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A DENSE STRONG MOTION ARRAY OBSERVATION IN KUSHIRO CITY FOR EVALUATING THE EFFECTS OF SURFACE GEOLOGY ON SEISMIC MOTION

JAPANESE WORKING GROUP ON EFFECTS OF SURFACE GEOLOGY
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ABSTRACT

After the 1993 Kushiro Oki earthquake, a dense strong motion observation was conducted in Kushiro city by the Japanese Working Group on Effects of Surface Geology. During one and half year operation, many weak motion as well as a few strong motion data sets were obtained. The records from the 1994 Hokkaido Toho Oki earthquake were the most valuable in terms of acceleration level and frequency contents. This is the preliminary results on the spatial variation of ground motions in Kushiro city. Site effects on seismic motion were examined by using the geotechnical data, microtremors, weak and strong motion data at one site. No significant non-linear effects was found.

KEYWORDS

Strong ground motion, high acceleration, effects of surface geology, spatial variation, Kushiro city (Japan), Hokkaido Toho Oki earthquake.

INTRODUCTION

A large earthquake (Mw=7.6) occurred just beneath Kushiro city, at a depth of 107 km, east coast Hokkaido, Japan, on Jan. 15 in 1993. The earthquake shaking in Kushiro city was so severe as that liquefaction occurred at many places, the port facilities and lifeline systems were heavily damaged in lowland. It is also noted that the maximum acceleration of 0.9 g was observed at the Kushiro JMA observation station, however, the damage of buildings near the site was not heavy as we expected from the acceleration level. On the other hand, the maximum accelerations at three sites located in low-land were 0.3 - 0.5 g. The Japanese Working Group on the Effects of Surface Geology on Seismic Motion (JWG-ESG), noting the significant implications of these facts and the scarcity of strong motion observation sites, organized the temporal strong motion array observation consists of 23 sites within a radius of 3 km in Kushiro city. During one and half years operation, we could obtain various types of recordings. Among them, the records from the Hokkaido Toho-Oki earthquake (Mw8.2) of October 4, 1994 were the most valuable in terms of acceleration level (0.15 - 0.5 g), frequency contents and so on (JWG-ESG, 1995). The spatial variation of ground motion in Kushiro city is discussed using the records from the Hokkaido Toho Oki earthquake. As a case study, amplifications of seismic motion due to sedimentary layers and non-linear behaviors of soft soil are investigated at the site where geotechnical data are available.

SPATIAL VARIATION OF THE GROUND MOTION

Geology and Observation Sites in Kushiro city

Figure 1 shows the map of Kushiro city as well as the locations of temporal strong motion observation sites together with the stationary sites such as JMA, PHRI and BRI. The station codes, locations, instruments and contributors are found in Table 1. The instruments used in the observation were mostly acceleration type, however, velocity type instruments were also used at three sites.

Kushiro city is geologically characterized into two regions, that is, low-land and terrace regions. The Old Kushiro river is a border of the two regions. The east bank of the river has steep slope and formed a terrace. Figure 2 shows the schematic east- west geological section of the Kushiro area. The common layer of the two region is the Urahoro formation of Palaeogene and the Nemuro formation of Cretaceous period. In the low-land region, shallow underground structure is formed by alluvial deposits of sand, gravel and soft silt layers. The depth to the Urahoro formation becomes gradually deep to the west. In the terrace region, the Kussharo pumice flow deposits of Pleistocene period predominated at shallow surface layers and the Otanoshige formation of sand layer is underlying. The depth to the Urahoro formation from the highest point of the terrace is about 20 m. The S-wave velocity logging data at JMA/ BRI sites (located at the top of terrace region) have been reported by Building Research Institute (1994) as that S-wave velocities are 110-140 m/s , 220-350 m/s and 510-650 m/s for the surface Kussharo, the Otanoshige and the Urahoro formations, respectively.

