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SITE EFFECTS IN KUSHIRO DURING THE 1993 KUSHIRO-OKI AND THE 1994 HOKKAIDO TOHO-OKI EARTHQUAKES

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ABSTRACT

Kushiro city is one of the test sites of the Japanese Working Group on the Effects of Surface Geology on Seismic Motion (JWG-ESG). The 1993 Kushiro-Oki earthquake (M_{JMA}=7.8) attacked this city and caused heavy damage there. After this big event, JWG-ESG organized the dense strong motion array observation in Kushiro city and obtained a lot of strong motion data, including those from the 1994 Hokkaido Toho-Oki earthquake (M_{JMA}=8.1). We review the site effects in Kushiro city during the 1993 event and show a preliminary analysis of the site effects during the 1994 event. The qualitative relationship between the surface geology and the spatial variation of ground motions is obtained. Nonlinear ground response is also observed during strong shaking.

KEYWORDS

Effects of surface geology on seismic motion, the 1993 Kushiro-Oki earthquake, the 1994 Hokkaido Toho-Oki earthquake, nonlinear ground response, spatial variation of ground motions, Kushiro city.

INTRODUCTION

A prediction of strong ground motion taking into consideration on effects of surface geology is one of the goals in the field of engineering seismology. The extensive damage in Mexico city during the 1985 Michoacan earthquake has demonstrated the importance of the site effects on seismic motion. After this event, various test sites to study the effects of surface geology on seismic motion have been set up in the world: Mexico City, Ashigara Valley in Odawara, Turkey Flat in California, EURO SEISTEST in Greece, and so on. Kushiro city is one of the test sites of the Japanese Working Group on the Effects of Surface Geology on Seismic Motion (JWG-ESG).

Kushiro city is a moderate city in the eastern part of Hokkaido, Japan (Fig. 1). A large earthquake (the 1993 Kushiro-Oki earthquake; M_{JMA}=7.8) attacked this city on January 15, 1993 and caused heavy damage there. Paying attention to the variety of strong ground motion in Kushiro city during this earthquake, JWG-ESG has started cooperative observations of earthquakes and microtremors since August in 1993. Our dense array succeeded in observation of strong ground motions during the 1994 Hokkaido Toho-Oki earthquake (M_{JMA}=8.1). In this paper, we review site effects in Kushiro city during the 1993 event and show a preliminary analysis of the site effects during the 1994 event.

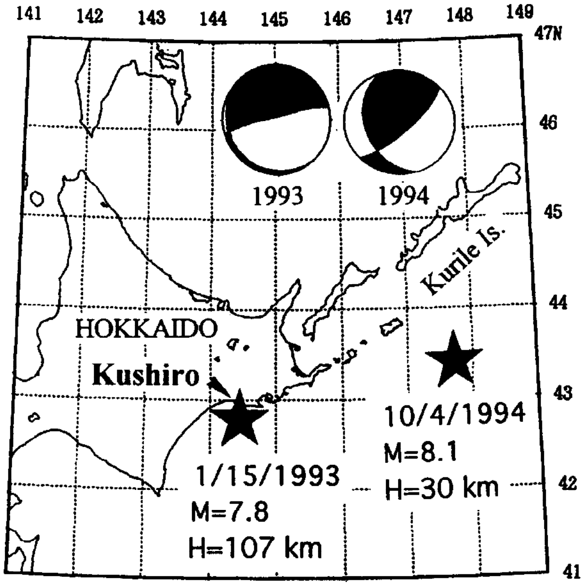


Fig. 1. Location map showing Kushiro city and epicenters of the 1993 Kushiro-Oki and the 1994 Hokkaido Toho-Oki earthquakes. The focal mechanisms are taken from Takeo et al.(1993) for the 1993 event and Kikuchi and Kanamori (1995) for the 1994 event and the source parameters are taken from JMA.

GEOLOGICAL STRUCTURE OF KUSHIRO CITY

First we refer to a brief geological structure of our test site. Kushiro city is geologically characterized by two regions, that is, lowland and terrace regions (Fig. 2). The Old Kushiro river is a border of the two regions. The eastern part of the river forms a terrace and the western part is lowland dune. Figure 3 shows the schematic east-west geological section of the Kushiro area. In the terrace region, the Kussharo pumice flow deposits of Pleistocene period predominate at shallow surface layers and the Otanoshige formation of sand layer is underlying. The depth to the Urahoro formation of Cretaceous period from the highest point of the terrace is about 20 m. In the lowland region, shallow layers are alluvial deposits of sand, gravel and soft silt. The depth to the Urahoro formation becomes gradually deep to the west.

