

地震動特徵專題講座之一 - 地震動模擬技術應用之現況與展望

地震波模擬技術應用簡介

顏 銀 桐

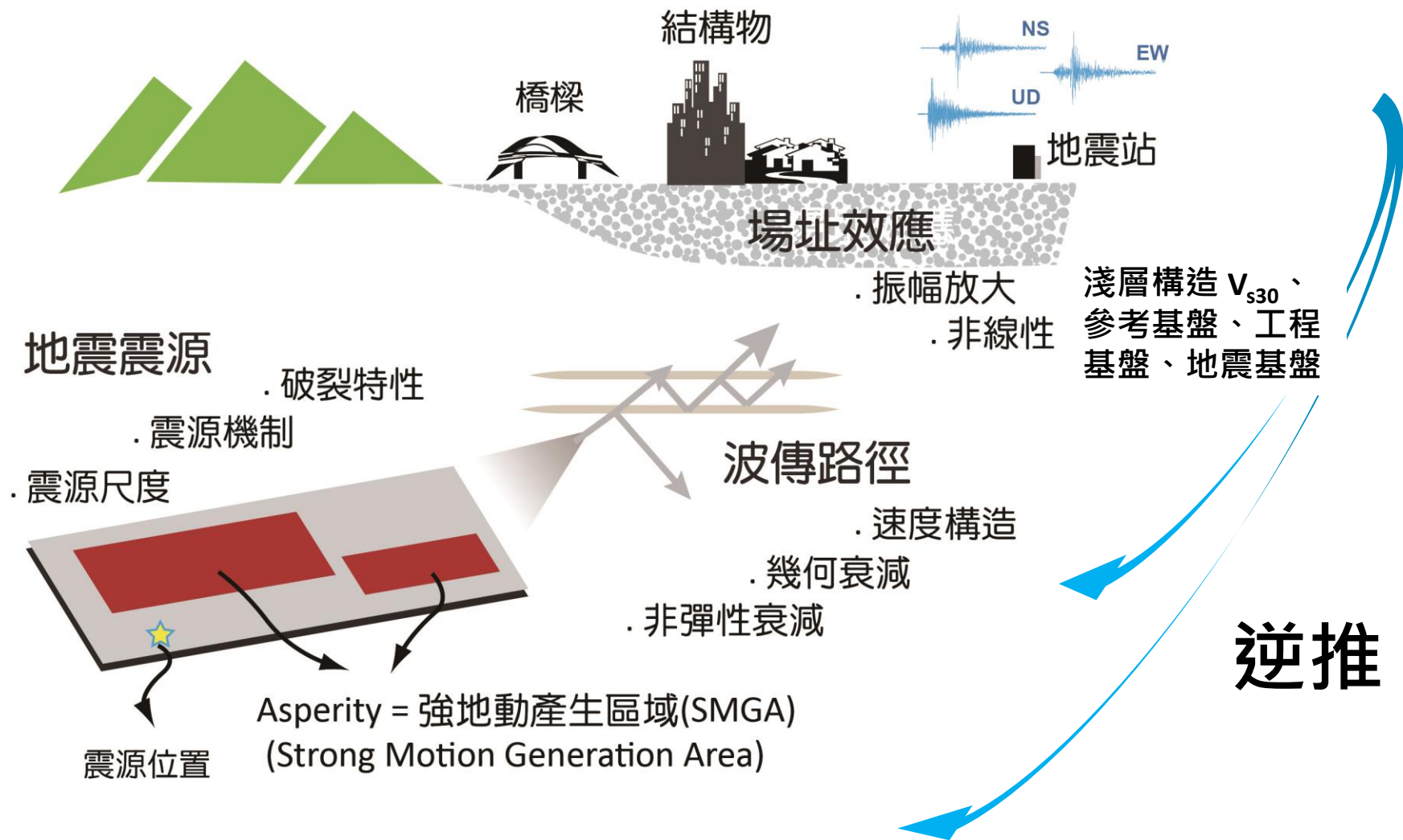
財團法人中興工程顧問社 防災科技研究中心

2018.08.28 @ 國家實驗研究院 國家地震工程研究中心

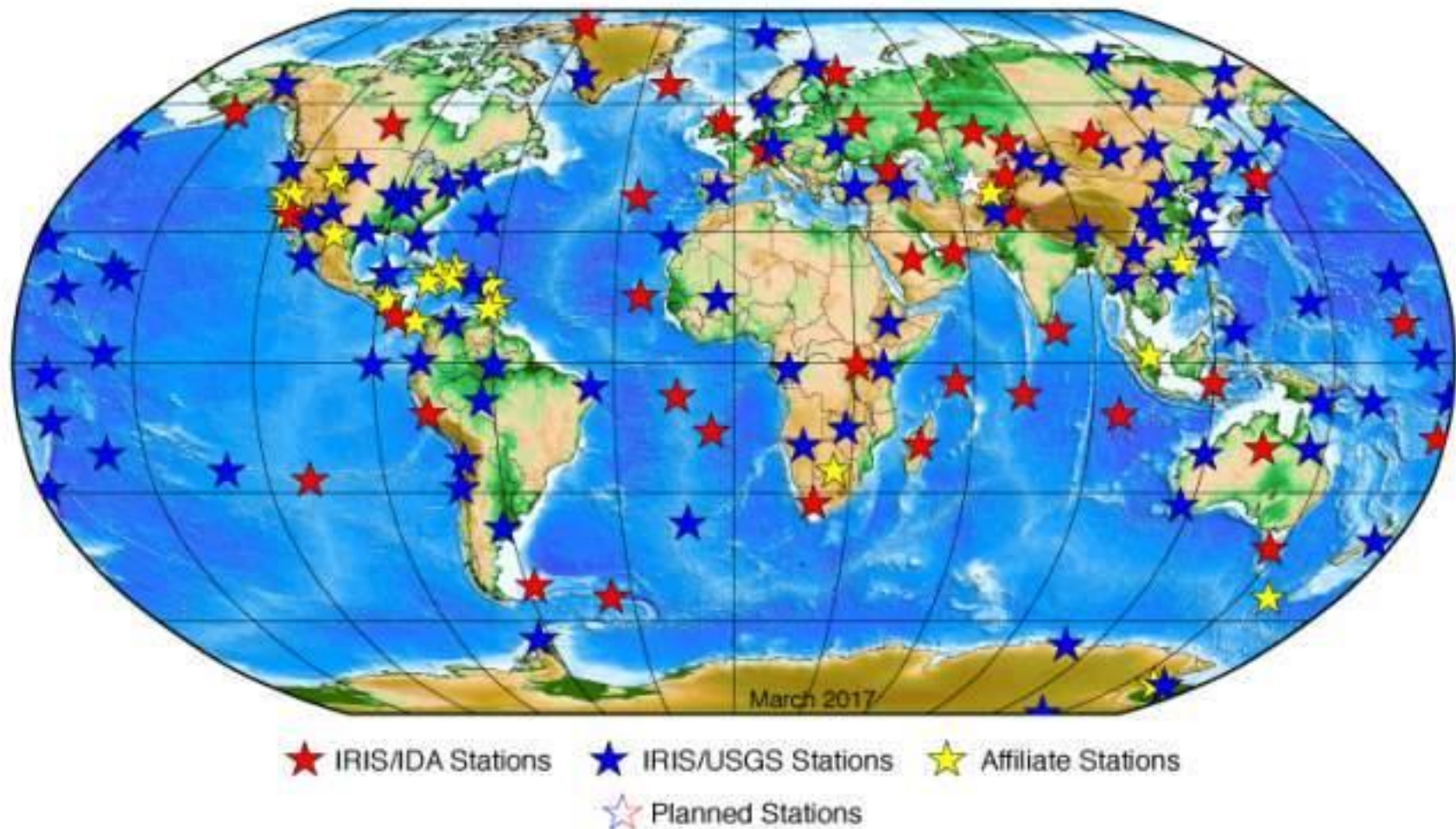
內容大綱

- 演進背景及衍生議題
- 美日核電之應用概況
- 發展應用之願景淺談

演進背景及衍生議題



資料應用範疇 - I



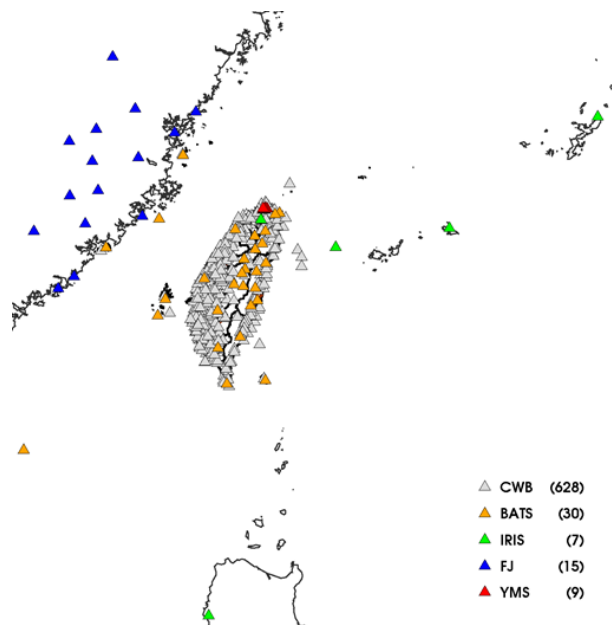
全球地震監測網, 美國地震聯合研究機構

Global Network, Incorporated Research Institutions for Seismology, USA

資料應用範疇 - II

CWBSN

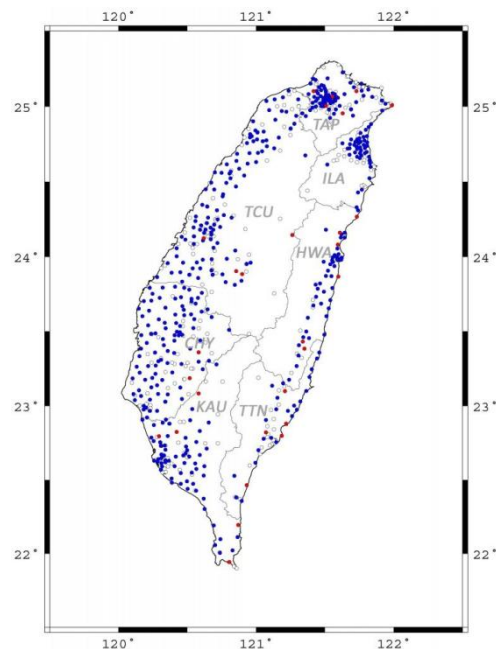
中央氣象局地震觀測網



- ◆ 地震目錄建置
- ◆ 地震速報預警
- ◆ 海嘯資訊發布
- ◆ 地體構造與地震相關研究

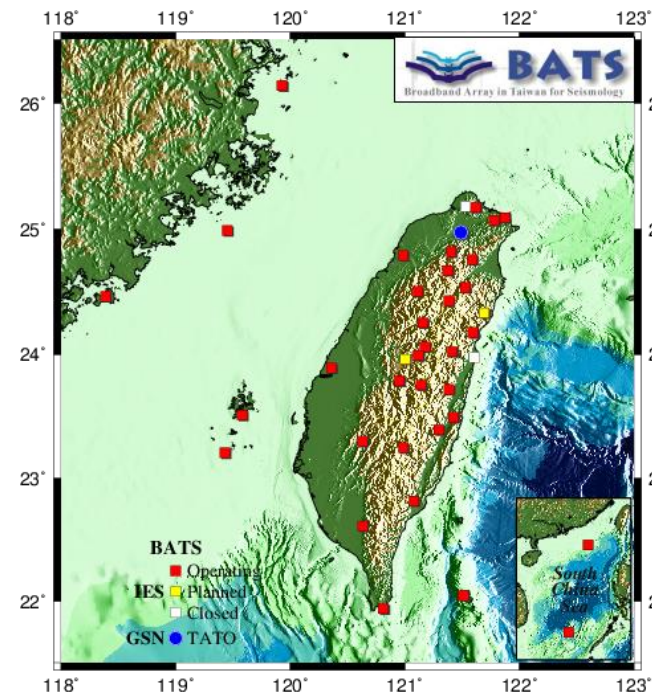
TSMIP

台灣強地動觀測網



- ◆ 強震紀錄資料庫建置
- ◆ 強地動觀測學研究
- ◆ 耐震設計規範
- ◆ 地震工程應用

中央研究院 地球科學所



Data Management Center, Institute of Earth Sciences, Academia Sinica
<http://dmc.earth.sinica.edu.tw> <http://bats.earth.sinica.edu.tw>

- ◆ 科研應用
- ◆ 即時震源機制

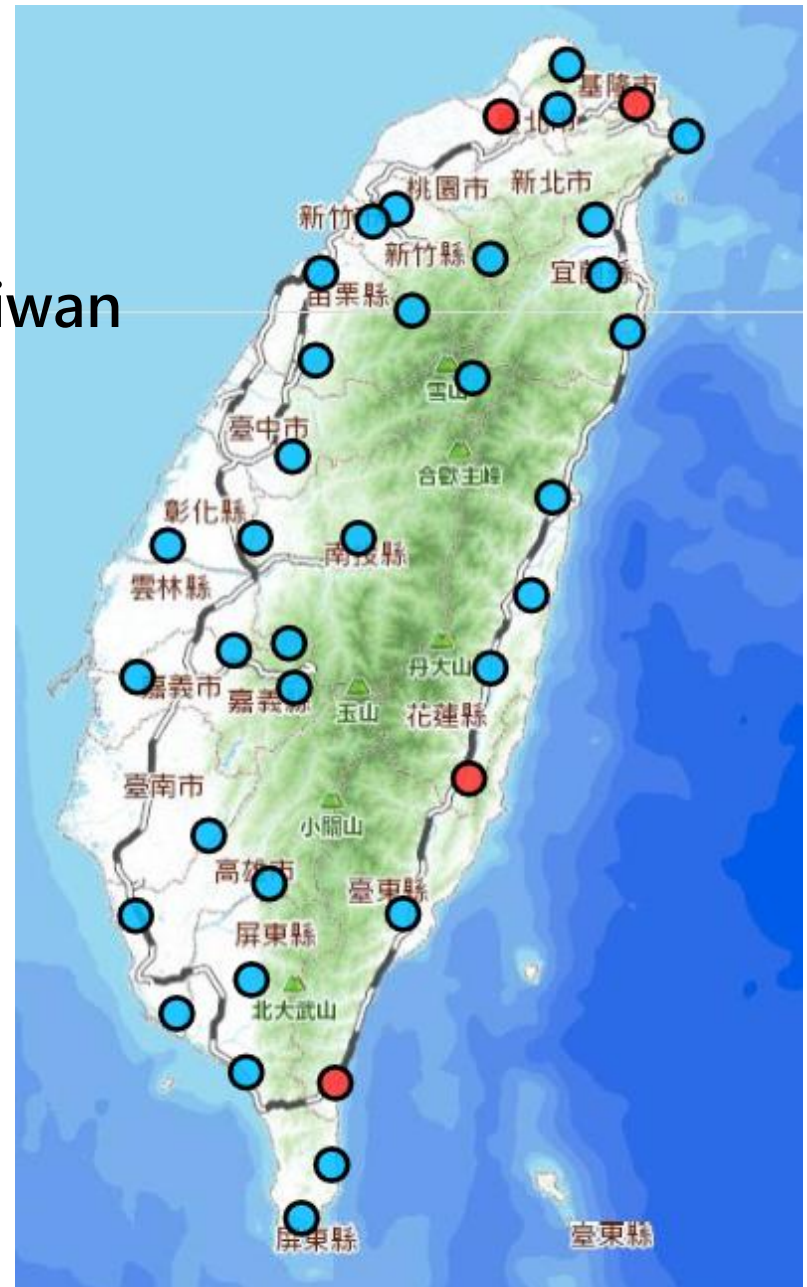
資料應用範疇 - III

國家地震工程中心

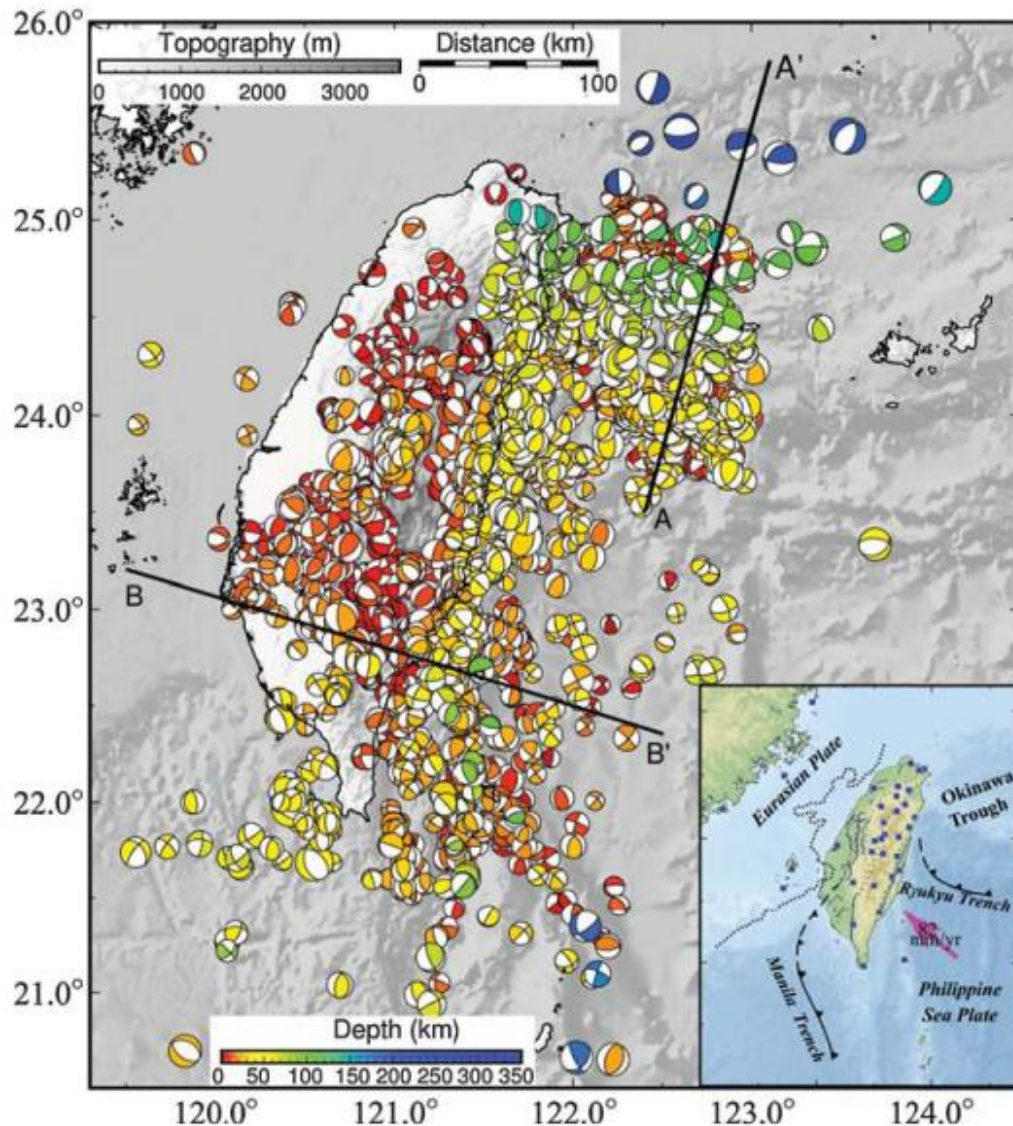
The Seismic Array of NCREE in Taiwan
(SANTA)

~ 40 stations

- Strong Motion
- Broadband



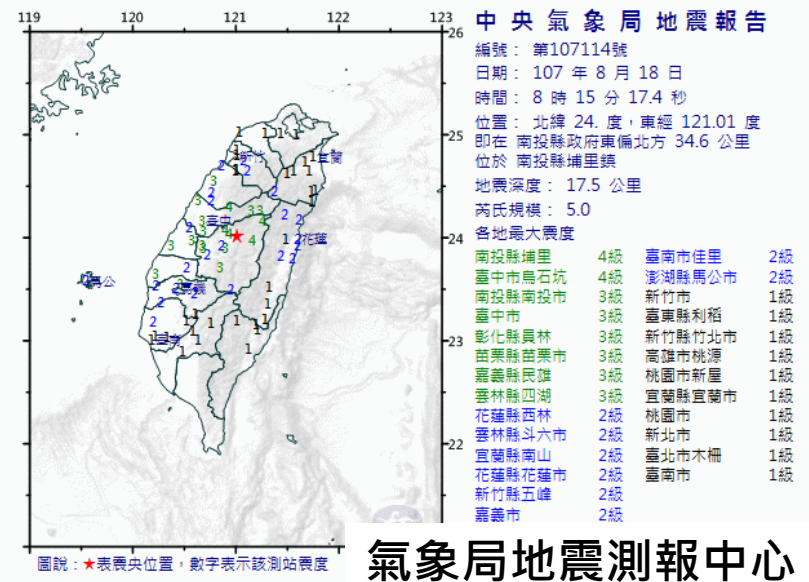
地震震源 -> 路徑 -> 場址



(Jian et al., 2018)