Fig. 1. A map showing the major part of Kushiro city, Hokkaido, Japan and the locations of strong motion observation sites. Except JMA, BRI and PHRI, the observation sites were temporally operated during August 1993 and March 1995.

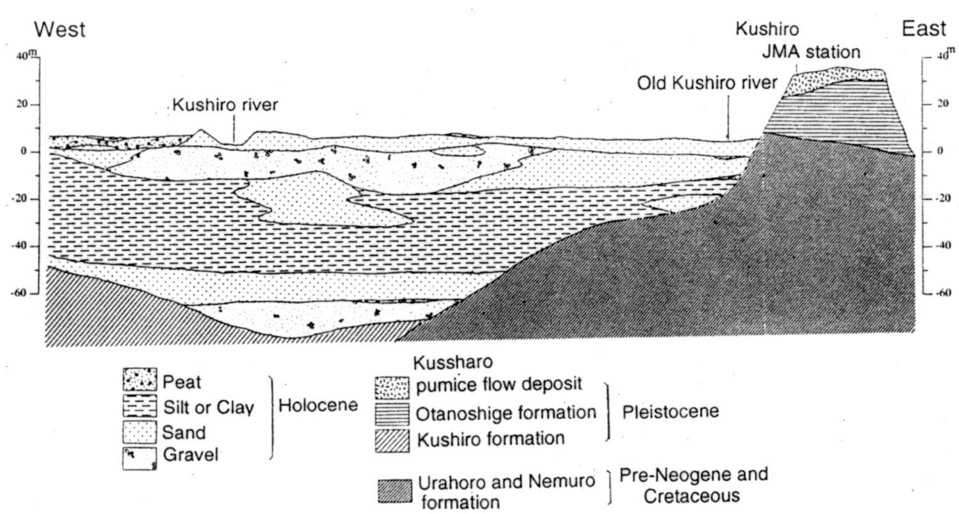

Fig. 2. Schematic east-west geological section of Kushiro city. (reproduced from Izumi et al., 1993)

Table 1. Station data of cooperative strong motion observation in Kushiro, Hokkaido, Japan

