SCALING LAWS OF FAULT PARAMETERS OF INTRA-SLAB EARTHQUAKES AND STRONG GROUND MOTION SIMULATION

D. JU[1], K. DAN[1], S. DORJPALAM[1], H. TORITA[1]

[1] Ohsaki Research Institute, Inc., Japan

E-mail contact of main author: judianshu@ohsaki.co.jp

Abstract. A procedure for evaluating fault parameters of asperity models for ground motion prediction from intra-slab earthquakes was published by the Headquarters for Earthquake Research Promotion (HQERP), Japan, in June 2016. This official procedure was validated for intra-slab earthquakes in Japan. The scaling laws of fault parameters for intra-slab earthquakes that are adopted in this official procedure were established based on the fault parameters of intra-slab earthquakes in Japan. This study aims at investigating the applicability of the official procedure to ground motion prediction of intra-slab earthquakes outside Japan.

For that, at first, we collected the fault parameters of intra-slab earthquakes in and outside Japan, and examined the locality of the parameters. The relationships between the seismic moment and short-period level, and between the seismic moment and asperity area of the intra-slab earthquakes outside Japan are found to be consistent with the scaling laws in the official procedure of Japan. Next, we evaluated fault parameters for the 1986 Vrancea, Romania, earthquake (M_W 7.1) according to the procedure, and carried out strong ground motion simulation using the empirical Green's function method. The results showed that the peak ground accelerations and pseudo velocity response spectra of the synthesized motions agreed well with those of the observed records. Therefore, we concluded that the official procedure of Japan can be applied to the Romanian intra-slab earthquake.

Key Words: Intra-slab earthquake; Asperity model; Fault parameter; Ground motion prediction

1. Introduction

The Headquarters for Earthquake Research Promotion (*e.g.* 2005, [1]), Japan, published procedures for evaluating fault parameters of asperity models for prediction of strong ground motions from crustal and subduction plate-boundary earthquakes. In June, 2016, the procedure for intra-slab earthquakes was added to the existing procedures [2].

The scaling laws of fault parameters for intra-slab earthquakes which were used in this official procedure were established based on Japan earthquake data only. Also, the official procedure has been validated for intra-slab earthquakes in Japan only.

Therefore, this study aims at investigating the applicability of the official procedure to ground motion prediction of intra-slab earthquakes outside Japan. For that, at first, we collected the fault parameters of intra-slab earthquakes in and outside Japan, and examined the locality of the parameters. Next, we evaluated fault parameters for the 1986 Vrancea, Romania, earthquake (M_W 7.1) according to the procedure, and carried out strong ground motion simulation using the empirical Green's function method and compared them with the strong motion recordings of the 1986 Vrancea earthquake.

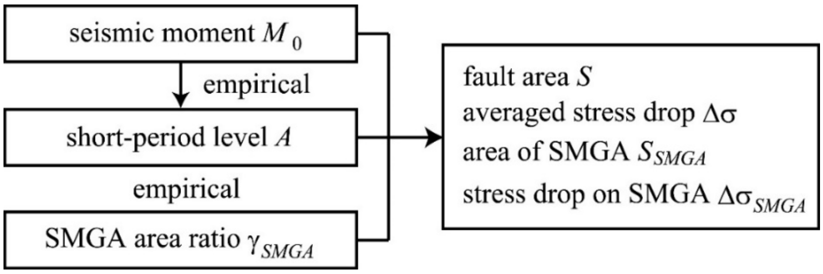


FIG. 1. Official procedure of evaluating fault parameters of intra-slab earthquakes for strong motion prediction by the Headquarters for Earthquake Research Promotion (2016, [2])

2. Overview of the procedure for evaluating fault parameters for predicting strong ground motions

The procedure to set up the asperity model in predicting strong ground motions for intra-slab earthquakes published by HQERP (2016, [2]) is illustrated in a flowchart in Figure 1. The asperity model for intra-slab earthquakes is described by six main parameters which include source fault area S, averaged stress drop $\Delta\sigma$, area of strong motions generation area (SMGA hereafter) S_{SMGA}, stress drop on SMGA $\Delta\sigma_{SMGA}$, seismic moment M_0, and short-period level A.

Given the size of the target earthquake, which can also be expressed by the seismic moment M_0, the short-period level A and the ratio of the SMGA area to the area of the entire fault γ_{SMGA} can be calculated using equations (1) to (3):

$$A_{sasatani}[\mathbf{N}\cdot \mathrm{m/s}^2] = 9.84\times 10^{10}\times (M_0\times 10^7[\mathbf{N}\cdot \mathrm{m}])^{1/3}, \quad (1)$$

$$S_{asasatani}[\mathrm{km}^2] = 1.25\times 10^{-16}\times (M_0\times 10^7[\mathbf{N}\cdot \mathrm{m}])^{2/3}, \quad (2)$$

$$\gamma_{SMGA} = S_{SMGA}/S = (16A^2_{sasatani}S^2_{asasatani})/(49\pi^4\beta^4 M_0{}^2). \quad (3)$$

Here, equation (1) is an empirical relation between seismic moment and short-period level by Sasatani *et al*. (2006, [3]). Equation (2) is an empirical relation between seismic moment and asperity area by Sasatani *et al*. (2006, [3]). Finally, γ_{SMGA} is derived by equation (3) from equation (1) and equation (2).

Once the seismic moment, the short-period level, and the SMGA area ratio are known, the area of the entire fault S, the average stress drop $\Delta\sigma$, the stress drop on SMGA $\Delta\sigma_{SMGA}$, and the SMGA area S_{SMGA} can be calculated using the following equations (4) to (6):

$$\Delta\sigma = (7/16)M_0/(S/\pi)^{1.5}, \quad (4)$$

$$\Delta\sigma_{SMGA} = (S/S_{SMGA})\Delta\sigma, \quad (5)$$

$$A = 4\pi\beta^2(S_{SMGA}/\pi)^{1/2}\Delta\sigma_{SMGA}. \quad (6)$$

Here, equation (4) is a relation between fault area S, seismic moment M_0, and average stress drop $\Delta\sigma$, and it is derived from the circular crack equation by Eshelby (1957, [4]). Equation (5) is a general formula for asperity models by Madariaga (1979, [5]). Although equation (6) is an empirical formula by Brune (1970, [6]) for the circular crack model, Boatwright (1988, [7]), using dynamic rupture simulations, demonstrated that the formula can be applied to asperity models.

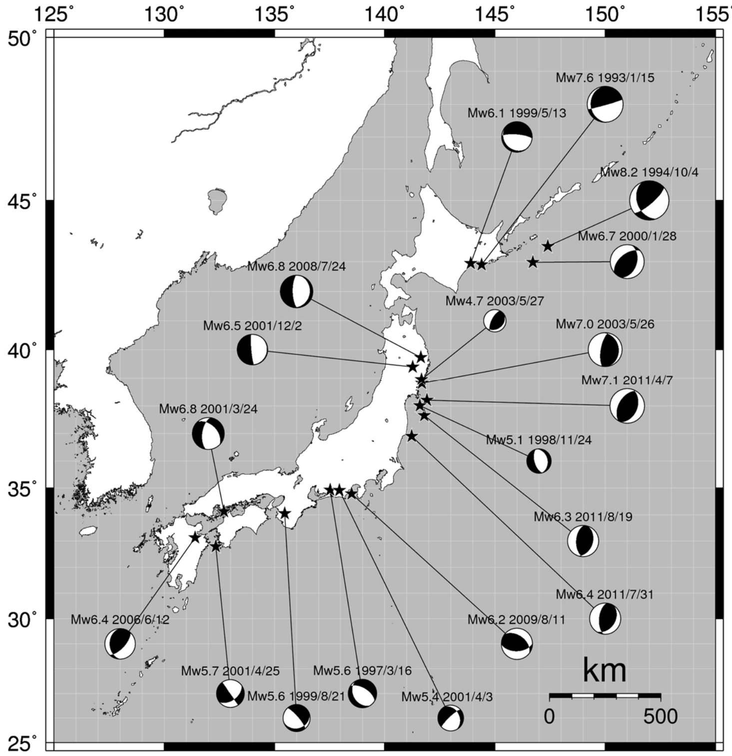


FIG. 2. Locations of the epicenters and the focal mechanisms of the collected intra-slab earthquakes in Japan examined in this study.

