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SOIL-STRUCTURE INTERACTION TESTS OF FIVE-STORY STEEL FRAME BUILDING BY SERVOHYDRAULIC-TYPE VIBRATOR

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SUMMARY

Forced vibration tests for a full-scale steel frame building was performed by means of a servohydraulic-type vibrator to examine experimentally effects of soil-structure interaction. Theoretical studies were also compared with the experimental results. It was found that the position of excitation has a large influence on the effects of soil-structure interaction; also, responses for excitation at the first floor are much more convenient than those at the roof, when evaluating interaction effects, and agrees with an actual case of a structure subjected to incident waves.

INTRODUCTION

Many forced vibration tests of a full-scale building have been performed to evaluate dynamic characteristics of a superstructure largely ignoring the effects of soil-structure interaction, but the results obtained from them seem to have more or less contained the effects. The aim of this study is to evaluate the effects of soil-structure interaction during forced vibration tests, and in particular, how the position of excitation influences those effects.

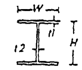
For the purpose of this study, a full-scale steel frame building was tested. It is located in the Uji campus of Kyoto university and has the same frame as the institute buildings in principle; Figure 1 shows some parts of these buildings. The structure consists of 6 pieces of isolated reinforced concrete footings, a five-story steel frame and reinforced concrete slabs. It is 15 m long in E-W direction, 3.75 m wide in N-S direction, 17.37 m high, and the slabs are about 12 cm thick. The staircase is built separately from the structure and both of the foundations are independent of each other. So they have little influence on the dynamic characteristics of the structure. In this study, both the structure itself and two model footings were forced to excite. The footings were settled to provide a source of excitation, 16 m south ('South footing') and 30 m east ('East footing') from the center of the structure. Both of them had a square area of $4m\times4m$ and were $1m$ high.

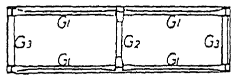
Although forced vibration tests of the structure had been done previously using an eccentric-mass type vibrator, some observed results fluctuated in the vicinity of resonant frequencies [1]. At this time, we used a servohydraulic-type vibrator we had just developed [2]. An excitation force is generated when a cylindrical inertial-mass oscillates around a center of the rod; This is shown in Figure 2. All the tests were performed by linear-sweep excitation so that the vibrator could have a large effect on them.

Table 1. Dimensions of column and girder.

		W	H	t1	t2
Column	1,2F	400	400	19	12
	3,4,5F	400	400	12	9
Girder	G_1*	300	500	14	9
	G_2*	250	500	12	9
	G_3	200	500	12	9

* Honeycomb Beam





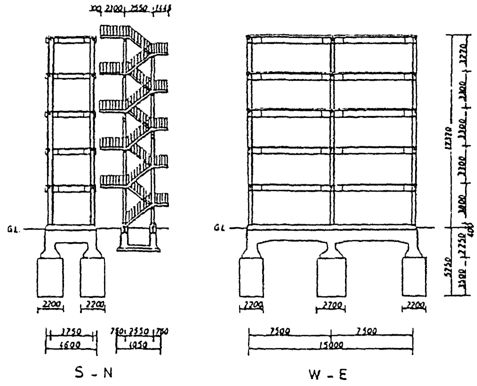


Fig. 1. Elevation view of the structure.

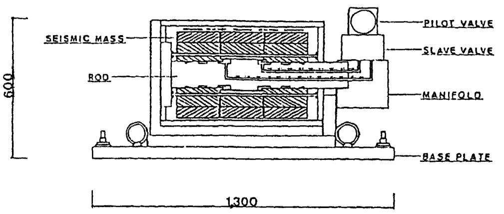


Fig. 2. Side schematic view of the servocontrolled vibrator.

EFFECTS OF VIBRATOR POSITION ON STRUCTURAL RESPONSES

The effects of different positions of the vibrator on the dynamic characteristics of structural responses are described. The structure was excited by means of the vibrator placed on the roof or the first floor of the structure.

The resonant frequency and damping ratio evaluated by the half-power method for each test are shown in Table 1. It is noted that the position of excitation has a significant influence on the damping ratio.

Figure 3 shows the amplitude and phase characteristics of the velocity response of the roof and the first floor of the structure in N-S direction for the fundamental mode, swaying and rocking ratios of the response of the first floor compared with the response of the roof, and the variation of the mode shape. It is noted that the first floor response to excitation at the first floor decreases at a somewhat higher frequency than the resonant frequency (1.97 Hz), swaying and rocking ratios have minimum values close to this frequency, and the phase characteristics between the roof and the first floor response gradually become opposite to each other as the frequency of excitation becomes higher than this frequency. Such characteristics of the structural response to excitation at the roof are, however, not recognized.