St. No.	St. CODE	Location		Instrument	Installation / Organization	Maintenance Contact persons
		Latitude (N)	Longitude (E)			
01	KTC	43° 00' 47. 0"	144° 15' 51. 0"	SSA-2 (ACC.)	Faculty of Eng. Hokkaido Univ.	Hiroshi Kagami Nobuo Takai
02	KOS	43° 00' 27. 0"	144° 18' 41. 0"	SSA-2 (ACC.)	Faculty of Eng. Hokkaido Univ.	Hiroshi Kagami Nobuo Takai
03	KJM	43° 00' 39. 0"	144° 20' 51. 0"	SAMTAC-17S (ACC.)	Kajima Tech. Res. Inst., Kajima Corp	Toru Sasaki Masanori Niwa
04	TTR	43° 00' 36. 0"	144° 21' 24. 6"	PC-98/JA-5V/C (ACC.)	Hachinohe Inst. Technology	Naomi Sakajiri
05	JSI	43° 00' 25. 0"	144° 22' 34. 0"	CV-701/SS-1 (ACC.)	Tech. Res. Inst. Obayashi Corp.	Kunio Wakamatsu
06	TIS	43° 00' 00. 0"	144° 22' 51. 7"	PDAS-100/VS-1 (VEL.)	Graduate Shool of Sci., Hokkaido Univ	Tsutomu Sasatani Hideki Nagumo
07	SMZ	42° 59' 49. 5"	144° 23' 18. 7"	DATOL-100/SD-203 (ACC.)	Shimizu Corporation	Shun'ichi Kataoka Hiroshi Kawase
08	TBS	42° 59' 42. 5"	144° 20' 37. 7"	SAMTAC-17 (ACC.)	Tobishima Corporation	Shin'ichiro Mori Shigeru Miwa
09	KMB	42° 59' 50. 0"	144° 22' 13. 0"	CV-901N (ACC.)	Eng. Res. Center Sato Kogyo Co.	Iwao Suetomi
10	KTA	42° 59' 34. 0"	144° 22' 37. 0"	CV-901N (ACC.)	Eng. Res. Center Sato Kogyo Co.	Iwao Suetomi
11	KTS	42° 59' 17. 4"	144° 22' 45. 0"	SAMTAC-17S (ACC.)	Maeda Contruct. Co. Ltd.	Satoshi Jodai
12	KAI	42° 59' 09. 7"	144° 22' 57. 8"	DR-M2a/VSE 11 ·12 (VEL.)	DPRI. Kyoto Univ.	Tomotaka Iwata Kojiro Irikura
13	NSM	42° 59' 13. 0"	144° 23' 17. 0"	SPC-35F/VSE-15 (ACC.)	Tech. Res. Inst. Nishimatsu C. Co.	Yukio Tomatsu Takashi Kobayashi
14	ASH	42° 59' 06. 0'	144° 23' 36. 0"	CV-901N (ACC.)	Res. Devel. Inst. Takenaka Corp.	Yoshiyuki Sato Masatake Naganoh
15	KCH	42° 58' 56. 7"	144° 23' 08. 1"	SMAD-2 (ACC.)	ERI. Univ. Tokyo	Kazuyoshi Kudo Minoru Sakaue
16	TQH	42° 58' 55. 0"	144° 24' 31. 0"	SV-555/CV-901 (ACC.)	Inst. Tech. Tokyu Construct. t.	Eiji Kojima
17	HEU	42° 58' 42. 6"	144° 24' 04. 5"	SMAD-1 (ACC.)	ERI. Univ. Tokyo	Kazuyoshi Kudo Masayoshi Takahashi
18	KBO	42° 58' 26. 4"	144° 23' 19. 0"	SMAD-2 (ACC.)	ERI. Univ. Tokyo	Kazuyoshi Kudo Minoru Sakaue
19	TEP	42° 58' 14. 2"	144° 22' 59. 7"	SMAD-2 (ACC.)	ERI. Univ. Tokyo	Kazuyoshi Kudo Masayoshi Takahashi
20	KKP	42° 58' 11. 4"	144° 23' 54. 2"	SMAD-2 (ACC.)	ERI. Univ. Tokyo	Kazuyoshi Kudo Minoru Sakaue
21	SSK	42° 58' 21. 0"	144° 24' 32. 0"	SAMTAC-15X/SS-1 (ACC.)	Tokyo Electric Power Company	Tomiichi Uetake Akira Masuda
22	KRK	42° 58' 47. 2"	144° 24' 47. 4"	PDAS-100/VS-3 (VEL.)	Graduate School of Sci., Hokkaido Univ	Tsutomu Sasatani Hideki Nagumo
23	TYR	42° 58' 42. 2"	144° 23' 31. 8"	SPC-35E (ACC.)	Ashikaga Institute of Technology	Tokiharu Ohta

Extensive microtremors measurements were carried out at several ten sites including strong motion observation sites by the research group on microtremors (Seo, 1994). The peak frequency at JMA was about 5 Hz. However, the distribution of peak frequencies in terrace region were complex. In the low-land region, the change of the peak frequency is systematic, due to the change of thickness of alluvium. The peak frequency in the east side of low-land is 1 to 2 Hz and it tends to lower frequency than 1Hz to the west.

