Fault Length and Direction of Rupture Propagation for the 1993 Kushiro-Oki Earthquake as Derived from Strong Motion Duration

Yasuo Izutani

Faculty of Engineering, Shinshu University,
Nagano 380, Japan

The Kushiro-Oki earthquake occurred off Kushiro, Hokkaido, Japan, on January 15, 1993. The epicentral coordinates given by the Japan Meteorological Agency (JMA) are 42°51'N and 144°23'E. The focal depth is 107 km and the JMA magnitude is 7.8. According to Kasahara (1993), this earthquake took place in the Pacific plate descending beneath Hokkaido. The double-planed deep seismic zone appears in this region and the present earthquake is located on the lower seismic plane. A cluster of aftershocks was observed in an area of about $40 \times 40\,\mathrm{km}^2$ and the epicenter of the main shock is located near the southeast corner of the aftershock area. Kasahara (1993) named this the Kushiro-Oki cluster. Another cluster of aftershocks was observed in a small area which is located at about 50 km east of the epicenter of the main shock. This one is called the Akkeshi-Oki cluster by Kasahara (1993) and the activity is not so energetic as that of the Kushiro-Oki cluster. There is a seismic gap in space between the two clusters. The hypocenters of the Kushiro-Oki cluster formed an almost horizontal plane at a depth of about 100 km and the hypocenter of the main shock is also located on it.

The main shock is composed of the main event and the pre-event that occurred 6 s before the main event. A focal mechanism solution has been obtained for the pre-event (Kasahara, 1993). The dip direction and the dip angle of P-wave nodal plane I are 338° and 10°, and those of plane II are 158° and 80°. It may be reasonable to expect that the focal mechanism of the main event is similar to that of the pre-event as suggested by Kasahara (1993). Further, the hypocenter distribution of the Kushiro-Oki cluster seems to suggest that plane I is the fault plane of the main event, and that the rupture during the main event was propagated in a direction lying between the north and the west through a distance of about 40 km.

According to Kasahara (1993), the Akkeshi-Oki cluster is further separated into two groups. The earthquakes of one of the groups are located on the upper seismic plane and their depths range from 50 to 70 km. The seismic activity of this group did not seem to change so significantly at the time when the main shock occurred. It is possible to consider that a little high seismicity along the upper seismic plane was induced by the main shock. On the other hand, the other group is located at a depth of about 100 km and the activity began just after the main shock. Therefore, the

Received June 29, 1993; Accepted September 22, 1993

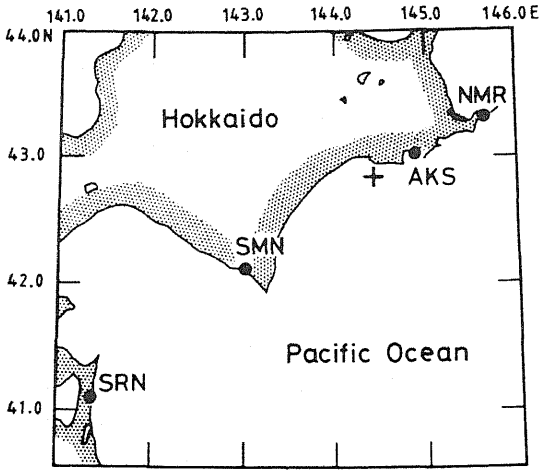

Fig. 1. Epicenter of the Kushiro-Oki earthquake (cross) and locations of observation stations (solid circles).

earthquakes belonging to the deeper group of the Akkeshi-Oki cluster can be regarded as aftershocks of the Kushiro-Oki earthquake. As mentioned previously, however, the location of the Kushiro-Oki cluster suggests that the rupture of the main shock was propagated in the direction opposite to the Akkeshi-Oki cluster. It seems very difficult to explain the reason for the existence of the seismic gap between the Akkeshi-Oki cluster and the hypocenter of the main shock.

