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RESPONSE OBSERVATION OF A SCALED MODEL STRUCTURE TO A STRONG EARTHQUAKE

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SUMMARY

Scaled model building structures with reduced seismic strength from 1/3 to 1/2 were constructed in 1983 in order to collect earthquake response data. Monitoring devices were installed in the model structures as well as in the surrounding soil. On December 17 in 1987, the model structures experienced the strongest shock since 1983. More than 300 cm/sec^2 of a peak acceleration was recorded on the ground surface at the observation site. This paper describes the structural damages of a steel braced frame model with recorded response results, the soil vibration and the interaction between the structural base and the soil surface.

INTRODUCTION

Actual data by directly observing ground motions, response of structural systems and their interaction are useful for analysis of the actual behavior of soils and structures as well as in verifying and developing theoretical analysis. The Institute of Industrial Science, University of Tokyo, initiated in 1983 a project for the response observation of model structures with the reduced seismic strength, which may be damaged even by moderate earthquakes, and the observation of soil behavior. On December 17 in 1987, the model structures experienced the strongest shock since 1983, the intensity of which was assigned grade V of the JMA Scale. This paper describes the structural damages of a steel braced frame model, the recorded response forces and displacements, the soil vibration and the interaction between the structural base and the soil surface.

STRUCTURE MODEL, SOIL CONDITION AND INSTRUMENTION

A three-story braced frame model was constructed on the ground surface as well as the other structural models. The models were designed according to usual design practices, but the design strength was reduced in order to obtain response data in the collapsing state even due to moderate earthquakes. The braced frame model are composed of H-shaped columns (H - 100 × 50 × 5 × 7), H-shaped girders attached to the R/C floor surface, and braces. The braces in the x-direction are composed of a rectangular section (Plate 6 × 10 × 400)connected to angles (L - 65 × 65 × 6). The braces in the y-direction are composed of angle members (L - 65 × 65 × 6). The members and their dimensions are summarized in Table 1 and Fig. 1. The yield base shear force in the x-direction (the weaker direciton) is 9% of the total building weight, and this strength is less than one-third of those in the design practice.

A reinforced concrete base (5 meter square) was constructed directly on the surface of the Kanto loam after the top soil was removed. The soil layer profile is illustrated with the characteristic values in Fig. 1. Various types of transducers were installed on the model to measure the following data.

1) Three dimensional accelerations of each floor and a base.
2) Inter-story displacements as well as rotaions.
3) Flexural strains of the 1st story columns and the axial strains of the braces.

Additionally, the underground accelerations at the depths of 1 meter, 10 meters, 20 meters and 40 meters are recorded simultaneonsly. The data acquisition is automatically started once 10 mm/sec^2 is sensed at the depth of 40 meters, and the data are converted into a digital form every sample time of 5 milliseconds.

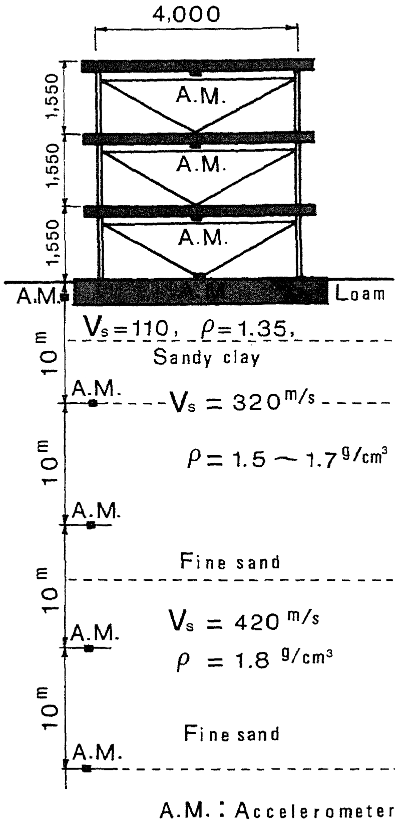


Fig. 1 Model and Soil Layer

Table 1 Model Parameters

Stories	3
Area of each floor	25.1m^2
Weight of each floor	172 KN
Steel grade	JIS SS41
Steel members	C : H - 100 × 50 × 5 × 7 G : H - 200 × 100 × 5.5 × 8 B : PL - 6 × 10

