財團法人中興工程顧問社
SINOTECH ENGINEERING CONSULTANTS, INC.

# Ground motion simulation and prediction for earthquake engineering and hazard mitigation


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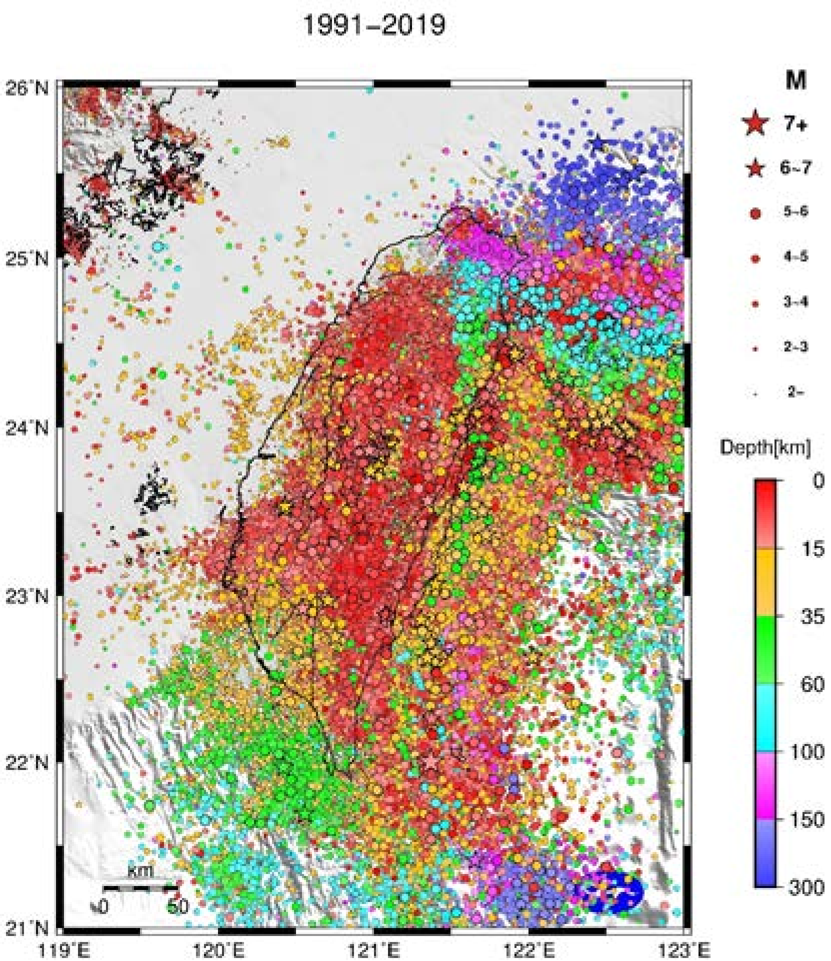
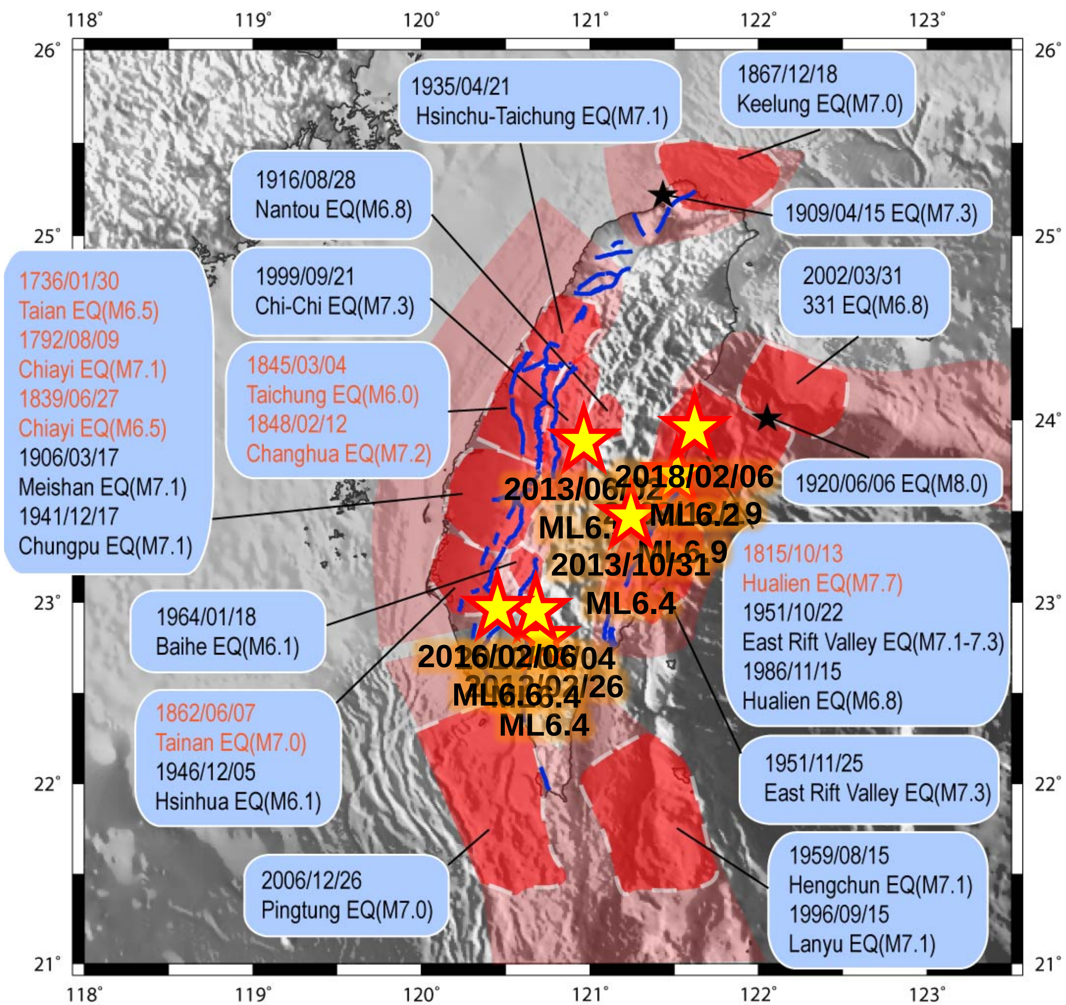
2020.06.05 Dept. of Earth Science, NCU

# Past - Present - Future

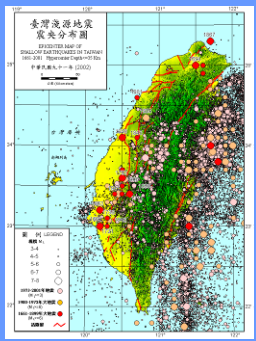



Source : Central weather bureau



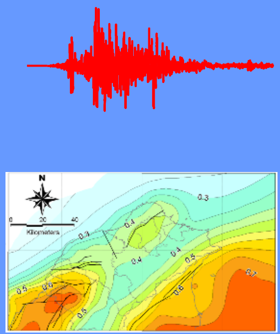
# What can we do ?

## Hazard



**Faulting**

- Active Faults
- Instrument quakes
- Historical earthquakes
- Geodetic strain



**Shaking**

- **Ground motion prediction equations**
- Shaking amplification in soil and basins
- **Scenario simulation**

## Risk

**Exposure**

- Population
- Building
- Remote sensing

**Damage**

- Vulnerability
- Damage data
- Fragility functions

## Impact

**Action**

- **Urban scenarios**
- Decision tools
- Risk transfer tools
- **Building design codes**

# Outline

- Ground motion simulation
  - Means and methods
  - Linking to engineering application
- Application cases
  - Taiwan SSHAC Level 3 project
  - A scenario earthquake on the Shanchiao fault

# Before Scenario Simulation

**Source** → **Fault** → **Path** → **Site**

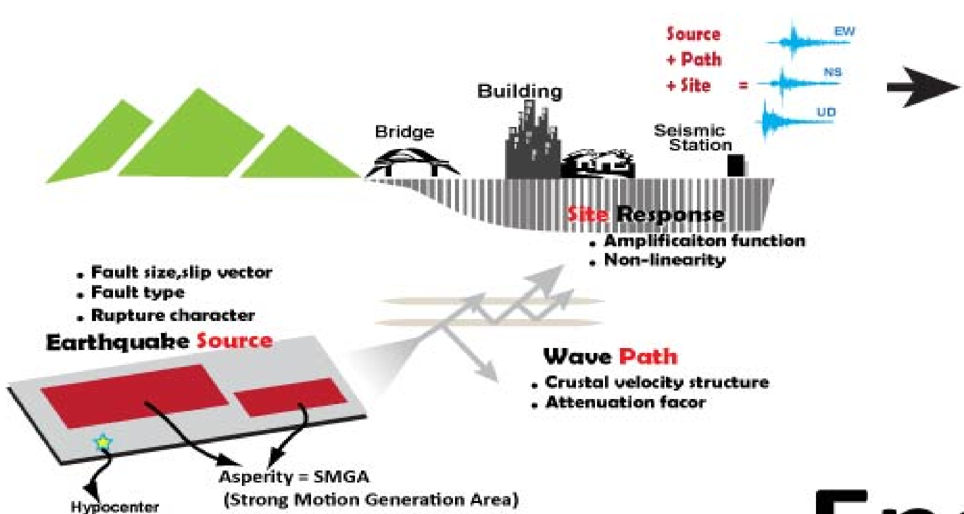
Normal
Reverse
Strike

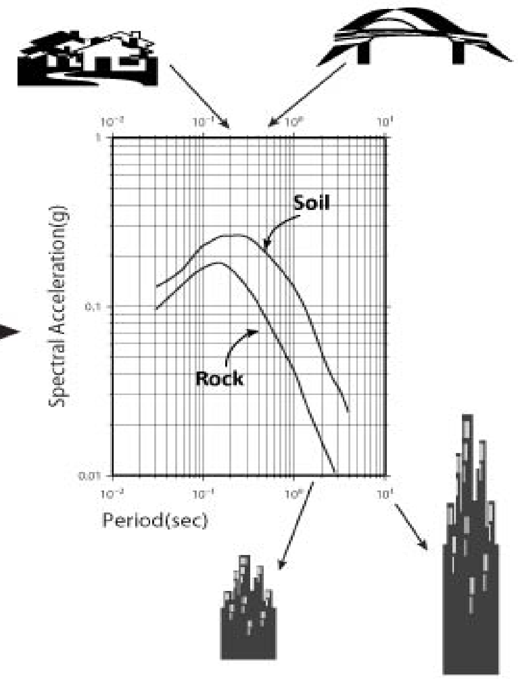
Dimension
Rupture direction
Dislocation

Velocity structure,
Attenuation model

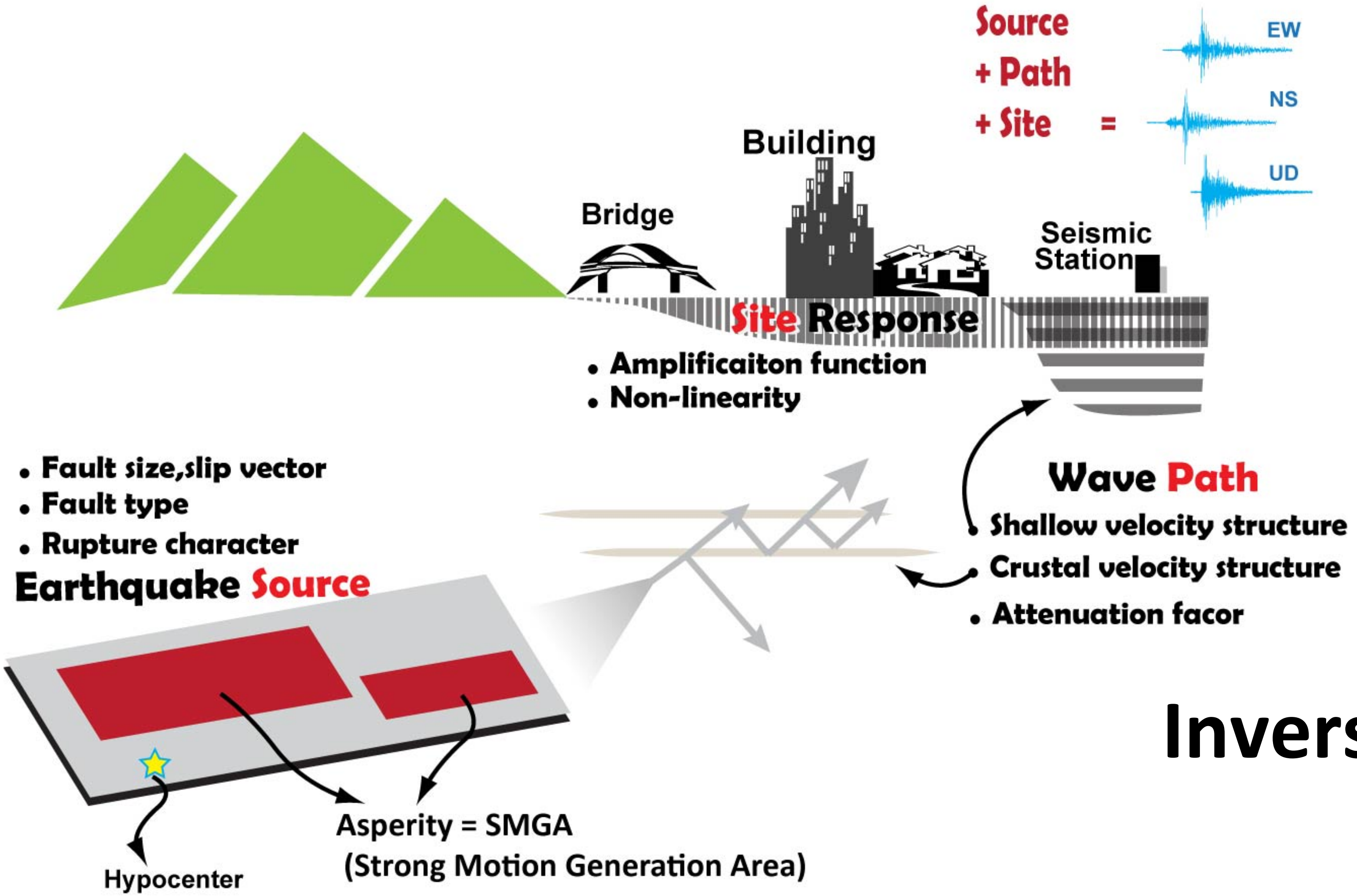
Shallow velocity, $V_{s30}$ 、
Bedrock(engineering, seismic)

