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LOCAL SITE EFFECTS OF SURFACE GEOLOGY ON STRONG EARTHQUAKE MOTION DURING THE 1993 KUSHIRO-OKI EARTHQUAKE

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ABSTRACT

Large maximum accelerations fo both 711 and 919 gal were observed at the JMA Kushiro Observatory during the 1993 Kushiro-Oki Earthquake. In order to find the origin of these large values, a comprehensive analysis of the geology and of the results of drillings, PS logging, microtremor measurement in the vicinity of the Observatory is performed. One- and two-dimensional response analyses are carried out to clarify the response characteristics of the ground. The results show that the effect of surface geology is larger than the effect of topography on the values of acceleration, at least for the area under study.

KEYWORDS

Strong earthquake motion; Local site effects of surface gelogy; 1D-response analysis; 2D-FEM response analysis; PS logging; Microtremor measurment

1. INTRODUCTION

Large maximum accelerations of both 711 and 919 gal were observed during the 1993 Kushiro-Oki Earthquake on the ground surface by JMA-87-Type Seismometer and by SMAC-MD Accelerometer (Building Research Institute) respectively, which were installed at the JMA Kushiro Observatory. Comprehensive examinations of the source process, the wave propagation from the earthquake fault and the site response of the surface-layers should be made to find out the causes of such large accelerations. In this study, however, examination was made focusing on the site response of the hilly zone surrounding the Observatory. In particular, a two-dimensional response analysis by FEM was executed at the hilly zone, and the effect of the irregular groundstructure namely, the ridge topography, was analyzed.

2. TOPOGRAPHY AND GEOLOGY

Kushiro City is situated at the mouth of the Kushiro River, and the urban area is located on low lands, at about 2 to 4 m from the sea level. At the left bank of the Kushiro River, there is a terrace called the "Kushiro surface," which has an altitude of about 30 m and comes into contact with the low land through a steep cliff. On this "Kushiro surface" the JMA Kushiro Observatory is situated. The geology of the "Kushiro surface" has the Urahoro-group, a Yubetsu formation of the Paleocene, as the bedrock. This terrace is covered by the Kushiro group consisting of sand, silt and gravel layers. Further, the surface layer of the terrace is covered with volcanic ash of Kussharo pumice flow. Figure 1 shows the schematic cross section of this terrace formation, and Figure 2 shows its bird's-eye view.

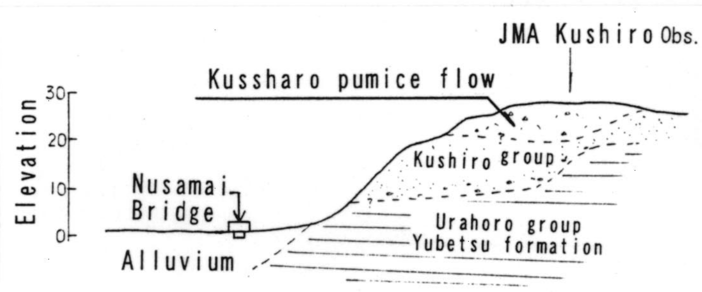


Fig.1 Schematic cross section of the part.

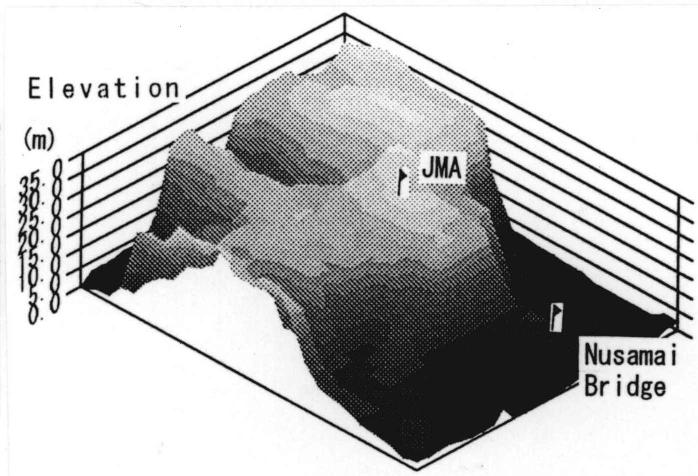


Fig.2 Bird's-eye view of the Kushiro terrace.

