SEISMIC RESPONSE OF NTT KOBE EKIMAE BUILDING WITH CONSIDERATION OF NONLINEAR SOIL-STRUCTURE INTERACTION DURING THE 1995 HYOGO-KEN NANBU EARTHQUAKE

Taku INABA[1], Hiroshi DOHI[2], Kenji OKUTA[3], Taku SATO[4] And Hisanobu AKAGI[5]

SUMMARY

The seismic response characteristics of NTT Kobe Ekimae Building during the 1995 Hyogo-ken Nanbu Earthquake were estimated by means of a nonlinear soil-structure interaction analysis using the two-dimensional FEM model. The validity of this model was confirmed through the simulation of observed seismic waves on the 8th floor and the 3rd basement of the building. The relation between the ground motion and the damage of the building was quantitatively estimated by the maximum relative story displacement of the building. As the result, the site nonlinearity has a large influence on the amplification characteristics of the surface soil, and the local nonlinearity caused by rocking of building has a large influence on the seismic response characteristics of the building.

INTRODUCTION

The Hyogo-ken Nanbu Earthquake of 17th January 1995 brought about an enormous damage to structures in the Hanshin and Awaji areas. After the earthquake, the characteristics of the ground motion and the damage to the structures have been investigated from the viewpoint of seismology, earthquake engineering and structural engineering. It is pointed out the importance of investigating the relationship between the ground motion and the damage to buildings.

In order to evaluate quantitatively relationship between the ground motion and the damage to the buildings and to predict accurately a seismic motion entering to the building, it is necessary to make sure the effect of the soil-structure interaction on the nonlinear behavior of surface soil during the strong motion (Dohi et al. 1998).

The strong seismic motions were observed at the 8th floor and the 3rd basement of the NTT Kobe Ekimae Building during the 1995 Hyogo-ken Nanbu Earthquake. In this study, the seismic response characteristics of NTT Kobe Ekimae building was discussed by means of a nonlinear soil-structure interaction analysis using the two-dimensional FEM model. The nonlinear behavior of the soil was evaluated by means of the total stress analysis using the nonlinear step-by-step integration method.

THE NTT KOBE EKIMAE BUILDING AND SOIL SEDIMENT STRUCTURE

The NTT Kobe Ekimae Building (built in 1972, lat. 34^{o}41'10" N. and long. 135^{o}12' 24" E.) is situated in the area which was designated as 6th degree seismic intensity of Japan Meteorological Agency at the 1995 Hyogo-ken Nanbu Earthquake. The distance from epicenter to the building is about 17km. Figure 1 shows the location of the site and the causative fault. Figure 2 shows the site plan, a plan of the 3rd basement, and a section view of this building. Figure 3 shows the soil profile near the building. The building of a SRC structure has eight stories

[1] Research and Development Department, NTT POWER AND BUILDING FACILITIES INC., Tokyo, Japan, E-mail: inaba@rd.ntt-f.co.jp
[2] Research and Development Department, NTT POWER AND BUILDING FACILITIES INC., Tokyo, Japan, E-mail: inaba@rd.ntt-f.co.jp
[3] Research and Development Department, NTT POWER AND BUILDING FACILITIES INC., Tokyo, Japan, E-mail: inaba@rd.ntt-f.co.jp
[4] Research and Development Department, NTT POWER AND BUILDING FACILITIES INC., Tokyo, Japan, E-mail: inaba@rd.ntt-f.co.jp
[5] Building Engineering Department, NTT BUILDING TECHNOLOGY INSTITUTE, Tokyo, Japan, E-mail: akagi@ntt-bti.co.jp

above the ground and three stories under the ground. Its foundation is a direct foundation on the bearing ground at GL-16m which is composed of sand and gravel layer. The geological data of soil sediment from GL to GL-65m is shown in Table 1. The P-wave and S-wave velocities of the soil sediment are investigated by PS logging.
The damage caused by the Hyogo-ken Nanbu Earthquake to this building was relatively slight. The shear ruptures occurred on some of the anti-seismic walls with an opening from the 2nd to 5th story. No more than 1mm wide cracks were observed on the other structural members of the building.