## Seismology




## Engineering

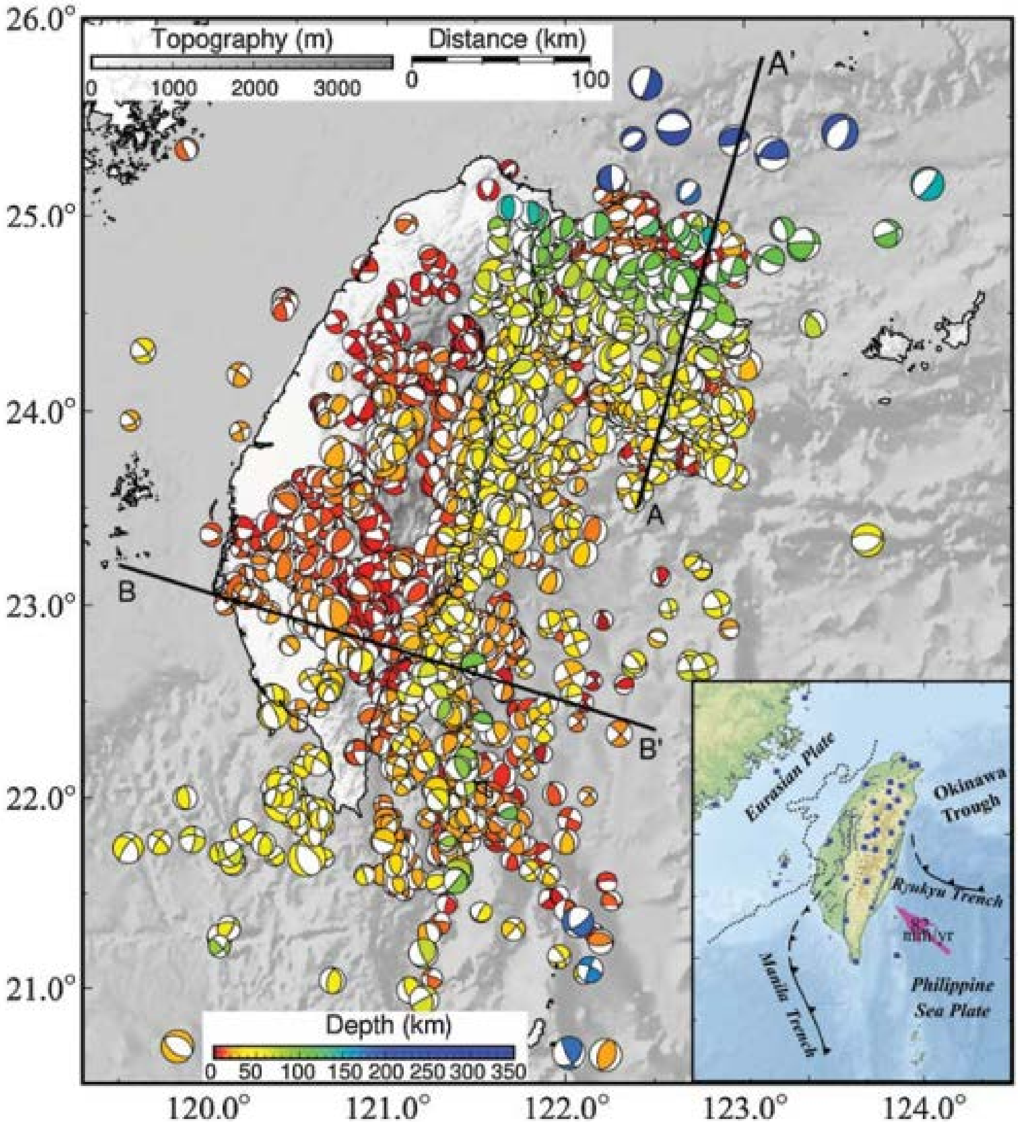

Source
+ Path
+ Site =
EW
NS
UD
Building
Bridge
Seismic
Station
Site Response
• Amplificaiton function
• Non-linearity
• Fault size,slip vector
• Fault type
• Rupture character
Earthquake Source
Wave Path
• Shallow velocity structure
• Crustal velocity structure
• Attenuation facor
Hypocenter
Asperity = SMGA
(Strong Motion Generation Area)

# Inversion

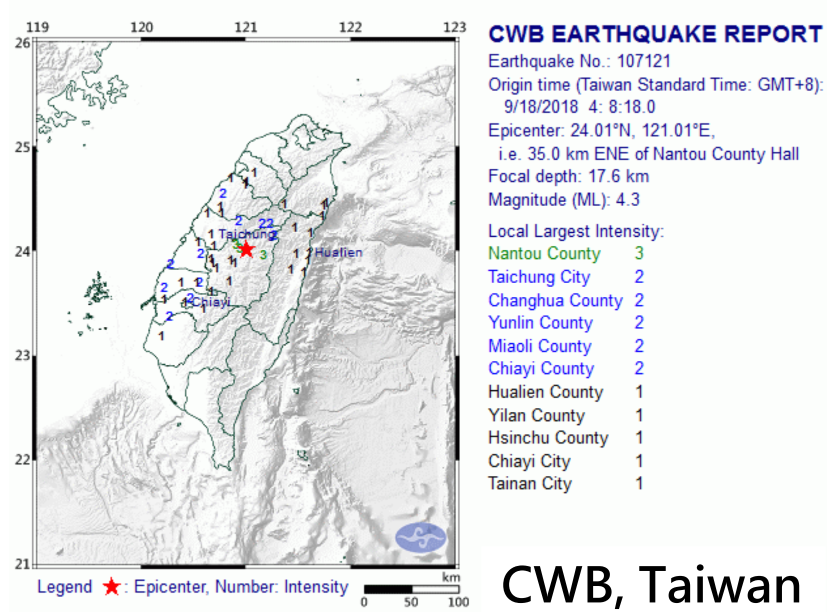
Source ➡ Fault ➡ Path ➡ Site

# Focal Mechanism

- CWB
- BATS, IES
- USGS
- Global CMT




(Jian et al., 2018)




CWB, Taiwan

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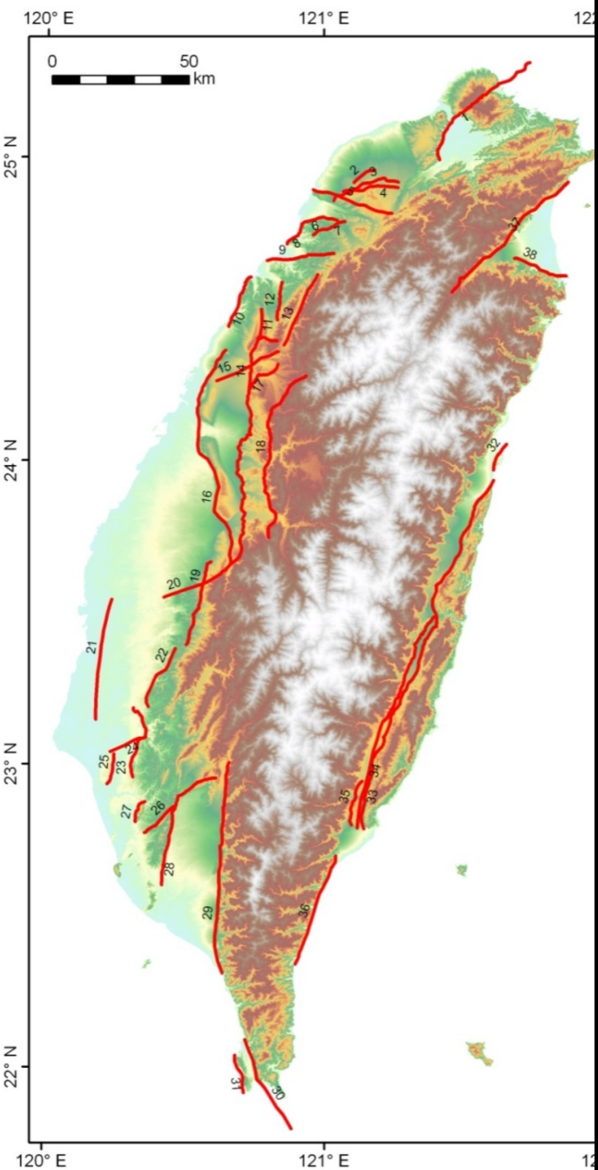
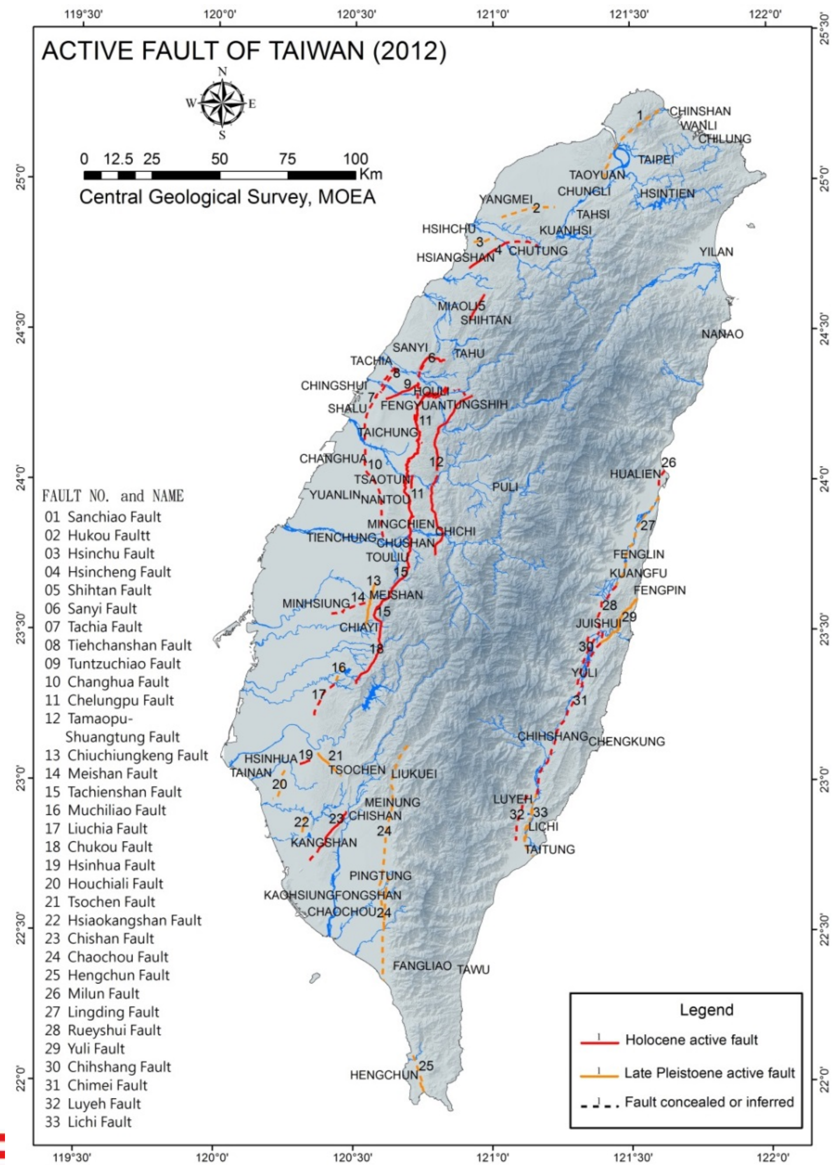
Source → Fault → Path → Site

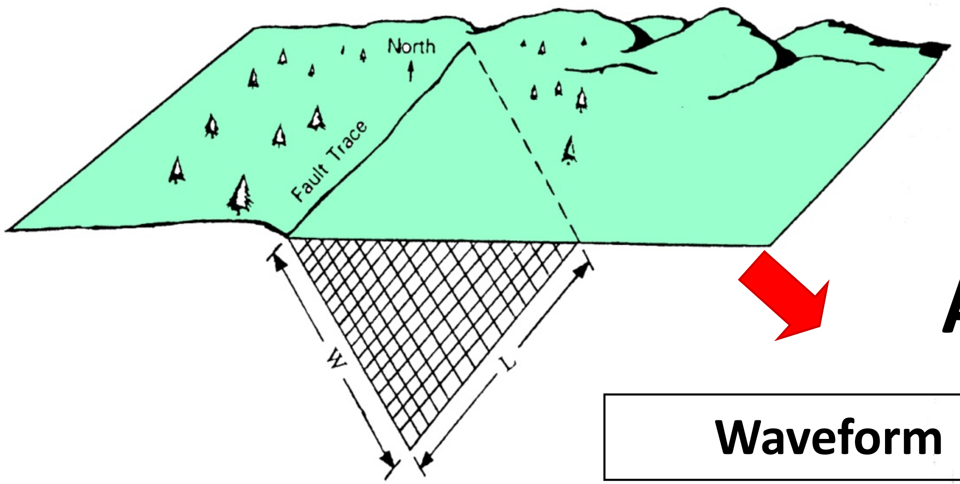



| No. | Fault Name |
|---|---|
| 1 | Shanc[illegible]lt |
| 2 | Shuanglienpo structure |
| 3 | Yangmei fault |
| 4 | Hukou fault |
| 5 | fengshan river strike-slip structure |
| 6 | Hsinchu fault |
| 7 | Hsincheng fault |
| 8 | Hsinchu frontal structure |
| 9 | Touhuanping structure |
| 10 | Miaoli frontal structure |
| 11 | Tunglo structure |
| 12 | east Miaoli structure |
| 13 | Shihtan fault |
| 14 | Sanyi fault |
| 15 | Tuntzuchiao fault |
| 16 | Changhua fault |
| 17 | Chelungpu fault |
| 18 | Tamaopu - Shuangtung fault |
| 19 | Chiuchiungkeng fault |
| 20 | Meishan fault |
| 21 | Chiayi frontal structure |
| 22 | Muchiliao - Liuchia fault |
| 23 | Chungchou fault |
| 24 | Hsinhua fault |
| 25 | Houchiali fault |
| 26 | Chishan fault |
| 27 | Hsiaokangshan fault |
| 28 | Kaoping River structure |
| 29 | Chaochou fault |
| 30 | Hengchun fault |
| 31 | Hengchun offshore structure |
| 32 | Milun fault |
| 33 | Longitudinal Valley fault |
| 34 | Central Range fault |
| 35 | Luyeh fault |
| 36 | Taimali coastline structure |
| 37 | Northern Ilan structure |
| 38 | Southern Ilan structure |