As mentioned above, the overall trends of the first floor response to excitation at the first floor are also common at high frequencies more than the 2nd mode.

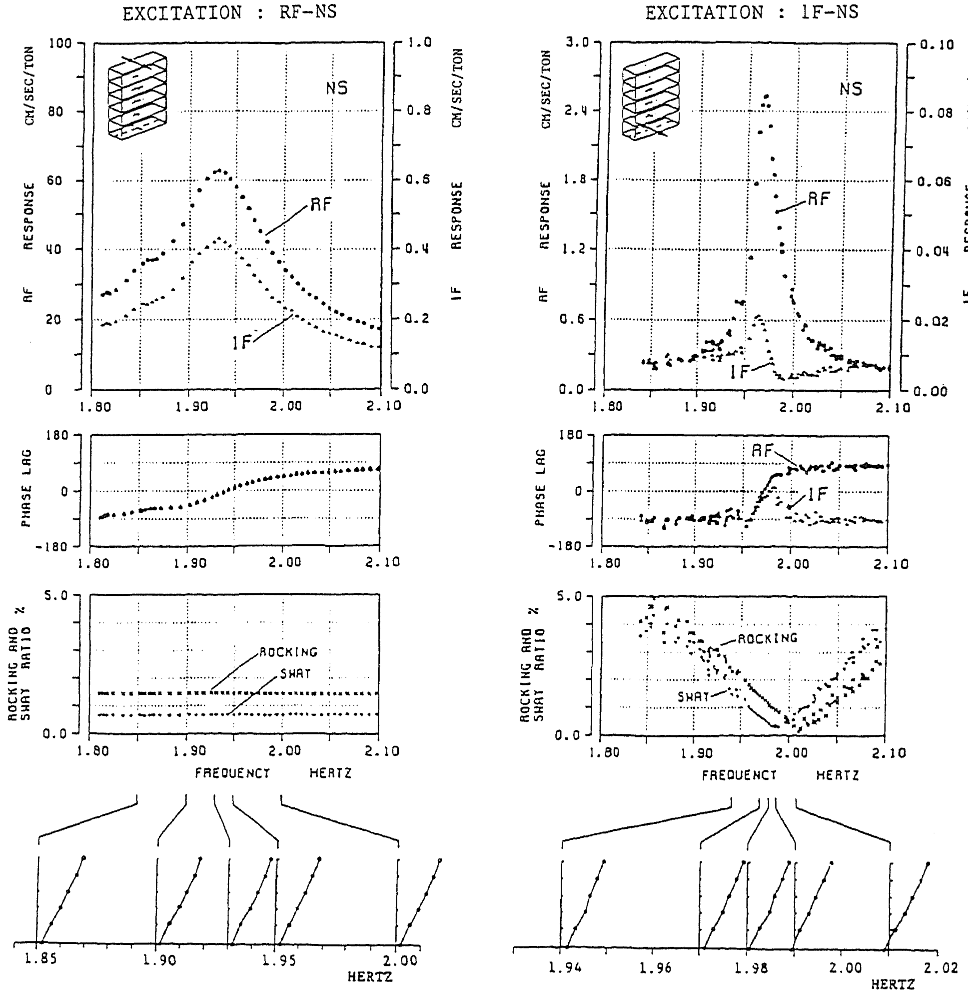
Table 2. Effects of excitation at different levels on the resonant frequency and damping ratio of the structure.

Dir.	Position (Vibrator)	Mode	Resonant Frequency (Hz)	Damping Ratio (%)
NS	FREE OSC.	1	1.96	2.39
	ROOF	1	1.93	2.33
		2	6.05	0.62
		3	10.87	0.55
		4	15.44	—
	FIRST FLOOR	1	1.97	0.45
		2	6.13	0.24
		3	11.05	0.32
		4	15.68	—
EW	FREE OSC.	1	1.90	0.22
	ROOF	1	1.88	—
		2	5.82	0.28
		3	10.08	0.89
	FIRST FLOOR	1	1.94	—
		2	5.88	0.17
		3	10.30	0.21

EFFECTS OF INCIDENT WAVES ON STRUCTUAL RESPONSES

The effects of the 'external' excitation on the dynamic characteristics of the structural response are described. The structure was excited by means of the vibrator placed on South footing or East footing near the 2nd, 3rd, and 4th resonant frequencies of the structure, which are about 6, 11, and 15 Hz, respectively, because incident waves generated by these footings are not powerful enough to excite the structure around the fundamental resonant frequency of about 2 Hz.