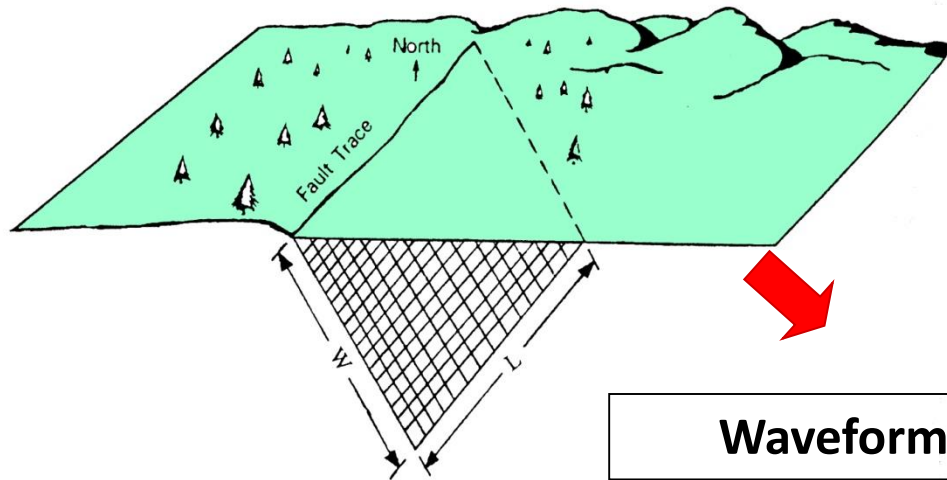
震源參數及機制解算單位

- 氣象局地震測報中心
- 中研院地球科學所(BATS)
- 美國地質調查所(USGS)
- Global CMT



斷層破裂面上之錯動量分布 (Source model or Slip distribution)

波形逆推 - 走向、傾角、滑移角 長度、寬度及滑移量



$$Ax = B$$

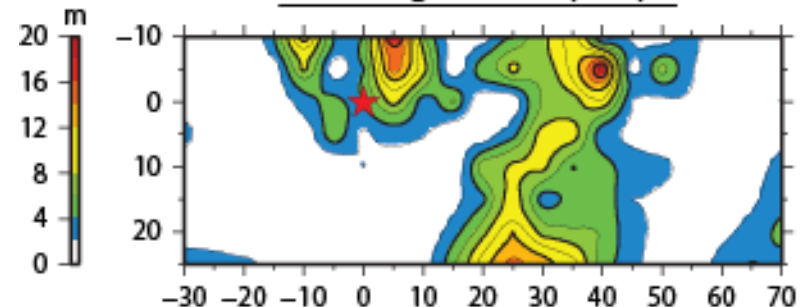
Waveform Inversion

震源部分
詳細分析



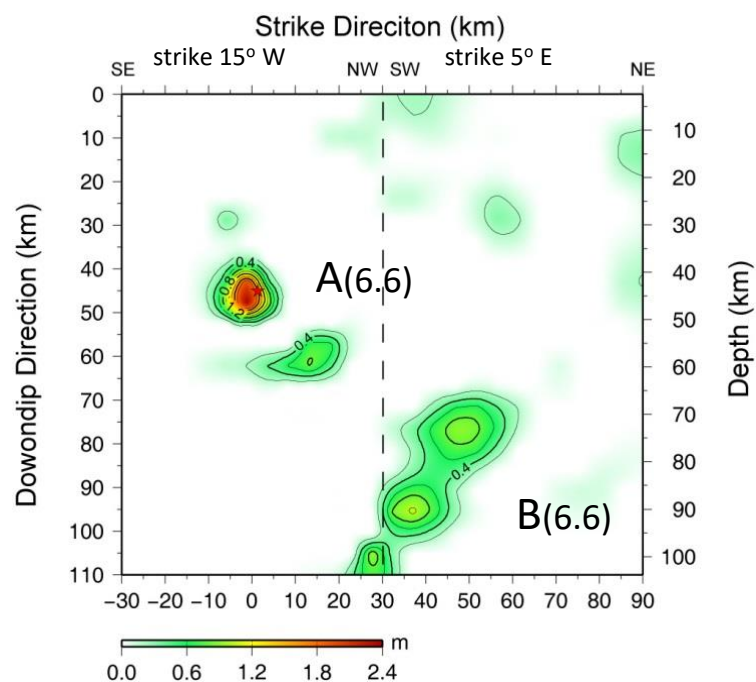
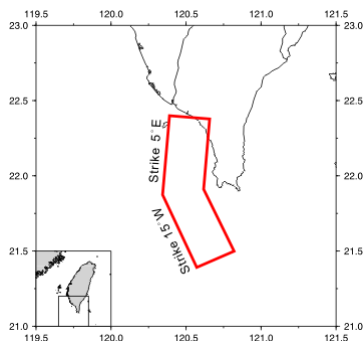
ChiChi 19990921 (M7.7)

Along Strike (km)



Dec. 26 12:26 earthquake

Slip distribution and waveform fitting



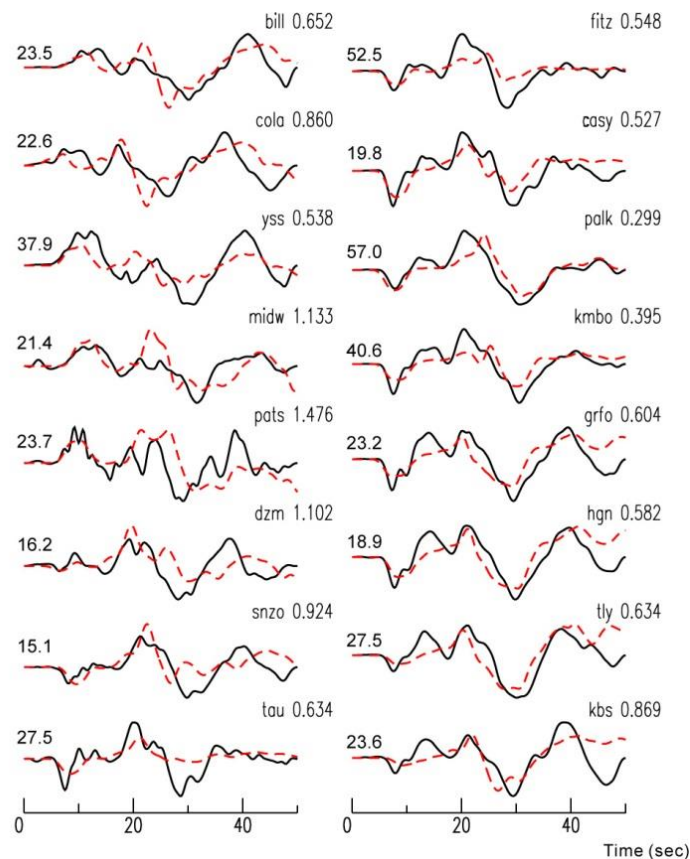
$M_0 = 2.7 \times 10^{26}$ dyne-cm ($M_w = 6.9$)

$D_{\max} = 2.30$ m

$V_r = 2.7$ cm/sec²

$\Delta\sigma_A = 3.19$ bars

$\Delta\sigma_B = 3.05$ bars

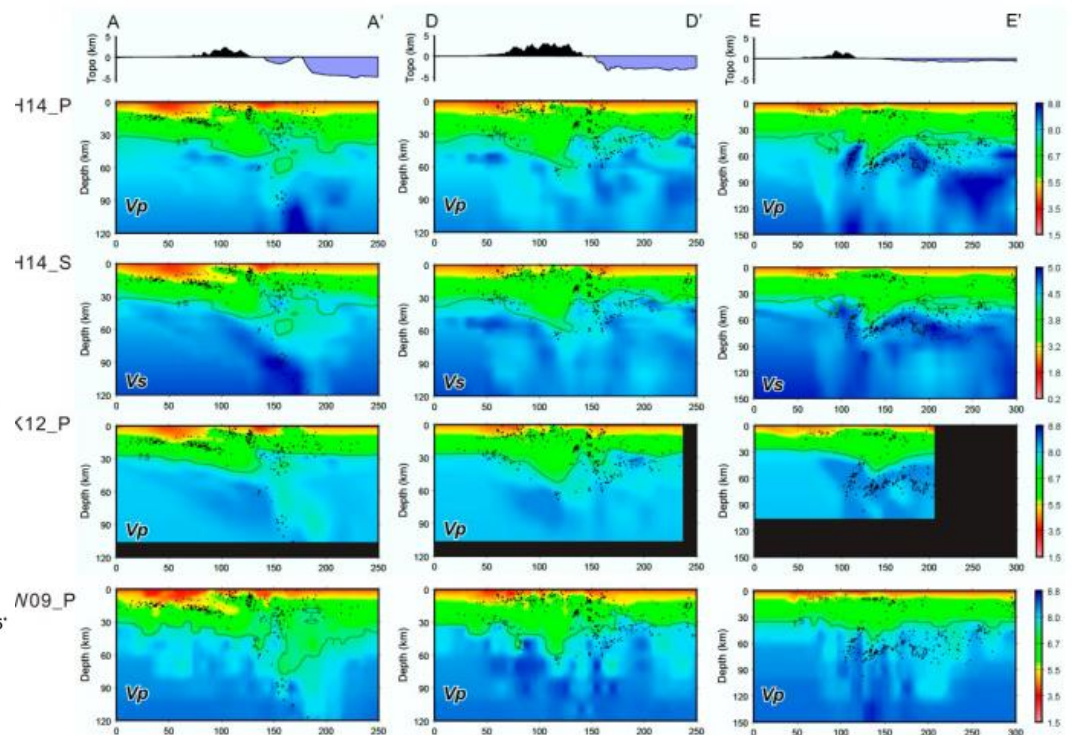
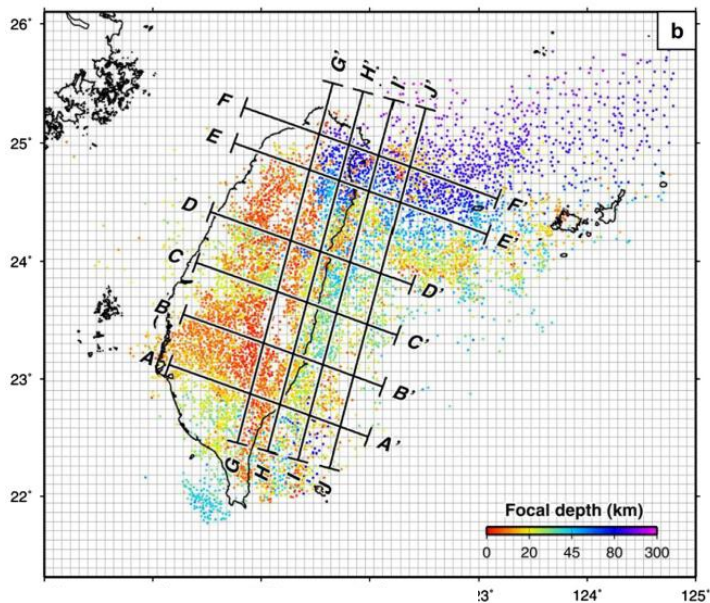
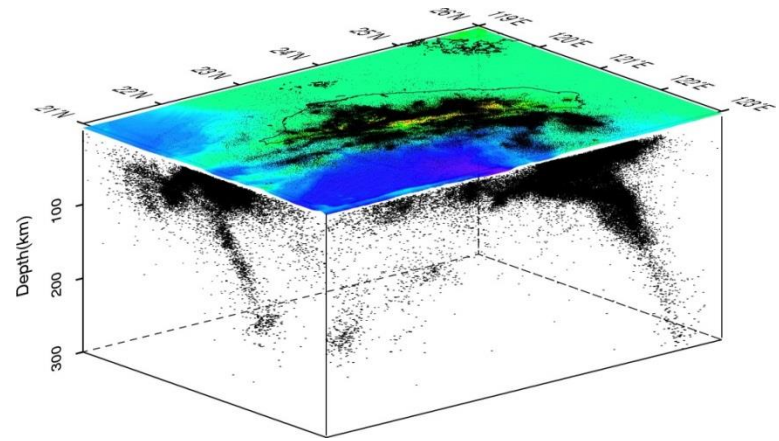
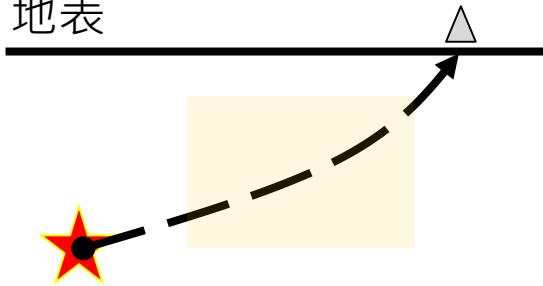


Misfit = 0.48

(Yen et al., 2008)

地震震源 -> 路徑 -> 場址

地表

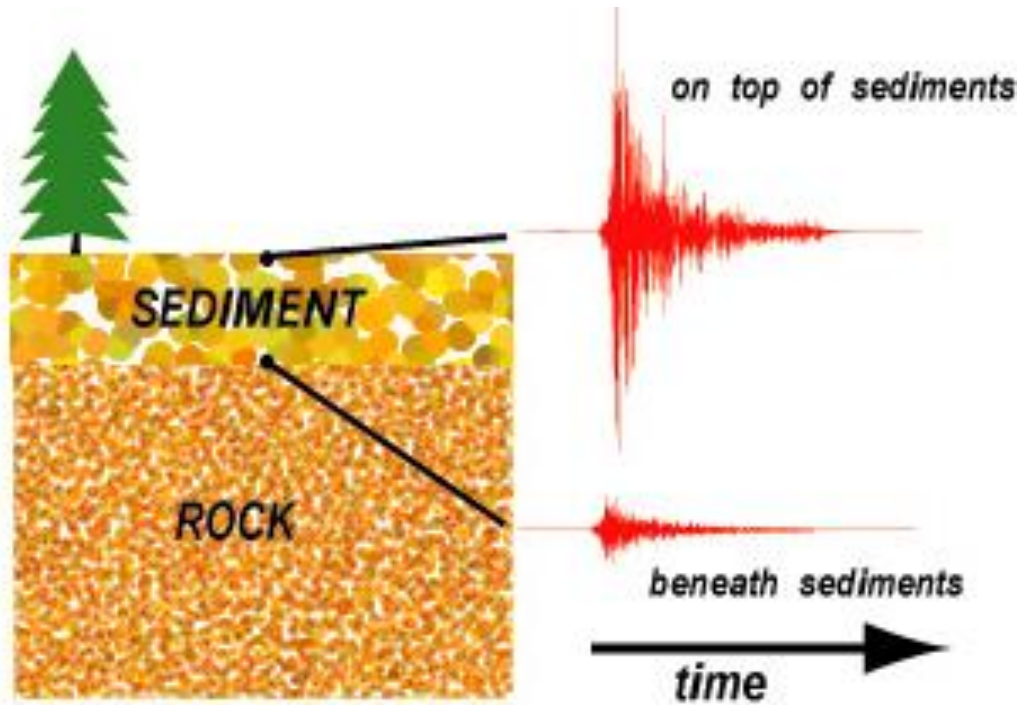


Huang et al., 2014

Kuo-Chen et al, 2012

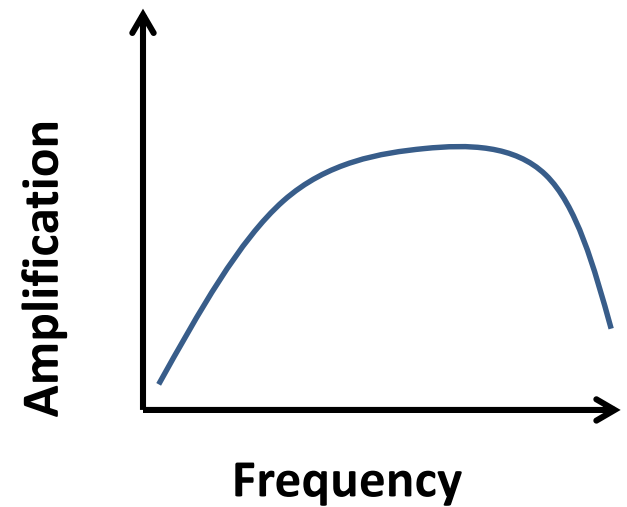
Wu et al., 2009

地震震源 -> 路徑 -> 場址



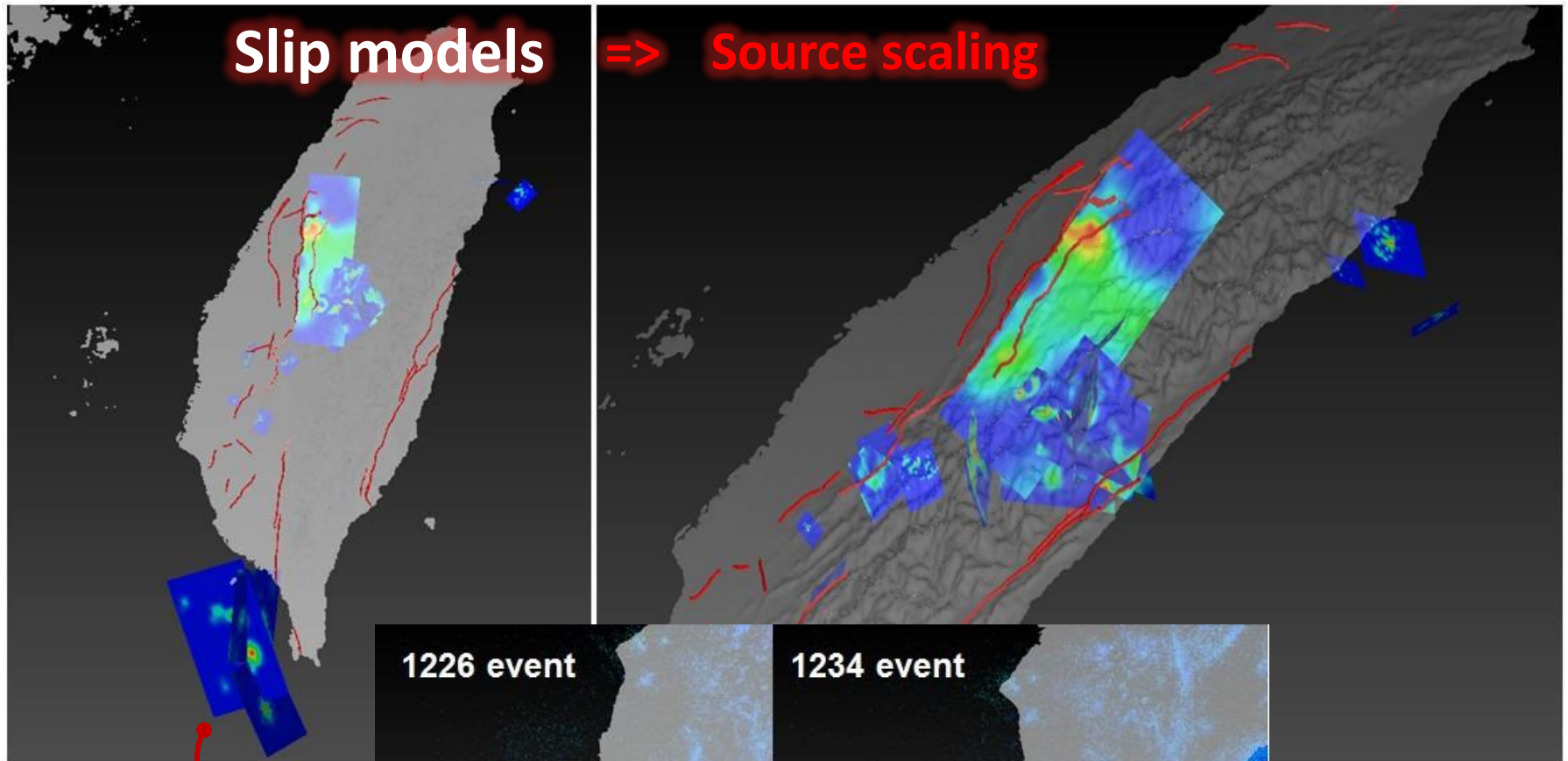
(Retrieved from pubs.usgs.gov)

