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SOURCE CHARACTERIZATION OF INLAND EARTHQUAKES IN JAPAN USING SOURCE INVERSION RESULTS

Ken MIYAKOSHI[1], Takao KAGAWA[2], Haruko SEKIGUCHI[3], Tomotaka IWATA[4] And Kojiro IRIKURA[5]

SUMMARY

Source characterization is needed to predict strong ground motions during large earthquakes. For characterizing the complex source process, Somerville et al. (1999) compiled slip models of fifteen earthquakes mainly in western North America for various magnitude range and obtained an empirical relation between asperity parameters and seismic moment. We estimate slip models of recent three M6 class earthquakes in Japan using records of dense strong ground motion network of K-NET. One is dip-slip earthquake and the other two are strike-slip earthquakes. We obtain asperity parameters of three earthquakes following the same criterion by Somerville et al. (1999). Rupture areas and combined areas of asperities of three earthquakes agree with those deduced from the empirical relation by Somerville et al. (1999). The average slips of three earthquakes are about a half of those deduced from the empirical relation. The large slip appears at the depth from 4 to 10 km for strike-slip earthquakes and appears shallower depth at about 4km for dip-slip earthquakes in this study.

INTRODUCTION

It is recognized that strong ground motions in the near-source area are controlled by heterogeneous source processes. Therefore source characterization is one of key issues for accomplish precise strong ground motion prediction. Several studies have already started to compile heterogeneous source models of past earthquakes and try to extract their characteristics such as spatial variations of slip, slip velocity, or rupture velocity.

Somerville et al. (1993) compiled slip models of earthquakes occurred both in western North America and in Japan. For characterizing the slip model, they estimated asperity parameters such as rupture area, average slip and combined area of asperities. Asperity is defined as the area where the amount of slip is larger than the average slip. A combined area of asperities is defined as a total area of asperities over the fault. Comparing asperity parameters of earthquakes in Japan with those in western North America, they found that the average slips of earthquakes in Japan were about 2 times larger than those in western North America and the fault areas of earthquakes in Japan were about a half of those in western North America for the same seismic moment event. They pointed out that static stress drops of earthquakes in Japan were about 3 times larger than those in western North America. However, there are some source models with poor spatio-temporal resolution in Japanese earthquakes because there are not enough ground motion data.

Recently, Somerville et al. (1999) introduced a standard criterion to extract asperity parameters from fine source models. They compiled asperity parameters of fifteen earthquakes mainly occurred in western North America with seismic moment and obtained an empirical relation. To obtain the empirical relation between asperity parameters of earthquakes in Japan and seismic moment, it is necessary to estimate and compile slip models with high spatio-temporal resolution as those of them. Here, we start to estimate the slip models of earthquakes with

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[1] *Geo-Research Institute, 4-3-2, Itachibori, Nishi-ku, Osaka, Japan*
[2] *Geo-Research Institute, 4-3-2, Itachibori, Nishi-ku, Osaka, Japan*
[3] *Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji , Japan*
[4] *Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji , Japan*
[5] *Disaster Prevention Research Institute, Kyoto University, Gokasho, Uji , Japan*

Figure 1. Map of epicenters for three earthquakes in Japan.

Table 1. Parameters of assumed fault plane models with hypocenter depth.

Earthquake	Date	M_{JMA}	Mech.	Strike(°)	Dip(°)	Depth(km)
Kagoshima(3/26)	1997.3.26	6.3	SS	280	79	7.6
Yamaguchi	1997.6.25	6.1	SS	52	88	8.3
Iwate	1998.9.3	6.1	RV	233	41	7.5

Abbreviations: “SS”, strike-slip; “RV”, dip-slip

a same source inversion procedure using dense strong ground motion network records by K-NET, which is established since 1996. We obtain asperity parameters of earthquakes in Japan following the same criterion and discuss the relation between asperity parameters and seismic moment with the empirical relation obtained by Somerville et al. (1999).

