11 WCEE

Copyright © 1996 Elsevier Science Ltd
Paper No. 310. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ESTIMATION OF NONLINEAR GROUND RESPONSE CHARACTERISTICS IN HACHINOHE CITY, JAPAN

JUN TOBITA and YOSHIHIRO SUGIMURA

Department of Architecture and Building Engineering, Tohoku University,
Aramaki-aza-Aoba, Aoba-ku, Sendai 980-77, Japan

ABSTRACT

Ground response characteristics in Hachinohe city during destructive earthquakes are investigated by use of observed strong motion records and nonlinear response analyses. During recent two earthquakes, the 1994 Sanriku-haruka-oki earthquake and the 1995 Iwate-ken-oki earthquake, building damage occurred in different area in Hachinohe city. Observed strong motion records at several sites also have different characteristics. By the results of the response calculation, it is found that the variation of ground motion in Hachinohe city is appropriately evaluated considering ground amplification with the bedrock of $Vs \fallingdotseq 3$ km/s. The relation between ground conditions, ground response characteristics and building damage is also discussed.

KEYWORDS

the 1994 Sanriku-haruka-oki earthquake, the 1995 Iwate-ken-oki earthquake, nonlinear response of ground, surface geology, nonlinear response analysis, step-by-step integration, Ramberg-Osgood model.

INTRODUCTION

On December 28, 1994, the Sanriku-haruka-oki earthquake with magnitude M_{JMA} 7.5 occurred beneath the Pacific Ocean in off-Sanriku area, north-eastern part of Japan. The Hachinohe meteorological observatory determined intensity at Hachinohe as VI of JMA (Japan Meteorological Agency) scale, which approximately corresponds to IX or X of Modified Mercalli scale. During this earthquake, severe damage to RC buildings was observed in relatively limited area around the central business area of Hachinohe city (Figure 1). Ten days after the main shock, the 1995 Iwate-ken-oki earthquake with magnitude M_{JMA} 6.9, the largest aftershock of the Sanriku-haruka-oki earthquake, occurred on January 7, 1995. Hachinohe city was hit again by strong shaking of intensity V of JMA scale, and buildings were damaged in eastern hilly area, especially in residential sites. It is possible that such a difference in distribution of building damage during the two earthquakes were derived from characteristics of incident waves and amplification of surface layer. In this paper, variation of ground response characteristics in Hachinohe city is investigated by use of observed strong motion records at several sites and nonlinear response analysis of ground.

GEOLOGICAL CONDITION IN HACHINOHE CITY

Geological condition of surface ground in Hachinohe city is roughly divided into two areas, alluvial plain along rivers and terrace area as shown in Figure 1. This classification is related with predominant period