場址放大函數



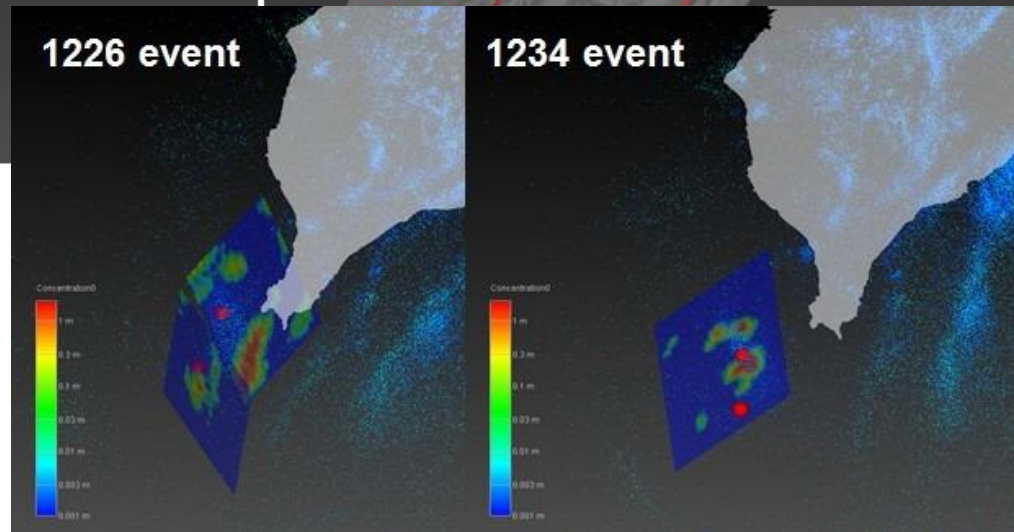
Slip models

=> Source scaling

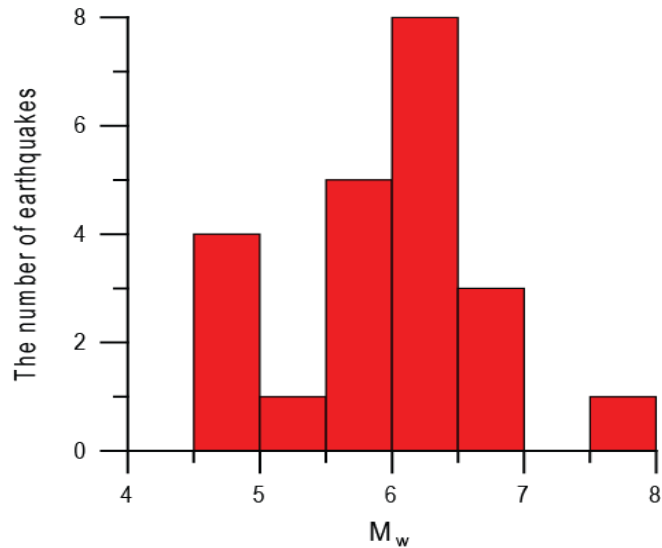


1226 event

1234 event



The data in Taiwan region



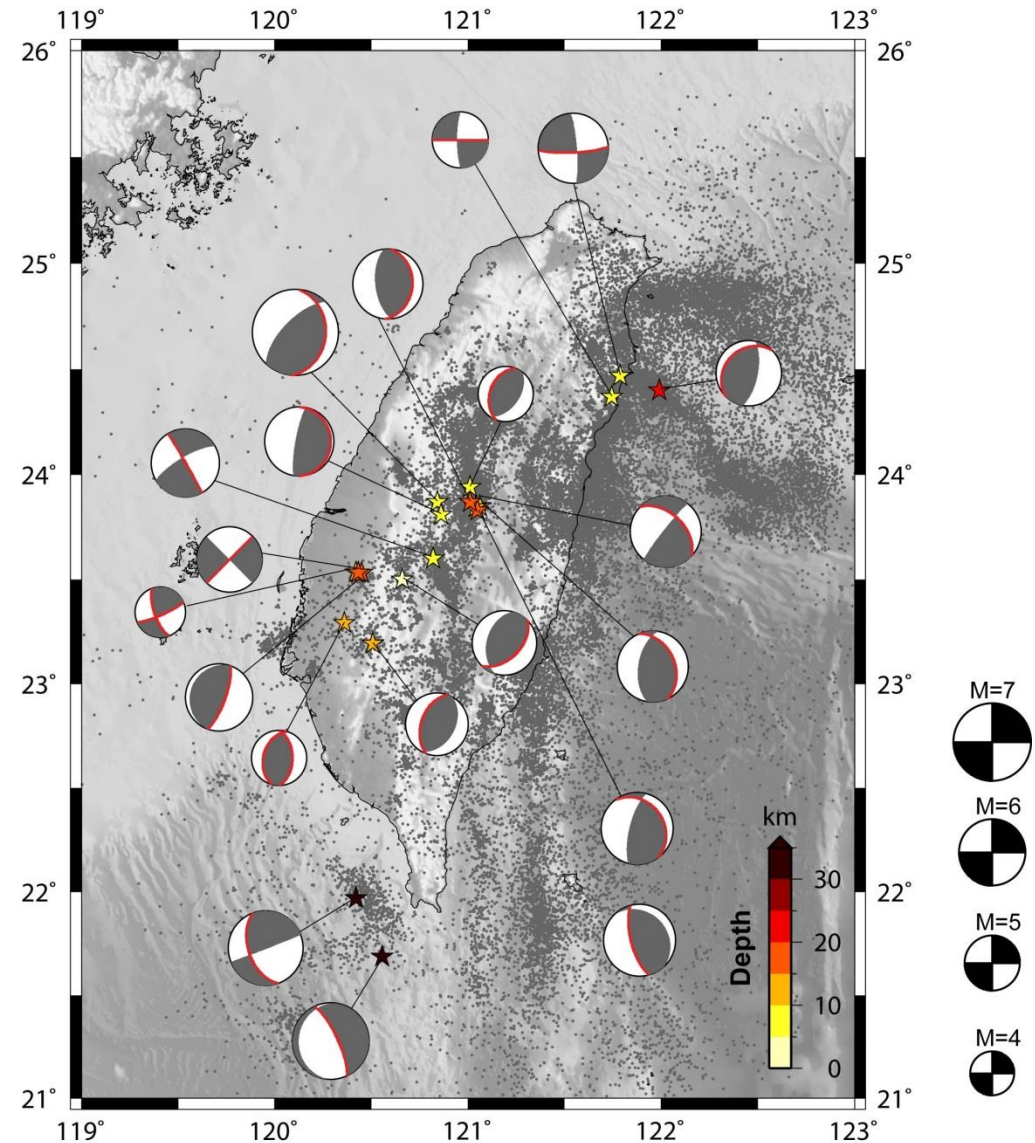
Total event number : 19

Fault type		num.	eq.
Strike		8	7
Dip	Reverse (13)	14	12
	Normal (1)		

$7.75 \times 10^{15} \text{ Nm } M_w(4.6)$

$\sim 3.79 \times 10^{20} \text{ Nm } M_w(7.7)$

(Yen and Ma, 2011)



Background Seismicity $M_L > 3$ (1990-2007)

Characterizing of slip model dimension

$$f(u) = \overline{D}_u = \frac{\sum_{i=1}^N (D_{ui} \times W_s)}{W}$$

u : the order of grids along
strike direction

D : the slip of each grid

N : the number of grids
along dip direction

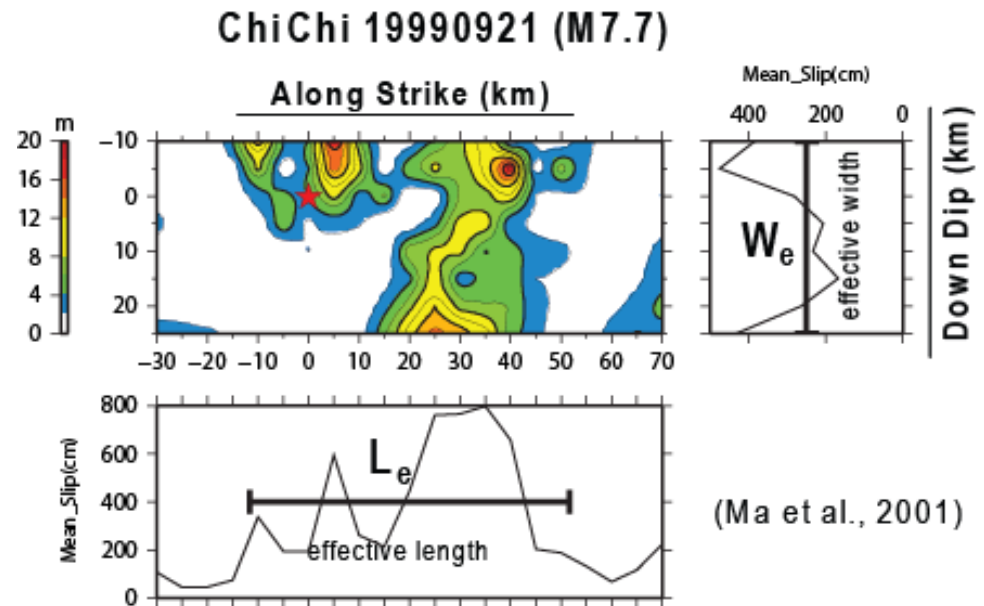
W_s : subfault length

W : fault width from slip models

(Bracewell, 1986; Mai and Beroza, 2000)

$$f * f = \int_{-\infty}^{\infty} f(u) \cdot f(u - x) du$$

$$L_e = (\int_{-\infty}^{\infty} f * f dx) / (f * f|_{x=0})$$



$$D_e = M_0 / (\mu L_e W_e)$$

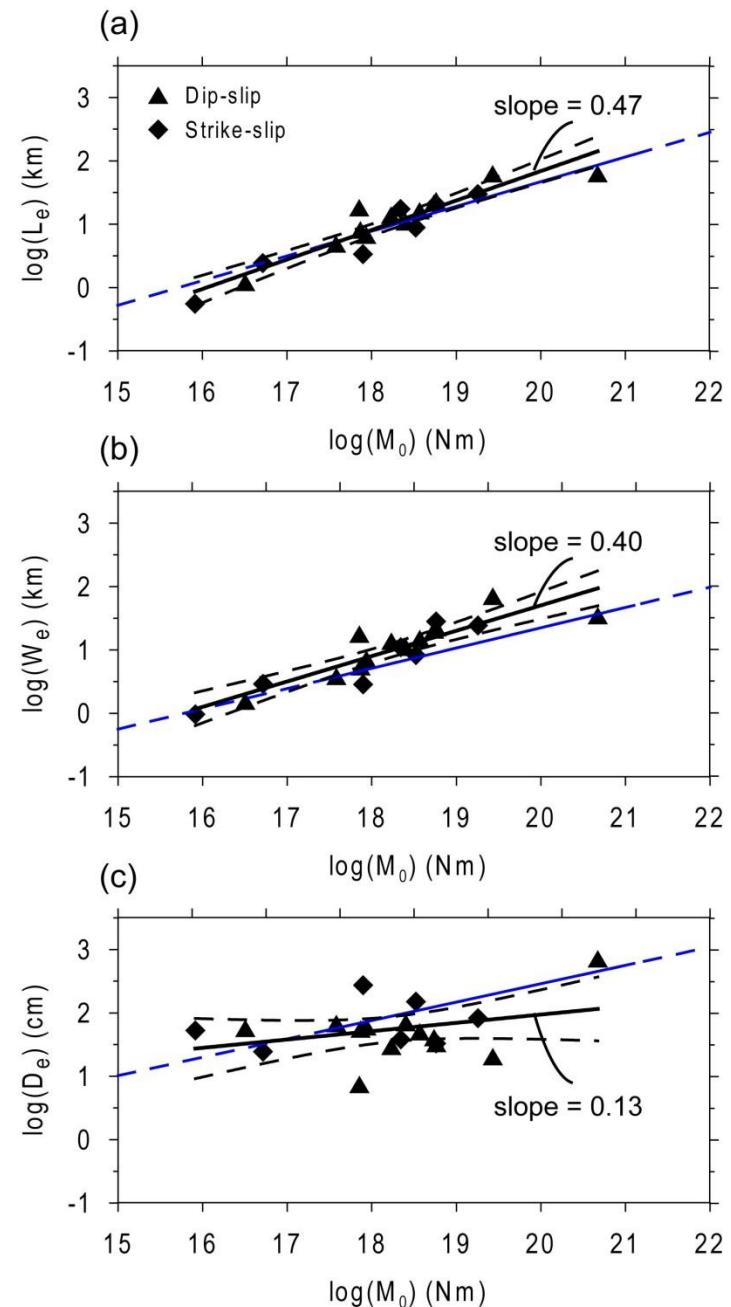
The scaling properties

A slope of near 1/2 for relation between the dimensions (L_e , W_e) and seismic moment (M_0).

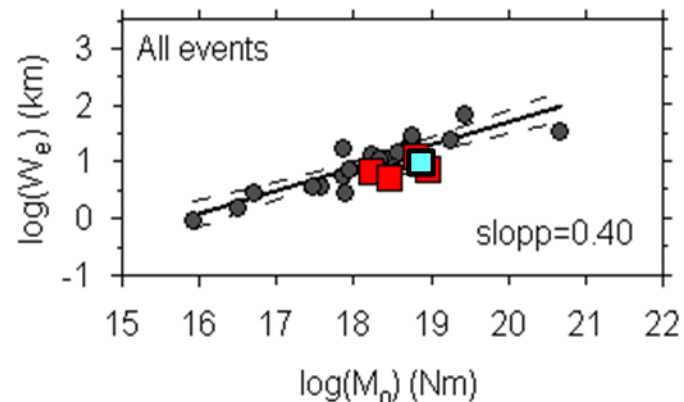
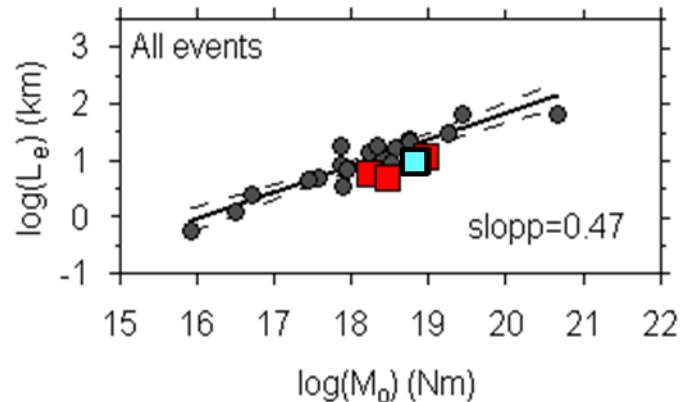
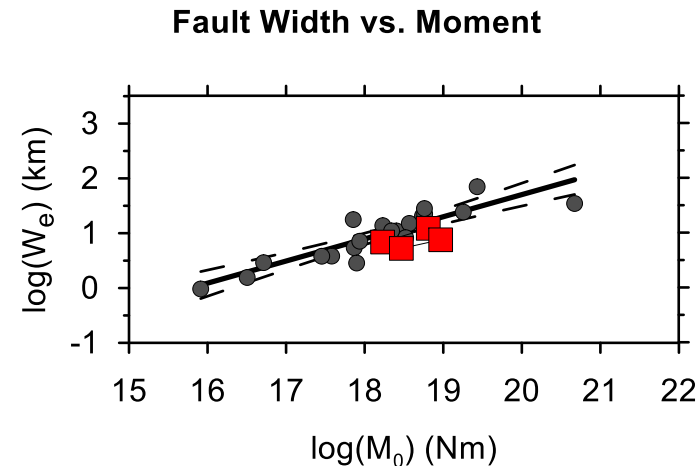
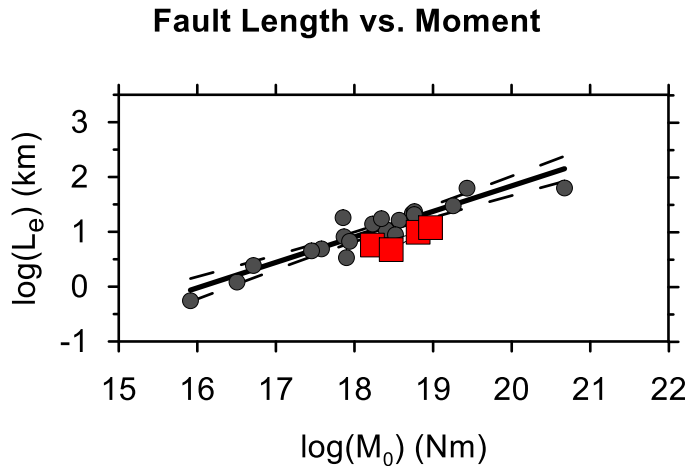
A constant trend for relation between mean slip (D_e) and seismic moment (M_0).

The regression of Mai&Beroza(2000) has less predicted width.

Roughly, mean slip follows the regression of Mai&Beroza(2000).



Magnitude scaling relations of Yen and Ma in 2011



 **New data after 2010**

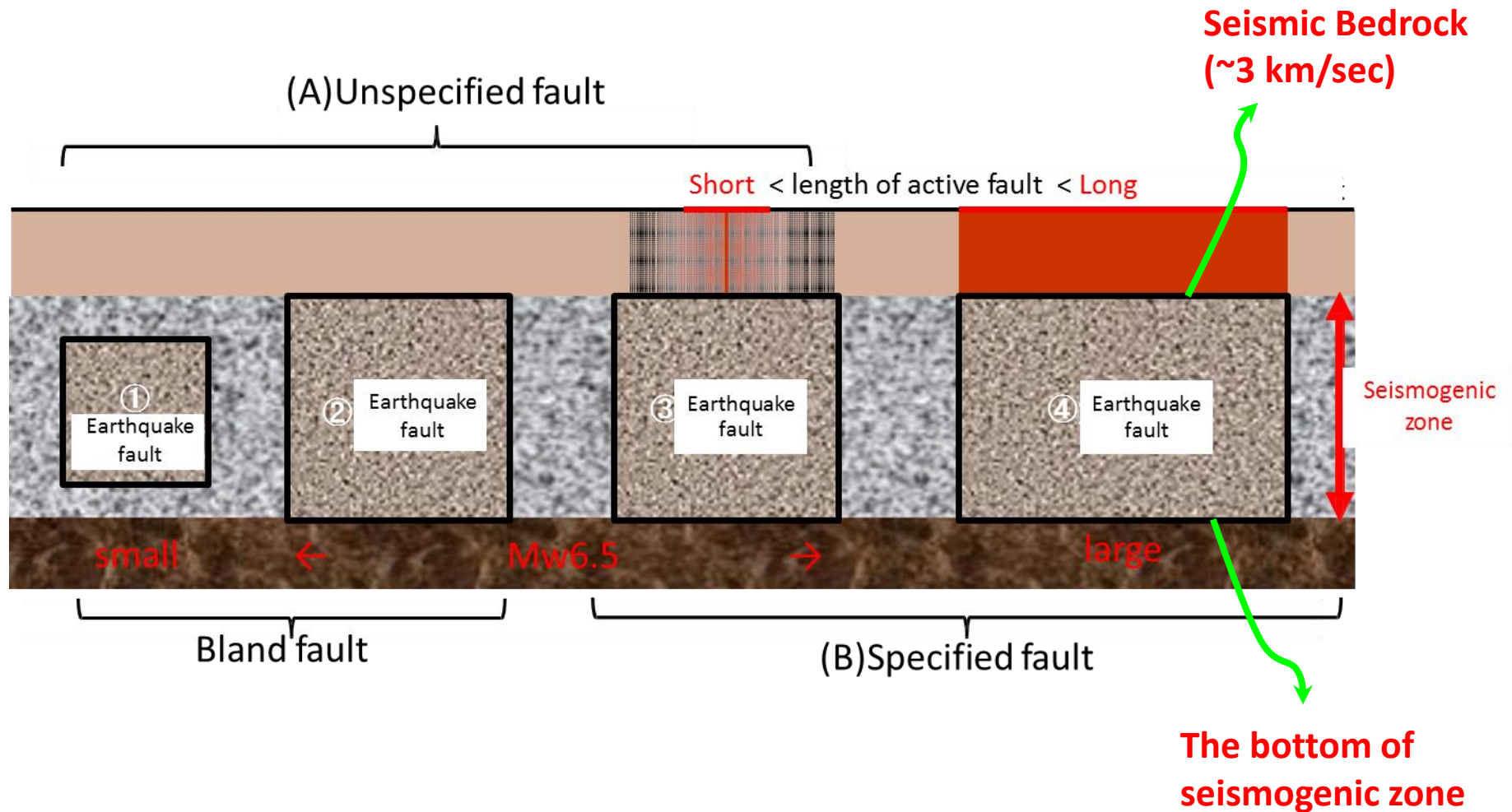
 **0206 Meinong earthquake**

Distinction of magnitude scaling relations

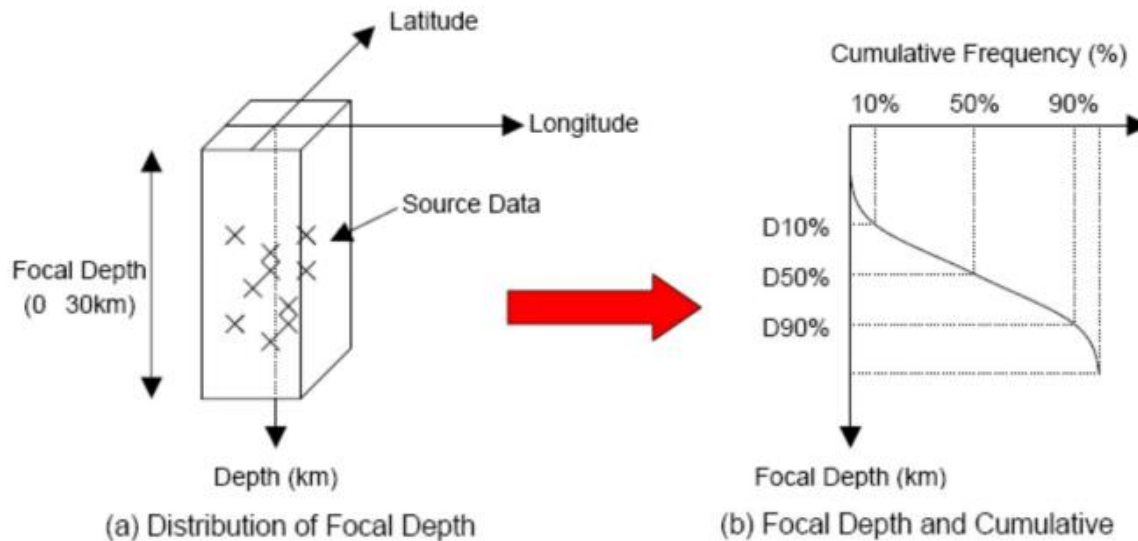
Compilation of suggested magnitude scaling relationships