ANALYSIS

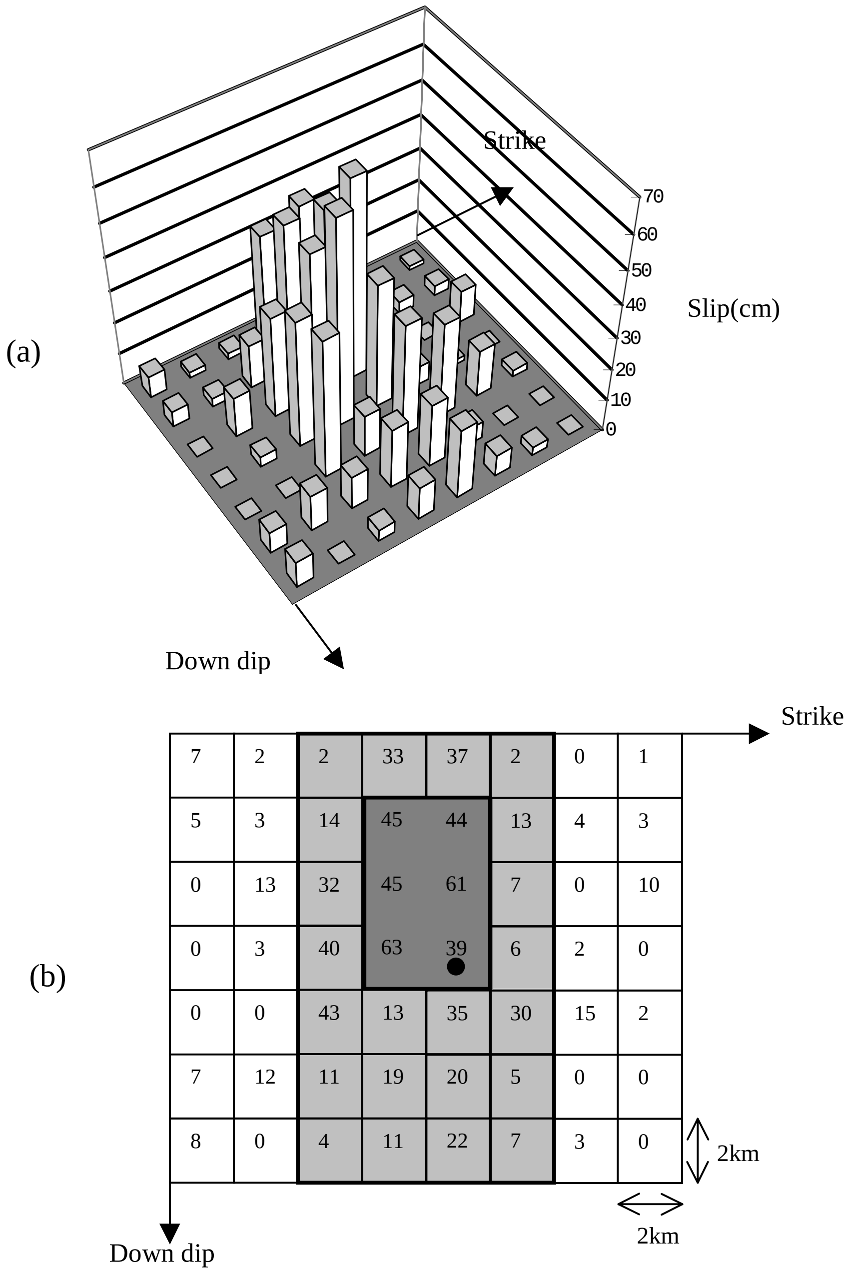
Data

We estimate the source models of M6 class earthquakes using strong ground motion records by K-NET. Figure 1 shows a map of epicenters for three earthquakes analyzed here. Our inversion analysis is performed using strong motion seismograms at ten stations at distances less than 50 km from each epicenter. Original K-NET data are three components of acceleration seismograms sampled by a 0.01-sec interval. Seismograms are processed into displacement by double integration and band-pass filtered from 0.1 to 0.5 Hz. We use a 20-sec period data from P-wave onset with a 0.1-sec re-sampling interval.