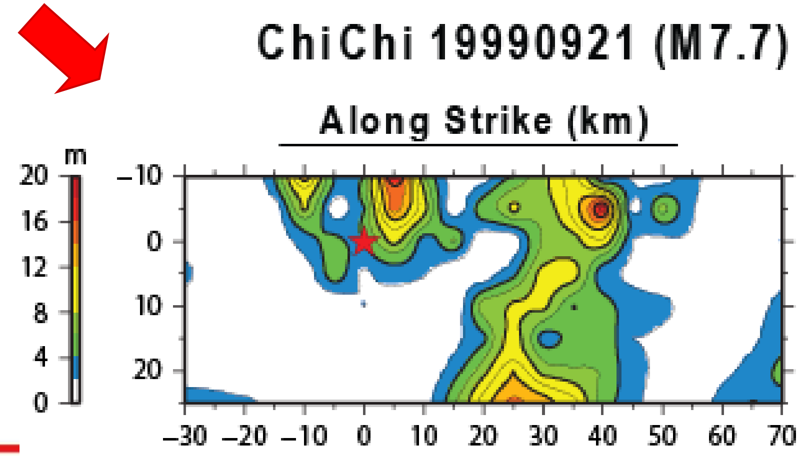
**Source** → **Fault** → **Path** → **Site**

# Waveform Inversion - Strike, dip, rake, length, width and slip



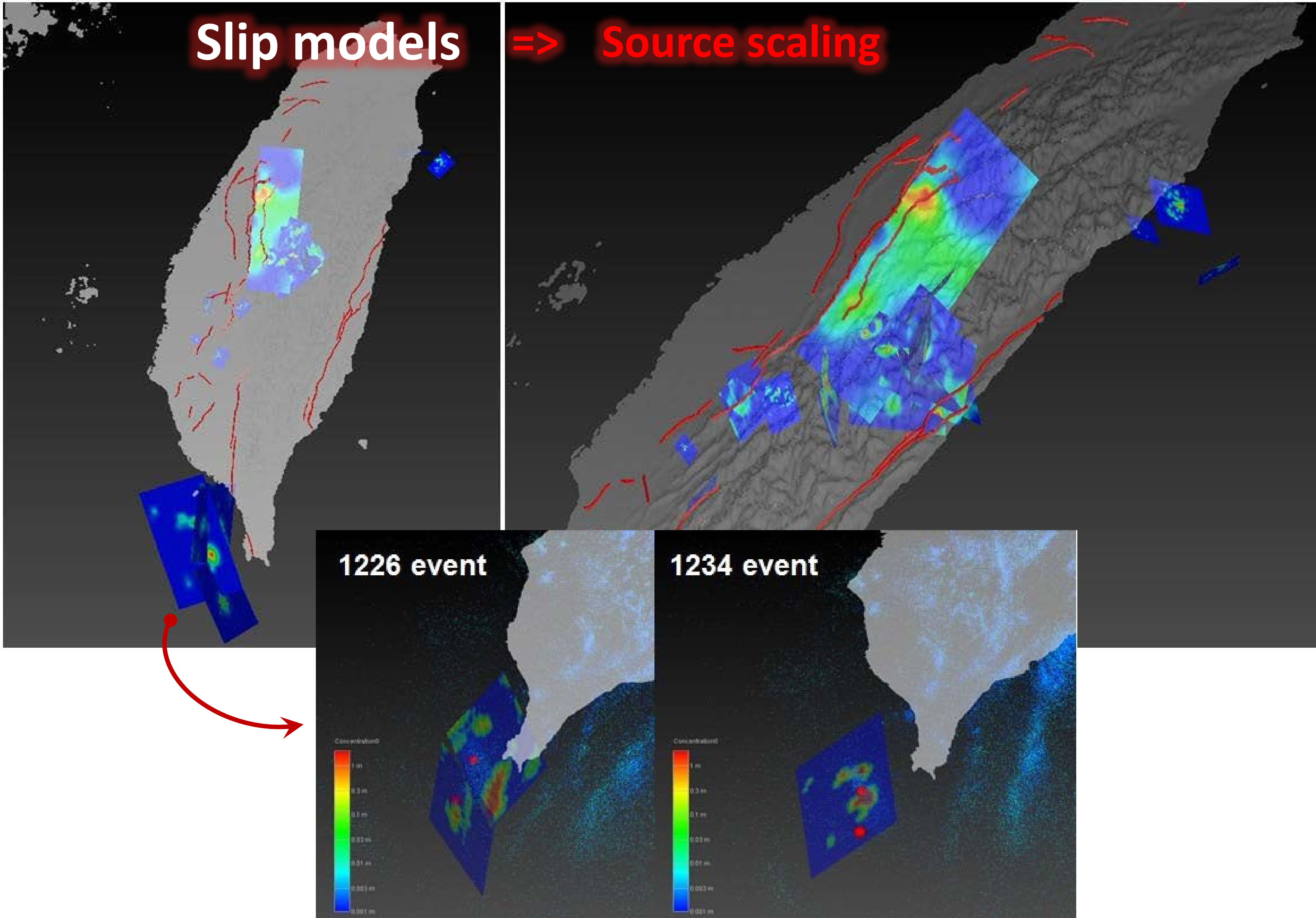

**A x = B**

**Waveform Inversion**



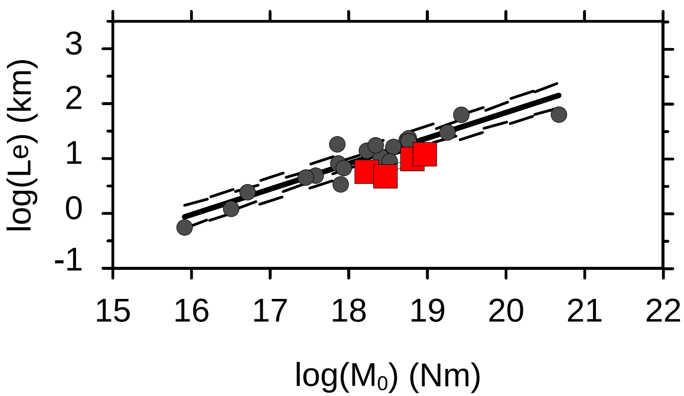

## Source model or

## Slip distribution

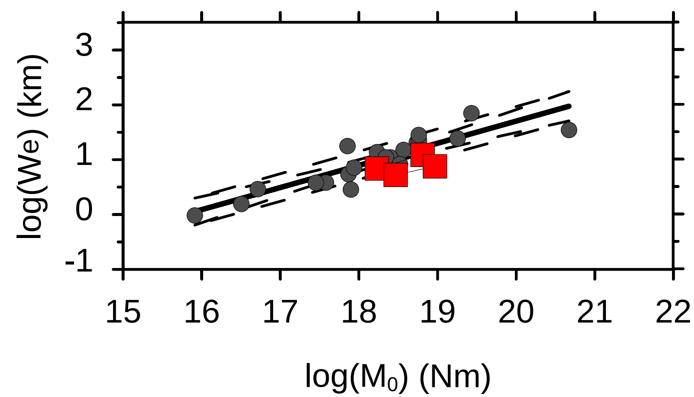

Slip models
=> Source scaling
1226 event
1234 event

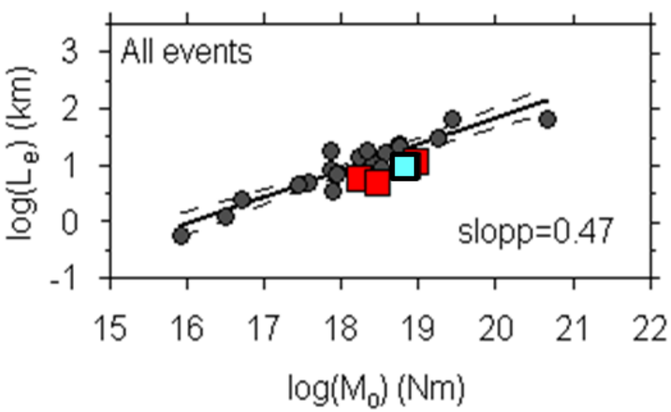
# Magnitude scaling relations of Yen and Ma in 2011

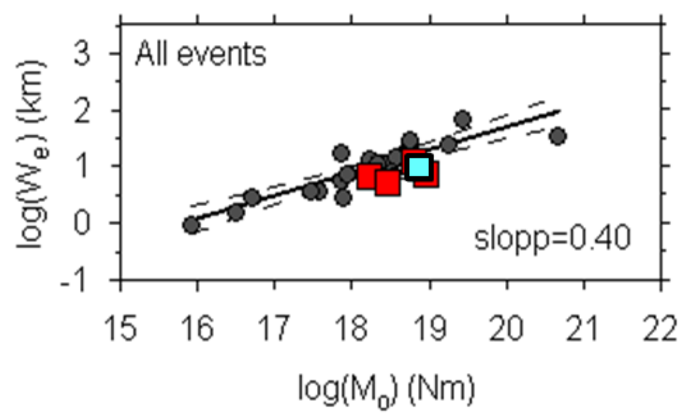
**Fault Length vs. Moment**




**Fault Width vs. Moment**



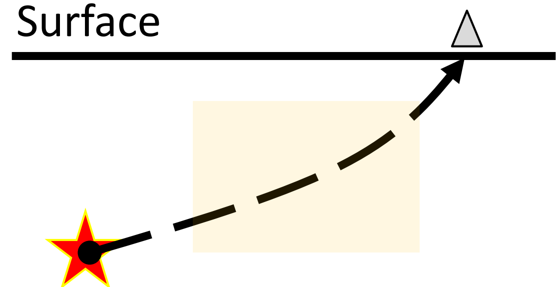

**New data after 2010** **0206 Meinong earthquake**

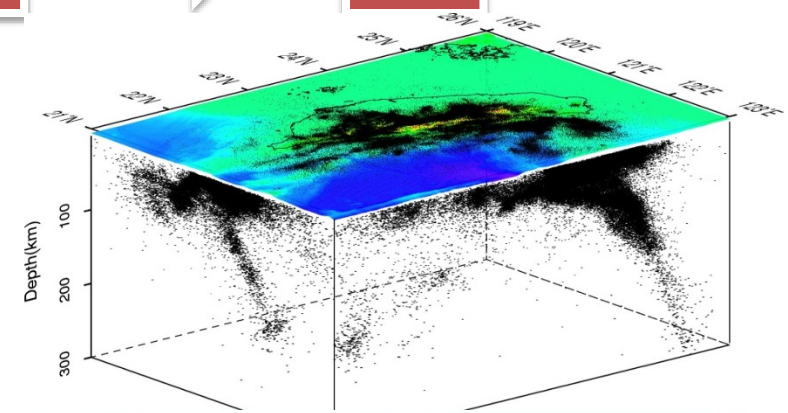
# Distinction of magnitude scaling relations

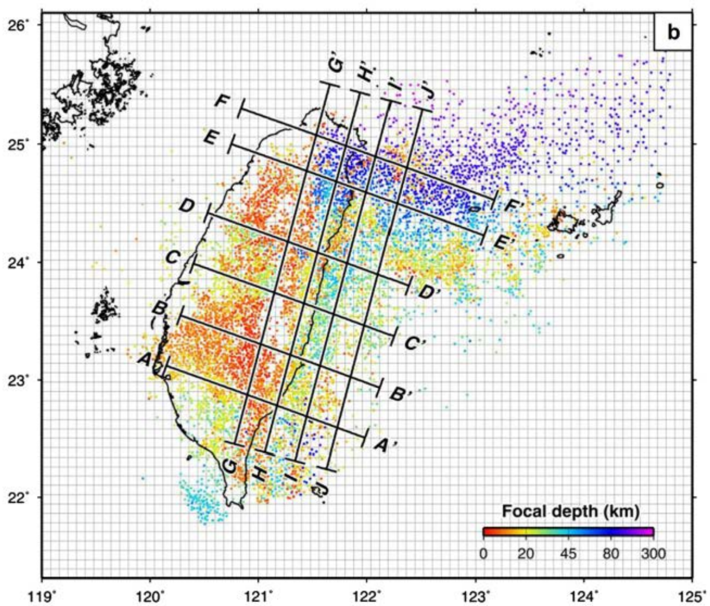
## Compilation of suggested magnitude scaling relationships

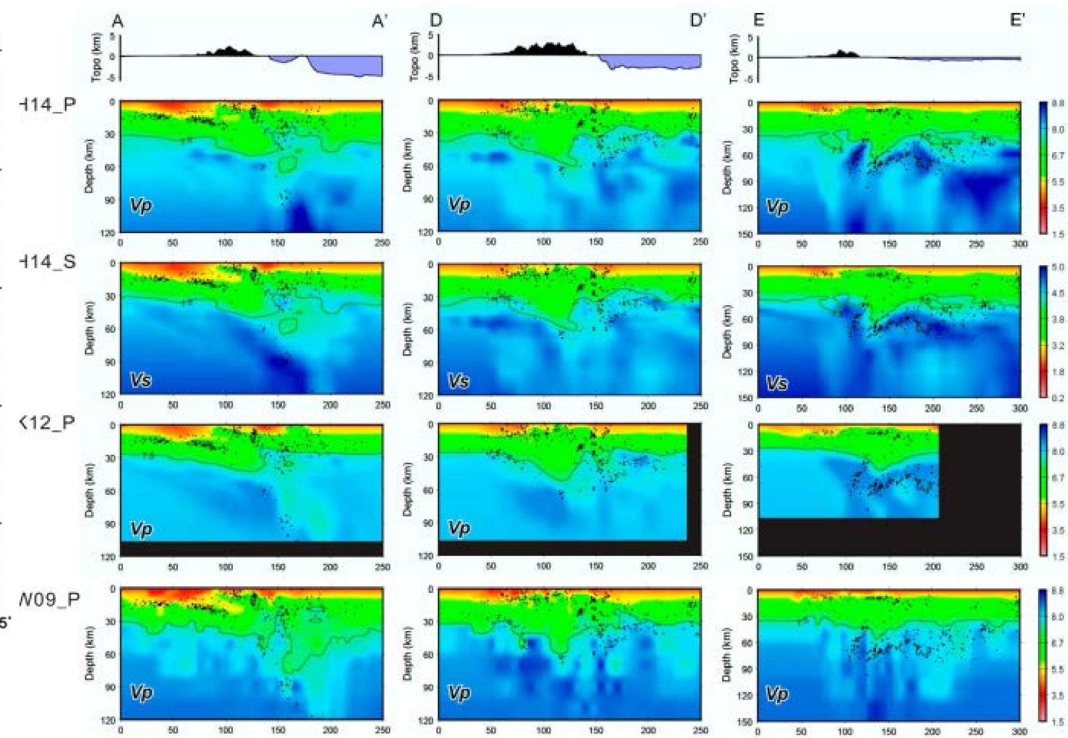
| Tectonic Regime | Reference | Source type | M range | Relation |
|---|---|---|---|---|
| Crustal (global scale or local scale for Taiwan) | Wells and Coppersmith, 1994 | All, SS, R, N | surface : 5.2-8.1<br>subsurface : 4.8-8.1 | M-L |
| | | | 4.8-7.9 | M-A |
| | Hanks and Bakun, 2008;2014 | SS | 5-8 | 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 |