Tectonic Regime	Reference	Source type	M range	Relation
Crustal (global scale or local scale for Taiwan)	Wells and Coppersmith, 1994	All, SS, R, N	surface : 5.2-8.1	M-L
			subsurface : 4.8-8.1	
			4.8-7.9	M-A
	Hanks and Bakun, 2008;2014	SS	5-8	M-A
	Wesnousky, 2008	All, SS, R, N	5.9-7.9	M-L
	Leonard, 2010	All, SS, DS(R,N)	5.0-8.0	M-A&M-L
	Yen and Ma, 2011	All, SS, R, N	4.6-7.6(8.9)	M-A&M-L
Suduction /oceanic	Blaser et al. 2010	All, SS, R, N	5.3-9.5	M-L
Subduction – interface	Murotani et al., 2008	Undefined	6.7-8.4	M-A
	Strasser et al, 2010	R	6.3-9.4	M-A&M-L
Subduction – intraslab	Ichinose et al., 2006	Undefined	5.3-7.9	M-A
	Strasser et al, 2010	R	5.9-7.8	M-A&M-L

An issue for the seismogenic zone



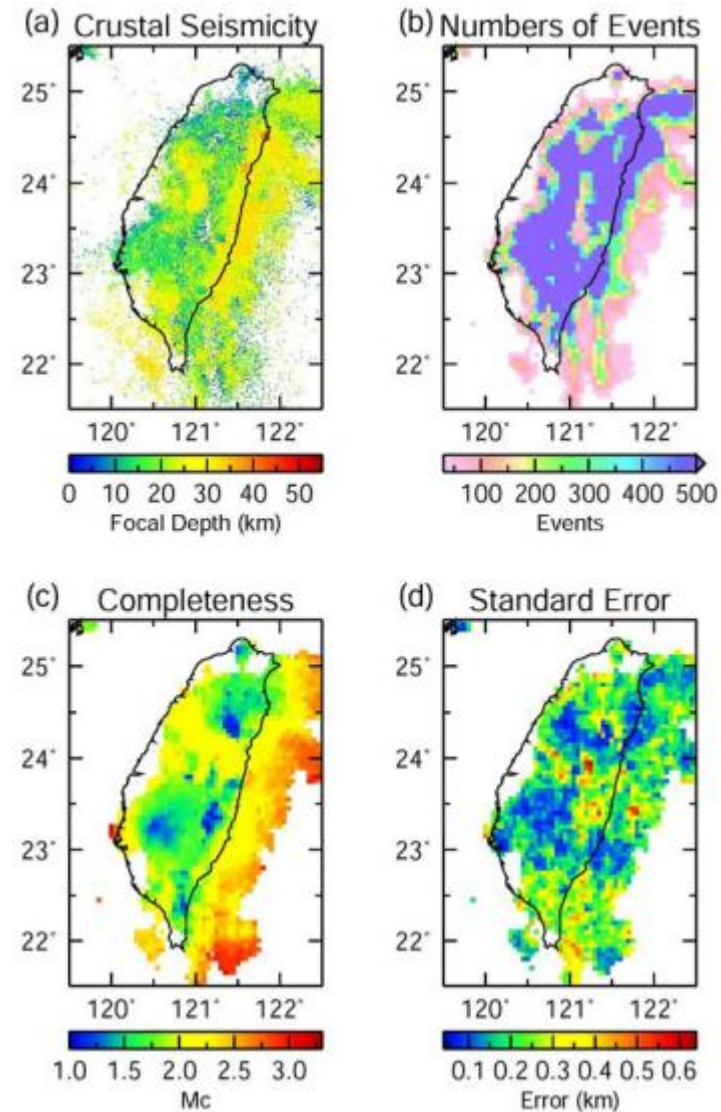
孕震深度 Seismogenic depth



(Motohashi et al., 2004)

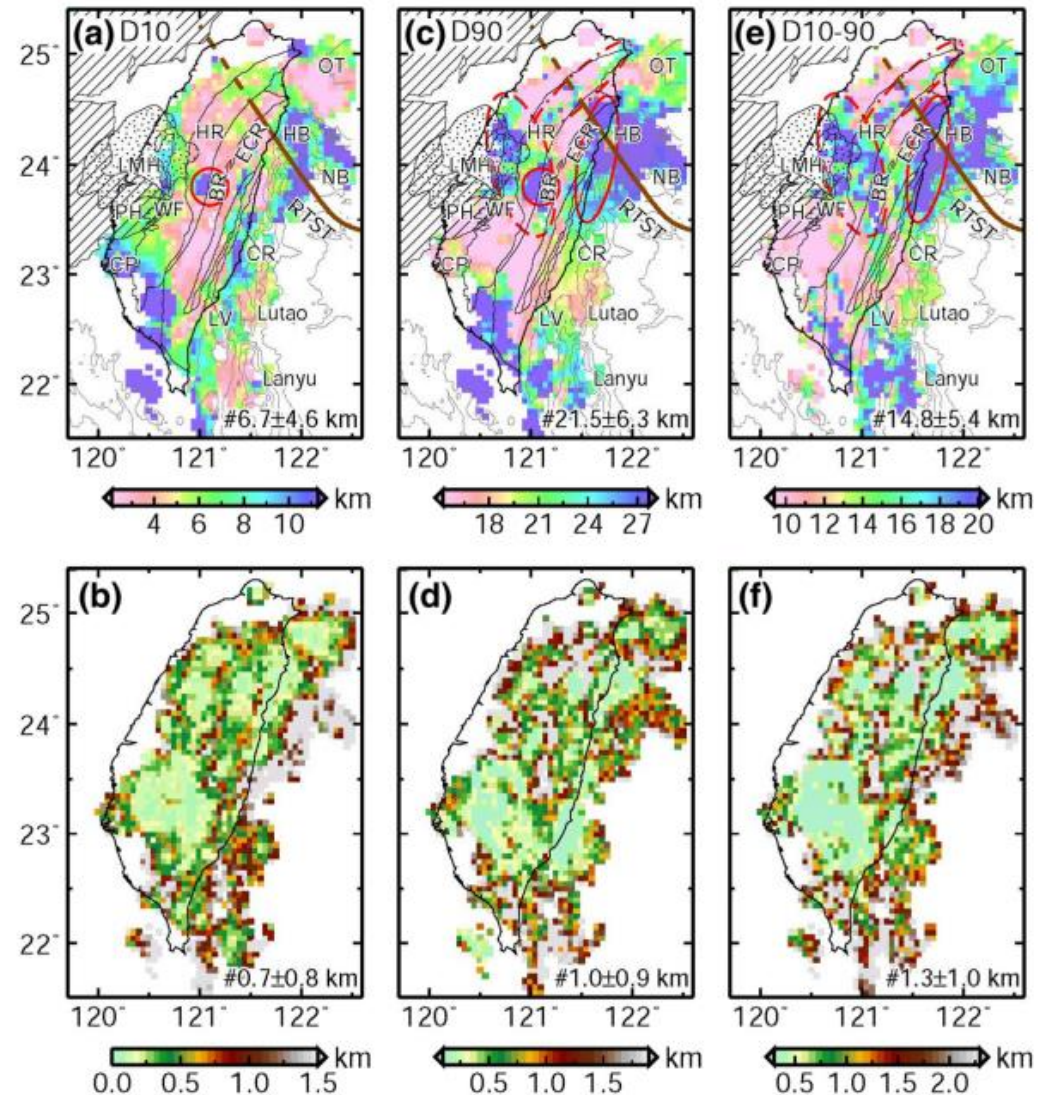
Eqk depth-frequency relation is dominated by small eqks and has less physical meanings.

We use the earthquake **depth-moment release distribution** to determine not only the seismicity cutoff depth.

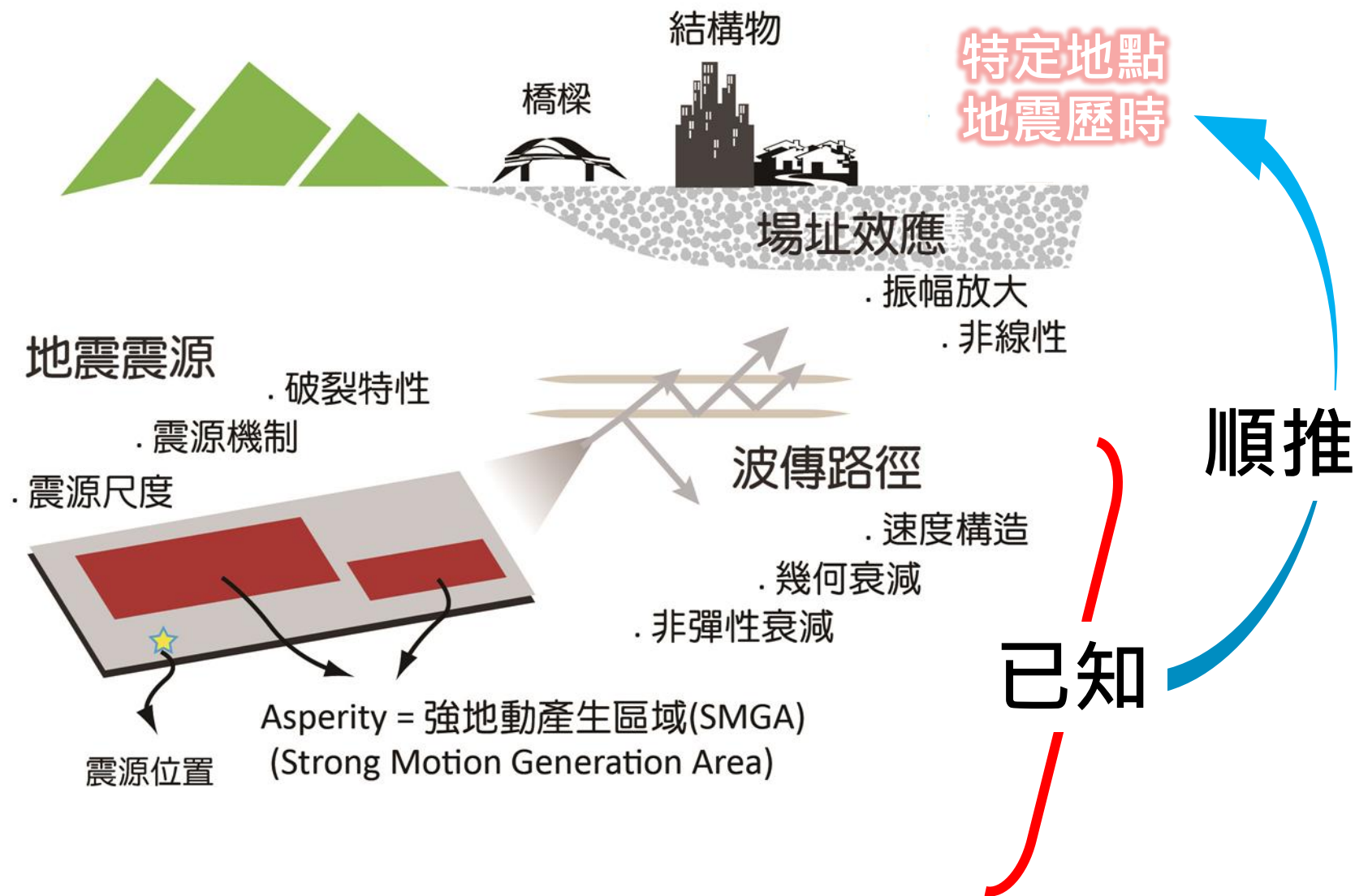


The depth-to-top rupture extent in a strong motion simulation is crucial for seismic hazard mitigation.

To achieve a more accurate seismic hazard model, a more realistic estimation of the rupture width with lateral variations is required.

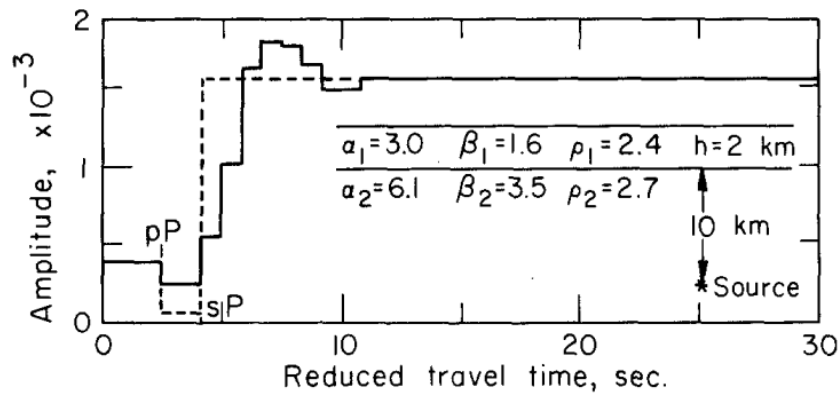


(Wu & Yen et al., 2017)

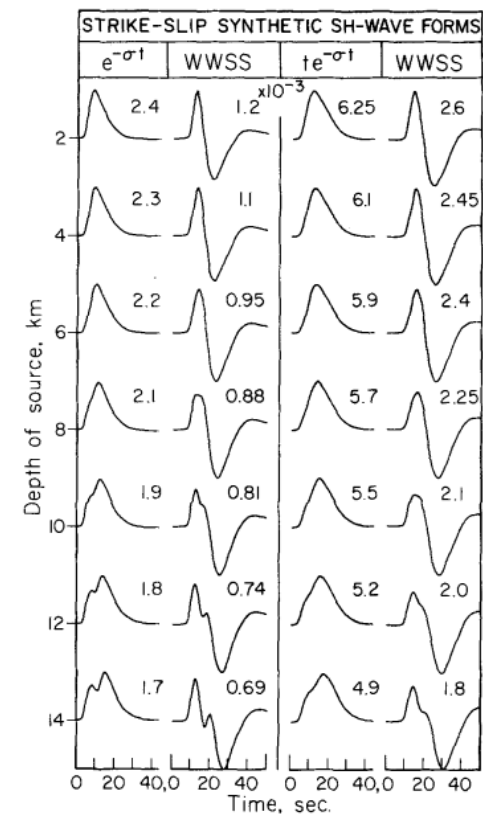
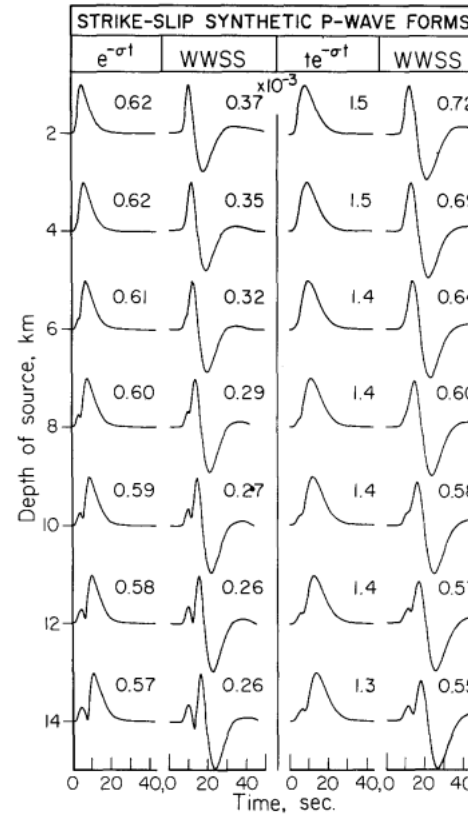


點震源地震波模擬

Generalized ray expansions of the P, SH, and SV displacement potentials resulting from a point-source dislocation are evaluated at the surface of a layered half-space.

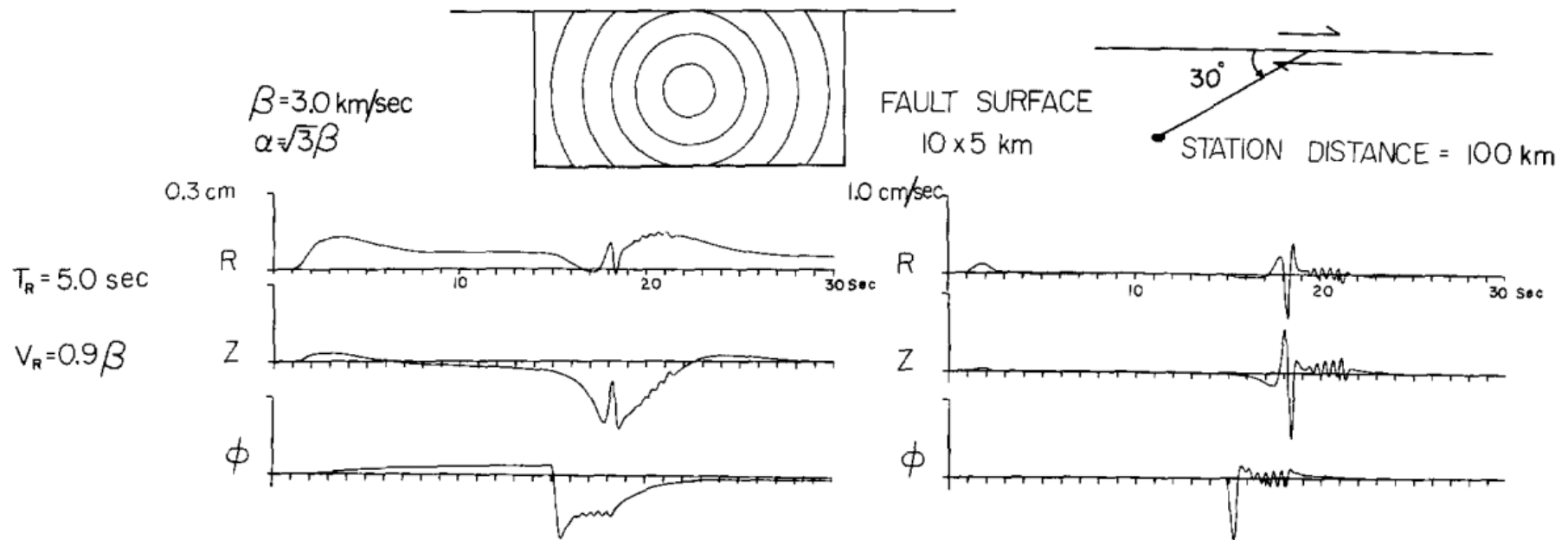


(Helmberger, 1974)



面震源地震波模擬

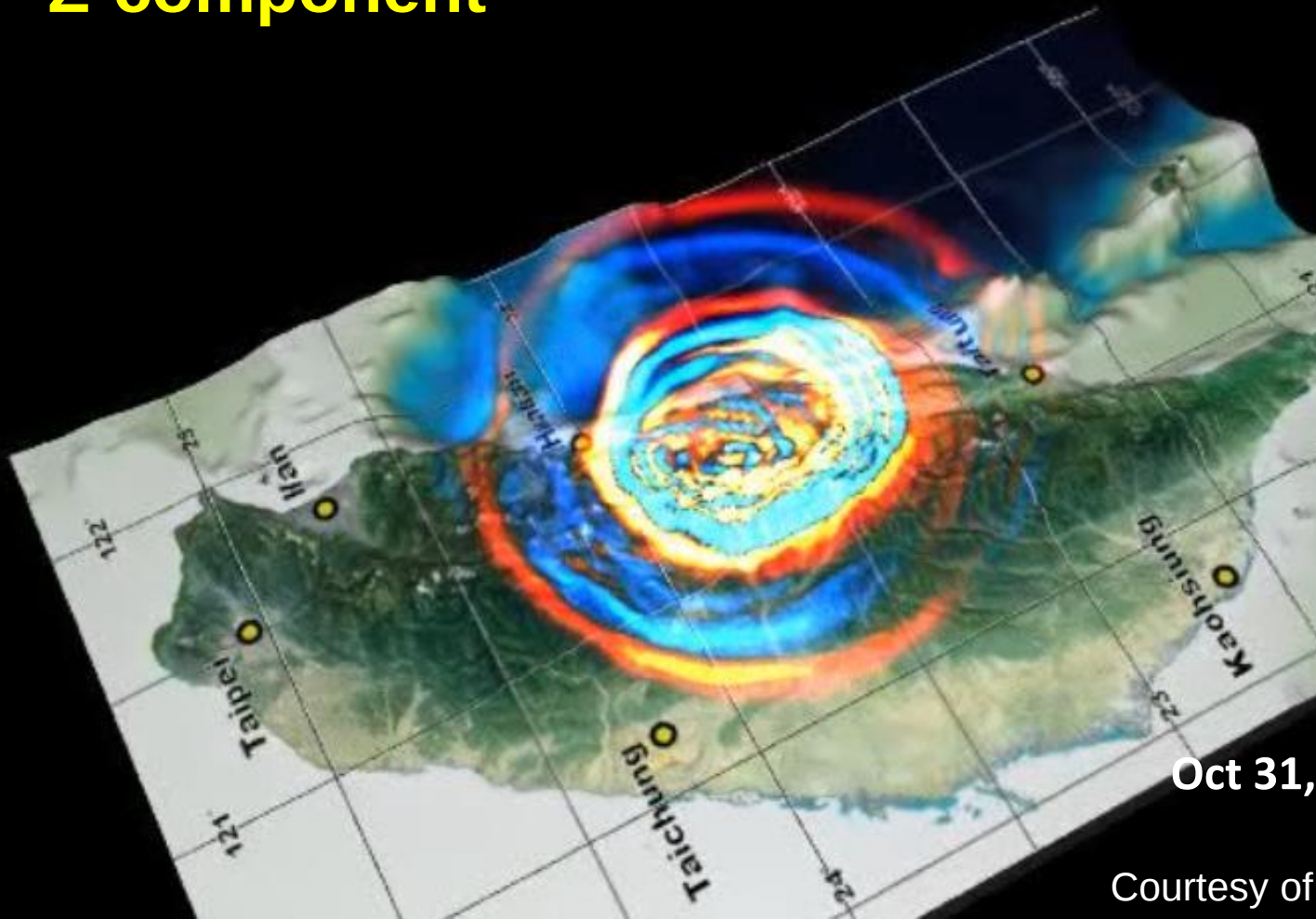
Ground motion produced by finite, kinematic fault surfaces is modeled at the surface of a homogeneous half-space. The Green's functions for point dislocations are summed to investigate the effects of different rupture velocities and source rise times.