The short-period level A for the target earthquake can be calculated from the empirical relation between seismic moment and short-period level expressed by equation (1), or can be referred to the value of the short-period level estimated for past intra-slab earthquakes in the region of interest.

3. Scaling Laws of Fault Parameters of Intra-Slab Earthquakes

3.1.Collection of fault parameters for intra-slab earthquakes in Japan

We collected the following fault parameters for intra-slab earthquakes in Japan to examine the short-period levels and asperity areas: location of the hypocenter, moment magnitude, seismic moment, short-period level, stress drop on the asperities, asperity area, and shear-wave velocity.

Figure 2 shows the locations of the epicenters and the focal mechanisms of the collected intra-slab earthquakes in Japan. The largest one is the 1994 Hokkaido Toho-oki earthquake of M_W 8.2, the second one is the 1993 Kushiro-oki earthquake of M_W 7.6. Both of them occurred in the Pacific plate. There are also intra-slab earthquakes that occurred in Philippine Sea plate, such as 2001 Geiyo earthquake of M_W 6.8. The collected fault parameters are listed in Appendix 1.

3.2.Scaling laws of the fault parameters for intra-slab earthquakes in Japan

Figure 3 shows the relationship between the seismic moment M_0 and the short-period level A of the collected intra-slab earthquakes in Japan. The open circles are the earthquakes in

Pacific plate, and the black circles are the earthquakes in Philippine Sea plate. The red line is

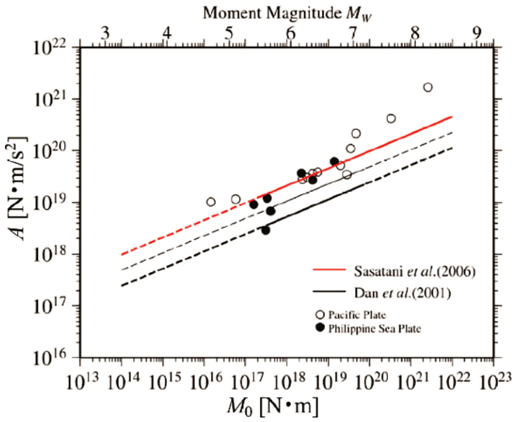


FIG. 3. Relationship between the seismic moment M_0 and the short-period level A of the collected intra-slab earthquakes in Japan.

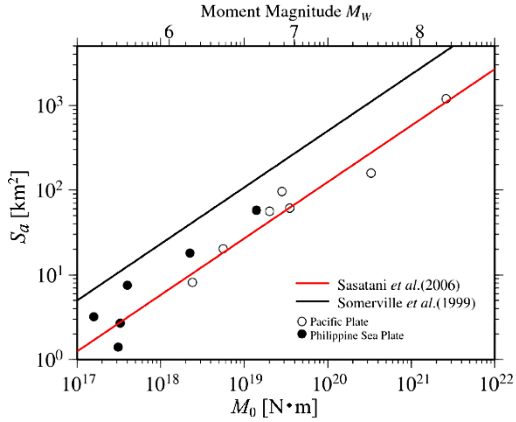


FIG 4. Relationship between the seismic moment M_0 and the asperity area S_a of the collected intra-slab earthquakes in Japan.

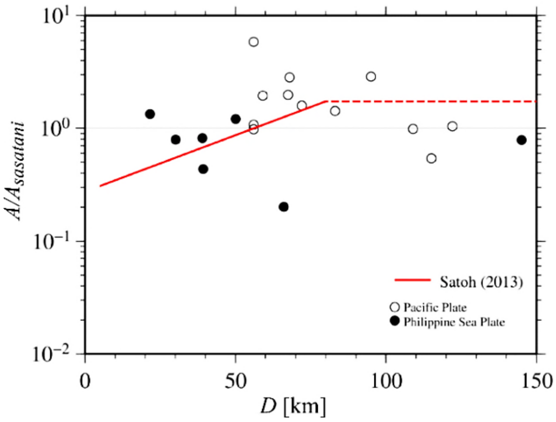


FIG. 5. Relationship between the focal depth D and the ratio of the short-period level $A/A_{sasatani}$.

the empirical relationship between the seismic moment M_0 and the short-period level A proposed by Sasatani *et al*. (2006, [3]) for intra-slab earthquakes in Japan, which is given by equation (1).

This relationship is used in the official procedure as a scaling law for the instar-slab earthquakes in the Pacific plate.

The thin black line is a half of the red line, which is used in the official procedure as the scaling law for the Philippine Sea plate.

For reference, the thick black line is the empirical relationship between the seismic moment M_0 and the short-period level A proposed by Dan *et al*. (2001, [8]) for crustal earthquakes:

$$A_{dan}[\mathrm{N\cdot m/s^2}] = 2.46\times 10^{10}\times (M_0[\mathrm{N\cdot m}]\times 10^7)^{1/3} \tag{7}$$

This relationship is one fourth of the red line. The open circles seem to be consistent with the red line by Sasatani *et al*. (2006, [3]), which is used in the official procedure as a scaling law for the Pacific plate. The black circles are smaller than the red line around M_W 5.5, and seem to be consistent with the thin black line, which is used in the official procedure as the scaling law for the Philippine Sea plate, but the earthquakes of M_W lager than 6.0 seem to be consistent with the red line.

Figure 4 shows the relationship between the seismic moment M_0 and the asperity area S_a of the collected intra-slab earthquakes in Japan. The red line is the empirical relationship between the seismic moment M_0 and the area of asperities S_a proposed by Sasatani *et al.* (2006, [3]) for intra-slab earthquakes in Japan, which is given by equation (2).

For reference, the black line is the empirical relationship between the seismic moment M_0 and the area of asperities S_a proposed by Somerville *et al*. (1999, [9]) for crustal earthquakes:

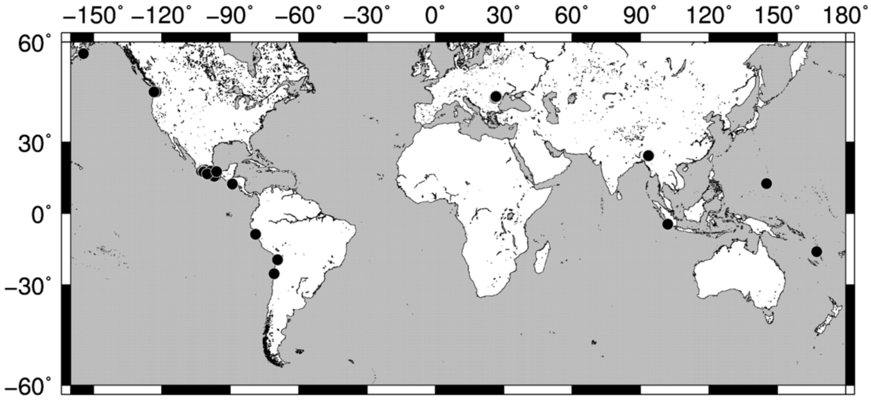


FIG. 6. Locations of the epicenters of the intra-slab earthquakes outside Japan examined in this study.

$$Sa_{somerville}[\mathrm{km}^2] = 5.00 \times 10^{-16} \times (M_0[\mathrm{N \cdot m}] \times 10^7)^{2/3} \quad (8)$$

This relationship is four times the red line. All these circles seem to be consistent with the red empirical relationship by Sasatani *et al*. (2006, [3]).

Figure 5 shows the relationship between the focal depth D and the normalized short-period level A/A_{sasatani} for intra-slab earthquakes in Japan. The red line is the empirical relationship between focal depth D and the normalized short-period level proposed by Satoh (2013, [10]) for intra-slab earthquakes in Japan.

In shallow focal depths, the normalized short-period level A/A_{sasatani} seems to be proportional to the focal depth, which is consistent with the red empirical relationship by Satoh (2013, [10]). Most of the black circles, which are shallow earthquakes in Philippine Sea plate, are smaller than or equal to 1. And most of the open circles, which are the deep earthquakes in Pacific plate, are larger than or equal to 1. This may suggest the locality of the plate characteristics.

3.3.Collection of fault parameters for intra-slab earthquakes outside Japan

We collected the following fault parameters for intra-slab earthquakes outside Japan to examine the short-period levels and asperity areas: location of the hypocenter, moment magnitude, seismic moment, short-period level, stress drop on the asperities, asperity area, and shear-wave velocity.