Table 2 Peak Values of Responses

Direction		x (weak)	y (strong)
Acc. (mm/sec^2)	-40m	810	960
	-20m	1060	950
	-10m	1180	1260
	- 1m	2830	3330
	Base Fl.	2840	3010
	2 Fl.	1840	4200
	3 Fl.	1670	5210
	R Fl.	1980	7410
Story shear (KN)	1st st.	166.5(0.32)	114.4(0.22)
	2nd st.	158.5(0.45)	91.9(0.26)
	3rd st.	96.8(0.56)	46.7(0.26)
Story drift (mm)	1st st.	20.6	6.5
	2nd st.	1.7	2.4
	3rd st.	0.7	1.0

* Values in parentheses indicate story shear coefficients

DAMEGE AND OBSERVED RESPONSE

Structural damages The structural damages due to Dec. 17 earthquake are illustrated in Fig. 2. The weak braces in the x-direction of the 1st and the 2nd story were buckled and underwent considerable yielding. The strong braces in the y-direction were observed to be considerably yielded at the joints. The story shear vs drift relationships and their time histories are shown in Figs. 3 and 4.

Hysteretic behavior

It was observed in the figures that the buckling of the braces occurred after several reversals of the forces in the elastic range and the maximum value of the first story shear was attained (denoted by A in Fig. 3). The values in the x- and y- directions are also shown in Fig. 2. The buckling was followed by considerable story drift (the values also shown in Fig. 2). Finally, these loops were merged into small loops with much smaller stiffness than that of the initial loop. The braces in the y- direction were installed to prevent complete failure due to twisting vibrations. Therefore, these braces were proportioned according to practical design rules. As shown in Fig. 4, the hysteresis loops give the evidence of the yielding. In fact, the Lüder's lines were noticed at the gusset plates which are connected with the braces by high strength bolts.

Peak values of observed responses

The peak values of response accelerations in the structure as well as in the soil are summarized in Table 2. The maximum values of the story shear were calculated from the recorded accelerations. Sideway drifts were measured by the displacement meters at each floor.

SPECTRAL ANALYSIS

The FFT techniques are utilized in order to identify the spectral characteristics of the soil-structure interaction systems. The energy spectrum or the Fourier square amplitude spectrum of the input time series, denoted by Sxx, and the cross spectrum of the input and output time series, denoted by Sxy, are calculated under the following definitions:

$$Sxx = \frac{1}{T} X^{*}(\omega)X(\omega) \qquad (1)$$

$$Sxy = \frac{1}{T} X^{*}(\omega)Y(\omega) \qquad (2)$$

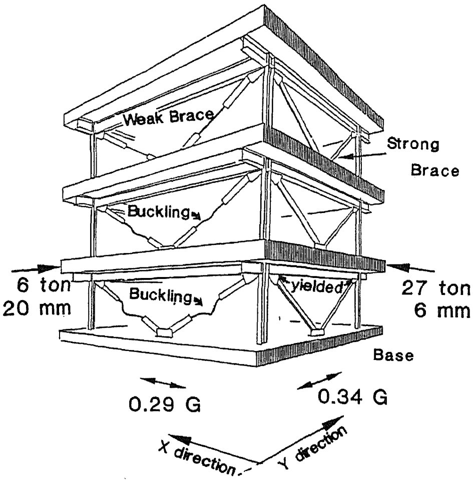


Fig. 2 Damages of Model

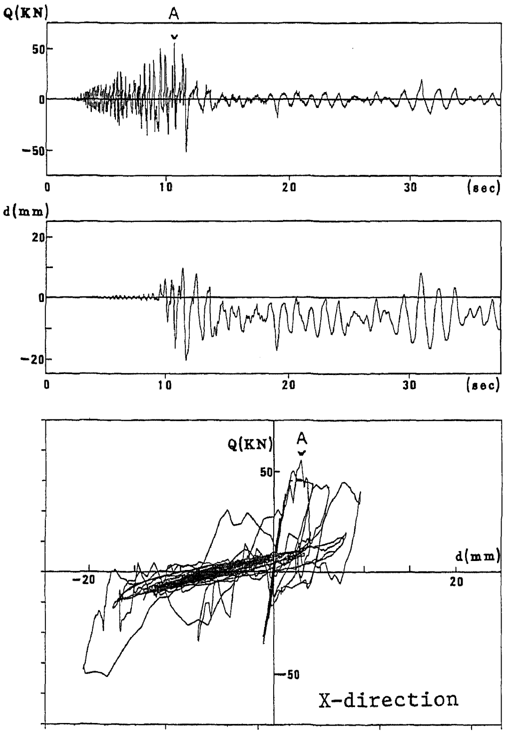


Fig. 3 Responses of story shear Q and Displacement d (Dec. 17, 1987)