(Hartzell et al, 1978)

Z-component

16.13 [sec]

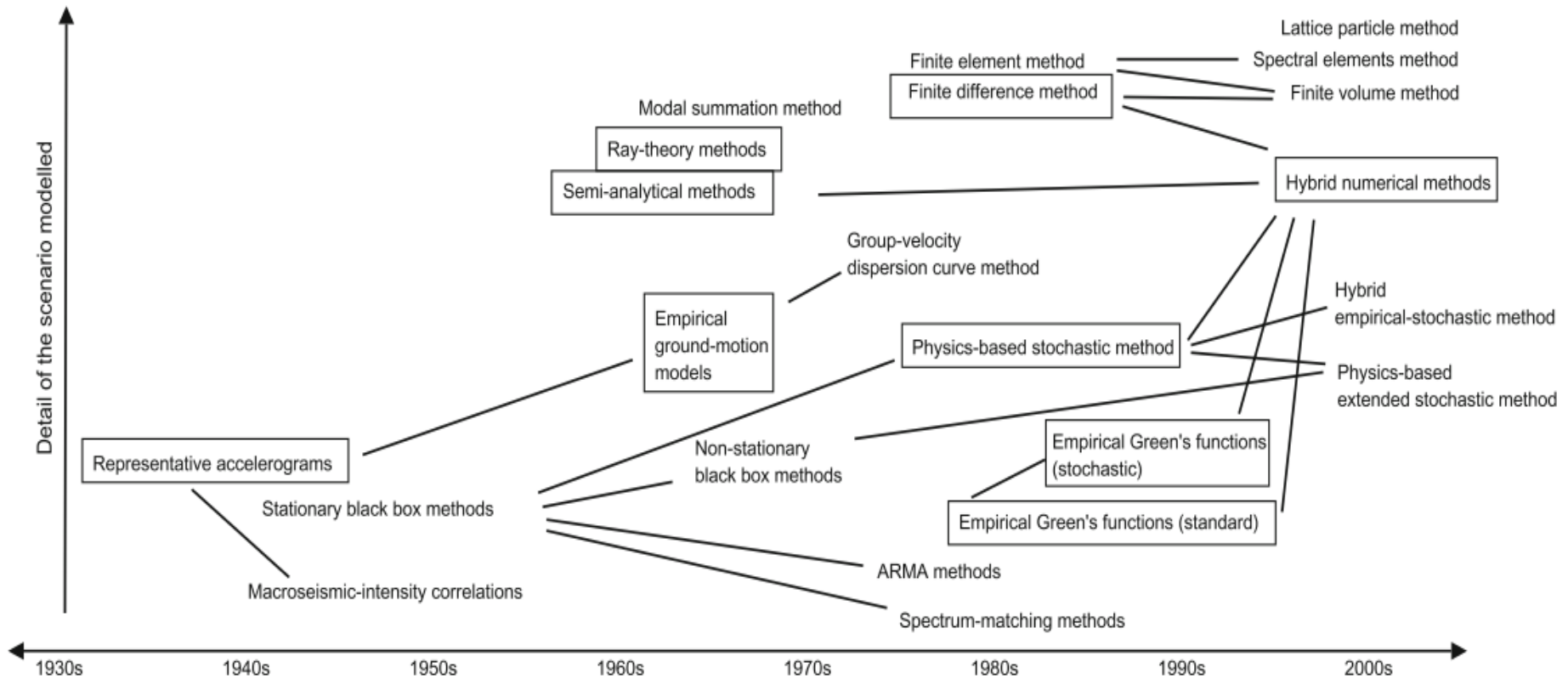


震源破裂
波傳介質
場址效應
計算資源
維運組織

Oct 31, 2013 Ruisui EQK

Courtesy of Dr. Ming-Che Hsieh

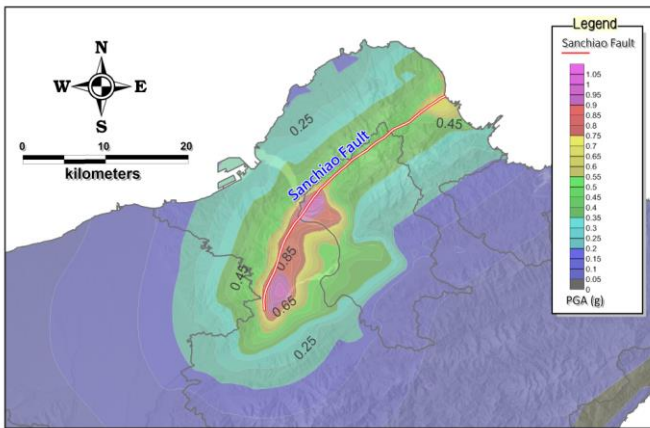
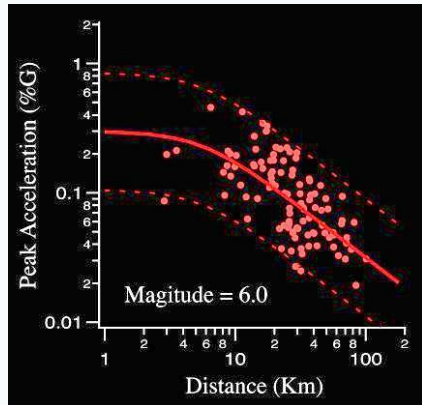
理論方式模擬的類型



(Douglas and Aochi, 2008)

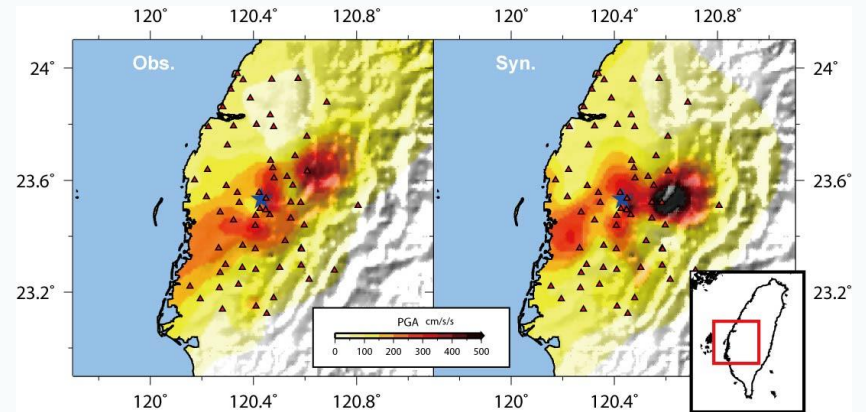
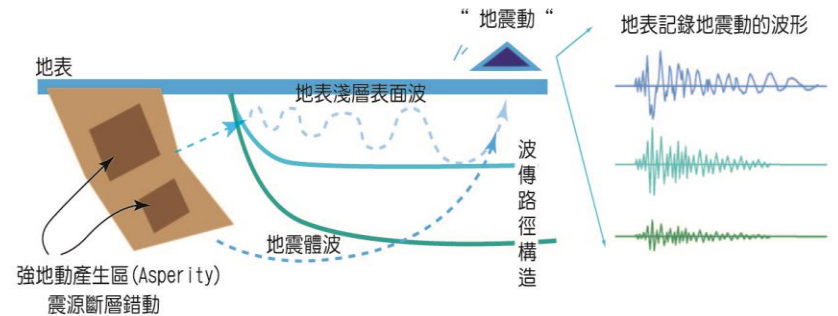
地動模擬與評估

經驗方法



理論方法

活斷層震源推估地震動示意圖



理論方式的應用發展性

經驗方式基於實際觀測地動資料的範圍(規模、距離、場址等)相對無法完整掌控震源、波傳路徑及土壤條件對於影響震動變化的變異性。理論地動模擬可以提供以下問題解答：

- 近斷層範圍的地動特性(ex. pulse-like and fling-step)
- 破裂方向性(directivity effect)
- 斷層上盤效應 (hanging wall effect)
- 大規模的地殼及隱沒帶地震事件震動特性
- 盆地中長週期地震波的複反射效應
-

工程應用上之地震動量測及延伸資訊

- 最大地表加速度 (peak ground acceleration, PGA)
- 最大地表速度 (peak ground velocity, PGV)
- 震度(Intensity) (與PGA相關)
- 工程應用上所需週期範圍之反應譜(response spectrum)
(SA0.3及SA1.0)



強地動加速度歷時
(ground acceleration time-history)

美日核電之應用概況

DSHA & PSHA

定值法地震危害度分析

Deterministic Seismic Hazard Analysis

- 目的是去評估特定斷層的地動，一般以景況模擬稱之。模擬方法有二：經驗地動衰減式；理論地震波模擬。
- 一般地震設計，需求即為特徵最大地動(ex.水庫、核電廠)
- 景況模擬之地震事件可能非最嚴重，但是視為很有可能發生的地震，一般提供進行震損與應變計畫
- 不確定性沒有完全被景況模擬涵蓋，地震發生的頻率沒有被考量

機率法地震危害度分析

Probabilistic Seismic Hazard Analysis

- 目的是去評估超出特定基準回歸期之地動對應機率。(考量區域震源、斷層震源、經驗地動衰減式。)
- 整合所有可能引致地動的地震震源，加上地動發生之年頻率資訊
- 允許不確定性的明確處理
- 以風險為原則的提供決策基礎資訊

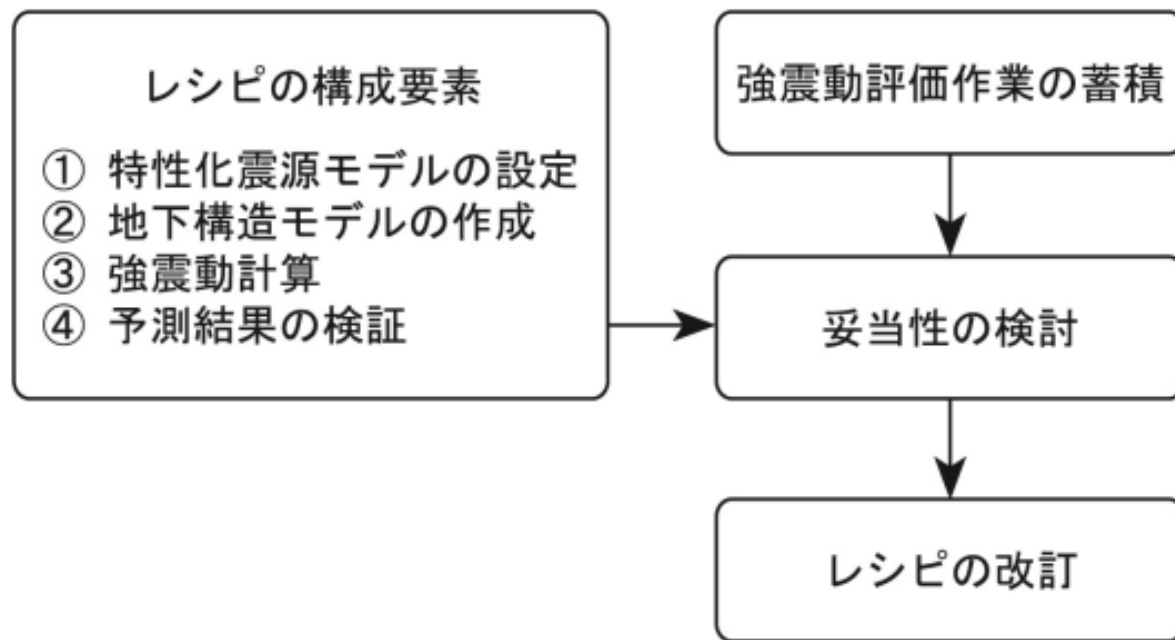
日本與美國的**邏輯**差異

日本核能納入地震模擬之簡要歷史發展

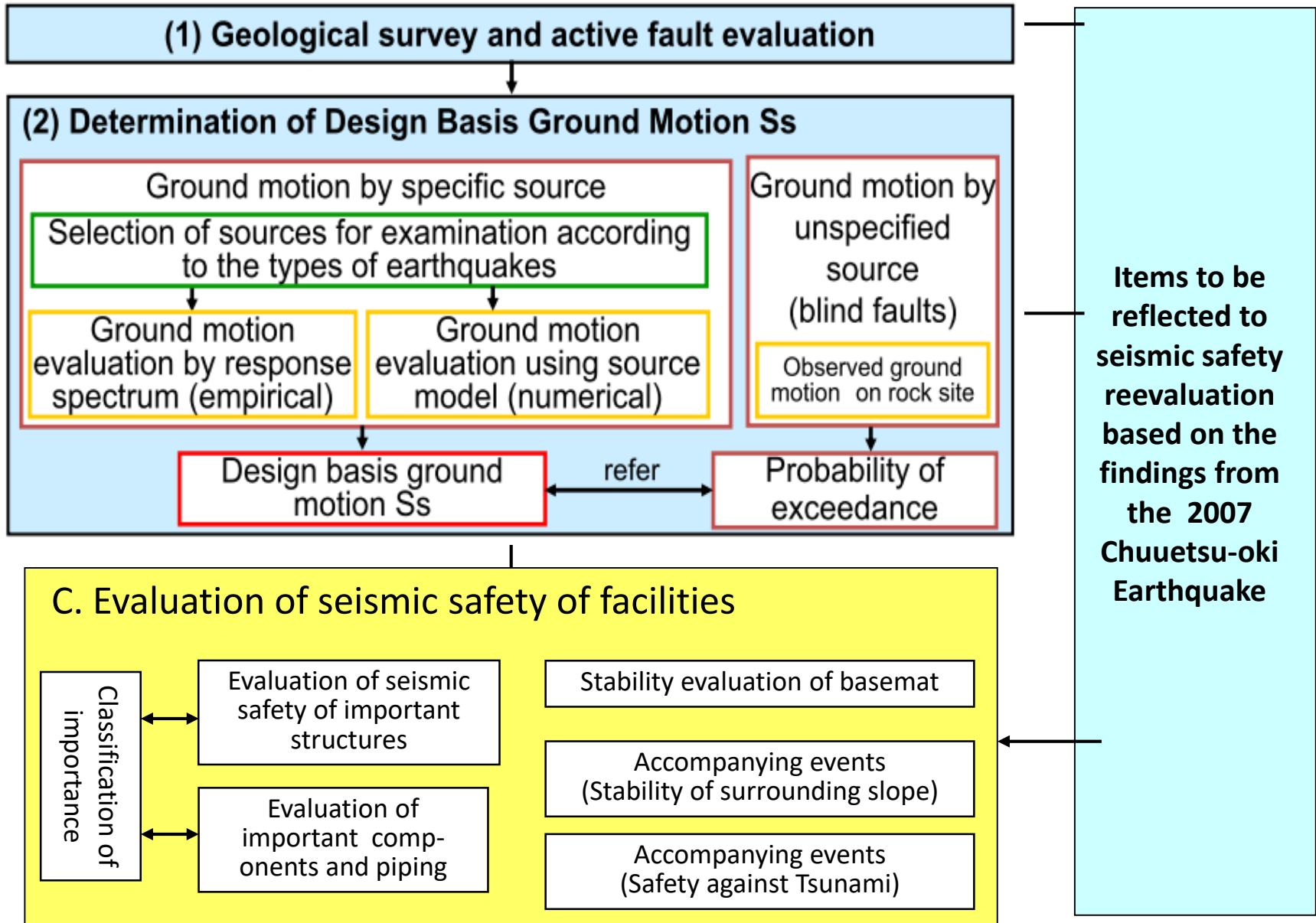
- 1995日本神戶大地震後，耐震相關法規重起檢視。
- 2001年地震調查研究推進本部陸續針對特定斷層以Recipe程序評估地動分布，並逐步以實際地震觀測紀錄資料驗證Recipe程序執行之地動模擬結果，並進行Recipe內容調整。於2008年公布第一版Recipe。
- 2006年日本核能耐震設計審查規範中，正式納入以地震模擬之方式，提供慣有經驗評估方式之外，另外考量斷層震源、路徑及場址效應所評估之設計地震動結果。
- 2006年之後日本核電廠陸續依據新法規執行重新審查，地震模擬主要依據地震調查研究推進本部之Recipe程序執行。