The current geological information around the Observatory was gathered and compiled, and geological cross sections were drawn along A-A' (N153° E) and B-B' (N063° E), shown in Figure 3 (Hokkaido Association of Authorized Architect Kushiro Branch, 1982, Yamamoto, 1993, Building Research Institute of Japan, 1994). Among then, the B-B' cross section is shown in Figure 4. The Urahoro formation, bedrock, consists of sandstone and mudstone (Uh1 to Uh4), and is covered by sand and silt layers (Ks1, Ks2 and Kc) of the Kushiro formation. The surface layer is volcanic ash (Ku) of the Kussharo pumice flow, and has on top a layer of filled clayey soil (Fc). As seen in Figure 4, the boundary between the Urahoro and the Kushiro layers has a deep depression starting from the Kushiro Development Construction Department (KDCD) to the southwest.

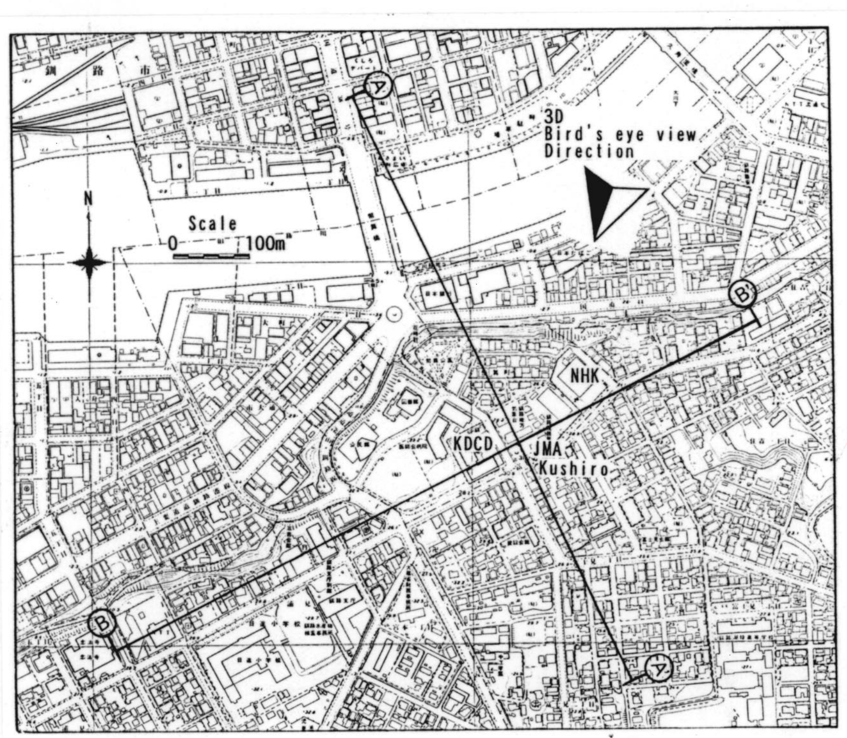
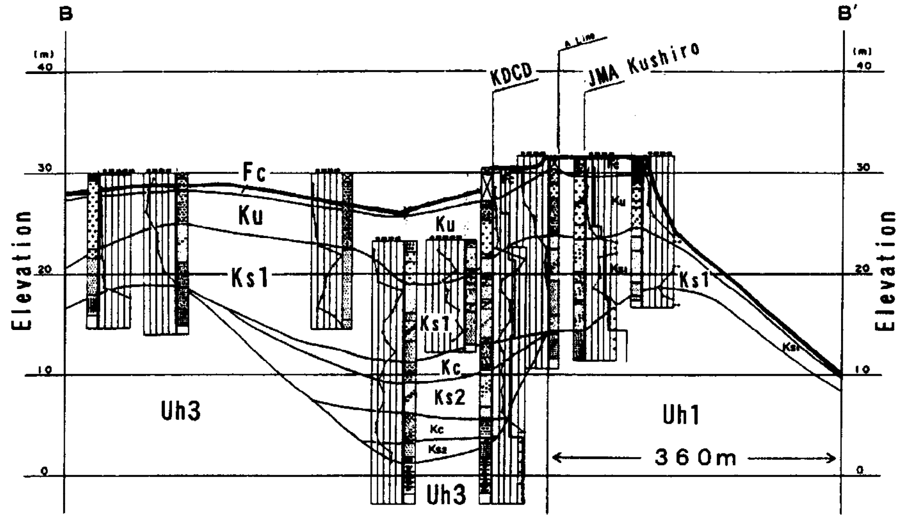