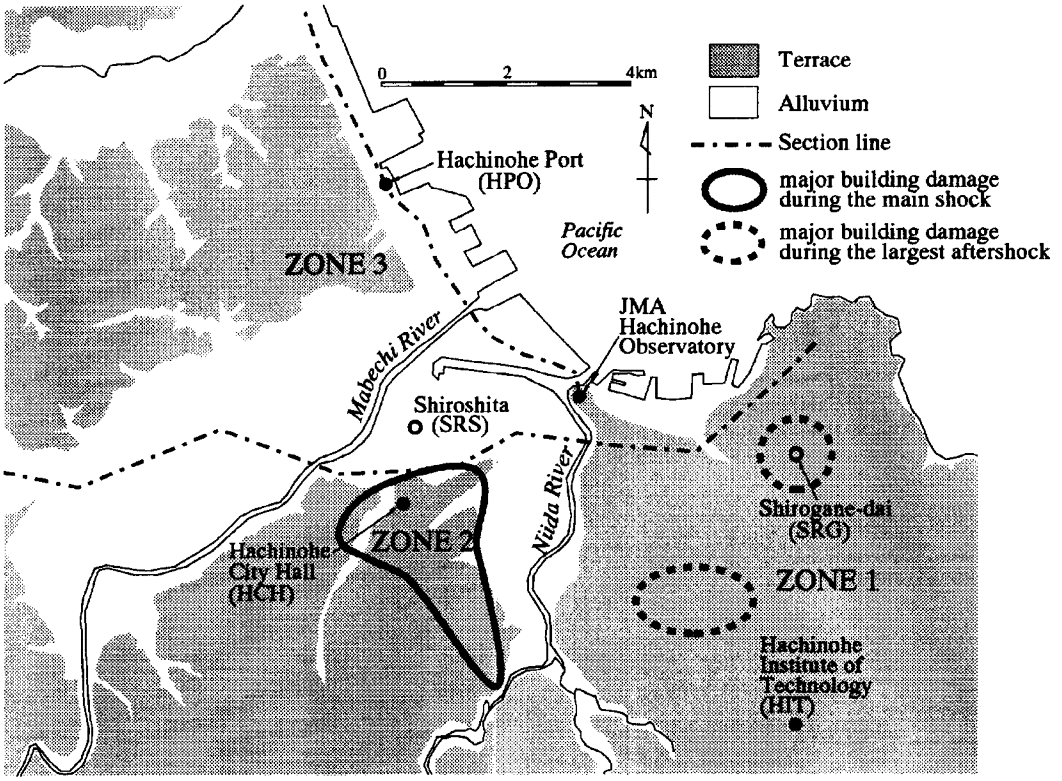


Fig. 1 Map of Hachinohe city.

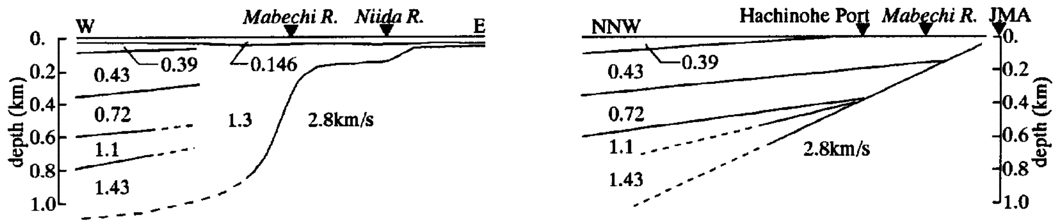
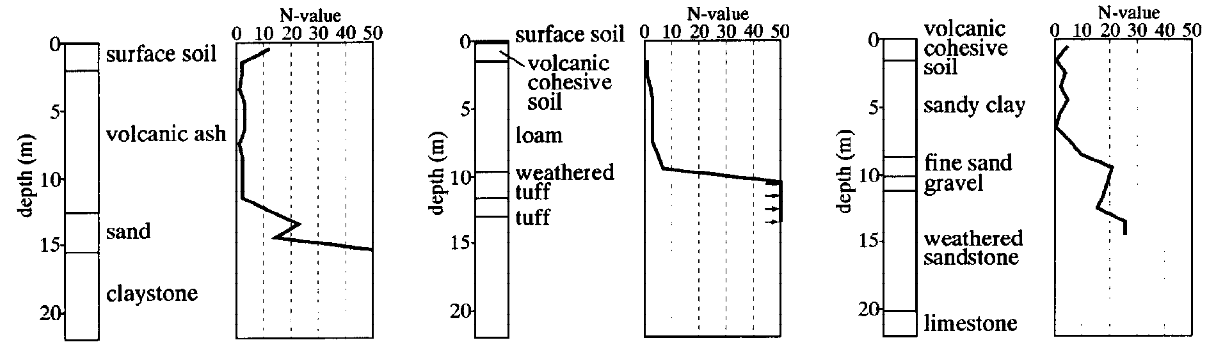


Fig. 2 S-wave velocity of ground in Hachinohe city (Sakajiri, 1983, Sakajiri *et al.*, 1990).

of short-period microtremors which represents dynamic characteristics of relatively shallow surface layers. On the other hand, considering depth of the seismic bedrock with high shear wave velocity of about 2.8km/s, the Hachinohe area is classified into three major zones which are bordered by two major rivers, *i.e.*, Mabechi River and Niida River (Sakajiri, 1993). In the first zone which is located in the eastern part of Niida River, the depth of bedrock is shallow, from several meters to about 20 meters. Major building damage was observed in this zone during the largest aftershock. The second zone is placed between the Niida River and Mabechi River. The bedrock is placed at about 100m depth in this zone, gradually become deep from east to west. The central part of Hachinohe city, which was heavily damaged during the main shock, belongs to this zone. The third zone is northern part of the Mabechi River, where the bedrock is covered by thick soil deposit of several hundred meters. S-wave velocity along east-west and north-south section lines in Figure 1 was estimated as Figure 2 by observation of long-period microtremors (Sakajiri, 1983, Sakajiri *et al.*, 1990). It is expected that such variation of shallow and deep ground condition caused spatial variation of earthquake shaking characteristics in Hachinohe city.

