地震波模擬於地震動評估應用案例

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加州大地震
5月29日（週五）救援第一線 3D同步上映

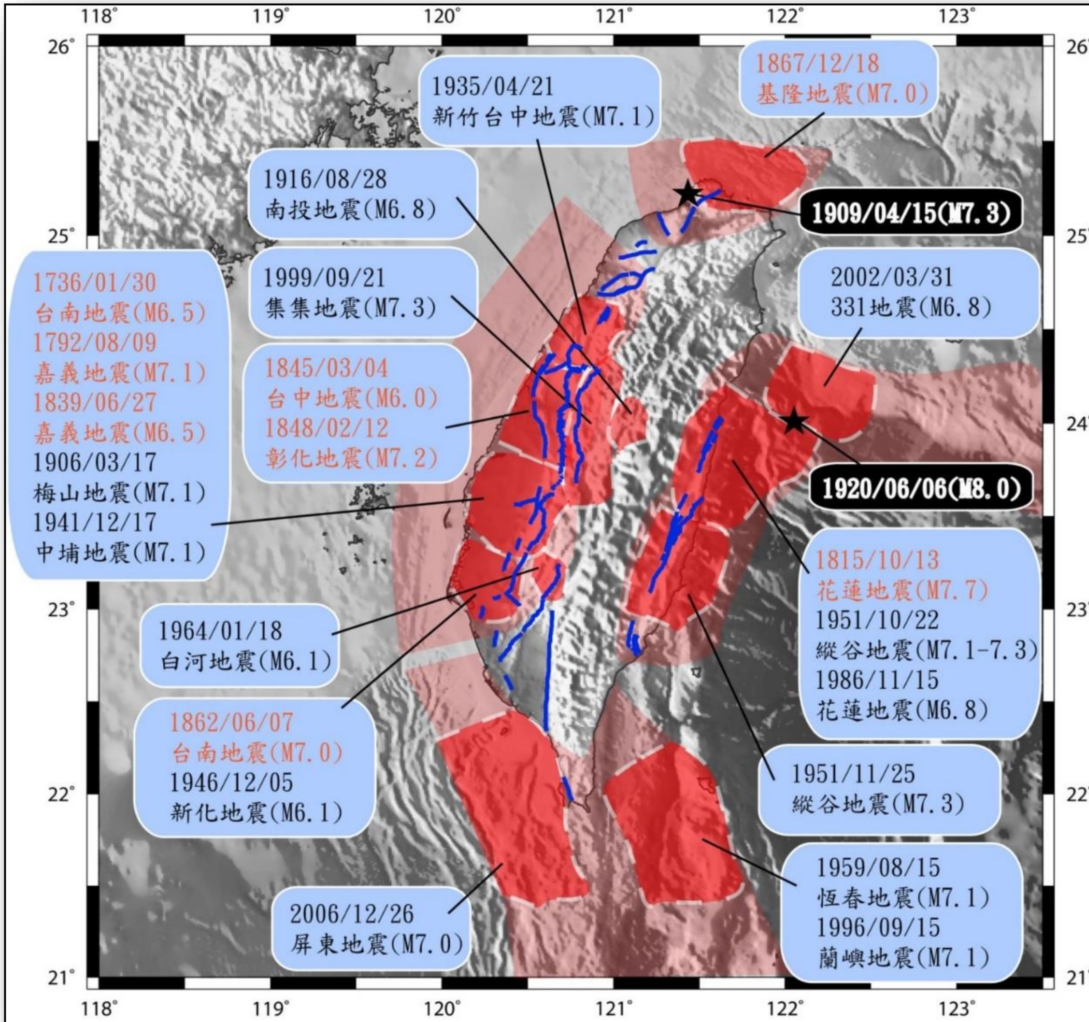
Dynamics of fault rupture

Nonlinear shallow crustal effect


Tsunami generation

Performance of tall buildings

Earthquake Hazards & Earthquake Rupture Probability in 30 Years



(Taiwan Earthquake Model, TEM)

Outline

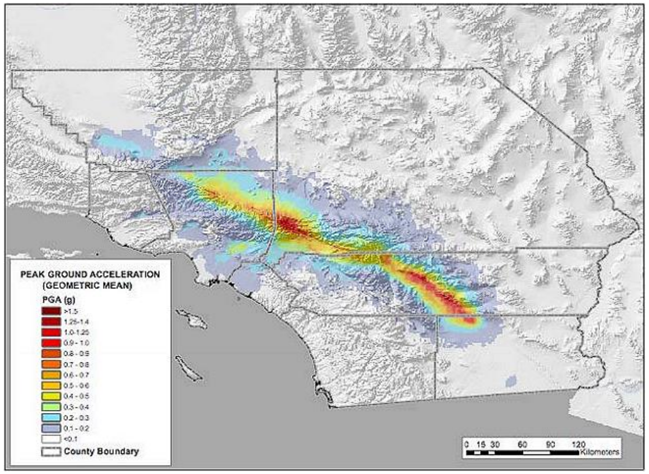
01 **地震波模擬與地震動評估**

02 **核能電廠地震動評估**
以1909臺北地震為例

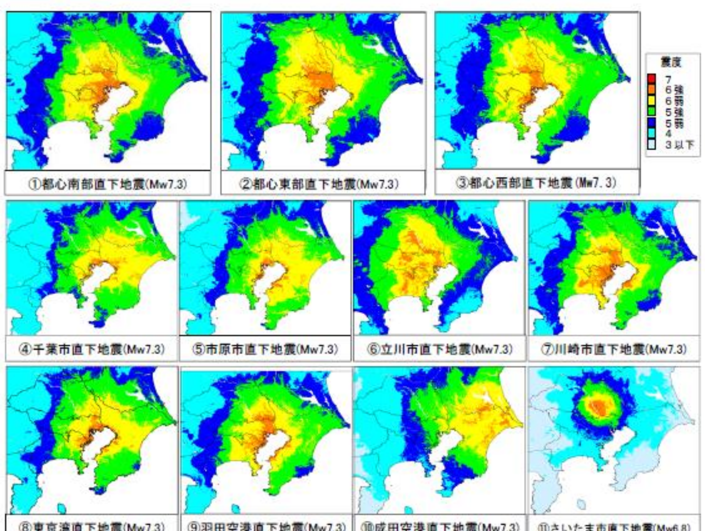
03 **科學園區地震動與地震危害度評估**
以西南臺灣孕震構造情境模擬為例

04 **都會防災**
以山腳斷層與臺北都會區為例

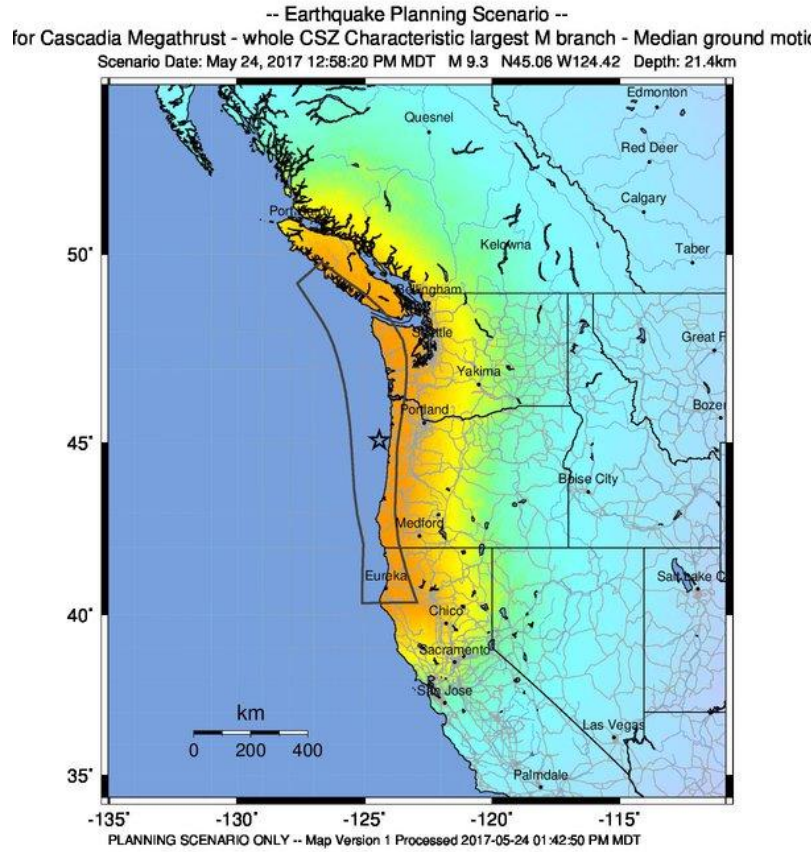
Ground Motion Simulation
- Foreign Cases -



M8 scenario (Southern CA)



M7 scenarios (Tokyo)

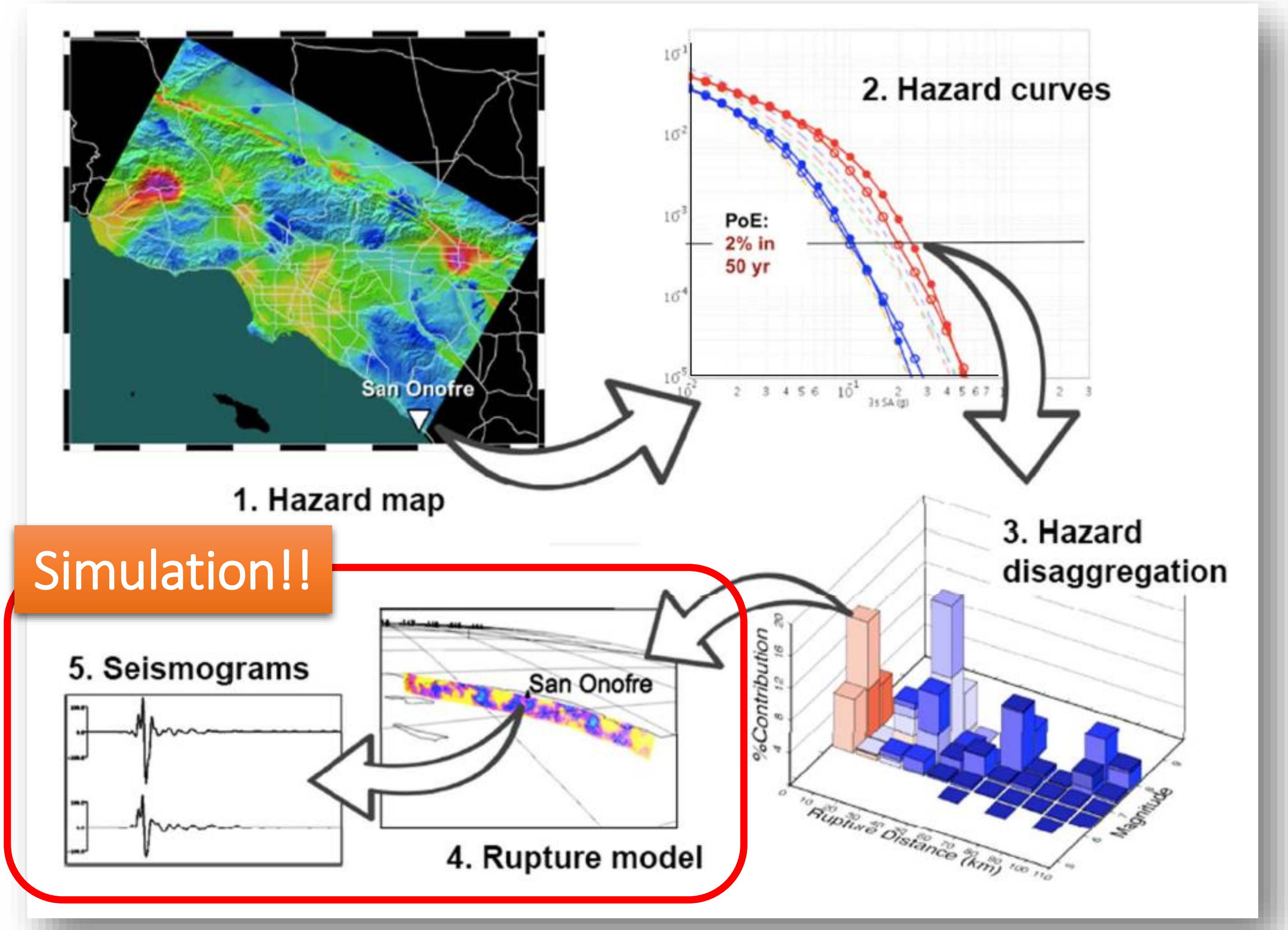


PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.05	0.3	2.8	6.2	12	22	40	75	>139
PEAK VEL.(cm/s)	<0.02	0.1	1.4	4.7	9.6	20	41	86	>178
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Worden et al. (2012)

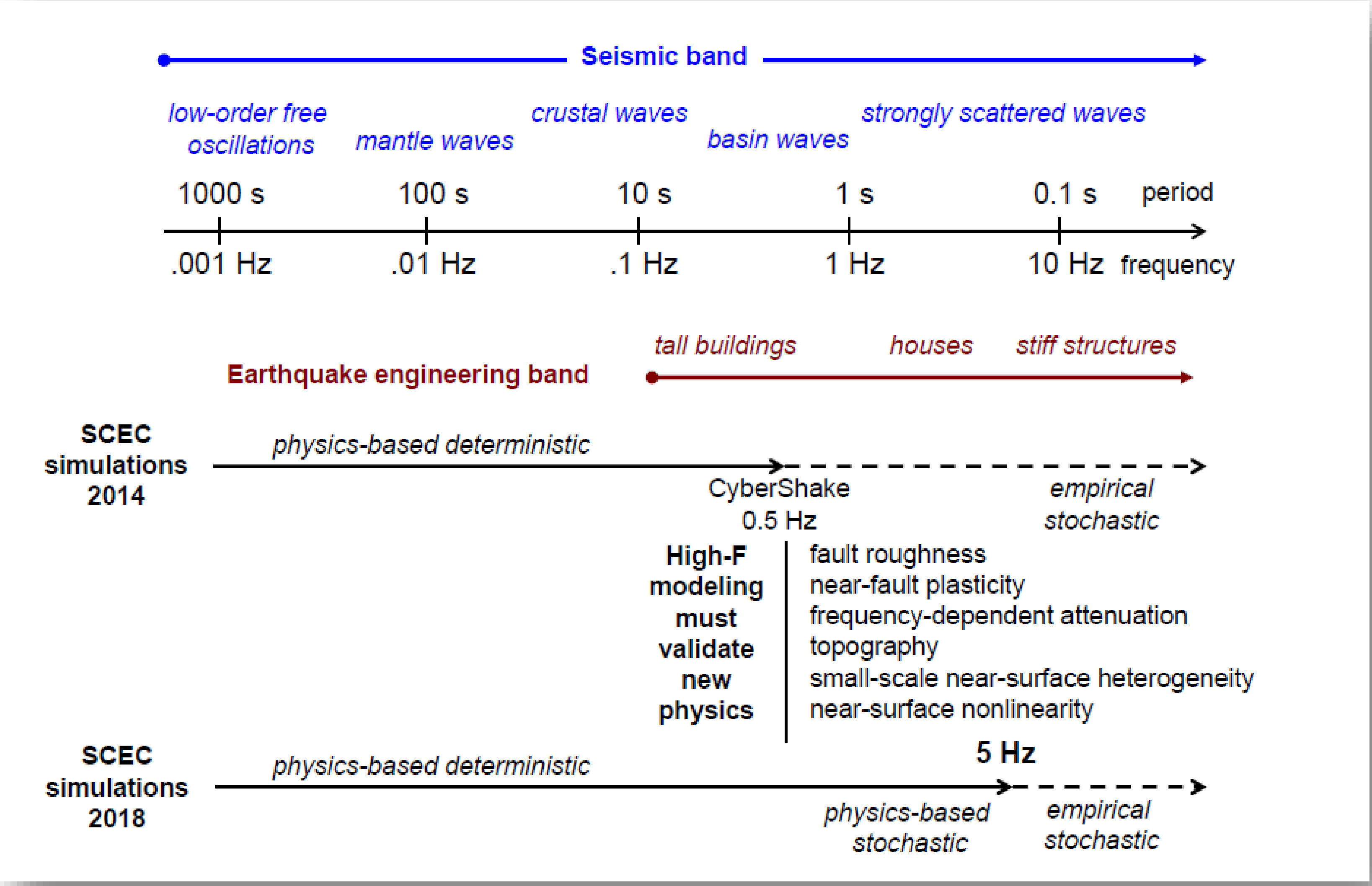
M9 scenario (Cascadia subduction zone)

Ground Motion Simulation
- Foreign Cases, USA -



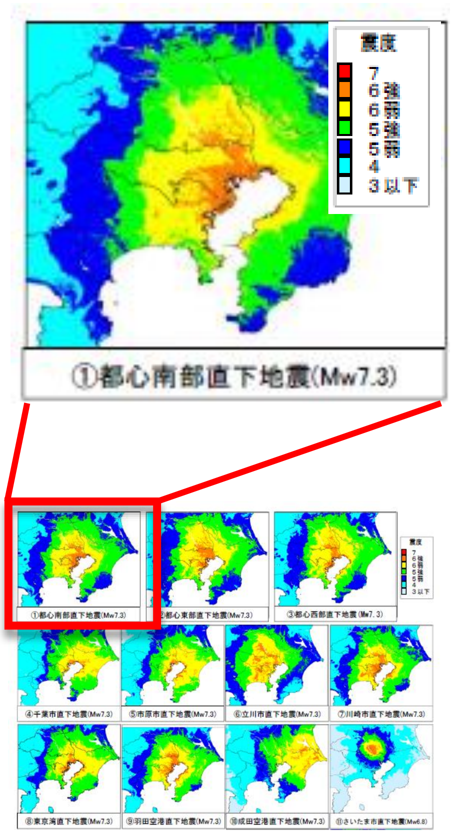
The CyberShake Platform: physics-based PSHA (courtesy of Jordan et al. 2014)

Ground Motion Simulation
- Foreign Cases, USA -

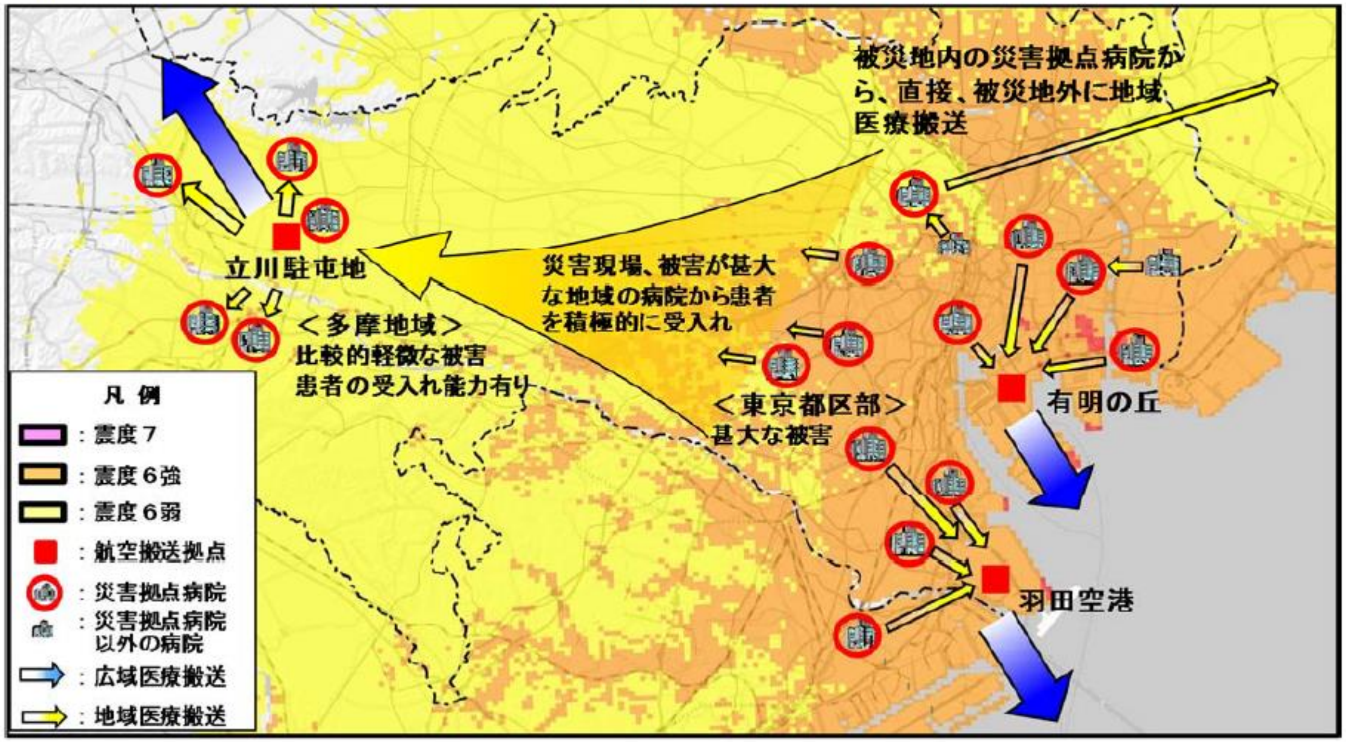


High-F Project (courtesy of Jordan et al. 2014)