Fig.3 Map of the area



《Legend》

Geological Age		Stratum	Soil Type	Symbol
Quaternary		Filling	Clay	Fc
	Pleistocene	Kussharo pumice flow	Volcanic ash (Silt)	Ku
		Kushiro group	Sand	Ks1 Ks2
			Clay	Kc
Tertiary Oligocene		Urahoro group Yubetsu formation	Sandstone Mudstone	Uh1 ~Uh4

Fig.4 Geological cross section (B-B', N063°E).

3. OBSERVED RECORDS

The strong ground motion records obtained by the Building Research Institute of Japan, Ministry of Construction, at the JMA Kushiro Observatory are analyzed (Kashima et al, 1993). These were recorded using a SMAC-MD-Type Accelerometer, shown in Figure 5 together with their Fourier spectra. The predominant periods are about 0.23 sec in the both direction.

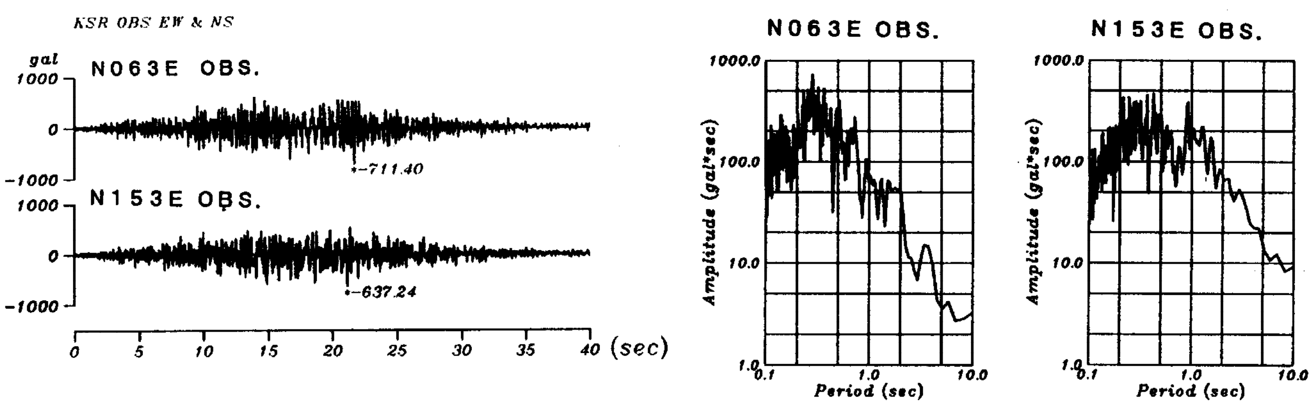


Fig.5 Observed waves at JMA Kushiro (BRI SMAC-MD type).

4. ONE-DIMENSIONAL GROUND MODEL

After the earthquake a boring survey and PS logging were carried out close to the site (Building Research Institute of Japan, 1994). A model of the surface layer at the JMA Kushiro Branch Observatory was prepared using the survey results at Borehole A, where is close to the accelerometer. PS logging was also performed at the Kushiro Development Construction Department (KDCD) located on the west side of Kushiro Observatory, shown in Figure 3. The both models of the ground surface layer at the two locations is presented in Table 1. The depth of the Urahoro layer, considered to be the bedrock, is significantly different at the two sites, due to the depression of the bedrock shown in Figure 4. The S-wave velocity of the bedrock shows also a significant difference, such as Vs=650 m/s at the JMA Kushiro Observatory site, at the KDCD site Vs=470 m/s. The measured waveforms from the PS logging at both locations should also be compared in the future..