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. An example of S-wave velocity profiles in the terrace and lowland regions is shown in Fig. 4. The surface layers have S-wave velocities of 100 to 400 m/s, but the basement has a S-wave velocity of about 700 m/s. The thickness of the surface low velocity layers is about 50 m at SMZ and about 20 m at BRI. These reflect the geological structure as shown in Fig. 3. We may expect the different resonant frequencies of the amplification function from site to site: about 1.4 Hz at SMZ and about 4 Hz at BRI. Instead of PS logging, array observations of microtremors have been done to estimate S-wave velocity profile in Kushiro city (Miyakoshi and Okada, 1996; Suetomi and Nakamura, 1996).

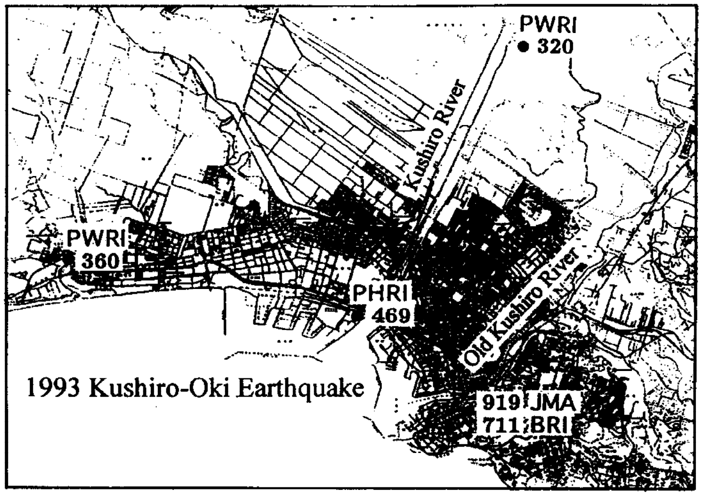


Fig. 2. A map showing the major part of Kushiro city, Hokkaido, Japan. Peak horizontal accelerations during the 1993 Kushiro-Oki earthquake are also shown.

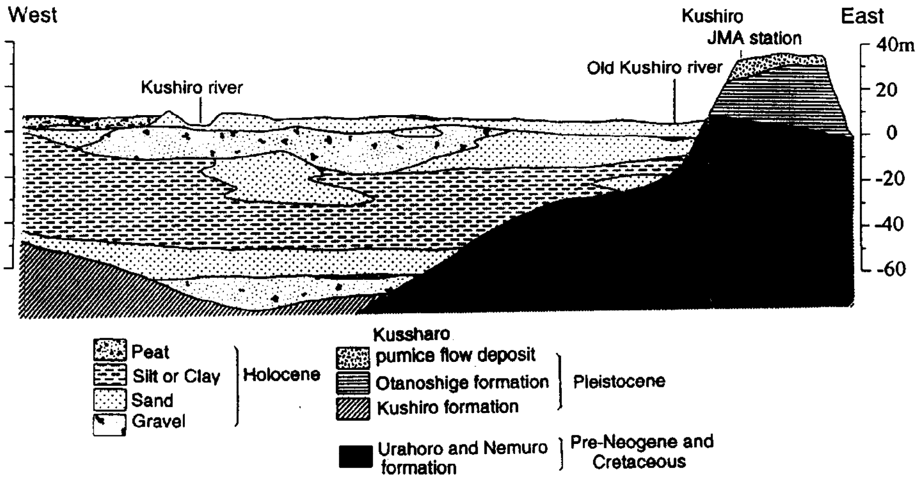


Fig. 3. Schematic east-west geological section of Kushiro city. (reproduced from Izumi et al., 1993)