**Source** → **Fault** → **Path** → **Site**



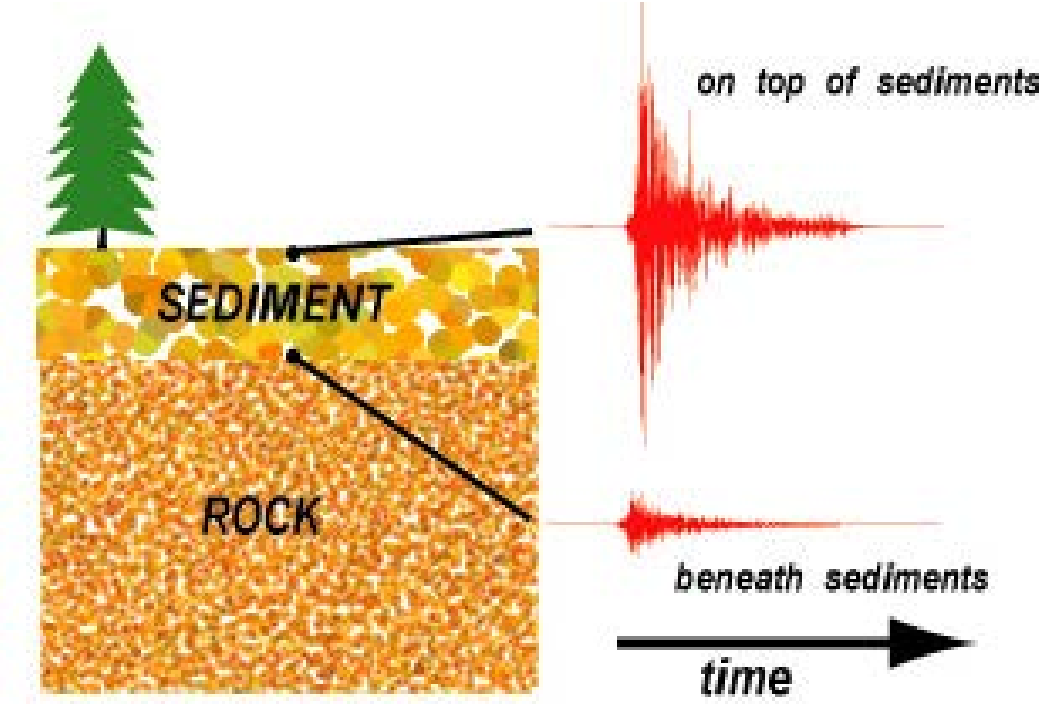



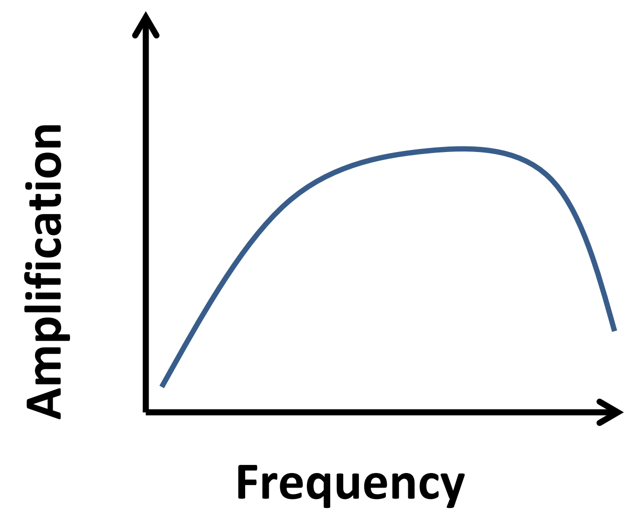

**Huang et al., 2014**
Kuo-Chen et al, 2012
Wu et al., 2009

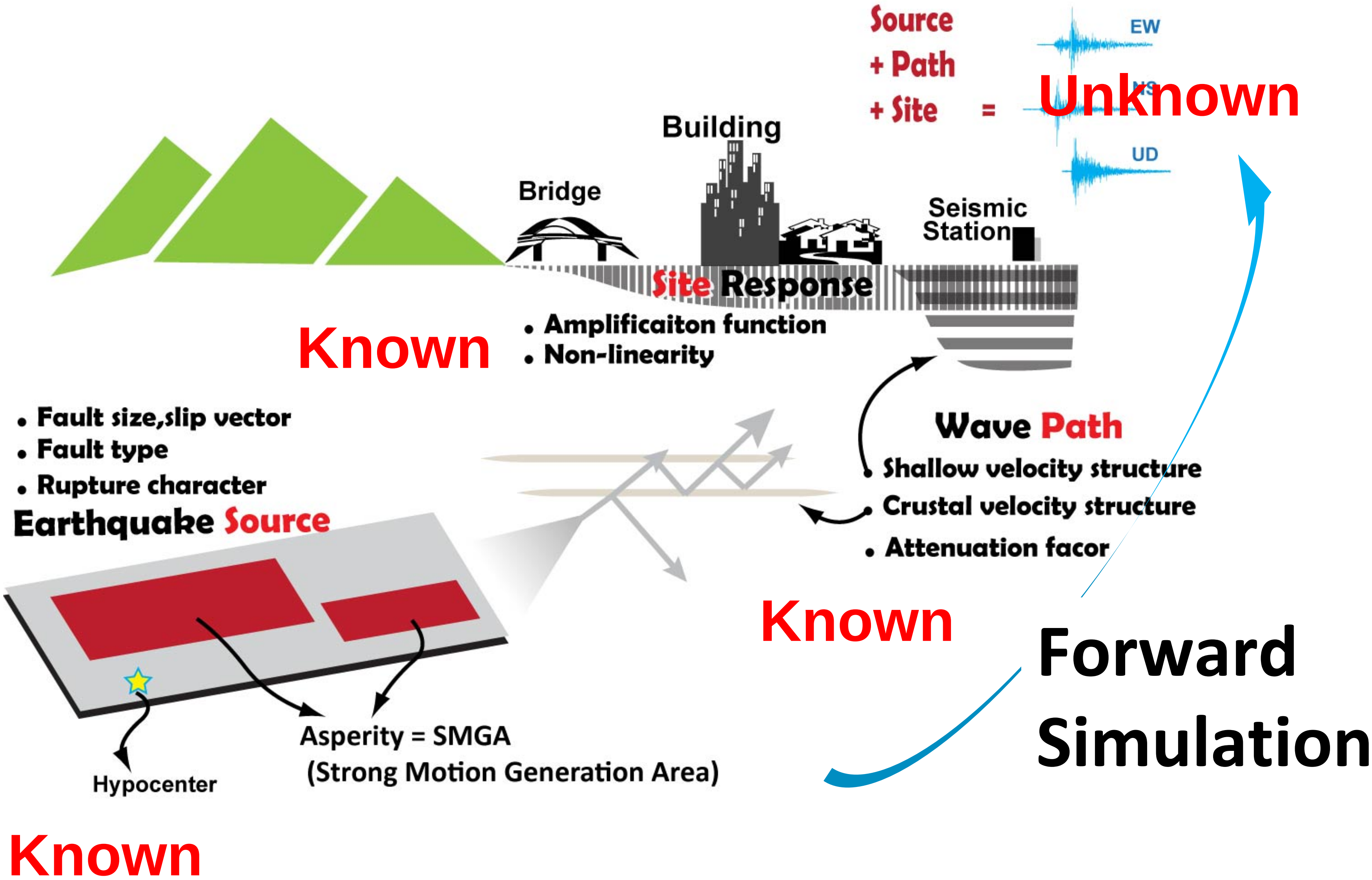
**Source** → **Fault** → **Path** → **Site**

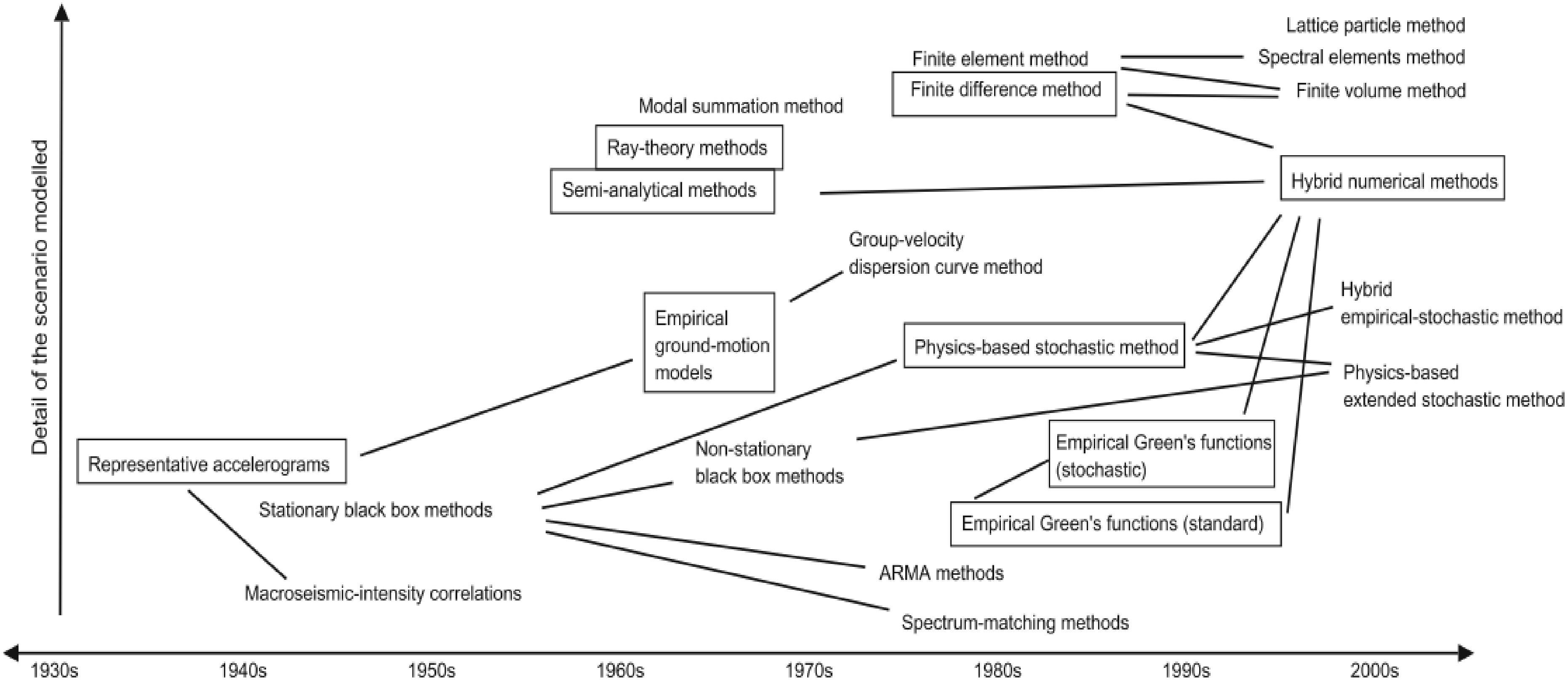



(Retrieved from pubs.usgs.gov)

# Amplification Function



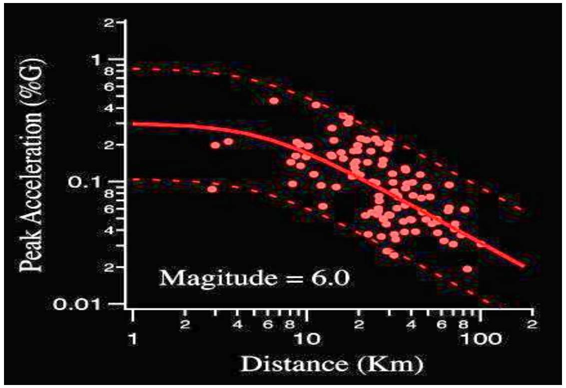

Source
+ Path
+ Site
=
EW
UD
Unknown
Building
Bridge
Seismic Station
Site Response
• Amplificaiton function
• Non-linearity
Known
• Fault size,slip vector
• Fault type
• Rupture character
Earthquake Source
Wave Path
Shallow velocity structure
Crustal velocity structure
• Attenuation facor
Known
Forward
Simulation
Hypocenter
Asperity = SMGA
(Strong Motion Generation Area)
Known

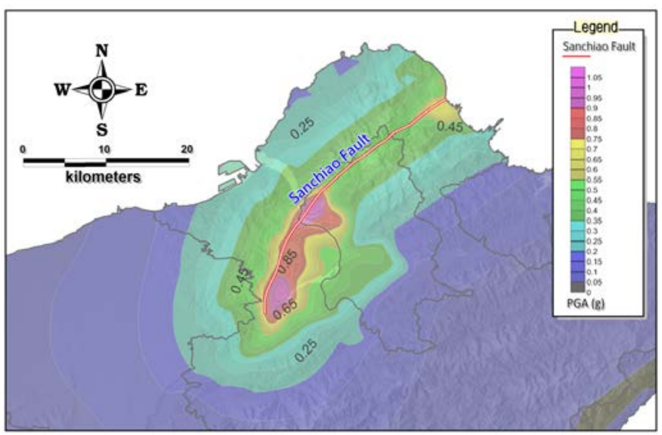



(Douglas and Aochi, 2008)