The aim of the present study is to estimate the fault length and the direction of rupture propagation independently of the hypocenter distribution of earthquakes. Inoue *et al.* (1993) observed strong ground motions of the Kushiro-Oki earthquake at Nemuro (NMR), Akkeshi (AKS), Samani (SMN), and Shiranuka (SRN). The locations of the observation stations are shown in Fig. 1. Accelerographs are installed on hard rocks at the stations. Accelerograms are filtered by a 5 to 10 Hz band-pass filter and then cumulative power curves are calculated as shown in Fig. 2. The strong motion duration, D, is defined as the time interval between 0.05 and 0.85 of the cumulative power curve. It can be seen that D's for NMR and AKS are significantly shorter than those for SMN and SRN. A simple method for evaluating fault parameters is applied to the observed strong motion durations. The validity of the method has been confirmed through analyses of rupture processes for the 1968 Tokachi-Oki earthquake and the 1983 Japan Sea earthquake (Izutani and Hirasawa, 1987a, b).

According to equation (4) of Izutani and Hirasawa (1987a), the relationship between fault parameters of an earthquake and D observed at a station during the earthquake is expressed as

$$D=A\frac{L}{v}\left(1-\frac{v}{c}\cos\theta\right)+B \qquad (1)$$

for unilateral and unidirectional rupture propagation. Here L is the fault length, v is

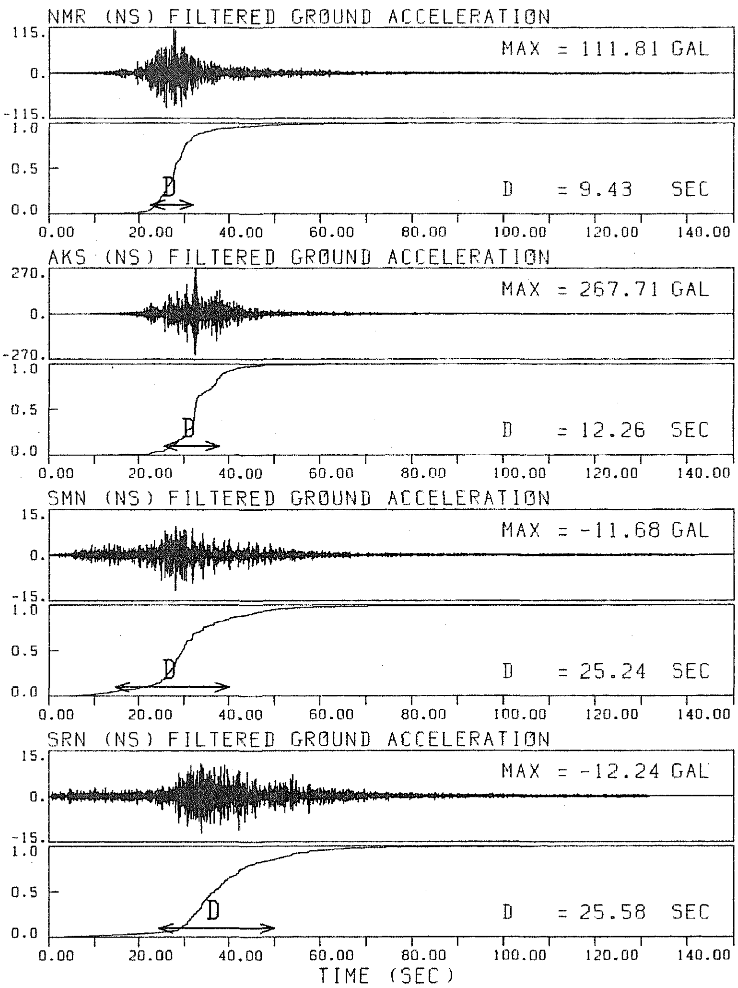

Fig. 2. Examples of 5 to 10 Hz band-pass filtered accelerograms and cumulative power curves. D denotes the strong motion duration defined as the time interval between 0.05 and 0.85 of the cumulative power curve.

the rupture velocity along the fault, θ is the angle between the propagation direction of rupture and the ray direction of S-waves to the station, and c is the S-wave velocity. The site constants A and B should empirically be obtained through a regression analysis of D as a function of L by using many strong motion records observed at the station for earthquakes with known fault length.