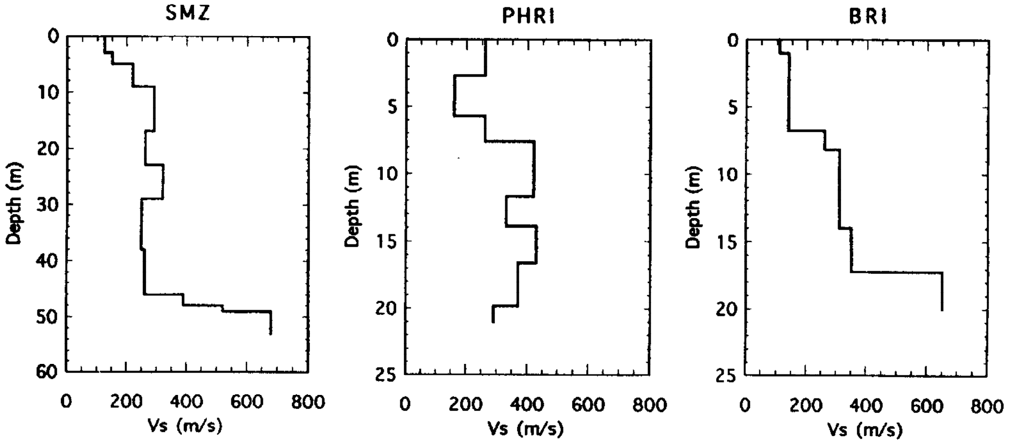


Fig. 4. S-wave velocity profiles at SMZ, PHRI and BRI. These are taken from Kudo and Kataoka (1996) for SMZ, Iai et al.(1995) for PHRI and BRI (1994) for BRI, respectively.

THE 1993 KUSHIRO-OKI EARTHQUAKE

A large, intermediate-depth earthquake (M_{JMA}=7.8) occurred just beneath Kushiro city, at a depth of 107 km, on January 15, 1995 (Fig. 1). This earthquake occurred in the subducting lithosphere and has the focal mechanism as shown in Fig. 1. The earthquake shaking in Kushiro city, whose epicentral distance is about 15 km, was so severe as that liquefaction occurred at many places, and that the port facilities and lifeline systems were heavily damaged in the lowland region. At that time, only five strong motion stations were operated in Kushiro city. Their peak horizontal accelerations are shown in Fig. 2. The maximum horizontal acceleration of about 0.9 g was observed at the Kushiro JMA observation station on the terrace. However, the damage of building near the station was not so heavy as we expected from the acceleration level. On the other hand, the peak horizontal accelerations at three sites located in the lowland are 0.3 ~ 0.5 g. Since the source and path effects on these stations are nearly the same, the spatial variation of peak horizontal accelerations is attributed to the local site effect.

By comparing the accelerograms at PHRI and JMA as shown in Fig. 5, we can point out a distinctive difference in the response of ground. The N-S component at PHRI, which is on the former beach line, has the following characteristics: most of the high frequency motions after about 30 seconds are filtered out and instead cyclic motion becomes predominant with a period of about 1.5 seconds overlain by a spike at each peak of the motion. Iai, et al. (1995) interpreted this spiky acceleration as the cyclic mobility of the dense sand deposit, in which contraction and dilation of sand alternately make the stiffness of the sand soften and stiffen during cyclic loading. This indicates nonlinear response of the subsurface ground. On the other hand, we can identify no spiky acceleration at JMA, where the predominant frequency of the acceleration is several Hz.

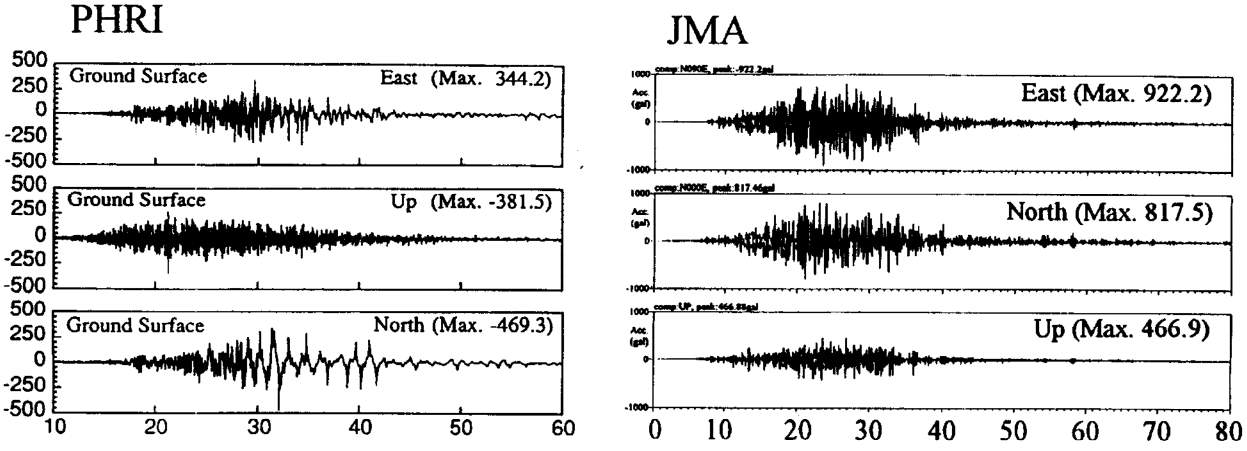


Fig. 5. Accelerograms at PHRI and JMA during the 1993 Kushiro-Oki earthquake.

