Paper No. 1635. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

CHARACTERISTICS OF STRONG GROUND MOTIONS OBSERVED AT KUSHIRO METEOROLOGICAL OBSERVATORY

TOSHIHIDE KASHIMA*, IZURU OKAWA** and SHIN KOYAMA*

*International Institute of Seismology and Earthquake Engineering (IISEE),
Building Research Institute (BRI), Ministry of Construction
1 Tatehara, Tsukuba-shi, Ibaraki 305, Japan
**Structural Department,
Building Research Institute (BRI), Ministry of Construction
1 Tatehara, Tsukuba-shi, Ibaraki 305, Japan

ABSTRACT

An accelerograph recorded a strong ground motion with a peak acceleration of 711 cm/s^2 at the Kushiro Meteorological Observatory during the 1993 Kushiro-oki (off Kushiro) Earthquake (M_{JMA}=7.8, h=103 km) of January 15, 1993. The JMA (Japan Meteorological Agency) seismic intensity for Kushiro was six. The damage to the observatory and buildings of surrounding area was minor, although the acceleration level of the strong motion recorded correspond to what we may expect the severe damage to buildings. We conducted a soil survey at the observatory and installed an accelerometer in the borehole beneath the existing one on the ground to investigate the effect of surface geology. Twenty-six earthquakes were recorded in 1994, including the 1994 Hokkaido-toho-oki (east off Hokkaido) Earthquake (M_{JMA}=8.1, h=30 km) of October 4. The amplification effect and the non-linearity of the surface geology at the observation site are discussed using various earthquake records in this paper.

KEYWORDS

1993 Kushiro-oki Earthquake; 1994 Hokkaido-toho-oki Earthquake; strong earthquake motion; site effect; amplification of soil deposit; non-linearity of soil deposit;

INTRODUCTION

Building Research Institute, Ministry of Construction started a strong motion observation program covering Japan in 1957 and is currently operating 35 observation sites. The program aims at discussing dynamic characteristics of earthquake ground motions and buildings. At half sites, accelerometers are installed at the top and the bottom of buildings to investigate the dynamic behavior of buildings during earthquakes. At other sites, installments are set up on the ground or at the basement floors of low-rise buildings. This observation program has obtained a number of strong motion records including records from disastrous earthquakes.

Four disastrous earthquakes occurred in the two years, 1993 and 1994, around northern Japan, and two of those struck eastern Hokkaido. The first one was the 1993 Kushiro-oki (off Kushiro) Earthquake with the magnitude of 7.8 on January 15, 1993. An accelerograph recorded a strong ground motion with a peak acceleration of 711 cm/s^2 at the Kushiro Meteorological Observatory, Japan Meteorological Agency, in Kushiro, which is the closest city from the epicenter. The damage to the observatory and buildings in surrounding area was not serious, although the acceleration amplitudes were extraordinarily large.

We made a soil survey after the earthquake and installed an accelerometer in the borehole beneath the existing accelerograph to investigate the amplification effect of the surface soil layers. Several precious strong motion records, including a one from the 1994 Hokkaido-toho-oki Earthquake, have been successfully obtained to date. This paper introduces characteristics of strong ground motions observed at Kushiro Meteorological Observatory and discusses amplification of earthquake motions due to the surface soil.

TOPOGRAPHY, GEOLOGY AND INSTRUMENTATION

Kushiro city is located in the eastern region of Hokkaido, which is the second largest island in Japan. The downtown of Kushiro city is topographically divided into two areas by the Kyu-Kushiro river as outlined by the Hokkaido Architect Society (1982). An alluvial plain spreads toward the north-west from the river as shown in Fig. 1. Surface geology of the plain is generally classified into two types, inland peat and sand dune along the coast. The diluvial terrace covered with volcanic ash rises on the south-eastern side of the Kyu-Kushiro river. The Kushiro Meteorological Observatory stands on the terrace, which is 30 meters high above the sea level.

The layout of buildings at the Kushiro Meteorological Observatory is shown in the right side of Fig. 1. An accelerograph is installed on the embedded concrete base in a small hut which is put up in a corner of the site. The instrument, which is called SMAC-MD, is an up-to-date digital type with 16-bit A/D converters. SMAC-MD has an internal tri-axial servo-type accelerometer and records strong motions into IC memory cards.