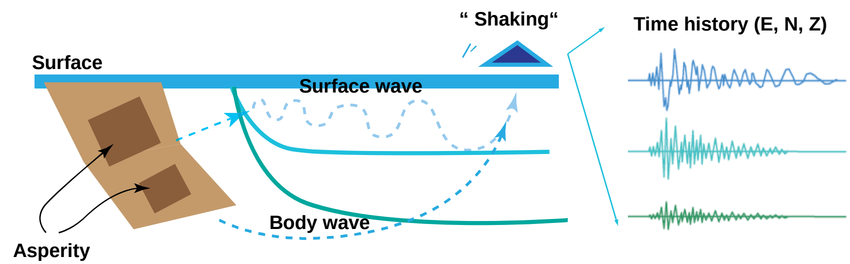
# Ground motion estimation

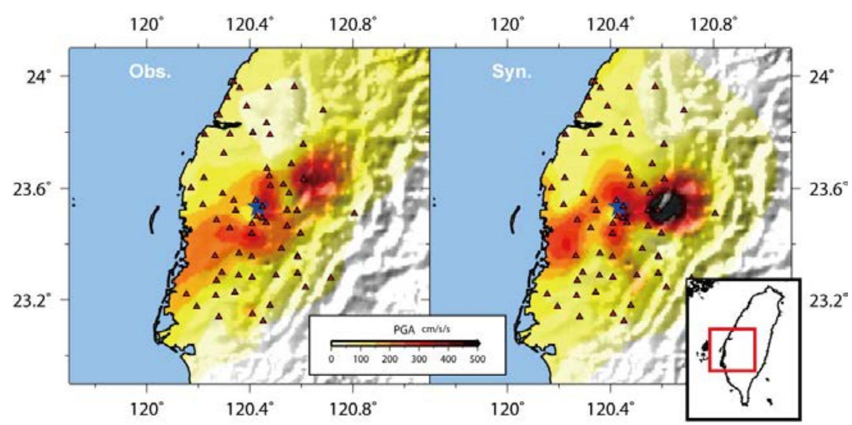
## Empirical




## Theoretical



# Ground Motion Prediction Equations

- Empirical regressions of recorded data
- Estimate ground shaking parameter (peak ground acceleration, peak velocity, spectral acceleration or velocity response) as a function of
  (1) magnitude
  (2) distance
  (3) site
- May consider fault type (strike-slip, normal, reverse)

Art McGarr, 2006

# Steps for building GMPE

- Establish database
- Select form of predictive equation
- Perform regression analyses
- Evaluate uncertainty

$$Y=f(M,R,P_i)$$

*Y*: Ground motion parameter of interest

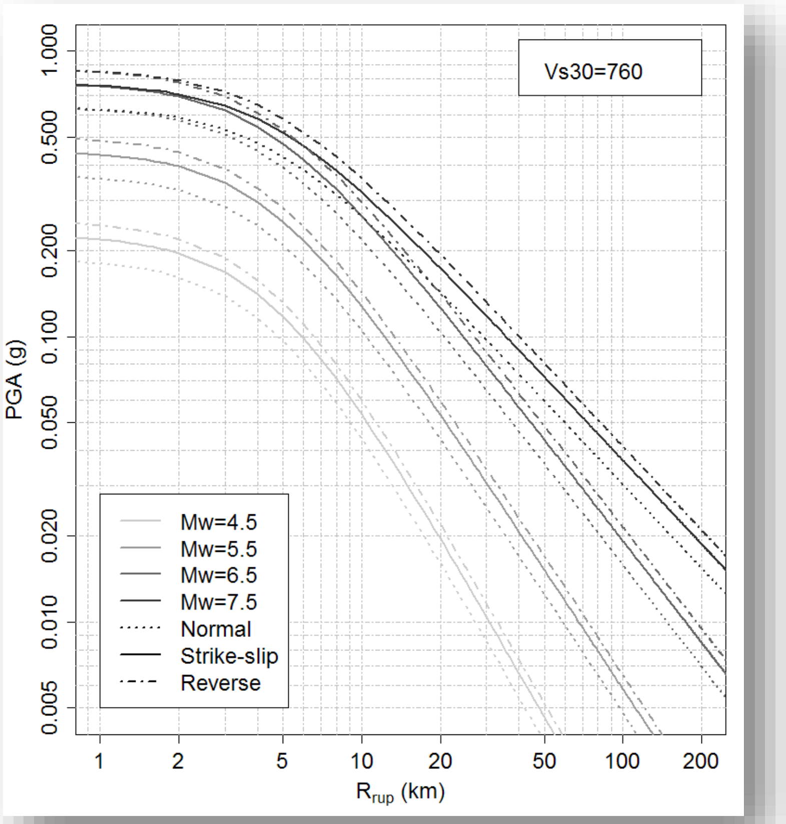
- *M*: The magnitude of the earthquake
- *R*: Distance from the source to the particular site
- $P_i$: Other parameters (earthquake source, local site conditions, wave propagation path…)

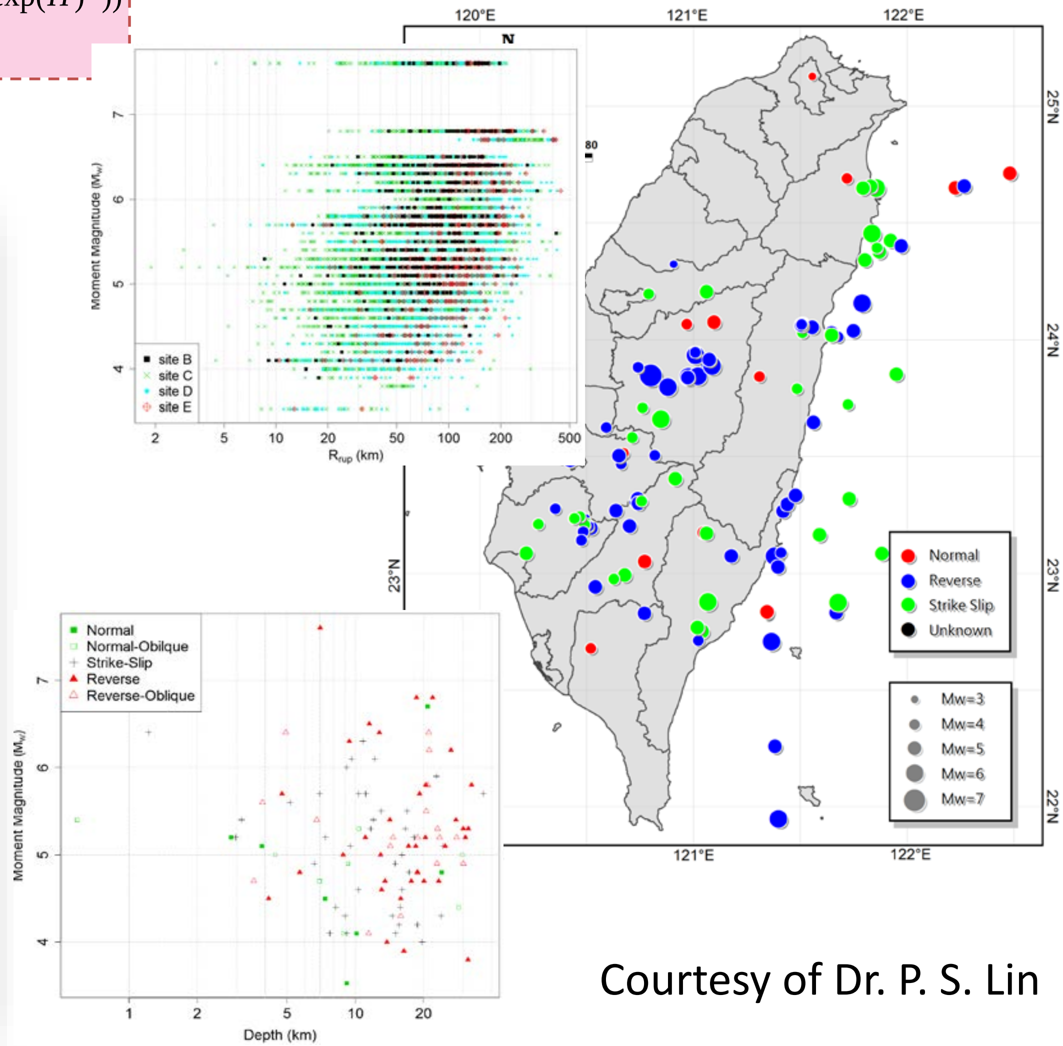
# Strong-motion data for GMPE – Crustal

## For Crustal Earthquake

$$\ln y = C_1 + F_1 + C_3(8.5 - M_W)^2 + (C_4 + C_5(M_W - 6.3))\ln(\sqrt{(R^2 + \exp(H)^2)}) + C_6 F_{NM} + C_7 F_{RV} + C_8 \ln(VS_{30}/1130)$$

$$\begin{cases} F_1 = C_2(M_W - 6.3) & Where \quad M_W \le 6.3 \\ F_1 = (-H \cdot C_5)(M_W - 6.3) & Where \quad M_W > 6.3 \end{cases}$$




Courtesy of Dr. P. S. Lin

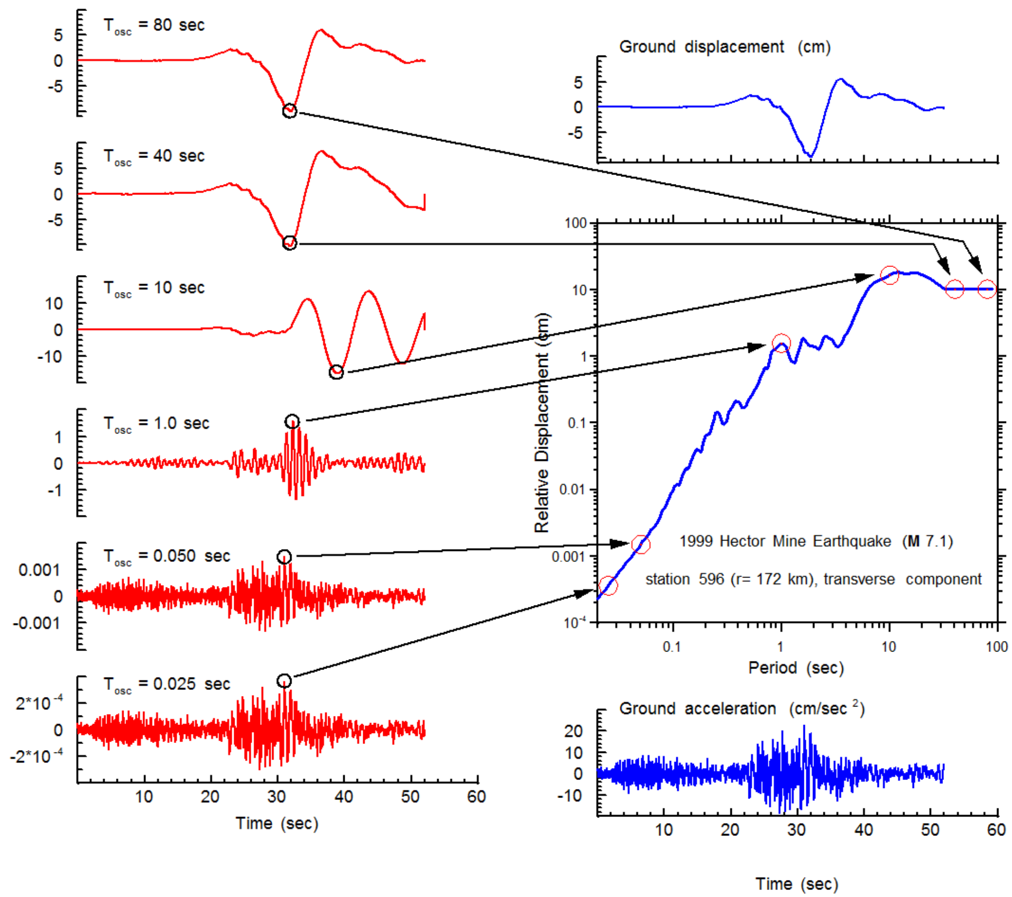
# What parameters to be used ?

- Peak ground acceleration, **PGA**
- Peak ground velocity, **PGV**
- **Intensity** (Can be related to PGA and PGV)
- Response spectrum （**SA0.3 & SA1.0**）(elastic, inelastic at periods of engineering interest )

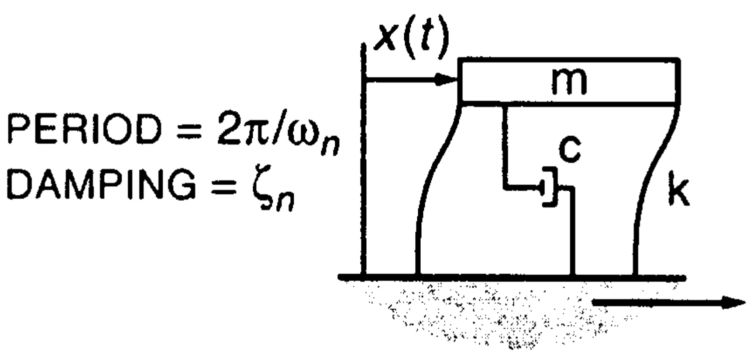
# Linking to engineering

## Response spectrum

**An envelope of the peak responses of many single-degree-of-freedom (SDOF) systems with different periods**




From Boore, 2015, EERI Utah Chapter Short Course on Seismic Ground Motions

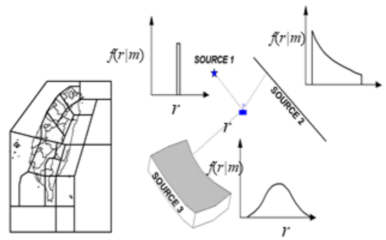



**Base acceleration**

# Probability Seismic Hazard Analysis

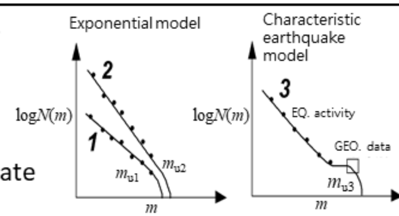
## 1.Source model and zonation

- Active fault
- Area sources
- Subduction zone



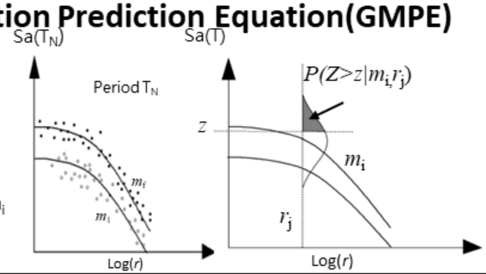

## 2. Source parameter

- Earthquake catalog
- Source geometry
- Fault slip-rate
- Earthquake occurrence rate
- Max. Earthquake



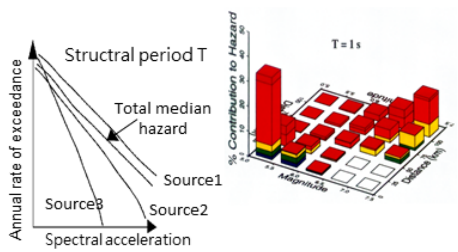

## 3. Ground-Motion Prediction Equation(GMPE)

Calculate the probability of ground-motion Sa(T) exceed z, using response spectrum GMPE at period T, magnitude $m_i$ and distance $r_j$



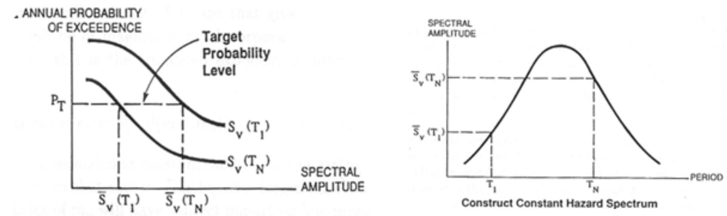

## 4.Hazard curve

Use logic tree method to handle the uncertainty of parameters and models, calculate the annual rate of exceedance at specific ground motion.