Table 1. Ground model of the surface layers

JMA Kushiro[Model A(Boring)]

1.00	110	1.56
5.85	140	1.63
1.30	260	1.67
5.85	310	1.78
3.15	350	1.78
	650	1.89

JMA Kushiro[MoDEL B(FEM)]

2.10	110	1.40
6.10	180	1.40
9.10	330	1.90
	650	1.95

KDCD Model

4.50	110	1.40
4.50	240	1.40
7.50	330	1.90
10.00	270	1.80
	470	1.95

《Legend》

Thickness (m)	Vs (m/sec)	Density (g/cm³)
2.10	110	1.40

5. TWO-DIMENSIONAL GROUND MODEL

A ground models of two-dimension for FEM analysis were prepared using the geological cross sections. Figure 6 shows the mesh model in the N063° E direction. A depth of 60 m and a Vs=780 m/s were adopted for the seismic bedrock (Uh4) of this model, determined from the micrometer array measurements performed by Miyakoshi et al (1994). Among the properties of soil layers, a hysteresis curve based on the studies carried out at the KDCD was adopted for the calculation of the soil response (Yamamoto, 1993).

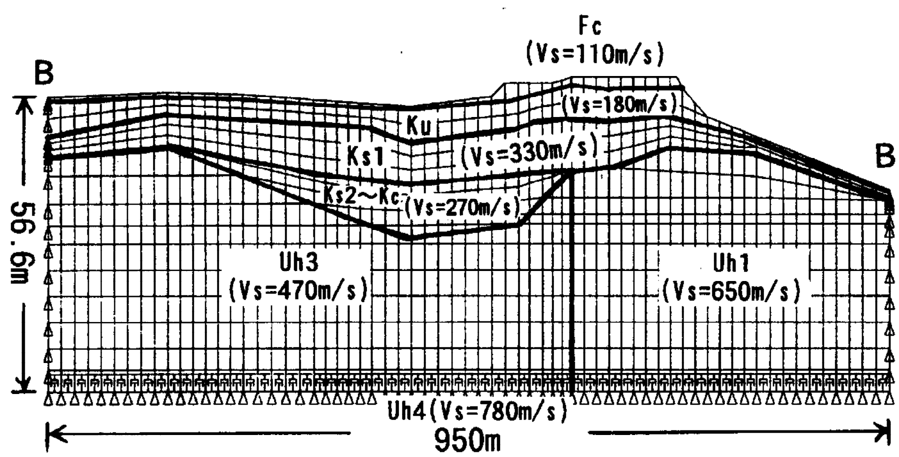


Fig.6 2-D mesh ground model (B-B', N063° E).

6. TWO-DIMENSIONAL RESPONSE ANALYSIS

Using the FEM two-dimensional ground mesh model, the dynamic soil response was calculated. Rollers and viscous damper elements were adopted as the boundary conditions at the side and bottom of the model, respectively. The incident wave at the bedrock level was obtained from the one-dimensional response analysis of both Model A and Model B. The average S-wave velocities at each ground layer for Model B were adopted for the two-dimensional model. This represented a distribution of the S-wave velocities at the JMA Kushiro Observatory site, and was different from that of the Model A.

Figure 7 shows the used incident waves (N063° E, Model A and Model B). The calculated waves at the JMA Kushiro Observatory, along with their Fourier spectra, are shown in Fig. 8, comparing observed ones.