Unfortunately, the values of A and B are not known for the stations used in the present study. The value for A is assumed to be 0.75 by taking into account the average value of A's for stations dealt with by Izutani and Hirasawa (1987a, b). Izutani and Hirasawa (1984) estimated values of B for two sediment sites and one hard rock site.

They found that the value of B for the rock site is much smaller than those for the sediment sites and is nearly equal to 0 s. On the basis of their result, B is assumed to be 0 s for stations used in the present study. Equation (1) becomes

$$D=0.75\frac{L}{v}\left(1-\frac{v}{c}\cos\theta\right). \tag{2}$$

In the following analysis, the rupture is assumed to be propagated in a certain direction on one of the two P-wave nodal planes. The direction of the rupture propagation, ϕ, is defined as the angle from the strike of a nodal plane measured clockwise on the plane; the strike azimuths are 248° for plane I and 68° for plane II. As defined before, θ in Eq. (2) is the angle between the propagation direction of rupture and the ray direction of S-waves to a station and can be expressed as a function of ϕ for each station. In this study the ray path is approximated by a straight line connecting the hypocenter with a station. Considering the limited number of stations available, ϕ is taken as a parameter and varied from 0° to 360° at 10° interval. The best fit values of L/v and v/c for each values of ϕ are thus obtained by minimizing

$$\varepsilon=\sum_{k=1}^{4}(D_k^{(o)}-D_k^{(c)})^2\,, \tag{3}$$

where the subscript, k, stands for stations, $D^{(o)}$ denotes the average value of D's of the

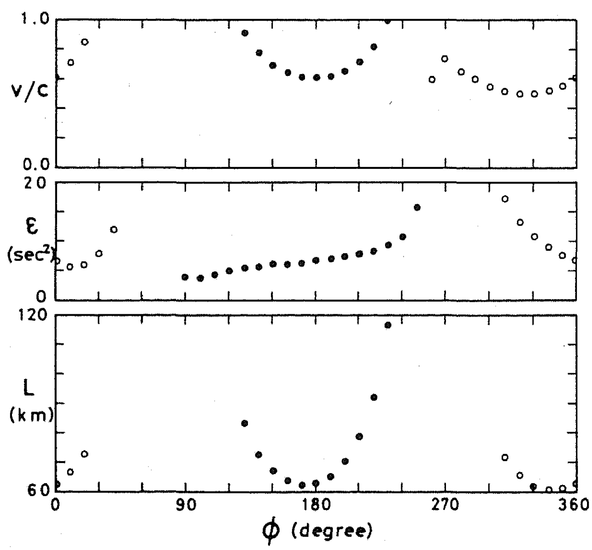

Fig. 3. The best fit values of v/c obtained for various values of ϕ, the direction of rupture propagation. Here, v is the rupture velocity, c is the S-wave velocity, and ϕ is measured clockwise from the strike of each of the P-wave nodal planes. The solid circles denote the result for plane I and the open circles that for plane II. ε is the sum of squares of the residuals and L is the fault length.

two horizontal components of observed accelerograms and $D^{(c)}$ denotes the calculated value by Eq. (2).

Figure 3 shows the best fit values of v/c for various ϕ and the sum of squares of the residuals, ε. The solid and open circles denote the results for plane I and for plane II, respectively. It is found from the figure that the two conditions of $0<v/c\leq 1.0$ and $\varepsilon\leq 20\,\mathrm{s}^2$ are both satisfied only when $130°\leq\phi\leq 230°$ for plane I and $-50°\leq\phi\leq 20°$ for plane II. The rupture propagation in these directions is acceptable as far as the observations of strong motion duration are concerned.

Figure 4 shows the focal mechanism solution of the pre-event presented by Kasahara (1993). The solid curves indicate the intersections of each of the P-wave nodal planes with the focal sphere. The thicker parts of the solid curves show the acceptable directions of rupture propagation of the main event obtained above. The rupture of the main event is revealed to have been propagated in a direction lying between the north northeast and east southeast. This result differs from the rupture propagation direction suggested by the aftershock distribution.