Ground Motion Simulation
- Foreign Cases, Japan -

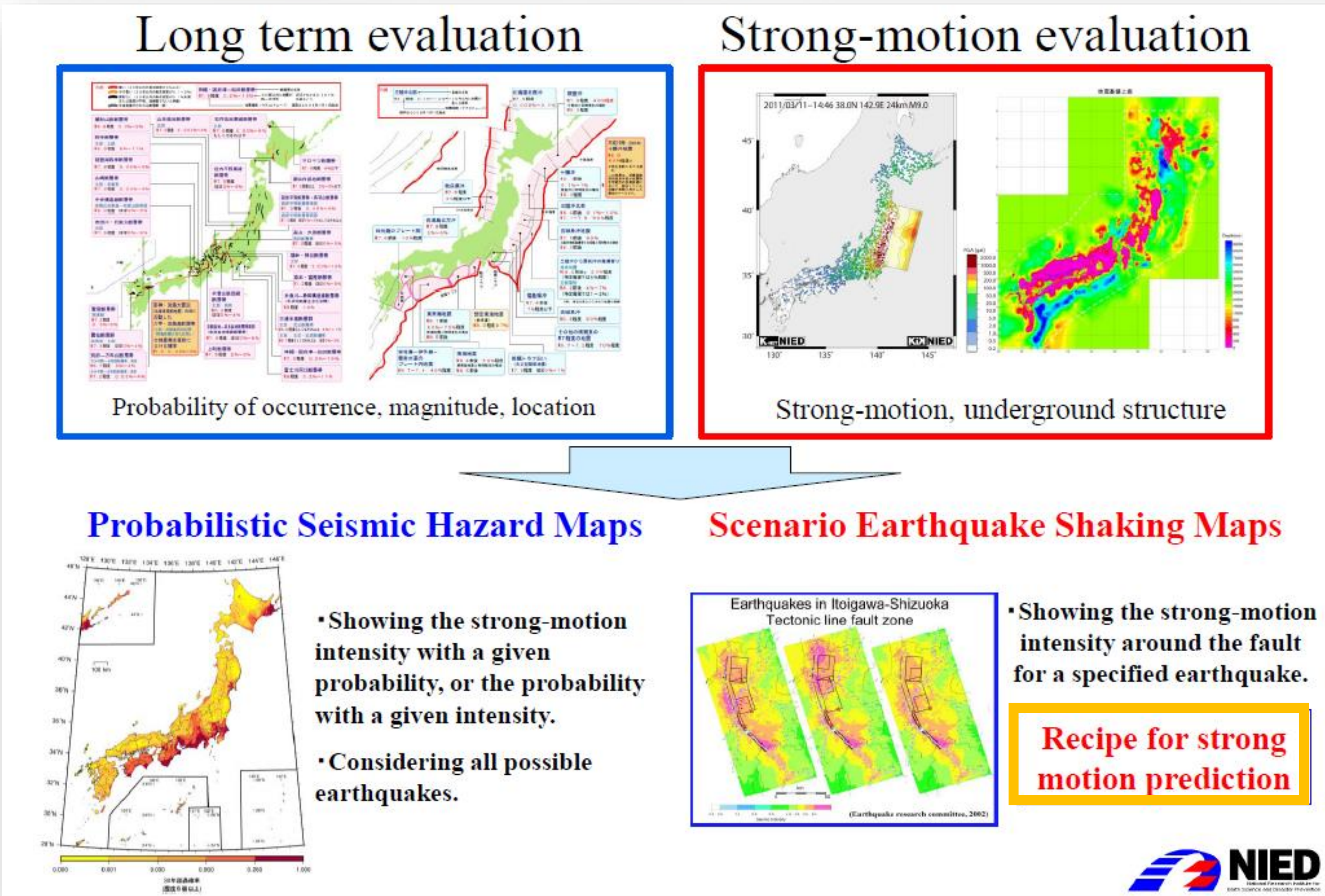


＜例：都心南部直下地震における患者搬送イメージ＞



首都直下地震における
具体的な応急対策活動に関する計画

Ground Motion Simulation
- Foreign Cases, Japan -



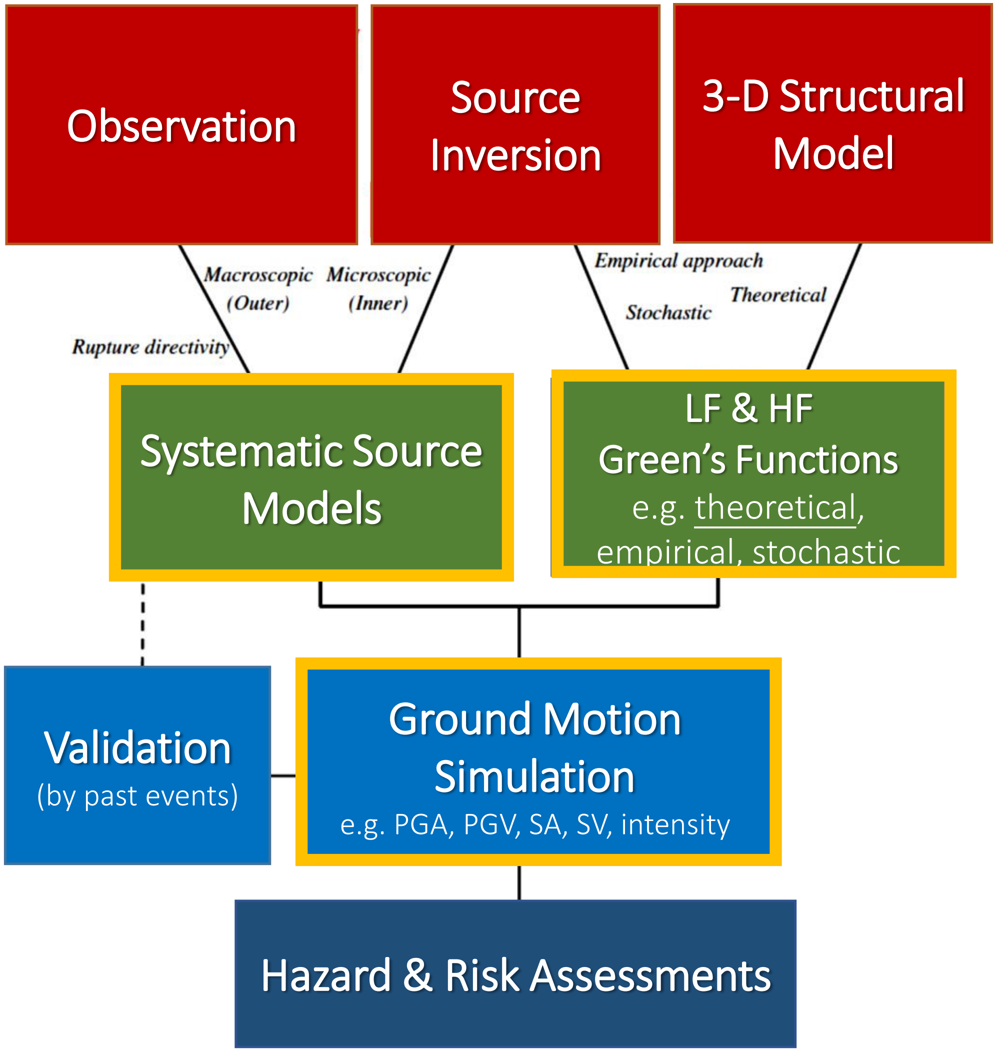
National seismic hazard maps for Japan (courtesy of Fujiwara & Morikawa, *ESG5*, 2016)

Ground Motion Simulation

- *Recipe* -

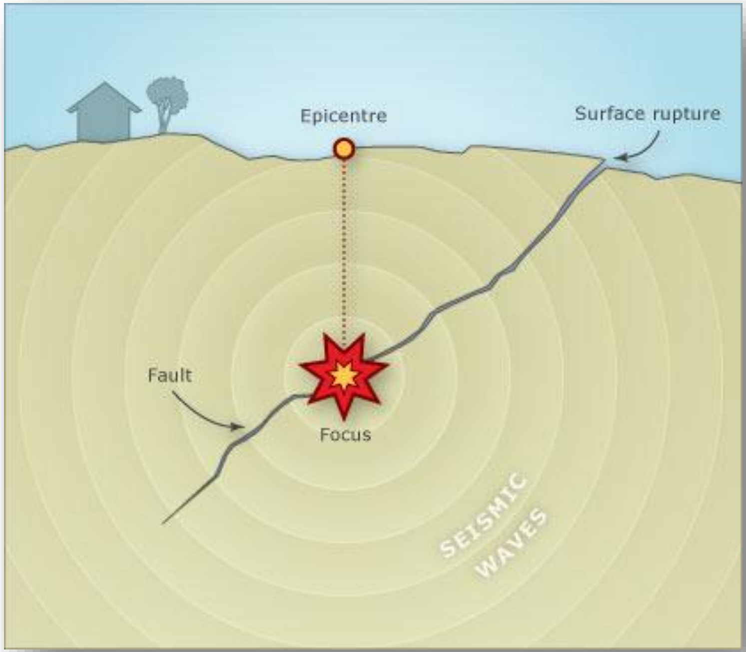
震源断層を特定した地震の強震動予測手法(Recipe)

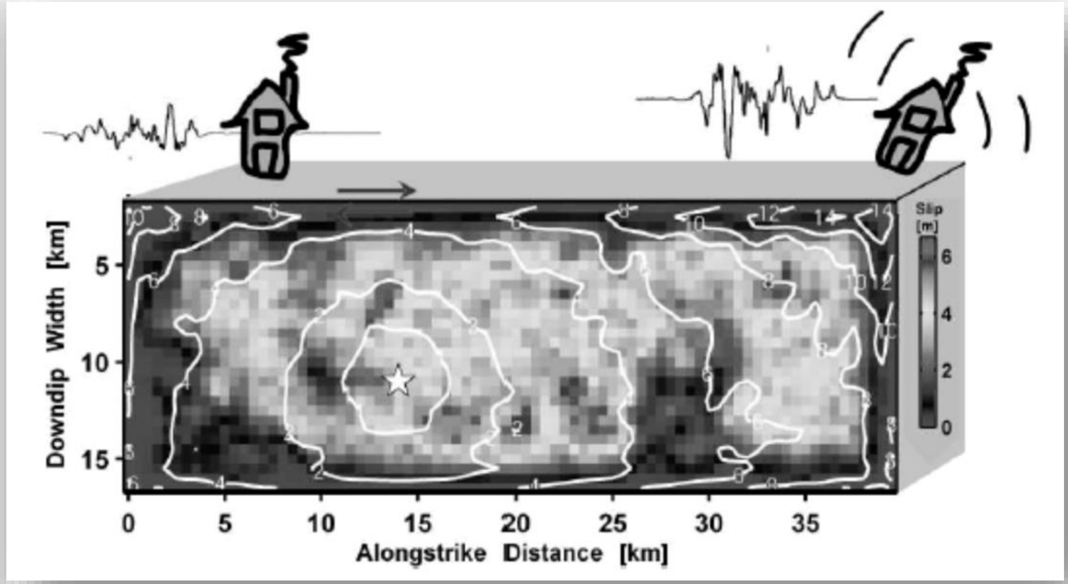
- Predicting strong ground motions
    - From **earthquake-source physics** to **earthquake engineering**
- **Re-evaluation of seismic safety** of nuclear power plants in Japan
- **Scenario shaking maps** of major active faults by **NIED** in Japan
- A hybrid ground motion simulation scheme based on ***Recipe*** has been established and applied to practical cases in Taiwan



(Irikura & Miyake, 2009)

Earthquake Source





Curtesy of Mai & Ampuero (2006)

Seismic source studies

- **Source imaging:** infer the kinematic properties of earthquake rupture
- **Dynamic rupture modeling:** the physics of nucleation, propagation and arrest of earthquake rupture
- **Earthquake scaling:** from small to large, from nucleation to arrest
- **Ground-motions and seismic hazard:** high-frequency radiation due to earthquake source complexity

Waveform Simulation Methods in Various Frequency Bands

Low frequency

~10^{-3}Hz — 1-D Earth Model (Global)

- Direct Solution Method (DSM)
- Normal Mode Summation

~10^{-1}Hz — 1-D Structure Model (Regional)

- Frequency-Wavenumber (FK)

~10^{-1} to 10^{1}Hz — 2-D or 3-D Structure Model (Regional to Local)

- Finite-Difference Method (FDM)
- Spectral-Element Method (SEM)

Empirically full frequency content — Reference Model Independent

- Empirical Green's Function (EGF)
- Stochastic Method

High frequency

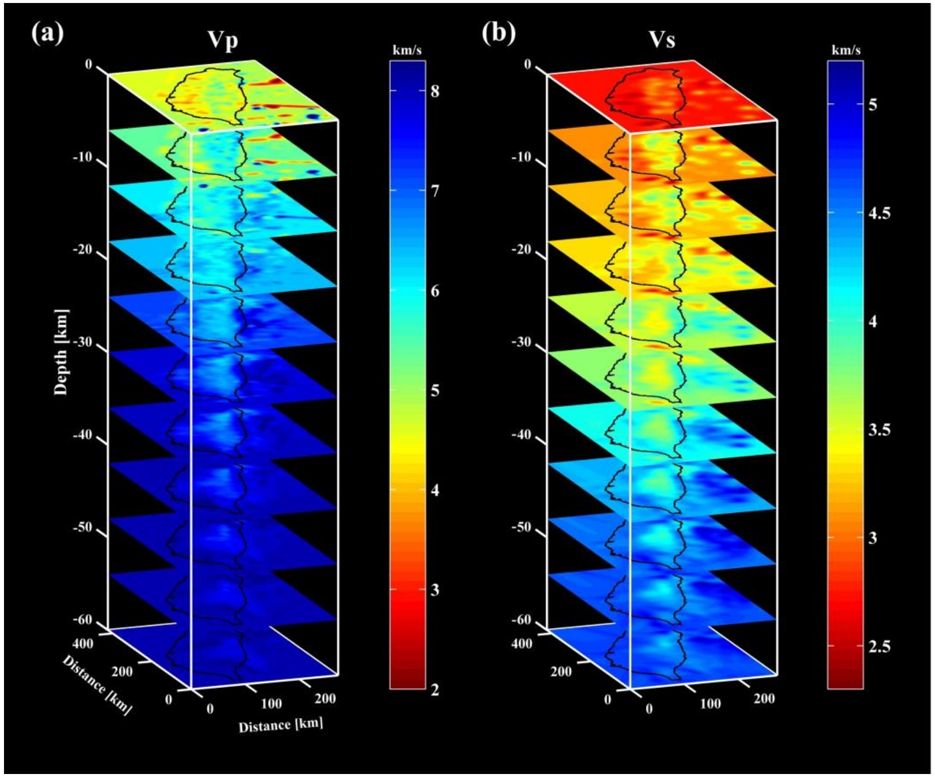
Long-Frequency Time History
- Finite-Difference Method -

- Governing equations

$$\rho\frac{\partial \mathbf{v}}{\partial t} = \nabla\cdot\sigma + \mathbf{f}$$ (Equation of Motion)

$$\frac{\partial \sigma}{\partial t} = \mathbf{C} : \frac{1}{2}[\nabla\mathbf{v} + (\nabla\mathbf{v})^T] - \dot{\mathbf{m}}$$ (Constitutive Law)

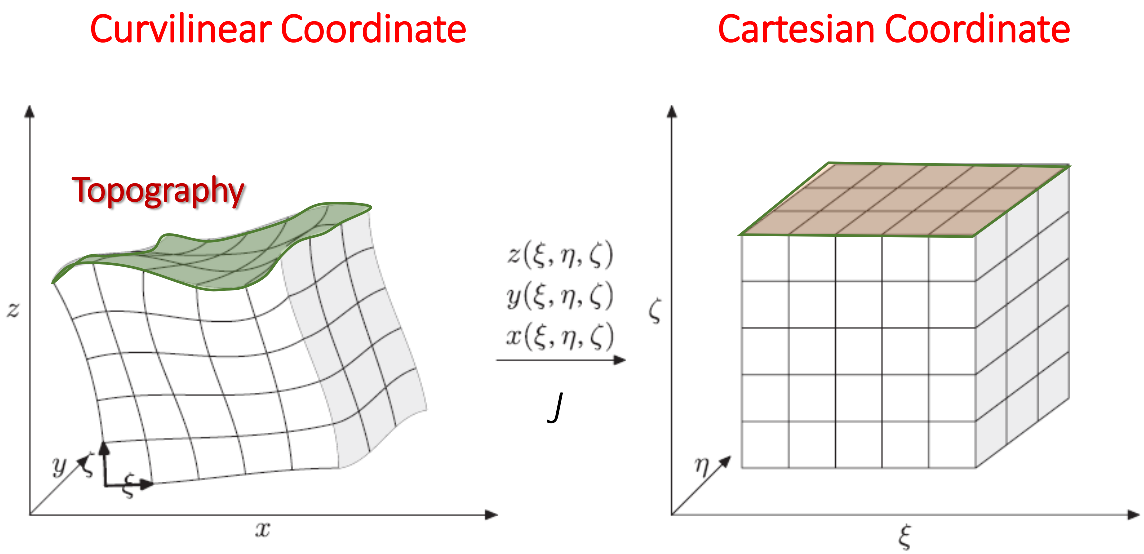
- FDM of Zhang & Chen (2006)
  - Straightforward mesh generation
  - DRP/opt MacCormack scheme
  - Local operators (easily to be parallelized)
  - Traction-image method for free-surface topography



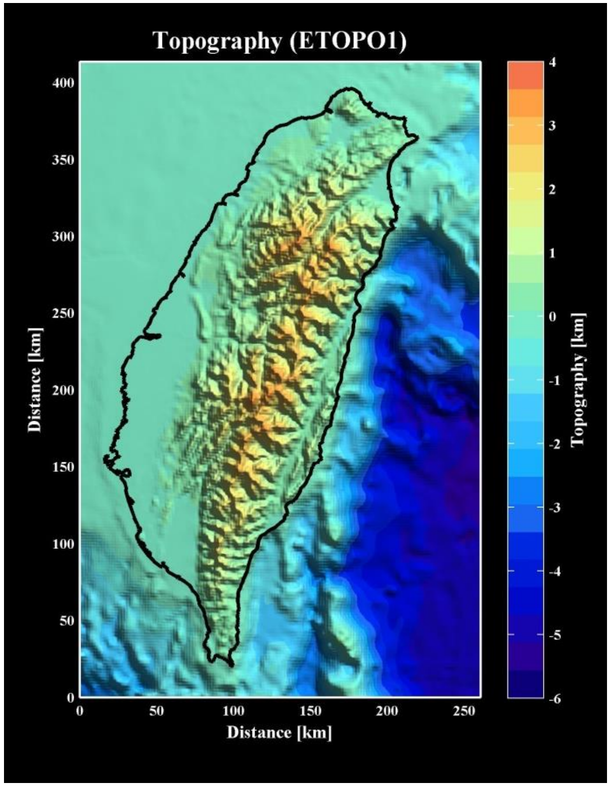
3-D Velocity Model
(Kuo-Chen *et al.*, 2012)