Ground Motions from the 1994 Hokkaido Toho Oki Earthquake

The Hokkaido Toho Oki earthquake was prominent in terms of magnitudes (Mw=8.2) as well as the wealth of high frequency motion. Source parameters determined by Kikuchi and Kanamori (1994) are: location of initial break = (43.48° N: 147.40° E), source depth = 56 km (in the oceanic lithosphere), seismic moment = 2.6×10^{21}Nm (Mw=8.2), source area = $120\times60\text{km}^2$, the average slip = 5.6 m, and the stress drop = 11Mpa. The distances from the initial break and the west wedge of the aftershock area to Kushiro city were approximately 250 km and 150 km, respectively. The peak ground accelerations (PGA) recovered in the north-east Japan were significantly higher than those expected by empirical attenuation relations of PGA (e.g. Fukushima and Tanaka, 1990).

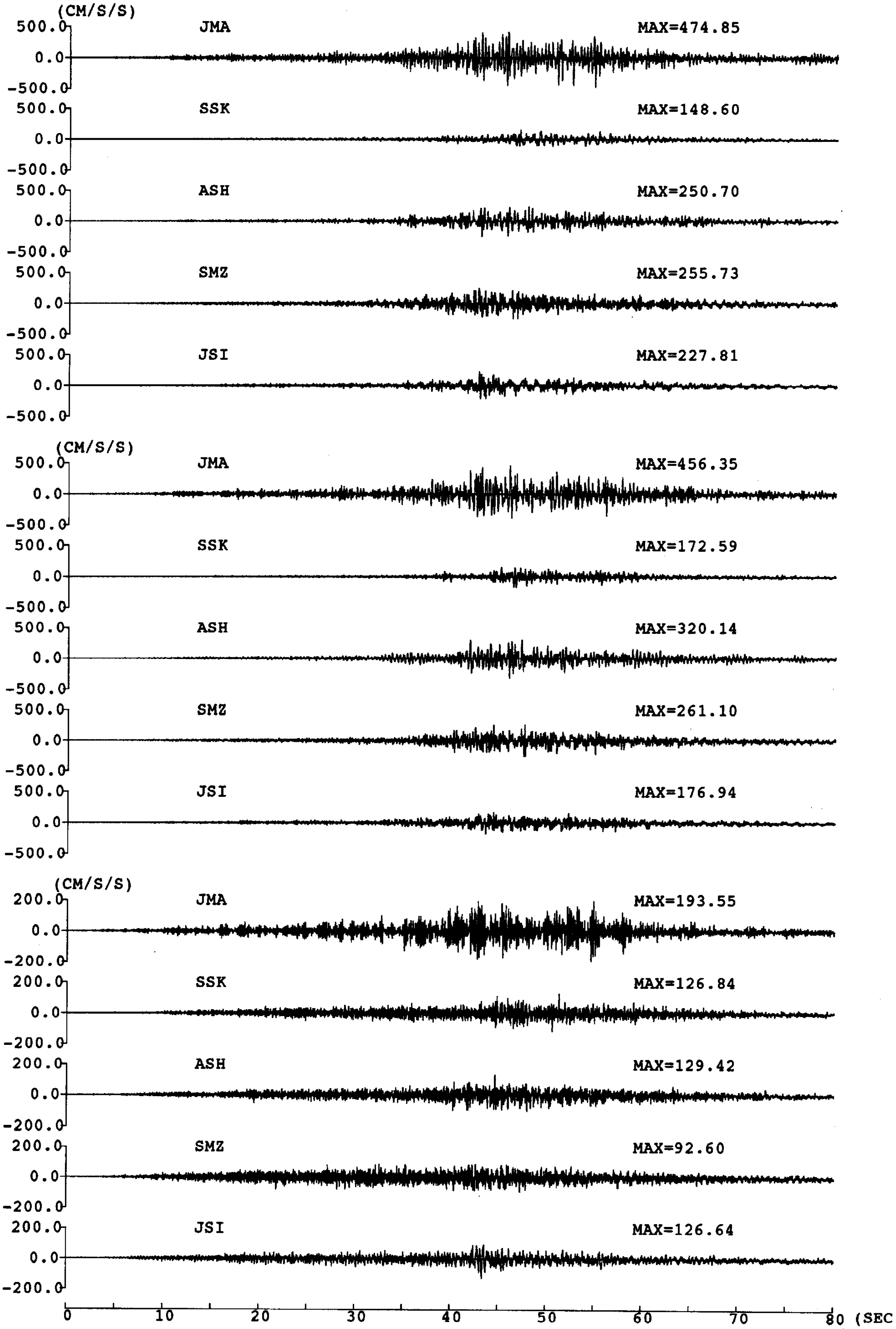

Fig. 3. Acceleration time histories of 5 sites in Kushiro city observed during the 1994 Hokkaido Toho Oki earthquake.