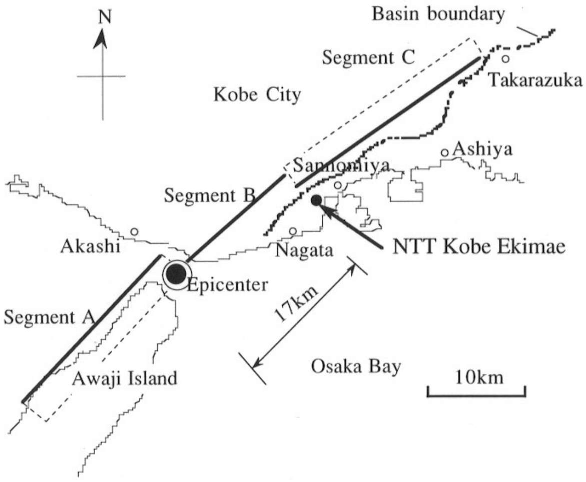


Figure 1: Location of site and causative fault of Hyogo-ken Nanbu Earthquake

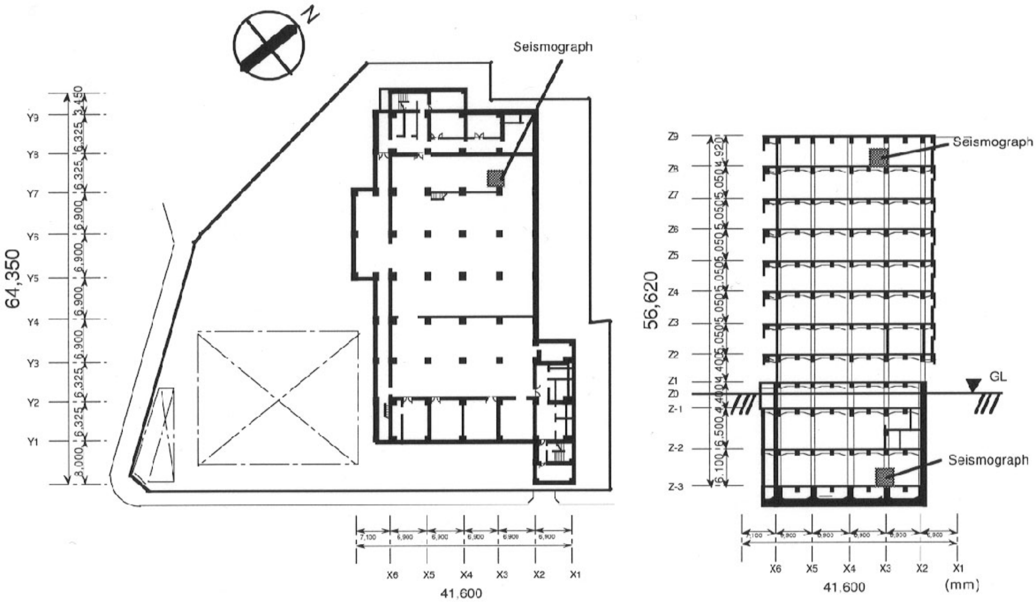
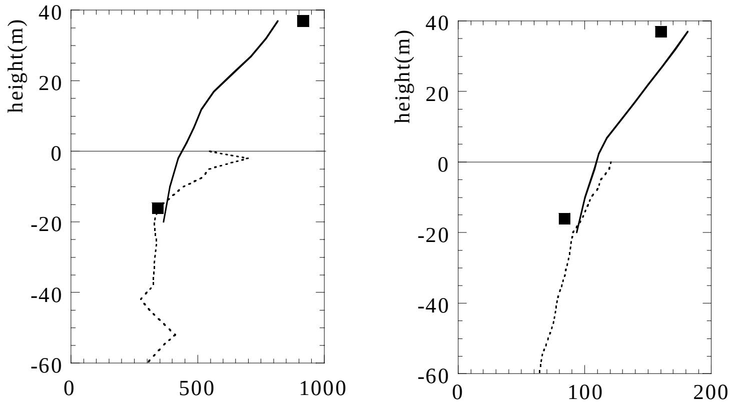


Figure 2: Plan and section view of NTT Kobe Ekimae Building and location of seismograph (in mm)