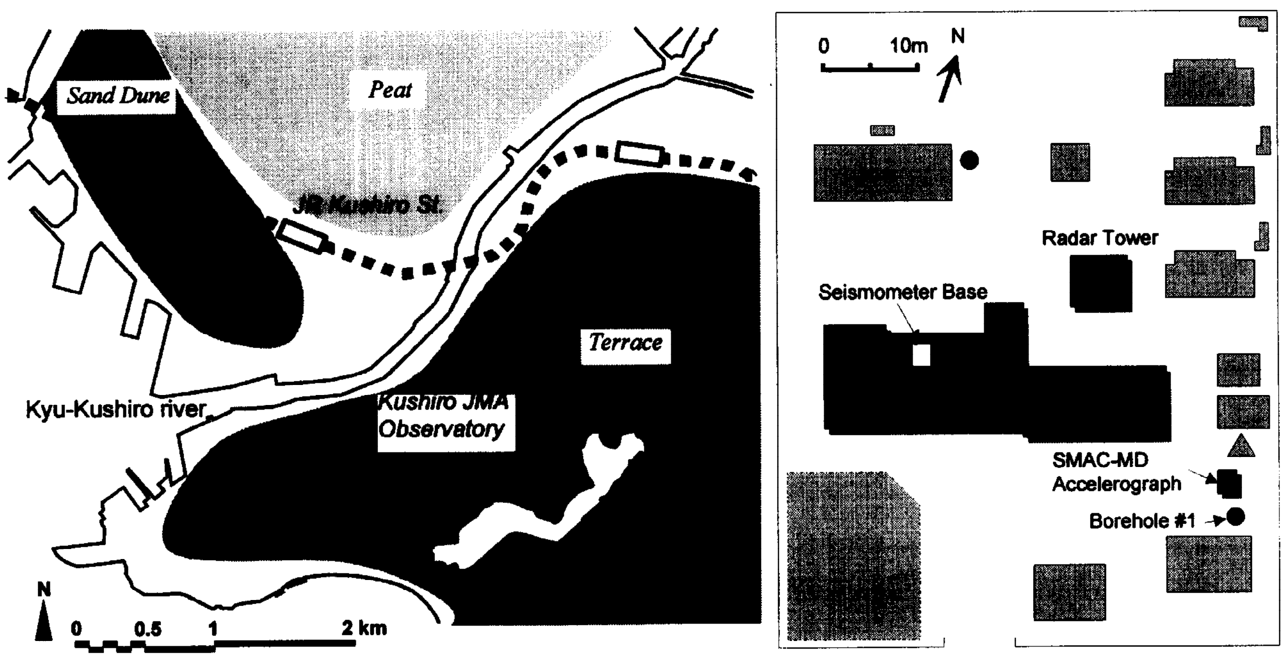


Fig. 1 Outline of geology in Kushiro (Hokkaido Architect Society, 1982) and layout of Kushiro Meteorological Observatory

The soil survey at the observatory conducted in November, 1993, as one of the research activities caused by the 1993 Kushiro-oki Earthquake. The place of the borehole is close to the hut of SMAC-MD as indicated in Fig. 1, and the geological properties were obtained as shown in Table 1 (Building Research Institute, 1994). Under banking, volcanic ash layers are heaped up 15 meters thick, and sand stone with a shear wave velocity of 650 m/s lies below it. The shear wave velocities of volcanic ash layers are between 140 m/s and 350 m/s.

Table 1 Soil profile obtained from borehole #1 at Kushiro Meteorological Observatory (Building Research Institute, 1994)

#	*Depth (m)*	*Soil Type*	*P-wave Velocity (m/s)*	*S-wave Velocity (m/s)*	*Density (ton/m³)*
1	0 ~ 1.00	Fill	230	110	1.56
2	1.00 ~ 1.90			140	
3	1.90 ~ 6.85	Silty Volcanic Ash			1.63
4	6.85 ~ 8.15	Volcanic Ash	1130	260	1.67
5	8.15 ~ 14.00	Volcanic Ash Sand		310	1.78
6	14.00 ~ 17.15			350	
7	17.15 ~	Sand Stone	2850	650	1.89

A tri-axial accelerometer was installed in the borehole 20 meters below the ground after the soil survey. SMAC-MD was improved for the six-channel processing and is recording internal three components and underground three components simultaneously.

STRONG MOTION RECORD OF THE 1993 KUSHIRO-OKI EARTHQUAKE

On January 15, 1993, a big earthquake was occurred near Kushiro city. The magnitude (M_{JMA} : Japan Meteorological Agency Magnitude) was 7.8, and the focal depth was 103 km. SMAC-MD at the Kushiro Meteorological Observatory, which was 10 km distant from the epicenter, was triggered and recorded an extraordinary strong motion (Kashima et al., 1993). Peak accelerations were 711 cm/s^2 in the N063°E component, 637 cm/s^2 in the N153°E component, and 363 cm/s^2 in the vertical component. The acceleration wave forms observed are shown in Fig. 2. Severe shakes continued for more than 20 seconds.