Figure 6 shows the locations of the epicenters of the collected intra-slab earthquakes outside Japan, such as Alasaka, Cascadia, Mexico, Peru, Chile, Romania, Sumatra, and Guam. The largest one is the 2000 Sumatra earthquake of M_W 7.8. Because the analysis or strong ground motion records of the intra-slab earthquake are rare, we couldn't find many data on the short period levels or sizes of the asperities. The collected fault parameters are listed in Appendix 2.

3.4.Scaling laws of the fault parameters for intra-slab earthquakes outside Japan

Figure 7 shows the relationship between the seismic moments M_0 and the short-period levels A of the collected intra-slab earthquakes outside Japan. Here we classified the data according to the slab. For example the open circles are for Mexico earthquakes, and the black circles are for Romania earthquakes. At M_W between 4 and 5, the open circles which are the Mexico earthquakes are slightly smaller than the red line by Sasatani *et al*. (2006, [3]), and the black

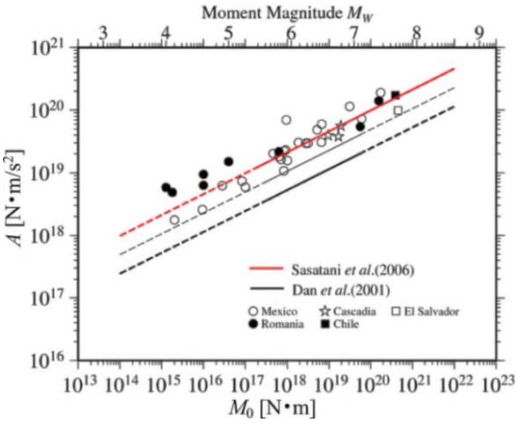


FIG. 7. Relationship between the seismic moment M_0 and short-period level of the collected intra-slab earthquakes outside Japan.

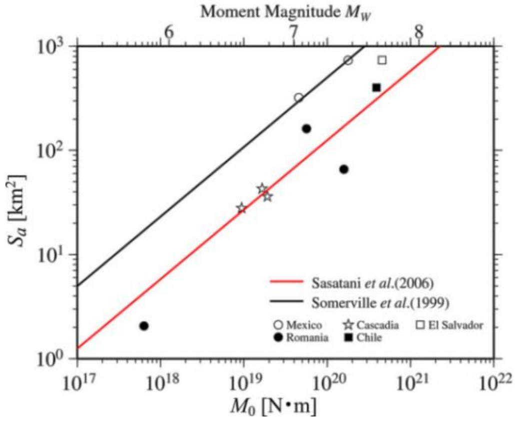


FIG. 8. Relationship between the seismic moment M_0 and the asperity area S_a of the collected intra-slab earthquakes outside Japan.

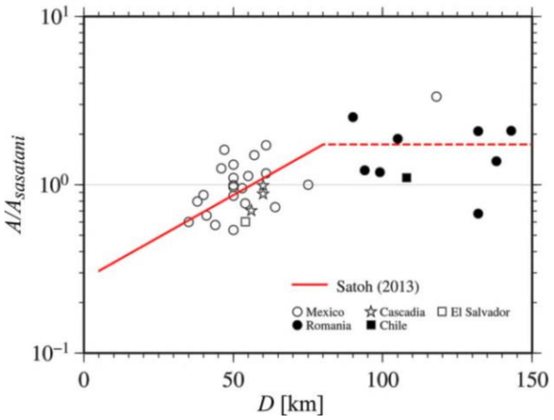


FIG. 9. Relationship between the focal depth D and the ratio of the short-period level $A/A_{sasatani}$ of the collected intra-slab earthquakes outside Japan.

circles which are the Romania earthquakes are larger than the red line. At M_W between 6 and 8, these data seem to be very consistent with the red line by Sasatani *et al*. (2006, [3]). There is no clear locality on the slab.

Figure 8 shows the relationship between the seismic moments M_0 and the areas of asperities S_a of the collected intra-slab earthquakes outside Japan. Although the data have large variations, all these circles seem to be relatively consistent with the red empirical relationship by Sasatani *et al.* (2006, [3]).

Figure 9 shows the relationship between the focal depth D and the normalized short-period level A/A_{sasatani} for intra-slab earthquakes outside Japan. In shallow focal depths, the normalized short-period level A/A_{sasatani} seems to be proportional to the focal depth. In deep focal depths, it seems to be flat with constant level. This is consistent with the red empirical relationship by Satoh (2013, [10]), although the data have large variations. The data form clusters, which indicates that the focal depth can be specified when the slab is specified.

4. Strong Ground Motion Simulation

4.1. Target event: 1986 Vrancea, Romania, earthquake

We referred to the study by Oth *et al*. (2007, [11]) on intra-slab earthquakes in the Vrancea (Romania) seismogenic zone, and chose the 1986 Vrancea earthquake (M_W 7.1) as our target event and the 1999 earthquake (M_W 4.6) as our small event (EGF). Figure 10 shows the locations of the target and small events and the recording stations discussed in this paper.

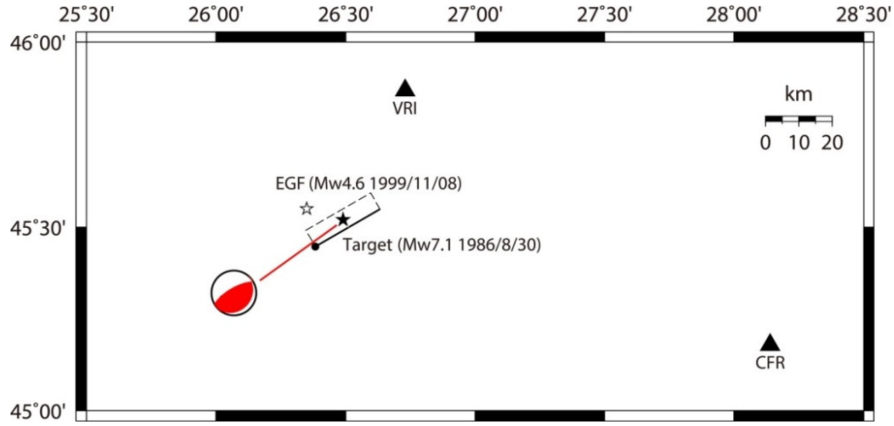


FIG. 10. Locations of the target and EGF events and the recording stations (solid star: target event, open star: EGF, solid triangles: recording stations)

4.2.Fault parameters

From Oth *et al*. (2007, [11]), we adopted four source parameters: the moment magnitude of the target event M_{Wl}=7.1, the corner frequency of the small event f_{cs}=4.0 Hz, subfault division number for the target-event fault plane N=16, and stress drop ratio between the target and small events C=2.0. Based on these four parameters, we determined the fault parameters for the target and small events.

We started with calculating the seismic moment of the target event M_{0l} from the moment magnitude M_{Wl} using equation (9) by Kanamori (1977, [12]):

$$M_{0l}[\mathrm{N\cdot m}] = 10^{1.5M_{Wl}+9.1}. \quad (9)$$

Then, from the seismic moment of the target event M_{0l}, we calculated the remaining five of the six main fault parameters, which were mentioned in the previous section, in accordance with the official procedure for strong ground motion prediction for intra-slab earthquakes by HQERP (2016, [2]).