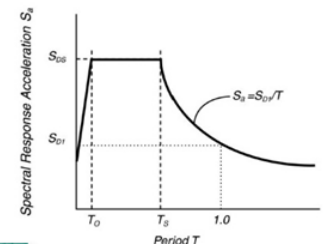

# Uniform Hazard Response Spectrum

The uniform hazard response spectrum was obtained by PSHA for the spectral acceleration (Sa) level of each structural period in the same return period.



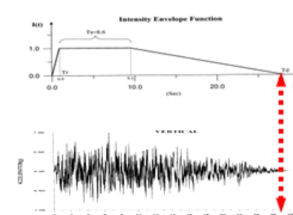

# Design Response Spectrum

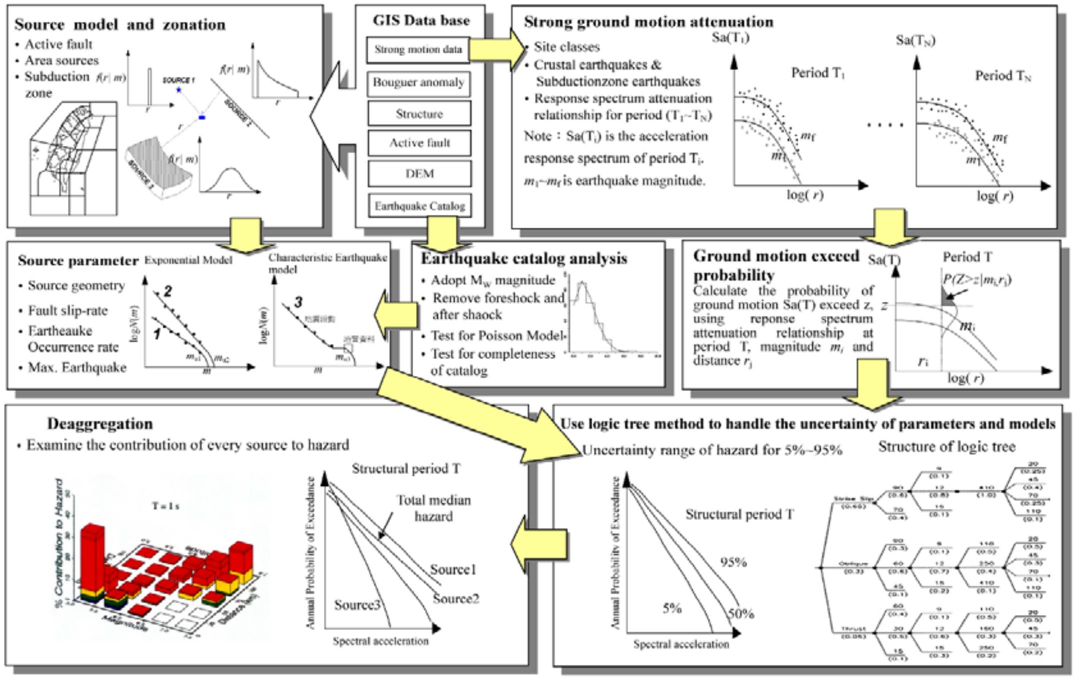
For each specific site you define a Maximum Considered Earthquake (MCE) (an event with a 2% probability of exceedance in 50 years or a T = 2475 years). The design earthquake is 2/3 the MCE.




# Synthetic accelerograms

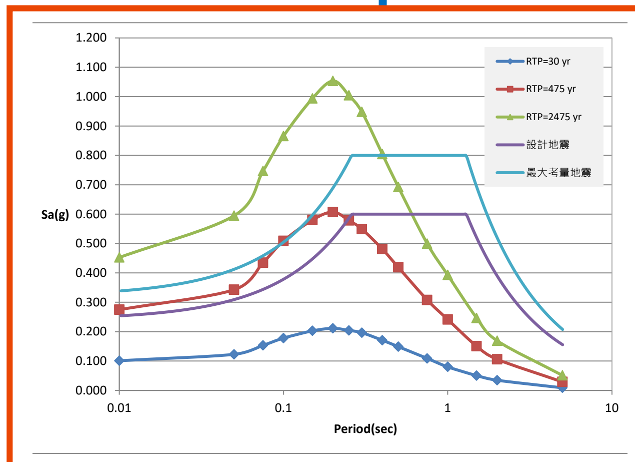
- A strong motion record with earthquake focal mechanism similar to MCE earthquake and site condition similar to target site was adopted.
- The synthetic time-histories kept the phase property of the real time-histories.

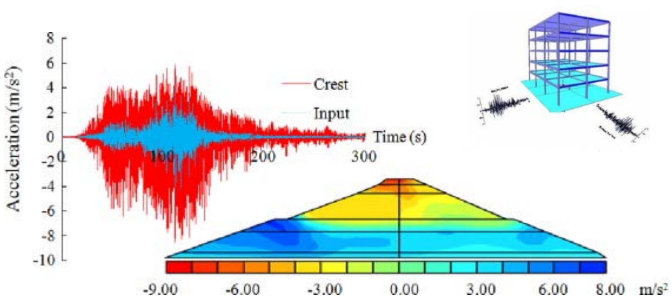


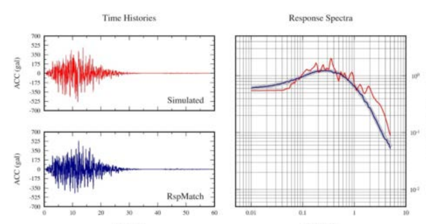



# Conventional way

UHRS



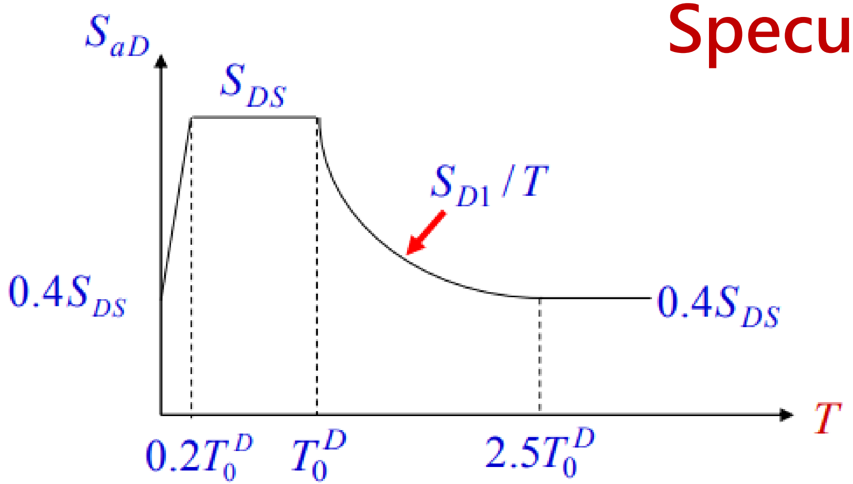




**Dynamic analysis** ← **Time history analysis** ← **Design RS**

(Charatpangoon et al., 2014) (Dabiri et al., 2015)

# PSHA – Design response spectrum




Speculation

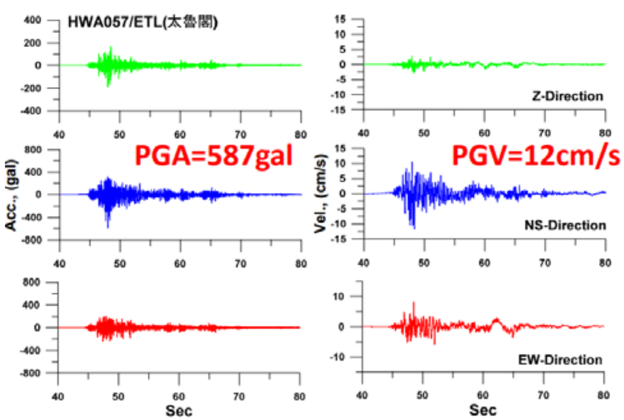
R.P.(475yr)

Zoning factor

Site classification

Importance factor

Near fault



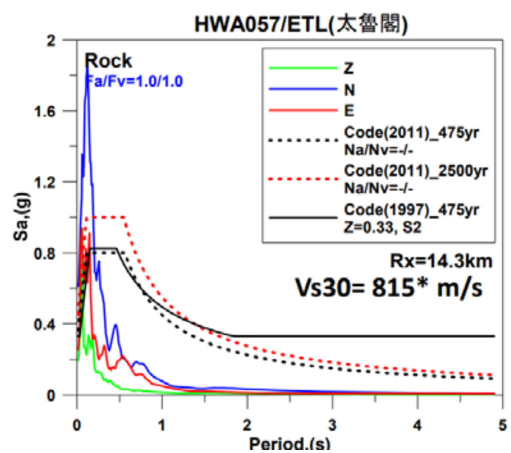




Fig. source: NCREE

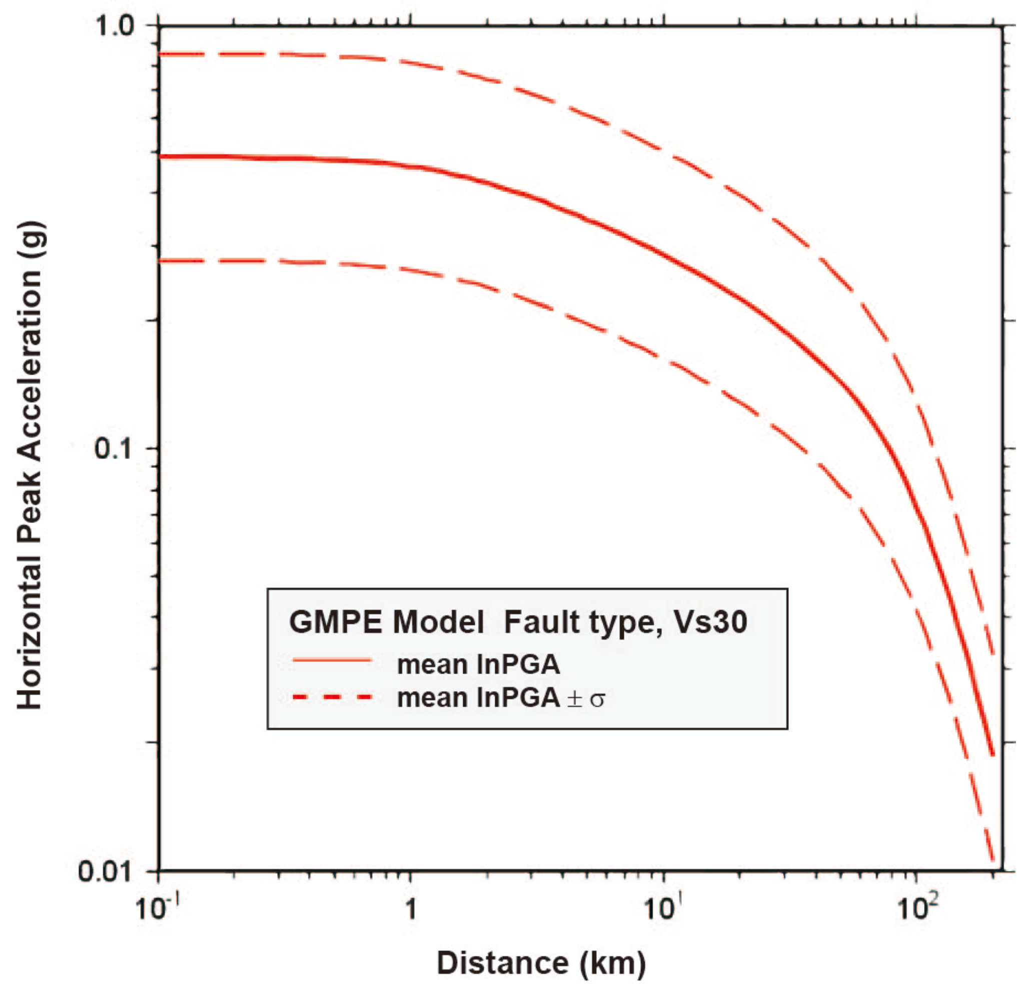
# Ground Motion Prediction Equation (GMPE)

An equation that can be used to predict the possible ground-motion value during future earthquakes.

