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Analysis of the strong motion records obtained from the 2007 Niigataken Chuetsu-oki earthquake and determination of the design basis ground motions at the Kashiwazaki Kariwa Nuclear Power Plant (Part1: Outline of the strong motion records and estimation of factors in large amplification)

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1 ABSTRACT

In the Niigataken Chuetsu-Oki Earthquake of July 16, 2007, a large ground motion was observed at the Kashiwazaki Kariwa Nuclear Power Plant, which was larger than the average ground motion of the magnitude of the Niigataken Chuetsu-Oki Earthquake. In addition, even in the Kashiwazaki Kariwa Nuclear Power Plant, there was large variation in recorded ground motion at different parts of the observation point.

In this paper, we examined the source, propagation and site effect of the Niigataken Chuetsu-Oki Earthquake, with the analysis of observed records and ground motion simulation analysis, in order to investigate the characteristics of the seismic ground motion observed at the Kashiwazaki Kariwa Nuclear Power Plant in the Niigataken Chuetsu-Oki Earthquake.

As a result, it is concluded that the short-period source spectrum in the Niigataken Chuetsu-Oki Earthquake was larger than the average event of Mj6.8, and it made the ground motion about 1.5 times higher. And we concluded that the ground motion became about 2 times larger because of the propagation effect. In addition, we concluded that the folding structure below the Kashiwazaki Kariwa Nuclear Power Plant made the ground motion about 2 times larger in southern part of the site.

2 INTRODUCTION

The Niigataken Chuetsu-Oki Earthquake occurred on July 16, 2007, with the epicenter in the Sea of Japan off the Niigata Prefecture. The magnitude of the event was Mj6.8 determined by Japan Meteorological Agency. With this earthquake, strong ground motion was observed at the Kashiwazaki Kariwa Nuclear Power Plant of the Tokyo Electric Power Company, which was larger than the average ground motion of Mj6.8 supposed from the attenuation relationship of Noda et al. (2002). In addition, in the Kashiwazaki Kariwa Nuclear Power Plant, there were large variations in recorded ground motion at different parts of the observation point, especially records in the southern part of the site were larger than these in the northern part of the site.

In this paper, we examined the source, propagation and site effect through the analysis of the observation records and ground motion simulation, in order to investigate the major factors that induced the large ground motion at the Kashiwazaki Kariwa Nuclear Power Plant in the Niigataken Chuetsu-Oki Earthquake.

3 OUTLINE OF THE SITE, THE EVENT AND THE OBSERVATION RECORDS

Fig. 1 shows the location of the Kashiwazaki Kariwa Nuclear Power Plant and the epicenter of the Niigataken Chuetsu-Oki Earthquake. The site is located along the coast of the Sea of Japan in the Niigata Prefecture, Japan, and the distance to the epicenter is about 16km from the site.

Fig. 2 shows the plan of the Kashiwazaki Kariwa Nuclear Power Plant, including the location of seismic observation points. The site covers an area of 4 square kilometers. There are seven power units in the site, Units 1-4 located in the southern part of the site, Units 5-7 in the northern part of the site. We have been monitoring the ground motion on the base mat of each reactor and turbine building. We have also installed down-hole array seismometers in the free field near Unit 1 and 5, but the observation records of the Niigataken Chuetsu-Oki Earthquake were overwritten by the records of aftershocks and lost, due to insufficient amount of the memory.