Above facts indicate the strong site effects on seismic motion in Kushiro city. In order to obtain the quantitative and intimate relationship between the surface geology and the seismic response, JWG-ESG organized the temporal strong motion array observation in Kushiro city. The array consists of 23 stations within a radius of about 3 km as shown in Fig. 6. The station codes, locations, instruments and contributors have been listed in Table 1 of Kudo and Kataoka (1996). During one and half years operation, we could obtain various types of recordings, including those from the Hokkaido Toho-Oki earthquake (M_{JMA}=8.1) of October 4, 1994.

THE 1994 HOKKAIDO TOHO-OKI EARTHQUAKE

The Hokkaido Toho-Oki earthquake occurred far east off Hokkaido on October 4, 1994 (Fig. 1), about two

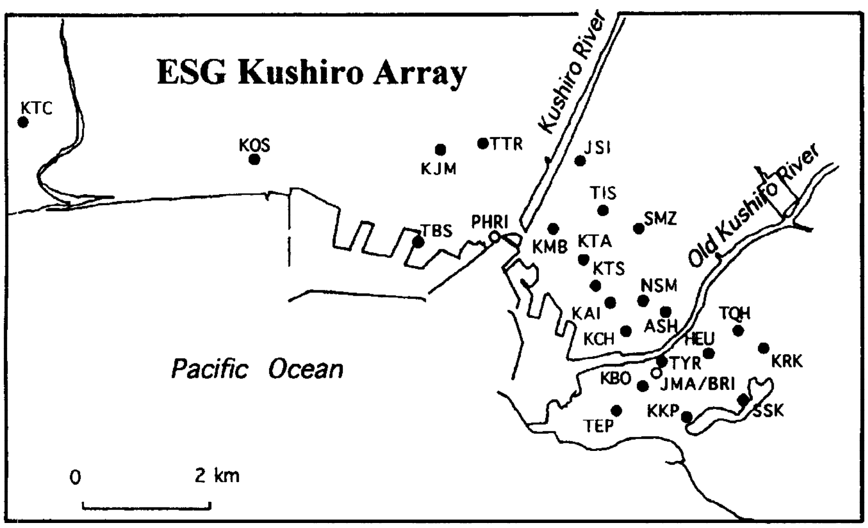


Fig. 6. Map showing locations of strong motion observation sites. Except JMA, BRI and PHRI, the observation sites were temporally operated during August 1993 and March 1995.

years after the 1993 Kushiro-Oki earthquake. This earthquake, having the different focal mechanism (Fig. 1) from those of the plate boundary large earthquakes in this region, rupture through a substantial part of the subducting lithosphere (Kikuchi and Kanamori, 1995; Sasatani et al., 1996). A large tsunami and strong shaking caused severe damage to the eastern part of Hokkaido and the southern part of the Kurile islands. In Kushiro city with an epicentral distance of about 270 km, liquefaction occurred again in the lowland.

Figure 7 shows the peak horizontal accelerations in Kushiro city during the 1994 Hokkaido Toho-Oki earthquake. The maximum value (475 cm/s/s) is obtained at JMA as in case of the 1993 Kushiro-Oki earthquake. Comparing Fig. 2, our dense array clarifies the detailed spatial variation of ground motions in Kushiro city. In Fig. 8, we show the peak horizontal accelerations as a function of the distance from the JMA station. The high accelerations are found around the JMA station on the terrace. The peak values in the lowland region decrease with distance from the JMA site, while their distribution in the terrace region is rather complex. We can qualitatively relate the distribution of the peak horizontal accelerations to the geological structure shown in Fig. 3: the surface sedimentary layers strongly affect the peak acceleration. In Fig. 8, the peak horizontal accelerations during the 1993 Kushiro-Oki earthquake are also shown. The distribution pattern is nearly the same as that during the 1994 Hokkaido Toho-Oki earthquake, though their focal depths