It shall be mentioned here that the short-period level of the target event A_l was estimated not from the empirical relation of equation (1) between seismic moment and short-period level but from the four source parameters obtained by Oth *et al*. (2007, [11]) from the recordings. For that, we determined the short-period level for the small event A_s. Then, the seismic moment of the small event M_{0s} was calculated from C and N values adopted from Oth *et al*. (2007, [11]) using equation (10):

$$M_{0l} / M_{0s} = CN^3 = 8192. \quad (10)$$

Assuming Brune's (1970, [6]) ω^{-2} model, the total fault area S_s and the stress drop $\Delta\sigma_s$ of the small event can be calculated from the corner frequency of equation (11) and the circular-crack stress drop of equation (12):

$$f_{cs} = \beta\sqrt{(7/16)/S_s} = 4.0\,\mathrm{Hz}, \quad (11)$$

$$\Delta\sigma_s = (7/16)M_{0s} / (S_s/\pi)^{1.5}. \quad (12)$$

Next, using the values of the fault area S_s and the stress drop $\Delta\sigma_s$ of the small event, the short-period level of the small event A_s was calculated from equation (13):

TABLE 1: FAULT PARAMETERS OF THE ASPERITY MODEL FOR THE TARGET EVENT: THE 1986 VRANCEA, ROMANIA, EARTHQUAKE

fault parameters		notes
moment magnitude: M_{Wl}	7.1	Table 1 in Oth *et al*. (2007)
seismic moment: M_{0l}	5.62E+19 N・m	M_{0l}[N・m]=10^(1.5M_{Wl}+9.1)
short-period level: A_l	1.39E+20 N・m/s^2	$A_l=A_s CN$, C=2 and N=16 from Oth *et al*. (2007)
short-period level by Sasatani: $A_{sasatani}$	8.12E+19 N・m/s^2	$A_{sasatani}$[N・m/s^2]=9.84×10^{10}×(M_0[N・m]×10^7)$^{1/3}$
SMGA area by Sasatani: $S_{asasatani}$	85 km^2	$S_{asasatani}$[km^2]=1.25×10^{-16}×(M_0[N・m]×10^7)$^{2/3}$
SMGA area ratio by Sasatani: γ_{SMGA}	0.12	$\gamma_{SMGA}=(16A_{sasatani}{}^2 S_{asasatani}{}^2)/(49\pi^4\beta^4 M_0{}^2)$
fault area: S_l	403 km^2	$S_l=(7\pi^2\beta^2 M_0)/(4A\,\gamma_{SMGA}{}^{0.5})$
fault length: L_l	20.1 km	$L_l=W_l$=sqrt(S_l)
fault width: W_l	20.1 km	$L_l=W_l$=sqrt(S_l)
averaged slip: D_l	1.99 m	$D_l=M_{0l}/(\mu S_l)$, μ=7E10 N/m^2 from Oth *et al*. (2007)
averaged stress drop: $\Delta\sigma_l$	17 MPa	$\Delta\sigma_l=(7/16)[(M_{0l}/(S_l/\pi)^{1.5}]$
area of SMGA S_{SMGA}	50 km^2	$S_{SMGA}=S_l\times\gamma_{SMGA}$
stress drop on SMGA: $\Delta\sigma_{SMGA}$	137 MPa	$\Delta\sigma_{SMGA}=(S_l\Delta\sigma_l)/S_{SMGA}$
slip on SMGA: D_{SMGA}	4.0 m	$D_{SMGA}=2D_l$
seismic moment of SMGA: M_{0SMGA}	1.39E+19 N・m	$M_{0SMGA}=\mu S_{SMGA} D_{SMGA}$, μ=7E10 N/m^2 from Oth *et al*. (2007)
seismic moment of background: M_{0back}	4.23E+19 N・m	$M_{0back}=M_{0l}-M_{0SMGA}$
area of background: S_{back}	353	$S_{back}=S_l-S_a$
slip on background: D_{back}	1.71 m	$D_{back}=(S_l D_l-S_a D_a)/S_{back}$
effective stress on background: σ_{back}	21 MPa	$\sigma_{back}=(D_{back}/W_{back})/(D_{SMGA}/W_{SMGA})\Delta\sigma_{SMGA}$
strike, dip, rake	240, 72, 97	Global CMT

TABLE 2: FAULT PARAMETERS OF THE CRACK MODEL FOR THE EGF EVENT: THE 1999 VRANCEA, ROMANIA, EARTHQUAKE

fault parameters		notes
moment magnitude: M_{Ws}	4.5	M_{Ws}=(log10(M_{0s}[N・m])-9.1)/1.5
seismic moment: M_{0s}	6.86E+15 N・m	$M_{0s}=M_{0l}/(C\cdot N^3)$
stress drop: $\Delta\sigma_s$	41 MPa	$\Delta\sigma_s=(7/16)[(M_{0s}/(S_s/\pi)^{1.5}]$
fault area: S_s	0.55 km^2	$S_s=(7/16)(\beta/f_c)^2$, β=4.5km/s from Oth *et al*. (2007)
fault length: L_s	0.74 km	$L_s=W_s$=sqrt(S_s)
fault width: W_s	0.74 km	$L_s=W_s$=sqrt(S_s)
averaged slip: D_s	0.18 m	$D_s=M_{0s}/(\mu S_s)$, μ=7E10 N/m^2 from Oth *et al*. (2007)
corner frequency: f_{cs}	4.0 Hz	Table 2 in Oth *et al*. (2007)
short-period level: A_s	4.34E+18 N・m/s^2	$A_s=4\pi\beta^2(S_s/\pi)^{1/2}\Delta\sigma_s$

$$A_s = 4\pi\beta^2 (S_s/\pi)^{1/2}\Delta\sigma_s. \tag{13}$$

Once the short-period level of the small event A_s was found, the short-period level of the target event was computed by the following equation (14):

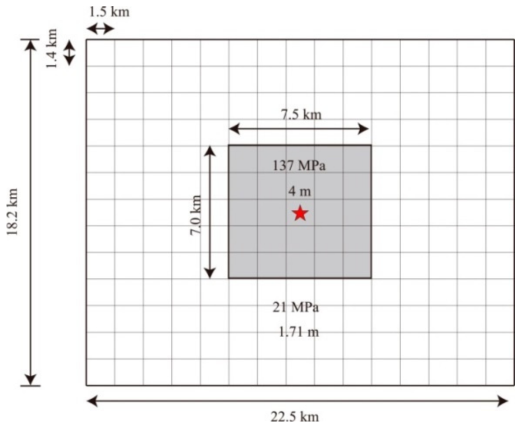


FIG. 11. Asperity model for the target event: the 1986 Vrancea, Romania, earthquake (red star: hypocenter)

$$A_l / A_s = CN = 32. \quad (14)$$

From the seismic moment M_{0l} and the short-period level $A_{sasatani}$ of the target event, we calculated the SMGA area ratio (ratio of the SMGA area to the total fault area) γ_{SMGA}, the source area S_l, the average stress drop $\Delta\sigma_l$, the stress drop on the SMGA $\Delta\sigma_{SMGA}$, and the SMGA area S_{SMGA}.

Furthermore, the averaged slip of the target event D_l was calculated using the following equation (15):

$$D_l = M_{0l} / (\mu S_l). \quad (15)$$

Here, the value for the shear modulus μ is equal to 7×10^{10} N/m^2 (Oth *et al*., 2007, [11]).

The averaged slip on the SMGA D_{SMGA} is 2 times of averaged slip over the fault:

$$D_{SMGA} = 2 \times D_l. \quad (16)$$

Finally, the slip and the effective stress on the background area were calculated using equations (17) and (18):

$$D_{back} = (D_l S_l - D_{SMGA} S_{SMGA}) / (S_l - S_{SMGA}), \quad (17)$$

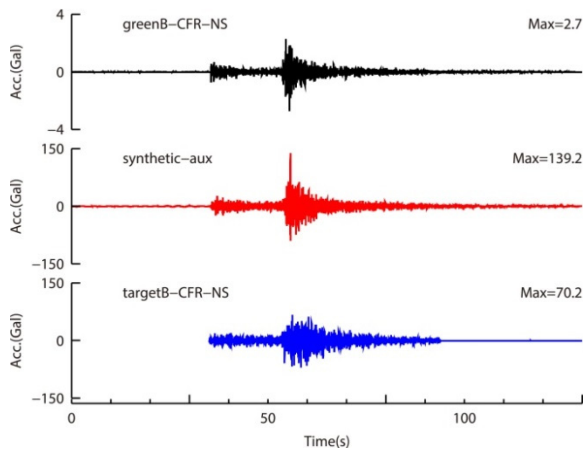
$$\sigma_{back} = (D_{back} / W_{back}) / (D_{SMGA} / W_{SMGA}) \cdot \Delta\sigma_{SMGA}. \quad (18)$$

Here, we assumed that the width of the background area is equal to the width of the fault $W_{back}=W_l$ and that the SMGA is square, *i.e.* $W_{SMGA}=sqrt\ (S_{SMGA})$.

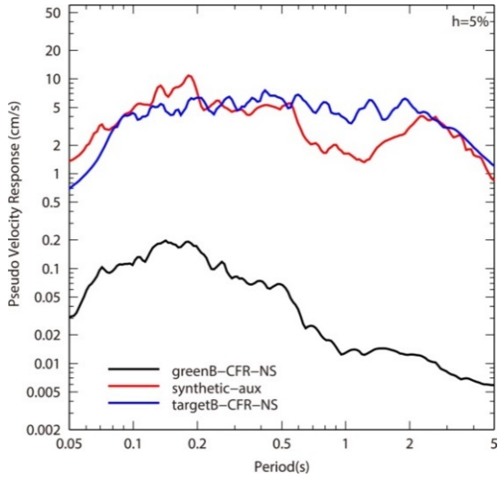
All the fault parameters of the asperity model for the target event, which were determined above, are compiled in Table 1. The fault parameters for the small event are compiled in Table 2. The asperity model for the target event is illustrated in Figure 11.