## Limitation :

1. **A fault plane**
2. **Uncertainty for a lack of observed data**

Scheme of Ground Motion Prediction Equation



# Why simulation is useful to GMPE?

- To understand some of the underlying physical parameters that control observed ground motion and their variability
- To evaluate the effect level of GMPEs that are not well represented by the empirical database
- To address questions for model comparisons between various region with difference of data completeness
- Final goal is that we can improve the results of PSHA

**An integral part of building codes in the United States, Minimum Design Loads and Associated Criteria for Buildings and Other Structures**

**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."

# U.S. Guideline

NUREG/CR-6372
UCRL-ID-122160
Vol. 1

Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts

Main Report

Prepared by
Senior Seismic Hazard Analysis Committee (SSHAC)
R. J. Budnitz (Chairman), G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, P. A. Morris

**Lawrence Livermore National Laboratory**

**Prepared for**
**U.S. Nuclear Regulatory Commission**
**U.S. Department of Energy**
**Electric Power Research Institute**

NUREG/CR-6372 (1997)

U.S.NRC
United States Nuclear Regulatory Commission
*Protecting People and the Environment*

NUREG-2117, Rev. 1

**Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies**

Office of Nuclear Regulatory Research

NUREG-2117 (2012)

# 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

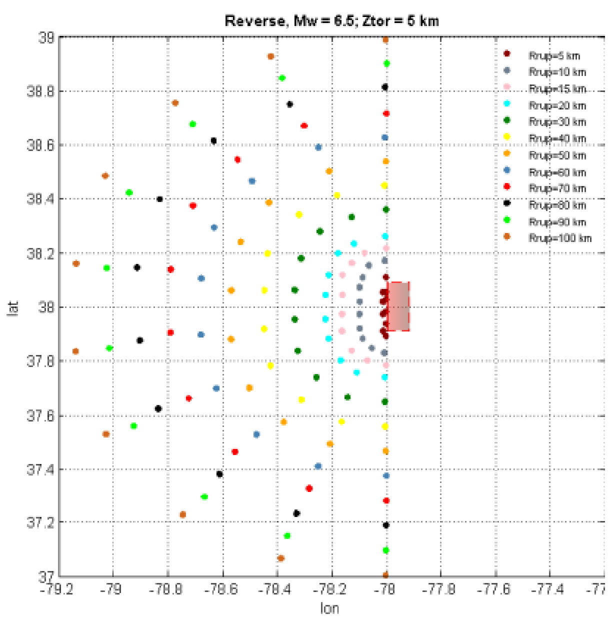
# NGA-east GMC

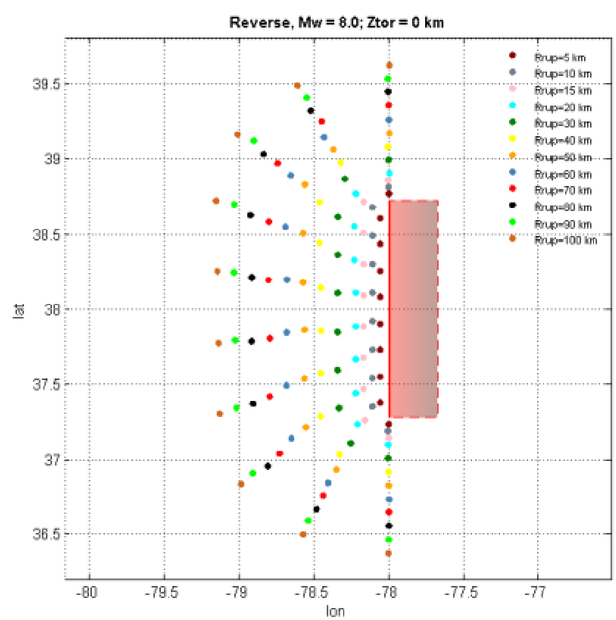
Reverse with a dip of 45°
and an average rake of 90°

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 |

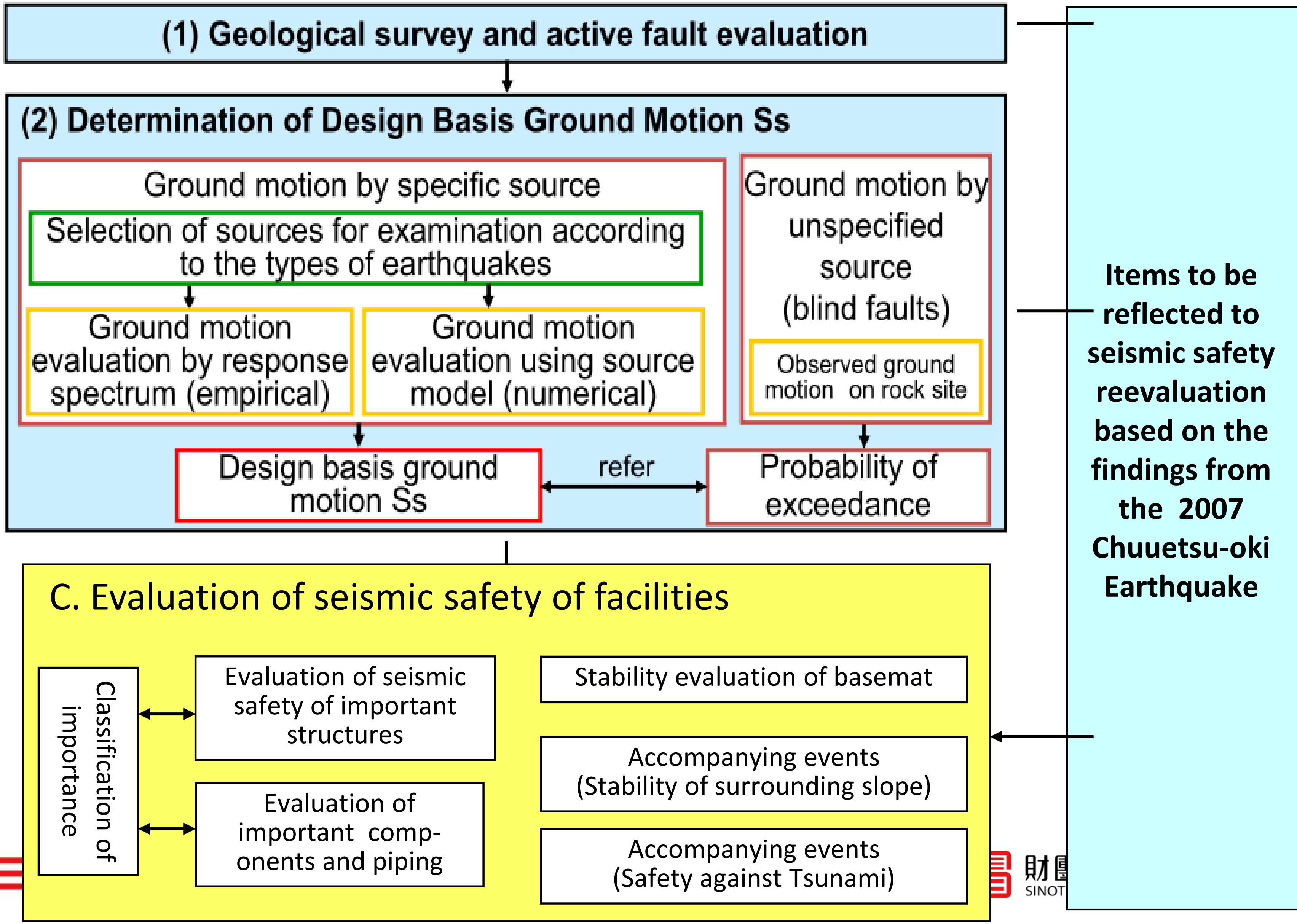


# Japan – Regular guide

| 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" |

# Flow of Seismic Reevaluation
# According to New Seismic Regulatory Guide



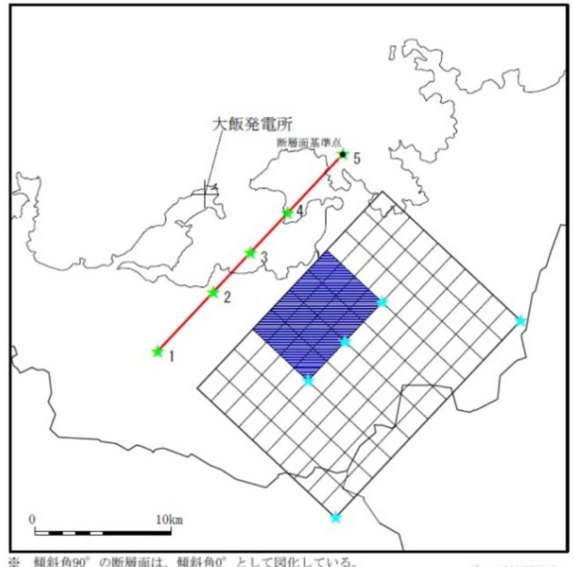
# Oi nuclear power plant

Seismic Reevaluation
According to New Seismic
Regulatory Guide

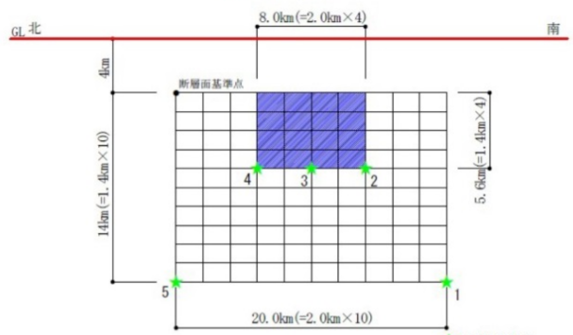
(1) Fault survey

**(2) Evaluation of design basis ground motion**

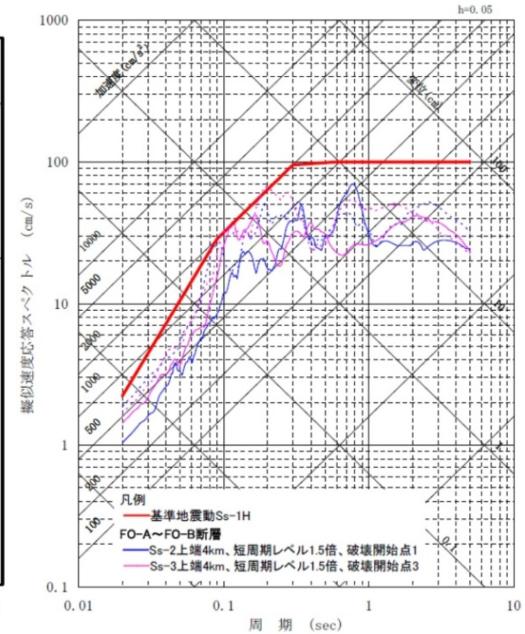
(3) Evaluation of seismic safety of facilities

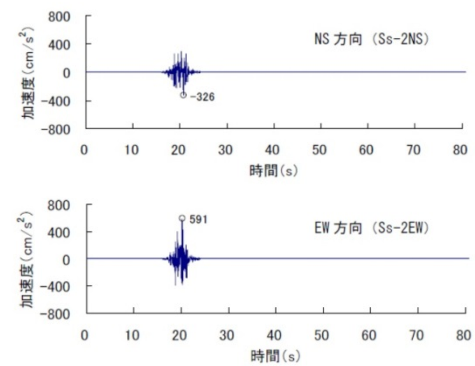



i）断層配置図




ii）断面図



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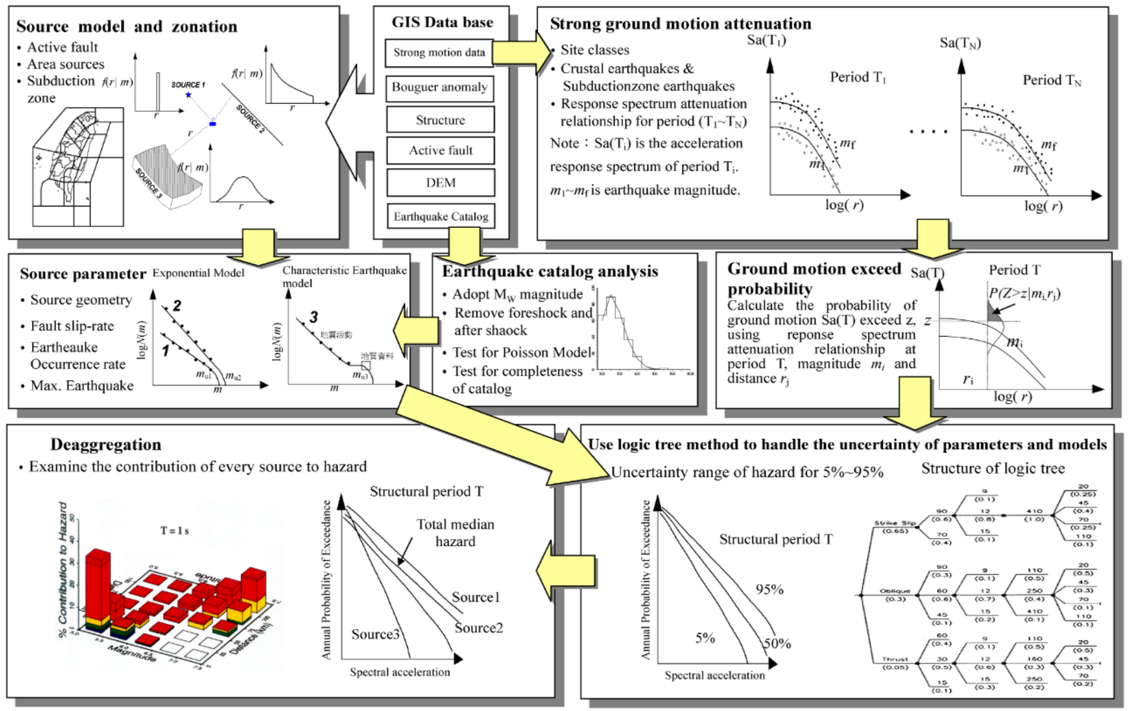
SINOTECH ENGINEERING CONSULTANTS, INC.

# 「Reevaluation of Probabilistic Seismic Hazard of Nuclear Facilities in Taiwan Using SSHAC Level 3 Methodology」

**Taiwan Power Company**

**National Center for Research on Earthquake Engineering, NCREE**

**Sinotech** Engineerng Consultants, Inc.

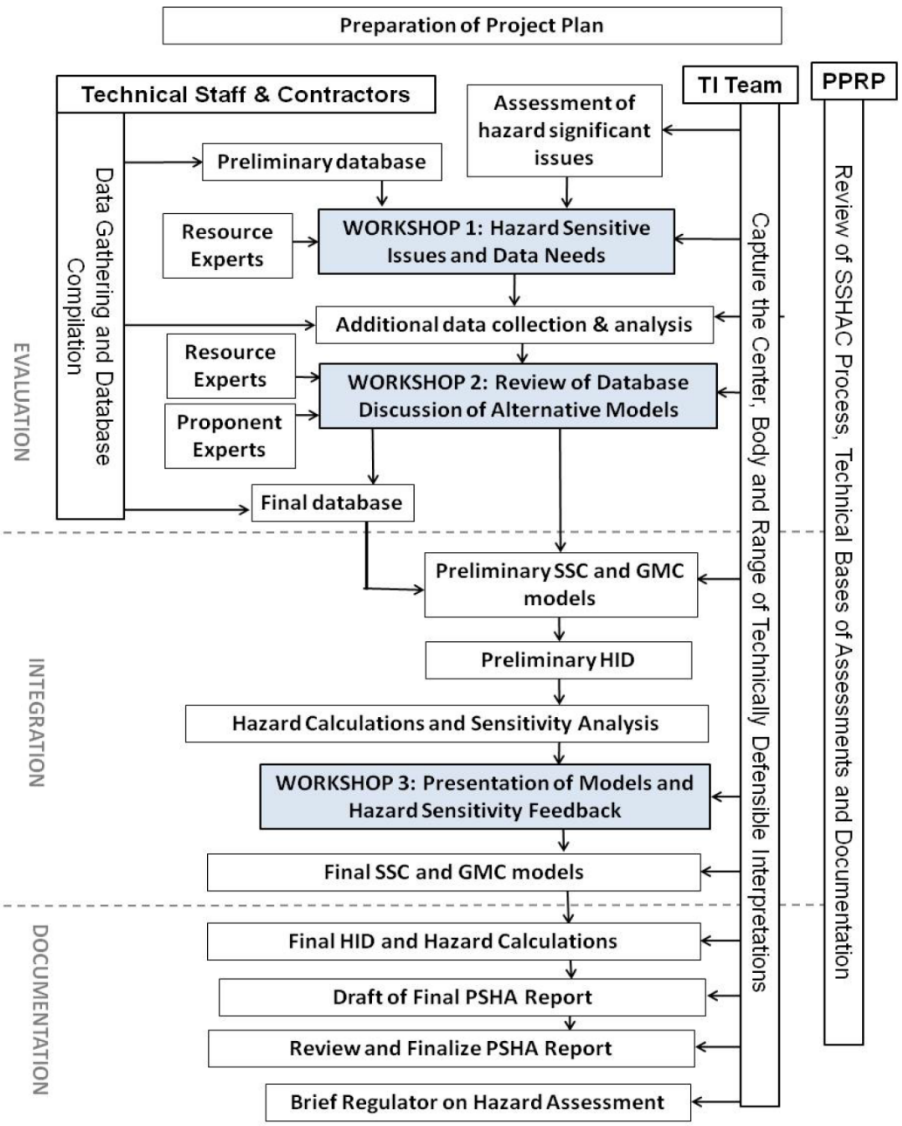



The objective of this study is to develop SSC and GMC models that capture the center, body and range (CBR) of the technically defensible interpretations (TDI) with SSHAC Level 3 methodology as described in NUREG 2117 (NRC, 2012) for use in PSHA for the study sites.