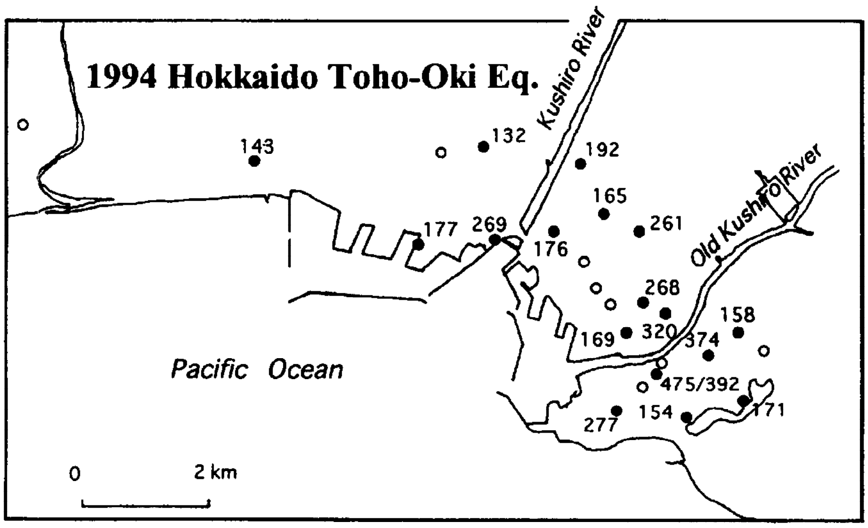


Fig. 7. Peak horizontal accelerations in Kushiro city during the 1994 Hokkaido Toho-Oki earthquake.

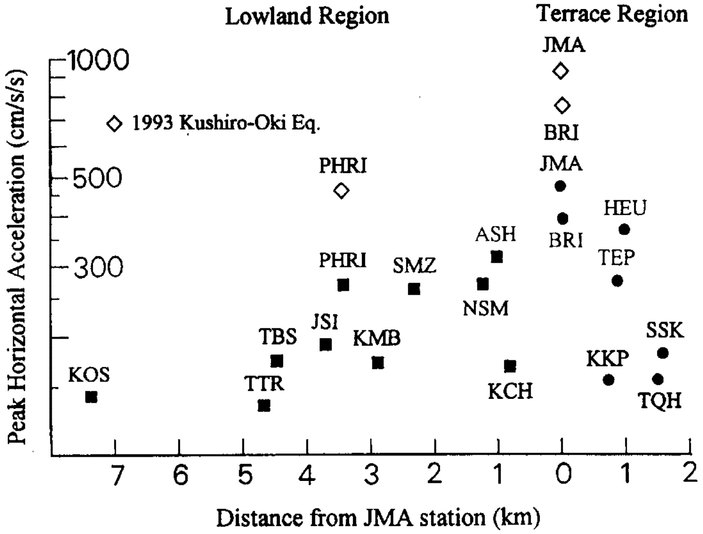


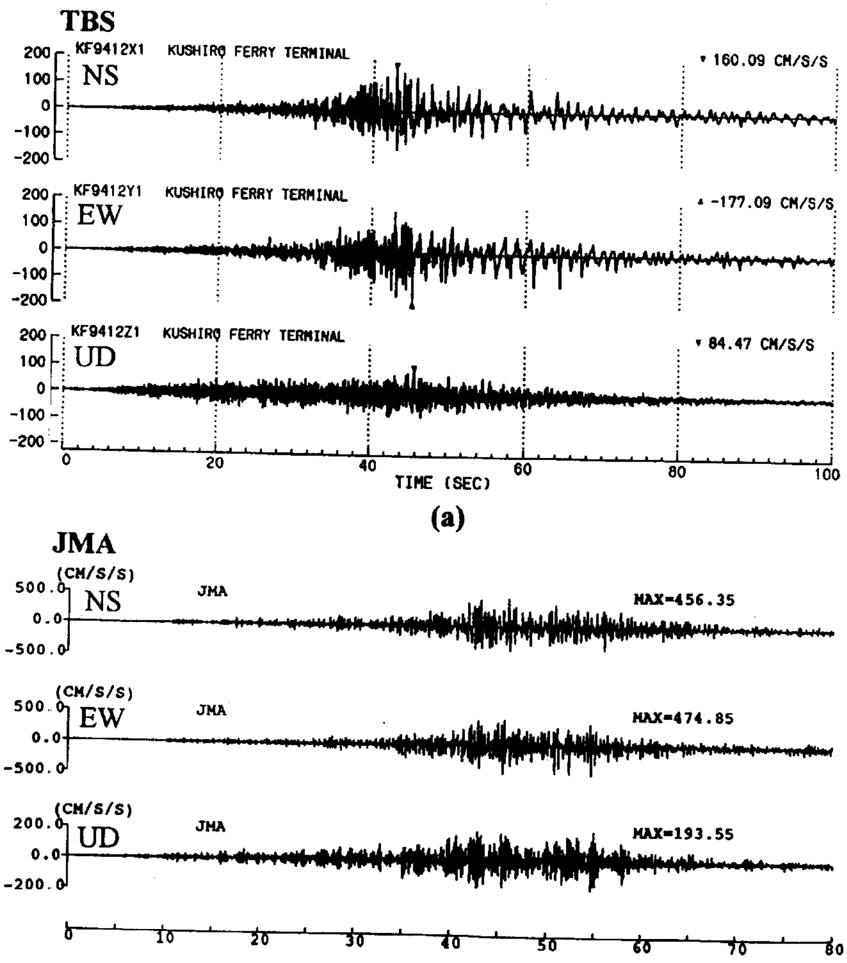
Fig. 8. Distribution of peak horizontal accelerations as a function of distance from the JMA station.