where $X(\omega)$, $Y(\omega)$ are the Fourier transforms of $x(t)$ and $y(t)$, respectively, and $X^*(\omega)$ denotes the conjugate of $X(\omega)$. Evidently, Sxx and Sxy indicate the contribution of each spectral component to the two integrals $\frac{1}{T}\int_{-T/2}^{T/2}[x(t)]^2dt$ and $\frac{1}{T}\int_{-T/2}^{T/2}x(t)y(t)dt$. The computed spectral values, Sxx and Sxy, are smoothed by a rectangular spectral window, the band width of which is set to 0.3 HZ. The smoothed energy spectrum and the smoothed cross spectrum are denoted by $\overline{Sxx}$ and $\overline{Sxy}$, respectively. The system function of this input-output system, denoted by $H(\omega)$, is defined as

$$Y(\omega) = H(\omega)\ X(\omega) \qquad (3)$$

The function $H(\omega)$ can be identified by

$$H(\omega) = \overline{Sxy}\ /\ \overline{Sxx} \qquad (4)$$

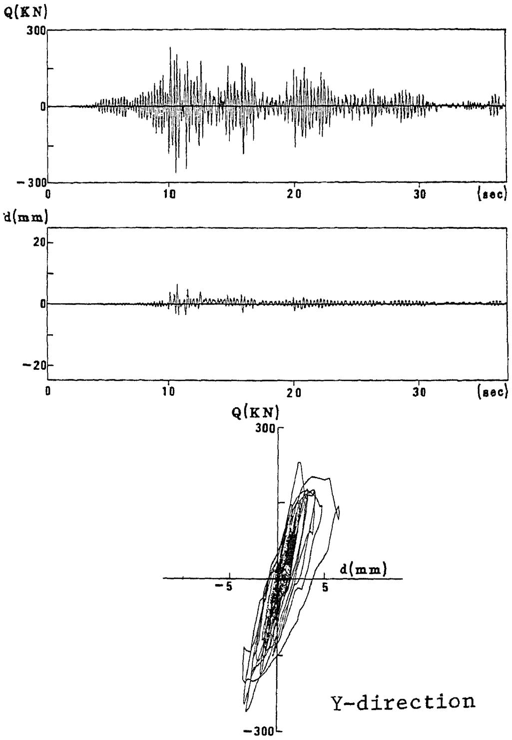
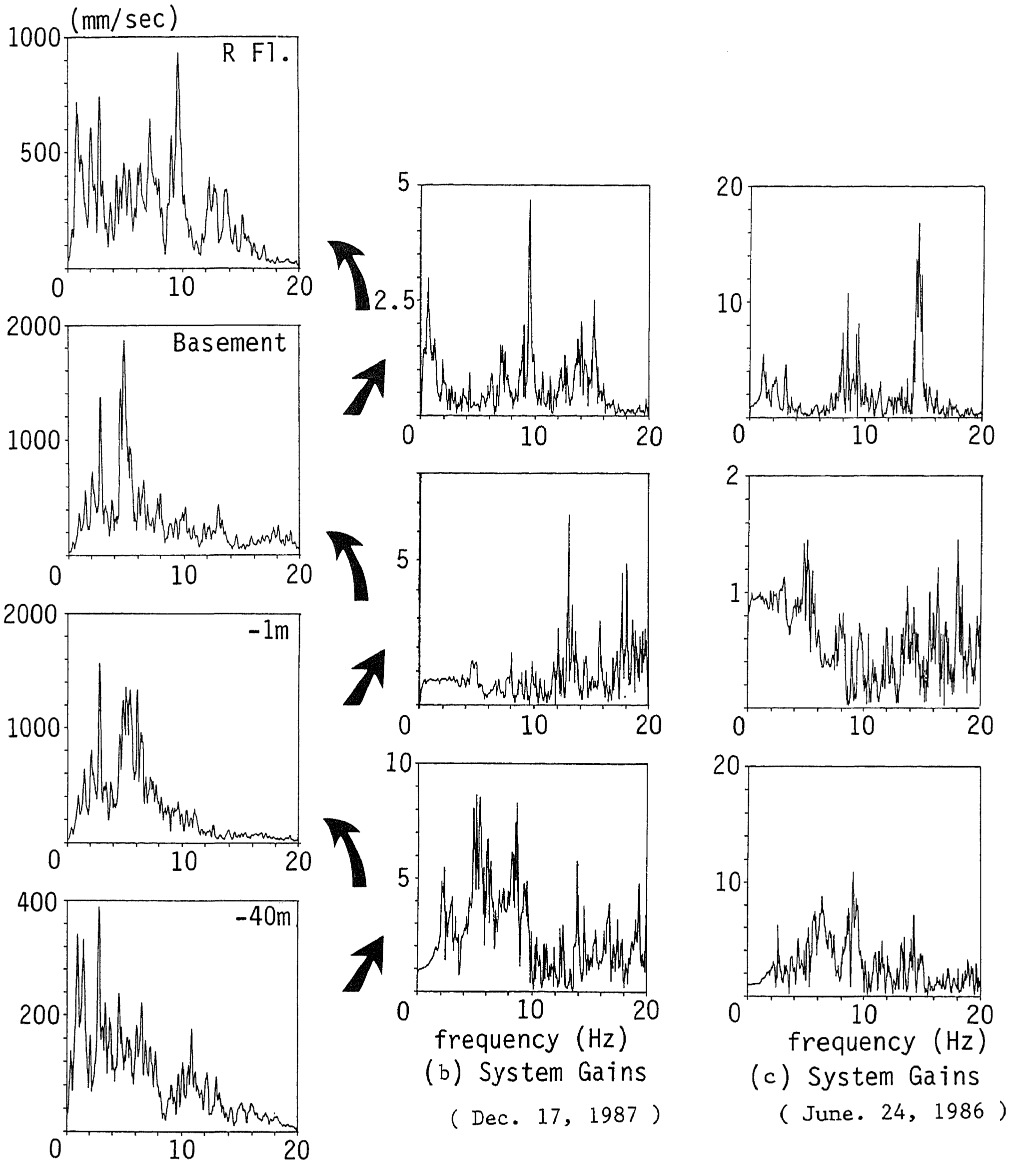