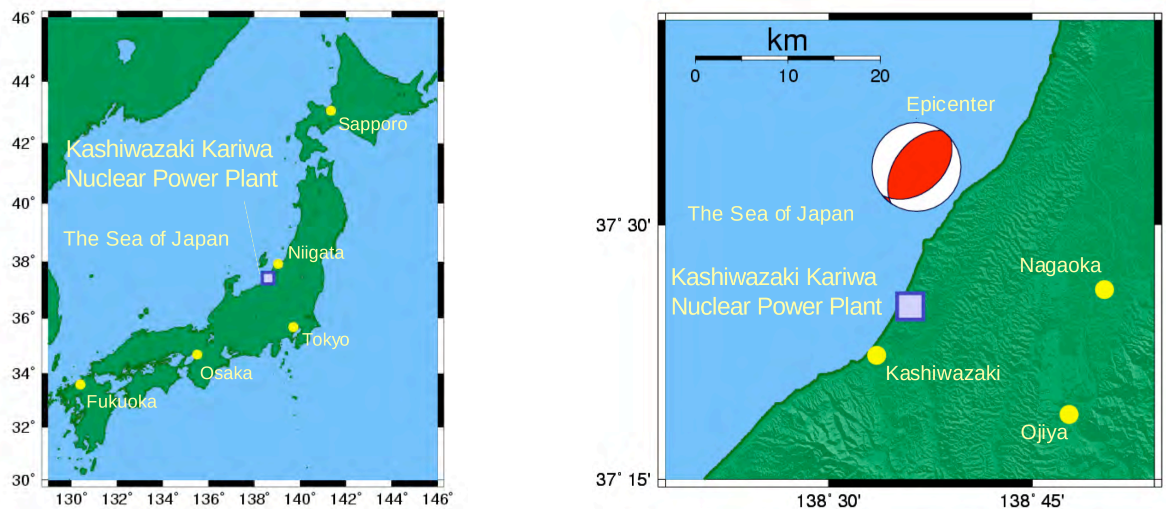


Figure 1. Location of the epicenter of the Niigataken Chuetsu-Oki Earthquake and the Kashiwazaki-Kariwa Nuclear Power Plant

