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Earthquake Research Panel, November 6-8, 2002
- Morioka, Japan -

Recipe for Predicting Strong Ground Motion from Inland and Subduction-Zone Earthquakes

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Framework of predicting strong ground motions for scenario earthquakes

1. Long-term forcasting of earthquakes

Active fault survey
Historical earthquake records
GPS observation
Seismic activity monitoring

2. Strong motion observation and waveform inversion of source process

Strong motion records
Teleseismic records
Broad-band records
Earthquake damage records

3. Investigation of underground structures

Reflection and/or refraction profiling
Gravity survey
Boring, P-S velocity logging
Microtremor array measurement

Macroscopic (Outer) *Microscopic (Inner)*

Rupture directivity

Source modeling
(Outer source parameters)
(Inner source parameters)

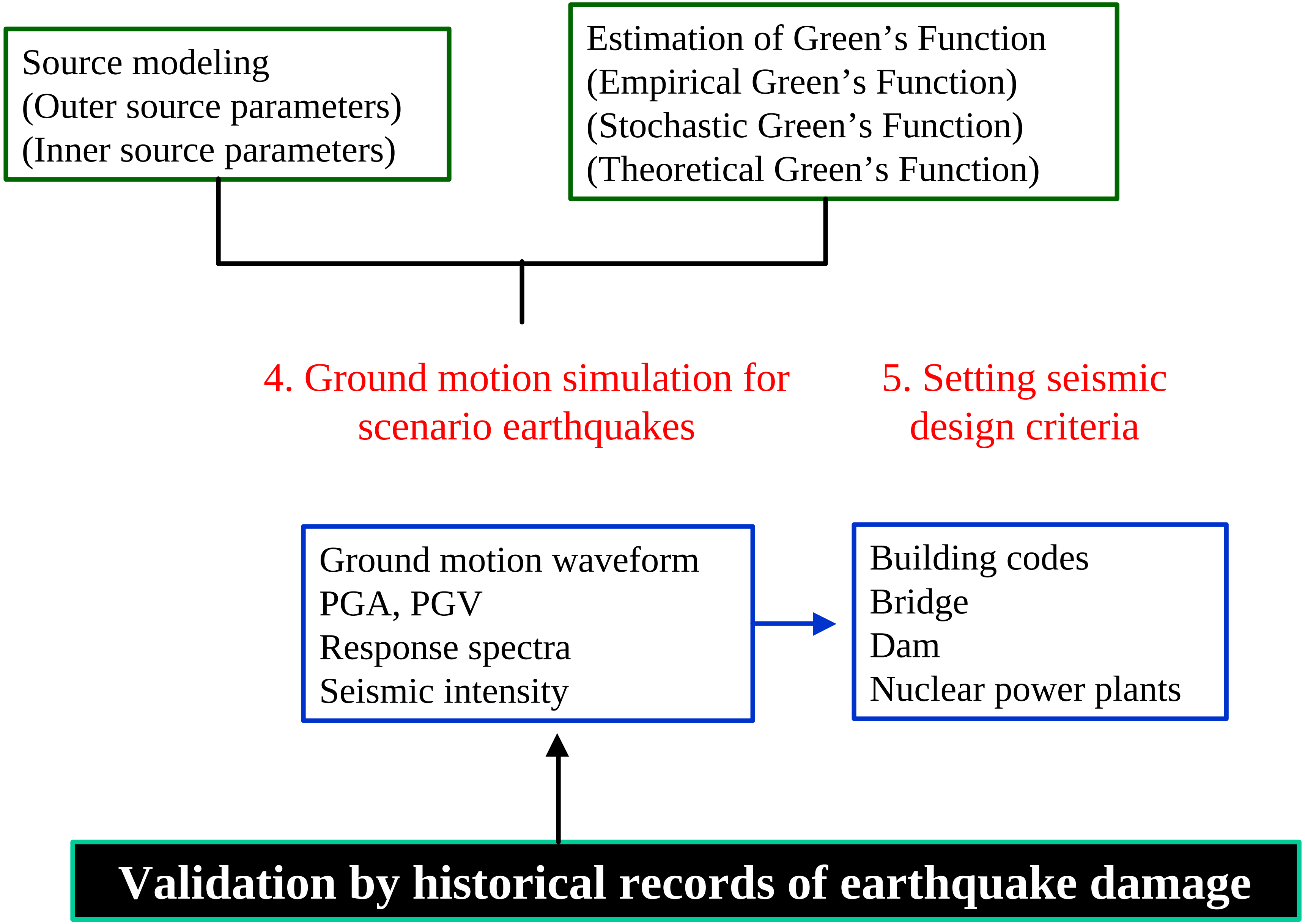
Empirical approach

Theoretical

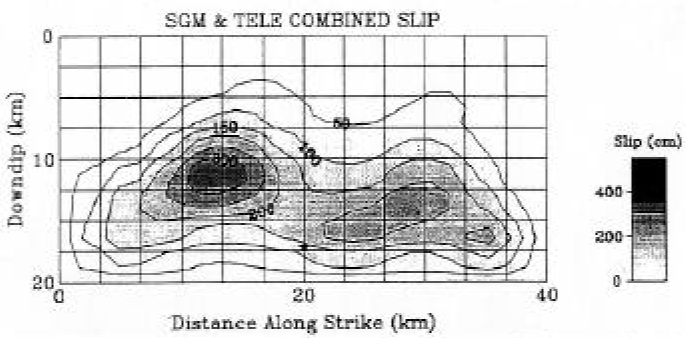
Stochastic

Hybrid

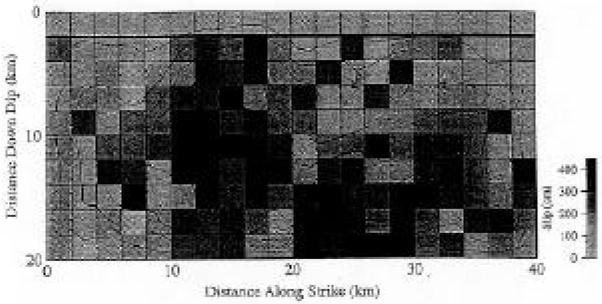
Estimation of Green's Function
(Empirical Green's Function)
(Stochastic Green's Function)
(Theoretical Green's Function)

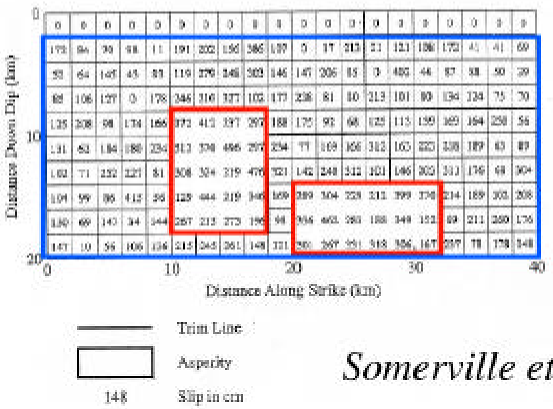

Source modeling
(Outer source parameters)
(Inner source parameters)
Estimation of Green's Function
(Empirical Green's Function)
(Stochastic Green's Function)
(Theoretical Green's Function)
4. Ground motion simulation for scenario earthquakes
5. Setting seismic design criteria
Ground motion waveform
PGA, PGV
Response spectra
Seismic intensity
Building codes
Bridge
Dam
Nuclear power plants
Validation by historical records of earthquake damage

Slip Heterogeneity from Waveform Inversion of Strong Motion Records



Wald et al. (1991)



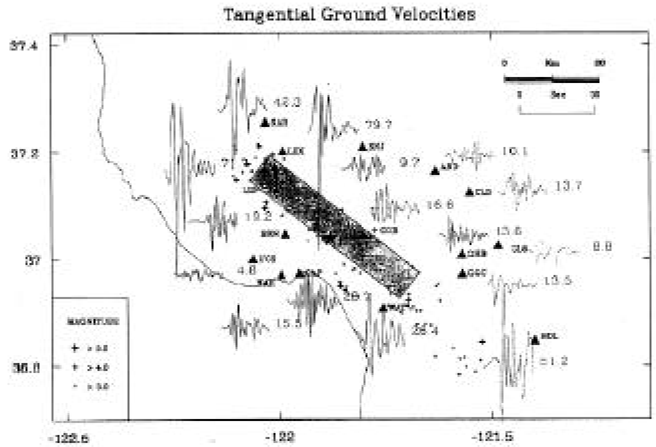


rupture area
($>= 0.3\Delta\bar{D}_{total}$)

asperity
($>=1.5\Delta\bar{D}_{rup}$)

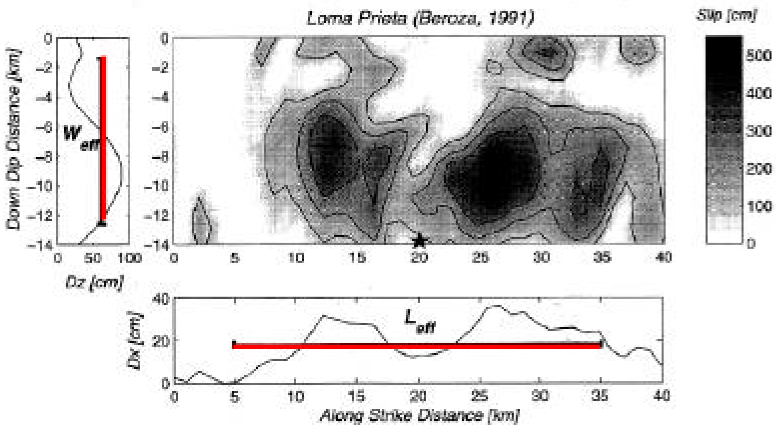
Somerville et al. (1999)