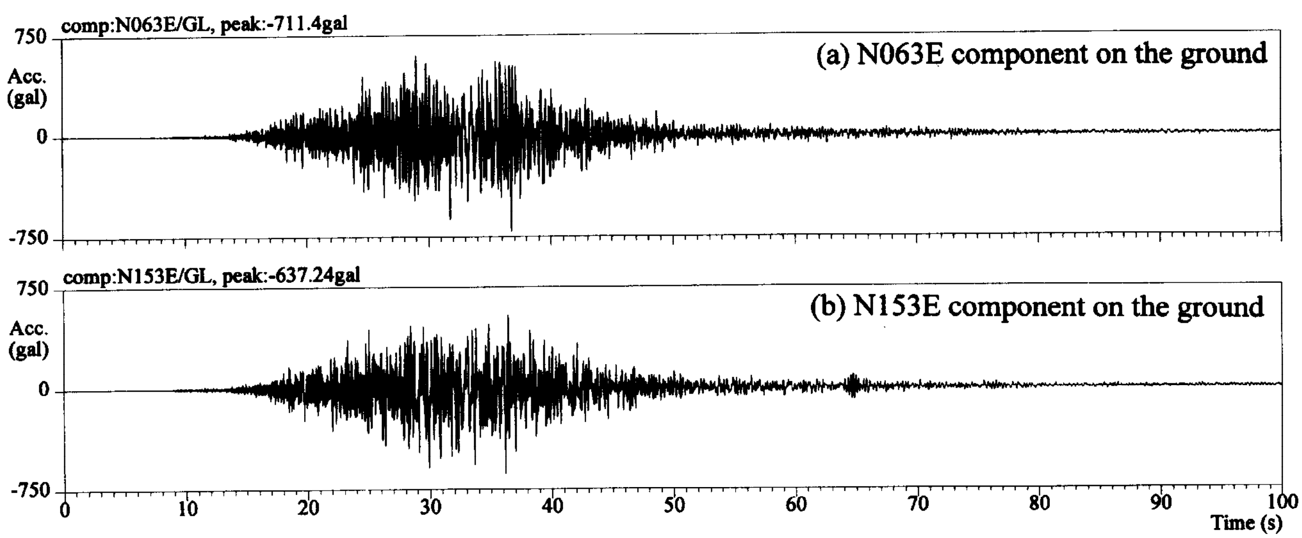


Fig. 2 Acceleration of the 1993 Off-Kushiro Earthquake of Jan. 15, 1993 observed at Kushiro Meteorological Observatory

Pseudo velocity response spectra with a damping ratio of 5 % for the horizontal motions are drawn in Fig. 3. Response spectra for the N-S component of 1940 El Centro records (ELC-NS, Earthquake Engineering Research Laboratory, 1971) and the N-S component of the 1968 Hachinohe records (HAC-NS, Committee for Digitized Strong-Motion Earthquake Accelerograms, 1972), Japan, are also plotted for reference. ELC-NS and HAC-NS are frequently used for the seismic design of buildings in Japan. Velocity responses for the records at the Kushiro Meteorological Observatory (KUS-N063E and KUS-N153E) are predominant in the short period range from 0.2 to 1.0 seconds, while the spectra in the long period range are low. As compared with ELC-NS and HAC-NS, seismic response in the period range of around 0.2 and 0.3 seconds is twice larger.

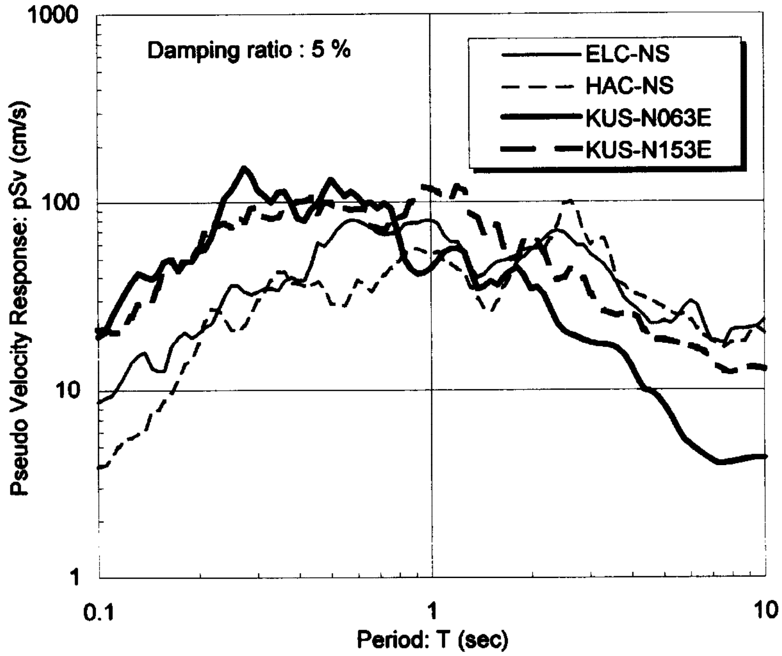


Fig. 3 Pseudo response spectra for the records of the 1993 Kushiro-oki Earthquake and famous strong motions