Long-Frequency Time History
- Finite-Difference Method -

- Traction-image FDM (Zhang & Chen, 2006)
  - **Non-uniform grid (coordinate mapping)**
  - Modeling internal interfaces and topography
  - Requiring less computational resources

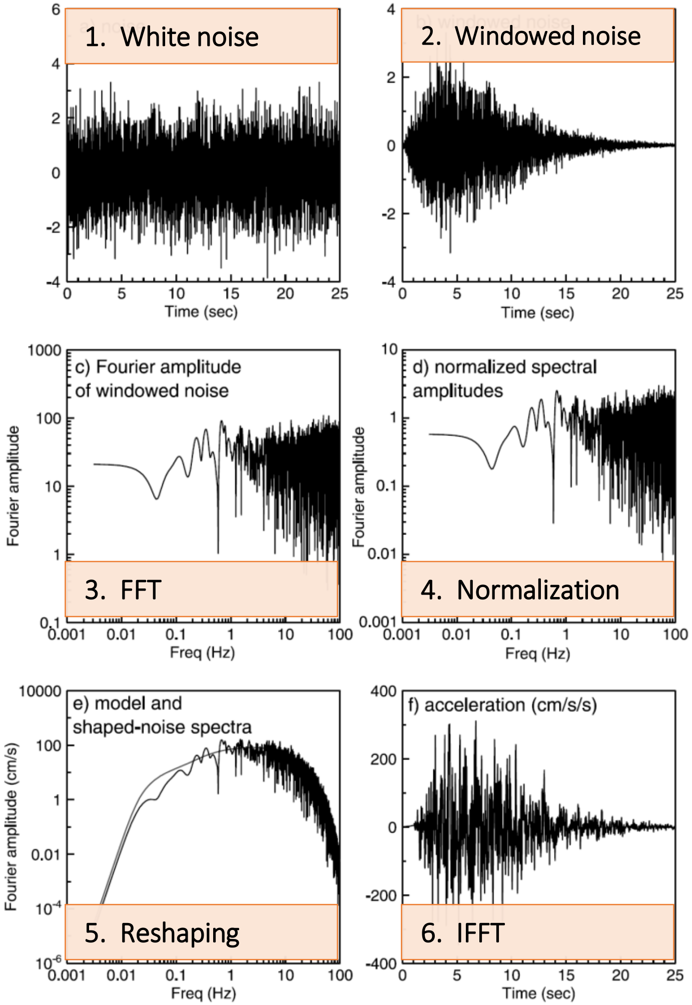


(Zhang *et al.*, 2012)

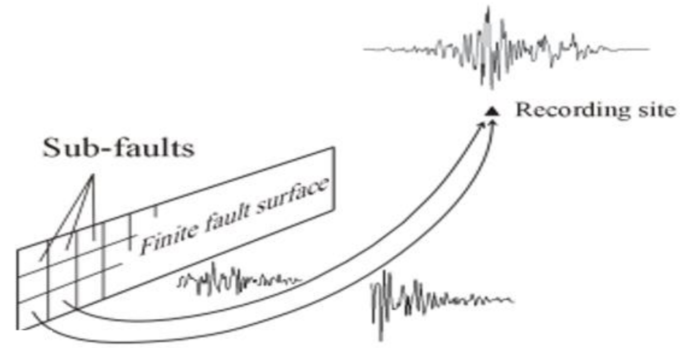


Topography: ETOPO1
- Released by **NOAA**
- 1-minute resolution (~1.85km)

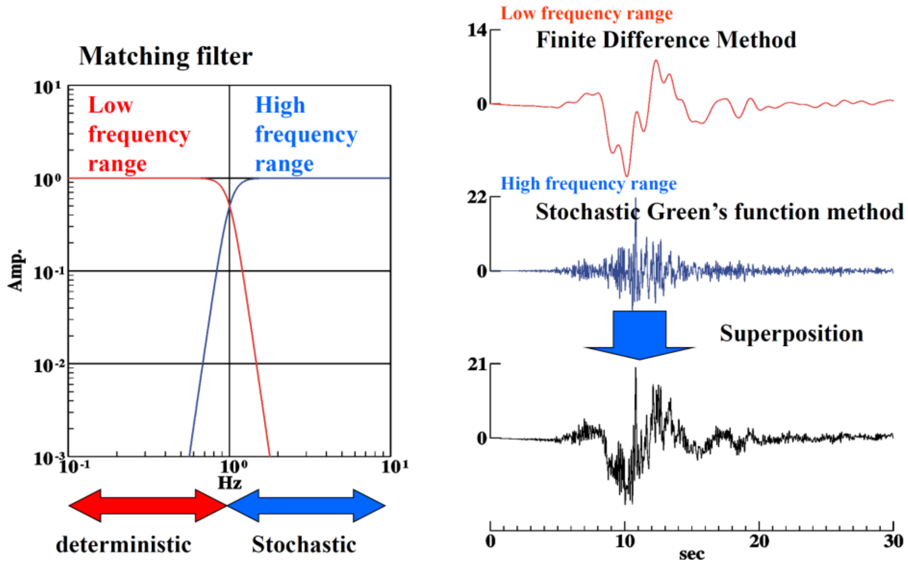
High-Frequency Time History
- Stochastic Method -



Point-source HF Synthetic
Boore (2003)



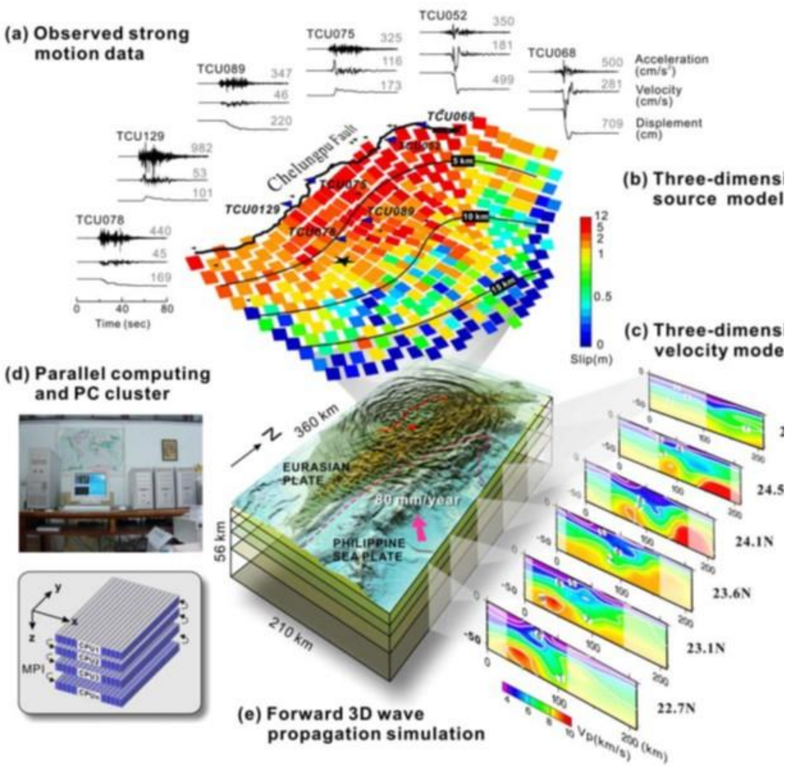
Finite-Fault HF Synthetic



Hybrid Method for Evaluation of Ground Motion
Fujiwara & Morikawa (*ESG5*, 2016)

High Performance Computation (HPC) for Ground Motion Simulation

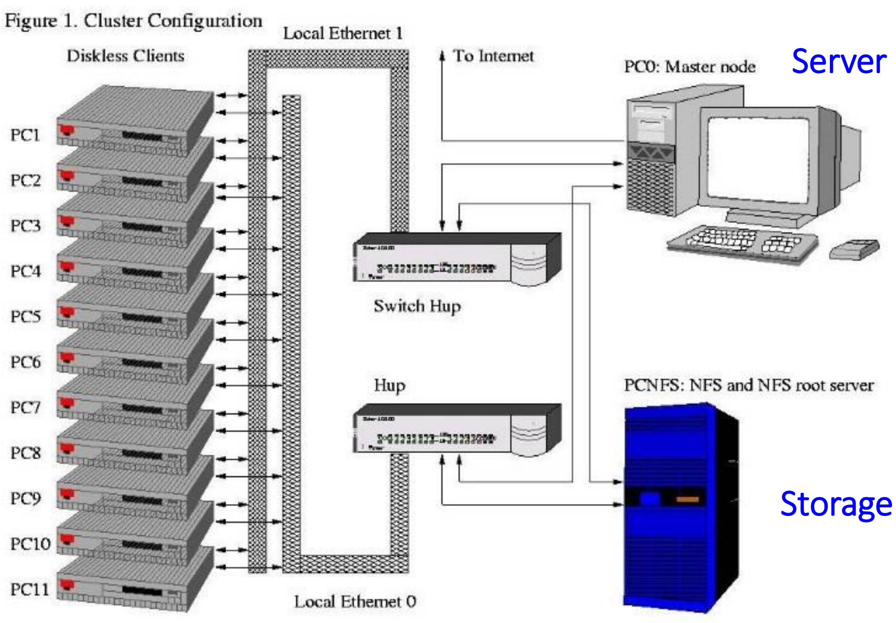
Numerical simulation → computational resources are required



Ground Motion Simulation Framework

Courtesy of Lee *et al.* (2007)

Computation



Cluster Configuration

(http://proj1.sinica.edu.tw/~statphys/computer/buildPara.html)

High Performance Computation (HPC) for Ground Motion Simulation

Numerical simulation → computational resources are required

鴻海 HPC (6 PFlops)

iPhone X

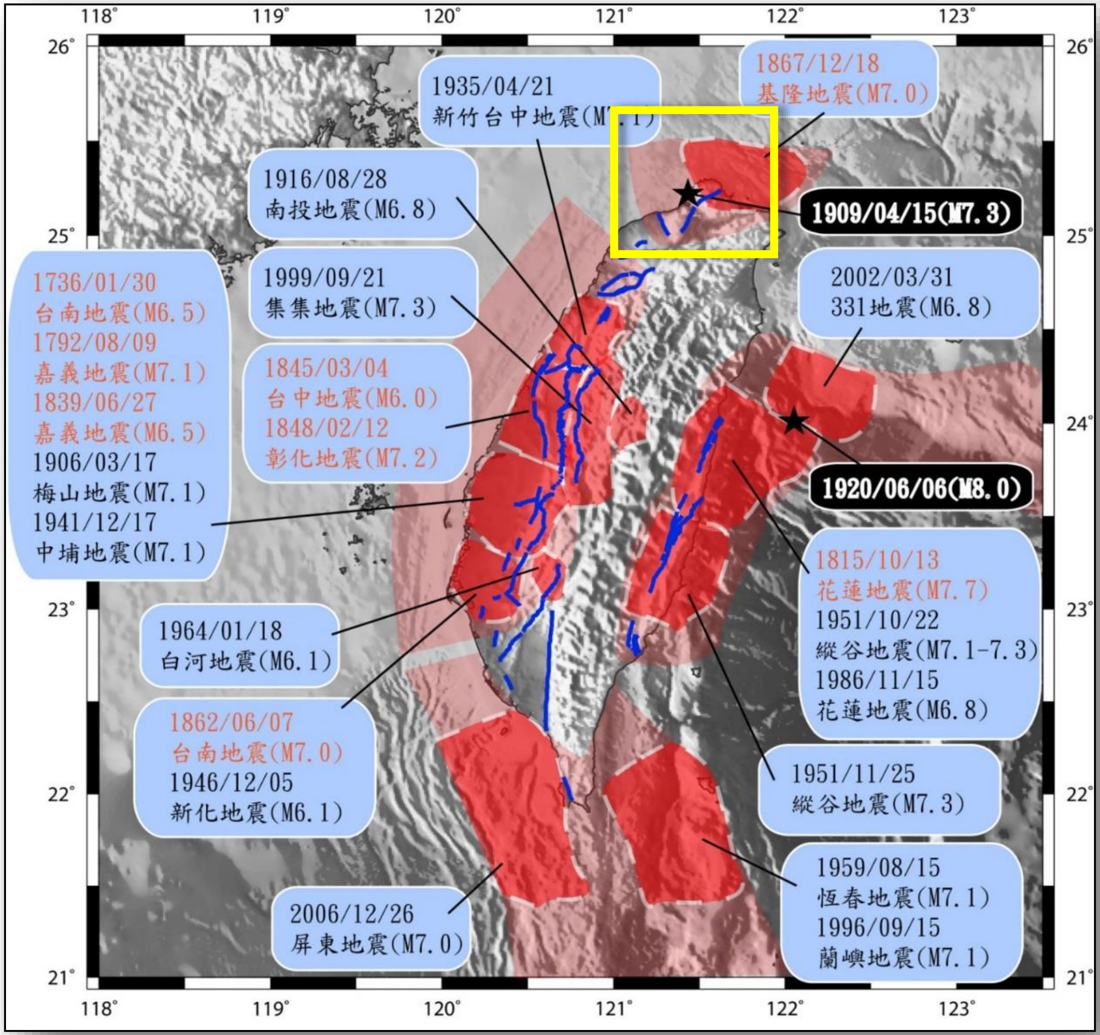
X 5,400,000

Rank	System	Cores	Rmax (TFlop/s)	Rpeak (TFlop/s)	Power (kW)
1	**Sunway TaihuLight** - Sunway MPP, Sunway SW26010 260C 1.45GHz, Sunway , NRCPC National Supercomputing Center in Wuxi China	10,649,600	93,014.6	125,435.9	15,371
2	**Tianhe-2 (MilkyWay-2)** - TH-IVB-FEP Cluster, Intel Xeon E5-2692 12C 2.200GHz, TH Express-2, Intel Xeon Phi 31S1P , NUDT National Super Computer Center in Guangzhou China	3,120,000	33,862.7	54,902.4	17,808
3	**Piz Daint** - Cray XC50, Xeon E5-2690v3 12C 2.6GHz, Aries interconnect , NVIDIA Tesla P100 , Cray Inc. Swiss National Supercomputing Centre (CSCS) Switzerland	361,760	19,590.0	25,326.3	2,272
4	**Gyoukou** - ZettaScaler-2.2 HPC system, Xeon D-1571 16C 1.3GHz, Infiniband EDR, PEZY-SC2 700Mhz , ExaScaler Japan Agency for Marine-Earth Science and Technology Japan	19,860,000	19,135.8	28,192.0	1,350
5	**Titan** - Cray XK7, Opteron 6274 16C 2.200GHz, Cray Gemini interconnect, NVIDIA K20x , Cray Inc. DOE/SC/Oak Ridge National Laboratory United States	560,640	17,590.0	27,112.5	8,209

The World's Top 5 Super Computers in 2017

The World's Top 1 Super Computer
神威 太湖之光 (93 PFlops)

Earthquake Hazards & Earthquake Rupture Probability in 30 Years



(Taiwan Earthquake Model, TEM)

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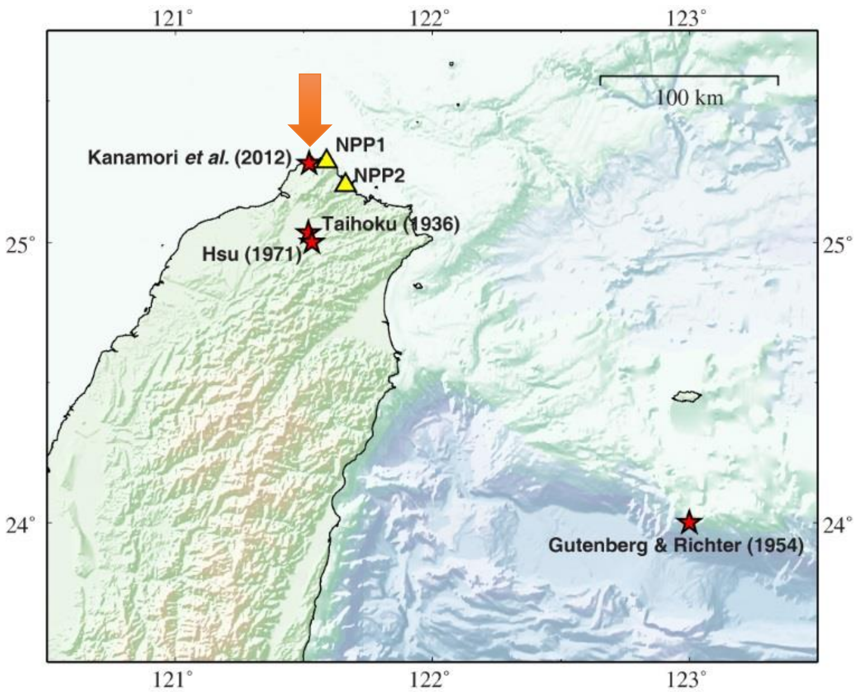
Ground Motion Simulation
- The 1909 Taipei Earthquake -



Relocation of the 1909 Taipei Earthquake

Geophysical Journal International

Geophys. J. Int. (2012) **191**, 126–146 doi: 10.1111/j.1365-246X.2012.05589.x

The 1909 Taipei earthquake—implication for seismic hazard in Taipei

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SUMMARY

The 1909 April 14 Taiwan earthquake caused significant damage in Taipei. Most of the information on this earthquake available until now is from the written reports on its macro-seismic effects and from seismic station bulletins. In view of the importance of this event for assessing the shaking hazard in the present-day Taipei, we collected historical seismograms and station bulletins of this event and investigated them in conjunction with other seismological data. We compared the observed seismograms with those from recent earthquakes in similar tectonic environments to characterize the 1909 earthquake. Despite the inevitably large uncertainties associated with old data, we conclude that the 1909 Taipei earthquake is a relatively deep (50–100 km) intraplate earthquake that occurred within the subducting Philippine Sea Plate beneath Taipei with an estimated M_W of 7 ± 0.3. Some intraplate events elsewhere in the world are enriched in high-frequency energy and the resulting ground motions can be very strong. Thus, despite its relatively large depth and a moderately large magnitude, it would be prudent to review the safety of the existing structures in Taipei against large intraplate earthquakes like the 1909 Taipei earthquake.

Key words: Earthquake dynamics; Earthquake ground motions; Earthquake source observations; Seismicity and tectonics; Site effects.