1989 Loma Prieta earthquake (M_w6.9)

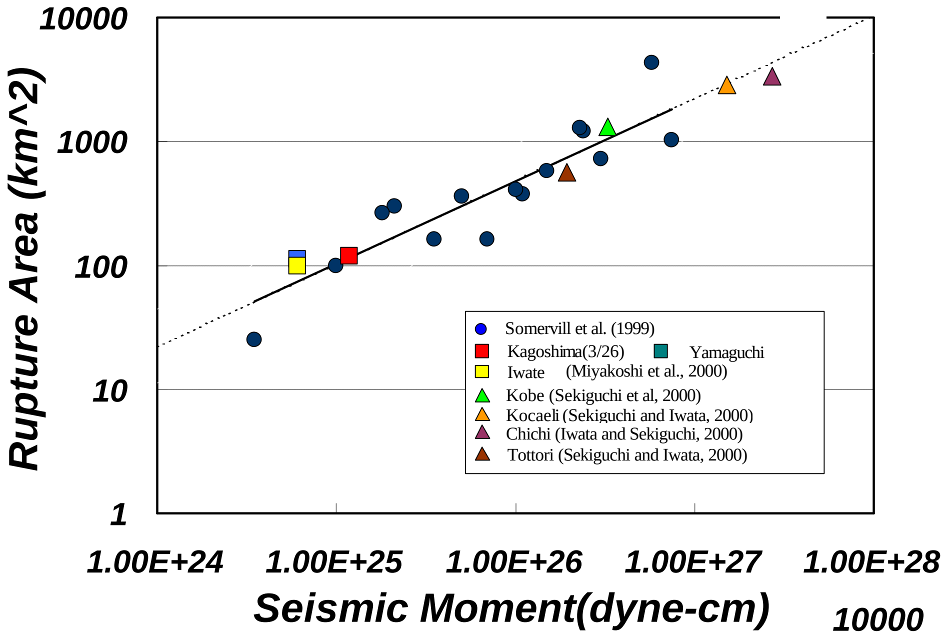


effective source dimension

(L_{eff}, W_{eff} are derived by auto-correlation of slip distribution)



Mai and Beroza (2000)

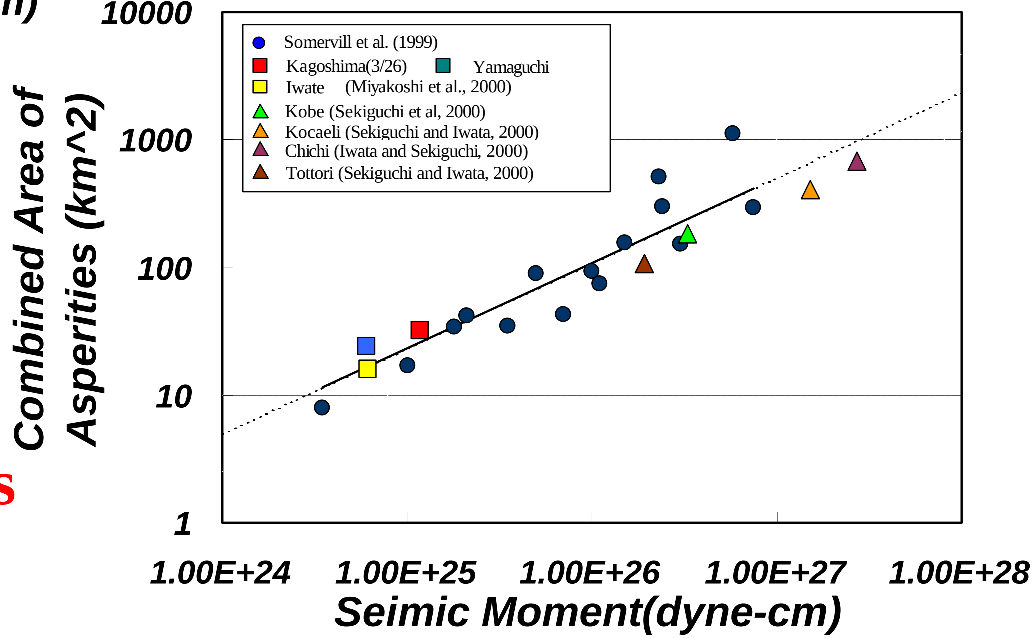


Relation between Rupture Area and M_0

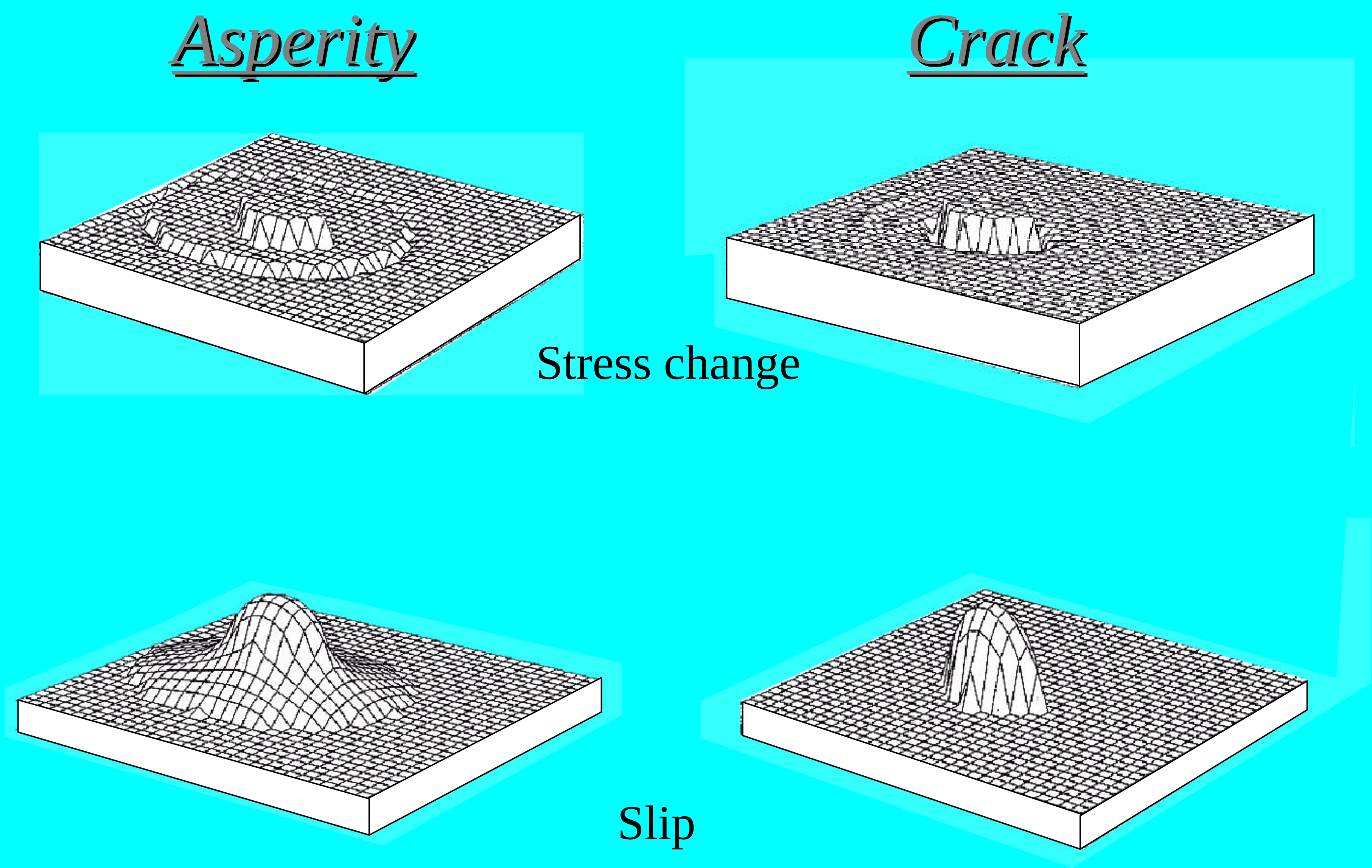
→ **Outer Fault Parameters**

Relation between Combined Area of Asperities and M_0

→ **Inner Fault Parameters**



Somerville *et al*. (1999) and Miyakoshi *et al*. (2001)



Boatwright (1988)

Recipe Combined with Dynamic Asperity-Source Model (Irikura et al., 2002)

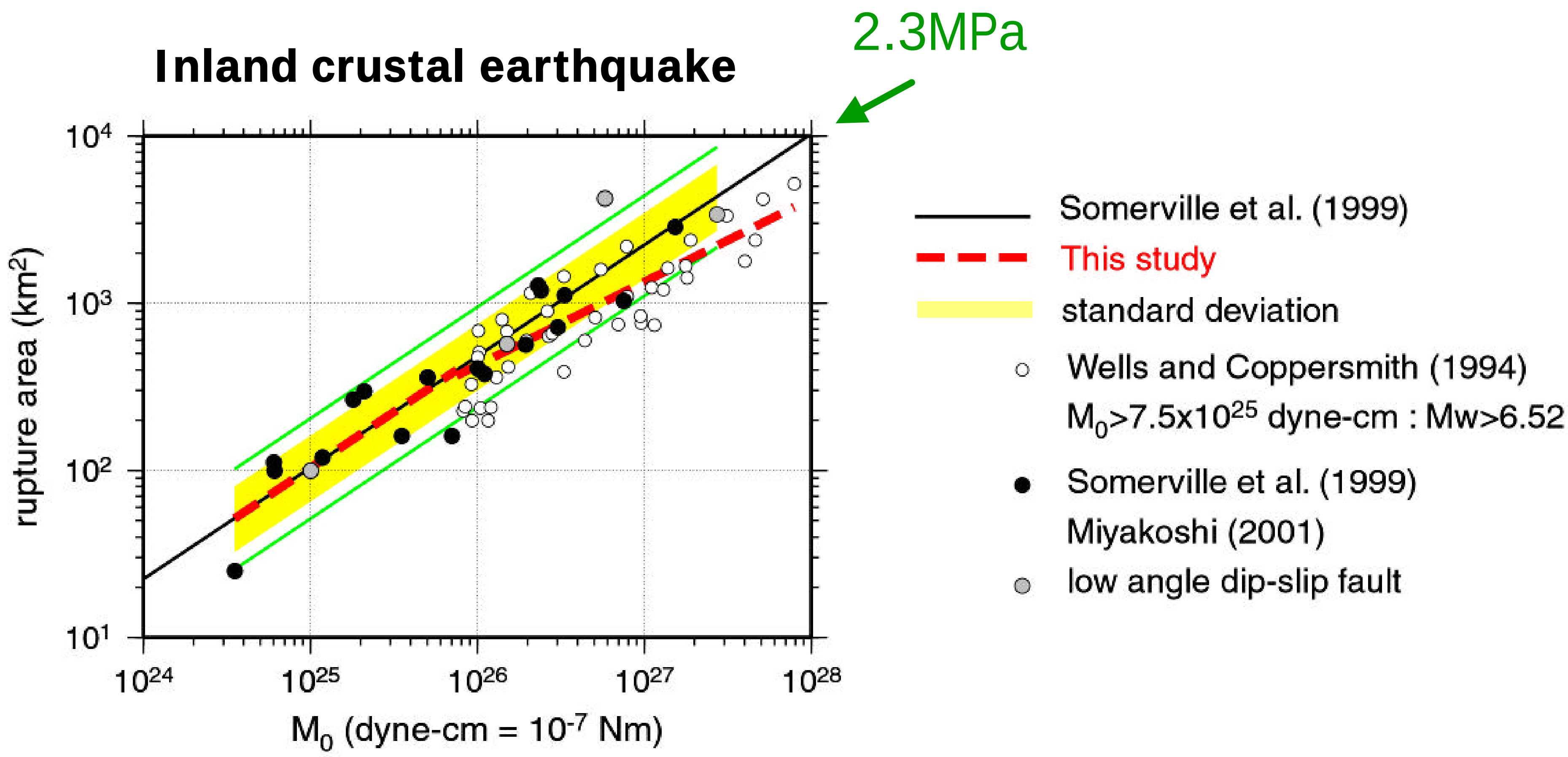
Strong ground motions are estimated from inner fault parameters for fault heterogeneity as well as outer fault parameters for entire rupture area and total seismic moment.