AMPLIFICATION OF STRONG MOTION DUE TO SURFACE SOIL

We supposed such large accelerations were due to the surface geology, therefore we surveyed the surface geology and added an underground accelerometer as mentioned above. After the installation of the additional accelerometer, several earthquakes have been recorded. Major records are listed as #2 to #5 in Table 2. The biggest one was the 1994 Hokkaido-toho-oki (east off Hokkaido) Earthquake of October 4, 1994 (Kashima et al., 1994). The JMA magnitude of the earthquake was 8.1 and the JMA seismic intensity at Kushiro was six again. Acceleration wave forms and pseudo velocity response spectra for horizontal records observed on and under the ground at the Kushiro Meteorological Observatory are shown in Fig. 4. Horizontal peak accelerations on the ground are 314 and 392 cm/s^2, which are 3 and 4 times larger than ones observed 20 meters below the ground. Differences of response spectra on the ground to ones under the ground are conspicuous in the period range shorter than 1.0 second.

Pseudo velocity response spectra with the 5% damping ratio for the horizontal accelerogram from the earthquakes listed in Table 2 and the ratio of response spectra on the ground to ones under the ground are drawn in Fig. 5. The response spectra for the 1993 Kushiro-oki Earthquakes are also plotted for reference in Fig. 5(a). As the earthquake motion becomes bigger, the response in the long period range becomes larger. The spectra at the periods of 0.2 to 0.3 seconds are predominant in all cases. The theoretical transfer function of SH waves calculated from the soil structure described in Table 1 are also plotted in Fig. 5(b). Non-linear behavior of surface soil layers generally make the height of a peak low and the period of a peak long. It seems that influence of non-linearity slightly appears.

Three variables, R_A, R_S and T_S, are taken to represent magnification effect of the surface geology. R_A is the ratio of the peak acceleration on the ground to the one under the ground. R_S is the peak value of the response spectral ratio of the record on the ground to the one under the ground, and T_S is the period of this peak. Figure 6 shows the relation between the peak acceleration under the ground A_{max} and those variables representing the magnification effect of the surface geology for 25 earthquakes recorded in 1994. The broken line in Fig. 6 is the regression result using the following formula.

Table 2 List of strong motions observed at the Kushiro Meteorological Observatory

#	*Date*	*Epicenter*	*Depth*	*Dist.*	*Loc.*	*Peak Acc.* (cm/s^2)		
	Time	*Latitude, Longitude*	M_{JMA}	I_{JMA}		*N063E*	*N153E*	*U-D*
1	1993/01/15	Off Kushiro	103	9.6	GL	711.4	637.2	363.4
	20:06:06.9	042°53.5'N, 144°22.4'E	7.8	6				
2	1994/07/06	SE off Tokachi	108	42.3	GL	20.6	21.9	10.5
	01:27:33.3	042°45.0'N, 143°58.5'E	4.8	3	G20	4.1	4.2	3.9
3	1994/08/25	Off Nemuro Peninsula	65	67.9	GL	36.8	43.0	16.3
	10:24:47.3	042-44.9'N, 145°09.9'E	5.3	4	G20	7.5	9.5	6.1
4	1994/08/31	Near Kunashiri Island	84	146.9	GL	101.5	118.3	39.4
	18:07:29.0	043°29.4'N, 146°04.1'E	6.5	5	G20	34.8	31.5	19.3
5	1994/10/04	E off Hokkaido	30	269.1	GL	314.1	392.2	189.2
	22:23	043°22'N, 147°40'E	8.1	6	G20	100.2	94.8	74.4

M_{JMA} : Magnitude of Japan Meteorological Agency, *Dist.* : Epicentral Distance (km), I_{JMA} : Seismic Intensity of Japan Meteorological Agency at Kushiro, *Loc.* : Location of Accelerometer, GL: on the ground, G20: 20 meters below the ground.