- $M_W 7 \pm 0.3$ *intraplate* earthquake
- Seismic hazard
  - 9 deaths, 51 injuries
  - 122 collapsed, 252 partially destroyed
- **If it happens again in the Taipei Metropolitan Area??**

Ground Motion Simulation
- Source Scaling Relationship -

Magnitude vs. moment (energy) → **fault dimension** → **asperity dimension** → **slips on asperity & background areas**

- Fault area from seismic moment (m_0) (Wells & Coppersmith, 1994)

$$A = 4.24 \times 10^{-11} \times m_0^{\ 0.5}$$

- Fault length (L) = **2** x fault width (W) (Geller, 1976)
- Summed area of two asperities is **0.22** of full fault area (Somerville *et al.*, 1999)
- Area of major asperity : Area of 2nd asperity = **16:6** (Irikura & Miyake, 2001)
- Amount of slip (D): $D_{asperity}$=**2** x $D_{background}$ (Somerville *et al.*, 1999; Ishii *et al.*, 2000)
- For 1909 Taipei earthquake (M_W7.3, extreme case)
  - L=54 km, W=27 km
  - $D_{asperity}$=4.32 m , D_{back}=2.16 m

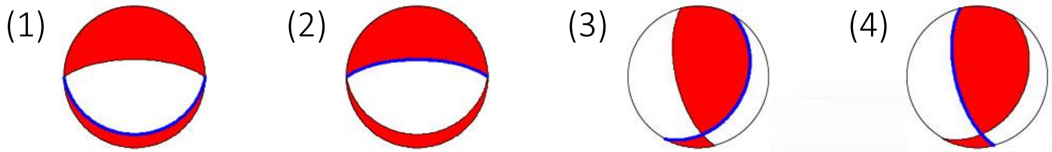
Ground Motion Simulation
- Source Rupture Parametrization -

Hypocenter and moment magnitude from Kanamori *et al.* (2012)

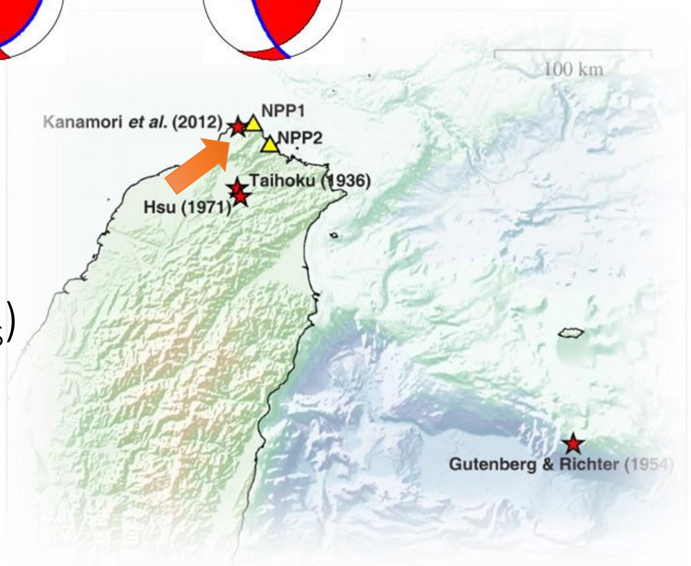
- Hypocenter: **121.52ºE / 25.28ºN / 75.0 km**
- Magnitude: **M_W7.3** (extreme case)

Bootstrap scheme for possible source ruptures

- Fault orientations and mechanisms



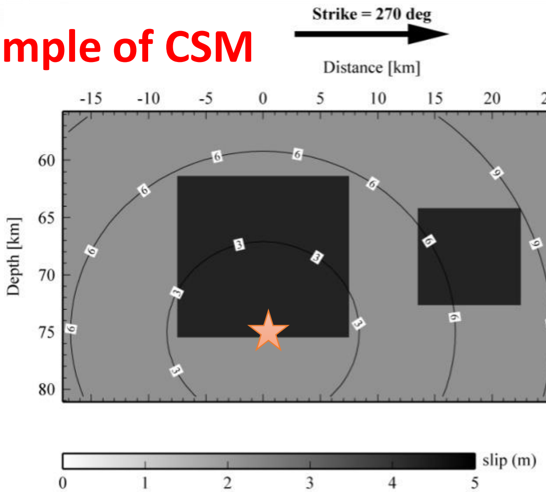
- Locations of major and secondary asperities
  - Two-asperity approach from ***Recipe***
- Possible rupture speeds (V_{RUP})
  - **3.5 km/s** (1.0 V_S), **2.8 km/s** (0.8 V_S), **2.1 km/s** (0.6 V_S)



Ground Motion Simulation
- Characteristics Source Model -

- **Characteristic source model (CSM)**
  - Focal mechanism
  - Asperity distribution
  - Rupture speed

An Example of CSM



Macroscopic Parameters

Location	Longitude: 121.52°E Latitude: 25.28°N Depth: 75 km
Magnitude (M_W)	7.3
Moment (Nt-m)	1.1×10^{20}
Dimension (km)	Length: 54; width: 27
Fault Area (km²)	1458
Fault Plane and Focal Mechanism (°)	(2) 270 / 70 / -90 (3) 29 / 33 / 128 (4) 166 / 65 / 68 (described by strike/dip/rake in deg.)
Subfault Dimension (km)	Length: 1.0; width: 1.0
No. of Subfault	Along strike: 54; down-dip: 27

A total of 432 rupture scenarios for ground motion simulation

Microscopic Parameters

Background		
Rupture speed (km/s)	(1) 3.5 (2) 2.8 (3) 2.1	
Slip (m)	~2.16	
	I (Major)	II (Minor)
Length (km)	~15	~9
Area (km²)	~225	~81
Slip (m)	~4.32	~4.32
Source Time Function	1-Hz Gaussian	1-Hz Gaussian

Strain Green Tensor (SGT) Database for Rapid Synthetic Calculations

- Seismic wavefield: $\mathbf{u}(\mathbf{r}_R, t; \mathbf{r}_S) = \mathrm{M} : [\nabla \mathbf{G}(\mathbf{r}_R, t; \mathbf{r}_S)]$

台灣地震科學中心通訊

Taiwan Earthquake Research Center Newsletter

TEC通訊 | 上一頁 | 下一頁

台灣地震科學中心通訊

18

2017.12

• 應變格林函數及其應用

在過去二十年中，隨著觀測(寬頻地震儀)與計算(高效能電腦及平行計算)技術的進步以及地震波傳理論與數值算法的發展，全波場波形模擬與反演已經逐漸成為地震學研究的主流方法。當考慮到地球結構的複雜性(如三維速度模型和地表地形)時，如何提高理論地震圖的計算效率是全波場研究中的重要課題。本文所介紹的應變格林函數就是一種能夠有效地提高全波場波形計算效率的方法。

一個在時空位置(r',t')的點震源，在位於測站r處的n方向位移可以表示成

$$u_n(\mathbf{r},t) = M_{ij}\partial_j{}' G_{ni}(\mathbf{r},t;\mathbf{r}',t') \quad (1)$$

此外，該方法也可以應用到地震危害度評估(seismic hazard assessment)中。如圖六所示，通過建立台灣島上2282個虛擬測站處的應變格林函數庫，我們可以無需模擬而迅速計算台灣地區任何可能發生的情景地震的地面運動，這是目前在複雜地球模型中進行基於物理的地震災害度評估(physics-based seismic hazard assessment)的唯一可行方法。南加州地震中心(SCEC)執行多年的CyberShake計畫，就是使用這一方法(Graves et al., 2011)。(由中央研究院地球科學研究所趙里研究員撰寫)

參考文獻:

- **Strain Green tensors** are calculated by **traction-image finite-difference method** (Zhang & Chen, 2006; Zhang *et al.*, 2012)
  - 3-D velocity model (Kuo-Chen *et al.*, 2012)
  - ETOPO1 topography (NOAA)

Physics-based

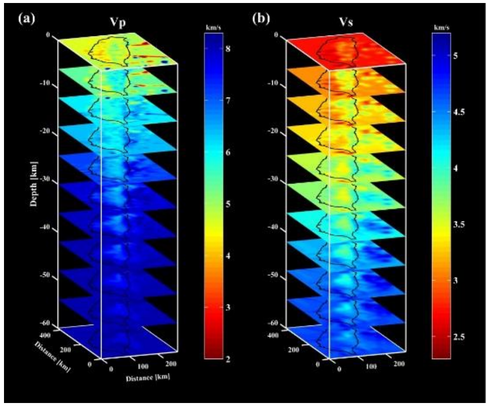
Strain Green Tensor (SGT) Database for Rapid Synthetic Calculations

SGT Database Construction for Taiwan

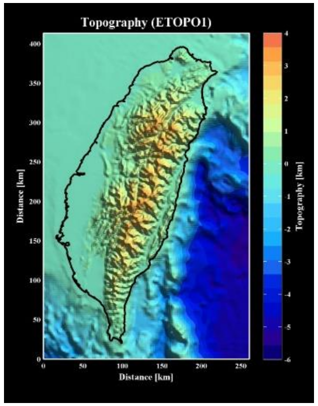
- **2286** surface grid points as receivers
- **~500k** source nodes
- 3-D velocity model
- ETOPO1 topography

Capability of SGT database

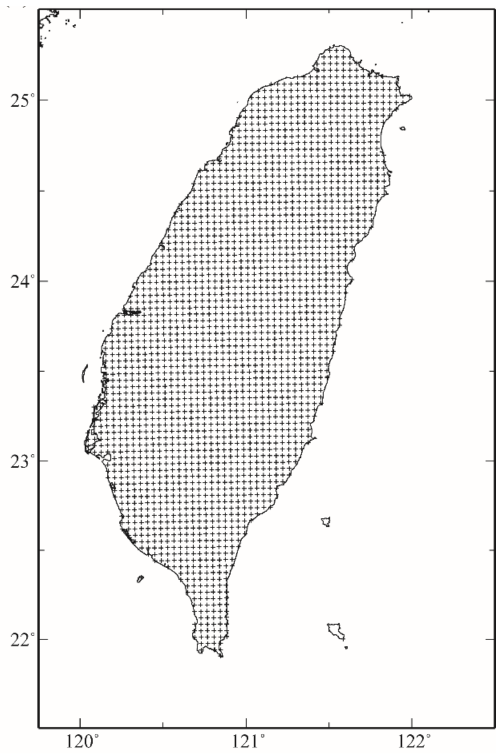
- Synthetic seismograms at 2286 surface locations from any source grid points within a second on a laptop PC



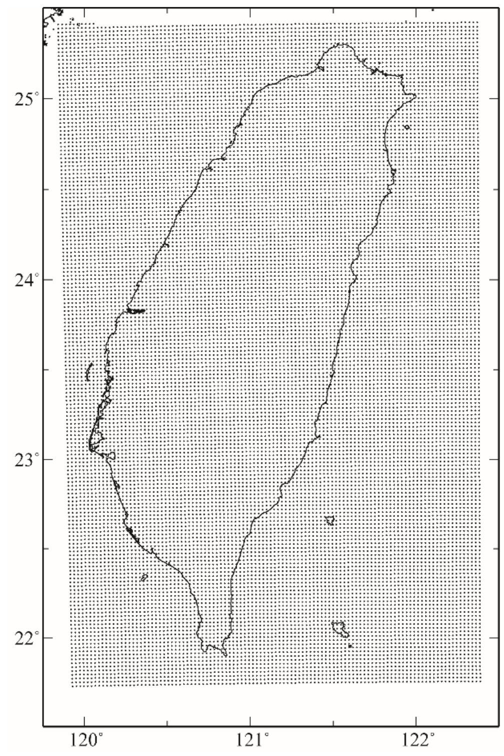
3-D model



Topography



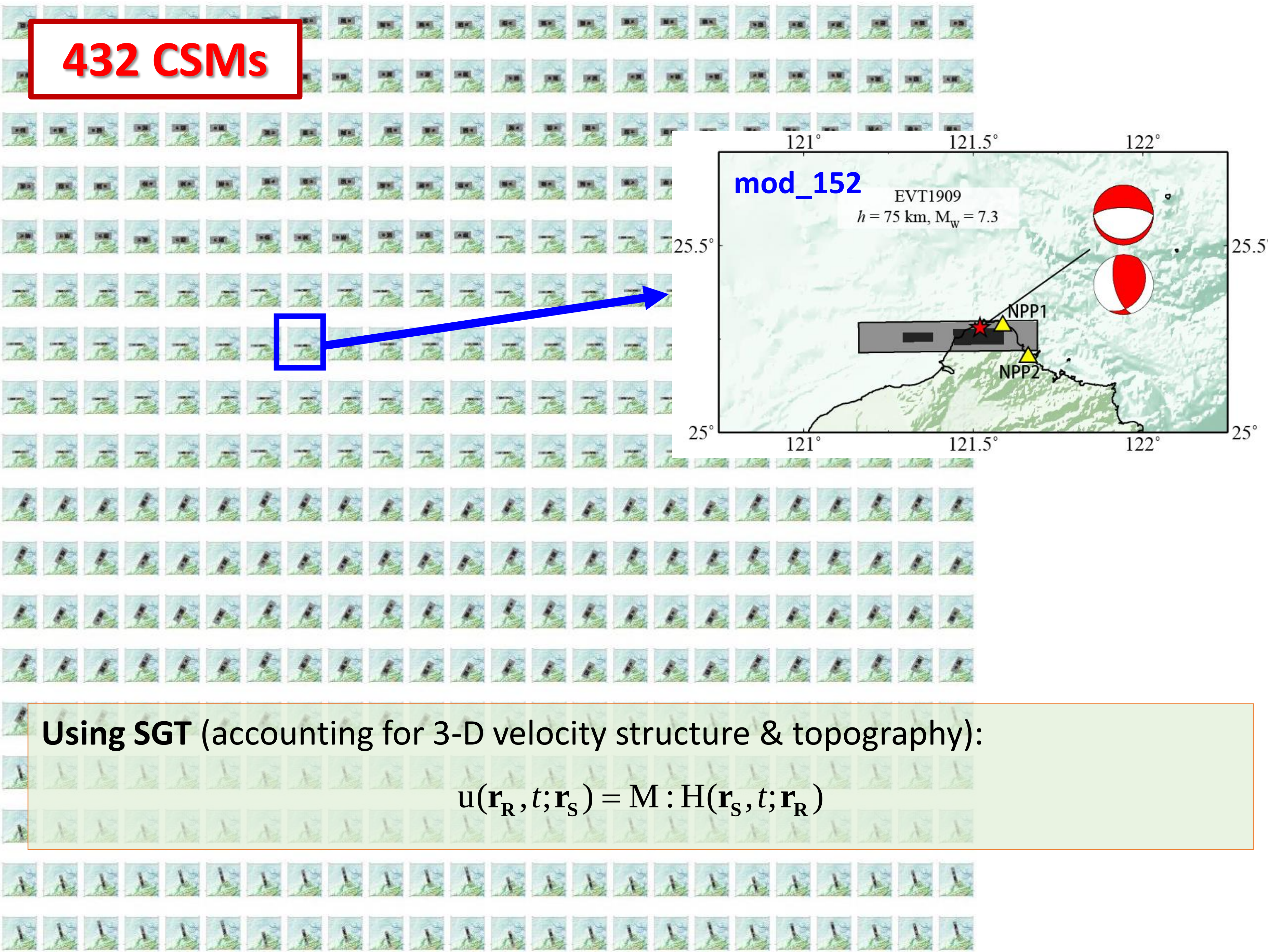
2286 receiver nodes on the surface (4-km spacing)



~500K source nodes to 60-km depth (2.4-km spacing)

(Hsieh *et al.*, 2014)

432 CSMs



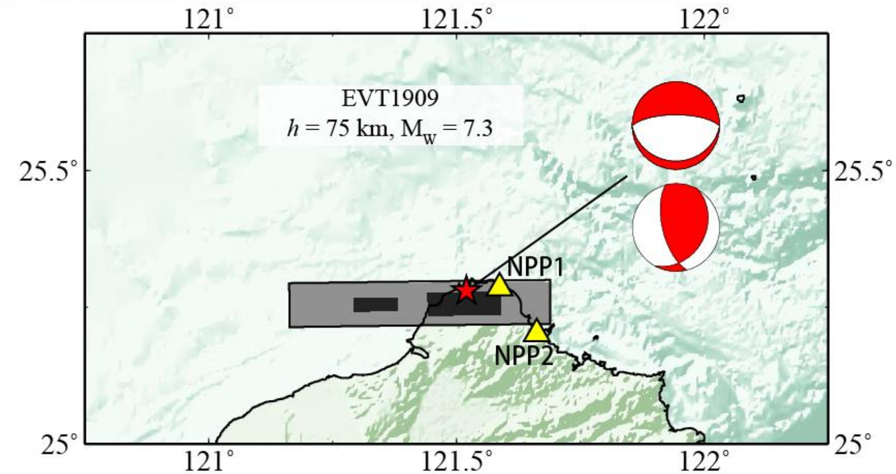
Using SGT (accounting for 3-D velocity structure & topography):

$$u(\mathbf{r}_R, t; \mathbf{r}_S) = M : H(\mathbf{r}_S, t; \mathbf{r}_R)$$

Ground Motion Simulation Result

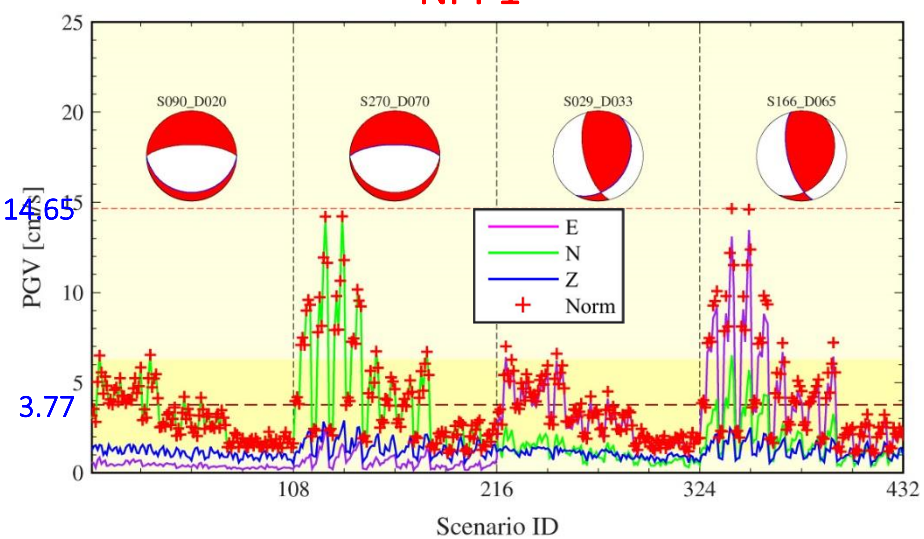
Ground Motions

- The PGA distribution from a total of 432 CSM at NPPs
  - **NPP1**
    - Max. PGV **14.65** cm/s
    - Mean PGV **3.77** cm/s (±2.52)
  - **NPP2**
    - Max. PGV **20.11** cm/s
    - Mean PGV **4.37** cm/s (±3.38)