We propose deductive source model based on multiple-asperity model. (Previous recipe was based on multiple-crack model.)

Applicability of the recipe is examined for the 2000 Tottori earthquake using stochastic Green's function method (Kamae et al., 1991)

Empirical Relationships for Outer Fault Parameters

- Total Rupture Area (S) and Seismic Moment (Mo) -



Irikura and Miyake (2001)

Outer Fault Parameters

- Step 1: Total rupture area (S) is given by products of total fault length (L) and fault width (W).

- Step 2: Average static stress-drop ($\Delta\bar{\sigma}_c$) on the fault is assumed.(inland crustal earthquake: about 2.3MPa)

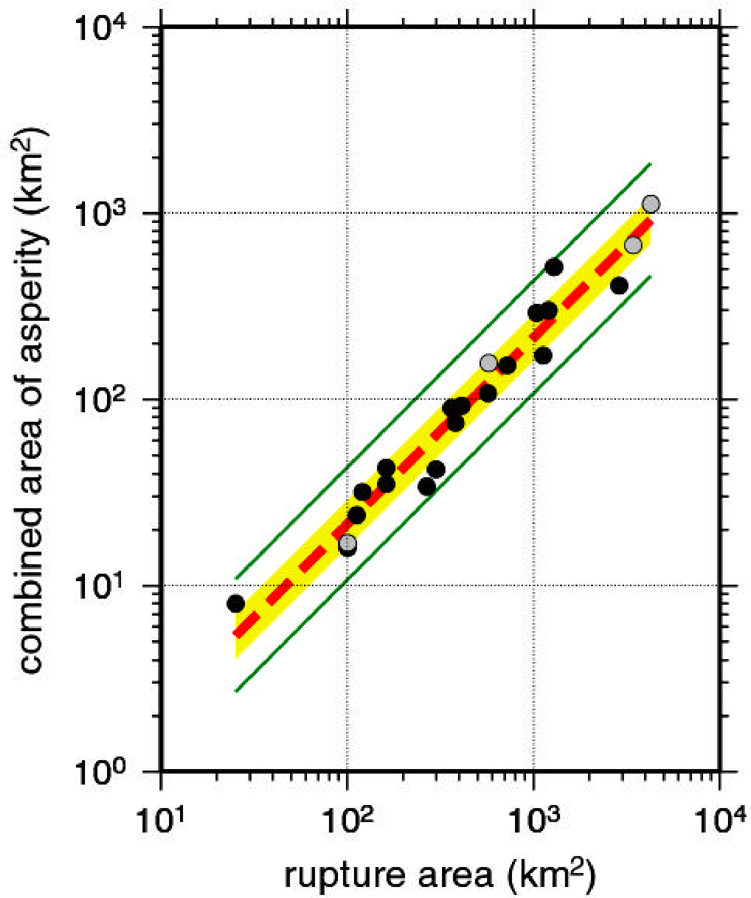
- Step 3: Total seismic moment (Mo) is estimated by S and $\Delta\bar{\sigma}_c$ assuming circular crack (Eshelby, 1957).

$$M_0 = \frac{16}{7\pi^{1.5}} \Delta\bar{\sigma}_c \cdot S^{1.5}$$

Empirical Relationships for Inner Fault Parameters (1)

- Combined Asperity Size (Sa) and Total Rupture Area (S) -

Inland crustal earthquake



Sa = 0.29 S (+ S.D.)

Sa = 0.215 S (average)

Sa = 0.16 S (- S.D.)

This study

standard deviation

● Somerville et al. (1999)

Miyakoshi (2001)

○ low angle dip-slip fault

Irikura and Miyake (2001)

Inner Fault Parameters (1)

- Step 4: Combined area of asperities (Sa) is estimated by the empirical relationship between Sa and S.
- Step 5: Stress stop on asperity is calculated by equations for multiple-asperity model.

  (inland crustal earthquake: about 10.5MPa)

$$\Delta\sigma_a = \Delta\bar{\sigma}_c \cdot \frac{S}{S_a}$$

- Step 6: Average slip for each asperity is estimated.

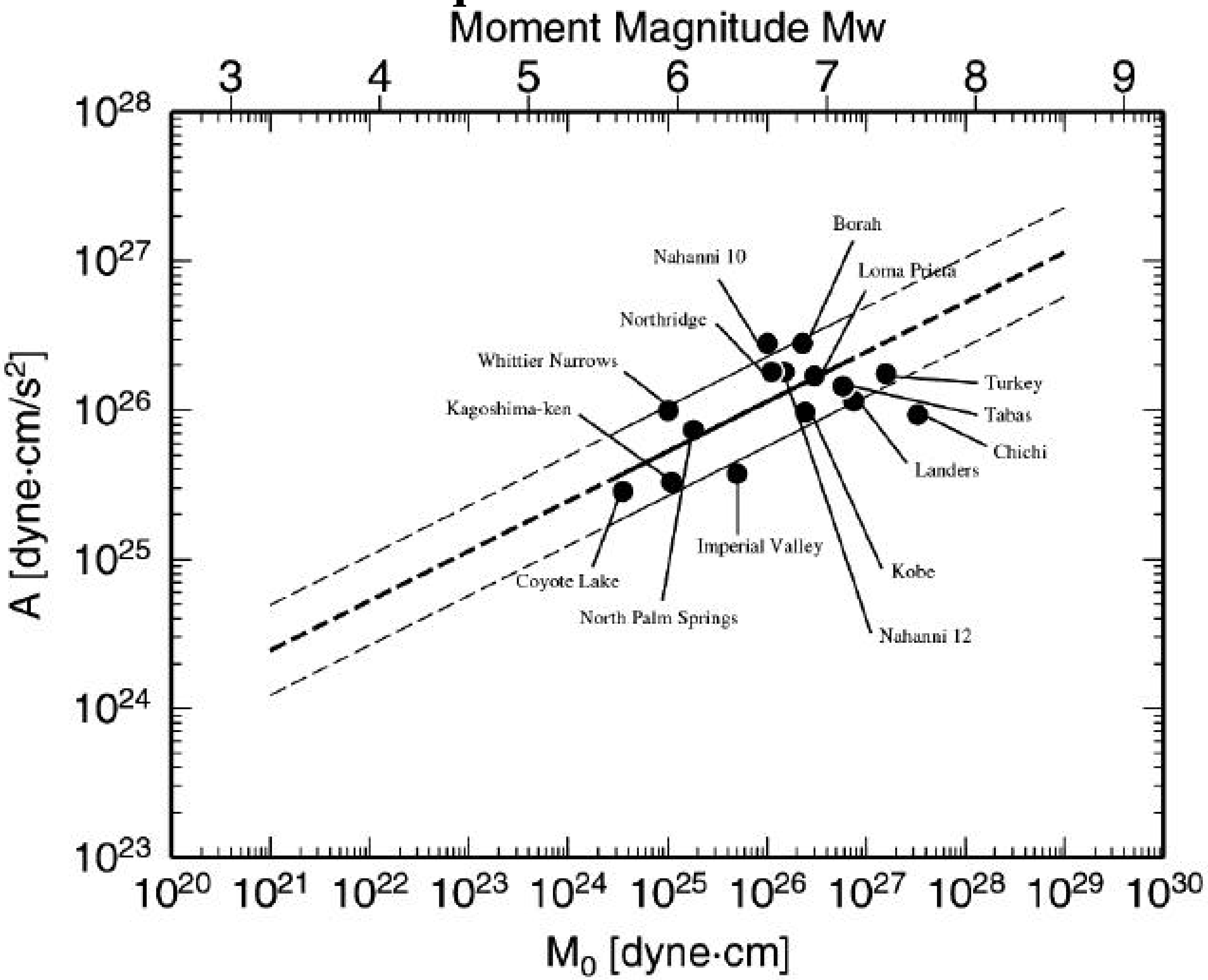
$$D_a^i = C \cdot \frac{\Delta\sigma_a}{\mu} \cdot r_i$$

- Step 7: Number of asperities is defined by Step 6.

Empirical Relationships for Inner Fault Parameters (2)

- Short-period Source Spectra Level (A) and Mo -

Inner Earthquakes



Empirical Relationship shows $A \propto Mo^{1/3}$

Dan et al. (2002)

Inner Fault Parameters (2)

- Stress drop on asperity ($\Delta\sigma_a$) is treated as effective stress (σ_a) on asperity.