Fig. 4 Responses of story shear Q and Displacement d (Dec. 17, 1987)

Four observed acceleration records obtained at 1) 40m deep in the soil, 2) 1m deep, 3) the base floor, 4) the roof are chosen to identify three kinds of input-output systems, from 1) to 2), from 2) to 3) and from 3) to 4). The smoothed Fourier amplitude spectra of the above four records and absolute values of the three system gains for Dec. 17 earthquake are shown in Figs. 5 and 6. For comparison, the system gains obtained for June 24 earthquake are also shown in these figures.

Soil condition The soil condition at the site should be classified as the grade suitable for structural constructions. Judging from the system gain in Figs. 5 and 6, the soil should be considered to remain elastic even after the strong vibration.

Interaction between soil and structures The system gain between the soil 1m below the surface and the base floor shows that the gains in less 5 HZ can be regarded as almost unity except that a big peak is observed in Fig.6(c). The frequency of this peak coincides with the dominant frequency of the model structure. This fact shows the existance of rocking movements caused by a rigid motion of the rigidly braced frame. In Fig.6(b), however, such a peak disappears. This fact can be explained as that a rocking movement during December 17 earthquake was dissolved by the stiffness decrease due to the yielding of braces.



(a) Fourier spectra

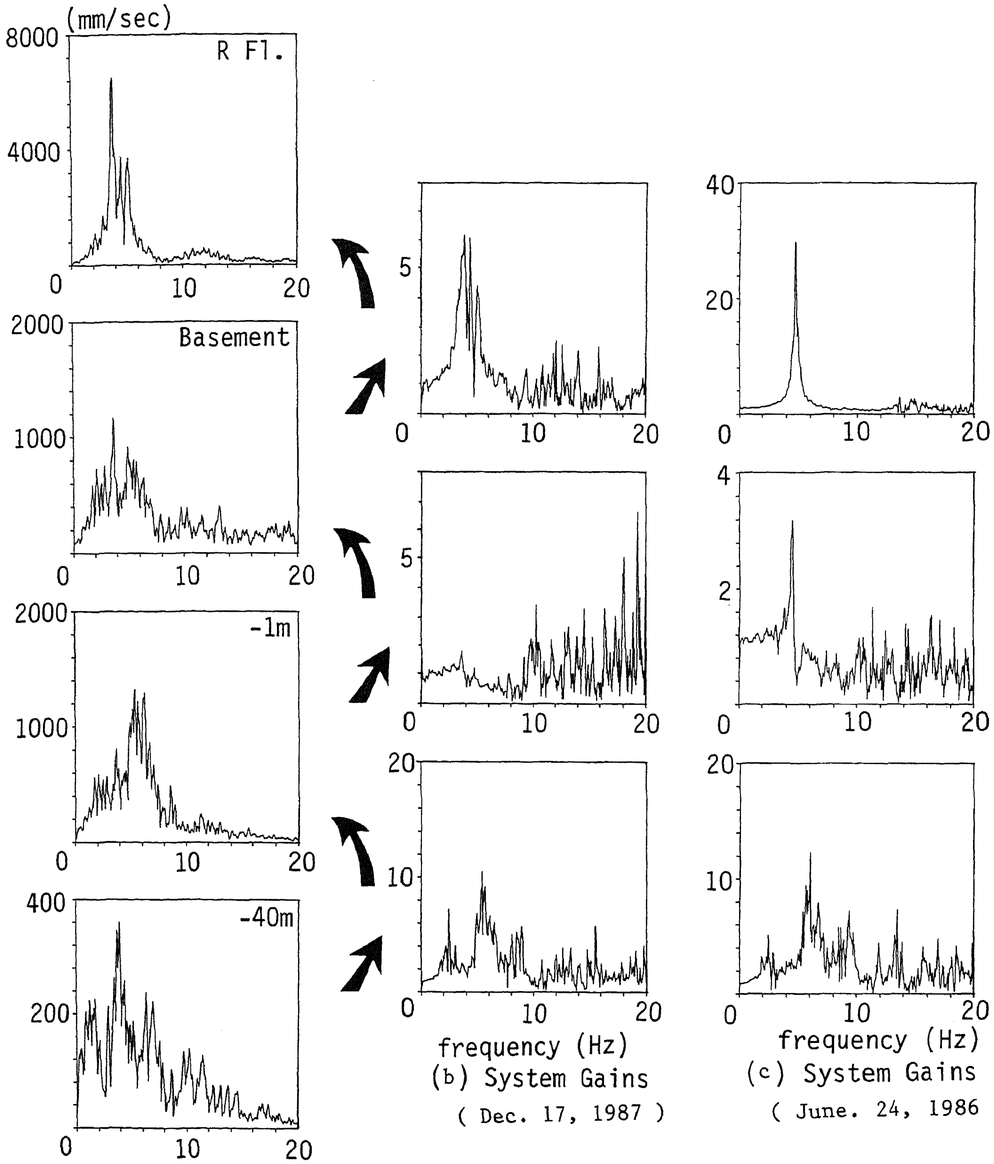
(b) System Gains (Dec. 17, 1987)

(c) System Gains (June. 24, 1986)

Fig. 5 Fourier Spectra and System Gains (X-direction)

CONCLUSIONS

(1) The elastic and inelastic responses of the structural model and the soil for a strong earthquake are outlined. The data acquisition system works well. Especially, inelastic responses of the steel structure accompanied by buckling and yielding of the braces have been successfully recorded.



(a) Fourier spectra

(b) System Gains (Dec. 17, 1987)

(c) System Gains (June. 24, 1986)

Fig. 6 Fourier Spectra and System Gains (Y-direction)

(2) System identification techniques using the Fast Fourier Transform are applied to the observed acceleration records. The identified system gains of the soil were obtained. The gain from the underground of 1m below the surface to the base floor is found to be a low-pass filter.