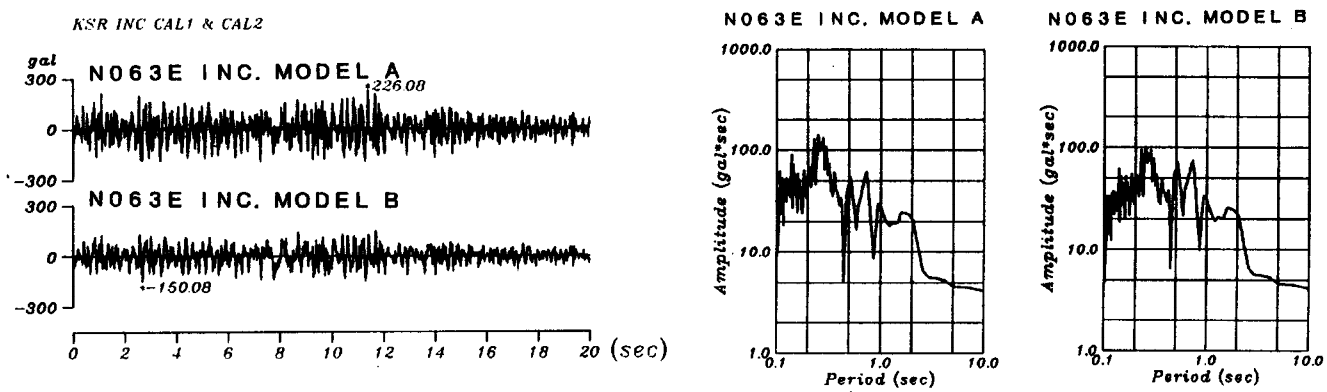
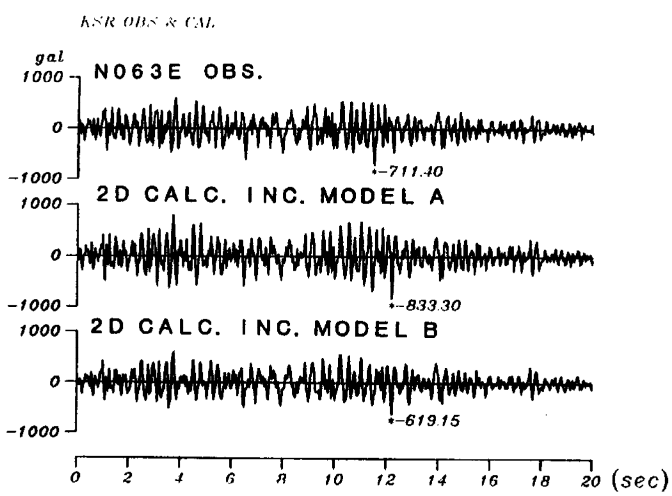


Fig.7 Incident waves at seismic bedrock (Uh4) obtained from the 1-D response analysis



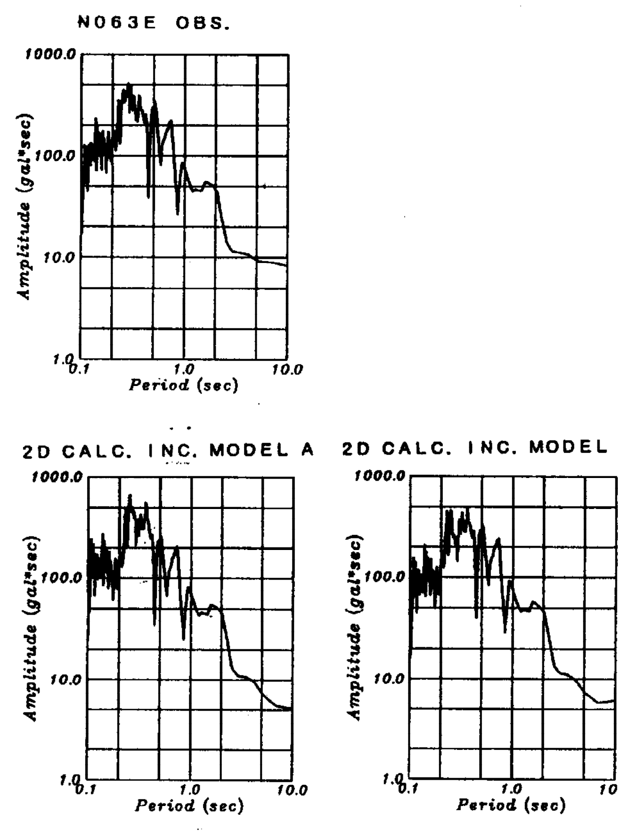


Fig.8 Observed and 2-D evaluated waves at the surface.