- Step 8: Summation of effective stress on asperities (σ_a) and background slip area (σ_b) is constrained by the empirical relationship between short-period spectral level and Mo.

$$A_0 = \sqrt{\sum_{i=1}^{N} \left(A_{0i}^{a}\right)^2 + \left(A_{0i}^{b}\right)^2}$$

asperities background

$$A_0^a = 4 p b v_R \cdot s_a \cdot r$$
$$= 4\sqrt{p}\, b v_R \cdot s_a \cdot \sqrt{S_a}$$

Then $Ao^a \propto Mo^{1/3}$

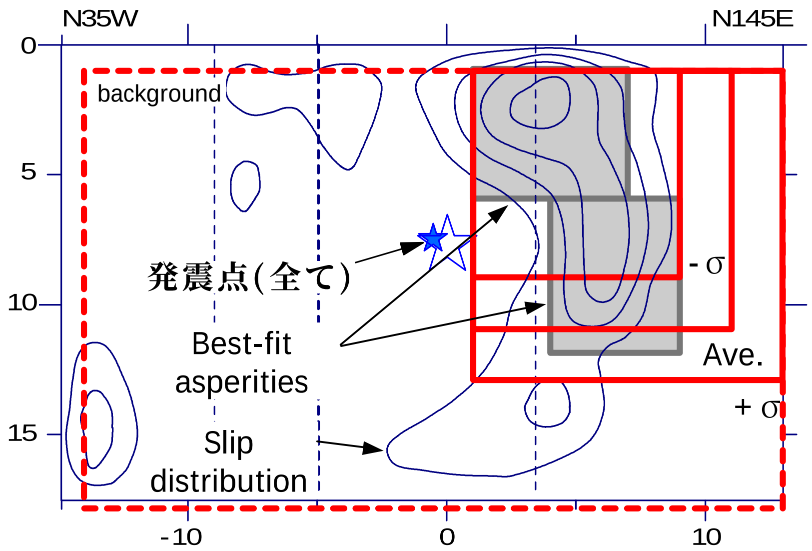
because $(S_a/S)^{1/2}$=const and $S^{1/2} \propto Mo^{1/3}$

- Step 9: parameterization of slip velocity time functions

Applicability of the Recipe

- 2000 Tottori-ken Seibu Earthquake: Mw6.6 -

Deductive source model



Effective stress on asperity and background is variable.

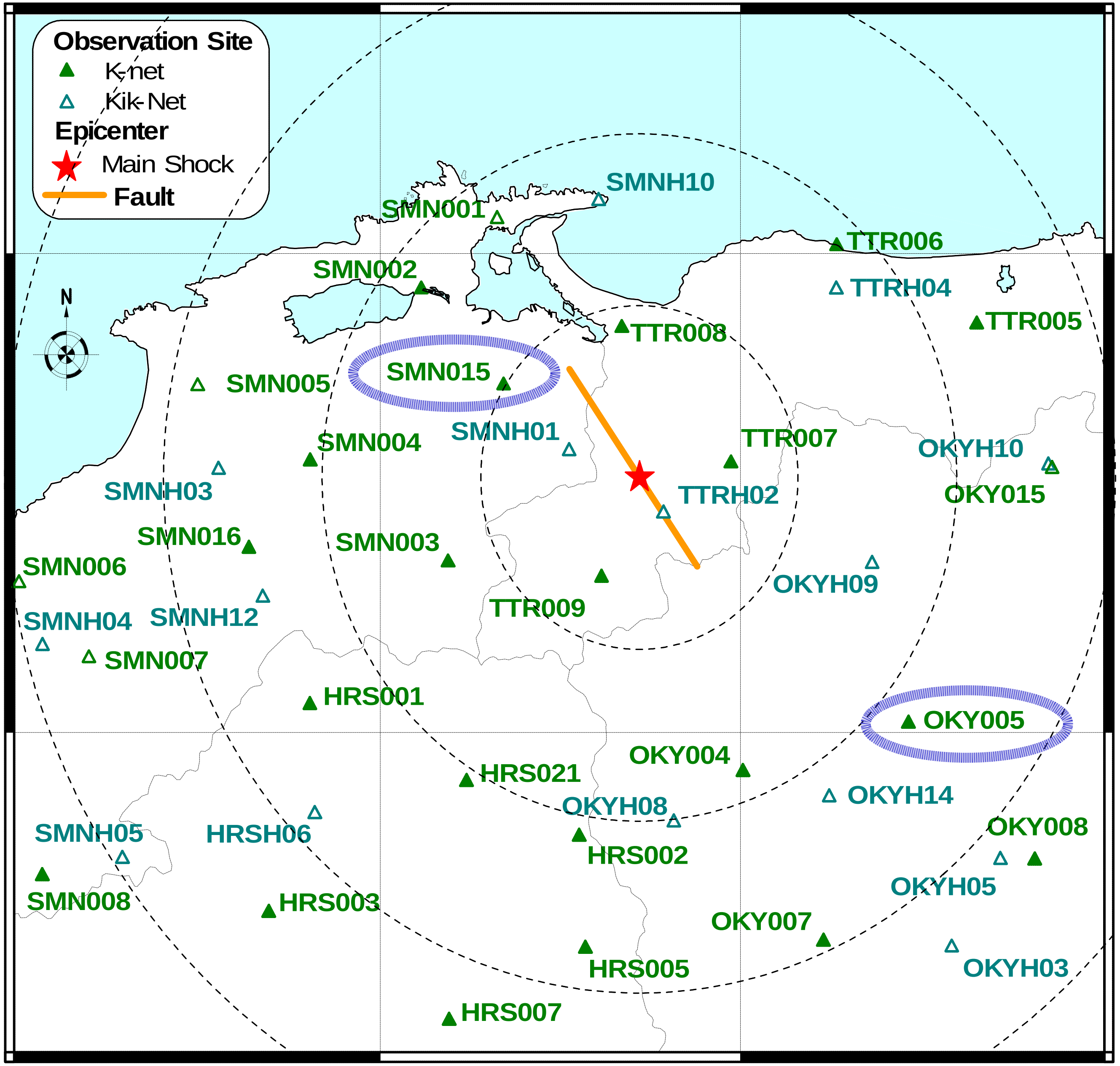
Ikeda et al. (2002)

Source parameters obtained by the recipe

		Case 1 (+σ)	Case 2 (ave.)	Case 3 (−σ)
total	Mo	9.6	9.6	9.6
	S	468	468	468
	Δσ	2.3	2.3	2.3
asperity	Mo	5.8	4.3	3.2
	S_a	141	105	78
	$\Delta\sigma_a$	7.7	10.3	13.8
	τ_a	1.32	1.13	0.98
Back ground	Mo	3.8	5.3	6.4
	S_b	327	363	390
	$\Delta\sigma_b$	5.1	4.0	2.2
	τ_b	2.01	2.11	2.18

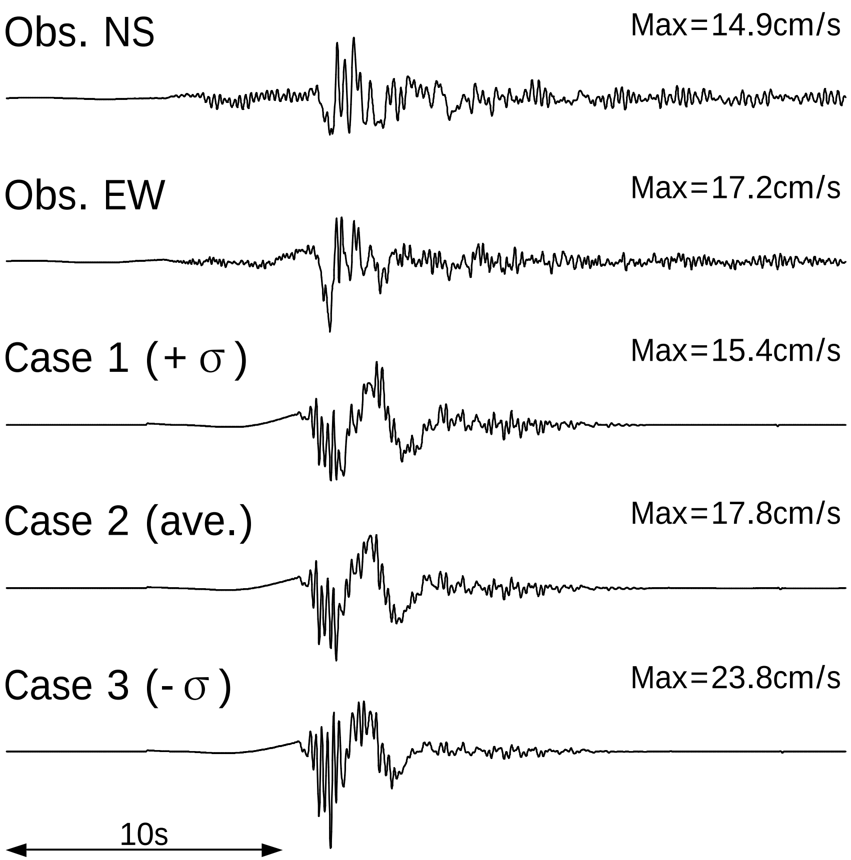
Mo(10^{25}×dyne・cm), S(km^2), Δσ(MPa), τ(s)