日本關於地震模擬的執执行程序概要及應用

Recipe for predicting ground motions from source faults of earthquakes

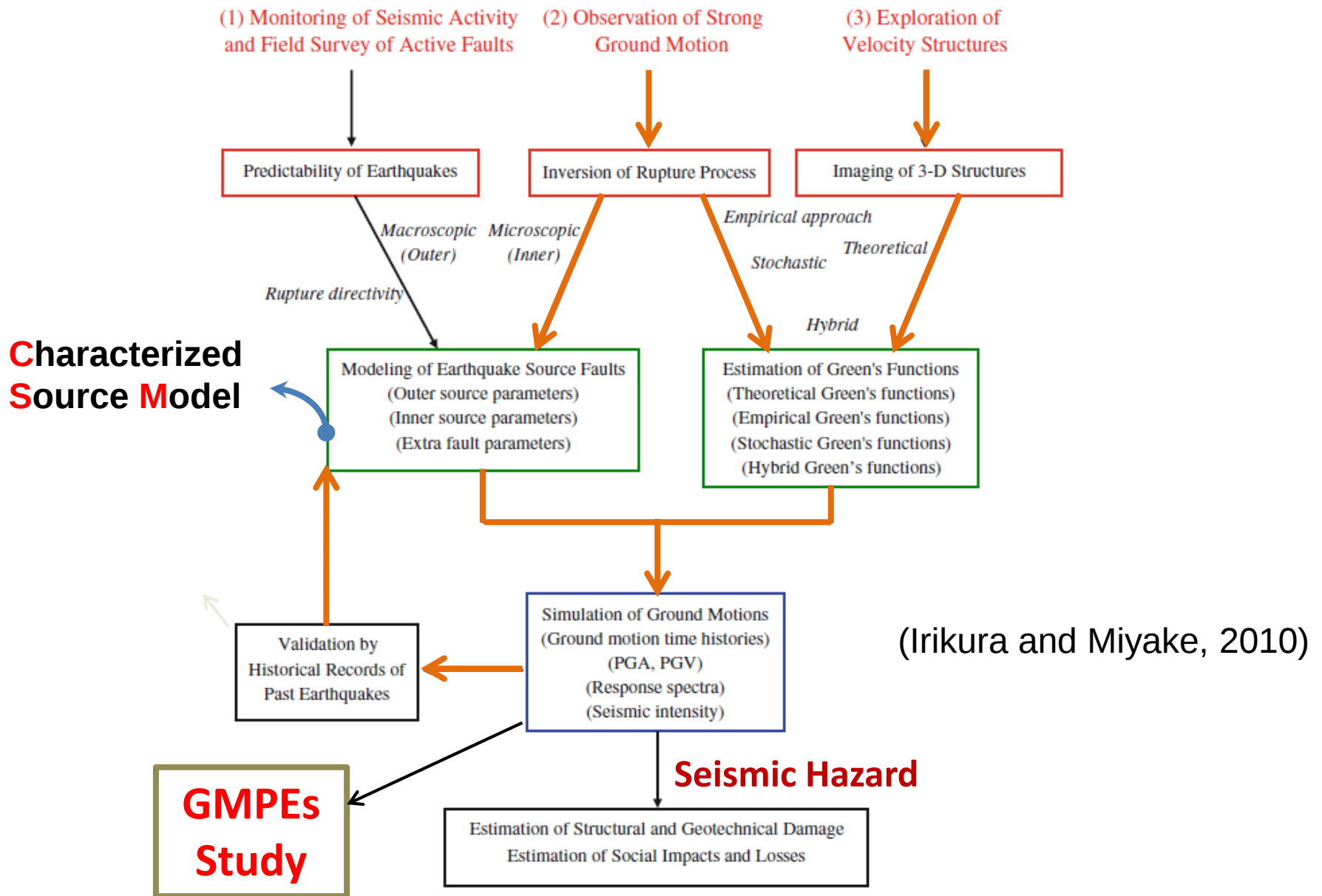


Flow of Seismic Reevaluation - New Seismic Regulatory Guide

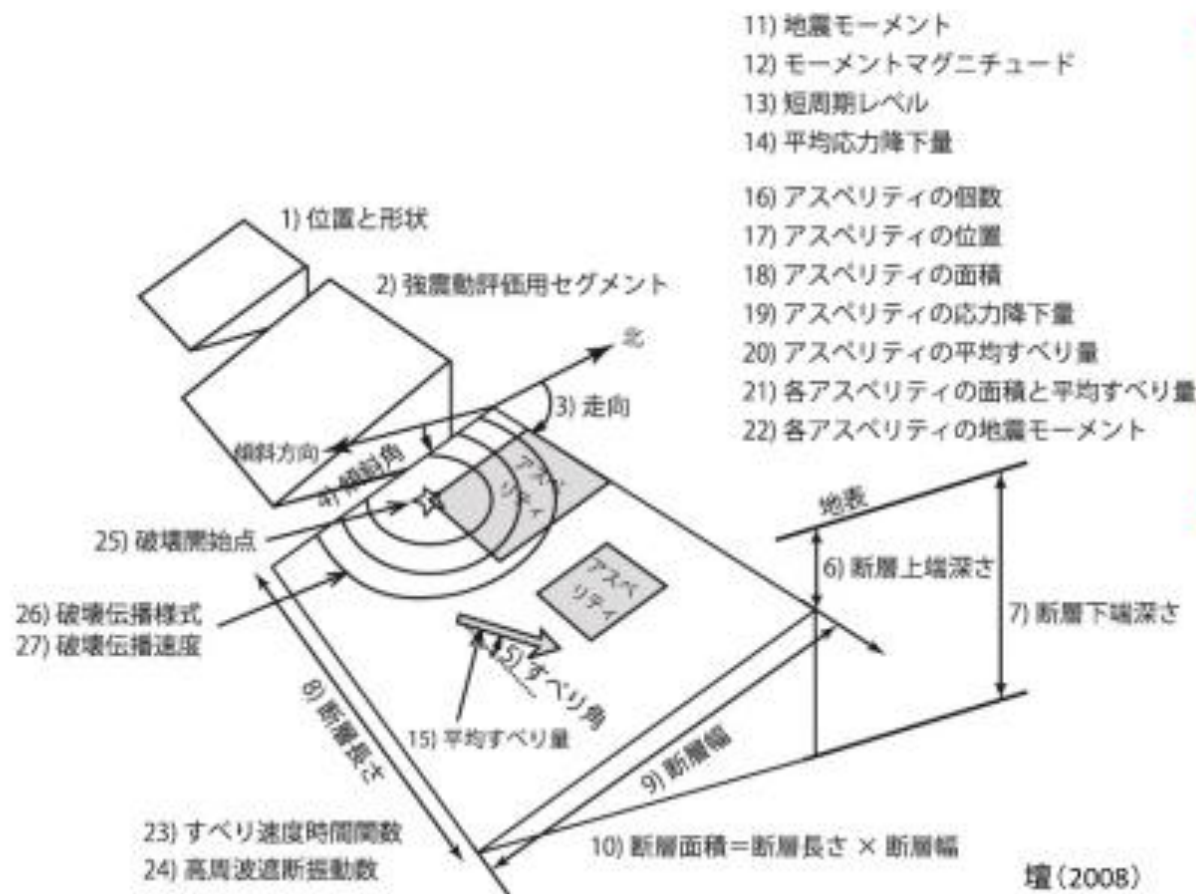


Guideline before & after Revision

Item	Before	After 2006
Active Fault	Active in the past 50 thousand years	Active in the past 120-130 thousand years
Vertical ground motion	Static ground motion	Static + Dynamic ground motion
Assumed Earthquake	At least M 6.5 10km under the plant	Based on the investigation results
Design ground motion	S1, S2	Ss
Seismic Classification	As, A, B, C	S,B,C
Evaluation method	Response spectrum	Response spectrum + Fault model
PSA evaluation	None	Recommended to evaluate on "Residual Risk"



断層パラメータ



断層面積: $S=LW$
 地震モーメント: $M_0=\mu SD$
 すべり量: D
 短周期レベル: A
 平均応力降下量: $\Delta\sigma$
 アスペリティの
 面積: S_a
 地震モーメント: M_0a
 平均応力降下量: $\Delta\sigma a$
 すべり量: D_a

Recipe for Strong Motion Prediction

Outer Fault Parameters

- **Rupture area S** is given.
- **Seismic moment M_0** from the empirical relation of **M_0 - S** .
- **Average static stress-drop $\Delta\sigma_c$** from appropriate physical model (e.g., circular crack model, tectonic loading model, etc.)

Inner Fault Parameters

- **Combined area of asperities S_a** from the empirical relations of **S - S_a** or **M_0 - A_0** .
- **Stress drop** on asperities $\Delta\sigma_a$ based on the multiple asperity model.
- **Number** of asperities from fault segments.
- **Average slip** of asperities **D_a** from **dynamic simulations**.
- **Effective stress** for asperities σ_a and background area σ_b are given.
- **Slip velocity time function** given as Kostrov-like function.

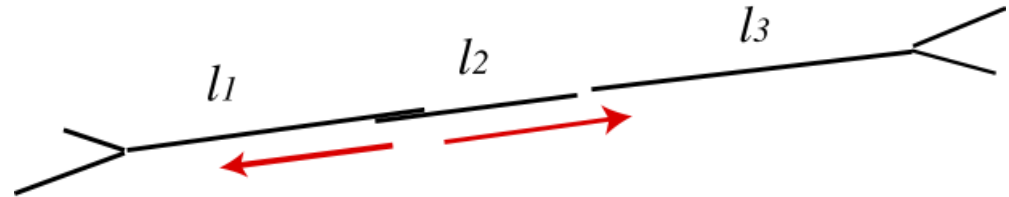
Extra Fault Parameters

- Rupture nucleation and termination are related to **fault geometry**.

Outer Fault Parameters

Parameters characterizing entire source area

Inland crustal earthquake



$$L = l_1 + l_2 + l_3$$

■ Step 1: Give **total rupture area** ($S = LW$)

- Fault length (L) is related to grouping of active faults from geological and geomorphological survey.
- Fault width (W) is related to thickness of seismogenic zones (H_s) and dip (θ), *i.e.* $W = H_s / \sin \theta$.

■ Step 2: Estimate **total seismic moment** (M_0)

empirical relationships

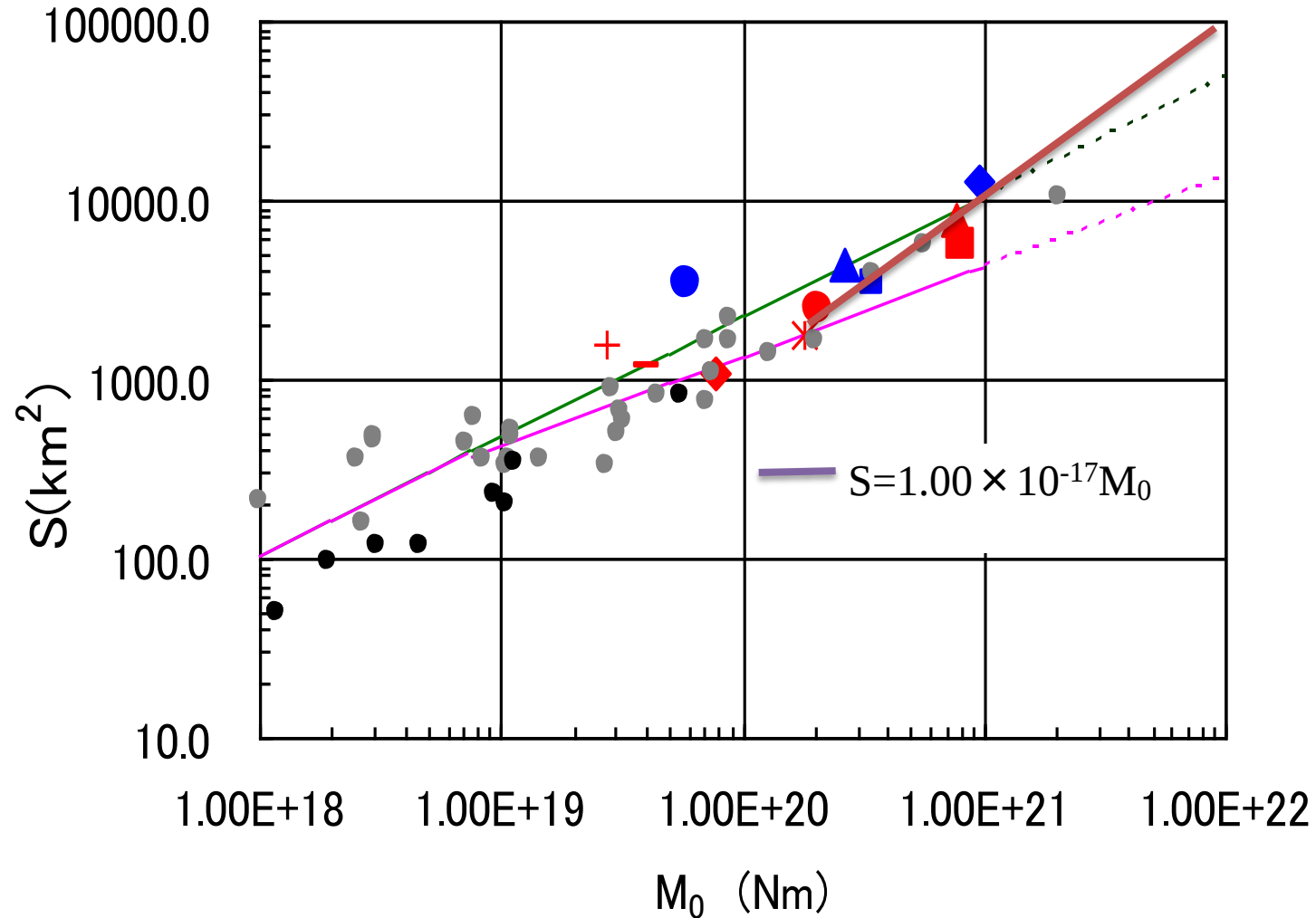
$$M_0 = \frac{16}{7\pi^{1.5}} \Delta \bar{\sigma}_c \cdot S^{1.5}$$

■ Step 3: Estimate **average static stress-drop** ($\Delta \sigma_c$) on the fault

a circular-crack model (Eshelby, 1957) for L/W less than 2

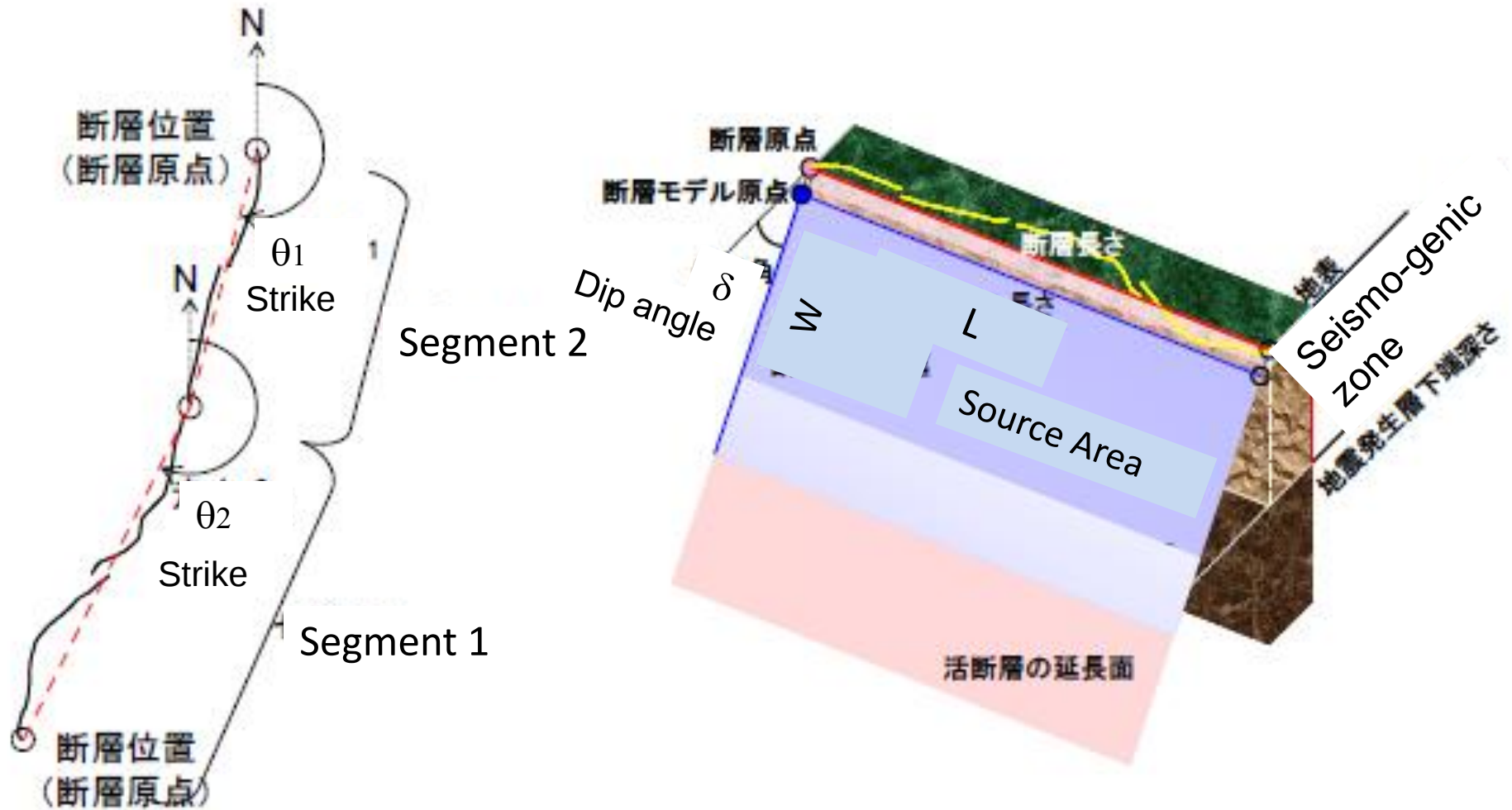
or a loading model (Fujii and Matsu'ura, 2000) for L/W more than 2.

Revised Scaling Relationship of Outer Fault Parameters -Rupture Area versus Seismic Moment-



(Murotani et al., 2009; Matsushima et al., 2010)

Outer Fault Parameters



Inner Fault Parameters

Slip heterogeneity or roughness of faulting

Inland crustal earthquake

- **Step 4: Estimate combined area of asperities (S_a) from empirical relation S_a - S**
(Somerville et al., 1999; Irikura and Miyake, 2001 →)

$$S_a/S = 0.22$$

S_a : combined area of asperities (inner)

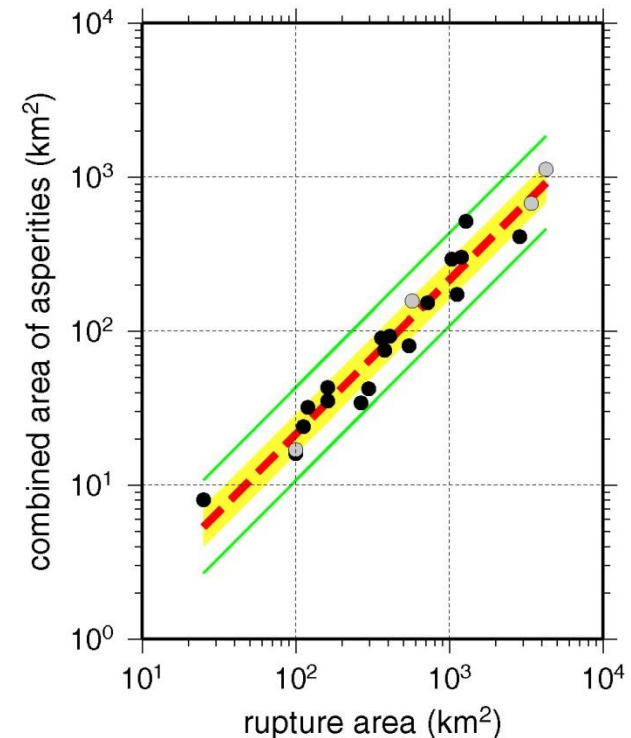
S : total rupture area (outer)

- **Step 5: Estimate Stress Drop on Asperities ($\Delta\sigma_a$)**
from multi-asperity model (Madariaga, 1979)

$$\Delta\sigma_a = \overline{\Delta\sigma_c} \cdot \frac{S}{S_a}$$

$\Delta\sigma_a$: stress drop on asperity (inner)

$\Delta\sigma_c$: average stress drop (outer)

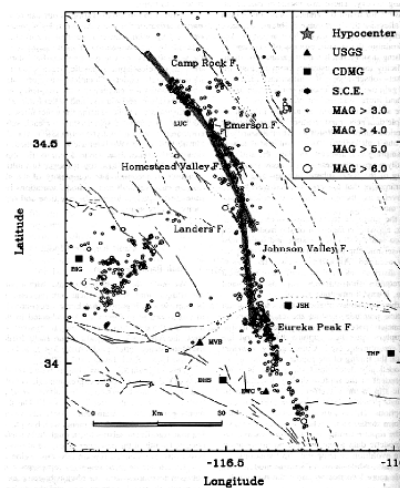


Inner Fault Parameters

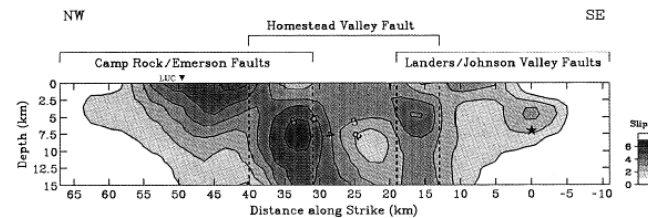
Slip heterogeneity or roughness of faulting

Inland crustal earthquake

- **Step 6:** Estimate **number of asperities** (N): The asperities in the entire fault rupture are related to the active-fault segments **location**
← from surface offsets measured along fault



1992 Landers earthquake



Wald and Heaton (1994)



Miyakoshi (personal comm.)

- **Step 7:** Estimate **average slip on asperities** (Da) based on **Step 6** and empirical relationships from dynamic simulations

(ex. $N=1 \rightarrow Da/D=2.3$, $N=2 \rightarrow Da/D=2.0$, $N=3 \rightarrow Da/D=1.8$)

reference: average $Da/D = 2.0$ (Somerville et al., 1999)

1

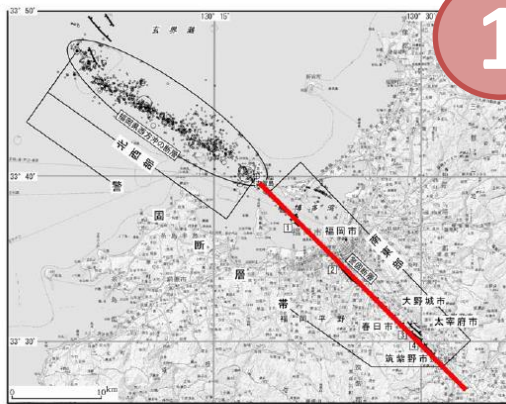


図1 警固断層帯の活断層位置図と強震動評価に用いた震源断層モデルの地表トレース

Fig.01 Surface trace of the Kego fault (red line) in Kyushu Island.