SITES FOR NONLINEAR RESPONSE ANALYSIS

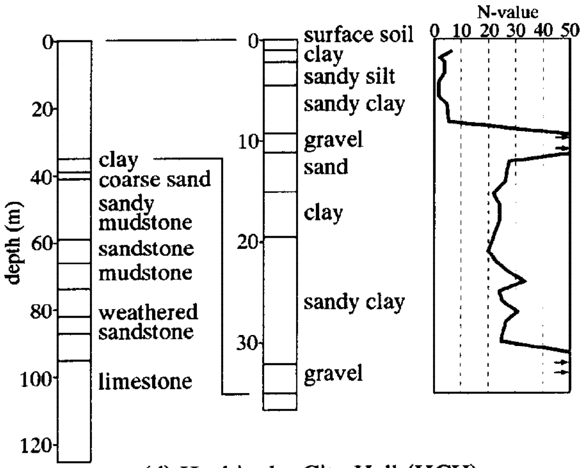
Nonlinear ground response analysis was performed at six sites in Figure 1, including four strong motion observation sites. Soil profiles of these points are shown in Figure 3 which were derived from shallow boring log data at each site and deep well data near the sites. At the site of Hachinohe Institute of



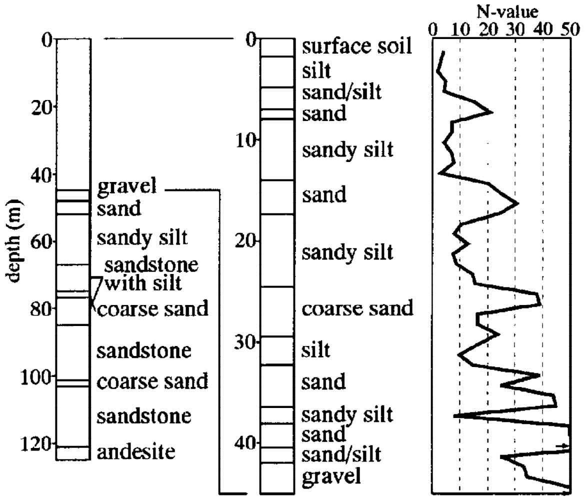
(a) Hachinohe Institute of Technology (HIT) : ZONE 1

(b) JMA Hachinohe Observatory (JMA) : ZONE 1

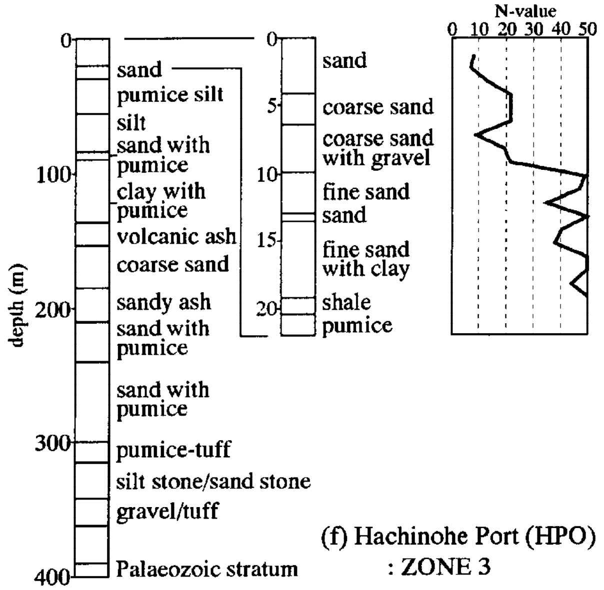
(c) Shirogane-dai (SRG) : ZONE 1



(d) Hachinohe City Hall (HCH) : ZONE 2



(e) Shiroshita (SRS) : ZONE 2



(f) Hachinohe Port (HPO) : ZONE 3

Fig. 3 Soil profiles of the objective sites of response analyses.