and epicentral distances are quite different from each other. This is an interesting fact relating to strong motion prediction.

Finally we show some evidences that indicate plausible nonlinear response. Figure 9(a) shows accelerograms obtained at TBS (see Fig. 6). This site is located reclaimed land in Kushiro West Port where heavy damage occurred due to liquefaction during the 1993 Kushiro-Oki earthquake. The thickness of reclaimed layer is about 8 m and SPT N-values are very small (3 to 6) in this layer. We can point out the similar waveform as observed at PHRI during the 1993 Kushiro-Oki earthquake (Fig. 5): most of the high frequency motion on horizontal components after about 50 seconds are filtered out and the spiky acceleration appears (Tobishima Co., 1994). As shown in Fig. 9(b), accelerograms at JMA have no such characteristics. Therefore we conclude that the accelerograms at TBS indicate nonlinear response, though the degree is not so severe as observed at PHRI (Fig. 5). Another nonlinear response has been indicated by Sasatani et al. (1996). They compare S-wave spectra at TIS (see Fig. 6) in the lowland region for the 1994 Hokkaido Toho-Oki earthquake and its largest aftershock (10/9/1994, M_{JMA}=7.3). As shown in Fig. 10, the spectral peak for the main shock is lower than that for the aftershock. The spectral peak shift during strong shaking has been observed at PHRI during the 1993 Kushiro-Oki earthquake (Iai et al., 1995). Figure 10 shows plausible nonlinear response at TIS during strong shaking (peak ground velocity ~ 20 cm/s). On the other hand, Kudo and Kataoka (1996) and Suetomi and Nakamura (1996) concluded that no distinct nonlinear response was observed at ASH, SMZ, JSI and KMB.

CONCLUDING REMARKS

We reviewed the site effects in Kushiro city during the 1993 Kushiro-Oki earthquake, which motivated the dense array observation there by the Japanese Working Group on the Effect of Surface Geology on Seismic Motion. We showed a preliminary analysis of the site effects based on our array data from the 1994 Hokkaido Toho-Oki earthquake. The qualitative relationship between the surface geology and the spatial variation of ground motions was obtained. Nonlinear ground response was also observed during strong shaking. Further studies on the site effects in Kushiro city are: 1) estimation of the amplification function at each site based on weak motion data, 2) systematic search of nonlinear response sites based on strong motion data, 3) quantitative interpretation of the site effects based on the geotechnical data.



(a)

(b)

Fig. 9. Accelerograms at TBS and JMA during the 1994 Hokkaido Toho-Oki earthquake.

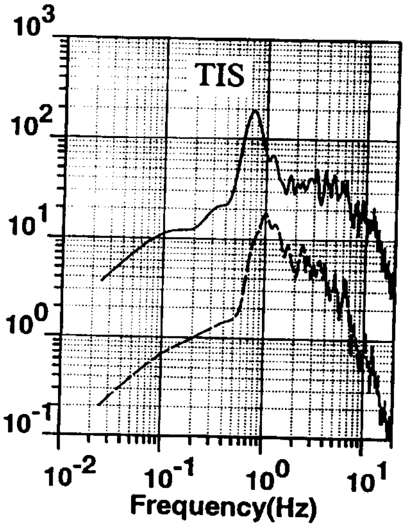


Fig. 10. S-wave acceleration spectra (transverse components) at TIS for the 1994 Hokkaido Toho-Oki earthquake (solid curve) and its largest aftershock (dashed curve).

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