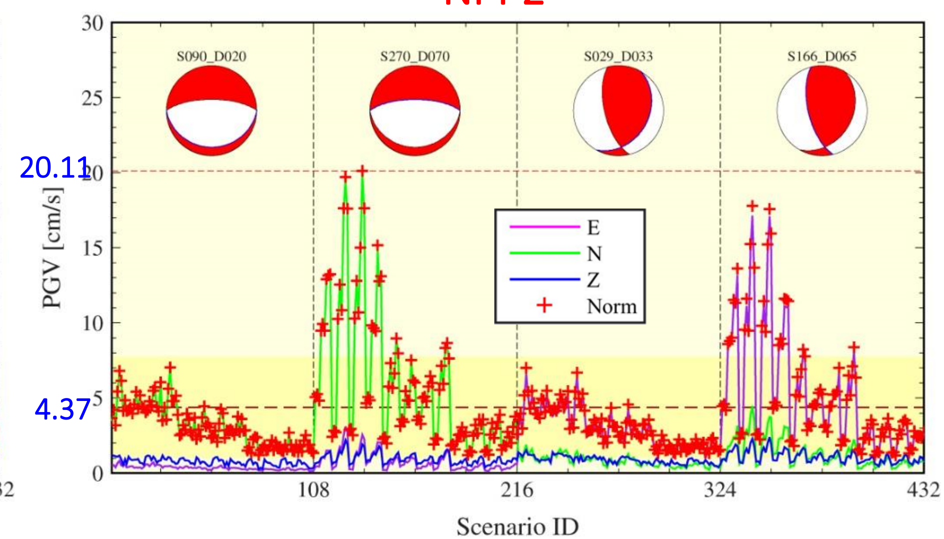


An example of the CSM for the 1909 Taipei earthquake

NPP1



NPP2



Outline

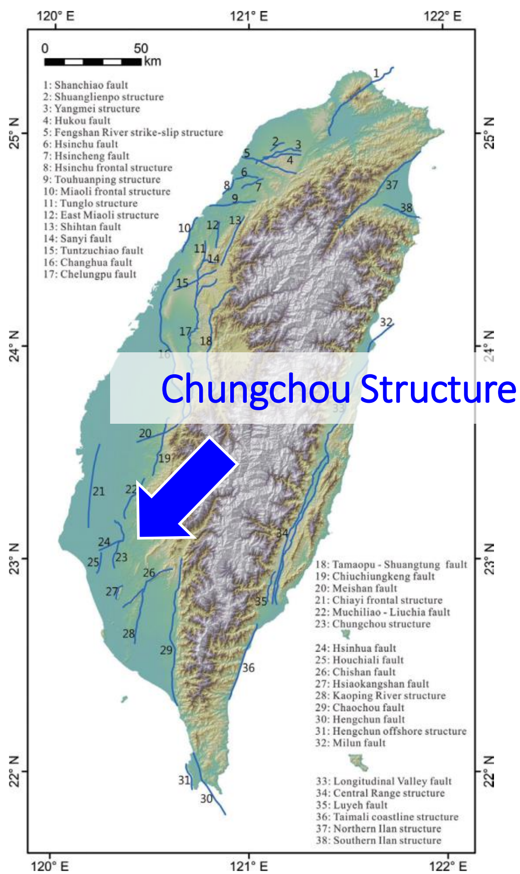
01 地震波模擬與地震動評估

02 核能電廠地震動評估
以1909臺北地震為例

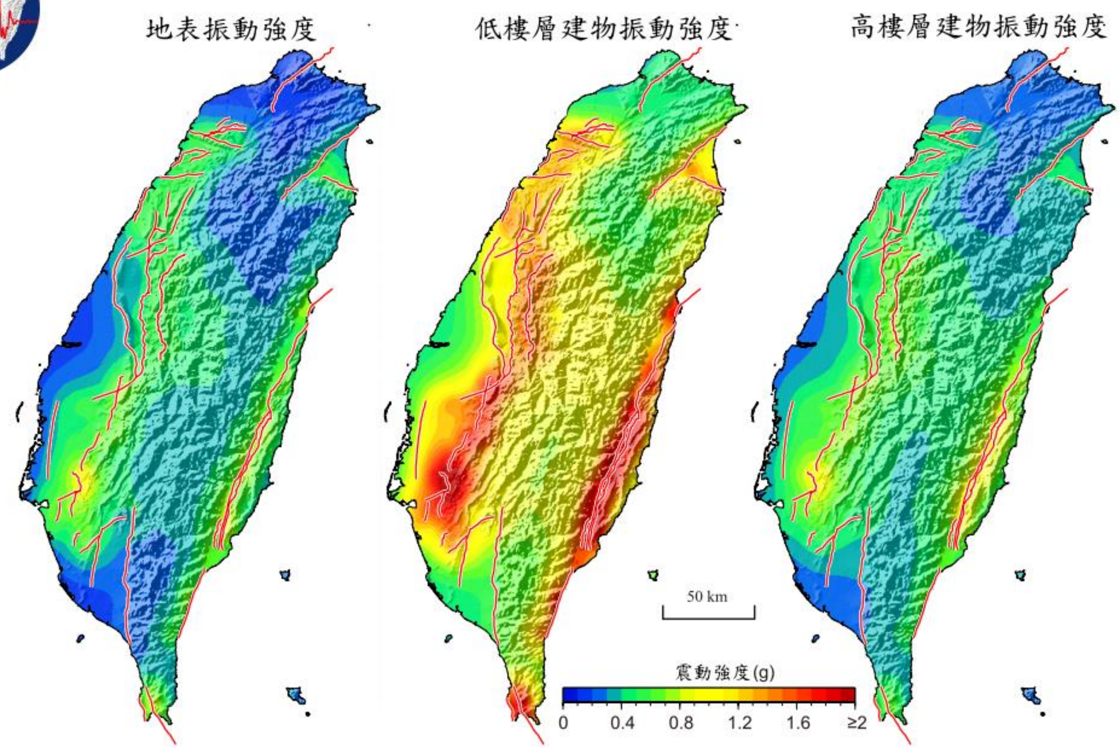
03 科學園區地震動與地震危害度評估
以西南臺灣孕震構造情境模擬為例

04 都會防災
以山腳斷層與臺北都會區為例

Physics-based Hybrid Ground Motion Simulation



38 seismogenic structures
(TEM, 2015; Shyu *et al.*, 2016)

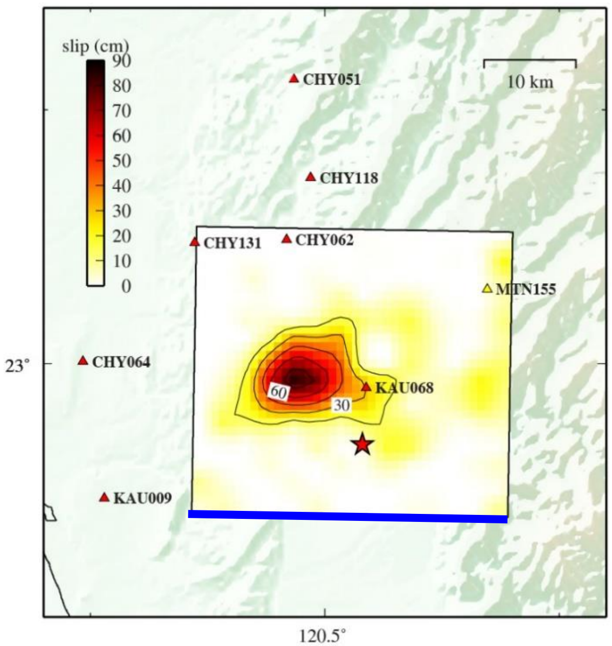


以台灣地震模型之斷層參數，評估台灣地區地表振動強度(PGA)低樓層建物振動強度(Sa0.3)，以及高樓層建物振動強度(Sa1.0)，在50年內超越機率10%之可能振動強度值分佈圖。

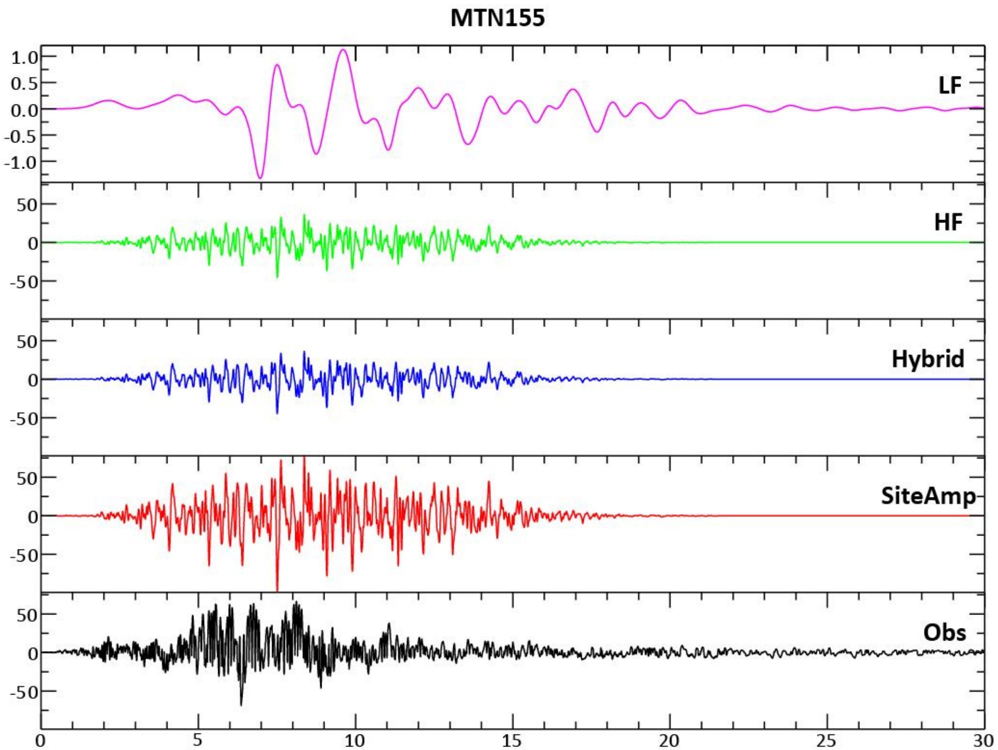
475-yr-return-period seismic hazard maps (TEM, 2015)

Physics-based Hybrid Ground Motion Simulation

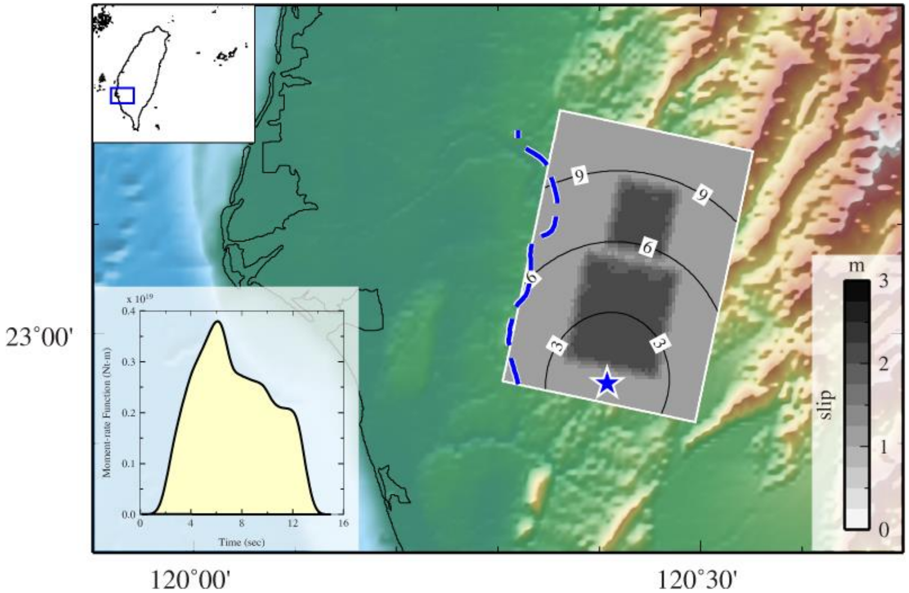
- Source generator: *Recipe* (Irikura & Miyake 2011)
- Low-frequency synthetics: 3D+Topo SGT by FDM (Zhao & *Chen, 2006*; Zhang et al., 2012)
- High-frequency synthetics: Stochastic method of ExSIM (Motazedian & Atkinson, 2005)
- Duration: Lee *et al.*, 2015
- Site amplification: Class B Atkinson & Boore, 2006; TW-C, D, E Huang *et al.*, 2007



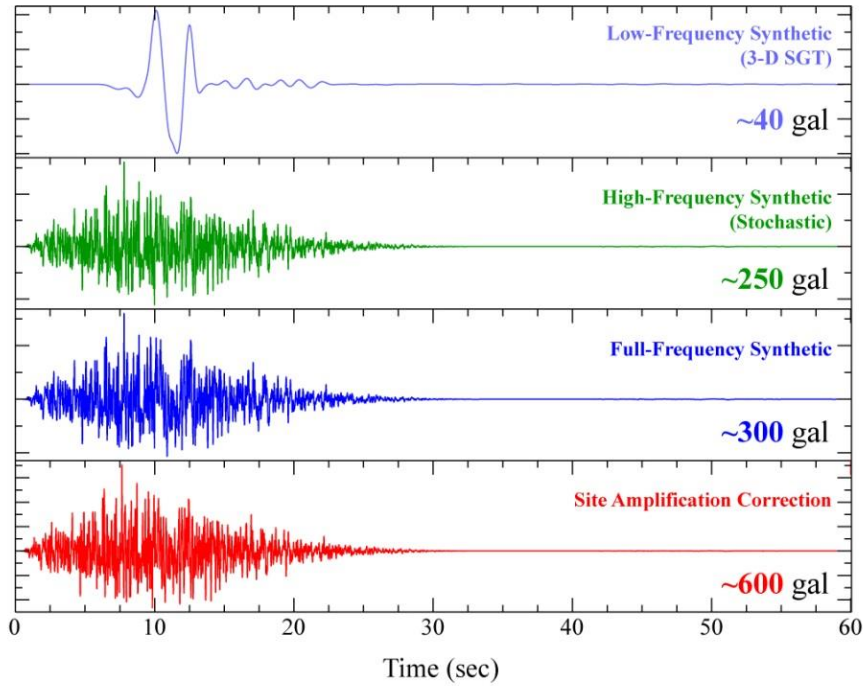
Validation:
2016-02-06 Meinong Earthquake



Physics-based Hybrid Ground Motion Simulation

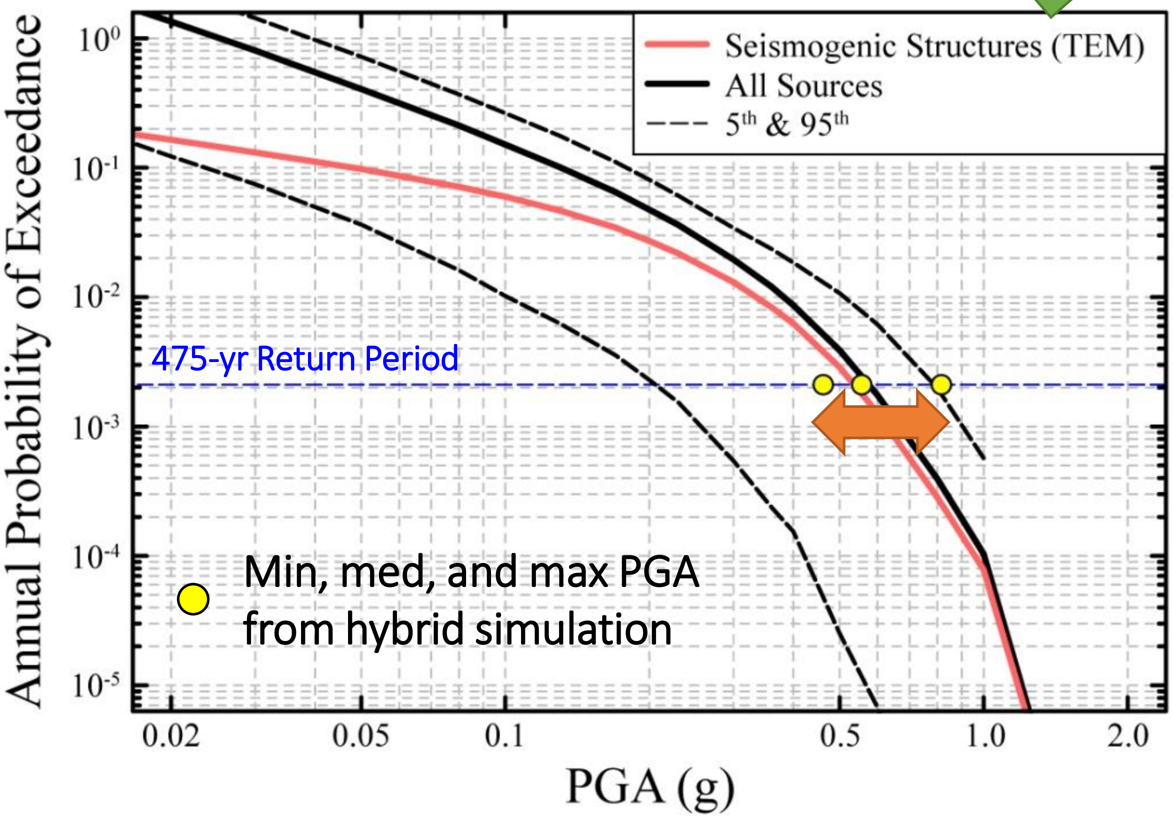


One rupture scenario of Chungchou Structure

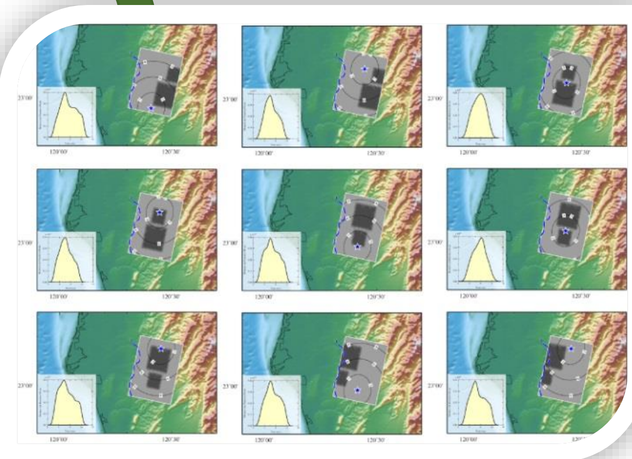


Synthetic seismograms at a specific site (Class D, V_S30~200 m/sec)

Physics-based Hybrid Ground Motion Simulation



Hazard curves at the specific site



A number of rupture scenarios for
hybrid ground motion simulations

Scenario & physics-based PSHA

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以山腳斷層與臺北都會區為例

都會區大規模地震情境模擬

- **因應大規模地震災害**

- 依 2017 年 5 月 11 日中央災害防救會報第 36 次會議報告決議，由科技部進行**「震源情境」**與**「災損推估」**工作，由內政部進行**「因應對策」**工作。

- 連結及盤點過往三面向議題之科研及實務成果，且選擇讓社會有感之衝擊案例，彰顯防災具體作為之嶄新議題。

- 整合**「震源情境」**、**「災損推估」**、**「因應對策」**三大方向，以研究成果呈現未來防災整備之重要參考依據。
  - 各級單位盤點防災量能，目標：**10年後，災損推估數字減半**

都會區大規模地震情境模擬
- 震源情境 -

- 設定目標斷層 (孕震構造)
- 建立地震源破裂情境模擬準則

  巨觀參數 - 斷層幾何

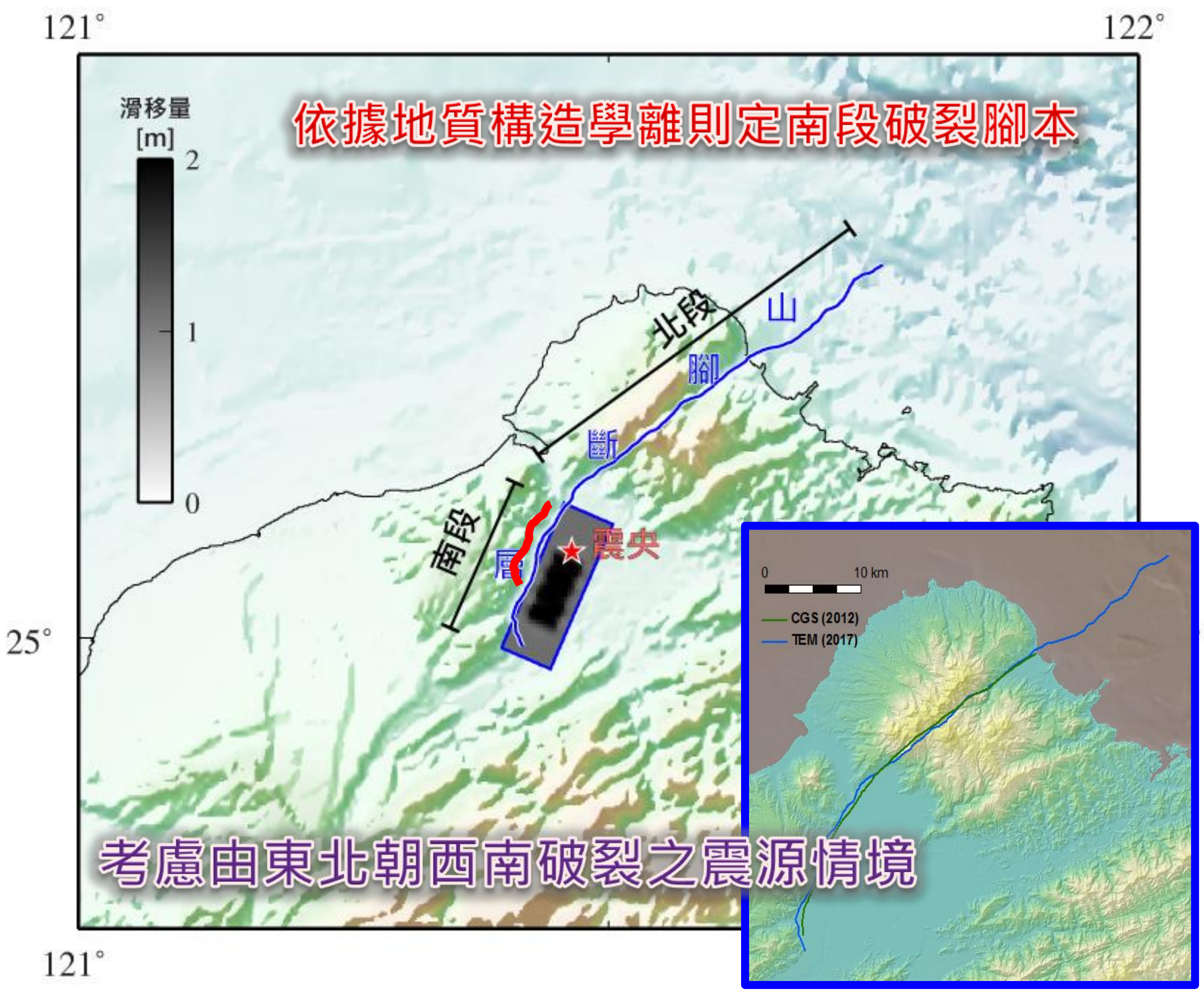
  - 震源參數

  微觀參數 - 滑移量高區分佈 (asperity distribution)