4.3. Synthesizing method

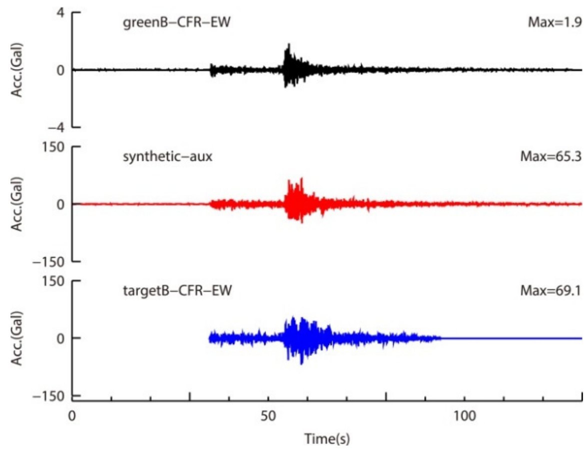
The synthetic ground motions were generated by using the empirical Green's function method of Dan *et al.* (1989, [13]). The strong ground motions were calculated at two stations, CFR and VRI. The locations of the stations with respect to the asperity model of the 1986 Vrancea earthquake (the target event) are shown in Figure 10.



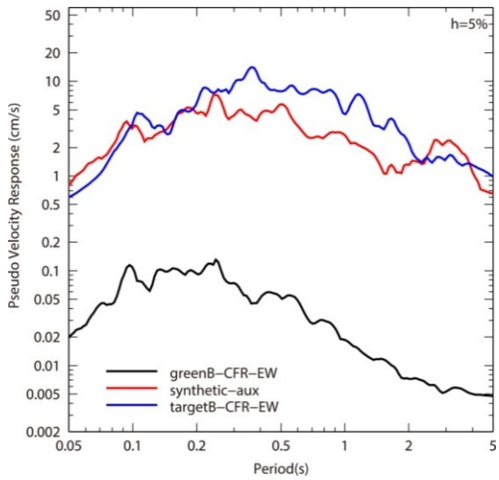
(a) NS accelerations



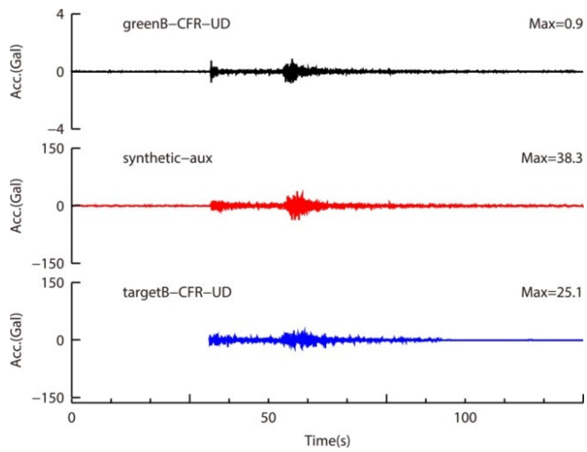
(d) NS response spectra



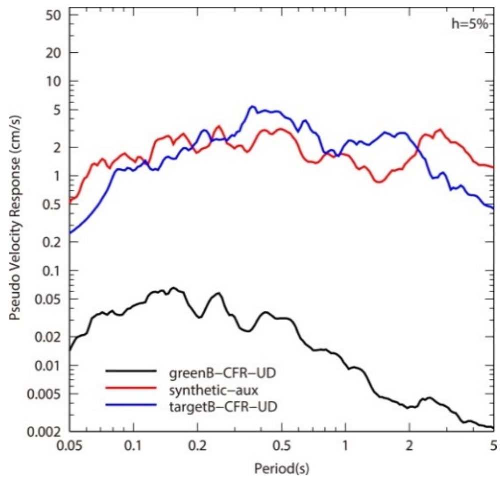
(b) EW accelerations



(e) EW response spectra



(c) UD accelerations



(f) UD response spectra

FIG. 12. Comparison of the synthesized results with the recordings at CFR

The rupture was assumed to initiate at the center of the fault area, and the rupture velocity was taken to be V_R=0.72β (here, β is S -wave velocity) according to Geller (1976, [14]).

4.4.Synthesizing results

The synthetic ground motions and the pseudo-velocity spectra computed for CFR station are plotted in Figure 12. In Figures 12(a) to (c), the black waveforms are the acceleration records of the small event (EGFs), the red waveforms are the synthetics calculated in this study, and the blue waveforms are the acceleration records of the target event. The peak values of the synthetic acceleration waveforms in NS direction is larger than the records, whereas the peak values of the synthetic acceleration waveforms in EW and UD directions are quite similar to the records, and the durations of the preliminary ground motions are reproduced well. Figures 12(d) to (f) are the plots of pseudo-velocity response spectra with 5% damping. In the period range between 0.3 to 2 seconds, the synthetic spectra underpredict the records, however, at periods shorter than 0.3 seconds the synthetic spectra reproduce the records well. Overall, the pseudo-velocity response spectra of the synthetics are very similar to those of the records.

5. Conclusions

We collected the fault parameters of the intra-slab earthquakes in and outside Japan and investigated the applicability of the scaling laws used in the official procedure for prediction of ground motions from intra-slab earthquakes by the Headquarters for Earthquake Research Promotion of Japan to intra-slab earthquakes outside Japan. We also studied the applicability of the official procedure to intra-slab earthquakes outside Japan on the example of Vrancea, Romania, earthquake.

The following conclusions were derived:

1) Both the relationship between the seismic moment and short-period level and that between the seismic moment and asperity area of the intra-slab earthquakes outside Japan, are found to be consistent with the scaling laws by Sasatani *et al*. (2006, [3]), which are adopted in the official procedure of Japan.

   Also the relationship between the focal depth and short-period level can be modeled by the empirical relationship by Satoh (2013, [10]).

2) The resultant synthetics waveforms by using the asperity model for the Vrancea earthquake according to the Recipe reproduced the records well. Therefore, the official procedure of Japan can be applied to the Romanian intra-slab earthquake.

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(to be continued).