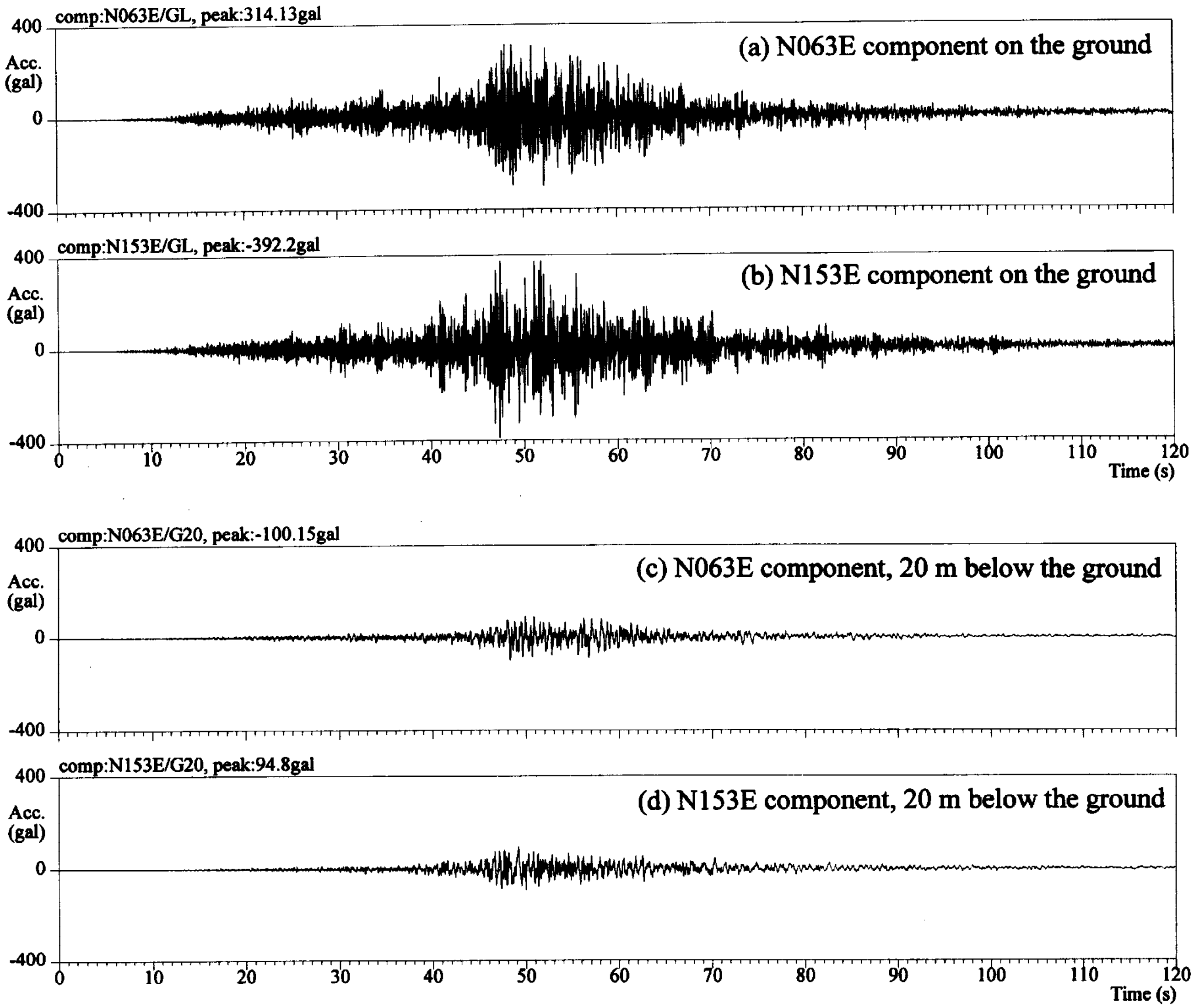


Fig. 4 Acceleration of the 1994 Hokkaido-toho-oki Earthquake 10/4/1994 observed at Kushiro Meteorological Observatory