  - 震源破裂方向
  - 震源時間函數

＊參考「日本地震調查研究推進本部」之「震源斷層を特定した地震の強震動予測手法」(Recipe) 律定震源參數

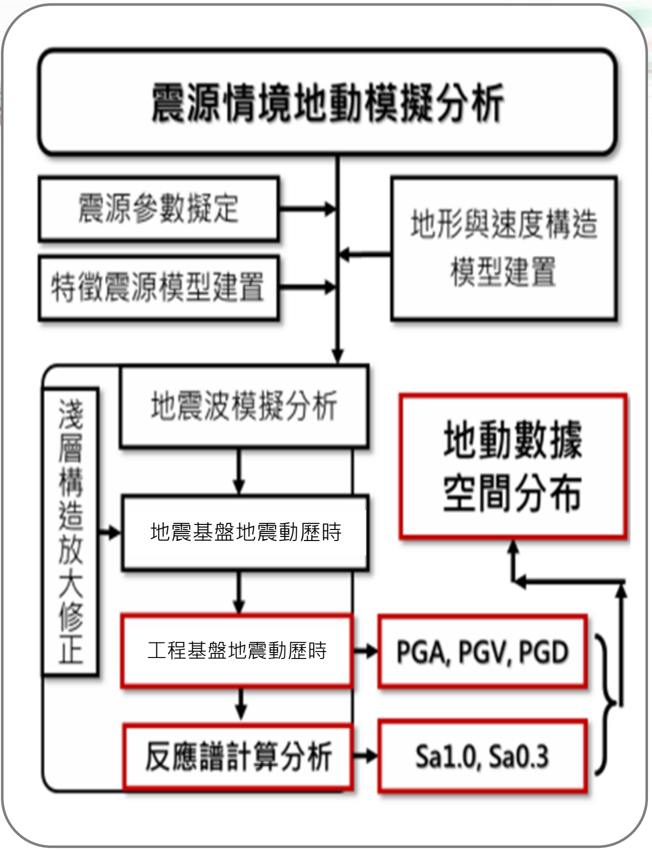
震源情境設定

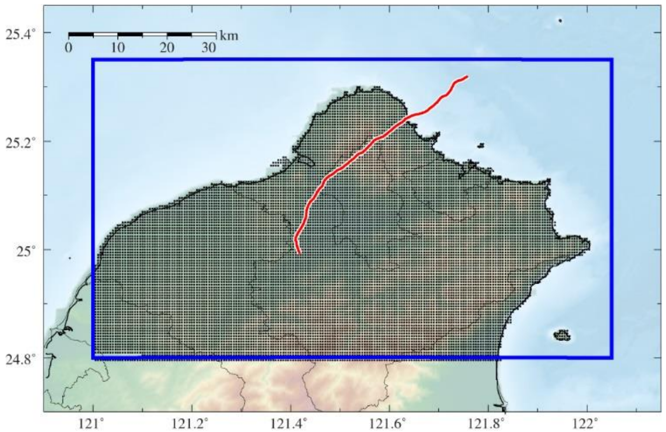


- 目標為存在於大臺北都會區之高危害潛勢之山腳斷層
- 綜合經濟部地質調查所公布之台灣活動斷層與科技部台灣地震模型 (TEM) 成果彙整山腳斷層南段之發震破裂幾合與運動模型

山腳斷層景況模擬
- 程序概要 -

- **斷層模式（山腳斷層):** 以**台灣地震模型**(TEM)及**地調所**山腳斷層參數作為依據
- **地形與速度構造模型:**
  考量**區域地下構造**、**地形**、**場址**等效應
  < 1 Hz 低頻地震波: **三維有限差分法**
  > 1 Hz 高頻地震波: **隨機式方法**
- **虛擬測站:** 考量NCDR 500公尺網格點作為虛擬測站分佈，共13,216 測站
- **場址效應修正:** 以場址放大函數進行各點位場址效應修正後，計算各點位於工程基盤處之**SA0.3, SA1.0, PGA, PGV, PGD** → 銜接災損推估





黑點: NCDR 500公尺網格

藍色框線: FD網格範圍，200 公尺格距

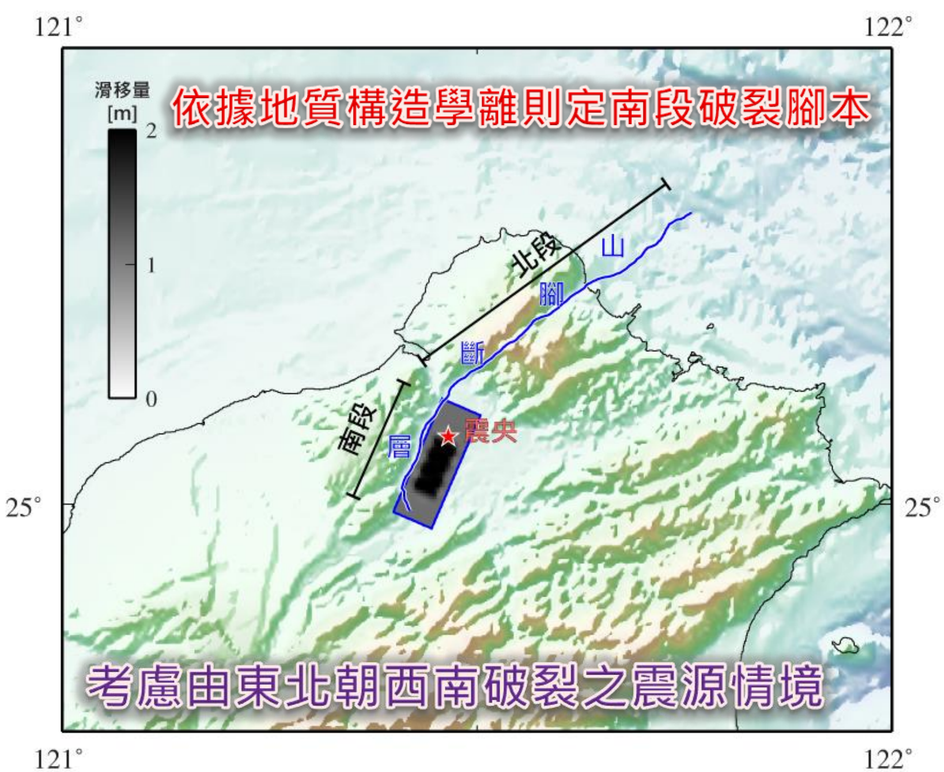
山腳斷層景況模擬
- 震源參數 -

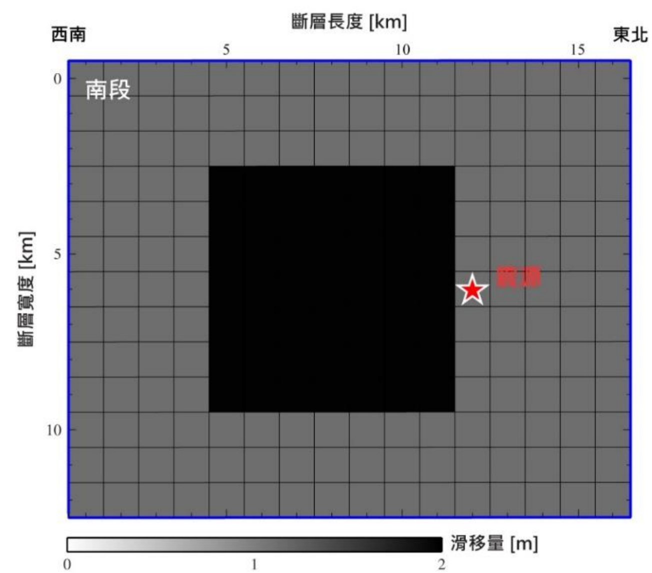
巨觀震源參數

地震矩規模, M_W	6.6
地震矩 (Nt-m)	0.83×10^{19}
斷層尺度 (km)	長：16、寬：13
斷層面積 (km^2)	208
斷層面與震源機制 (^{O})	走向：24；傾角：65；滑移角：-90

微觀震源參數

背景區域	
破裂速度 (km/s)	2.4
滑移量 (m)	1.13
震源時間函數	1-Hz 高斯函數
Asperity	
邊長 (km)	6.82
面積 (km^2)	46.60
滑移量 (m)	1.97
震源時間函數	1-Hz 高斯函數

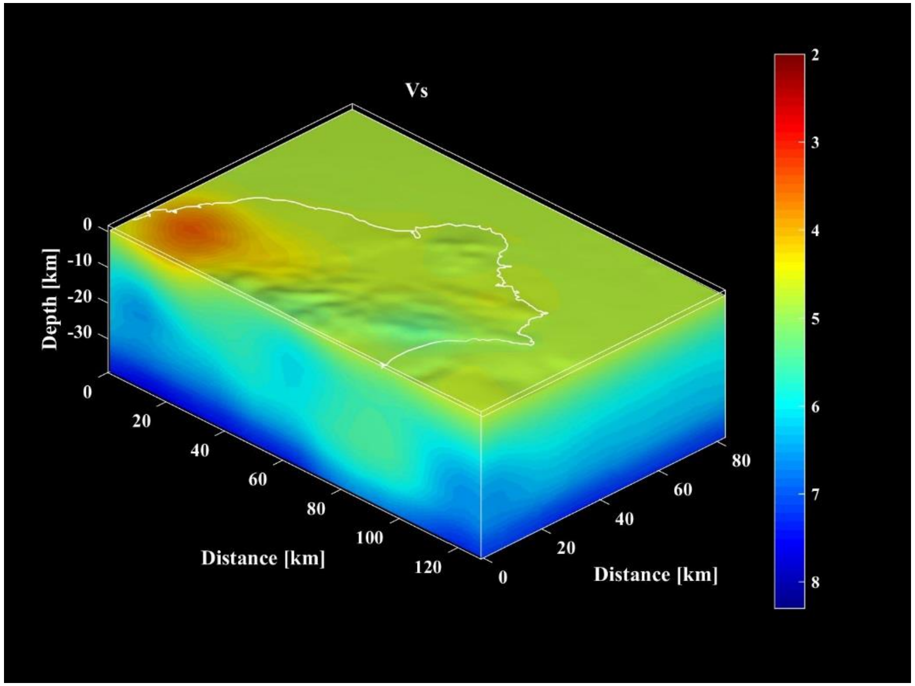




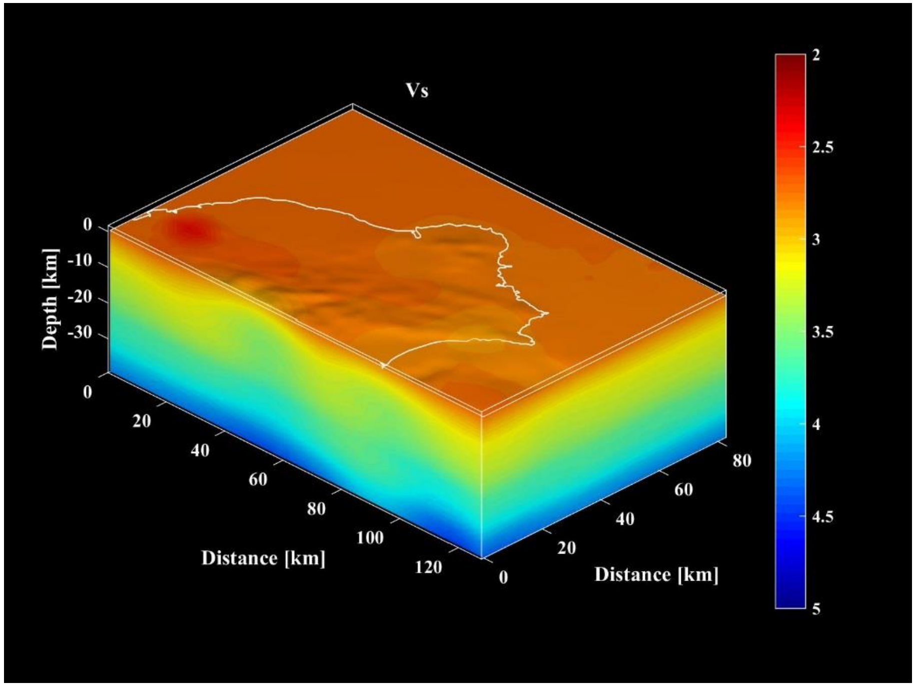
山腳斷層景況模擬

- 情境模擬之構造模型 (低頻模擬) -

- 考慮近期**地震波速度構造**(Kuo-Chen *et al.*, 2012)與**數值地形**(ETOPO1)模型
- 網格解析力為 200 公尺
- **高效能計算** (High Performance Computing, HPC)



壓縮波速度構造



剪力波速度構造

低頻模擬 + 高頻模擬 = 寬頻地震動模擬 ~ 10 Hz

山腳斷層景況模擬

- 情境模擬之構造模型 (高頻模擬) -

Shear wave velocity (β)	3.6 km/s
Density (ρ)	2.8 gm/cm^3
High frequency attenuation (κ)	0.05 sec
Geometric spreading 1/R^b	b = 1.0 (1-50 km) 0.0 (50-170 km) 0.5 (> 170 km)
Quality factor (Q)	Zone Sallow Taiwan : 80f$^{0.9}$ Zone Shallow Offshore : 120f$^{0.8}$ Zone Deep Taiwan : 60f$^{1.0}$

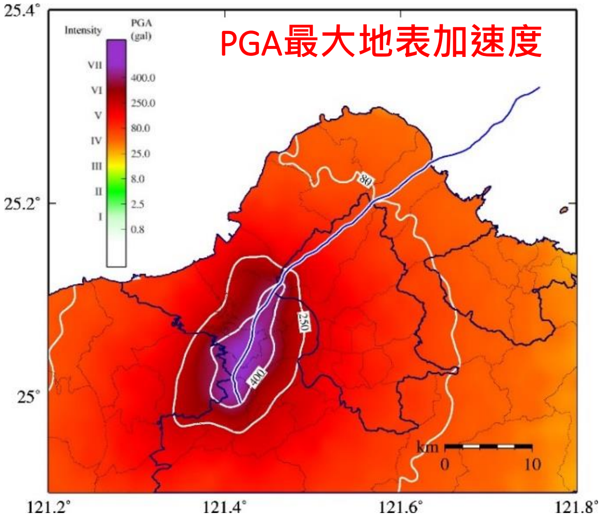
隨機式模型 **(Sokolov et al., 2006; 2009; Huang et al., 2017)**

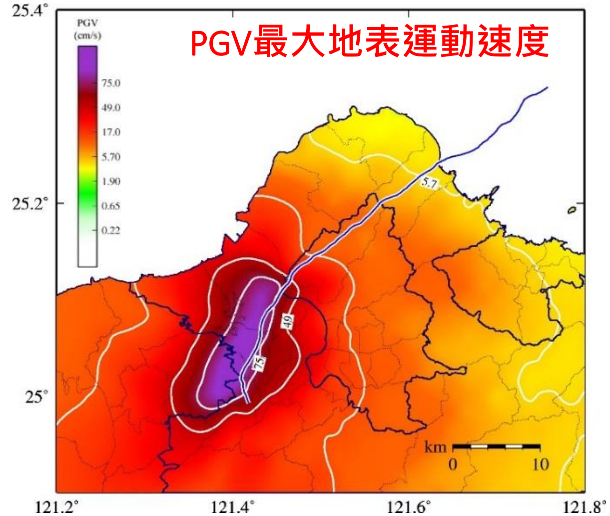
低頻模擬 + 高頻模擬 = 寬頻地震動模擬 ~ 10 Hz

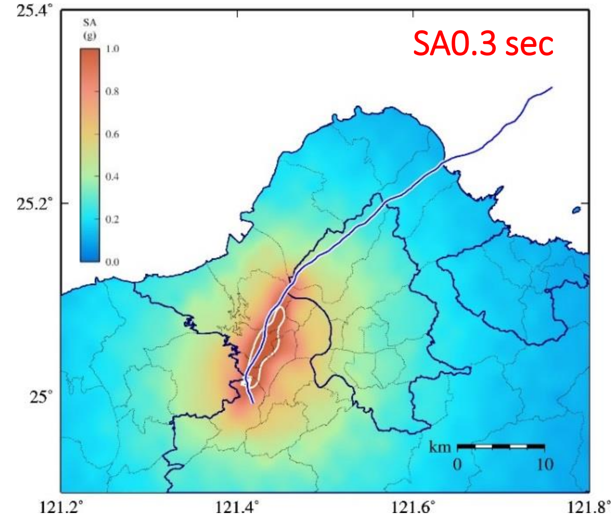
山腳斷層南段破裂情境模擬

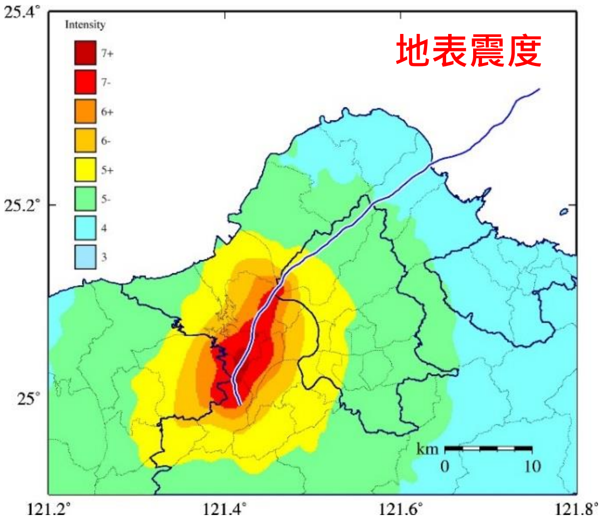
地震波傳遞情境模擬之災損評估相關參數

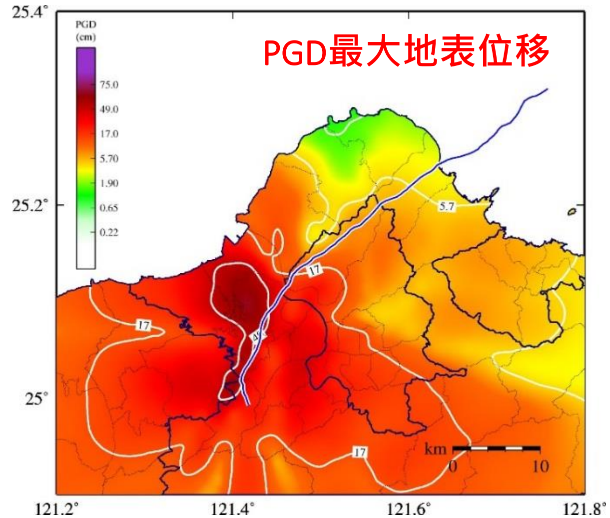
以工程基盤(剪力波速為760 公尺/秒)為基準

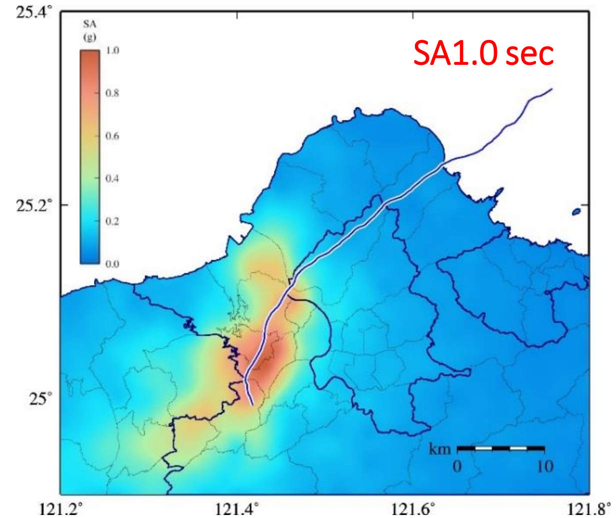




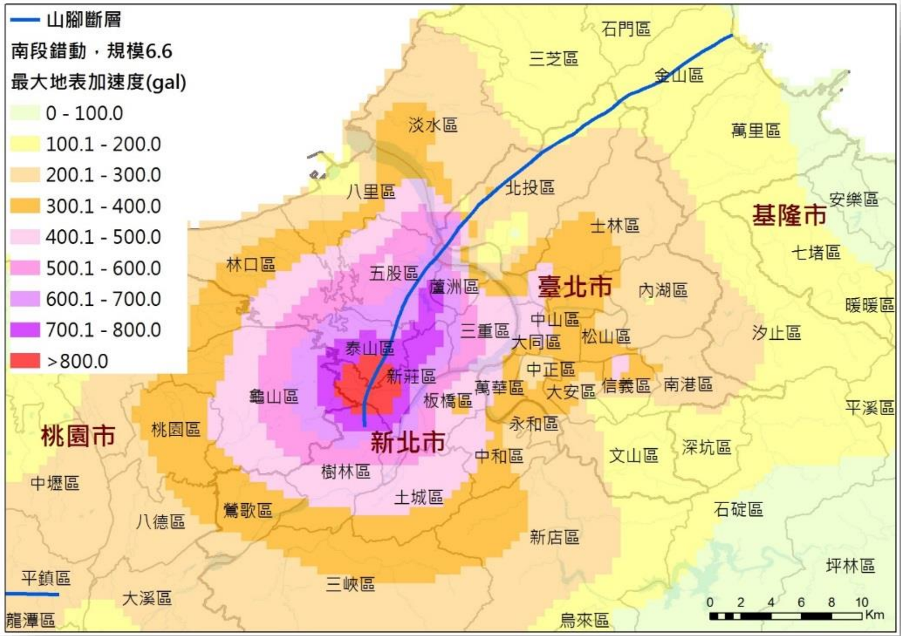








山腳斷層南段破裂情境模擬 災損推估



地震動輸入至災損推估平台
(災損推估組提供: NCREE, NCDR)