Table 1: Geological data of soil sediment at the NTT Kobe Ekimae Building

Depth (m)	Soil	Density (g/cm3)	Vp (m/s)	Vs (m/s)	Poisson ratio	Damping (%)
GL0-2.0	cobble stone	1.6	410	90	0.475	2.0
2.0-5.0	sand	1.8	1500	130	0.496	2.0
5.0-10.0	sand with gravel	1.9	1500	190	0.492	2.0
10.0-20.0	sandy	1.9	1720	250	0.489	2.0
20.0-38.0	sandy	2.0	1820	410	0.473	2.0
38.0-46.0	clay	2.0	1820	410	0.473	2.0
46.0-52.0	sand with gravel	2.0	1820	410	0.473	2.0
52.0-54.0	sand with gravel	1.9	1620	360	0.474	2.0
54.0-65.0	clay	1.9	1620	360	0.474	2.0

Figure 10 shows the distribution of the maximum response acceleration and velocity for the building and the free field. In comparison to the maximum response at the ground surface of the free field (548gal, 120kine), the maximum response at the 1st floor of the building shows approximately 17% less acceleration and approximately 7.5% less velocity. The input loss is caused by the soil-structure interaction effect.



a) acceleration (cm/sec^2) **b) velocity (cm/sec)**

Figure 10: Maximum acceleration and velocity distribution

Figure 11 shows the comparison of amplification ratio between at initial condition and during the earthquake. The former is obtained by the one-dimensional linear ground model (h=5%) using the initial stiffness shown in Table 1. The latter is the Fourier spectrum ratio of GL to GL-65m in the free field on the nonlinear analysis. The large component is shown in the period of 0.8 seconds or more in the Fourier spectrum ratio, in spite of the fact that the site amplification ratio is not large in these period ranges. This feature indicates that the site nonlinearity, the soil nonlinearity occurring on the propagation of seismic wave in the surface soil, has a large influence on the amplification characteristics of the surface soil.

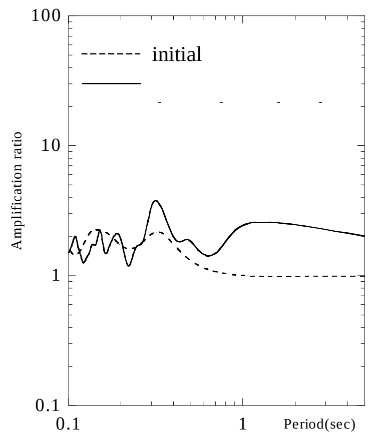


Figure 11: Comparison of the amplification ratio between at the initial condition and during the earthquake

Figure 12 shows the acceleration time histories at the ground surface of the free field and 1st floor of the building. Figure 13 shows the acceleration response spectrum (h=5%) of each. The amplitude at 1st floor of the building is smaller than at the ground surface of the free field, and the input loss is recognized in the period components of 0.8 seconds and less.

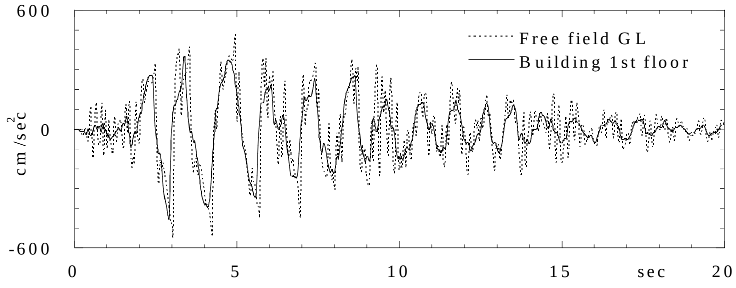


Figure 12: Comparison of acceleration time histories between 1st floor of the building and ground surface of free field