HIT, JMA, HCH and HPO are strong motion observation sites.

Table 1 Estimation of Vs from SPT N-value.

	alluvium	diluvium
humic soil	$Vs = 67.8\,N^{0.306}$	
clay	$Vs = 86.0\,N^{0.354}$	$Vs = 126\,N^{0.225}$
sand	$Vs = 73.2\,N^{0.341}$	$Vs = 86.7\,N^{0.365}$
gravel	$Vs = 90.4\,N^{0.360}$	$Vs = 148\,N^{0.219}$

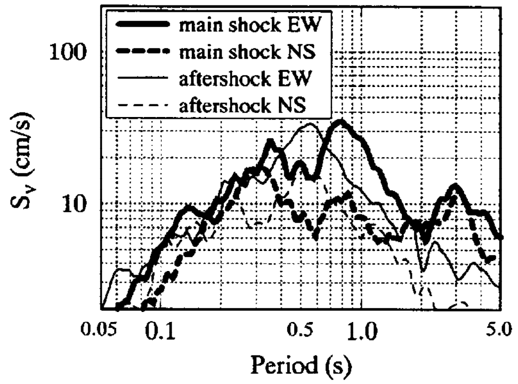


Fig. 4 Response spectra of input waves at 20m below the surface at HIT site.

Technology (HIT) in Zone 1, the dense strong motion array observation system is installed to a building and the ground, and more than 800 earthquake records have been observed (Takita *et al*, 1995). Records of an accelerograph settled in bedrock of 20m below the surface are used as input wave for the response analysis. Another strong motion observation site in Zone 1 is JMA Hachinohe observatory (JMA). An additional point for the response analysis was selected at Shirogane-dai (SRG) in damaged area of the largest aftershock. At the site of Hachinohe City Hall (HCH) in Zone 2, strong motion observation has been done by Building Research Institute, Ministry of Construction. A SMAC-MD type accelerograph is settled on the basement floor of the building. Shiroshita (SRS) site which has deep alluvial surface layer was additionally selected for comparison with HCH in the same zone. At the site of Hachinohe Port (HPO) in Zone 3, strong motion observation has been done by Port and Harbor Research Institute, Ministry of Transport.

NONLINEAR GROUND RESPONSE ANALYSIS

Sites were assumed to be horizontally layered and the soil profiles were modeled as a series of lumped masses connected by shear springs and dashpots. The shear wave velocity for different soil types was preliminary estimated from SPT N-values as Table 1, and was revised considering depth and confining pressure of the layer. Parameters of deep layers at points in Zone 2 and 3 were roughly determined based on Figure 2. The step-by-step time integral method was employed for nonlinear response analysis of soil. The hysteretic property of soil was modeled by the Ramberg-Osgood type stress-strain relationship with the Masing's rule (Ohsaki *et al.*, 1978, Karkee *et al.*, 1992). Parameters of the model were determined for clay, sand and gravel, considering general characteristics of experimental results (The Architectural Institute of Japan, 1993). At points in Zone 1, estimated nonlinear parameters at the site of HIT (Takita *et al*, 1995) are also considered. Rock layers in deep ground was treated as linear with 0.5% damping.

GROUND RESPONSE CHARACTERISTICS IN THREE ZONES IN HACHINOHE CITY

Figure 4 shows response spectra (h=5%) at the bedrock of HIT during the two earthquakes. Spectra predominate in the period ranges of 0.3 - 0.4s, 0.7 - 0.9s and longer than 1s during the main shock, and in 0.5 - 0.6s during the largest aftershock. The aftershock has the same or larger amplitude level in the short period range of less than 0.2s compared with the main shock. As the east-west component is larger than the north-south component during both of the two earthquakes, this component is used as input in the following response calculation. Figures 5 - 10 show response spectra (h=5%) of simulated ground response and Fourier spectral amplification ratios of surface layer at the six sites during the two earthquakes. Response spectra of observed waves are also plotted for the four strong motion observation sites.