2

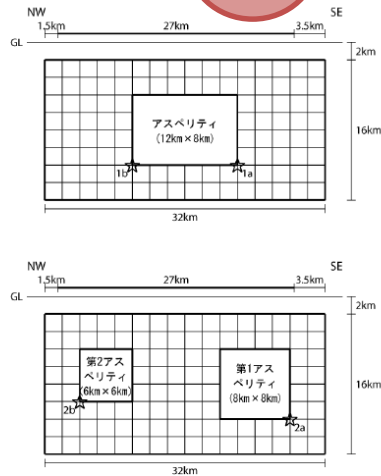


図2 震源断層モデル (形状、アスペリティ、破壊開始点)
(アスペリティの数と破壊開始点の位置によって4 ケースとなる。
1a、1b、2a、2bは破壊開始点であり、ケース名である。)

Fig.02 Source model (4 cases)

1a, 1b, 2a, 2b: Rupture starting point

3

Table 01 Source parameters.

表1 警固断層帯 (南東部) の震源断層パラメータ

パラメータ	ケース1	ケース2
長期評価による断層原点	北緯 33° 39'	
	東経 130° 19'	
長期評価による断層長さ L [km]	27	
長期評価による気象庁マグニチュード M	7.2	
断層のずれの向きと種類	左横ずれ (南西側隆起成分を伴う)	
断層モデル原点	北緯 33° 39' 38"	
	東経 130° 18' 21.6"	
断層上端深さ [km]	2	
断層長さ L_{model} [km]	32	
断層幅 W_{model} [km]	16	
断層面積 S_{model} [km ²]	512	
地震モーメント M_0 [N·m]	1.47 × 10 ¹⁹	
モーメントマグニチュード M_w	6.7	
走向 θ [°]	N136E	
傾斜角 δ [°]	90	
すべり角 λ [°]	0	
静的応力降下量 $\Delta\sigma$ [MPa]	3.1	
平均すべり量 D [m]	0.9	
剛性率 μ [N/m ²]	3.12 × 10 ¹⁰	
密度 ρ [kg/m ³]	2700	
S波速度 β [km/s]	3.4	
破壊伝播速度 V_f [km/s]	2.4	
短周期レベル A [N·m/s ²]	1.30 × 10 ¹⁹	
第1アスペリティ	面積 S_{a1} [km ²]	98.5
	地震モーメント M_{a1} [N·m]	5.53 × 10 ¹⁸
	平均すべり量 D_{a1} [m]	1.8
	突効応力 σ_{a1} [MPa]	16.0
第2アスペリティ	面積 S_{a2} [km ²]	98.5 (96)
	地震モーメント M_{a2} [N·m]	5.53 × 10 ¹⁸
	平均すべり量 D_{a2} [m]	1.8
	突効応力 σ_{a2} [MPa]	16.0
第3アスペリティ	面積 S_{a3} [km ²]	—
	地震モーメント M_{a3} [N·m]	—
	平均すべり量 D_{a3} [m]	—
	突効応力 σ_{a3} [MPa]	—
第4アスペリティ	面積 S_{a4} [km ²]	413.5 (416)
	地震モーメント M_{a4} [N·m]	9.13 × 10 ¹⁸
	平均すべり量 D_{a4} [m]	0.7
	突効応力 σ_{a4} [MPa]	2.8

(カッコ内は実際の計算で用いた面積)

4

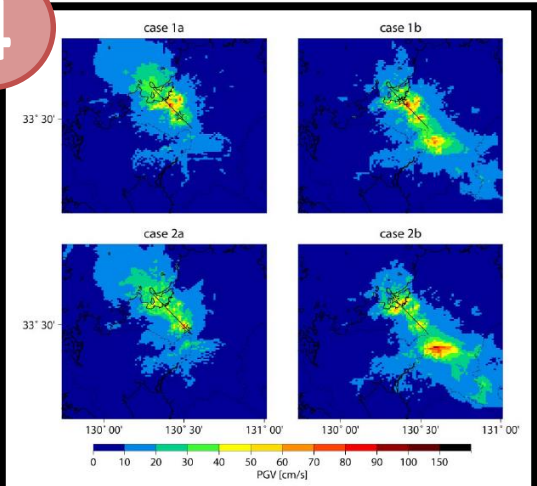


図17 「ハイブリッド合成法」による工学的基盤 ($\beta_s=600$ m/s) 上面の最大速度分布
(約 1km メッシュ; ☆は観測開始点の位置)

Fig.17 PGV distribution on engineering bed rock calculated by Hybrid simulation.

5

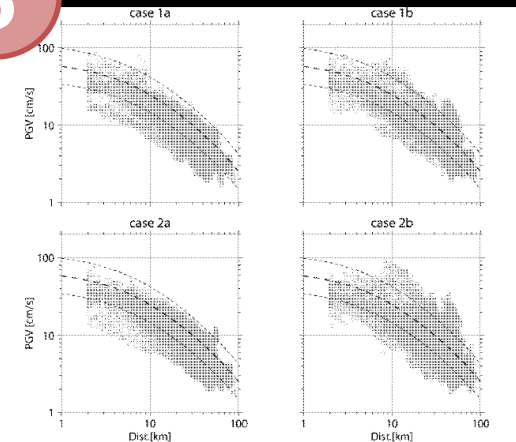
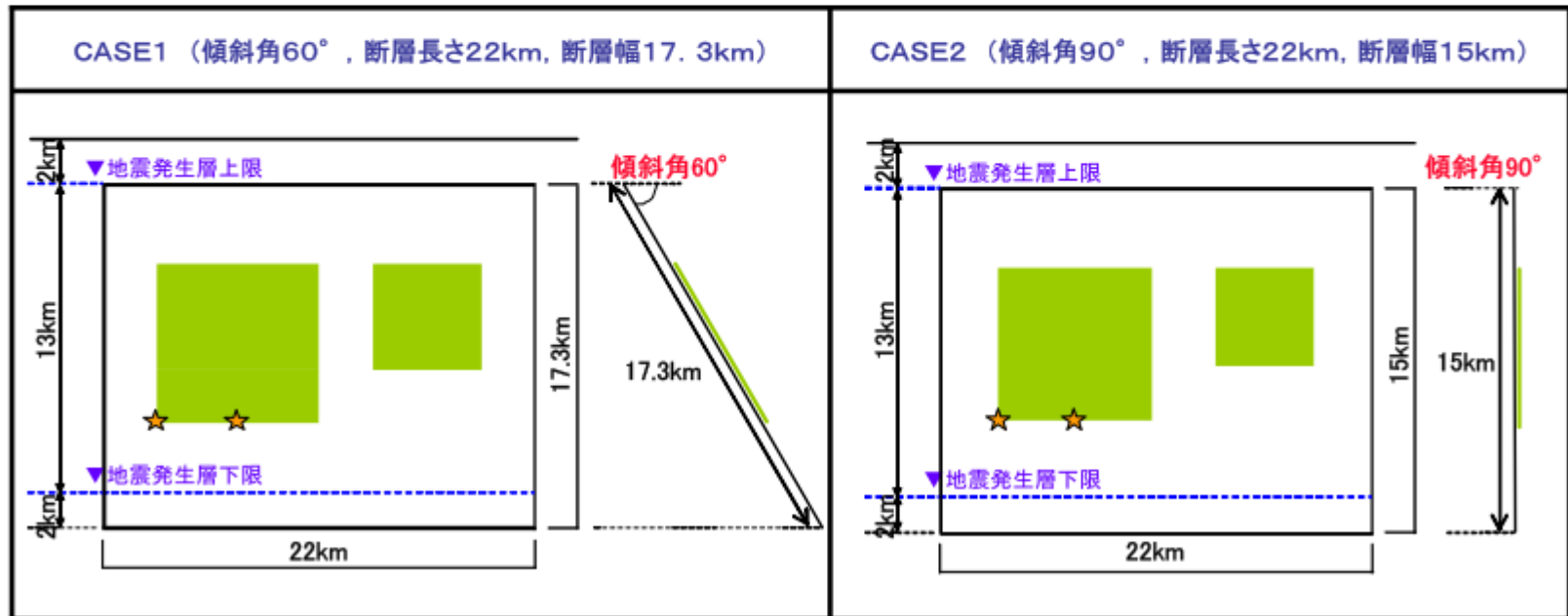


図7 工学的基盤上面における最大速度値を $\beta_s=600$ m/s 相当に換算した値と
司・翠川 (1999) の距離減衰式との比較
(約 1km メッシュ)

4. 震源を特定せず策定する地震動の検証のための震源断層モデル (2/5)

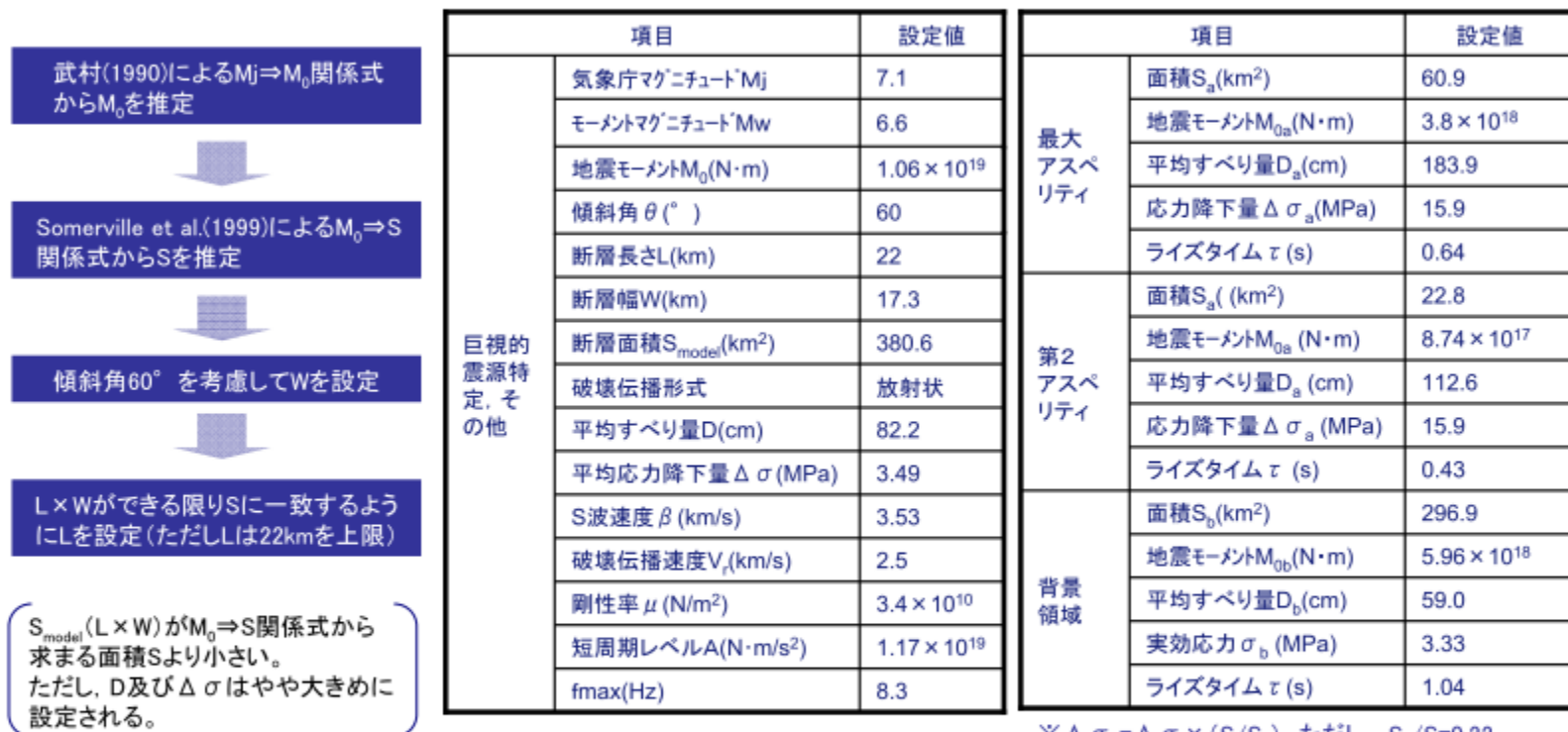
- 断層長さは「震源を特定する地震」が22kmであることから、「震源を特定しにくい地震」の断層の長さは22kmが上限と考え、安全側に22kmとする。
- 震源断層モデルとしては、以下の2ケースの断層パラメータを設定し、アスペリティ位置は地震発生層の中央、破壊開始点はアスペリティ下端とする。



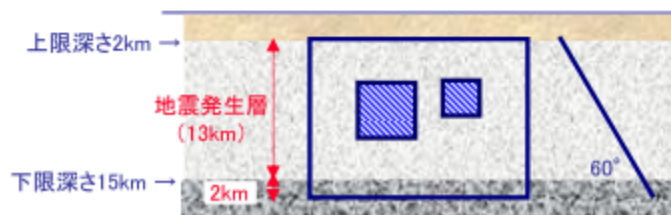
: アスペリティ
 : 破壊開始点

4. 震源を特定せず策定する地震動の検証のための震源断層モデル (3/5)

- CASE1の断層パラメータを、地震本部(2009)による強震動予測レシピを参考に下記フローに基づき設定。



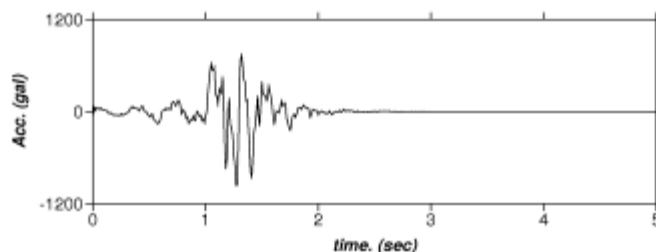
※ $\Delta \sigma_a = \Delta \sigma \times (S/S_a)$ ただし、 $S_a/S = 0.22$



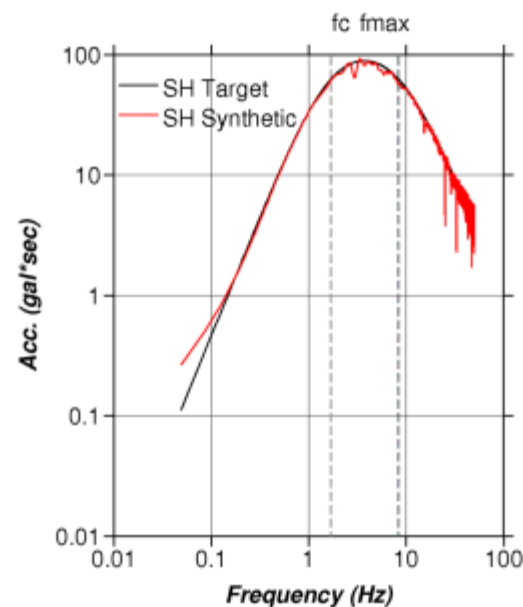
6. 統計的グリーン関数法に用いる要素地震

- 統計的グリーン関数としての要素地震は, Boore(1983)の方法を取り入れた釜江ほか(1991)に基づき作成する。(プログラムB)
- 震源断層モデルの最大アスペリティにおける要素地震の例(CASE1)を以下に示す。

地震モーメント(M_0)	1.764×10^{16} (N·m)
応力降下量($\Delta \sigma_a$)	15.9 (MPa)
$f_{\max}$	8.3 (Hz)
要素断層面積	$1.375 \times 1.331 = 1.83$ (km ²)



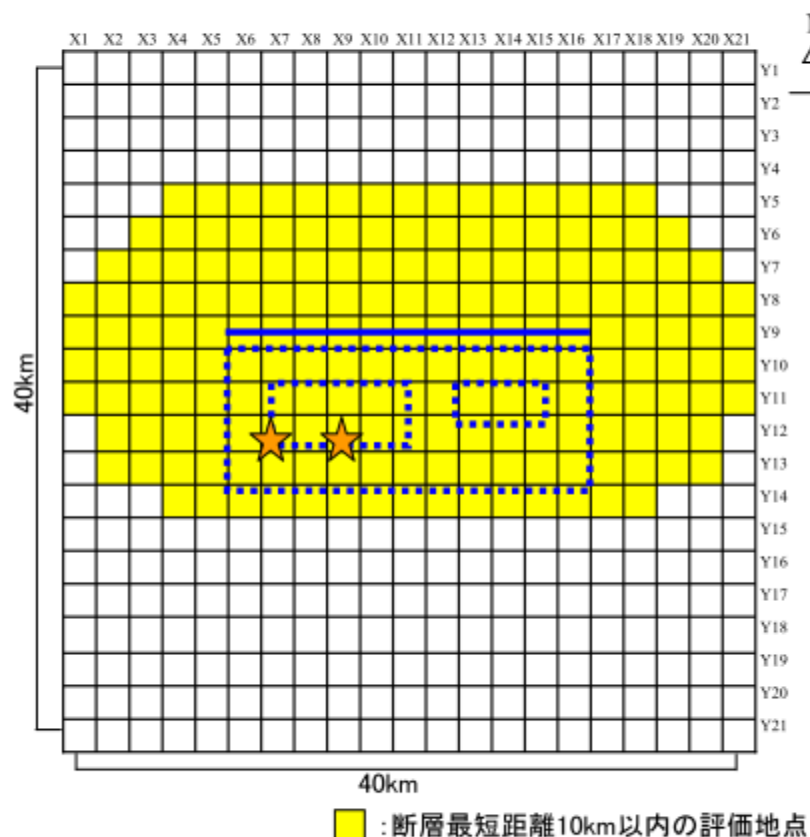
加速度時刻歴波形(単位距離)



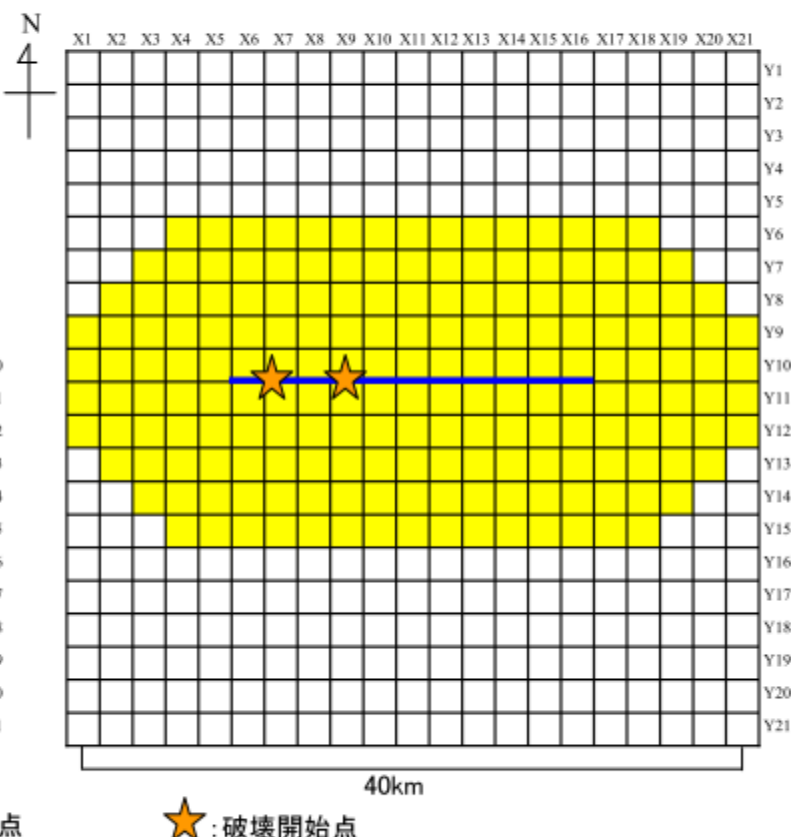
加速度震源スペクトル

7. 地震動評価地点(断層最短距離10km以内)