The amplitude and phase characteristics of the structure were normalized by the corresponding response of the excited footing. The resonant frequency and damping ratio evaluated by the half-power method for each test are shown in Table 3.



(a)

(b)

Fig. 3. Velocity response and mode shape for fundamental mode in N-S direction of the structure excited at (a) roof and (b) first floor.

Figure 4, like Figure 3, shows the response of the structure to excitation from South footing in N-S direction for the 2nd mode. Seeing the first floor response, the same characteristics as the first floor response of the structure shown in Figure 3(b) are also recognized here. It is found that the characteristics behavior of the first floor response and the values of the resonant frequency and damping ratio are in good agreement with the results for excitation at the first floor. The results obtained around the 3rd and 4th resonant frequency are also similar to the results for the 2nd mode.

THEORETICAL RESULTS

Simulation To study theoretically the effects of the position of the vibrator on structural responses, the model shown in Figure 5 is studied.

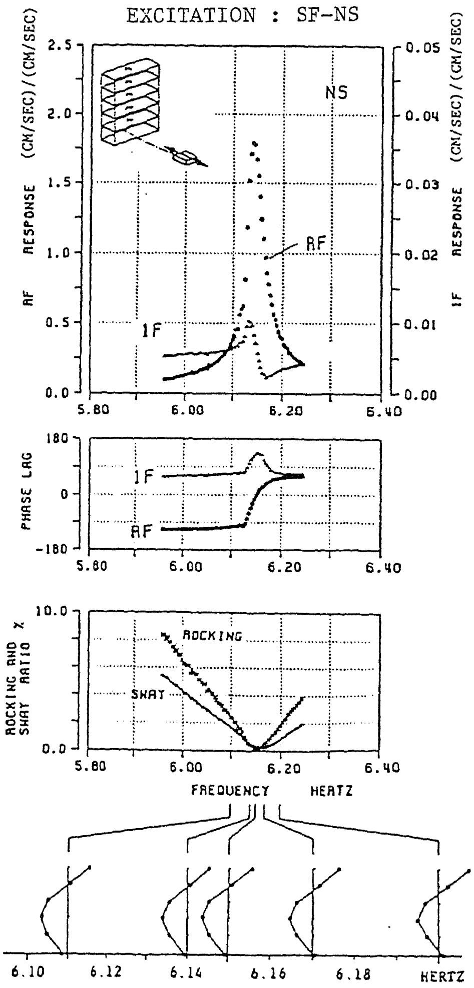


Fig. 4. Velocity response and mode shape for 2nd mode in N-S direction of the structure subjected to ground motion excited by South footing.

Table 3. Effects of different types of ground motion excited by South and East footing on the resonant frequency and damping ratio of the structure.

Dir.	Position (Vibrator)	Mode	Resonant Frequency (Hz)	Damping Ratio (%)
NS	SOUTH FOOTING	2 3	6.14 11.10	0.21 —
	EAST FOOTING	2 3	6.15 11.10	0.21 0.22
EW	SOUTH FOOTING	2 3 4	5.89 10.32 14.76	0.21 0.21 0.11
	EAST FOOTING	2 3 4	5.89 10.30 14.76	0.20 0.19 0.11