Stations

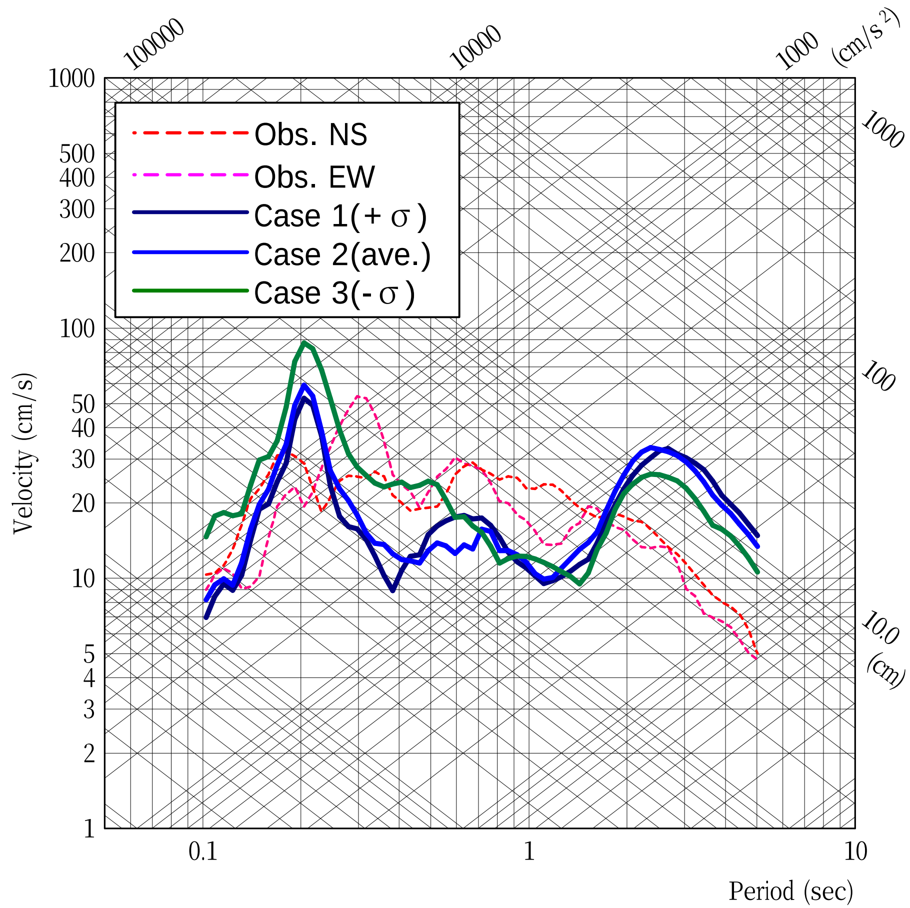


Ikeda et al. (2002)

Velocity at OKY005 (forward direction)

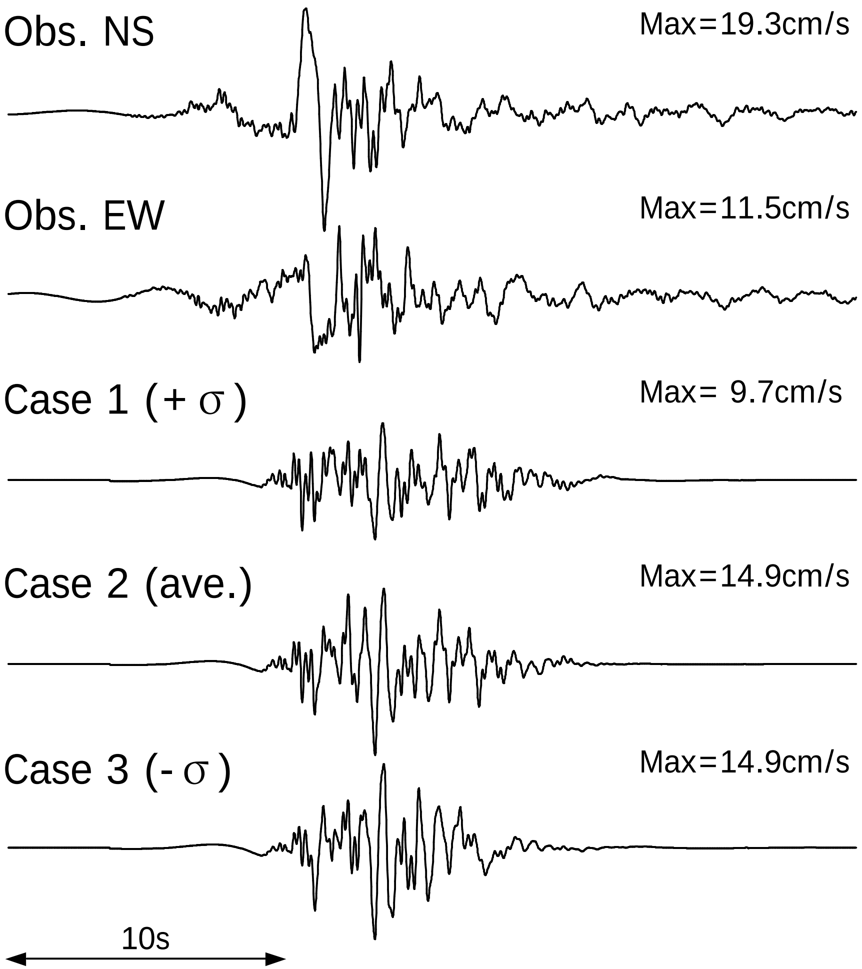


Acceleration Response Spectra at OKY005 (h=0.05)

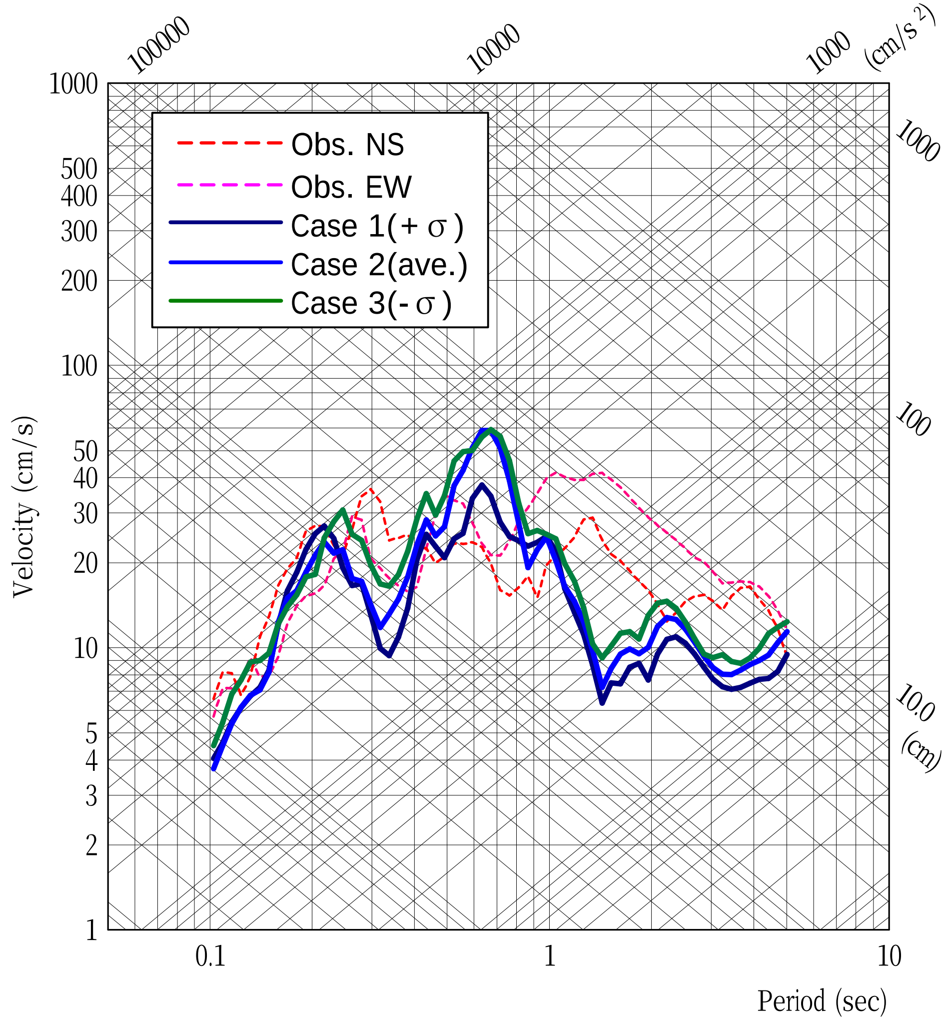


Ikeda et al. (2002)

Velocity at SMN015 (backward direction)



Acceleration Response Spectra at SMN015 (h=0.05)

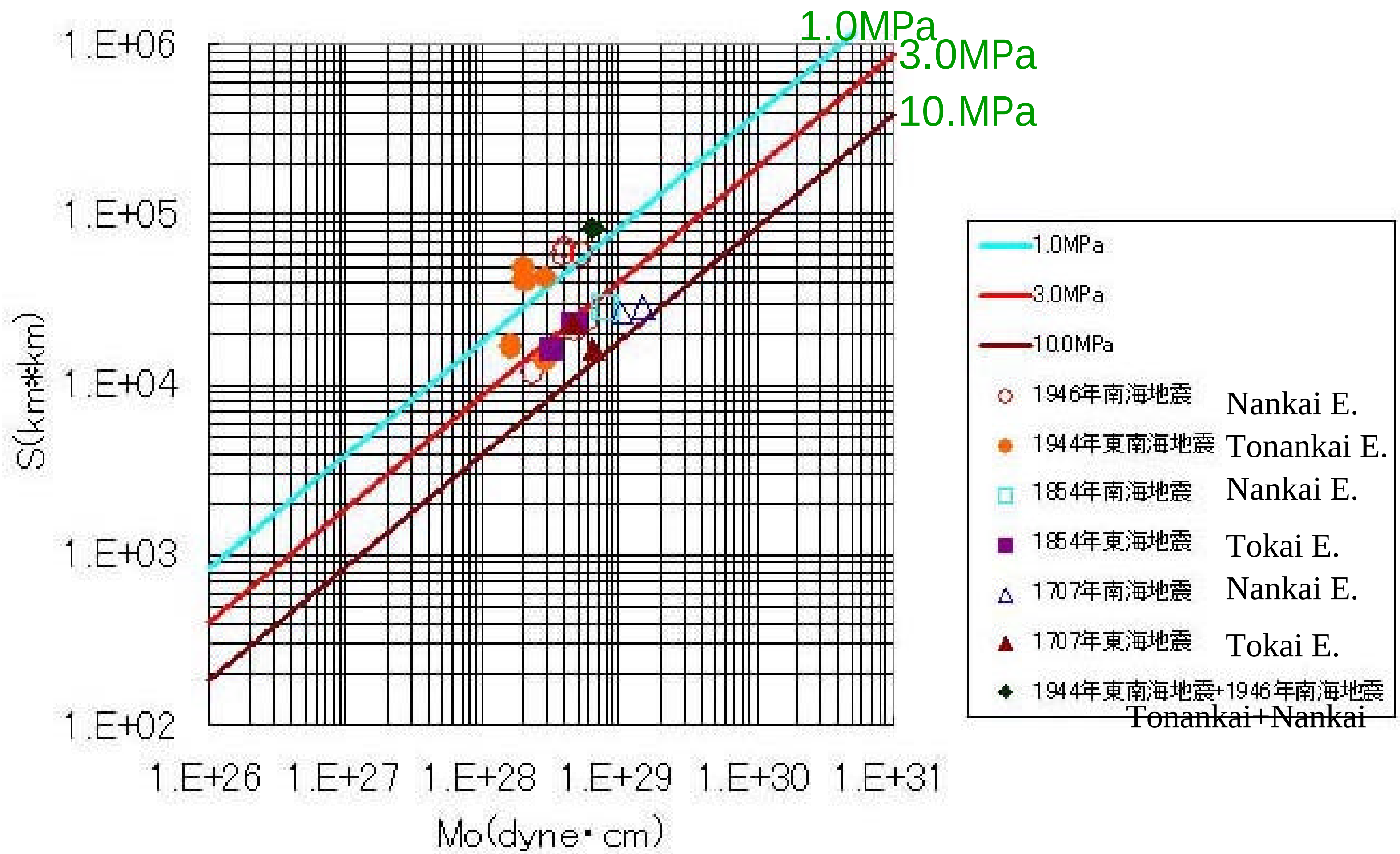


Ikeda et al. (2002)

