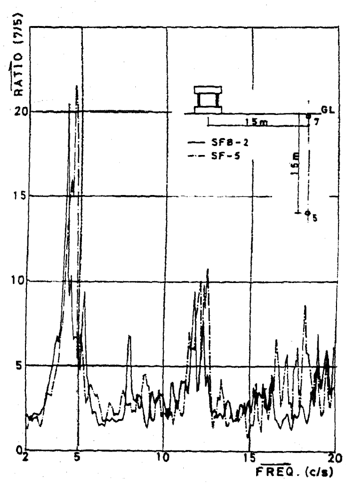

Fig. 10 Fourier Spectral Ratio.

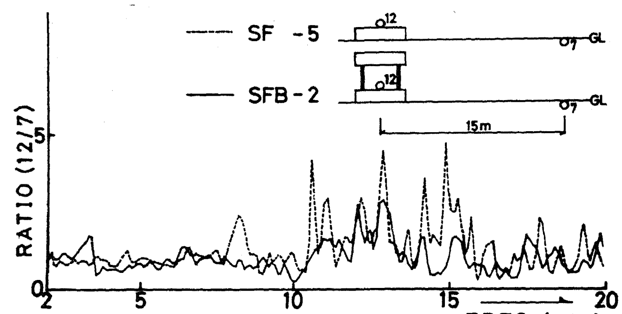

Fig. 11 Fourier Spectral Ratio.

Table 1 Data.

Eq. No.	SF-5	SFB-2
Date	03h.41m 18d,4,'75	07h.35m 16d,6,'76
Epicent.	36.2°N 139.9°E	35.6°N 138.9°E
Depth	60 km	20 km
Mag.	——	5.7
Int.	Tokyo II	Tokyo IV

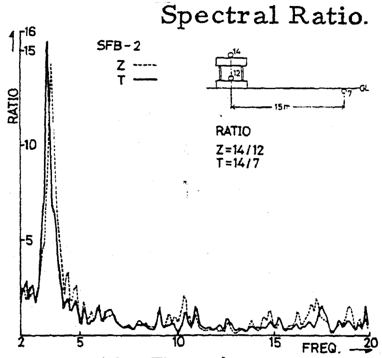

Fig. 12 Fourier Spectral Ratio.

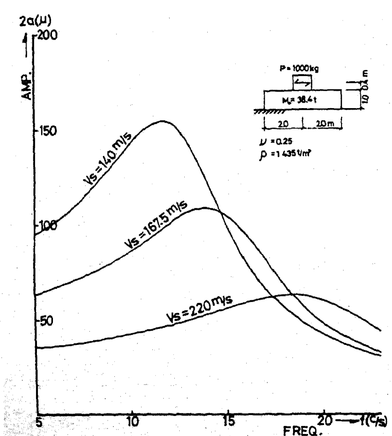

Fig. 13 Resonance Curve

Table 2 Results.

System \ Measured item / Method		Nat. freq. (c/s)	Damp h (%)	Amplitude (μ) Sway	Rock.	Rel. Disp.	Abs. Disp.	M.M.F. T	T'
S.F.	Forced Vib. Test	13.5 (13.8)	20. (31.0)	82.3 (34.4)	7.2 (10.2)		89.5 (44.6)	—	—
	Earthq. Obs.	13.0 (13.8)	—	—	—		—	3.6 (1.7)	(2.6)
S.F.B.	Free Vib. Test	3.4	1.0	16.2	29.2	159.1	204.5	—	—
	Forced Vib. T.	3.4	2.0	21.7	29.9	185.6	236.6	—	—
	Earthq. Obs.	3.4 (3.4)	—	—	—	—	—	16.0 (67.0)	(20.0)
Soil	Micro Trem.	4.7							
	Earthq. Obs.	4.5							
	Haskell's Method	(4.6)							

( ): calculated values

T' : modified value