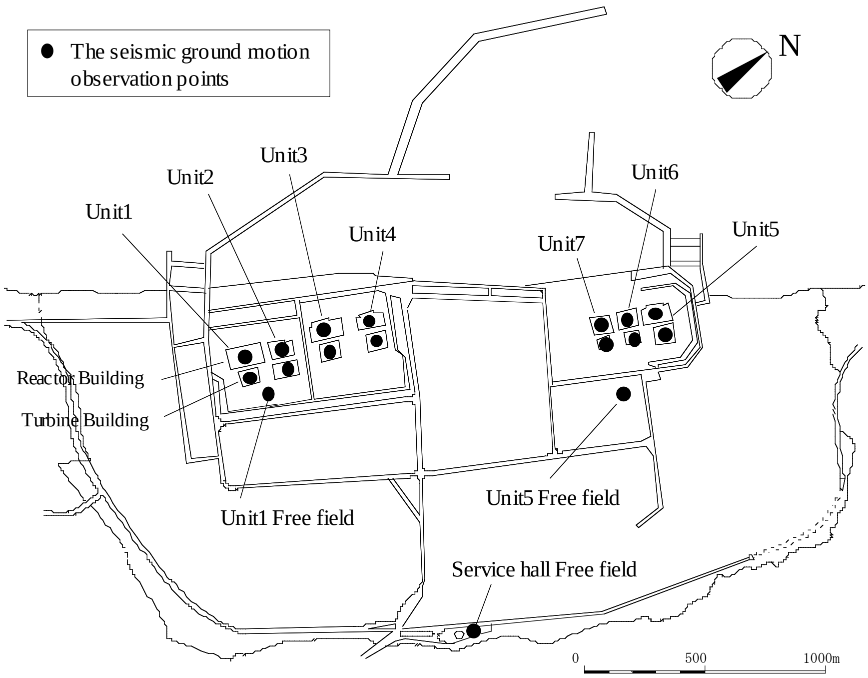
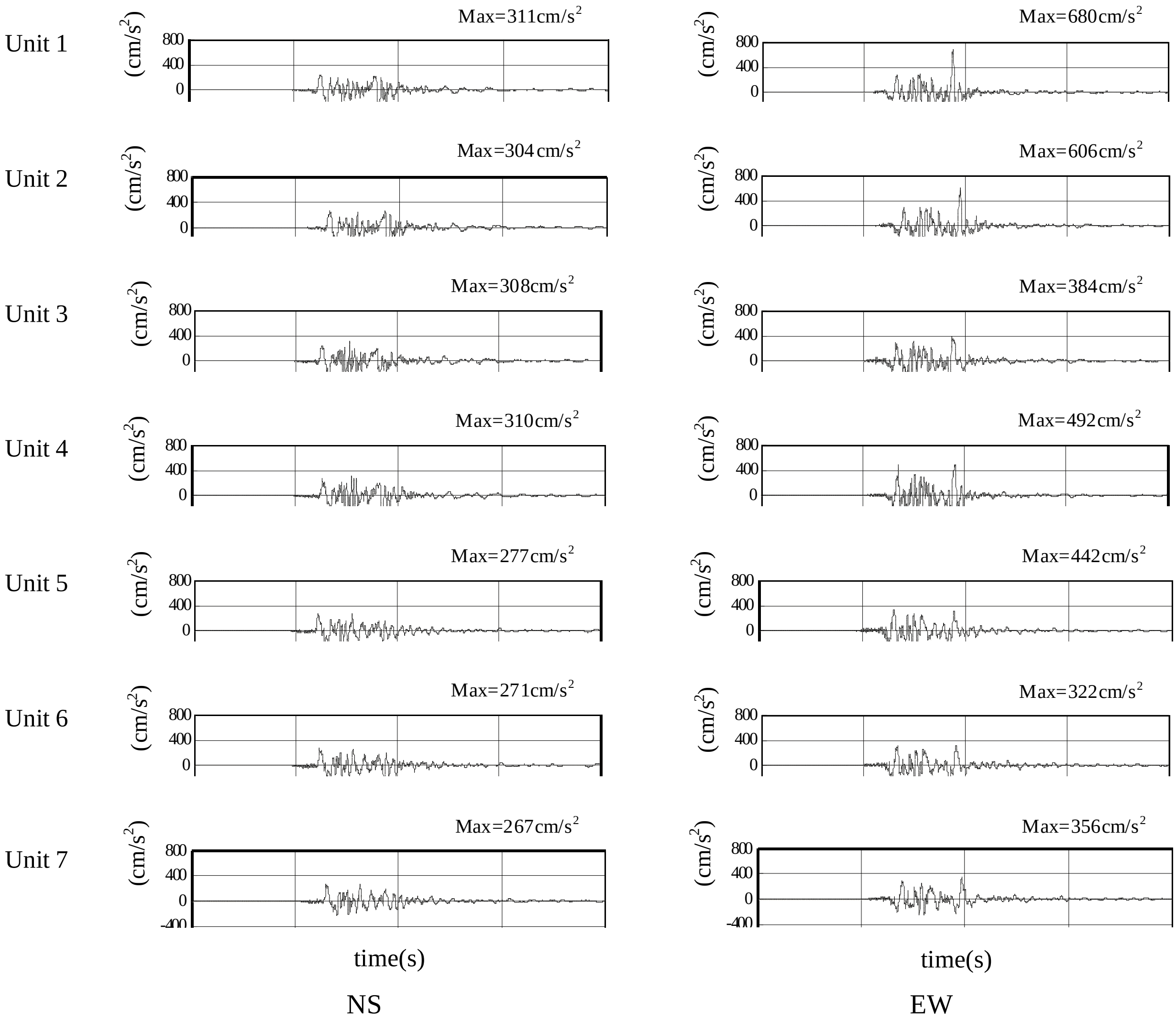
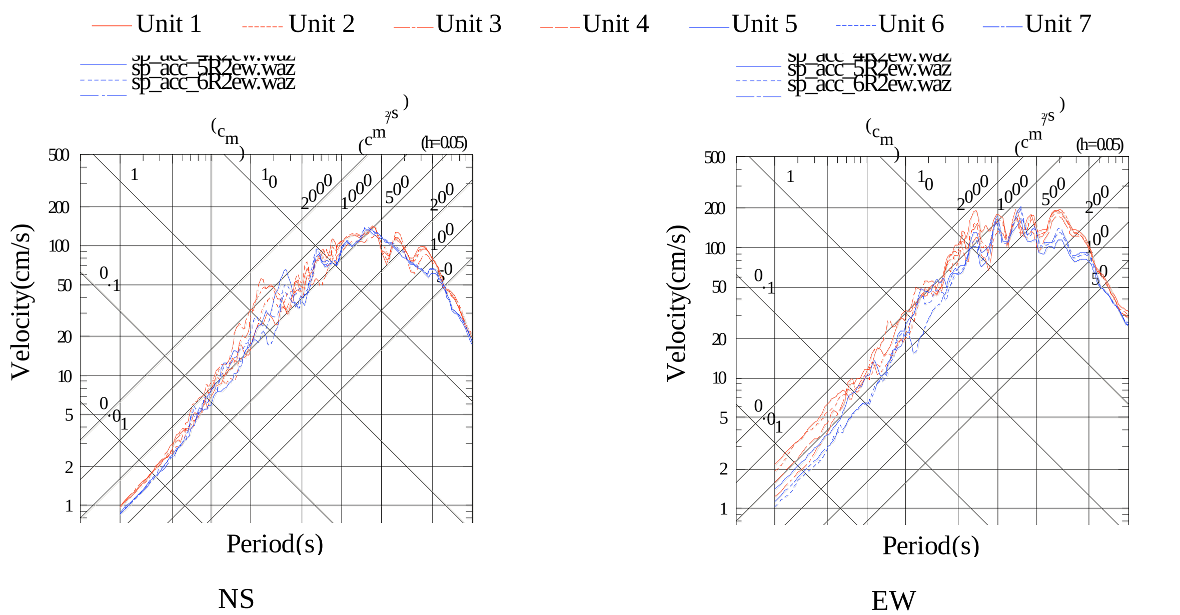