Empirical Relationship for Outer Fault Parameters

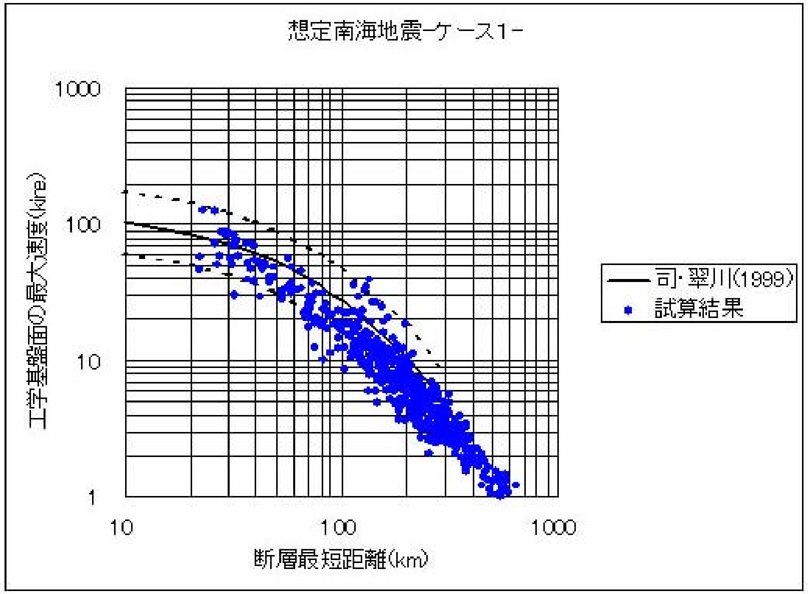
- Total Rupture Area (S) and Seismic Moment (Mo) -

- Subduction Earthquakes along Nankai Trough-



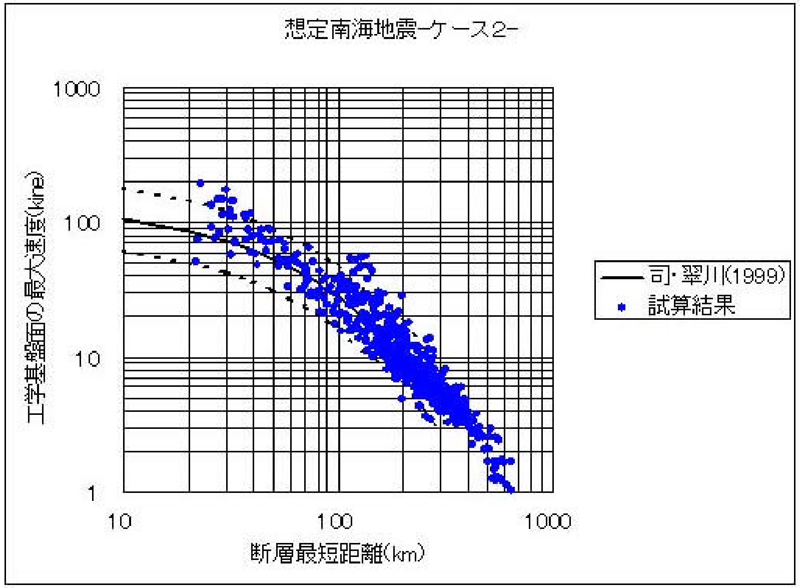
Earthquake Research Committee(2001)

Attenuation Curve for PGV



Case 1

Effective stress on asperities = 10.1MPa

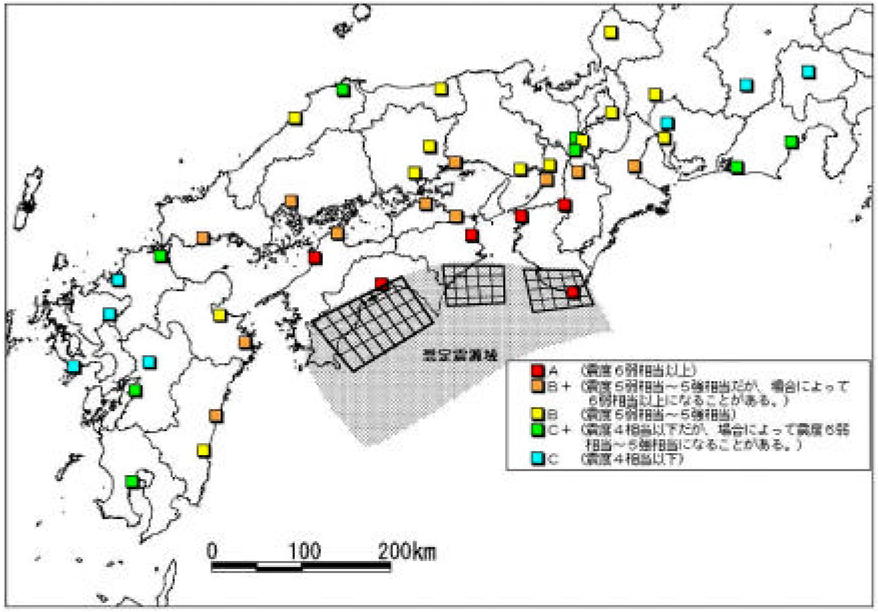


Case 2

Effective stress on asperities = 20.1MPa

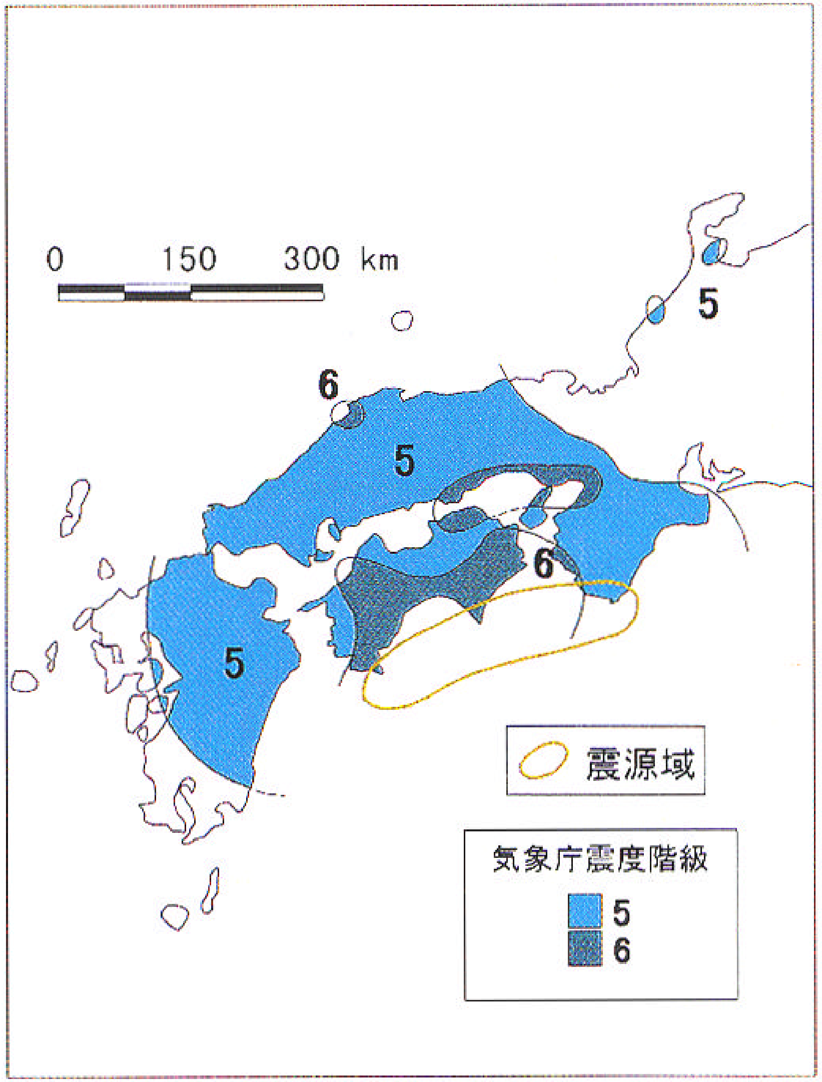
Earthquake Research Committee (2001)