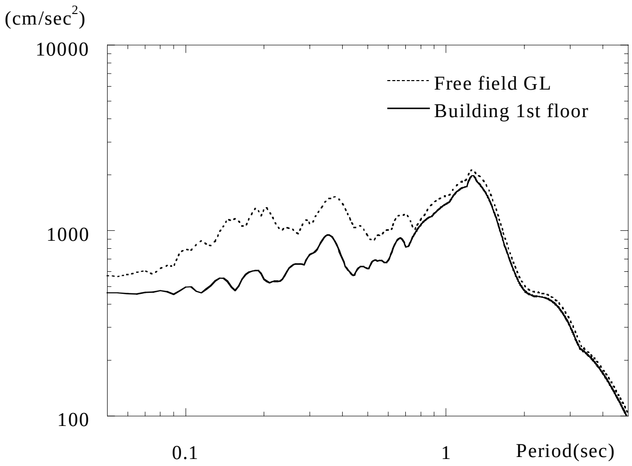


Figure 13: Comparison of acceleration response spectra between 1st floor of the building and ground surface of free field

Figure 14 shows the distribution of the maximum shear strain γ_{xy} with that of free field. The shear strain just under the building is small. On the other hand, large shear strains are shown diagonally downward to the outside of building. Especially in the sand layers from GL-32m to GL-38m near the building, large shear strains more than 0.43% are recognized.

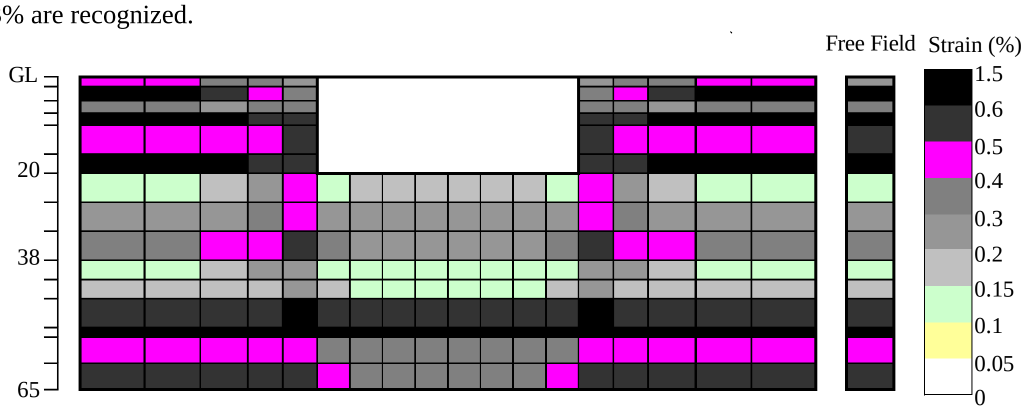


Figure 14: Distribution of maximum shear strain γ_{xy}

Figure 15 shows the distribution of the maximum shear strain related to the soil-structure interaction, which is obtained from subtracting the maximum shear strain of the free field from that of each element. Near the corners of building foundation, the maximum shear strain increases by 0.33% to 0.43% related to the effect of the soil-structure interaction.

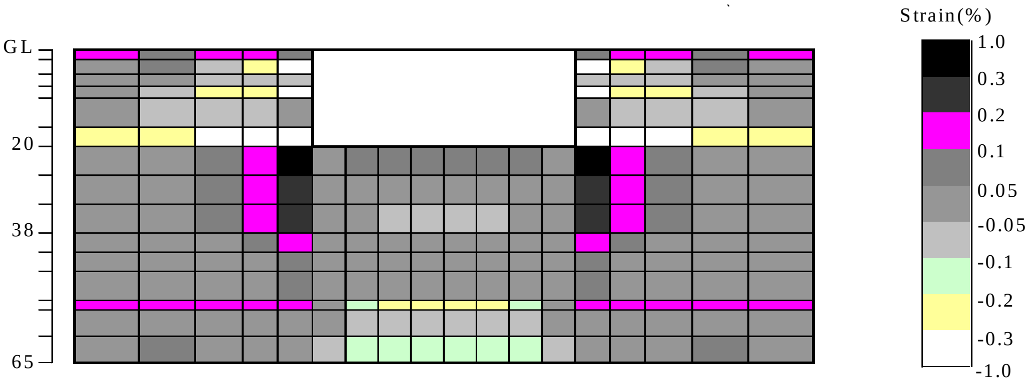


Figure 15: Distribution of maximum shear strain related to soil-building interaction

Figure 16 shows the vertical displacement time histories at the left end and the right end of building foundation. Because the left end and right end of building foundation moved vertically in the converse phase, the rocking is approved. From these figures, it is found that the local 0.33% increase in the shear strain near the corner of