Figure 2. Plan of Kashiwazaki-Kariwa Nuclear Power Plant including the seismic ground motion observation point



(a) Acceleration waveforms



(b) Response spectra

Figure 3. Acceleration waveforms and the response spectra observed on the base mat of each reactor building of the Niigataken Chuetsu-Oki Earthquake

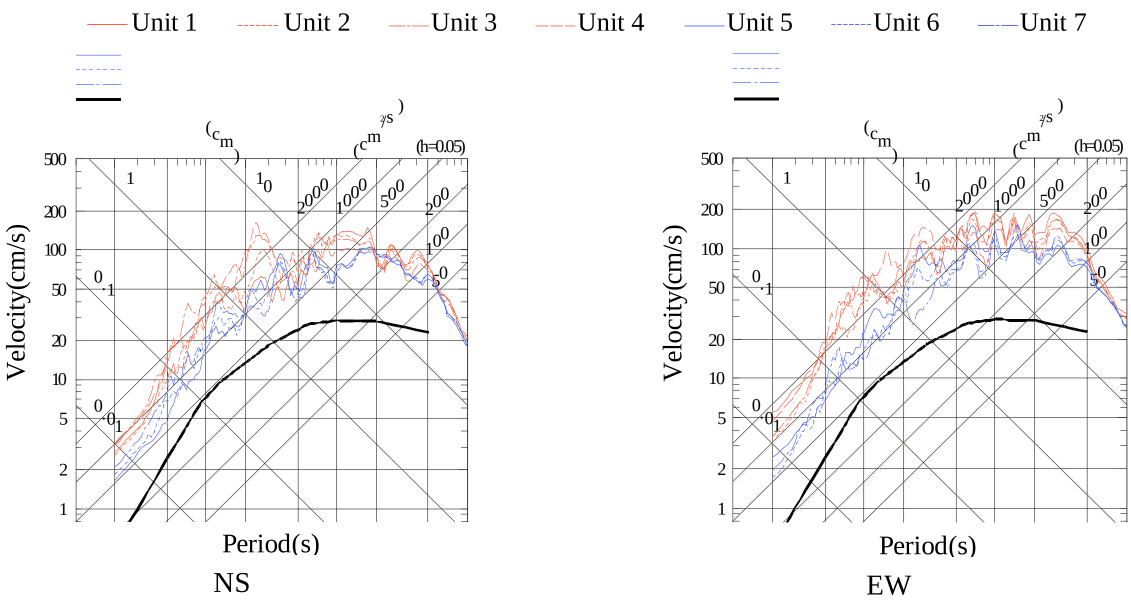


Figure 4. The response spectra on the free surface of the base stratum for each unit, estimated from the records on the base mat. Solid black line shows the standard response spectrum of Mj6.8 from the attenuation relationship of Noda et al. (2002).

Fig. 3 shows the acceleration waveforms and the response spectra observed on the base mat of each reactor building during the Niigataken Chuetsu-Oki Earthquake.

The design basis seismic ground motions of Japanese nuclear power plants are defined on the free surface of the base stratum, where the S-wave velocity is 0.7km/s or more. The depths of the free surface of the base stratum below each unit in the Kashiwazaki Kariwa Nuclear Power Plant are about 150-250m. So it is important to evaluate ground motions caused by the Niigataken Chuetsu-Oki Earthquake on the free surface of the base stratum of each unit. We estimated the ground motions on the free surface of the base stratum from ground motion records on the base mat of reactor buildings and amplitude ratios between the free surface of the base stratum and the base mat of reactor buildings, estimated from soil and structure model of reactor building of each unit. Fig. 4 shows the response spectra on the free surface of the base stratum evaluated from the response spectra on the base mat of each reactor building. The response spectra on the free surface of the base stratum are larger than those on the base mat of each reactor building, showed in Fig. 3, due to the effect of soil-structure interaction.

The standard response spectrum of Mj6.8, supposed from the attenuation relationship of Noda et al. (2002), is also showed as bold line in Fig. 4. The spectra of seismic ground motion of the Niigataken Chuetsu-Oki Earthquake observed in the site are larger than that of the attenuation relationship of Noda et al. (2002). In addition, the EW response spectra of Units 1-4 are larger than those of Units 5-7.

4 STUDY ON THE SOURSE EFFECT

In regard to the source effect, we estimated the moment density distribution on the fault through the inversion analysis using the empirical Green’s function method, with the observation records of the Kashiwazaki Kariwa Nuclear Power Plant and other regional records.