Waveform Inversion

The multi-time window linear waveform inversion procedure [Hartzell and Heaton, 1983] is used to obtain amount of moment release and slip vectors on each subfault in each time window. Parameters of assumed fault plane models are listed in Table 1. We divide the fault planes into $2*2km^2$ subfaults and put a point source at the center of each subfault. Four time windows at each 0.5 sec apart are used for the slip time history. The slip displacement in each time window is represented by a smoothed ramp function with a 1.0 sec rise time in the pure strike and the pure dipping directions. We set the rupture velocity at 3.0 km/s for the first time window.

The discrete wavenumber method [Bouchon, 1981] is used to calculate Green's functions. We assume the same velocity structure at all stations for individual earthquake. The Green's functions are also band-pass filtered from 0.1 to 0.5 Hz. As the velocity structure is not well tuned, we shift the synthetics to match the S-wave onset of observation and synthetics.



7	2	2	33	37	2	0	1
5	3	14	45	44	13	4	3
0	13	32	45	61	7	0	10
0	3	40	63	39 ●	6	2	0
0	0	43	13	35	30	15	2
7	12	11	19	20	5	0	0
8	0	4	11	22	7	3	0

Figure 2. An example of slip model for the 1997 Yamaguchi earthquake. (a) Final slip distribution on the assumed fault. (b) Identified rupture area and asperity area following the criterion by Somerville et al. (1999). The rupture area (light) and the asperity area (dark) are shaded. Number in each box denotes the final slip value of each subfault in cm. Closed circle denotes the hypocenter.

Rupture Area and Asperity Area

In order to estimate an actual rupture area and an asperity area, we use a standard criterion for trimming the edges of the slip models [Somerville et al., 1999]. The outline of the criterion is that an edge row or column of the slip model is removed if the average slip per fault element in the entire row or column is less than 0.3 times the average slip of the whole fault. An asperity, which is a region of large slip on the fault, is also defined to enclose fault elements whose slip is 1.5 or more times larger than the average slip over the fault and is