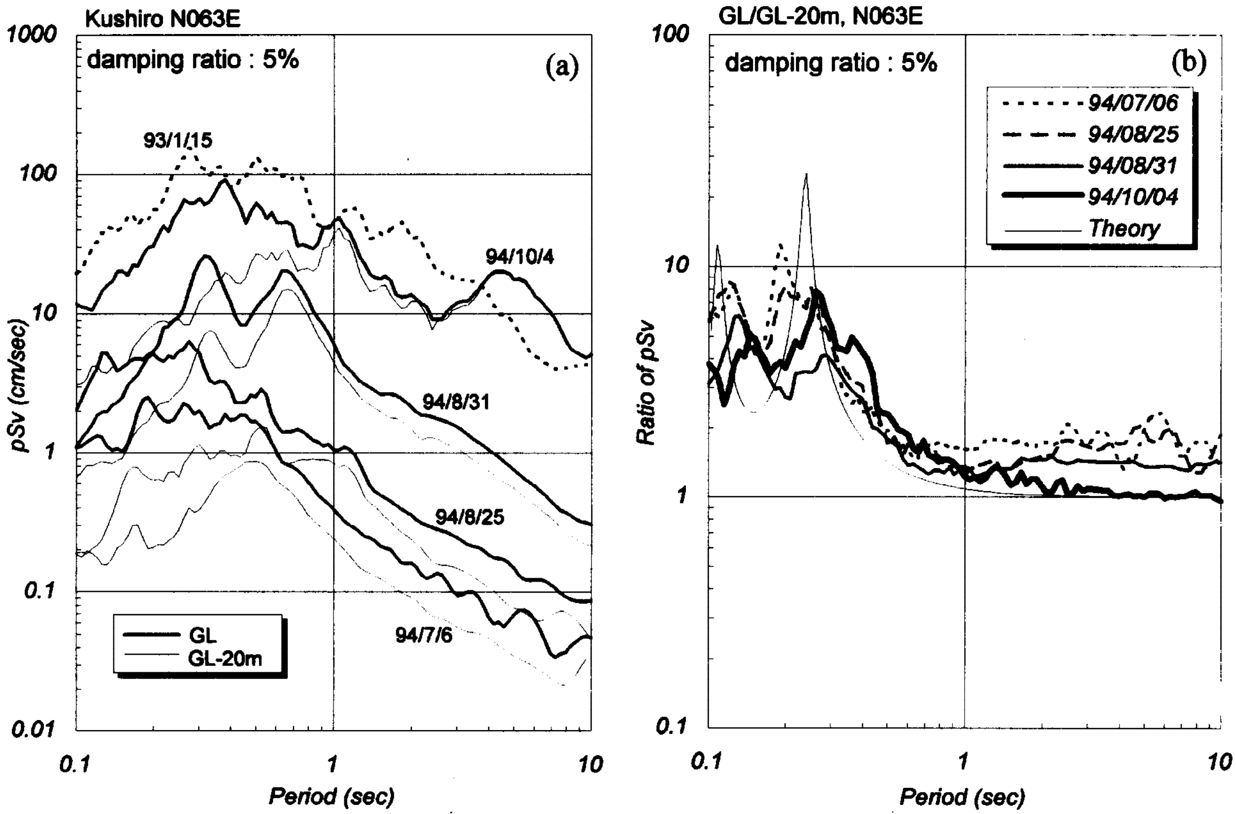
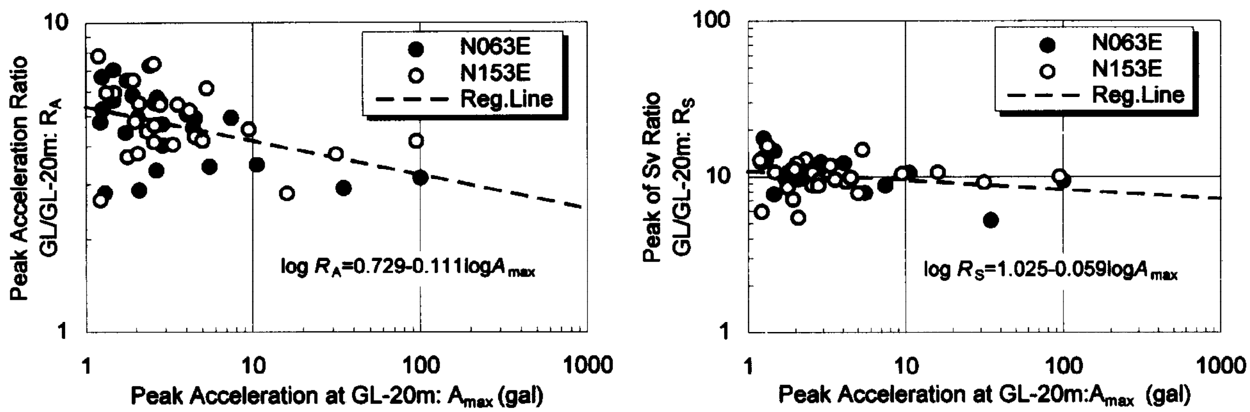
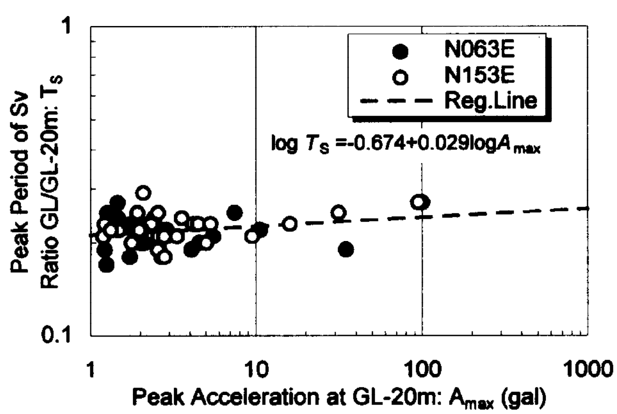


Fig. 5 Pseudo response spectra for the records on the ground (GL) and under the ground (GL-20m) and response spectral ratios (GL/GL-20m)