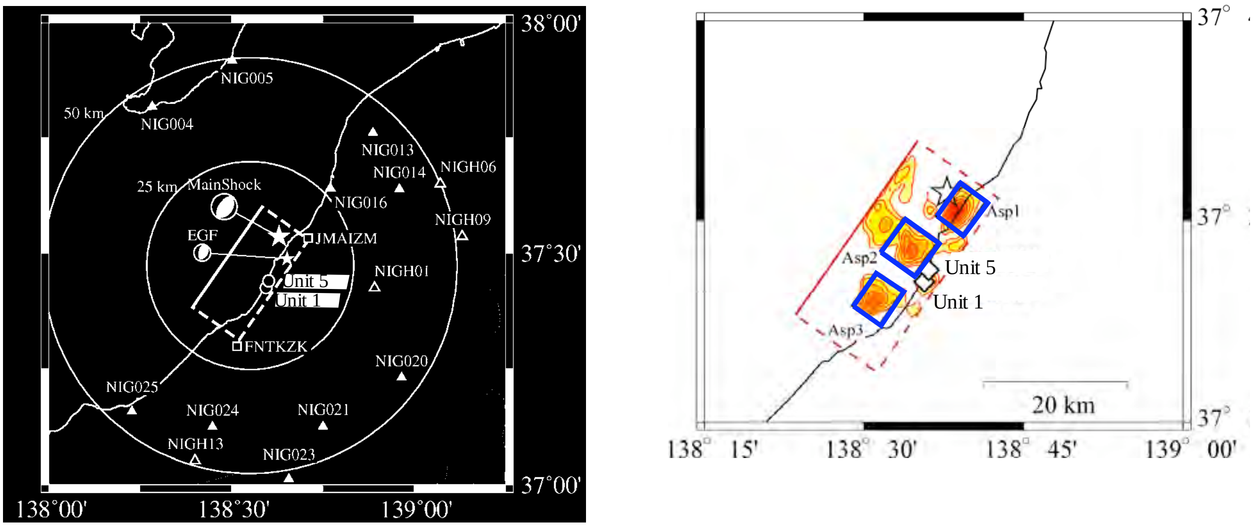
Fig. 5(a) shows the fault location we assumed as the Niigataken Chuetsu-Oki Earthquake, and the observation points we used for the inversion analysis. We referred the size of the fault from the Headquarters for Earthquakes Research Promotion. For the inversion analysis, we used the records on the base mat of Unit 1 and Unit 5 reactor building, and observation points within 50 km from the center of the assumed fault plane including the records obtained in K-NET, KiK-net and F-net by National Research Institute for Earth Science and Disaster Prevention, and the records of Japan Meteorological Agency. We used the aftershock of Mj4.4, showed the epicenter in Fig.5(a), as an empirical Green’s function. Fig. 5(b) shows the moment density on the fault estimated from the inversion analysis. We can recognize three asperities from Fig. 5(b).

We also estimated a characterized source model that describes the observation records of the site. Asperities are shown in Fig. 5(b) as three blue small rectangles. Table 1 shows the characterized source parameters we estimated. Fig. 6 shows the comparison of the waveforms of the Unit 1 and 5 on the base mat between the observation and calculation from the characterized source model. The waveforms are in the broadband frequency range from 0.1 to 10 Hz. These waveforms are in good agreements.

We evaluated the short-period source spectrum by the following,

$$A = \left(\sum_i A_i^{\,2} \right)^{1/2}, \quad A_i = 4\pi r_i \Delta\sigma_{ai} \beta^2 \qquad (1)$$

where A_i is the short-period source spectrum from each asperity, r_i is the equivalent radius, $_{ai}$ is the stress drop of each asperity, and is the S-wave velocity in the source region. Estimating from eqn.(1) with the parameters of the characterized source model shown in Table 1, the short-period source spectrum is evaluated as 1.83×10^{19} Nm/s^2. It is about 1.5 times larger than the average short-period source spectrum evaluated from the seismic moment by the National Research Institute for Earth Science and Disaster Prevention (9.3×10^{18} Nm), and the scaling rule between the seismic moment and short-period source spectrum.