Figure 3 shows the acceleration records recovered in Kushiro city during the Hokkaido Toho Oki earthquake. The differences of distance and azimuth among the sites in Kushiro city are negligibly small, so that the differences found in the records are due mainly to the local geology. Figure 4 shows PGA with respect to the distance from the JMA station. The high accelerations are found at the JMA site and its vicinities (terrace region) rather than those in low-land region. The PGA in low-land region decreases with distance from the JMA site, while their distribution in terrace region is complex. This tendency was also found during the 1993 Kushiro Oki earthquake.

Fourier spectra of the recorded ground motion during the 1994 Hokkaido Toho Oki earthquake are shown in Fig. 5. Columns from left to right in the figure correspond to the spectra of north-south, east-west and up-down components, respectively. A rough grouping of spectral shapes using the close sites each together has been made and they correspond to 5 rows in the figure. Some features are pointed out. Spectra at terrace region predominate at high frequency, however, the peak frequencies deviate site by site. The low-land spectra are rather stable and the peak frequency tends to lower frequency, say, 1 Hz. These correlate qualitatively with the geological data as shown in Fig. 2. In the computation, Fourier spectra were smoothed by Parzen window with bandwidth of 0.4 Hz and the velocity records were differentiated into acceleration. At two sites of velocity instruments, records have small clipping, however, no special treatment was done.

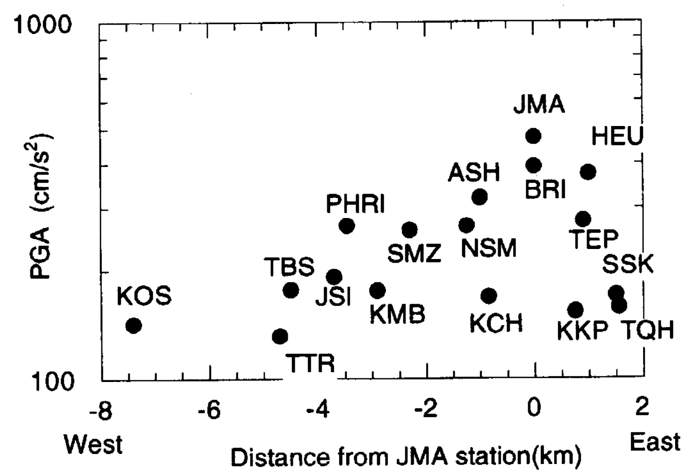

Fig. 4. Distribution of peak accelerations as a reference of the JMA station.

CASE STUDY OF SITE RESPONSE AT SMZ

Geotechnical data

Although over two hundred boring data have been compiled by Hokkaido Society of Architects and Building Engineers (1982), only a few P- and S-wave logging data are available in Kushiro area. SMZ is the only site in low-land region that these data are available to use. Figure 6 shows the S- and P-wave velocity structure and the standard penetration test (N-values). The top surface is artificial fill and sand layer extends to a depth of 29 m. The layer consists of silt is found at depth between 29 m and 48 m. The basement layer, Urahoro formation consists of sand stone is underlyed. Figure 7 shows the theoretical amplification factor computed using the S-wave velocity profiles for 1-D wave propagation. Peak frequencies of 1.4 and 4.2 Hz are expected.