7.MICROTREMOR MEASUREMENT

The microtremor measurement was carried out at the JMA Kushiro Observatory site. The using seismograph was velocity type with natural period one second. The time intervals of this measurment was twenty minites at midnight. Figure 9 shows the fourier spectram of microtremor at the site and both the amplification ratio and transfer function based on the SH-multiple reflection theory. The ground model was used in Table 1 (Segawa et al, 1994).

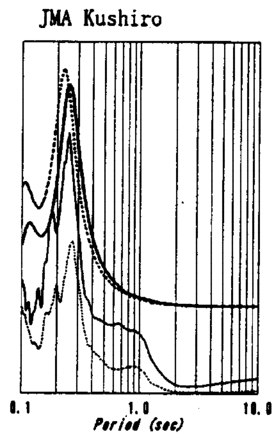


Fig.9 Fourier spectra of microtremor analysis and amplification ratio line

8. DISCUSSION

The observed and calculated waves of Figure 8 are compared. Both the phases of waves have been almost reproduced by the calculations. The maximum acceleration, however, is greatly affected by the difference in the incident waves derived from Models A and B.

The calculated results of the one-dimensional and the two-dimensional (FEM) response analyses at the hard layer of Urahoro layer (Uhl) are shown in Figure 10. The maximum accelerations of the two cases are