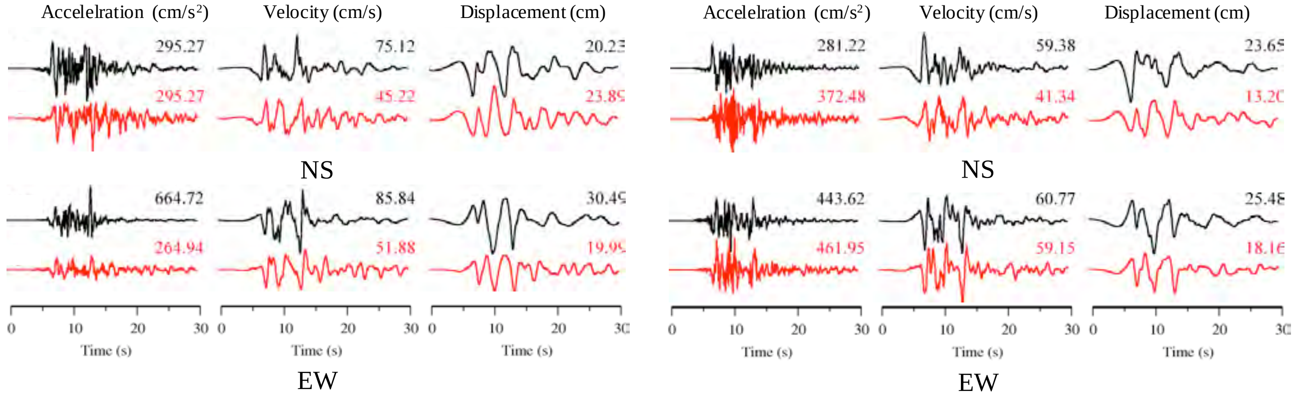
(a) Epicenters of main shock and aftershock used as an empirical Green's function, and the observation points used for the inversion analysis. Solid and open triangles show the K-NET and KiK-net stations respectively. Square shows the F-net and Japan Meteorological Agency stations.

(b) The relationship of the moment density derived from the inversion analysis and the characterized source model. Red and yellow images represent the moment density. Three blue rectangles show the asperities of the characterized source model. Star shows the epicenter of main shock.

Figure 5. Location of the fault of the Niigataken Chuetsu-Oki Earthquake and the Kashiwazaki-Kariwa Nuclear Power Plant. The rectangle with solid and broken line shows the fault plane.

Table 1. Characterized source parameters of the Niigataken Chuetsu-Oki Earthquake.

	Whole fault	**Asp.1**	**Asp.2**	**Asp.3**
Seismic moment (10^{18}Nm)	9.30	1.83	2.11	1.43
Rupture Area (Km^2)	540	31.4	39.2	31.4
Averaged slip (m)	0.55	1.87	1.72	1.46
Stress Drop (MPa)	1.8	25.47	20.84	19.91
Effective Stress (MPa)	—	25.47	20.84	19.91



(a) Unit 1 (b) Unit 5

Figure 6. Comparisons of the waveforms of the Unit 1 and 5 on the base mat between the observation (black line) and calculation from the characterized source model (red line) in the frequency range from 0.1 to 10 Hz. Numbers above the waveforms are the peak values.

5 STUDY ON THE PROPAGATION EFFECT

In order to evaluate the propagation effect of the Niigataken Chuetsu-Oki Earthquake, we analyzed the characteristics of the ground motion records obtained in the Kashiwazaki Kariwa Nuclear Power Plant in the past. Table 2 lists the events used for the analysis, and Fig. 7 shows the epicenter of the events of Table 2. For the analysis, we used the ground motion records obtained in the borehole array of Unit 1 and Unit 5, as free field records, shown in Fig. 2. The presences of ground motion records of each point are shown in the right side of Table 2. From these records, we calculated the ground motions on the free surface of the base stratum by 1-D wave propagation analysis with the soil model of each observation point.

Fig. 8 shows the spectral ratios between the response spectra of ground motions on the free surface of the base stratum and the average response spectra supposed from the attenuation relationship of Noda et al. (2002). Spectral ratios of the events occurred in the offshore area are shown as blue lines, and those occurred in the inland area are shown as red lines. The bold line of each color is the average of the spectral ratios. The average of the spectral ratio that the epicenter is in the offshore area is higher than that the epicentre is in the inland area.

From the analysis, we concluded that the ground motion of the offshore event becomes larger than that of the inland event, and we supposed that the ground motion of the Niigataken Chuetsu-Oki Earthquake, which had the characteristic of the offshore event, was more 2 times as large as the average ground motion.