If the S-wave velocity is known for the focal region, the fault length, L, can be estimated. Since the subduction structure in the Kuril trench deduced by Iwasaki *et al.* (1989) suggests that the P-wave velocity in the focal region of the main shock is about 8 km/s, c should be about 4.5 km/s. The values of L are also shown in Fig. 3 only for the acceptable directions of rupture propagation. The fault length is estimated to be from 60 to 80 km.

The horizontal direction of N68°E ($\phi=180°$ for plane I and $\phi=0°$ for plane II) is along the intersection of the two P-wave nodal planes. This direction falls in the middle

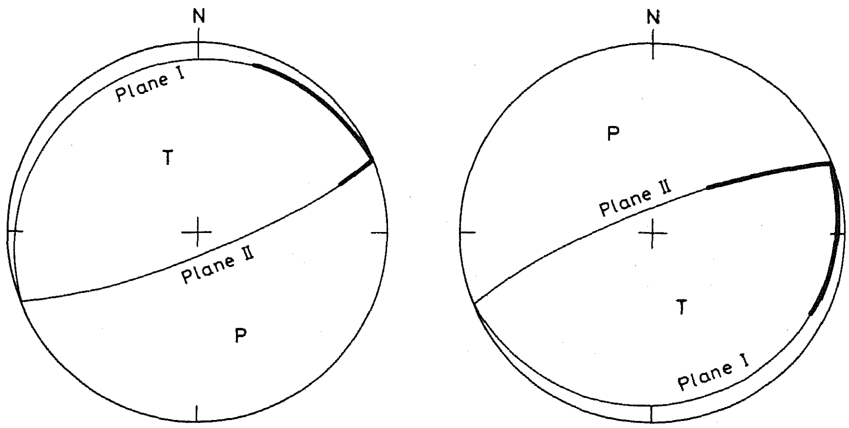

Fig. 4. Focal mechanism solution of the pre-event by Kasahara (1993): The lower half (left figure) and the upper half (right figure) of the focal sphere. **P** and **T** indicate the locations of the pressure axis and the tension axis, respectively. The solid curves indicate the intersections of each of the P-wave nodal planes with the focal sphere. The thicker parts of the solid curves show the acceptable directions of rupture propagation of the main event estimated in the present study.

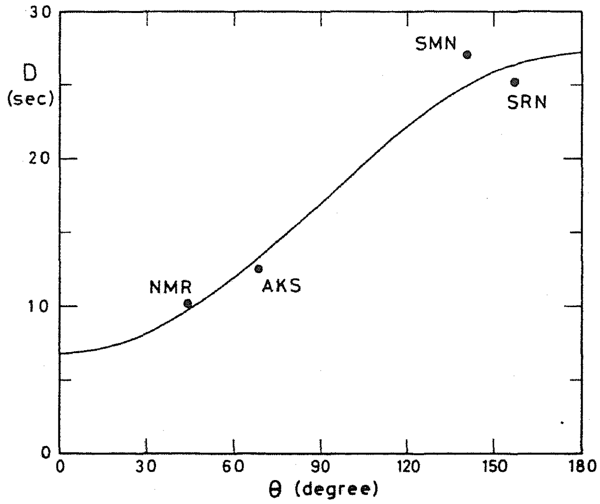

Fig. 5. Observed strong motion duration, D, plotted against θ, where θ is the angle between the propagation direction of rupture and the ray direction of S-waves to a station. The rupture is assumed here to be horizontally propagated in the direction of N68°E. The relation between D and θ is well approximated by $D=17\ (1-0.6\cos\theta)$, which is drawn with a solid line.

of the acceptable range of ϕ. As an example, by assuming the rupture propagation in this direction, the observed strong motion duration, D, is plotted against θ in Fig. 5. The relation between D and θ is well approximated by

$$D=17(1-0.6\cos\theta)\,, \tag{4}$$

which is drawn with a solid line in Fig. 5. Comparing Eqs. (2) and (4), the following results are obtained: Rupture direction = N68°E, $v=2.7$ km/s, and $L=60$ km.