In Zone 1, short period components approximately less than 0.4s tends to be amplified by thin surface layer. By this amplification characteristics, spectral amplitude of the two earthquakes were similar, however the aftershock predominate at 0.5s which were derived from input wave characteristics. It is possible that the building damage during the largest aftershock in this zone was caused by the two successive strong shaking of the main shock and the aftershock. This is in accord with the fact that many of the damaged buildings in this zone were relatively new wooden houses. Damage of embankment in reclaimed residential area is another possible cause. As seen elongation of periods and truncation of peak values in Fourier spectral ratios during the earthquakes compared with the results of linear response analyses, it is estimated that the behavior of the ground was highly in nonlinear range. Simulated nonlinear response showed shearing strains in soil deposits reached the maximum level of 10^{-3} order.

At HCH site in Zone 2, the response spectrum during the main shock clearly predominate in the period range around 0.8s, because the predominant period of input wave was almost the same with the natural period of surface layer. However the response spectrum level during the largest aftershock is lower than the main shock especially in the period range of longer than 0.4s. Thus it is estimated that the major damages in the central area of Hachinohe city were caused by the main shock. Similar response characteristics were obtained at SRS site in the same zone, but the predominant peak of 0.8 - 1.0s in the main shock response is not sharp because the natural period of the site is longer than HCH produced by thick alluvial surface layer.

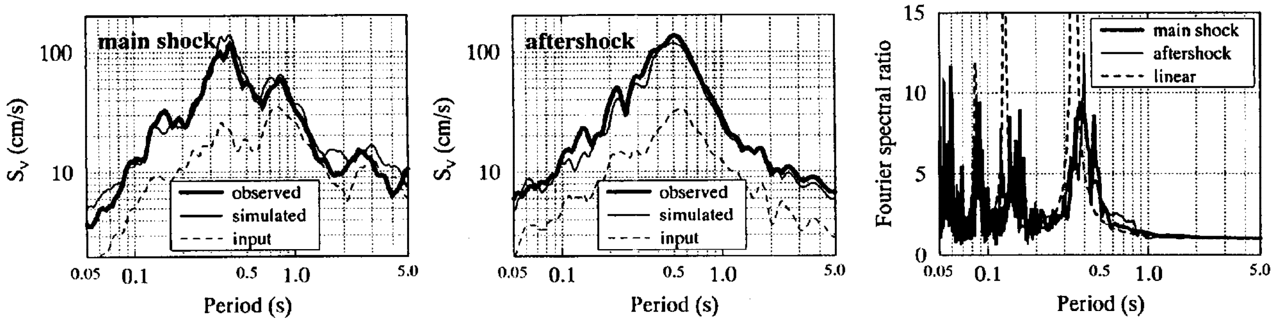


Fig. 5 Response spectra and Fourier spectral ratio of surface soil at HIT in Zone 1

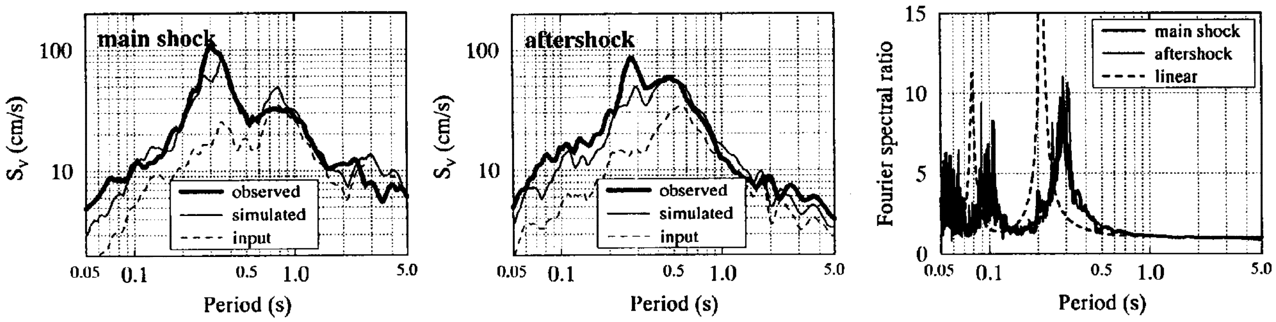


Fig. 6 Response spectra and Fourier spectral ratio of surface soil at JMA in Zone 1