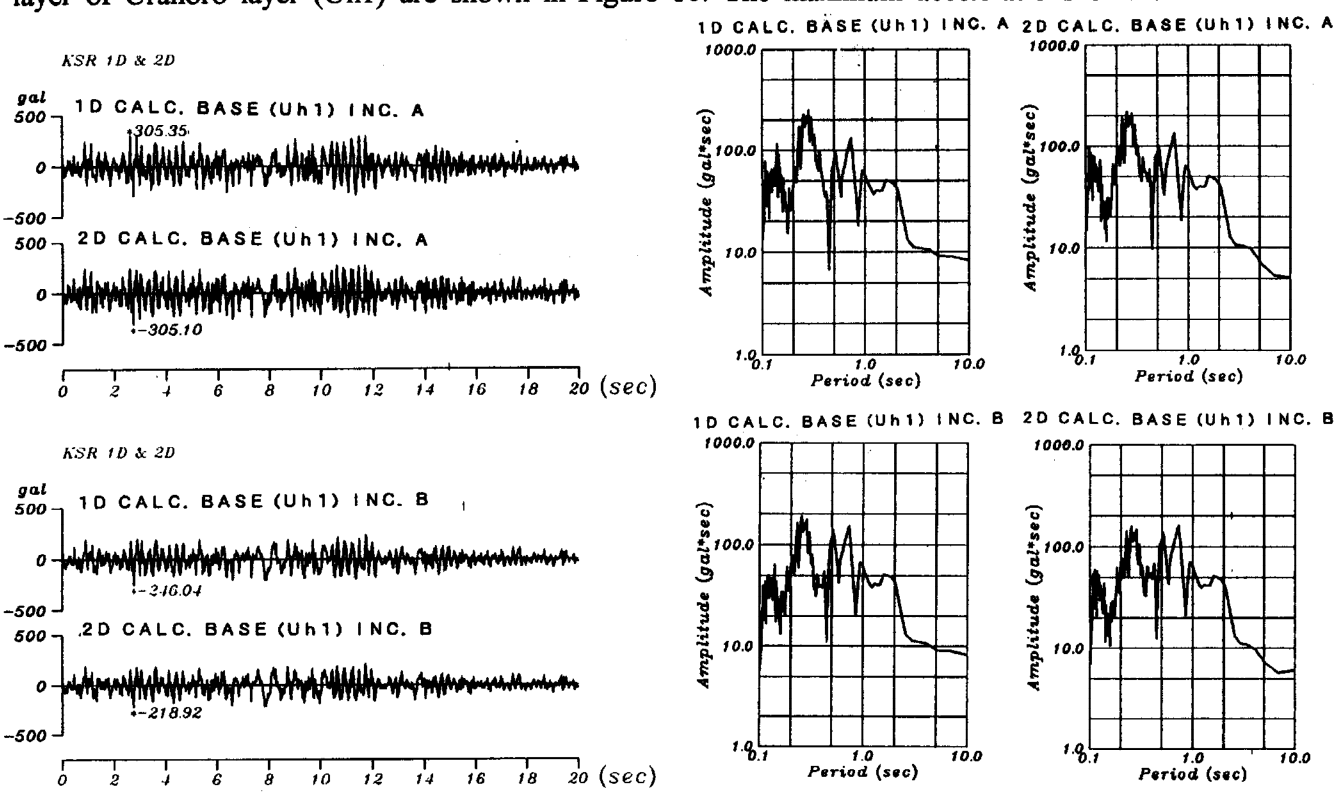


Fig.10 Comparison of the 1-D and 2-D results at the Urahoro layer (Uhl).

practically the same in spite of the error introduced by the equivalent linear calculation of the seismic response analysis. Table 2 shows the maximum acceleration values obtained from the one- and the two-dimensional analyses. The table also includes a similar comparison for the 1994 Hokkaido-Toho-Oki Earthquake (Kashima et al, 1994). It can be seen that the maximum acceleration is greatly affected by the difference in the incident waves adopted for Models A and B.

Table 2. Results of 1-D and 2-D analyses.

Calculation No.	1	2	3	4
Direction of Section	N063° E (B-B′ Section)			
Earthquake Name	1993 Kushiro-Oki Eq.		1994 Hokkaido Toho-Oki Eq.	
Max. Acceleration of Observation Wave(gal)	711.4		314.1	
2D FEM Max. Acc.(gal) (Surface,GL-0m)	833.3	619.1	372.2	354.7
2D FEM Max. Acc.(gal) (Bed Rock,GL-20m)	305.1	218.9	126.4	113.7
1D Max. Acc.(gal) (Bed Rock,GL-20m)	305.3	246.0	148.6	115.5
1D Incident Calc,Wave Max. Acc.(gal)(GL-60m)	226.1	150.1	93.5	80.4
Gl-20m Obs.Wave Max. Acc.(gal)	–		100.2	
Incident Wave Calc.Model	A (Boring)	B (FEM)	A (Boring)	B (FEM)

The distribution of the maximum acceleration along the ground surface in the N063° E direction obtained from the two-dimensional response analysis is shown in Figure 11. The maximum acceleration does not appear particularly high in the vicinity of the JMA Kushiro Observatory, but does appear on the east side of it. That is greatly affected by the ridge's edge effect. Figure 12 shows the vertical distribution of the maximum acceleration at the observation site. It is observed that the maximum acceleration has been greatly amplified by the layer of volcanic ash (Ku) of the Kussharo pumice flow.