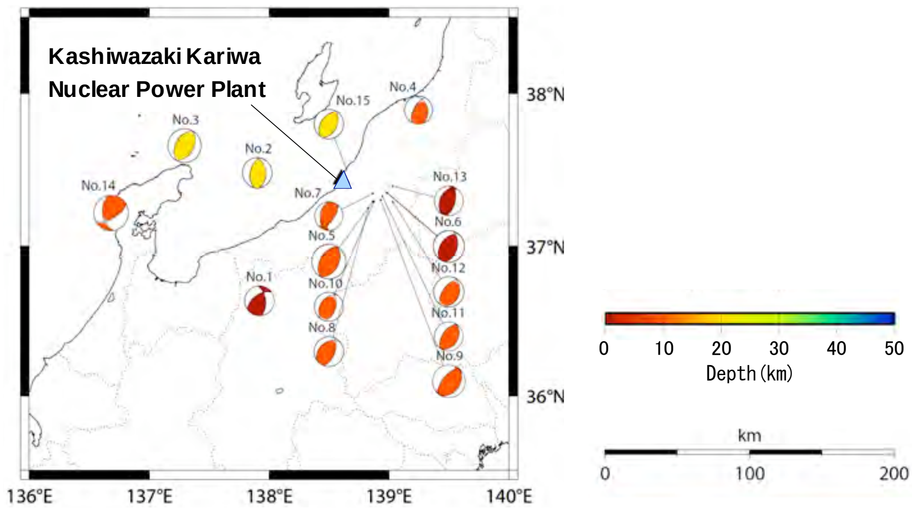
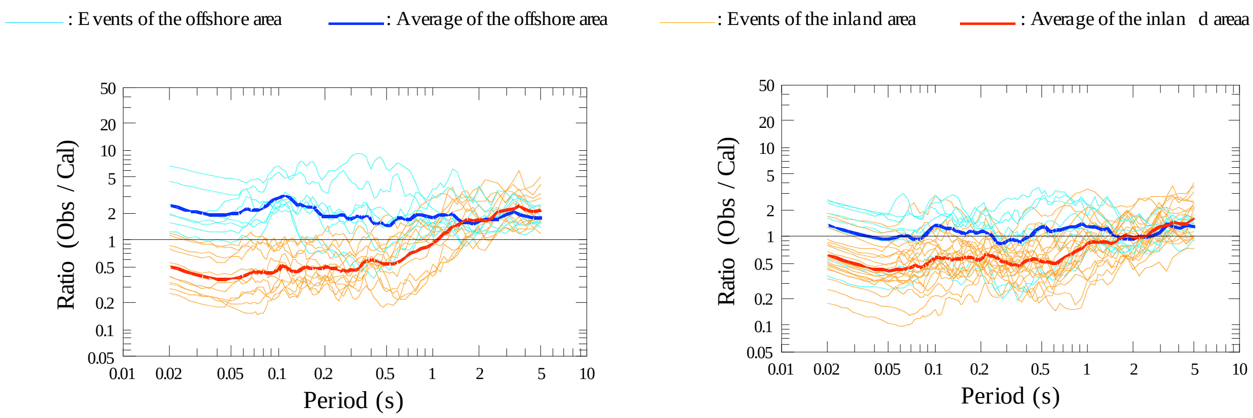


Figure 7. The distribution of the epicenter of the analyzed events. The number of each event corresponds to the number in Table 2.

Table 2. List of the analyzed event. Parameters are referred from the Japan Meteorological Agency. Circle shows the existence of observation records in the free field near Unit 1 and 5 in Fig. 2.

No.	Origin Time		epicenter		Mj	Depth (km)	Existence of the observation record	
			Longitude	Latitude			Unit 1	Unit 5
1	1986. 12. 30	9:38	137° 55.30'	36° 38.40'	5.9	3.3	○	○
2	1987. 03. 24	21:49	137° 54.20'	37° 28.90'	5.9	21.6	○	○
3	1993. 02. 07	22:27	137° 17.80'	37° 39.40'	6.6	24.8	○	○
4	1995. 04. 01	12:49	139° 14.88'	37° 53.47'	5.6	16.16	○	○
5	2004. 10. 23	17:56	138° 52.00'	37° 17.60'	6.8	13.08		○
6	2004. 10. 23	18:03	138° 59.00'	37° 21.20'	6.3	9.38		○
7	2004. 10. 23	18:07	138° 51.90'	37° 20.90'	5.7	14.9		○
8	2004. 10. 23	18:11	138° 49.80'	37° 15.20'	6.0	11.52		○
9	2004. 10. 23	18:34	138° 55.80'	37° 18.40'	6.5	14.17		○
10	2004. 10. 23	19:45	138° 52.57'	37° 17.74'	5.7	12.35	○	○
11	2004. 10. 25	6:04	138° 56.81'	37° 19.80'	5.8	15.2	○	○
12	2004. 10. 27	10:40	139° 02.00'	37° 17.51'	6.1	11.6	○	○
13	2004. 11. 08	11:15	139° 01.92'	37° 23.76'	5.9	0	○	○
14	2007. 03. 25	9:41	136° 41.10'	37° 13.20'	6.9	11	○	○
15	2007. 07. 16	15:37	138° 38.60'	37° 30.20'	5.8	11	○	○



(a) Unit 1 free field

(b) Unit 5 free field

Figure 8. The spectral ratios between the response spectra of ground motions on the free surface of the base stratum and the average response spectra supposed from the attenuation relationship of Noda et al. (2002).