No.	slab	region	date	hypocenter			moment magnitude	seismic moment	short-period level	stress drop on asperity	asperity area	S-wave velocity	references	notes
				long. [N]	lat. [E]	dep. [km]	M_W	M_0 (Nm)	A (N・m/s^2)	$\Delta\sigma_a$ (MPa)	S_a (km^2)	β (km/s)		
1	Pacific	Hokkaido-Toho-Oki	Oct. 4, 1994	43.5	147.4	56.0	8.2	2.6E+21 (KK) 3.0E+21 (H)	1.7E+21 (MS)	SMGA1:82 SMGA2: 82 SMGA3: 382 SMGA4: 300 SMGA5: 137 (MS)	SMGA1: 400 SMGA2: 256 SMGA3: 144 SMGA4: 144 SMGA5: 256 total: 1200 (MS)	4.6	Sasatani *et al*. (2006)	KK: Kikuchi and Kanamori (1995) H: Harvard CMT MS: Morikawa and Sasatani (2004) I2: Ikeda *et al*. (2004) M_0 (kk) -A in Figure2 M_0 (kk) -S_a in Figure3
				*	*	64.0	8.3	3.50E+21	*	28.7	2640.0	*	Iwata and Asano (2011)	Shao *et al*. (2006)
No.	slab	region	date	hypocenter			moment magnitude	seismic moment	short-period level	stress drop on asperity	asperity area	S-wave velocity	references	notes
				long. [N]	lat. [E]	dep. [km]	M_W	M_0 (Nm)	A (N・m/s^2)	$\Delta\sigma_a$ (MPa)	S_a (km^2)	β (km/s)		
2	Pacific	Kushiro-Oki	Jan. 15, 1993	43.0	144.3	95.0	7.7	3.3E+20 (T) 2.7E+20 (H)	4.2E+20 (MS) 2.0E+20 (I1)	model A SMGA1: 109 SMGA2: 381 SMGA3: 163 model B SMGA1: 82 SMGA2: 190 SMGA3: 109	model A SMGA1: 51.8 SMGA2: 72.0 SMGA3: 34.6 total: 158.6 model B SMGA1: 92 SMGA2: 144 SMGA3: 69 total: 305	4.6	Sasatani *et al*. (2006)	MS: Morikawa and Sasatani (2004), H: Harvard CMT I1: Ikeda (2002) T: Sasatani *et al*. (2006) M_0 (T) -A (modelA) in Figure2 M_0 (T) -S_a (modelA) in Figure3
				42.89	144.37	103.0	7.5	2.3.E+20	*	*	*	4.6	Kikuchi (2003)	
				42.92	144.36	100.6	*	*	*	*	*	*	Nozu (2003)	
				*	*	107.0	7.6	3.3.E+20	*	*	*	*	Takeo *et al*. (1993)	
3	Pacific	Miyagiken-Oki	Apr. 7, 2011	38.2	141.9	65.9	7.1	4.74E+19	*	*	*	4.46	Shiba and Noguchi (2012)	
				38.3	141.6	49.0	7.1	5.54E+19	*	*	*	*	Yamanaka (2011)	
				38.2	141.8	56.1	7.17	7.2.E+19	*	*	*	*	Ohta *et al*. (2011)	$\log M_0=1.5M_W+9.1$
				*	*	66.0	*	*	1.10.E+20	asp1: 70.6 asp2: 70.6	asp1: 10.2*10.2 =104.04 asp2: 10.2*10.2 =104.04	3.9	Harada and Kamae (2011)	$A=4\pi\beta^2\Delta\sigma_a(S_a/\pi)^{1/2}$
				*	*	*	*	*	*	SMGA1: 71 SMGA2: 71	SMGA1: 10.2*10.2 =104.04 SMGA2: 10.2*10.2 =104.04	3.9	Harada *et al*. (2012)	
				*	*	*	*	*	8.01E+19	SMGA1: 23.7 SMGA2: 70.8 SMGA3: 70.8	SMGA1: 35.6 SMGA2: 80.1 SMGA3: 35.6	3.82	Somei and Miyakoshi (2012a)	
				*	*	66.0	7.1	5.24E+19	*	*	*	*	Somei and Miyakoshi (2012b)	
				*	*	68.0	7.1	4.74E+19	2.17E+20	*	*	*	Satoh (2013)	M_0-A in Figure2
4	Pacific	Miyagiken-Oki	May. 26, 2003	38.8	141.7	72.0	7.0	3.49.E+19	1.1E+20 (S) 1.4E+20 (TS)	SMGA1: 105 SMGA2: 105 SMGA3: 105 (A2)	SMGA1: 3*3=9 SMGA2: 4*4=16 SMGA3: 6*6=36 total: 61.0 (A2)	3.98	Sasatani *et al*. (2006)	S: Satoh (2004) TS: Sasatanai *et al*. (2006) A2: Asano *et al*. (2004) M_0-A (S) in Figure2, M_0-S_a in Figure3
				*	*	*	7.0	3.80.E+19	*	*	*	*	Hikima *et al*. (2003)	
				38.9	141.8	52.0	7.0	4.0.E+19	*	*	*	*	Geospatial Information Authority of Japan (2003)	$\log M_0=1.5M_W+9.1$
				38.8	141.7	75.0	7.0	3.8E+19	*	*	*	*	Yamanaka and Kikuchi (2003)	
				38.8	141.7	72.0	7.2	7.6E+19	*	*	*	*	Aoi *et al*. (2003)	two planes
				*	*	68.0	7.1	5.62.E+19	*	*	*	*	Okada and Hasegawa (2003)	$\log M_0=1.5M_W+9.1$
				38.8	141.7	70.0	6.9	3.00.E+19	*	*	*	*	Yagi (2003)	
				*	*	72.0	7.0	6.20E+19	*	49.9	108.0	*	Iwata and Asano (2011)	Aoi *et al*. (2005)
				*	*	*	7.0	3.49E+19	1.20.E+20	*	*	*	Satoh (2013)	
5	Pacific	Iwateken-Nairikuengan-Hokubu	Jul. 24, 2008	39.739	141.670	115.0	6.9	2.82E+19	3.51.E+19	23.9	96	3.6	Iwata and Asano (2011)	$A=4\pi\beta^2\Delta\sigma_a(S_a/\pi)^{1/2}$ M_0-A in Figure2, M_0-S_a in Figure3
				39.739	141.670	115.0	6.9	2.82E+19	*	24	*	*	Suzuki *et al*. (2009)	
				*	*	*	6.8	1.72E+19	8.96E+19	*	*	*	Satoh (2013)	
6	Pacific	Hokkaido-Toho-Oki	Jan. 28, 2000	*	*	59.0	6.8	2.00E+19	5.2E+19 (TS)	62.4 (TS) 261 (A1)	56.3 (TS) 24.6 (A1)	*	Sasatani *et al*. (2006)	H: Harvard A1: Asano *et al*. (2003) TS: Sasatai *et al*. (2006) S_a (TS) in Figure3
7	Pacific	Iwateken-Nairiku-Nanbu	Dec. 2, 2001	*	*	122.0	6.4	5.6E+18 (H)	3.9E+19 (MF)	asp1: 87 asp2: 116 asp3: 116 (MF)	asp1: 5.8 asp2: 8.6 asp3: 5.8 (MF)	*	Sasatani *et al*. (2006)	MF: Morikawa and Fujiwara (2002) H: Harvard CMT M_0-A in Figure2
				*	*	*	6.4	5.34E+18	4.21E+19	*	*	*	Satoh (2013)	
8	Pacific	Kushiro-shicho-Chuunanbu	May. 13, 1999	42.94 (I1)	143.91 (I1)	109.0	6.2	2.4E+18 (H)	2.8E+19 (TS) 2.3E1 9(I1)	asp1: 73 asp1: 73 (TS)	asp1: 3.2 asp1: 4.9 (TS)	*	Sasatani *et al*. (2006)	H: Harvard CMT I2: Ikeda (2002) A (TS) in Figure2
9	Pacific	Fukushimaken-Oki	Jul. 31, 2011	*	*	56.0	6.4	4.15E+18	3.67E+19	*	*	*	Satoh (2013)	
10	Pacific	Fukushimaken-Oki	Aug. 19, 2011	*	*	56.0	6.3	3.19E+18	3.05E+19	*	*	*	Satoh (2013)	
11	Philippine Sea	Geiyo	Mar. 24, 2001	34.12 (YK)	132.7087 (YK)	50 (YK)	6.7 (YK)	1.4E+19 (YK)	6.2E+19 (M)	asp1: 47 asp2: 41 (A1)	asp1: 33.1 asp2: 24.8 (A1)	*	Sasatani *et al*. (2006)	A1: Asano *et al*. (2003) M: Morikawa *et al*. (2002), YK: Yagi and Kikuchi (2001) M_0-A in Figure2, M_0-S_a in Figure3
				*	*	46.46 (TS)	6.8 (TS)	2.1E+19 (KH)	6.0E+19 (I2)	*	*	*	Sasatani *et al*. (2006)	TS: Sasatani *et al*. (2006) KH: Kakehi (2004), I2: Ikeda *et al*. (2004)
				*	*	46.0	6.8	1.88E+19	*	81.0	24.3	*	Iwata and Asano (2011)	Kakehi (2004)
				*	*	46.0	7.0	3.36E+19	*	135.0	24.2	*	Iwata and Asano (2011)	Sekiguchi and Iwata (2002)
				34.1	132.7	46.5	6.8	1.51.E+19	*	*	*	*	Asano *et al*. (2004)	two asperities