(a) Relation between A_{max} and R_A

(b) Relation between A_{max} and R_S



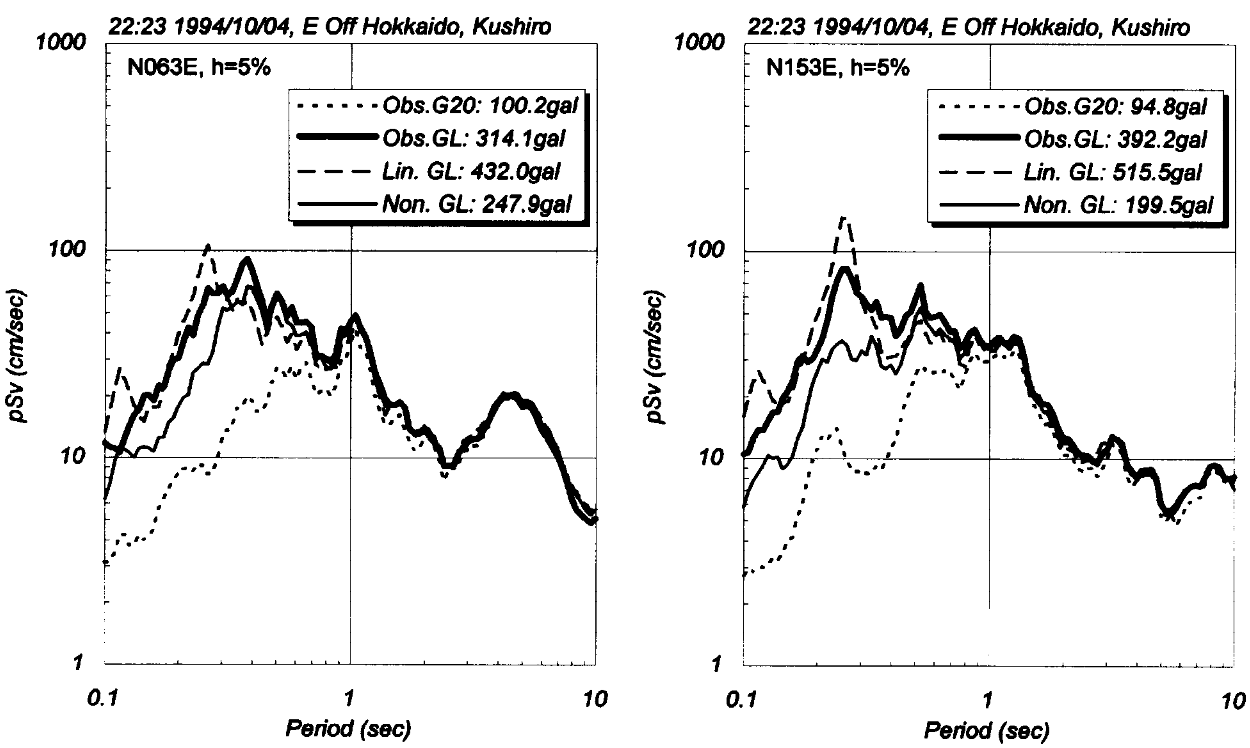
(c) Relation between A_{max} and T_S

Fig. 6 Relation of R_A, R_S and T_S to A_{max}

$$\log_{10}\begin{Bmatrix} R_A \\ R_S \\ T_S \end{Bmatrix} = a + b \log_{10} A_{max} . \quad (1)$$

a and b are regression coefficients in Equation (1). R_A and R_S become less, and T_S becomes longer, as the amplitude level of the earthquake motion A_{max} becomes larger. Such phenomena will be due to the non-linearity of the surface soil layers.