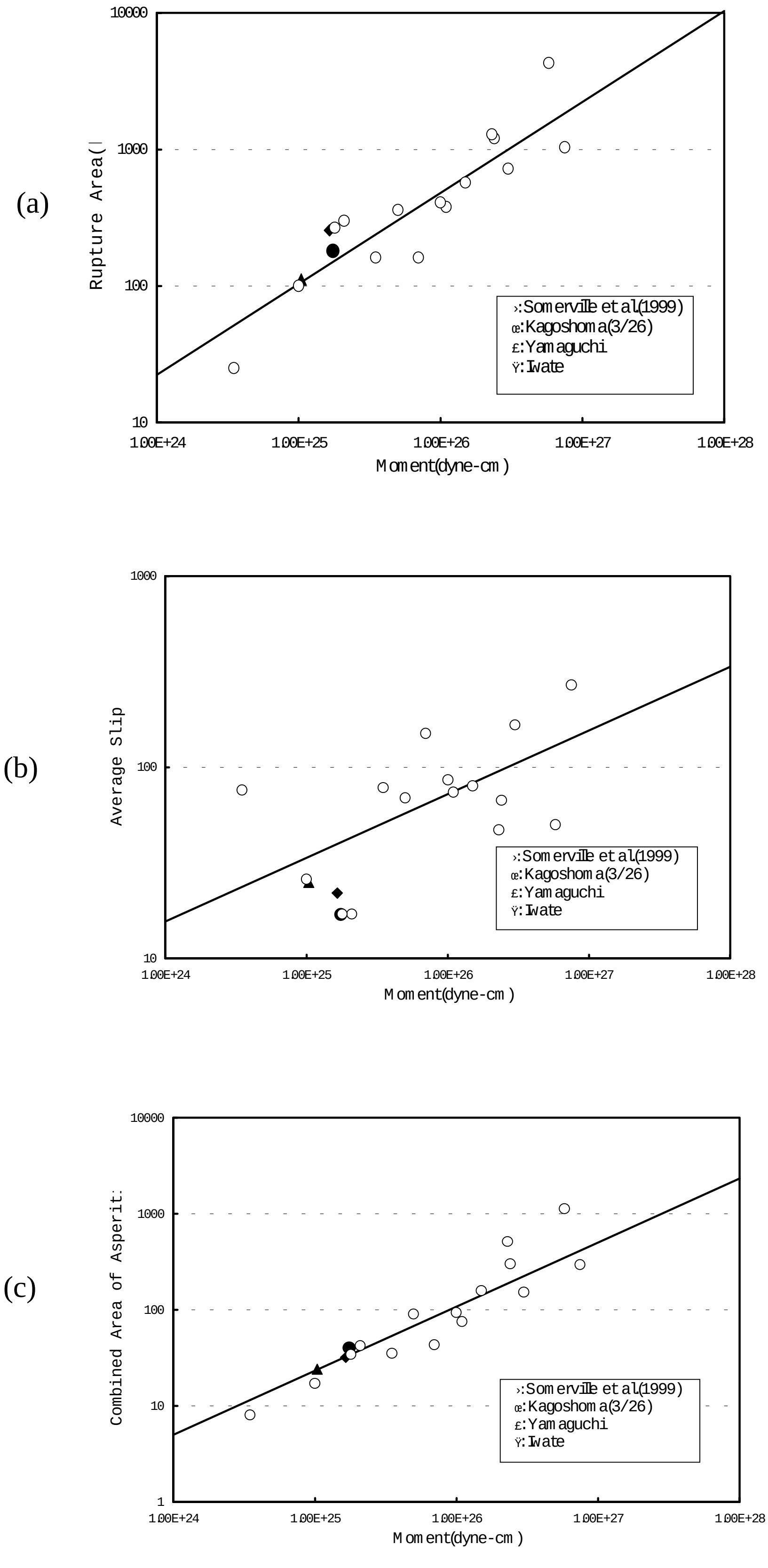


Figure 3. (a) Relation between rupture area (A) and seismic moment (M_o). Open circles represent events compiled by Somerville et al. (1999) and closed circle, triangle and lozenge denote the 1997 Kagoshima, the 1997 Yamaguchi and the 1998 Iwate earthquakes, respectively. Solid line is the empirical relation by Somerville

et al. (1999). (b) Relation between average slip (D) and seismic moment (M_o). (c) Relation between combined area of asperities (A_a) and seismic moment (M_o).

Table 2. Asperity parameters.

Earthquake	Mo	Area (A)	Length	Width	Av. Slip (D)	Max. Slip	Asperity area (A_a)		Av. Asp. Slip	
	dyne-cm	km^2	km	km	cm	cm	km^2	Norm./Area	cm	Norm./Av.Slip
Kagoshima(3/26)	1.75E+25	180	18	10	17	101	40	0.22	47	2.76
Yamaguchi	1.04E+25	112	8	14	25	63	24	0.21	50	1.98
Iwate	1.65E+25	256	16	16	22	175	32	0.13	60	2.72

Abbreviations: “Area”, rupture area trimmed by the standard criterion; “Av. Slip” , an average slip over rupture area; “Max. slip” , the maximum slip in asperity area; “Asperity area” , combined area of asperities; “Norm./Area” , the ratio of combined area of asperities to the rupture area; “Av. Asp. Slip”, an average slip over asperity area; “Norm./Av. Slip”, the ratio of an average slip over asperity area to an average slip over rupture area.

subdivided if any row or column has an average slip less than 1.5 times the average slip. The asperity is then trimmed until all of the edges have an average slip equal to or larger than 1.25 times the slip averaged over the entire rupture area.