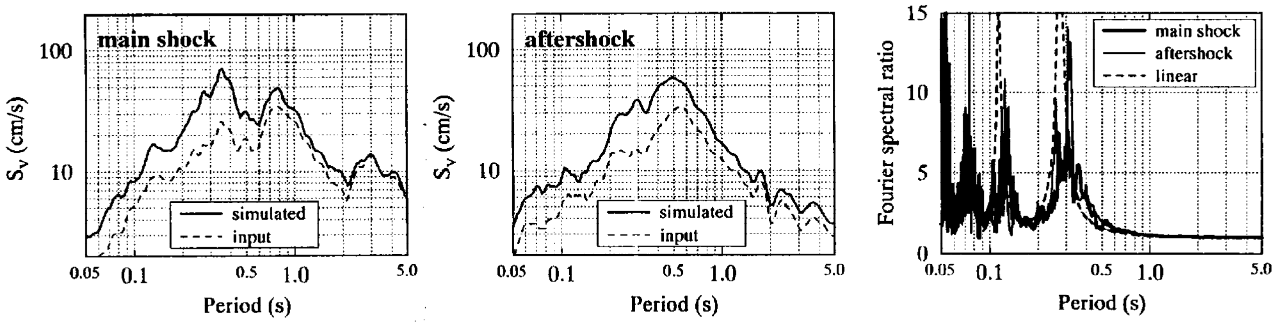


Fig. 7 Response spectra and Fourier spectral ratio of surface soil at SRG in Zone 1

At HPO site in Zone 3, the first natural period of deep soil layer is about 2.3s which is agree with predominant period of some observed records at this site including the 1968 Tokachi-oki earthquake. The observed response spectrum of the main shock has large amplitude by amplification of the higher natural period in 0.6 - 1.0s, while the aftershock has lower level of amplitude. Simulated response of the main shock shows good correspondence with the observed one in frequency content characteristics, however the amplitude level is underestimated especially in the short period range approximately less than 0.3s. This may be concerned with damping characteristics of the model for thick surface layer of about 400m, or with nonlinear characteristics of sandy layers. On the other hand, overestimation of amplitude around 0.5s of the aftershock possibly shows that the input of the aftershock at HIT is not suitable in this zone.

CONCLUSION

Earthquake amplification characteristic of ground in Hachinohe city was clarified by observed strong motion data and nonlinear response analyses with the seismic bedrock of $Vs \fallingdotseq 3$km/s. Ground condition in Hachinohe city was classified into several zones considering depth of the bedrock and shallow geological conditions. As the recent two large earthquakes had similar amplitude level with different frequency contents, it is estimated that ground shaking characteristics varied with ground amplification conditions of the site, and thus the concentrated distribution of building damage occurred in different zones.

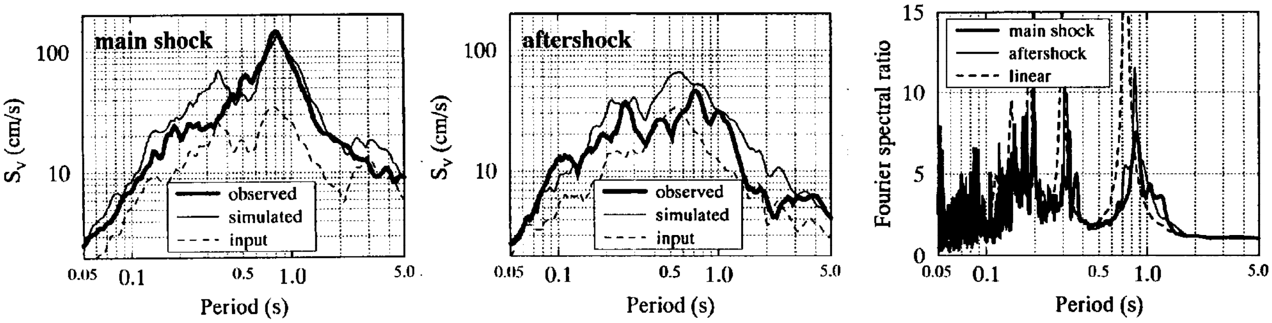


Fig. 8 Response spectra and Fourier spectral ratio of surface soil at HCH in Zone 2