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No.	slab	region	date	hypocenter			moment magnitude	seismic moment	short-period level	stress drop on asperity	asperity area	S-wave velocity	references	notes
				long. [N]	lat. [E]	dep. [km]	M_W	M_0 (Nm)	A (N・m/s^2)	$\Delta\sigma_a$ (MPa)	S_a (km^2)	β (km/s)		
12	Philippine Sea	Suruga-Wan	Aug. 11, 2009	*	*	21.6	6.2	2.25.E+18	3.71E+19	SMGA1: 75.1 SMGA2: 75.1	SMGA1: 3*2=6 SMGA2: 4*3=12 total: 18	*	Satoh (2010)	
				*	*	23.0	*	*	*	SMGA1: 35.7 SMGA2: 27.5	SMGA1: 3.6*3.6=13 SMGA2: 4.8*4.8=23	*	Asano and Iwata (2010)	two planes
				34.8	138.5	23.0	*	*	*	*	*	*	Nozu (2010)	two planes three asperities
				*	*	*	6.4	4.8.E+18	*	*	*	*	Ueno *et al*. (2009)	two planes
				34.7	138.5	17.1	*	*	*	asp1: 15 asp2: 15	asp1: 5.0*5.0=25 asp2: 5.0*5.0=25 total: 50.0	*	Kawabe *et al*. (2010)	
				*	*	23.0	*	*	*	asp1: 16.7 asp2: 17.6	asp1: 16.2 asp2: 45.0	*	Kurahashi *et al*. (2009)	two planes
13	Philippine Sea	Oitaken-Seibu	Jun. 12, 2006	*	*	145.0	6.4	4.2E+18	2.70.E+19	*	*	*	Ikeda (2010)	M_W=(logM_0-9.1)/1.5
14	Philippine Sea	Hyuga-Nada	Apr. 25, 2001	32.796 (I2)	132.342 (I2)	39.3 (I2)	5.7	4.00E+17	6.8E+18 (I2)	19 (A1)	2.2*3.4 =7.5 (A1)	*	Sasatani *et al*. (2006)	H: Harvard CMT A1: Asano *et al*. (2003) I2: Ikeda *et al*. (2004)
15	Philippine Sea	Wakayamaken-Hokubu	Aug. 21, 1999	*	*	66.0	5.6	3.1E+17 (H)	2.9E+18 (I2)	314 (A1)	1.4 (A1)	*	Sasatani *et al*. (2006)	H: Harvard CMT A1: Asano *et al*. (2003) I2: Ikeda *et al*. (2004)
16	Philippine Sea	Aichiken-Tobu	Mar. 16, 1997	*	*	39.0	5.6	3.3E+17 (H)	1.2E+19 (I2)	32 (A1)	2.7 (A1)	*	Sasatani *et al*. (2006)	H: Harvard CMT A1: Asano *et al*. (2003) I2: Ikeda *et al*. (2004)
17	Philippine Sea	Shizuokaken-Chubu	Apr. 3, 2001	35.039 (H) 35 (F)	138.095 (H) 138.1 (F)	30.11 (H) 35 (F)	5.4	1.58.E+17	9.12.E+18	34	3.2	4.6	Morikawa *et al*. (2002), NIED (2001)	H: Hi-net NIED 311.7, 74.8, 170.2 F: Fressia 341, 36, -62 two planes logM_0=1.5M_W+9.1
18	Pacific	Miyagiken-Oki	Nov. 24, 1998	*	*	83.1	5.1	5.73E+16	1.16E+19	*	*	*	Satoh (2004)	logM_0=1.5M_W+9.1
19	Pacific	Miyagiken-Oki	May. 27, 2003	*	*	67.5	4.7	1.43E+16	1.02E+19	*	*	*	Satoh (2004)	logM_0=1.5M_W+9.1

APPENDEX 2: FAULT PARAMETERS FOR INTRA-SLAB EARTHQUAKES OUTSIDE JAPAN (to be continued).

No.	slab	region	date	hypocenter			moment magnitude	seismic moment	short-period level	stress drop on asperity	asperity area	S-wave velocity	references	notes
				long. [N]	lat. [E]	dep. [km]	M_W	M_0 (Nm)	A (N・m/s^2)	$\Delta\sigma_a$ (MPa)	S_a (km^2)	β (km/s)		
1	S. Mariana	Guam	Aug. 8, 1993	12.98	144.80	45	7.7	*	*	*	*	*	Seno and Yoshida (2004)	
				12.982	144.801	50	7.7	3.5E+20	*	*	*	*	Tanioka *et al*. (1995)	
2	Sumatra	Sumatra	Jun. 4, 2000	-4.73	101.94	44	7.8	*	*	*	*	*	Seno and Yoshida (2004)	
				-4.72	102.09	33	*	1.5E+21	*	*	*	*	Zhou *et al*. (2002)	
3	Vanuatu	Vanuatu	Jul. 13, 1994	-16.50	167.35	25	7.1	*	*	*	*	*	Seno and Yoshida (2004)	
4	N. Chile	Taltal	Feb. 23, 1965	-25.67	-70.79	60	7.0	*	*	*	*	*	Seno and Yoshida (2004)	
				-25.67	-70.79	59	7.0	3.5E+19	*	*	*	4.5	Malgrange and Madariaga (1983)	
5	N. Chile	Tarapaca	Jun. 13, 2005	*	*	108	7.7	3.92E+20	1.71E+20	59.7	400	*	Iwata and Asano (2011)	$A=4\pi\beta^2\Delta\sigma_a(S_a/\pi)^{1/2}$ β is assumed 4.5 km/s.
				-20.01	-69.24	108	7.8	5.47E+20	*	*	*	*	Delouis and Legrand (2007)	
6	C. Peru	Peru	May. 31, 1970	-9.18	-78.82	43	7.9	*	*	*	*	*	Seno and Yoshida (2004)	
				*	*	*	*	1.0E+21	*	*	*	*	Abe (1972)	
7	El Salvador	El Salvador	Jun. 19, 1982	12.65	-88.97	52	7.3	*	*	*	*	*	Seno and Yoshida (2004)	
8	El Salvador	El Salvador	Jan. 13, 2001	12.97	-89.13	56	7.7	*	*	*	*	*	Seno and Yoshida (2004)	
				*	*	54	7.7	4.57E+20	9.83E+19	25.3	733	*	Iwata and Asano (2011)	$A=4\pi\beta^2\Delta\sigma_a(S_a/\pi)^{1/2}$ β is assumed 4.5 km/s.
				*	*	54	7.7	*	*	*	*	*	Vallee *et al*. (2003)	
9	Mexico	Oaxaca	Jan. 15, 1931	16.40	-96.30	40	7.7	*	*	*	*	*	Seno and Yoshida (2004)	
10	Mexico	Mexico	Jun. 16, 2013	18.108	-99.230	55	5.91	9.1E+17	2.32E+19	*	*	4.68	Singh *et al*. (2014)	$A=(2\pi f_c)^2 M_0$
11	Mexico	Mexico	Jul. 21, 2000	18.11	-98.97	50	5.89	8.49E+17	2.21E+19	*	*	4.68	Singh *et al*. (2014)	$A=(2\pi f_c)^2 M_0$
12	Mexico	Mexico	Nov. 15, 2012	18.407	-100.373	60.9	6.11	1.83E+18	3.04E+19	*	*	4.68	Singh *et al*. (2014)	$A=(2\pi f_c)^2 M_0$
13	Mexico	Mexico	May. 22, 2009	18.10	-98.43	46	5.71	4.60E+17	2.04E+19	*	*	4.68	Singh *et al*. (2014)	$A=(2\pi f_c)^2 M_0$
14	Mexico	Mexico	Dec. 11, 2011	17.82	-99.94	57	6.48	6.71E+18	6.00E+19	*	*	4.68	Singh *et al*. (2014)	$A=(2\pi f_c)^2 M_0$
15	Mexico	Mexico	Feb. 23, 1994	17.75	-97.27	75	5.8	6.28E+17	1.81E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				17.75	-97.27	75	5.8	*	*	*	*	*	Garcia *et al*. (2005)	
16	Mexico	Mexico	May. 23, 1994	18.02	-100.57	50	6.2	2.77E+18	2.97E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				18.02	-100.57	50	6.2	*	*	*	*	*	Garcia *et al*. (2005)	
17	Mexico	Mexico	Dec. 10, 1994	17.98	-101.52	50	6.4	5.20E+18	4.85E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				17.98	-101.52	50	6.4	*	*	*	*	*	Garcia *et al*. (2005)	
18	Mexico	Mexico	Jan. 1, 1996	17.04	-99.51	41	4.1	2.00E+15	1.76E+18	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
19	Mexico	Mexico	Jul. 19, 1996	17.24	-100.38	50	4.9	2.81E+16	6.25E+18	*	*	4.68	Garcia *et al*. (2004)	
20	Mexico	Mexico	Jan. 11, 1997	18.34	-102.58	40	7.1	*	*	*	*	*	Seno and Yoshida (2004)	
				18.34	-102.58	40	7.1	6.06E+19	7.24E+19	*	*	4.68	Garcia *et al*. (2004)	M_0-A in Figure6 $A=(2\pi f_c)^2 M_0$
				*	*	35	7.0	4.54E+19	2.59E+19	10.1	320	*	Iwata and Asano (2011)	M_0-S_a in Figure7 $A=4\pi\beta^2\Delta\sigma_a$ β is assumed 4.5 km/s.
				18.06	102.79	35	7.1	4.9E+19	*	*	300	*	Santoyo *et al*. (2005)	
21	Mexico	Mexico	May. 19, 1997	17.28	-100.45	44	4.6	9.41E+15	2.58E+18	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$