Weak motion

It will be preferable to use weak motion data rather than strong motion one to compare the above computation and the observation. Figure 8 shows the averaged Fourier spectra of weak motion data. Nine records with amplitudes of several cm/s/s (roughly correspond to velocity of 0.1 - 0.3 cm/s) and magnitude of the events greater than 5 were selected. The time window of 10.24 sec was used for the analysis. At first, normalization of root mean square of amplitudes was performed and then they were averaged. Therefore, effect of large amplitude records is not significant. Finally, the raw spectrum was

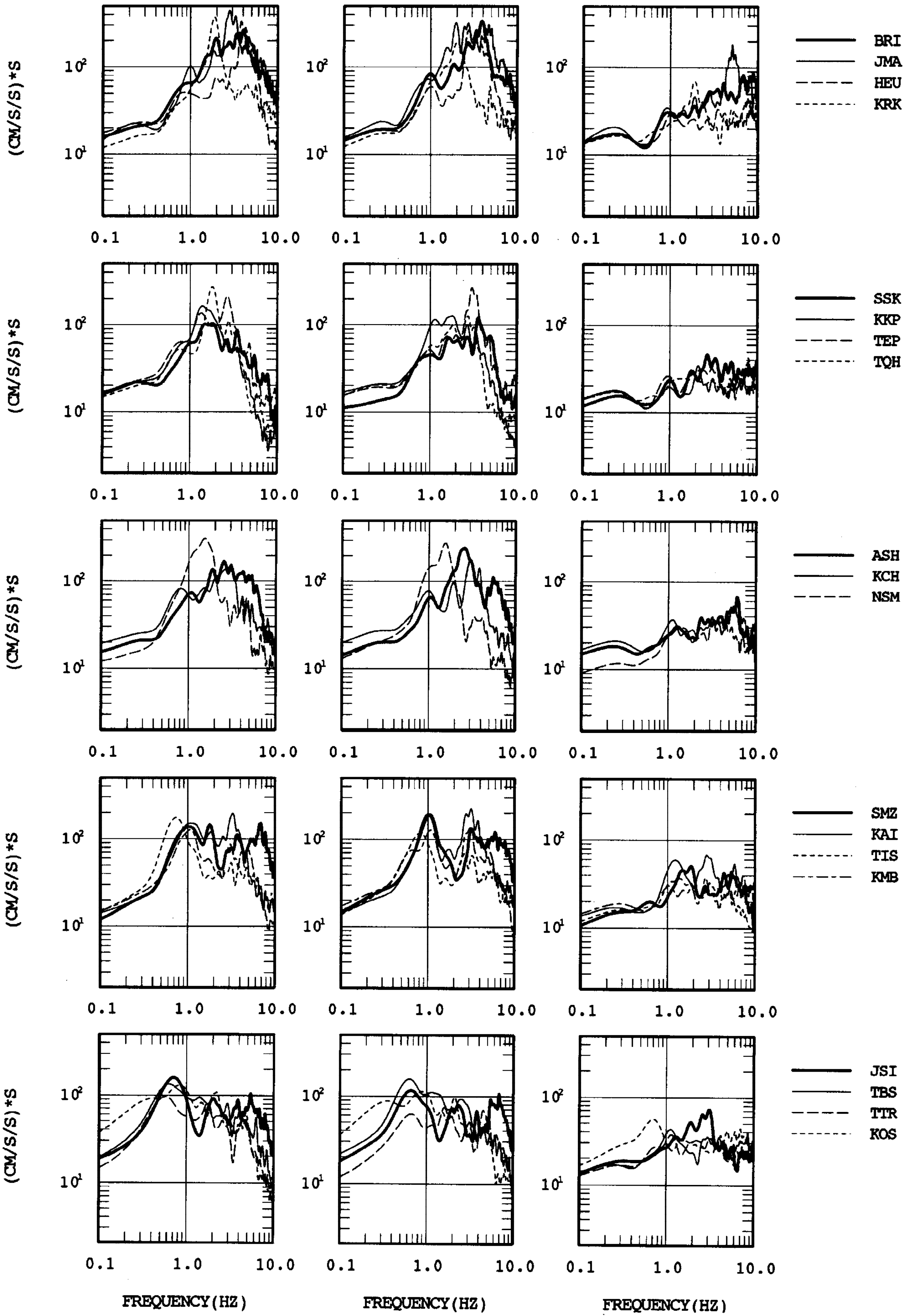

Fig. 5. Comparisons of Fourier amplitude spectra. Columns from left to right correspond to north-south, east-west and up-down components, respectively.

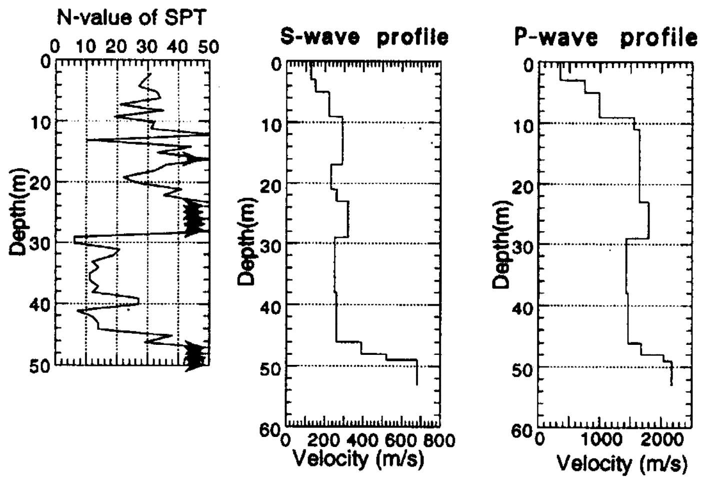

Fig. 6. S- and P-wave velocity profiles and the results of standard penetration tests at a low-land site SMZ.

smoothed by the Parzen window with bandwidth of 0.4 Hz. The peak frequencies of the averaged weak motion are 1.2 and 4 Hz and they correlate well with the computation. From the microtremors measurements, a peak frequency of about 1.2 Hz was also found. From these facts, the underground structure model is valid for the weak motion, or no amplitude dependency for the peak frequency is expected in an amplitude level of 10^{-4} cm/s (microtremors) to 10^{-1} cm/s (weak motion). In low-land region, underground structure is rather simple that ground response of other sites will be estimated using this S-wave velocity model and geological data.

Strong motion

Integrated velocity seismograms at SMZ from the Hokkaido Toho Oki earthquake are shown in Fig. 9. Considering the shear strain estimated from the ratio of peak ground velocity (~ 20 cm/s) due to the Hokkaido Toho Oki earthquake to the S-wave velocity of the surface layer (~125 m/s) at SMZ, it is a good example to investigate non-linear behaviors of soil during strong shaking. An attention has been made to a change of peak frequencies of spectra for two time windows: before and after parts of large amplitudes. Figure 10 shows the Fourier spectra of the two selected parts (shown in Fig. 9) of the ground motion. From the figure, peak frequency is 1.0 Hz for all case. This peak frequency is smaller than the result of weak motion so that one might expect non-linear effects. However, no change of peak frequencies before and after large amplitudes suggests less effects of non-linear behavior of soil. In addition, the borehole data at BRI dominated in 1 Hz (Kitagawa et al., 1995), therefore, a large amplitude of 1 Hz from the Hokkaido Toho Oki earthquake was plausibly not originated from the non-linear effects of soils.