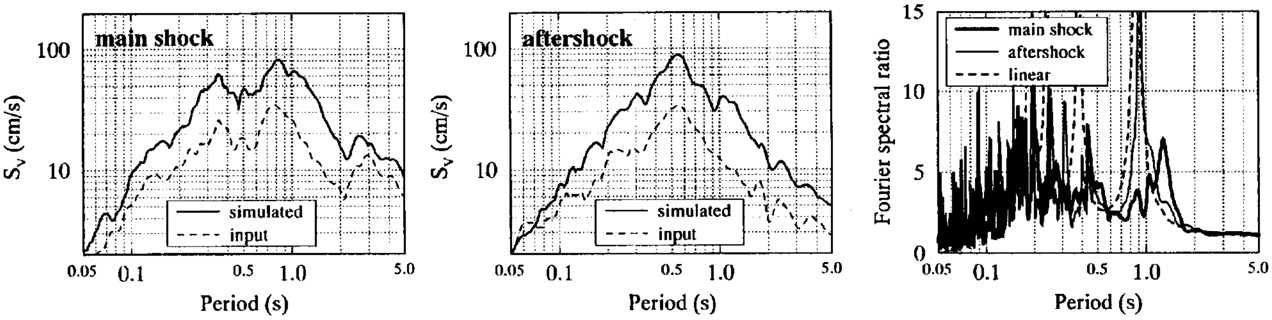


Fig. 9 Response spectra and Fourier spectral ratio of surface soil at SRS in Zone 2

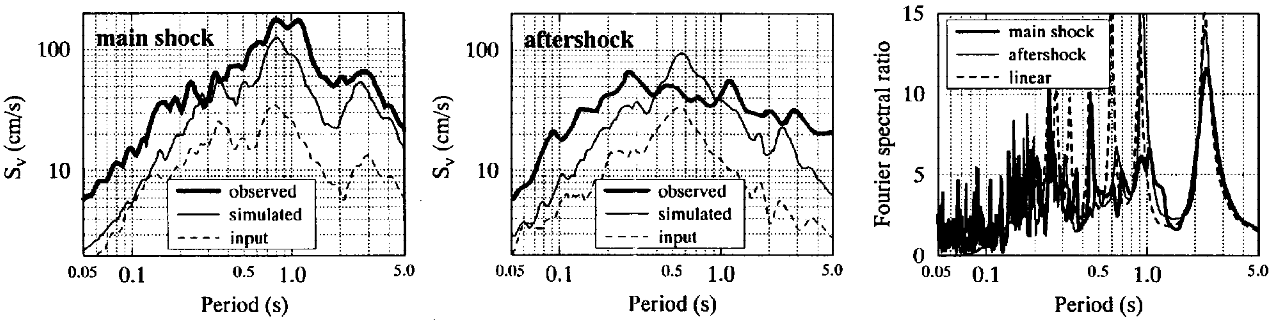


Fig. 10 Response spectra and Fourier spectral ratio of surface soil at HPO in Zone 3

ACKNOWLEDGMENTS

The authors wish to thank following agencies for providing strong motion data: Department of Architecture, Hachinohe Institute of Technology; Japan Meteorological Agency; Building Research Institute, Ministry of Construction; and Port and Harbor Research Institute, Ministry of Transport.

REFERENCES

Karkee, M. B., Y. Sugimura and J. Tobita (1992). Scaling a suite of ground motions for compatible levels of nonlinear ground response, *Journal of Structural and Construction Engineering (Transaction of AIJ)*, **440**, 29-42.

Ohsaki, Y., A. Hara and Y. Kiyota (1978). Stress-strain model of soils for seismic analysis, *Proc 5th Japan Earthquake Engineering Symposium*, 697-704. (in Japanese)

Sakajiri, N. (1983). Experimental study on fundamental characteristics of long-period microtremors, *Bulletin of Hachinohe Institute of Technology*, **2**, 112-154.

Sakajiri, N., T. Matsushima, N. Shiga, N. Goto and J. Umemura (1990). Relation between the nature of long-period microtremors and S-wave velocity structure - Observation in Hachinohe city -, *Butsuri-Tansa*, **43**(2), 85-96. (in Japanese)

Takita, M., M. Moro and K. Ito (1996). Seismic amplification of surface layers in the 1994 Far-Off Sanriku earthquake, *Proc. of 11th World Conference on Earthquake Engineering*.

The Architectural Institute of Japan (1993). *Earthquake Motion and Ground Conditions*, Part II, section 2.1, 231-275.