- 震源周辺の40km四方について、2km間隔で地震動評価を実施。これらのうち、断層最短距離10km以内の評価地点の地震動レベルを把握する。



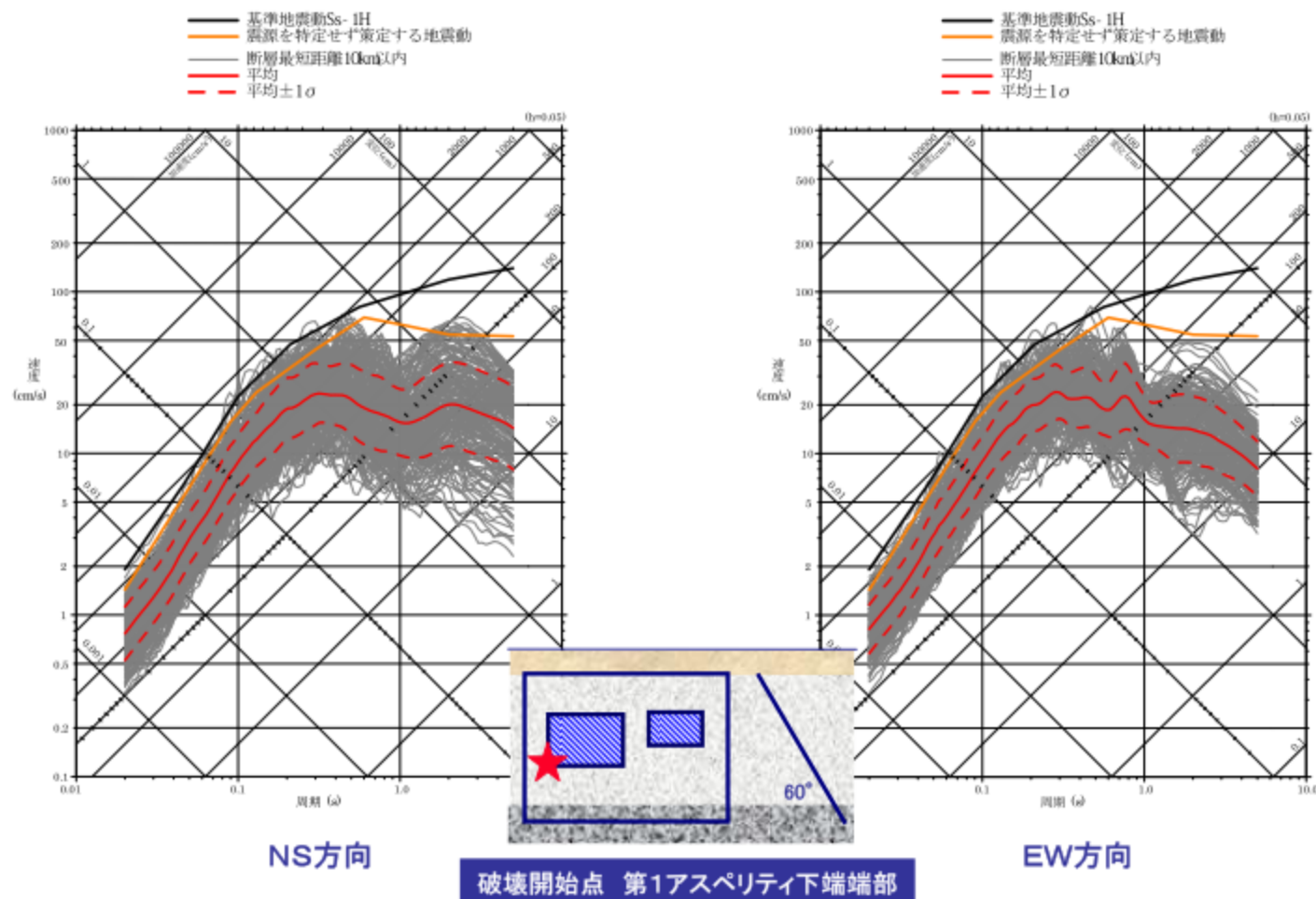
CASE1(傾斜角60°)の評価地点



CASE2(傾斜角90°)の評価地点

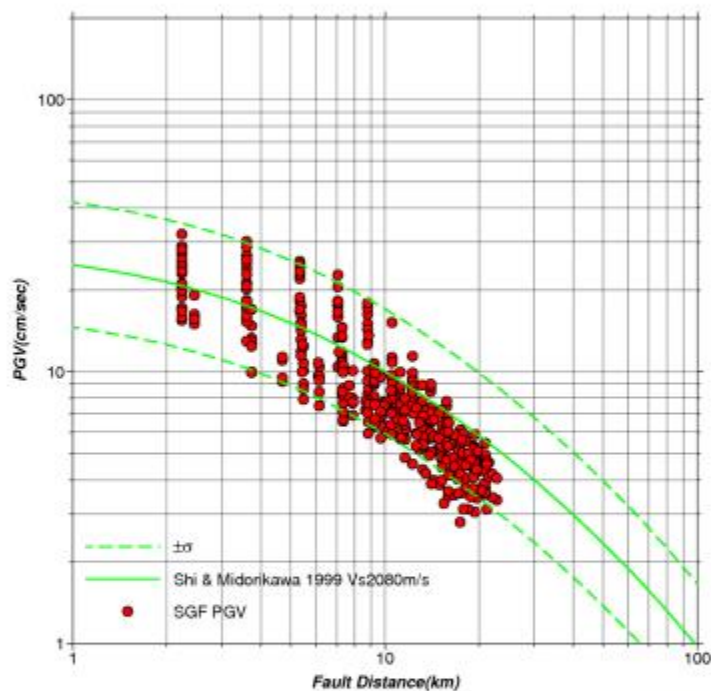
8. 地震動評価結果 (1/8)

- CASE1 (破壊開始点 : 第1アスペリティ下端端部) の平均的な地震動レベルは、島根サイトの「震源を特定せず策定する地震動」のレベルを下回る。



8. 地震動評価結果 (5/8)

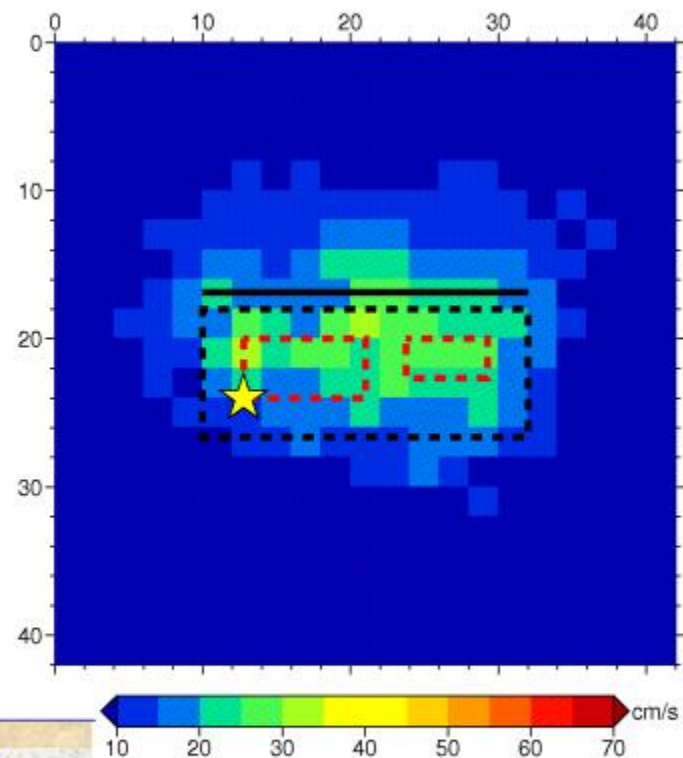
- CASE1 (破壊開始点 : 第1アスペリティ下端端部) の地震動評価結果は、震源近傍においては既往の距離減衰式と概ね対応している。



PGVと司・翠川(1999)による
距離減衰式との比較



破壊開始点 第1アスペリティ下端端部



法規與準則

- 土木構造物の耐震基準等に関する提言「第三次提言」解説，公益社団法人 土木学会，2000
- 大規模地震に対するダム耐震性能照査指針(案)，国土交通省河川局，2005
- NSCRG: L-DS-I.02 : Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities (Published in May 1978), The Nuclear Safety Commission of Japan(Latest Revision on 19 September 2006 by the Nuclear Safety Commission)
(発電用原子炉施設に関する耐震設計審査指針，原子力安全委員会，2006)
- 基準地震動及び耐震設計方針に係る審査ガイド，原子力規制委員会,2013 (地震調査研究推進本部-「震源断層を特定した地震の強震動予測手法」)

美國關於地震模擬於核電的相關應用

Finite-Fault Simulation Method of the Project

Yin-Tung Yen
GMC TI, support team

Taiwan SSHAC Level 3 PSHA Study
Working Meeting, Dec 7-10, 2015
Taipei, Taiwan

NGA-east GMC

Next Generation Attenuation Relationships for Central & Eastern North-America (Lack of observed data)

- Task E: Finite-Fault Simulations
 - To develop a database of low frequency simulated ground motions to supplement the recorded data for CENA using finite-fault models
 - Most of the simulations will be completed on the SCEC BroadBand platform
 - Dr. Frankel (USGS) is working independently, developing broadband synthetic seismograms using his own simulation methodology
- Task F: Point-Source Simulation Methods
 - To develop new alternative generalized (double-corner) point-source simulation models using CENA data and the finite-fault simulation results to constrain the source spectrum.
- Task G: Point-Source Simulations
 - To develop a database of simulated ground motions to be used in GMPE development

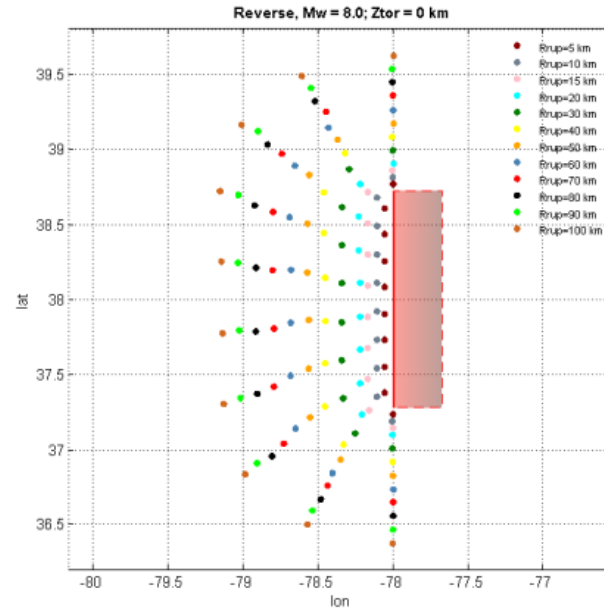
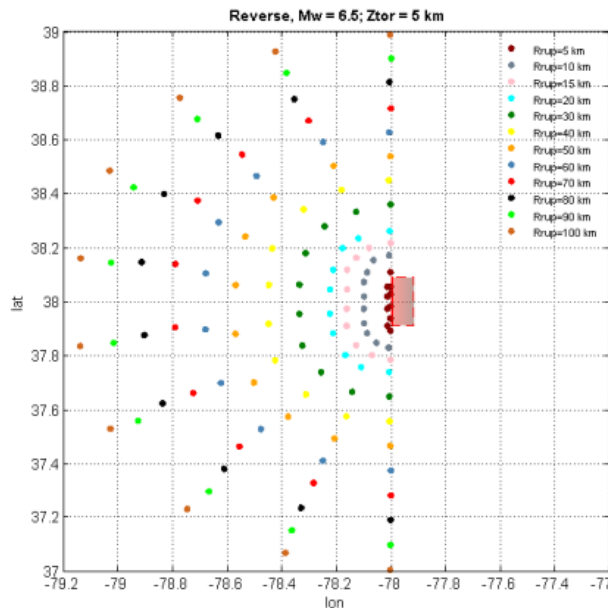
NGA-east GMC

Reverse with a dip of 45°
and an average rake of 90°

The simulations were
for footwall conditions

Table 1B.2 Summary of earthquake scenarios.

Magnitude	Length (km)*	Width (km)*	Area (km ²)*	Z_{TOR} (km) considered
5.0	2.5 (2.55)	2.5 (2.58)	6.25 (6.46)	0, 5, 10
5.5	5 (5.08)	4 (4.02)	20 (20.4)	0, 5, 10
6.5	20 (20.2)	10 (10.1)	200 (204)	0, 5, 10
7.5	80 (80.2)	25 (25.4)	2000 (2041)	0, 5, 10
8.0	160 (159.8)	40 (40.4)	6400 (6456.5)	0, 5



Handford GMC

- Hanford Sitewide Probabilistic Seismic Hazard Analysis
- GMC Databases : 3-D Wave Propagation Effects
 - 3-D Models of the Hanford Site Region
 - Ground Motion Simulations for Selected Earthquake Scenarios
 - Assessment of the Importance of 3-D effects
- Validation of Simulations – small earthquake
- Forward simulation : 3D/1D 0.5 – 10 sec
- Crustal earthquake & Subduction zone earthquake
 - 3-D wave propagation modeled using the finite difference code of Liu and Archuleta (2002)
 - 1D simulation using frequency-wavenumber integration code of Zhu and Rivera (2002).

Handford GMC

- Need to be amplified by factors of 4 or more to account for the basin effects caused by the uppermost sediment layers at the
- GMC TI Team reached the conclusion
 - while the presence of basin effects at the Hanford Site is accepted as a distinct possibility for many source-site combinations, the implied amplification factors found by Frankel et al. (2013) at periods of less than 2 sec are not considered reliable
 - the effect of any potential basin effects would be within the range of amplitudes implied by the ergodic standard deviations associated with the GMPEs

SWUS GMC

SOUTHWESTERN UNITED STATES GROUND MOTION CHARACTERIZATION SSHAC LEVEL 3

- **Validation and forward simulation:**
 - Part A : comparison between the simulated and observed PSA for past earthquakes
 - Part B : comparison between the simulated PSA and those computed using the NGA-West1 GMPEs for mag. and dist.
 - Part C : Forward simulation
- Addressed four issues: (GMC TI Team)
 - magnitude and distance scaling of **near-fault ground motions**
 - magnitude scaling for **HW effects for moderate**
 - rules for estimating ground motions from **complex ruptures**
 - rules for estimating ground motions from **splay ruptures**

SWUS GMC

	Motion in Europe (RESORCE)	$V_{S30} \geq 250$ m/s $N_{REC}/eqk \geq 3$ Adjusted to $V_{S30}=760$ m/s	
PEER-AZ _{PATH}	PEER Arizona	Earthquakes from NGA-West2 in Regions 1 and 2&3 recorded at stations in Arizona $N_{REC}/eqk \geq 3$ $N_{REC}/station \geq 5$	Estimation of the median path terms for Regions 1 and 2&3 (for PVNGS)
SIM _{DC-MED}	SCEC simulations using the broad band platform	SS: M5.5, M6.0, M6.6, and M7.2 REV: M5.5, M6.0, and M6.5	Evaluation of the median ground-motion model (for DCPD)
SIM _{HW}	SCEC simulations using the broad band platform	REV: M5.5, M6.0, and M6.5 Dips: 10, 20, 30, 45, 60 Z_{TOR} : 2.5, 7.5, 12 km	Evaluation of the scaling of the HW effect for magnitudes between M5 and M6.5 , and for Z_{TOR} scaling (for DCPD)

* Includes the following: $0 < R_x < 70$ km for both SS and REV; $0 < R_x < 70$ km & $R_y < 10$ km for SS; and $0 < R_x \leq 70$ km for SS, & Dip ≥ 80 deg.

美國ASCE規範

ASCE 7-16, 16.2.2. (Nonlinear Response History Analysis):

“A suite of not less than 11 ground motions shall be selected for each target spectrum. ... Where the required number of recorded ground motions is not available, it shall be permitted to supplement the available records with simulated ground motions. Ground motion simulations shall be consistent with the magnitudes, source characteristics, fault distances, and site conditions controlling the target spectrum.”

發展應用之願景淺談

臺灣地震波模擬幾個應用面向

- **SSHAC計畫** - 輔助GMPE於特定條件下之考量
- **地震風險控管** - 景況討論風險辨識提供避險決策
- **防災策略擬定** - 景況衍生災損及因應策略檢討
- **工程耐震檢核** - ???

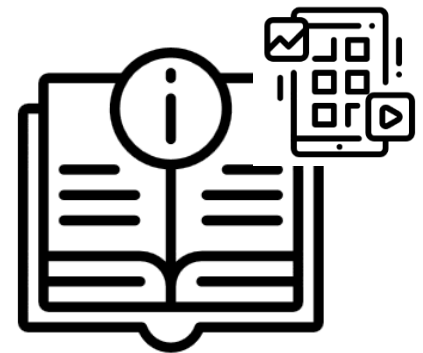
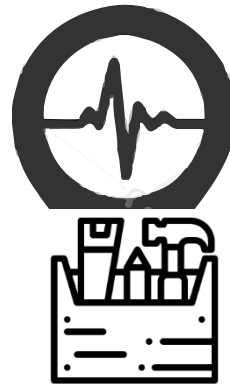
法規面向的可能性？

- 建築物耐震設計規範
- 鐵路橋梁耐震設計規範
- 水利建造物檢查及安全評估技術規範
- 核能法規 (國內未有核能法規)
 - 借鏡美國與日本

跨領域合作的推動使成果應用更務實

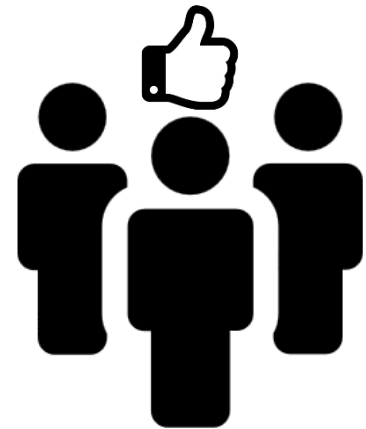
地震波模擬應用發展挑戰

- **基礎模型的建置** - 擬定模型的準確性影響模擬結果
- **模擬方法的統合** - 效率且系統性條件能有效實務化
- **法規使用的整併** - 沒有必然性的評估需求則無意義



還需要做些什麼？

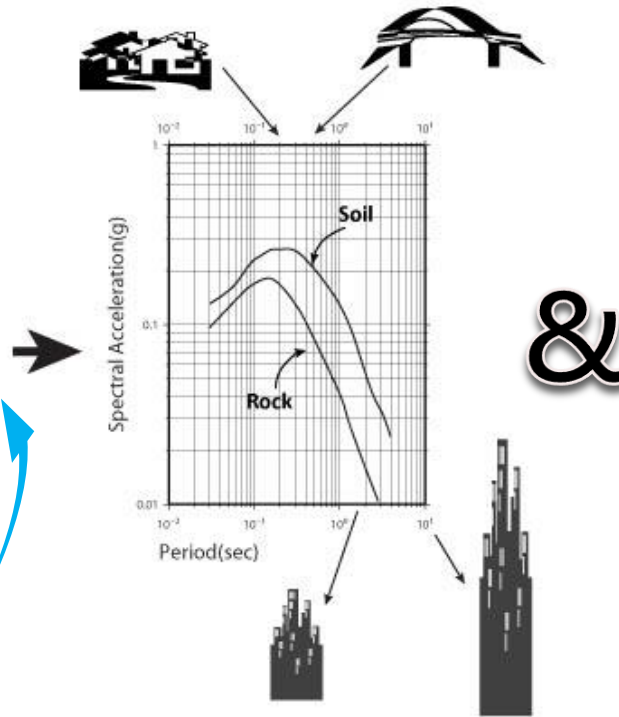
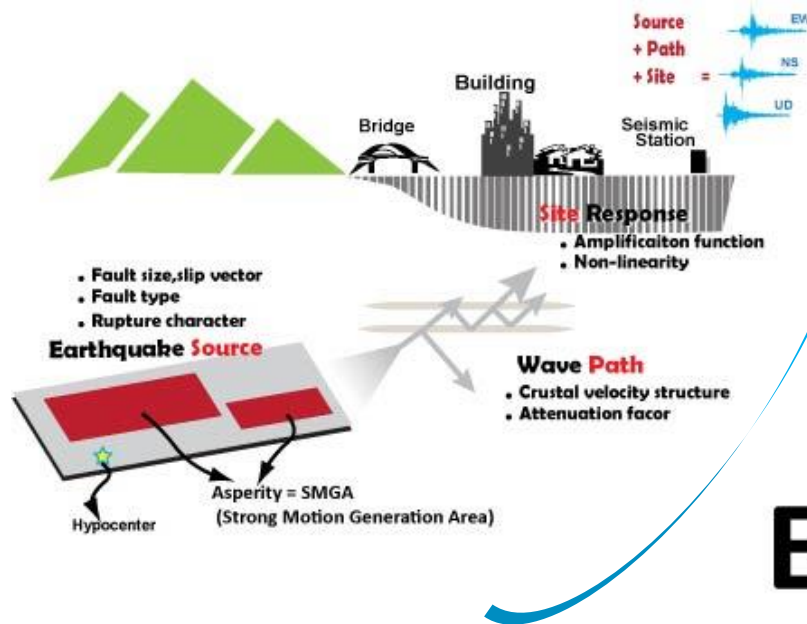
- 標準的程序 - 參數、模型及模擬程序與審查程序
- 公信的工具 - 不同的模擬方法必須有相似的結果
- 優秀的人力 - 專業訓練下可信賴之評估操作人員



地震與工程的連結

強地動時間歷時及頻率內涵

Seismology



Engineering

工程
+
災害
+
風險



工程實務

普遍性
操作性
規範性

協調

整合研究

協調

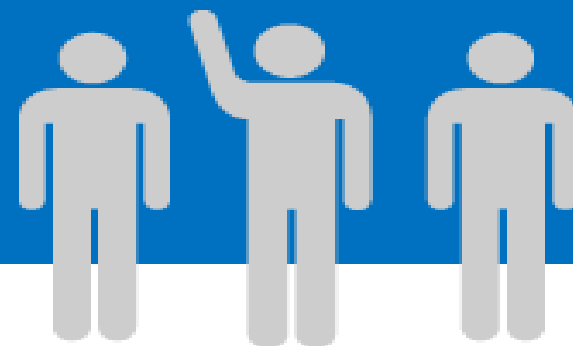
科學研究

創造性
複雜性
多樣性



感謝聆聽

Q&A



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