台北大地震模擬災損統計

項目		數量
建物破壞	一般建物 (棟) 公有建物受災高風險 (棟) 學校建物 (棟) 短期收容 (人)	4,400 (老舊810) 3 19 60,400
人員傷亡 (人)		4,100
交通破壞	道路封閉高風險 (路段) 橋梁封閉高風險 (座)	嚴重17；中度45 13 (結構嚴重損壞：公路5；鐵路2)
供水設施破壞	淨水場中度損壞 (座) 加壓站中度損壞 (座) 配水管線災損數 (條)	1 13 9,440
變電所破壞 (座)		9

資料來源 / 科技部，製表 / 賴子歆

情境地震災損統計

震度七級(PGA>400 gal)行政區

新北市(10區)：五股、蘆洲、三重、板橋、中和、土城、樹林、龜山、林口、八里等區

臺北市(5區)：士林、中山、大同、萬華、信義等區

桃園市(1區)：龜山區

山腳斷層南段破裂情境模擬 因應對策

建築物破壞防範與緊急因應對策

- 建築物耐震補強
- 危險建築物緊急鑑定
- 受災學校學生臨時轉移他學上課
- 政府持續運作
- 震災保險理賠

大量人員傷亡因應對策

- 強震即時警報推動與應用
- 受損建築物人命搜救
- 大量傷病患處理
- 大體安置，包括屍袋、冷凍櫃需求與調度、停放場所等規劃
- 死亡人員相驗、身分確認
- 推動韌性社區
- 推動民眾自備食物、飲水

大量災民收容安置因應對策

- 充實避難收容處所能量及整備物資
- 建置並整備防災公園
- 臨時收容場所(包含防災公園)開設、運作、收容人員記錄管理、所需緊急民生物資調度、徵集、分配
- 民間志工運用
- 治安維持

水、電等民生基礎設施破壞因應對策

- 電力供應網路防災防震功能強化、備援機制，以及停供中斷因應對策
- 停電區域緊急修復及針對重點區域優先復電對策
- 自來水供應(加壓站管)、淨水處理設施防災防震功能強化、備援機制，以及研擬停水因應對策
- 停水區域臨時供水因應對策

(內政部提供)

報導者 THE REPORTER　評論　專題　攝影　多媒體　議題

台北大地震？「大規模地震模擬」如何讓政府防災動起來

文 林韋萱　攝影 林佑恩　共同採訪 賴子歆　2018.3.30

別以為不可能！根據台灣地震模型團隊的資料，台北未來50年發生規模6.6地震的機率有20%。這20%一旦發生，將導致4,100人傷亡、4,400房屋毀損。這數字究竟怎麼算出來？我們又該如何搶救人命？

—

20XX年的冬天，日本南海發生規模9的大地震。

地震瞬間，四處充滿著玻璃爆破和尖銳的剎車聲；古蹟大塊崩落、大樓攔腰坍塌；橋梁如同水草大幅波動；電塔纜線一根根綳斷；水管破裂、土壤液化讓四處泥濘不勘。半小時後，海嘯逼近、衝擊堤防，淹過大街小巷，路旁的汽車如葉片漂流，海嘯警報和汽車防盜器的刺耳聲交錯不斷。

這場地震，在愛知最大震度七級、大阪六級；三重縣的志摩海嘯最大高度23公尺，靜岡縣的下田更高達31公尺。海嘯雖然

“台北大地震？「大規模地震模擬」如何讓政府防災動起來”

“報導者”平面媒體專訪

https://www.twreporter.org/a/earthquake-simulation

總結

- 結合震源物理與地震工程學理之全波形地震動模擬技術，可詳實考量震源破裂、震波傳遞過程各物性參數之耦合。產出之地震動時間序列，後續可作為評估災損、進行防災整備之關鍵參考依據。

- 本報告論述之**「混合式全波形地震動模擬」**技術，分別以有限差分法與隨機式方法模擬低頻與高頻地震波，合成人工地震歷時，再以經驗放大函數進行場址效應修正。

- 近期，地震波模擬技術已應用於 (1) **場址地震動評估** 與 (2) **都會區地震防災整備**等；其成果搭配地震危害度評估技術，對場域進行詳實評估。

- 更高頻、更準確之地震動模擬，仍高度仰賴震源、三維地下構造、場址效應等相關研究與模型更新。

Q & A

THANK YOU!

財團法人中興工程顧問社

Contact Info

https://dptrc.sinotech.org.tw

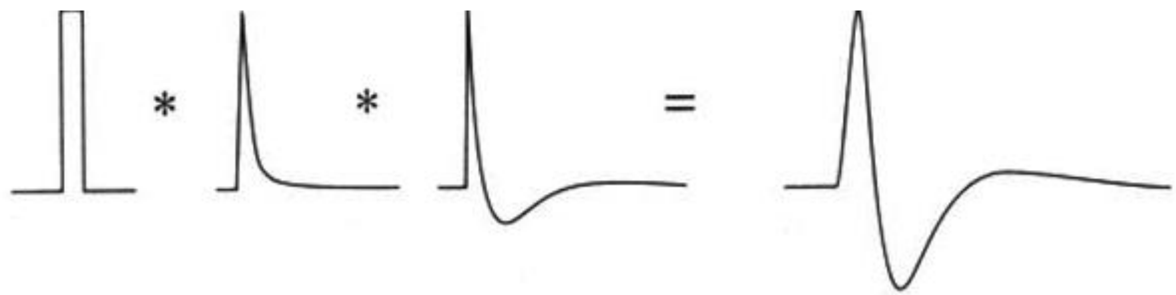
02-8791-9198 ext 316

mchsieh@sinotech.org.tw

Earthquake and Ground Motion

For source study

'What we want'	'What we need'	'What we have'	'What we have'
Source	Structure	Instrument	Seismogram
x(t)	*q(t)*	*i(t)*	*u(t)*

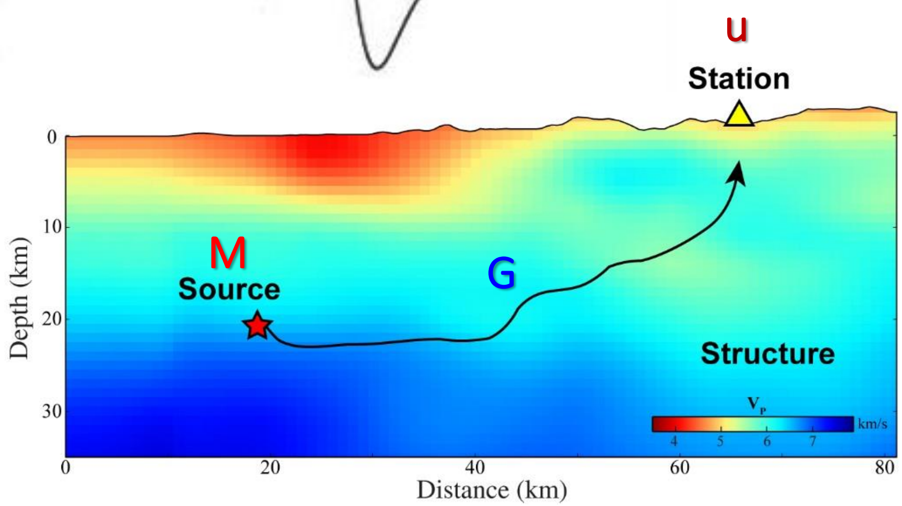


Representation Theorem (simplified form)

$$\mathbf{M} : [\nabla \mathbf{G}(\mathbf{r}_R, t, \mathbf{r}_S)] = \mathbf{u}(\mathbf{r}_R, t, \mathbf{r}_S)$$

Source
Moment tensor

Structure
Green's function

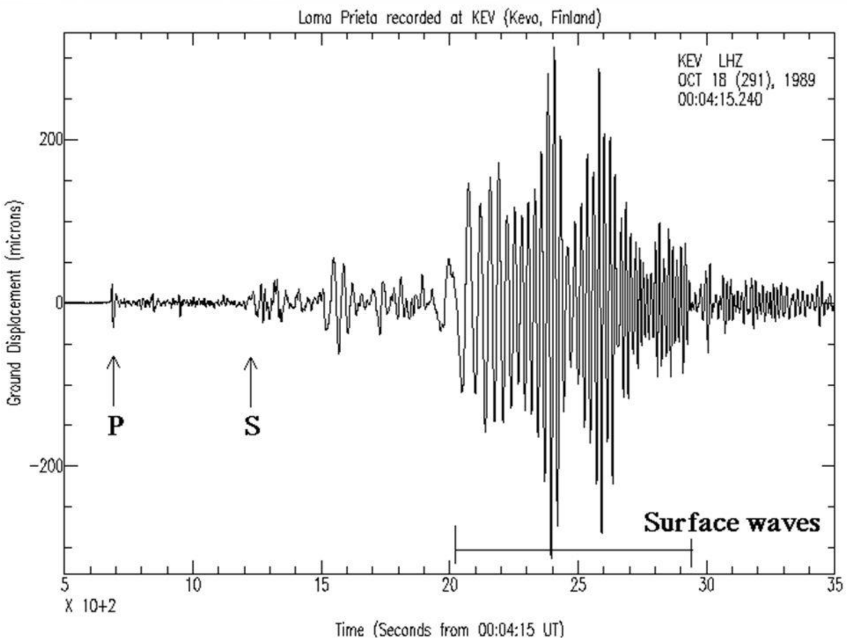


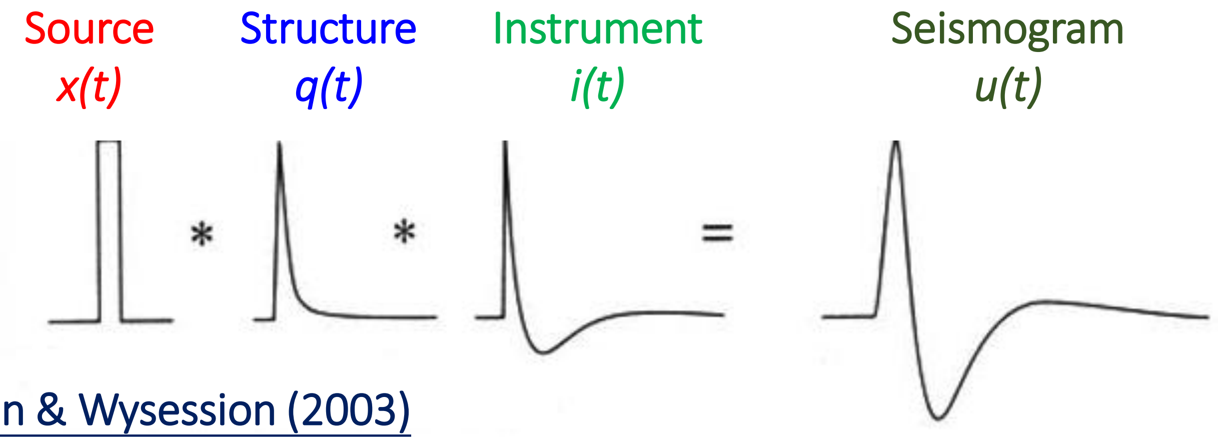
M, G are known, find u → Forward simulation

G is known, minimize $Res(u_{obs}, u)$ → Inverse problem

What is G ?

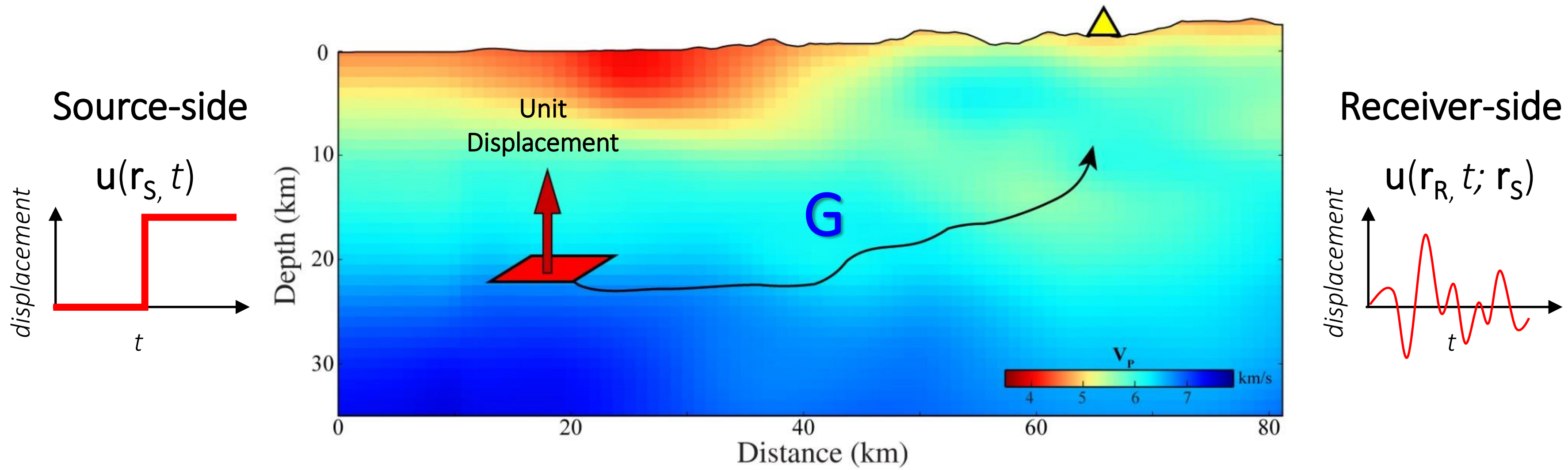
Earthquake and Ground Motion





Stein & Wysession (2003)

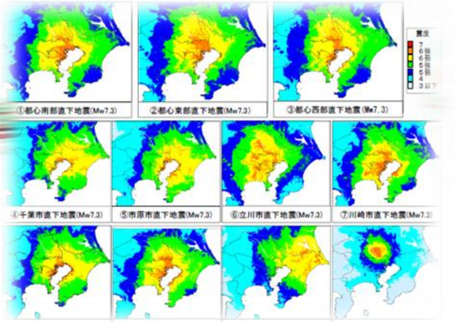
Green's Function ↔ Wave Propagation



- **Green's function:** the response from a unit displacement at receiver side
- Path effect (wave propagation)
  - Velocity structure (Vp, Vs)
  - Density (ρ)
  - Attenuation (Qp, Qs)
- The calculation of **Green's function**, **G**, is necessary for source inversion

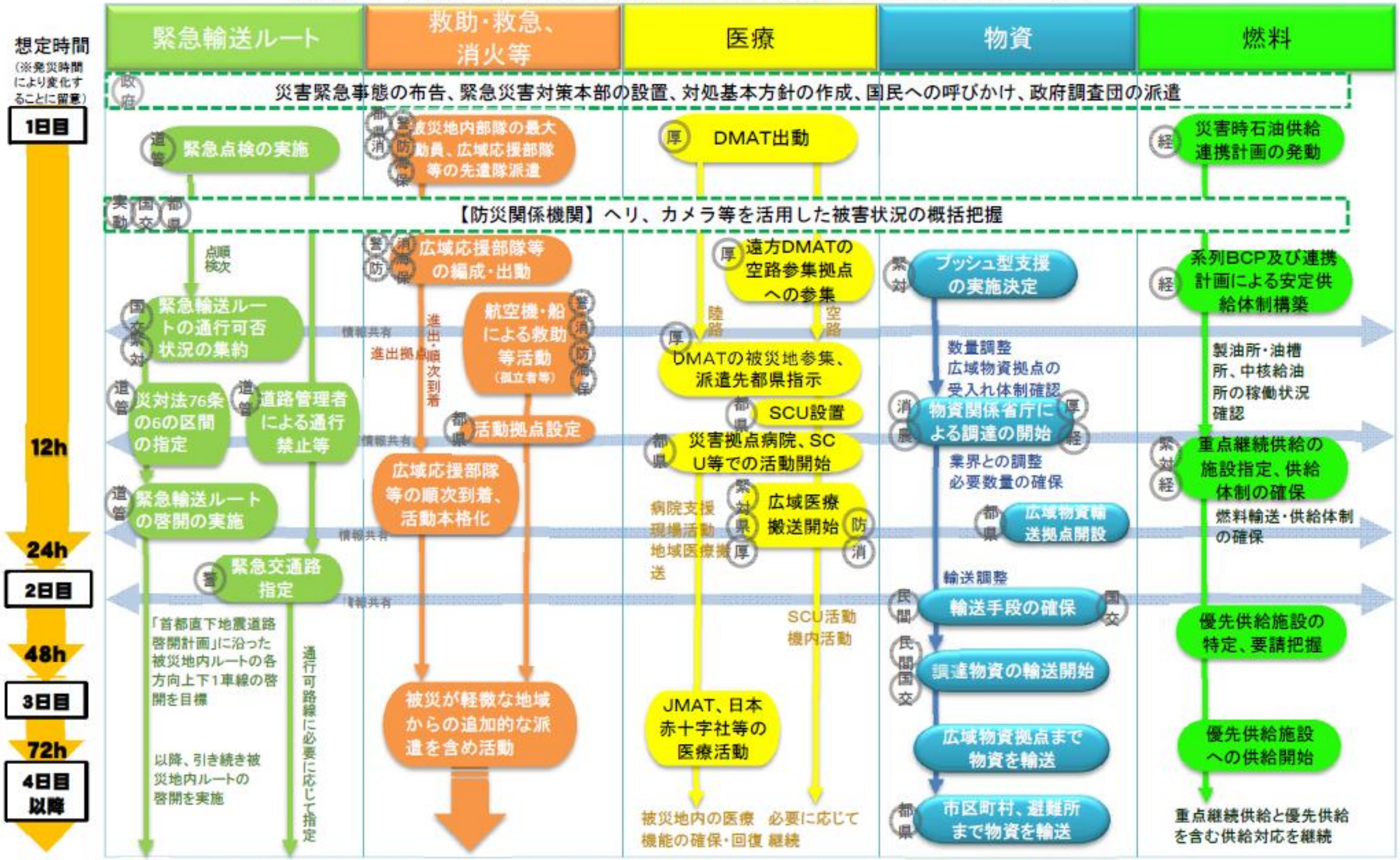
  → Green's function can be calculated by waveform simulation techniques