6 STUDY ON THE SITE EFFECT

Comparing the Fig. 8 (a) and (b), we can recognize the difference of the characteristics of spectral amplitude between Unit 1 and Unit 5. Fig. 9 shows the spectral ratio between the recorded ground motion in the free field near Unit 1 and 5, which are calculated for the events shown in Table 2 and Fig. 7. The spectral ratios for the offshore events are shown in Fig. 9(a), and Fig. 9(b) is those for inland events. The bold red line is the average of the spectral ratios. The average spectral ratio for the offshore events is about 1.5-2.0, while that for the inland events is almost 1.0.

From these spectral ratios, we can conclude that seismic ground motion that comes from the offshore area are amplified larger at Unit 1, the southern part of the site, than at Unit 5, the northern part of the site, and we assume these characteristics of spectral amplitude to be the site effect.

In order to clarify the site effect of the Kashiwazaki Kariwa Nuclear Power Plant, we also conducted the ground motion simulation with the 2-D soil model in the area below the site. For details of the 2-D simulation analysis, please refer to Part2.

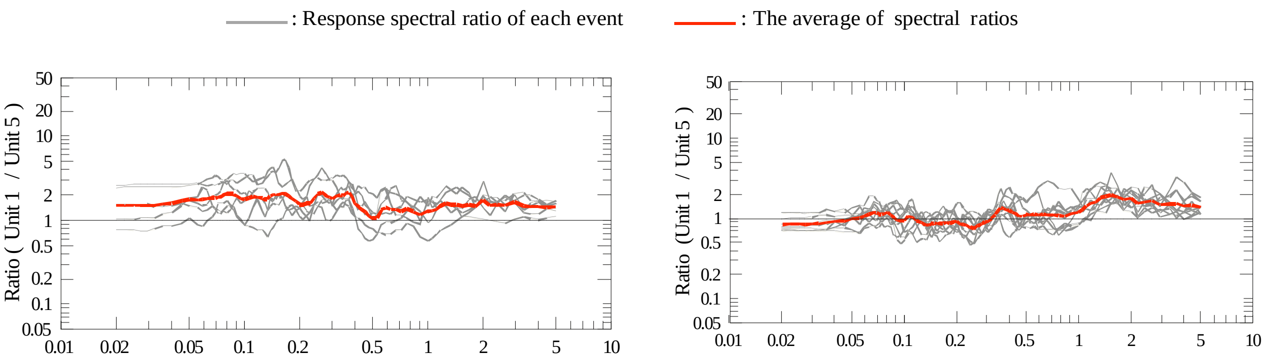


Figure 9. The response spectral ratios between the recorded ground motion of Unit 1 and Unit 5 free field.

7 CONCLUSION

From the results, we concluded that the short-period source spectra in the Niigataken Chuetsu-Oki Earthquake was higher than the average event of Mj6.8, and the ground motion became about 1.5 times higher. We also concluded that the ground motion became over 2 times larger due to the propagation effect for offshore events. In addition, the ground motion in the southern part of the site is amplified 2 times larger than that in the northern part due to the site effect.

REFERENCES

Noda, S. , K.Yashiro, K.Takahashi, M.Takemura, S.Ohno, M.Tohdo and T.Watanabe, RESPONSE SPECTRA FOR DESIGN PURPOSE OF STIFF STRUCTURES ON ROCK SITES, OECD-NEA Workshop on the Relations between Seismological DATA and Seismic Engineering, Oct.16-18, 2002, Istanbul, pp.399-408

A Report on Analysis of Seismic Observation Data Obtained at the Time of the 2007 Niigata-Chuetsu-Oki Earthquake at the Kashiwazaki-Kariwa Nuclear Power Station, and the Formulation of the Design-basis Seismic Motion, Tokyo Electric Power Company, 2008

Kazuo, D. , M.Watanabe, T.Sato, T.Ihii, SHORT-PERIOD SOURCE SPECTRA INFERRED FROM VARIABLE-SLIP RUPTURE MODELS AND MODELING OF EARTHQUAKE FAULTS FOR STRONG PREDICTION BY SEMI-EMPERICAL METHOD, J. Struct., Eng., AIJ, No.545, Jul., 2001, pp.51-62