The obtained slip model and the identification of asperities for the 1997 Yamaguchi earthquake are shown in Figure 2 as an example. The fault area is assumed to be 16 km in the strike direction and 14 km in the dip direction based on the aftershock distribution. The fault plane is divided into fifty-six subfaults of 2*2 km^2. Figure 2 (a) shows the final slip distribution on the fault. Following the criterion by Somerville et al. (1999), rupture area is trimmed into 8 km in the strike direction and 14 km in the dip direction. Asperity area is trimmed into 4 km in the strike direction and 6 km in the dip direction. In Figure 2 (b), the rupture area and the asperity area are shown as light and dark shaded rectangles, respectively. The asperity area appears in the shallower part of the rupture area and extends above the hypocenter. The rupture area and the asperity area are long in depth direction. On the contrary, the rupture areas and the asperity areas compiled in Somerville et al. (1999) are squares or long in strike direction.

DISCUSSION

First, we compare asperity parameters of the three events obtained in this study with those compiled by Somerville et al. (1999). Table 2 summarize asperity parameters of the three events. Normalized asperity area, the ratio of combined area of asperities to the rupture area, is 0.13 for the 1998 Iwate earthquake, which is about a half of those of the other two earthquakes. Figure 3 (a) shows the relation between rupture area (A) and seismic moment (M_o). Open circles represent events compiled by Somerville et al. (1999) and closed circle, triangle and lozenge denote the 1997 Kagoshima, the 1997 Yamaguchi and the 1998 Iwate earthquakes, respectively. Solid line is the empirical relation by Somerville et al. (1999):

$$A=2.23*10^{-15}*M_o^{2/3}$$

The relation between rupture area and seismic moment obtained in this study agree with the empirical relation. Figure 3 (b) shows the relation between average slip (D) and seismic moment (M_o). Solid line is the empirical relation:

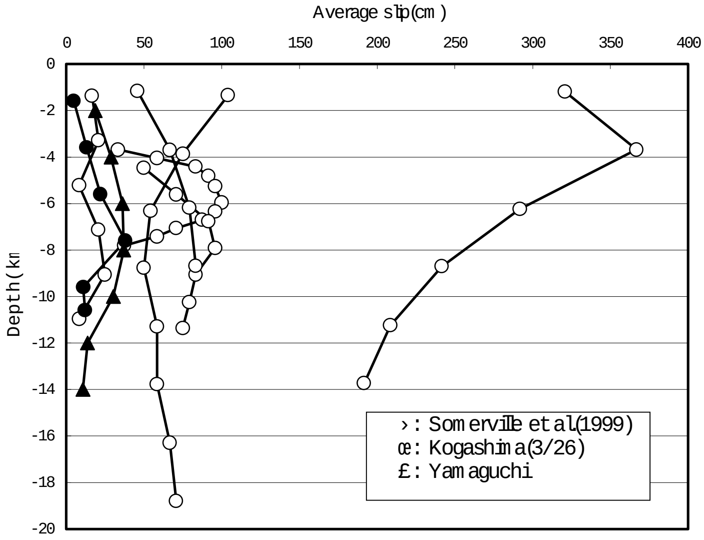
$$D=1.56*10^{-7}*M_o^{1/3}$$

The average slips of three events are about a half of those deduced from the empirical relation. Figure 3 (c) shows the relation between combined area of asperities (A_a) and seismic moment (M_o). Solid line is the empirical relation:

$$A_a=5.00*10^{-16}*M_o^{2/3}$$

The relation between combined area of asperities and seismic moment obtained in this study agree with the empirical relation.