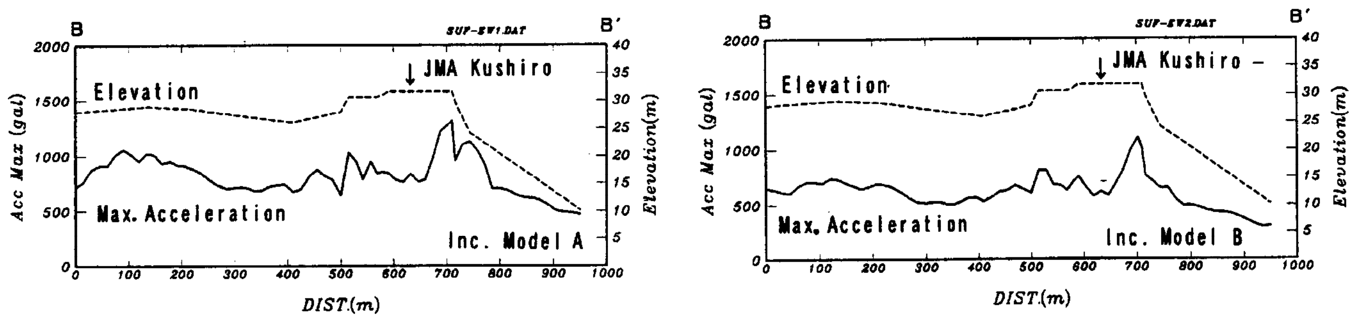


Fig.11 Maximum accelerations from the 2-D response analysis along the N063° E direction.

The predominant period from the microtremor measurement at the JMA Kushiro Observatory site is about 0.25 second as shown in Figure 9. This period is as same as fourier spectrams of observed and calculated incident waves and surface waves as shown in Figure 7, Figure 8 and Figure 10.

9. CONCLUSIONS

The following conclusions are drawn from this study:

1) At least for the JMA Kushiro Observatory area, the effect of the topography is relatively small, from the result of two-dimensional response analysis

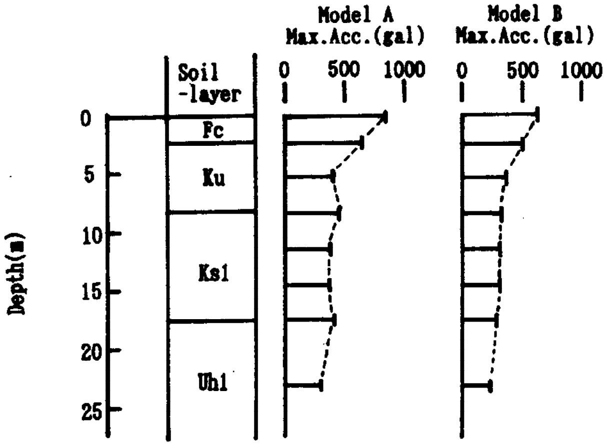


Fig.12 Vertical distribution of the maximum acceleration.

2) The amplification characteristics of the volcanic ash (Ku) of the Kussharo pumice flow, the top layer, have a much larger effect on the values of surface acceleration.

3) The two-dimensional response analysis showed that the effect of the topography is relatively large at the edge of hill.

4) The amplification characteristics of the surface ground can be seen also from the result of microtremor measurement.

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REFERENCES

Hokkaido Association of Authorized Architect Kushiro Branch (1982): *The ground of Kushiro City* (in Japanese).

Akio Yamamoto (1993): Microtremor measurement in Kushiro Development Construction Department, *Proceedings of the soft ground seismic response amplification symposium* (in Japanese), pp.61-68.

Building Research Institute of Japan (1994): Results of geological survey in JMA Kushiro branch office (in Japanese), *JSEEP NEWS*, No.136, May, pp.56-60.

Toshihide Kashima, Yoshikazu Kitagawa (1993): *Prompt report on strong-motion records from the 1993 Off Kushiro Earthquake*, Building Research Institute, Ministry of Construction.

Ken Miyakoshi, et al. (1994): Determination of geological structure in Kushiro City using microtremors and estimation of the site response associated with the geological structure (in Japanese), *Proceedings of the 90th SEGJ Spring Conference*, pp.230-234.

Toshihide Kashima, Yoshikazu Kitagawa (1994): *Prompt report on strong-motion records from the 1994 Hokkaido-toho-oki Earthquake*, Building Research Institute, Ministry of Construction.

Shukyo Segawa, Kaoru Jin, Yoshiaki Inagaki, Akio Yamamoto (1994): Microtremor measurement and response characteristics of the ground during the earthquake in Kushiro City (in Japanese), *Proceedings of the Ninth Japan Earthquake Engineering Symposium*, pp.157-162.