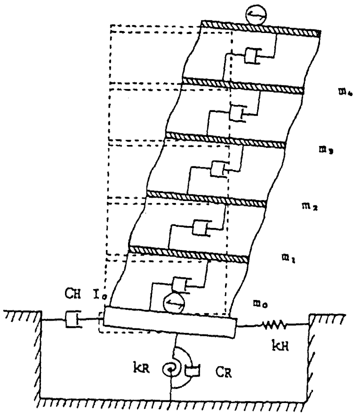


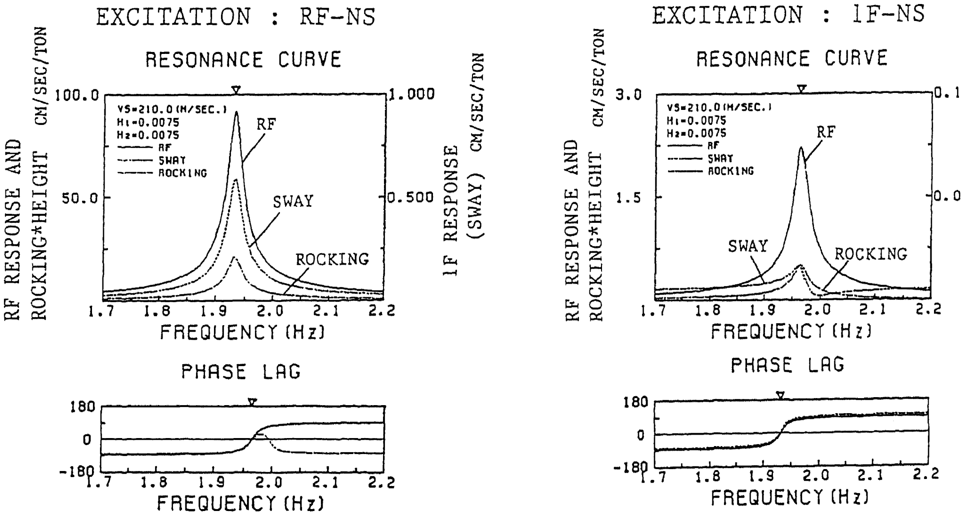
Fig. 5. Analytical model.

The superstructure is represented by a lumped mass model, and the subsoil is represented by springs and dashpots of swaying and rocking. The superstructure is assumed by a bending-shear type and Rayleigh damping, and the shear wave velocity, density and Poisson's ratio of the subsoil are assumed to be 210*m/sec*, $1.8\times10^{3}gr\cdot sec^{2}/cm^{4}$, and 1/3, evaluated respectively. The equivalent spring constant and damping coefficient are evaluated by using the numerical results of Wong and Luco 3).

Figure 6 shows the velocity response (amplitude and phase characteristics) of the model in N-S direction for the fundamental mode. In the figure, the rocking component of the foundation is represented as a rocking angular velocity multiplied by the height of the structure and is shown by a dot-broken line curve. Results of the theoretical study are in harmony with the experimental results. It is found that the degree of overturning moment, which is different for each excitation position, has a great influence on the structural responses.

Estimates of dynamic characteristics of the superstructure The natural frequency and modal damping ratio of the superstructure with the fixed base was examined by using the experimental results. In this study, it is assumed that the superstructure, while fixed at the base, has classical normal modes; modes more than the 2nd are neglected around the fundamental resonant frequency, considering the contribution of the higher modes as slight 4).

Figure 7 shows the fundamental fixed-base natural frequency and modal damping ratio evaluated to excitation at the first floor of the structure in N-S direction. The fundamental fixed-base natural frequency, about 2 Hz, is very close to the fundamental resonant frequency (1.97 Hz) of the complete soil-structure interaction system near that frequency. Although the modal damping ratio is unknown because of a large fluctuation, the value is less than 1 % near the fundamental resonant frequency. It seems closer to the corresponding value of the complete system to excitation at the first floor (0.45 %) of the structure rather than the roof (2.33 %)



(a) (b)

Fig. 6. Computed velocity response for fundamental mode in N-S direction of the structure excited at (a) roof and (b) first floor.

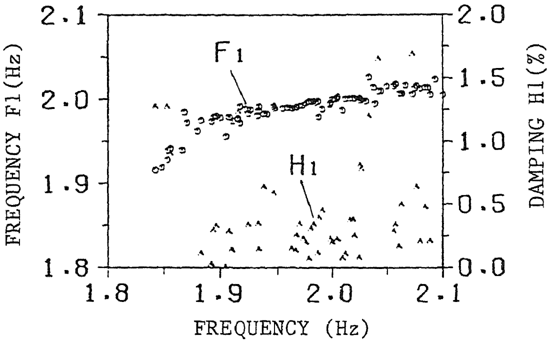


Fig. 7. Estimates of the fundamental fixed-base natural frequency and modal damping ratio in N-S direction.

CONCLUSIONS

From these results, the following conclusions are derived :

1. The first floor responses of the structure to excitation at the first floor are greatly different from those at the roof.
2. Effects of soil-structure interaction evaluated from the response of the structure to excitation at the first floor agree well with those subjected to horizontally incident SH or SV waves generated by the model footings.
3. A good agreement was found when comparing the computed velocity responses of the structure excited at the level of the roof and the first floor with those obtained from the experiments.

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