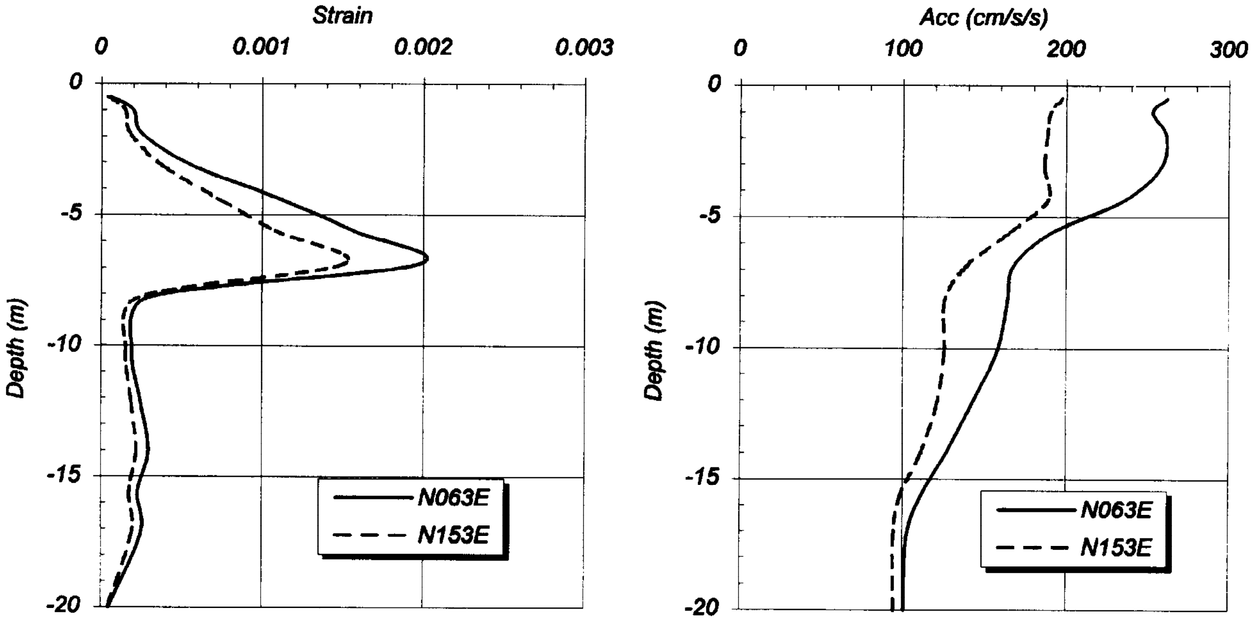
The linear and non-linear one-dimensional seismic response analyses were made to ascertain the dynamic behavior of the soil deposit. The Ohsaki's model (1982a, 1982b) is adopted as the non-linear hysteresis for the analysis. The soil type factors using for the Ohsaki's non-linear model were determined by referring of the dynamic soil test (Building Research Institute, 1994). Pseudo response spectra for the observed acceleration and the calculated acceleration on the ground are shown in Fig. 7. The thick solid line and the dotted line indicate response spectra for acceleration records observed on and under the ground, respectively. The broken line is response spectrum given by the linear analysis, and the thin solid line is by the non-linear analysis. The response spectra of the linear analysis are twice or three times as large as ones of the non-linear analysis in the short period range. The response spectra of observed records are in-between. In order to investigate the amplification effects of surface soil layers, the non-linear effect must be taken into account. In our case, the further discussion for dynamic parameters of the soil deposit is necessary.



(a) N063E component (b) N153E component

Fig. 7 Pseudo response spectra for observed and calculated results

Figure 8 represents distributions of peak shear strains and peak accelerations obtained from the non-linear analysis. The shear strains are concentrate on the volcanic ash layers 6 to 7 meters deep. The earthquake motion is remarkably amplified by the surface soil layers with a thickness of only 7 meters.



(a) shear strain (b) peak acceleration

Fig. 8 Distribution of peak shear strains and peak accelerations in soil layers by non-linear response analysis

CONCLUSIONS

Two big earthquakes attacked eastern Hokkaido twice for two years. The first earthquake surprised us generating a high accelerogram. After the earthquake, many research works were made including the array strong motion observation program. We have successfully obtained several precious strong motions on and under the ground at the Kushiro Meteorological Observatory. The preliminary analysis of these records was introduced in this paper. The influence of non-linearity of soil deposit was ascertained through the dynamic response analysis. The great amplification of the earthquake motion was produced by the thick surface soil layers.

REFERENCES

Building Research Institute (1994). Result of Soil Survey at Kushiro Meteorological Observatory. *JSEEP NEWS No.136*, Japan Society for Earthquake Engineering Promotion.

Committee for Digitized Strong-Motion Earthquake Accelerograms (1972). *Digitized Strong Motion Earthquake Accelerograms in Japan*. Association for Science Documents Information.

Earthquake Engineering Research Laboratory (1971). Strong Motion Earthquake Accelerograms. *Vol. II Part A, EERL71-50*, California Institute of Technology.

Hokkaido Architect Society, Kushiro Branch (1982). *Ground in Kushiro City*.

Kashima, T. and Kitagawa, Y. (1993a). *Prompt Report on Strong-motion Records from the 1993 Off Kushiro Earthquake*. Building Research Institute.

Kashima, T. and Kitagawa, Y. (1993b). *Prompt Report on Strong-motion Records from the 1994 Hokkaido-toho-oki Earthquake*. Building Research Institute.

Ohsaki, Y. (1982a). Dynamic Characteristics and One-dimensional Linear Amplification Theories of Soil Deposits. *Research Report 82-01*, Dept. of Architecture, Tokyo Univ.

Ohsaki, Y. (1982b). Dynamic Nonlinear Model and One-dimensional Nonlinear Response of Soil Deposits. *Research Report 82-02*, Dept. of Architecture, Tokyo Univ.