APPENDEX 2: FAULT PARAMETERS FOR INTRA-SLAB EARTHQUAKES OUTSIDE JAPAN

No.	slab	region	date	hypocenter			moment magnitude	seismic moment	short-period level	stress drop on asperity	asperity area	S-wave velocity	references	notes
				long. [N]	lat. [E]	dep. [km]	M_W	M_0 (Nm)	A (N・m/s^2)	$\Delta\sigma_a$ (MPa)	S_a (km^2)	β (km/s)		
22	Mexico	Mexico	May. 22, 1997	18.37	-101.82	54	6.5	6.53E+18	3.07E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				18.37	-101.82	54	6.5	*	*	*	*	*	Garcia *et al*. (2005)	
23	Mexico	Mexico	Apr. 20, 1998	18.35	-101.19	64	5.9	1.01E+18	1.57E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				18.35	-101.19	64	5.9	*	*	*	*	*	Garcia *et al*. (2005)	
24	Mexico	Mexico	Jun. 15, 1999	18.13	-97.54	61	6.9	3.10E+19	1.15E+20	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				18.13	-97.54	61	6.9	*	*	*	*	*	Garcia *et al*. (2005)	
25	Mexico	Mexico	Jun. 21, 1999	18.15	-101.70	53	6.3	3.11E+18	2.95E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				18.15	-101.70	53	6.3	*	*	*	*	*	Garcia *et al*. (2005)	
26	Mexico	Oaxaca	Sep. 30, 1999	15.70	-96.96	47	7.4	*	*	*	*	*	Seno and Yoshida (2004)	
				16.03	-96.96	47	7.4	1.72E+20	1.89E+20	*	*	4.68	Garcia *et al*. (2004)	M_0-A in Figure6 $A=(2\pi f_c)^2 M_0$
				*	*	40	7.5	1.79E+20	3.80E+19	9.8	731	*	Iwata and Asano (2011)	$A=4\pi\beta^2\Delta\sigma_a\,(S_a/\pi)^{1/2}$ β is assumed 4.5 km/s.
				16.00	-97.02	39.7	*	1.8E+20	*	*	*	*	Hernandez *et al*. (2001)	
27	Mexico	Mexico	Dec. 29, 1999	18.00	-101.63	50	5.9	8.29E+17	1.07E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
28	Mexico	Mexico	Jul. 21, 2000	18.11	-98.97	50	5.9	7.14E+17	1.63E+19	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				18.11	-98.97	50	5.9	*	*	*	*	*	Garcia *et al*. (2005)	
29	Mexico	Mexico	Mar. 5, 2001	17.15	-100.11	35	5.3	1.00E+17	5.91E+18	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				17.15	-100.11	35	5.3	*	*	*	*	*	Garcia *et al*. (2005)	
30	Mexico	Mexico	Mar. 6, 2001	17.14	-100.11	38	5.2	8.30E+16	7.35E+18	*	*	4.68	Garcia *et al*. (2004)	$A=(2\pi f_c)^2 M_0$
				17.14	-100.11	38	5.2	*	*	*	*	*	Garcia *et al*. (2005)	
31	Mexico	Mexico	Jan. 30, 2002	18.15	-95.98	118	5.9	9.43E+17	6.94E+19	*	*	4.68	Garcia et al. (2004)	$A = (2\pi f_c)^2 M_0$
				18.15	-95.98	118	5.9	*	*	*	*	*	Garcia *et al*. (2005)	
32	Alaska	Kodiak Island	Dec. 6, 1999	57.35	-154.35	36	7.0	*	*	*	*	*	Seno and Yoshida (2004)	
33	Cascadia	Seattle-Tacoma	Apr. 29, 1965	*	*	60	6.6	9.43E+18	3.96E+19	52.1	28	*	Iwata and Asano (2011)	β is assumed 4.5 km/s.
				47.38	-122.31	60	6.6	9.43E+18	*	*	28	*	Ichinose *et al*. (2004)	
34	Cascadia	Nisqually	Feb. 28, 2001	47.14	-122.53	47	6.8	*	*	*	*	*	Seno and Yoshida (2004)	
				*	*	56	6.8	1.66E+19	3.80E+19	40.4	43	*	Iwata and Asano (2011)	M_0-S_a in Figure7 $A=4\pi\beta^2\Delta\sigma_a\,(S_a/\pi)^{1/2}$ β is assumed 4.5 km/s.
				47.14	-122.71	56	6.8	1.66E+19	*	*	45	*	Ichinose *et al*. (2004)	
				*	*	60	6.67	1.11E+19	*	*	*	*	Ichinose *et al*. (2006).	
35	Cascadia	Olympia	Apr. 13, 1949	47.17	-122.62	54	7.1	*	*	*	*	*	Seno and Yoshida (2004)	
				*	*	60	6.8	1.91E+19	5.60E+19	65.0	36	*	Iwata and Asano (2011)	$A=4\pi\beta^2\Delta\sigma_a\,(S_a/\pi)^{1/2}$ β is assumed 4.5 km/s.
				*	*	60	6.8	1.91E+19	*	*	36	*	Ichinose *et al*. (2006).	
				47.13	-122.95	54	*	1.5E+19	*	*	*	4.5	Baker and Langston (1987)	
36	Cascadia	Satsop	Jul. 3, 1999	*	*	40	5.72	4.8E+17	*	*	*	*	Ichinose *et al*. (2006).	
37	Cascadia		Jun. 10, 2001	*	*	40	4.69	1.4E+16	*	*	*	*	Ichinose *et al*. (2006).	
38	Cascadia	Mt. Olympus	Apr. 25, 2003	*	*	46	4.49	6.8E+15	*	*	*	*	Ichinose *et al*. (2006).	
39	Romania	Vrancea	Mar. 4, 1977	45.77	26.76	94	7.4	*	1.40E+20	120	65.61	4.5	Oth *et al*. (2007)	$A=4\pi\beta^2\Delta\sigma_a\,(S_a/\pi)^{1/2}$
40	Romania	Vrancea	Sep. 6, 2002	45.64	26.43	105	4.1	*	4.84E+18	*	*	4.5	Oth *et al*. (2007)	$A=(2\pi f_c)^2 M_0$
41	Romania	Vrancea	Nov. 3, 2002	45.74	26.86	90	4.0	*	5.80E+18	*	*	4.5	Oth *et al*. (2007)	$A=(2\pi f_c)^2 M_0$
42	Romania	Vrancea	Nov. 8, 1999	45.55	26.35	138	4.6	*	6.32E+18	*	*	4.5	Oth *et al*. (2007)	$A=(2\pi f_c)^2 M_0$
43	Romania	Vrancea	Nov. 14, 1999	45.52	26.27	132	4.6	*	9.48E+18	*	*	4.5	Oth *et al*. (2007)	$A=(2\pi f_c)^2 M_0$
44	Romania	Vrancea	Apr. 6, 2000	45.75	26.64	143	5.0	*	1.51E+19	*	*	4.5	Oth *et al*. (2007)	$A=(2\pi f_c)^2 M_0$
45	Romania	Vrancea	Aug. 30, 1986	45.52	26.49	132	7.1	*	5.93E+19	30	161.78	4.5	Oth *et al*. (2007)	$A=4\pi\beta^2\Delta\sigma_a\,(S_a/\pi)^{1/2}$
46	Romania	Vrancea	Oct. 27, 2004	45.78	26.73	99	5.8	*	2.34E+19	90-120	2.06	4.5	Oth *et al*. (2007)	$A=4\pi\beta^2\Delta\sigma_a\,(S_a/\pi)^{1/2}$
47	Indo-Burman	Imphal	Jan. 3, 2016	*	*	55	6.7	1.56E+19	*	*	*	*	Parameswaran and Rajendran (2016)	

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