Seismic Intensity for Hypothetical Nankai Earthquake



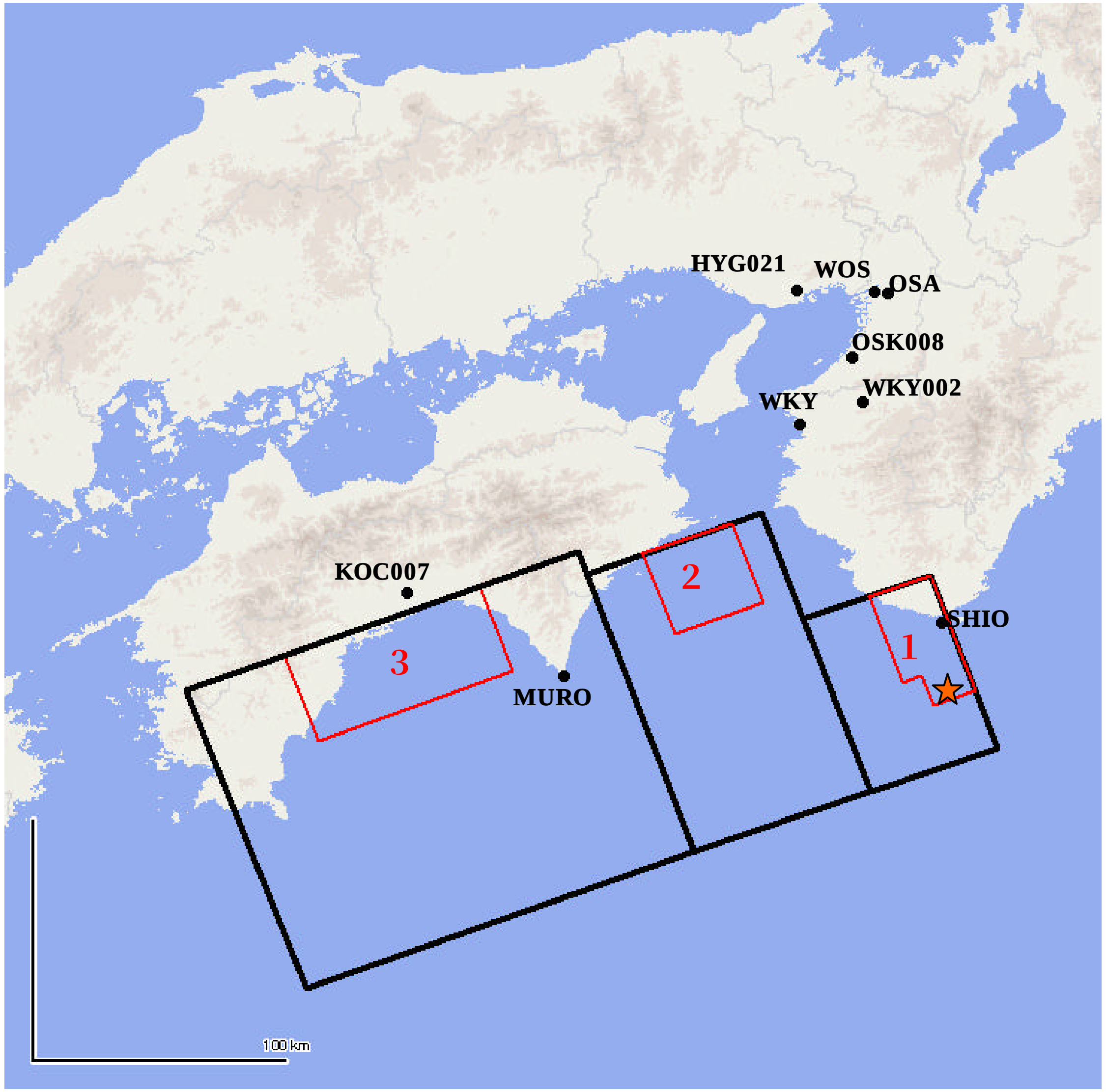
Earthquake Research Committee (2001)

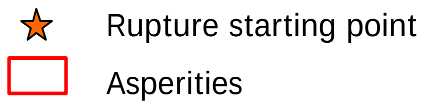
Seismic Intensity for the 1854 Ansei Nankai Earthquake



Earthquake Research Committee (1999)

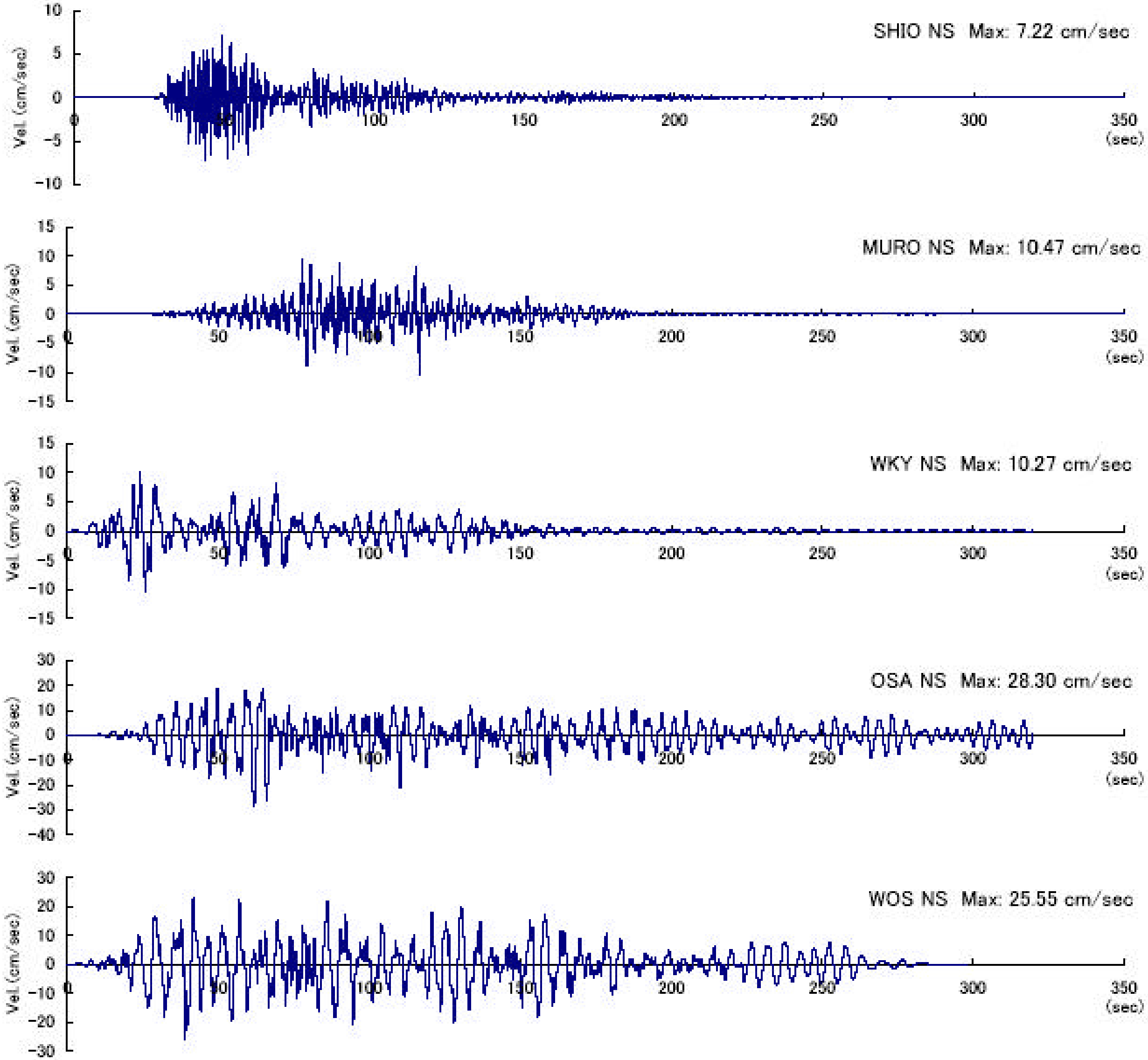
Source Model of Hypothetical Nankai Earthquake



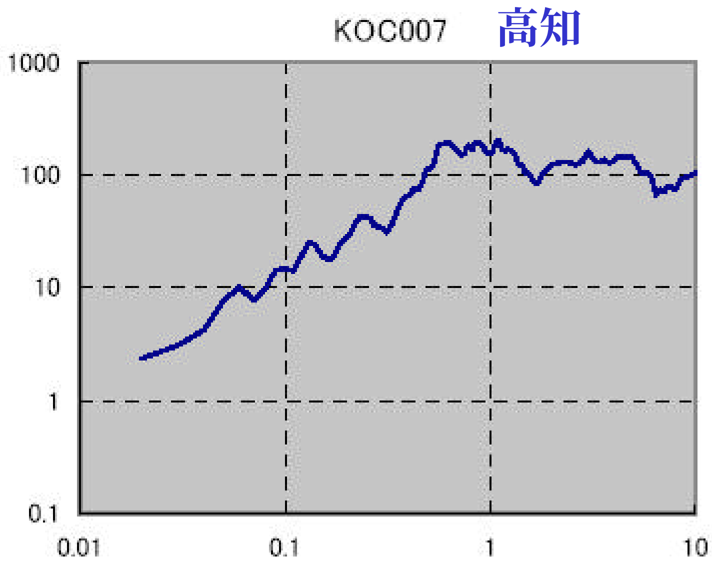


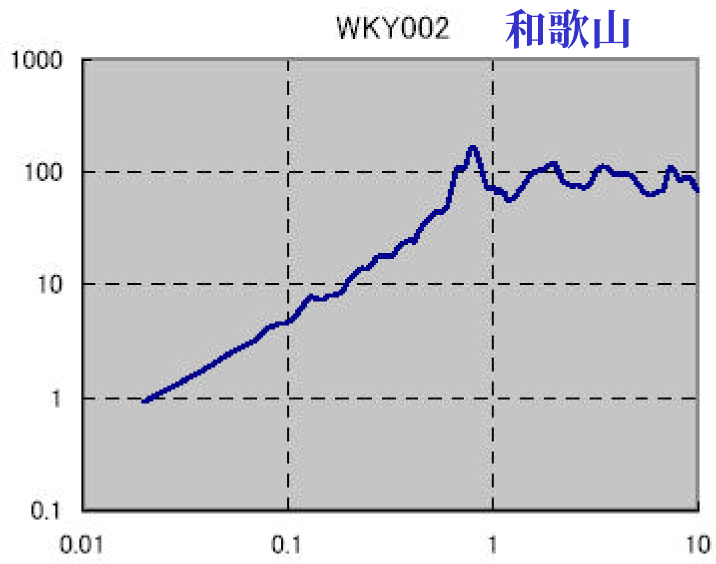
Synthetic Ground Motions from Hypothetical Nankai Earthquakes