Ground Motion Simulation
- Foreign Cases -



首都直下地震における
具体的な応急対策活動に関する計画

首都直下地震における各活動の想定されるタイムライン（イメージ）



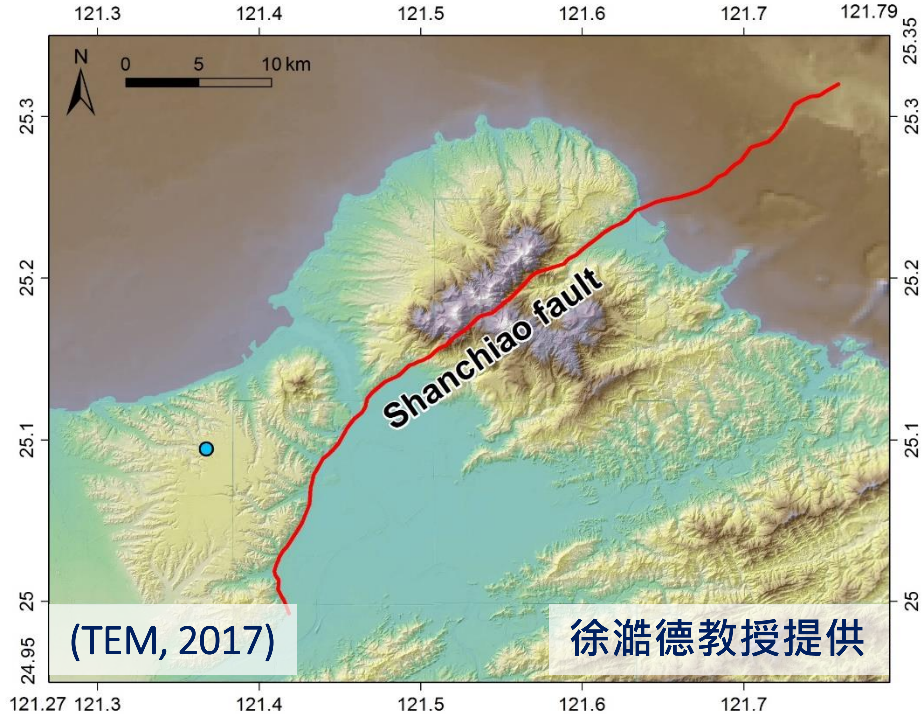
上記タイムラインは、防災関係機関による活動の事例として作成したものであり、実際の被災状況により相違があることに留意が必要。

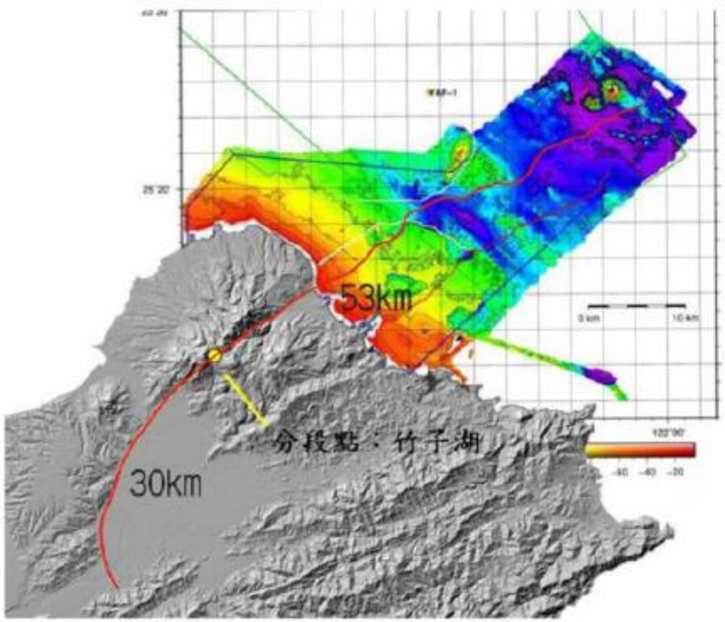
Source Parameters (Shanchiao Fault)

	TEM	CGS
Fault type	Normal	Normal
Length (km)	**54.1**	30, 53, 83
Fault dip (°)	Upper segm.: 60 ± 10 Middle segm.: 45 ± 10 Lower segm.: 30 ± 10	50 (weighting 0.2) **65 (weighting 0.6)** 80 (weighting 0.2)
Depth (km)	Upper segm.: 0 – 7 (± 0.5) Middle segm.: 7 (± 0.5) – 10 (± 1) Lower segm.: 10 (± 1) – 13.76 (± 2) (Geothermal)	10 (weighting 0.2) **12 (weighting 0.6)** 15 (weighting 0.2)
Area (km2)	727.1 – 1764.2	414 – 1145(邏輯樹中值)
Mw	6.85 – 7.24 (W&C) 6.86 – 7.30 (Y&M)	6.3 – 7.3 (W&C) 6.6 – 7.1 (Y&M)

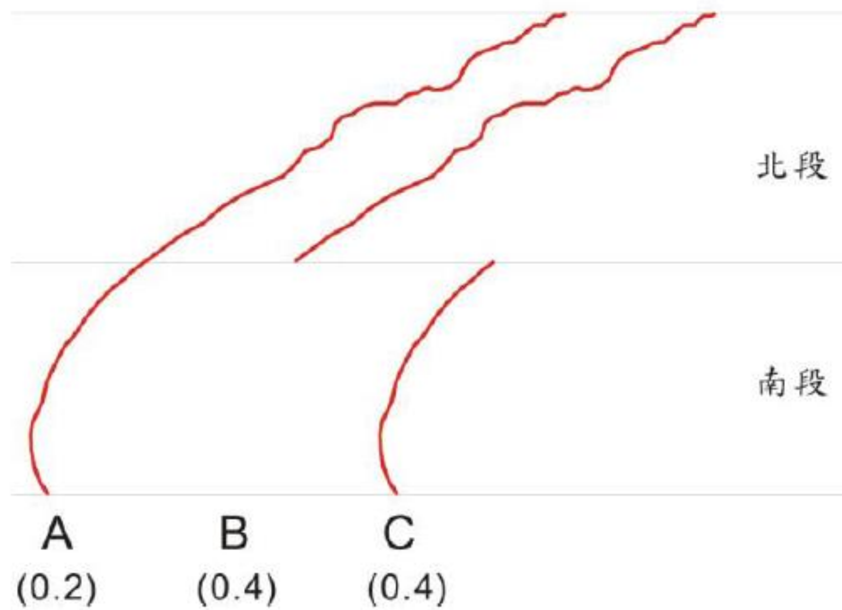
徐澔德教授提供

The Shanchiao Fault Traces





(CGS, 2016)



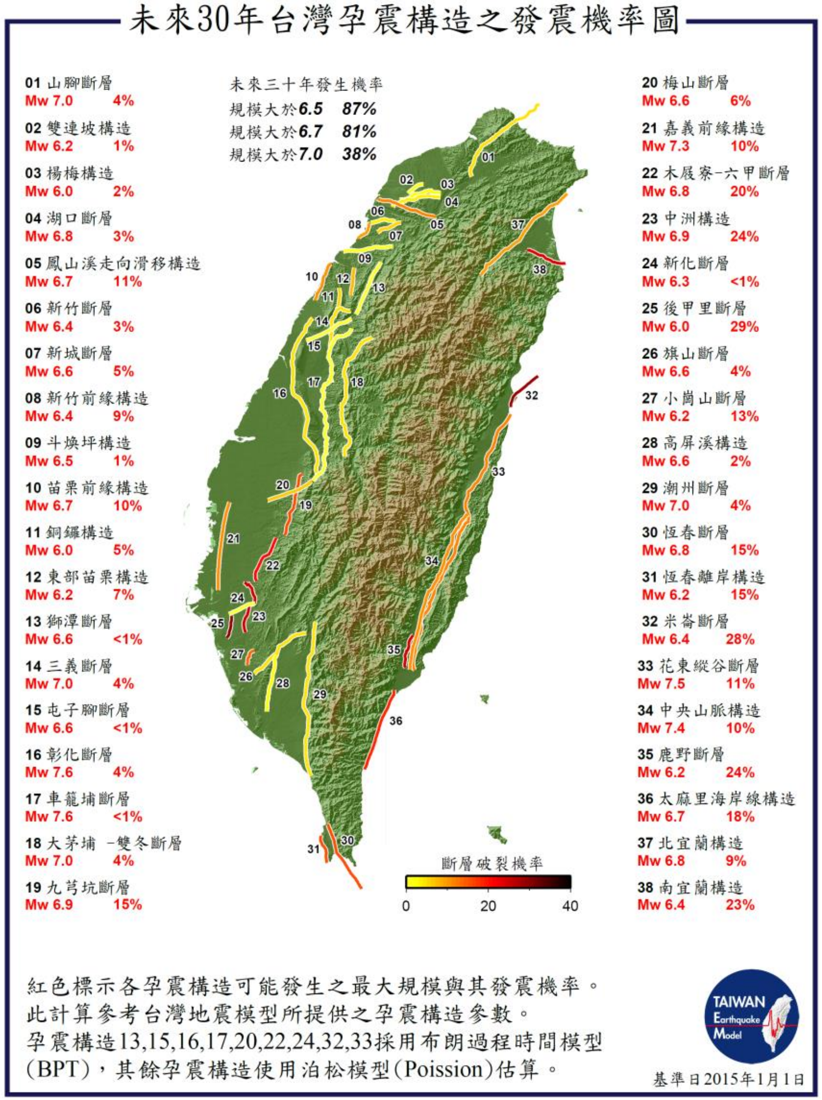
山腳斷層景況模擬

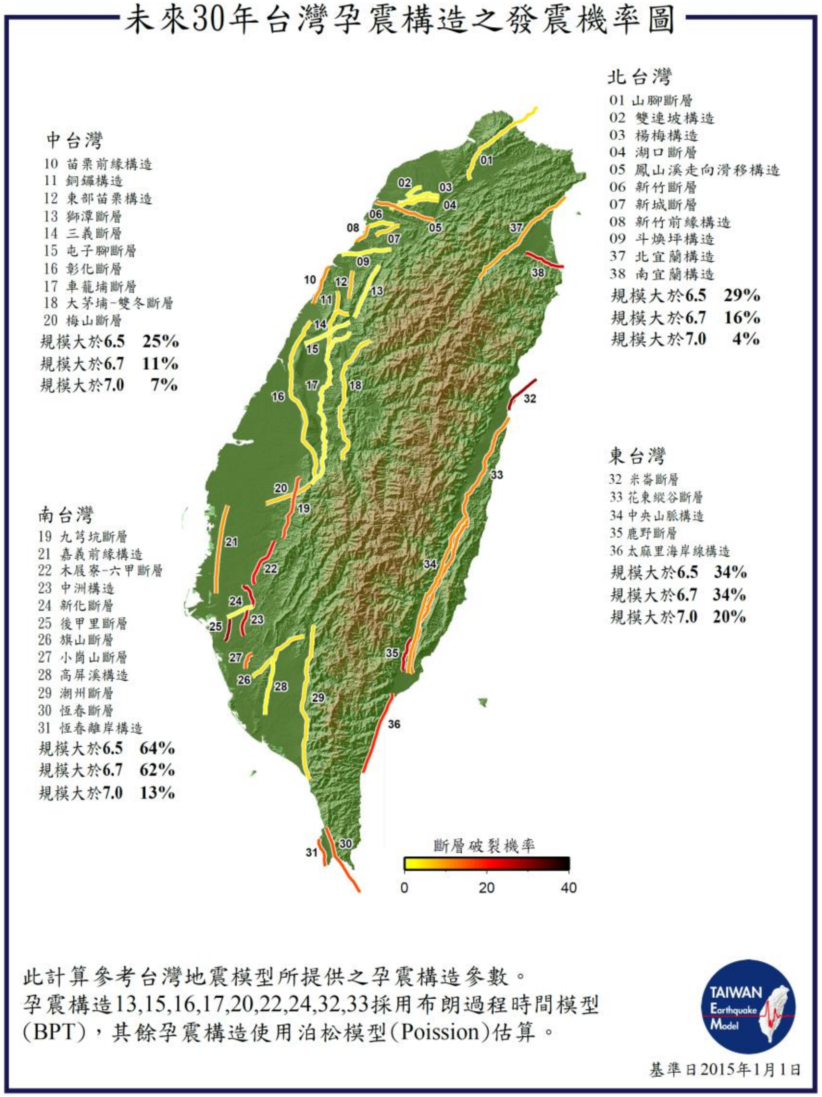
- 情境模擬之構造模型 (高頻模擬) -

Shear wave velocity (β)	3.6 km/s
Density (ρ)	$2.8 gm/cm^3$
Geometric spreading $\frac{1}{R^b}$: b =	1.0 (1–50 km) 0.0(50–170 km) 0.5(>170 km)
Quality factor (Q)	Zone ST: $80f^{0.9}$ Zone SO: $120f^{0.8}$ Zone DT: $60f^{1.0}$
High frequency attenuation (κ)	0.05 s
Crust amplification factor	Transfer function of ENA site A (ENA-A)
Magnitude transform equation	$M_L = 0.961Mw + 0.338 + -0.256$, $M_L < 6.0$ $M_L = 5.115 * (\ln(Mw)) - 3.131 + -0.379$, $M_L \geqq 6.0$
Stress drop (bar)	60, Mw < 5.5; 80, 5.5 ≦ Mw < 6.5 90, 6.5 ≦ Mw, including 1999 Chi-Chi Mw 7.6 earthquake

Stochastic Model Used by Huang *et al.* (2017)

台灣孕震構造與發震機率





國家政策導向 (台灣)

「災害防救白皮書」之編定，依據災害防救法第17條第3項規定：「行政院每年應將災害防救白皮書送交立法院」，用以說明政府災害防救施政成果、災害防救體系平時整備與臨災應變作業、政府災害防救預算配置情形及年度新興施政課題等。

議題：大規模地震情境模擬為基礎之減災規劃

挑戰：地震情境模擬技術整合與防災規劃應用

1. 需要建立更細緻之地震潛勢及情境模擬資料
2. 落實應用地震情境模擬結果於防災實務規劃

對策：強化地震情境模擬圖資建置及防災應用

1. 建立可供防災應用之地震發生潛勢圖資
2. 地震災害潛勢圖資之建置與公開
3. 依地震災害潛勢資料進行境況模擬及衝擊評估
4. 地震防災應用展示平臺之建立與推廣應用

國家政策導向 (台灣)

2015年中央研究院研擬出版『大規模地震災害防災策略建議書』，就大規模地震災害國家面臨問題，向政府建言。

(一)地動潛勢及危害度分析

- 儘速整合相關技術與地質調查研究資料，建立地震危害度分析結果與相關參數，並整合地球科學與地震工程領域之共識，依防救災需求產製更細緻之地震災害潛勢圖資。

具體工作重點如下：

- 檢視臺灣地震源斷層模式及地震源的長期及短期滑移速率，以評估可能的地震活動機率。
- 建立更精細的地下三維速度構造，完成虛擬地震地動時間序列之模擬。
- 研訂並公開具共識之全國地震潛勢資料。
- 整合研究成果、由主管機關訂定建物合理之地震設計參數。


中央研究院

大規模地震災害防治
策略建議書

中央研究院報告 No.13
104 年 4 月

國家政策導向 (全球)

2015年3月18日世界187個國家在日本仙台經5天討論，於「 第三屆世界減災會議」中通過今後15年的全球減災策略—「2015-2030 仙台減災綱領」(Sendai Framework for Disaster Risk Reduction, SFDRR）。

四大先優先推動項目：

1. 明瞭災害風險

2. 利用強化災害風險治理來管理災害風險

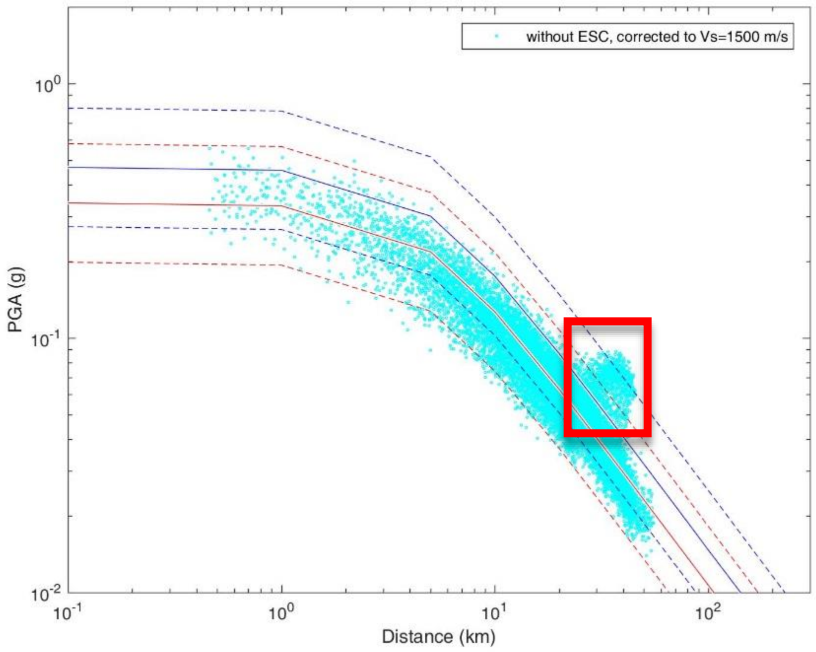
3. 投資減災工作及改進耐災能力

4. 增強防災整備以強化應變工作，並於重建過程中達成「更耐災的重建」之目標。

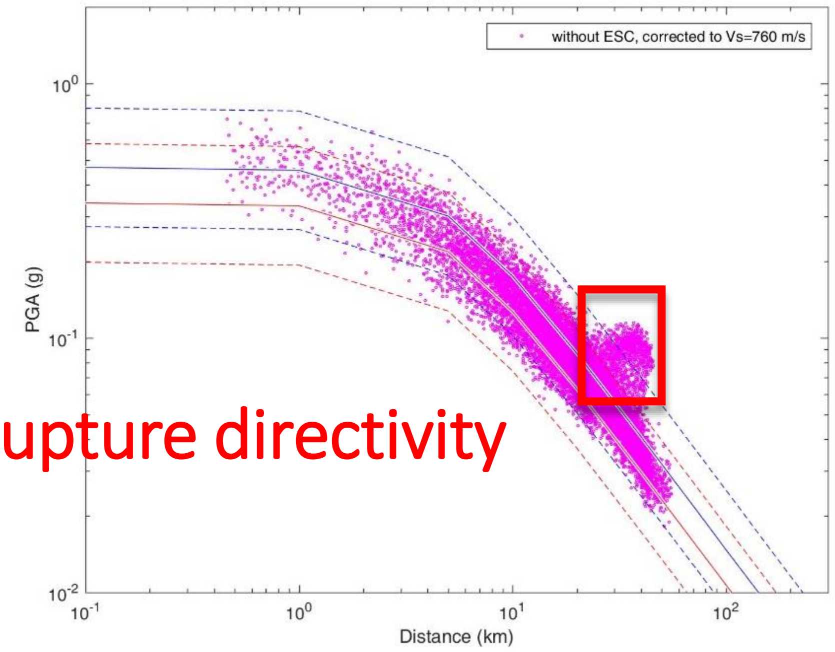
地震波傳遞情境模擬之災損評估相關參數

- 與地震動預估式比較 -

修正至 Vs30=1500 m/s 基盤面



修正至 Vs30=760 m/s 基盤面



Rupture directivity

GMPE: Lin et al. (2009)

Red lines (solid and dashed): Vs30=1500 m/s

Blue lines (solid and dashed): Vs30=760 m/s