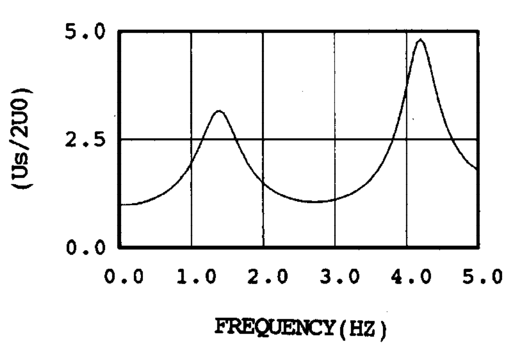

Fig. 7. Transfer function for S-waves at SMZ assuming 1-D wave propagation.

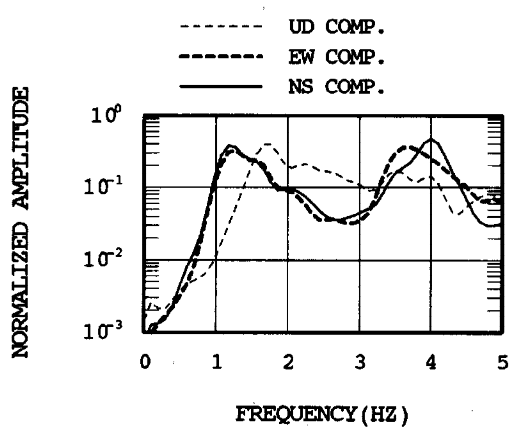

Fig. 8. Fourier amplitude spectra averaged by nine weak motion records obtained at SMZ.

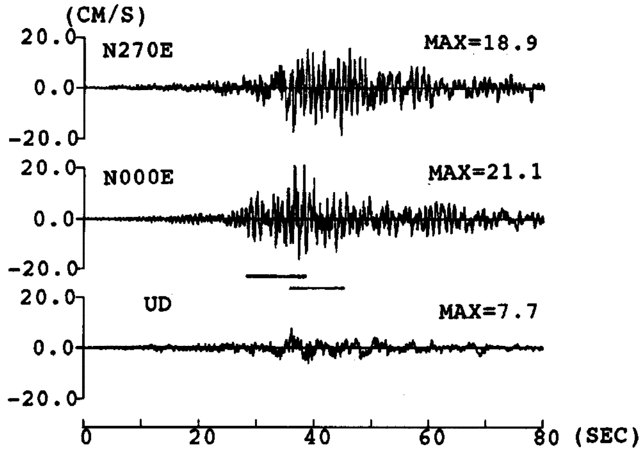

Fig. 9. Velocity time histories at SMZ obtained by numerical integration. Underlines shows the time windows used for spectral computation.

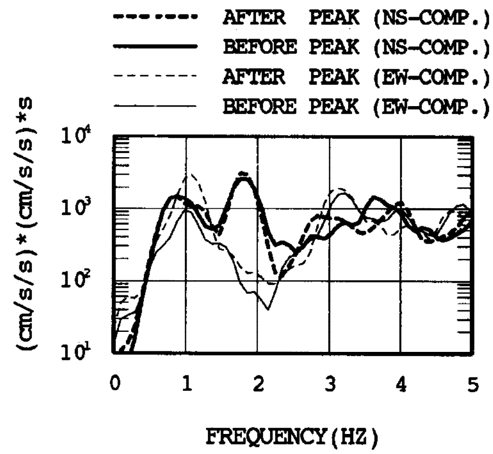

Fig. 10. Comparison of spectra of two time windows: before and after parts of large amplitudes.

SUMMARY

The dense strong motion observation in Kushiro city was operated in a short period of 1.5 years, however, the records permitted us to characterize the ground motions in Kushiro city : shallow surface sediments mostly contributed to the variation of peak acceleration and spectral shape in higher frequency than 0.5 Hz, that is, the ground motions in the terrace region were dominated in a high (2-5 Hz) frequency, and those in the low-land showed large amplifications at around 1 Hz. These different frequency responses of sites produced the large variation of peak acceleration in Kushiro city. A cooperative observation by many organization has an advantage to make observation densely, however, it has a disadvantage of differences in frequency characteristics or resolutions of instruments.

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