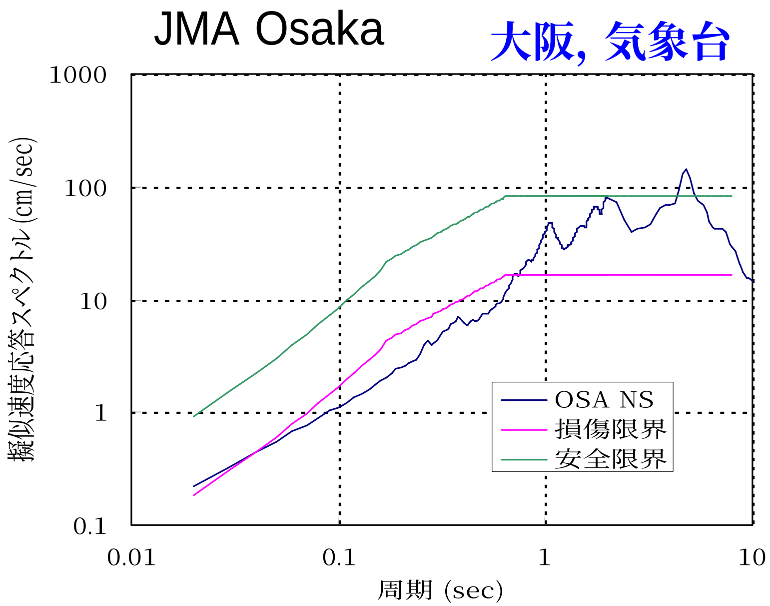
- Empirical Green's function Method -



Pseudo-Velocity Response Spectra of Hypothetical Nankai Earthquake







Conclusions

- Our recipe for predicting strong ground motion only needs total rupture area (S) and average stress drop ($\overline{\Delta\sigma_c}$) on the fault. Then, total seismic moment (Mo), and the size and effective stress of asperities are given.
- Effective stress is differently estimated for multiple-crack model and multiple-asperity model in case of number of asperities increasing.
- The maximum amplitude of predicted motions are within a factor of 0.5 to 2.0 for 1σ variance of the inner fault parameters.

Asperity Model and Crack Model

Case 1. single asperity

asperity

short period level $A^{1}_{0\,asperity} = 4pbv_R \Delta s_{\,a} a$

long period level $M_0^1 = \dfrac{16}{7} \Delta s_{\,a} a^2 R$

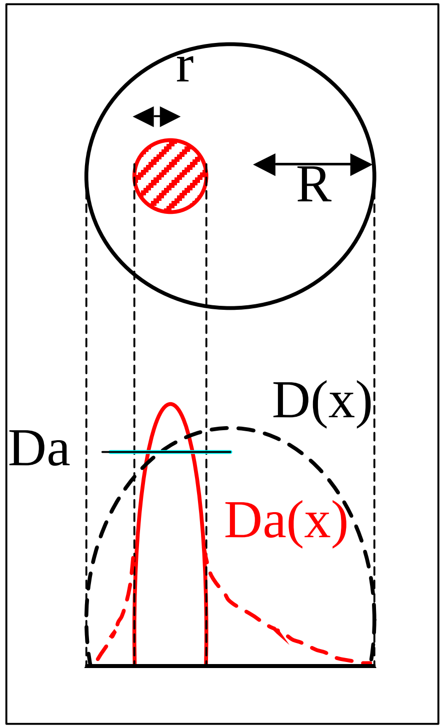
stress drop $\boldsymbol{\Delta\,\sigma}\,a = (7/16)\ M_0/(Rr^2)$

crack

short period level $A^{1}_{0\,crack} = 4pbv_R \Delta s_{\,c} a$

long period level $M^{1}_{0\,crack} = \dfrac{16}{7} \Delta s_{\,c} a^3$

stress drop $\Delta s_{\,c} = \dfrac{7p^{3/2}}{16} \dfrac{Mo_a}{S_a^{\,3/2}}$



r<<R

Δσ for single asperity (=9.5MPa) = Δσ for single crack (=9.6MPa)

Asperity Model and Crack Model

Case 2. multiple asperities

multiple asperity model

short period level

$$A_{0\ asperity}^{N} = \left\{ \sum_{i=1}^{N} (4pbv_R \Delta s_{ai} a_i)^2 \right\}^{\frac{1}{2}} = 4pbv_R \Delta s_{ai} a$$

long period level

$$M_0^N = \sum_{i=1}^{N} \left(\frac{16}{7} \Delta s_{ai} a_i^{\,2} R_i\right) = \frac{16}{7} \Delta s_{ai} a^2 R$$

stress drop

$$\Delta s_a = \Delta s_{ai} = \frac{7}{16} \frac{M_0^1}{a^2 R}$$

multiple crack model

short period level

$$A_{0\ crack}^{N} = \left\{ \sum_{i=1}^{N} (4pbv_R \Delta s_{ci} a_i)^2 \right\}^{\frac{1}{2}} = 4pbv_R \Delta s_{ci} a$$

long period level

$$M_{0\ crack}^{N} = \sum_{i=1}^{N} \left(\frac{16}{7} \Delta s_{ci} a_i^{\,3}\right) = \frac{1}{a} \frac{16}{7} \Delta s_{ci} a^3 \quad (1 < a < \sqrt{\mathrm{N}})$$

stress drop

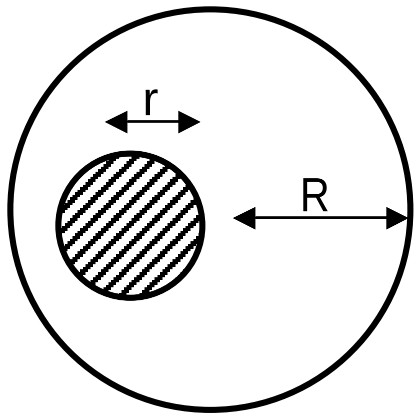
$$\frac{\Delta s_{ci}}{\Delta s_c} = \frac{A_{0\ crack}^{N}}{A_{0 crack}^{1}} = a \frac{M_{0\ crack}^{N}}{M_{0 crack}^{1}}$$

What's New ?　-Stress drop on asperity-

multiple-crack model　　multiple-asperity model

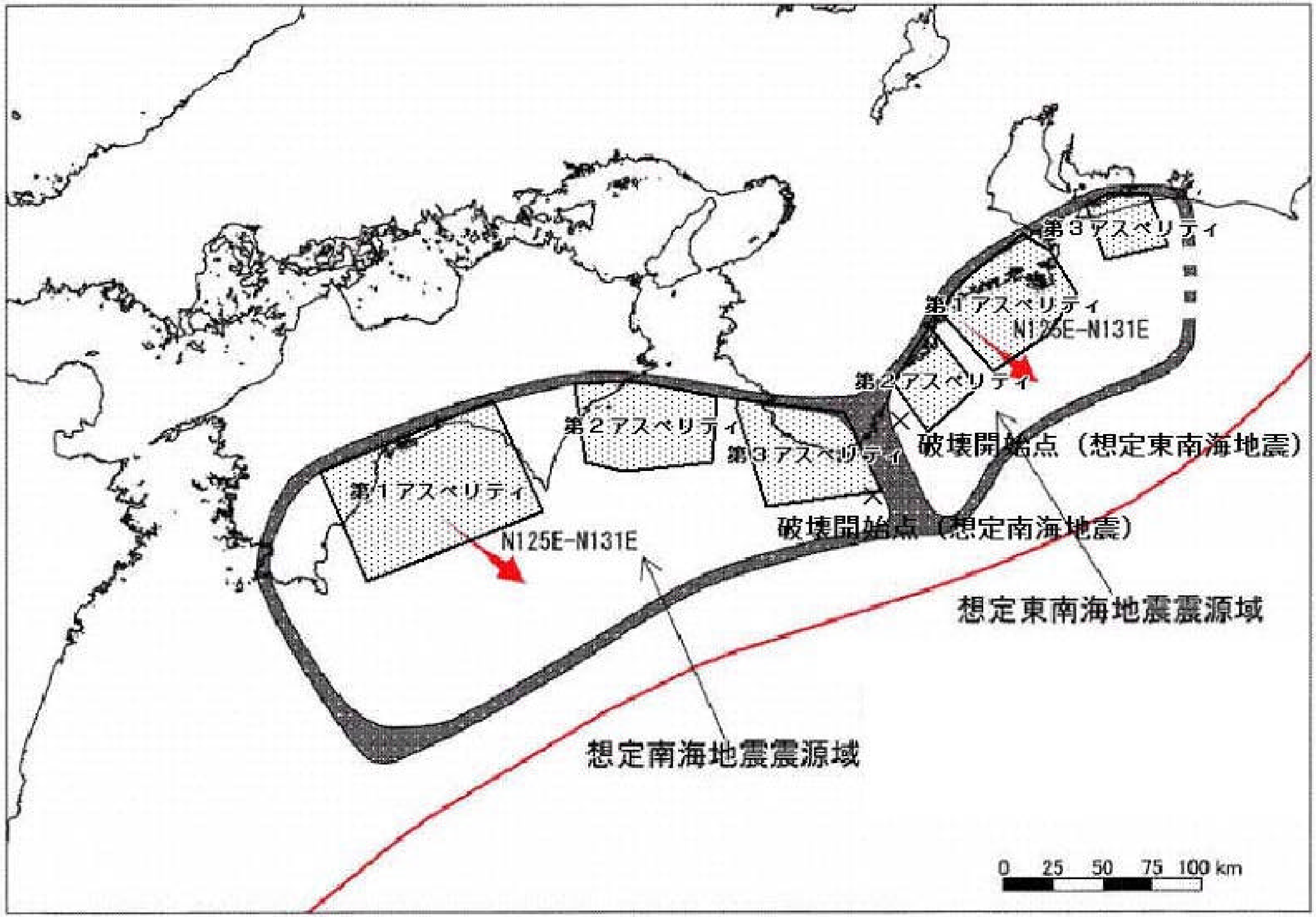
$$\Delta\sigma_c = \frac{7}{16}\frac{M_{0asp}}{r^3} \qquad \Delta\sigma_a = \frac{7}{16}\frac{M_0}{Rr^2}$$

	multiple-crack model	multiple-asperity model
n=1:	9.6MPa	10.5MPa
n=2:	9.6 - 13.6MPa	10.5MPa
n=N:	9.6 - 9.6 $\sqrt{N}$ MPa	10.5MPa



For $\pi r^2/\pi R^2=0.22$

Applicability of the Recipe
-Hypothetical Tonankai and Nankai earthquakes-



Earthquake Research Committee (2001)