The length and the direction of the arrow in Fig. 6 indicate the fault length and the direction of rupture propagation estimated here. The shadowed areas denote the epicentral areas of the Kushiro-Oki cluster (western area) and the Akkeshi-Oki one (eastern area) for the period from January 15 to February 10, 1993 (Kasahara, 1993). The arrow passes through the gap between the two areas. The present result suggests that the earthquakes belonging to the deeper group of the Akkeshi-Oki cluster occurred closely to the ruptured area of the main shock. Therefore, they are also aftershocks of the main shock in a narrow sense. The existence of the seismic gap between the two clusters is understood as that the rupture of the main shock broke down almost perfectly the material in this area and very few aftershocks occurred there.

In Fig. 6, the starting point of the arrow is placed at the epicenter of the main shock. This location, however, is the epicentral location of the pre-event but may not be that of the main event (Kasahara, 1993). According to the U. S. Geological Survey (USGS), the epicentral coordinates for the pre-event and the main event are (42.982°N, 144.165°E) and (43.300°N, 143.691°E), respectively. The difference in the epicentral locations by USGS suggests that the starting point of the arrow in Fig. 6 should be

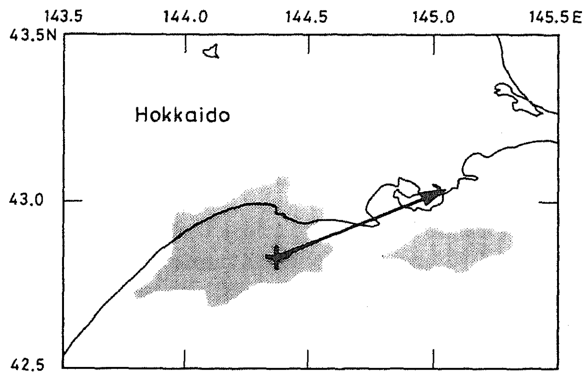

Fig. 6. Direction of rupture propagation and the fault length of the Kushiro-Oki earthquake obtained in the present study. The cross denotes the epicenter of the earthquake. The direction and the length of the arrow indicate the direction of rupture propagation and the fault length. The shadowed areas denote the Kushiro-Oki cluster (western area) and the Akkeshi-Oki one (eastern area) shown by Kasahara (1993).

moved a little westward. The rupture may have been propagated eastward through the area of the Kushiro-Oki cluster and the seismic gap.

The strong motion data analyzed in the present study were supplied by the Central Research Institute of Electric Power Industry. The author thanks the members concerned of the research institute. Comments from Prof. T. Hirasawa, Dr. M. Takemura and the reviewers were very helpful.

REFERENCES

Inoue, D., Y. Sawada, T. Iwadate, Y. Masuko, S. Sasaki, H. Yazima, K. Satou, S. Abe, Y. Siba, K. Ueda, S. Kawasaki, H. Totigi, Y. Shumuta, H. Ishida, and T. Sakakiyama,Characteristics and damage investigation of the 1993 Kushiro-Oki earthquake, *Rep. Cent. Res. Inst. Electr. Power Ind.*, **U92047**, 1–179, 1993.

Iwasaki, T., H. Shiobara, A. Nishizawa, T. Kanazawa, K. Suyehiro, N. Hirata, T. Urabe, and H. Shimamura, A detailed subduction structure in the Kuril trench deduced from ocean bottom seismographic refraction studies, *Tectonophysics*, **165**, 315–336, 1989.

Izutani, Y. and T. Hirasawa, Duration of strong ground motion and fault parameters, *Prog. Abstr. Seismol. Soc. Jpn.*, No. 1, 197, 1984.

Izutani, Y. and T. Hirasawa, Use of strong motion duration for rapid evaluation of fault parameters, *J. Phys. Earth*, **35**, 171–190, 1987a.

Izutani, Y. and T. Hirasawa, Rapid estimation of fault parameters for near-field tsunami warning, *Nat. Disas. Sci.*, **9**, 99–113, 1987b.

Kasahara, M., A preliminary report of the Kushiro-Oki earthquake of January 15, 1993, *News Lett. Seismol. Soc. Jpn.*, **4** (6), 9–15, 1993.