Secondly, we discuss the variation of slip with depth for strike-slip and dip-slip earthquakes. Figure 4 shows the distribution of slip with depth for strike-slip (a) and dip-slip (b) events. The (average) slip is an average per km of fault length along strike. Closed circles and triangles in Figure 4 (a) denote the 1997 Kagoshima and the 1997 Yamaguchi earthquakes, respectively. Slip variations with depth of the 1997 Kagoshima and the 1997



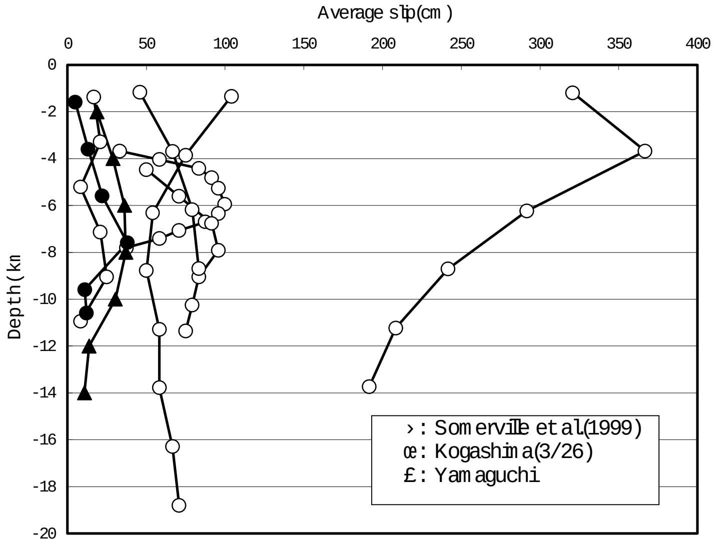


Figure 4. (a) The distribution of slip with depth for strike-slip earthquakes. Open circles represent events compiled by Somerville et al. (1999). Closed circles and triangles denote the 1997 Kagoshima and the 1997 Yamaguchi earthquakes, respectively. (b) The distribution of slip with depth for dip-slip earthquakes. Lozenges denotes the 1998 Iwate earthquake.

Yamaguchi earthquakes are similar as shown in Figure 4 (a). The large slip appears in the depth range form 4 to 10 km; around hypocenter and the shallower portion of it. Solid lozenges in Figure 4 (b) denote the 1998 Iwate earthquake. The large slip of this earthquake appears shallower depth at about 4 km above the hypocenter. For comparison, we also show the final slip distribution with depth compiled by Somerville et al. (1999) represented

(a)

by open circles in Figure 4. The distribution of slip with depth compiled by Somerville et al. (1999) was characterized by a very large degree of variability.

CONCLUSION

We estimate the slip models of three M6 class earthquakes in Japan with a same source inversion procedure using strong ground motion records from K-NET. We obtain asperity parameters such as rupture area, average slip, and combined area of asperities of three events following the same manner by Somerville et al. (1999). Rupture areas and combined areas of asperities of three earthquakes in Japan agree with those deduced from the empirical relation by Somerville et al. (1999) The average slips of three earthquakes in Japan are about a half of those deduced from the empirical relation. We discuss the variation of slip with depth for strike-slip and dip-slip earthquakes. The large slip appears at the depth from 4 to 10 km for strike-slip events and appears shallower depth at about 4 km for dip-slip event in this study.

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REFERENCES

Bouchon, M. (1981), “A simple method to calculate Green’s function for elastic layered media”, *Bull. Seism. Soc. Am.*, **71**, 959-971.

Hartzell, S. H. and Heaton T. H. (1983), “Inversion of strong ground motion and teleseismic waveform data for the fault rupture history of the 1979 Imperial Valley, California, earthquake”, *Bull. Seism. Soc. Am.*, **73**, 1553-1583.

Somerville, P. G., Irikura K., Iwasaki Y., Sawada S., Tai M. and Fushimi M. (1993), “A study on slip distribution on faults”, *Proc., of the 22th JSCE Earthquake Engineering Symposium-1993*, 291-294 (in Japanese).

Somerville, P. G., Irikura K., Graves R., Sawada S., Wald D., Abrahamson N., Iwasaki Y., Kagawa T., Smith N. and Kowada A. (1999), “Characterizing crustal earthquake slip models for the prediction of strong ground motion”, *Seism. Res. Lett.*, **70**, 59-80.