To complete the Hazard Input Document, HID for Probabilistic Seismic Hazard Analysis and the development of Ground Motion Response Spectrum (GMRS).

201508 – 2018 ~

# SSHAC Level 3 Procedure




- Two working groups: **SSC** & **GMC**
  - **SSC**: seismic source characterization
  - **GMC**: ground motion characterization
- Procedure
  - Evaluation
    - Hazard significant issues
    - Data gathering and databases compilation
  - Integration
    - Preliminary SSC and GMC models
    - Hazard sensitivity analysis
  - Documentation
- Review of SSHAC process, technical bases of assessments and documentation by **Participatory Peer Review Panel (PPRP)**

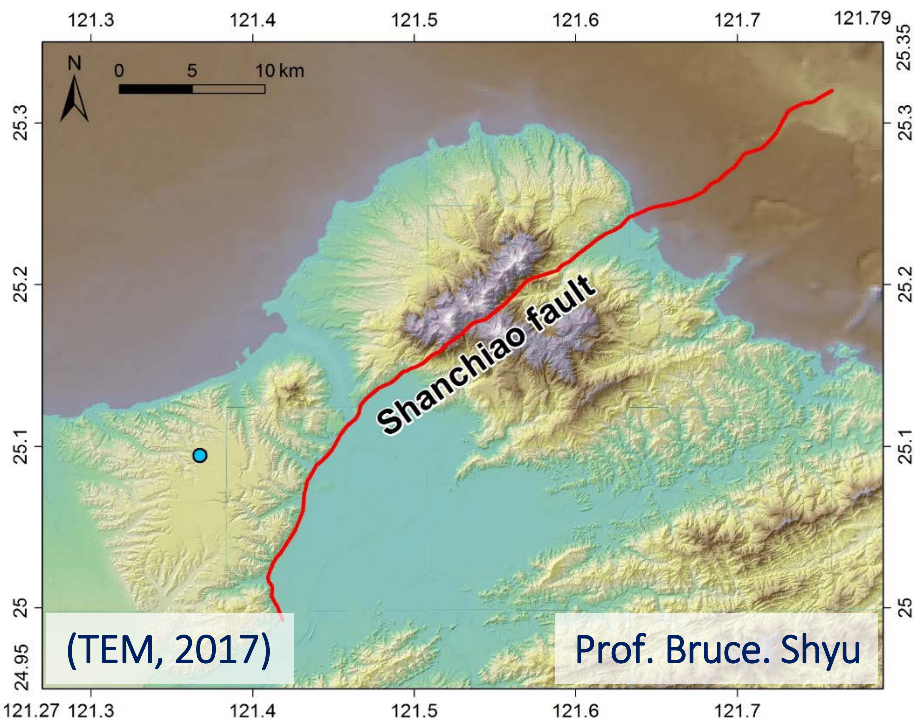
**http://sshac.ncree.org.tw**

財團法人中興工程顧問社 SINOTECH ENGINEERING CONSULTANTS, INC.

# Listric Fault in Northern Taiwan

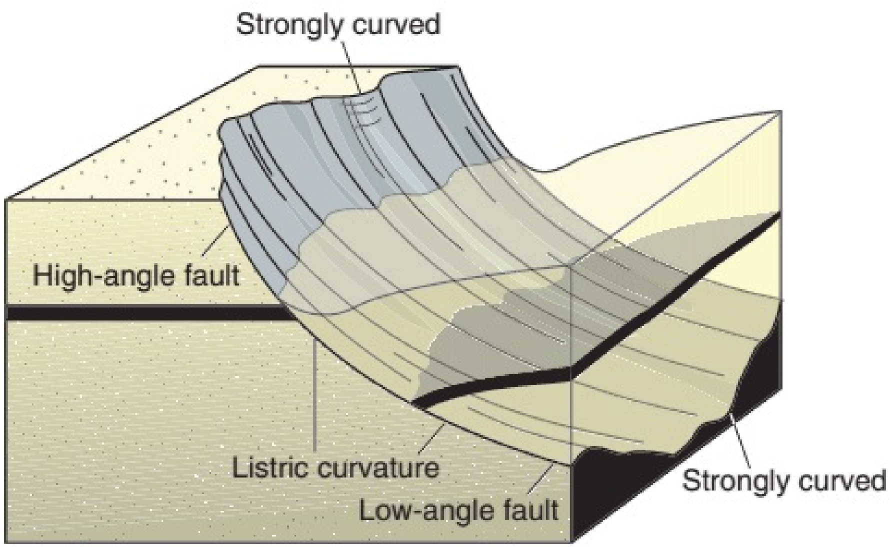
SSC Issue: branching & complexity in fault geometry of the Shachiao fault (listric fault)

GMC Issue: ground motion estimation from the Shanchiao fault at the target sites




Surface Trace of the Shanchiao Fault in Northern Taiwan

from **The Geo Models**
https://geomodelsvt.wordpress.com/2018/03/15/pulling-apart

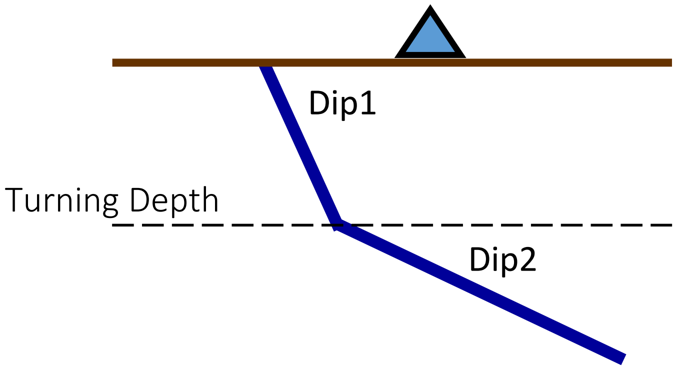


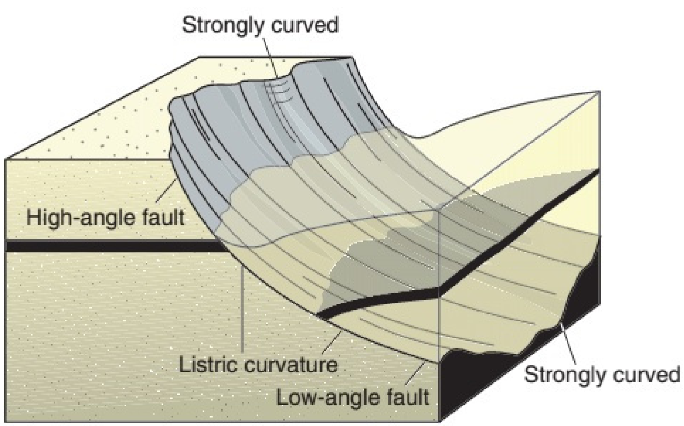

Shape of Listric Fault

# Application of GMPE to Listric Fault

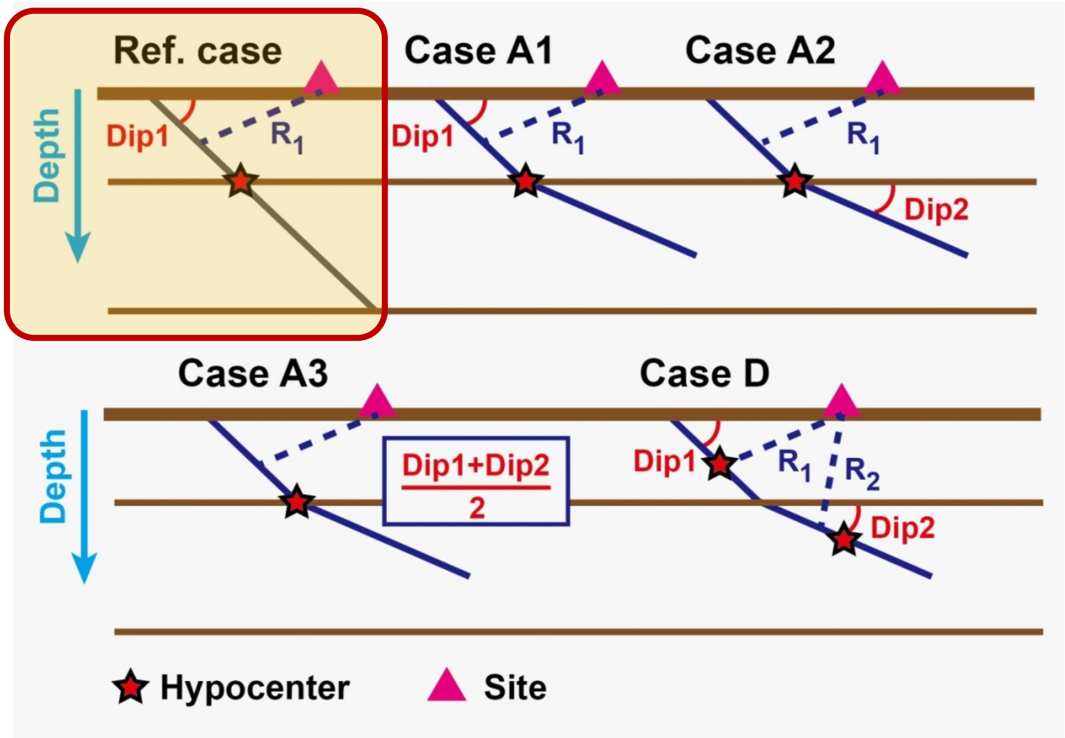
How can we input a proper DIPPING ANGLE to GMPE for predicting GM?

## Simplification of Listric Fault



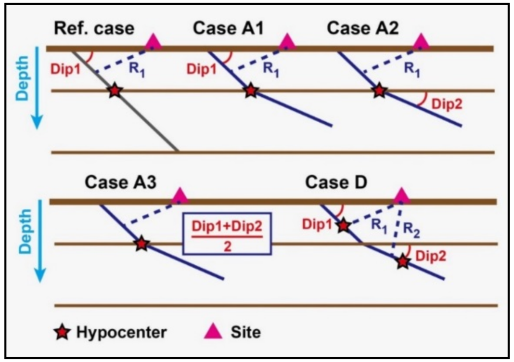




## Possible Inputs of Dipping Angle to GMPE

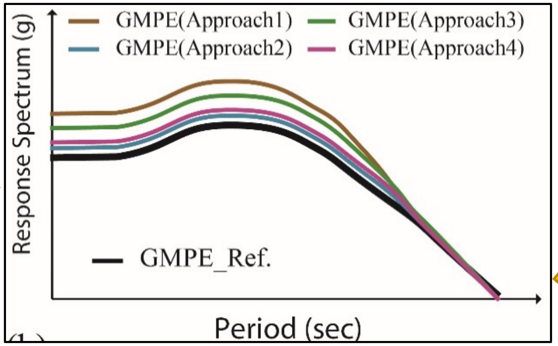


# The idea for the Ground Motion Simulation of Listric Fault

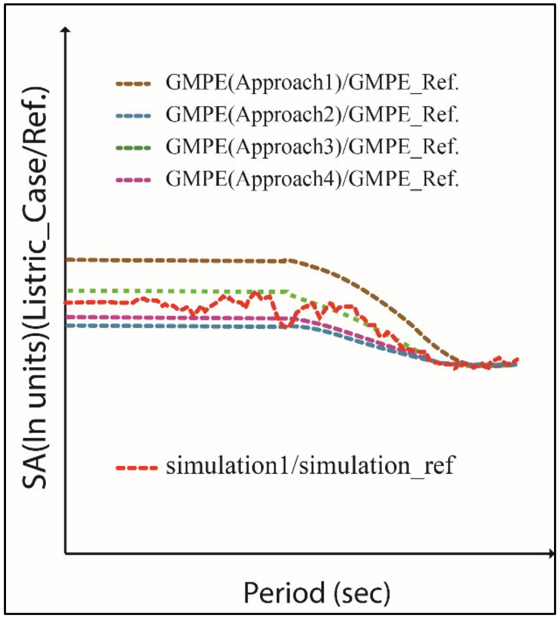
Approaches of Dipping Angle to GMPE

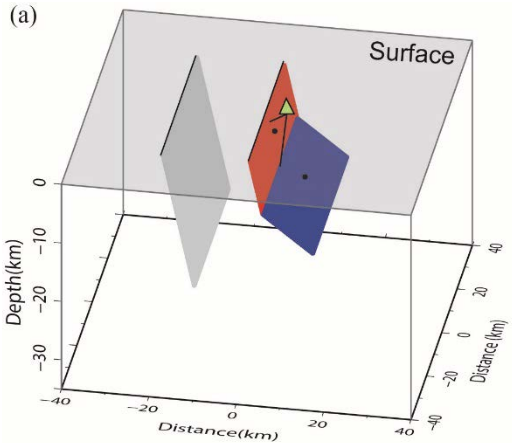


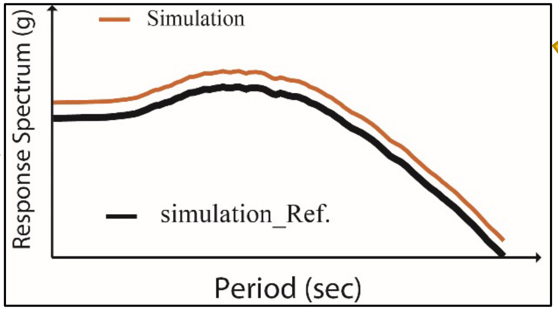

GM Estimation by GMPE




Comparisons of Spectral Acceleration Ratio at Each Period



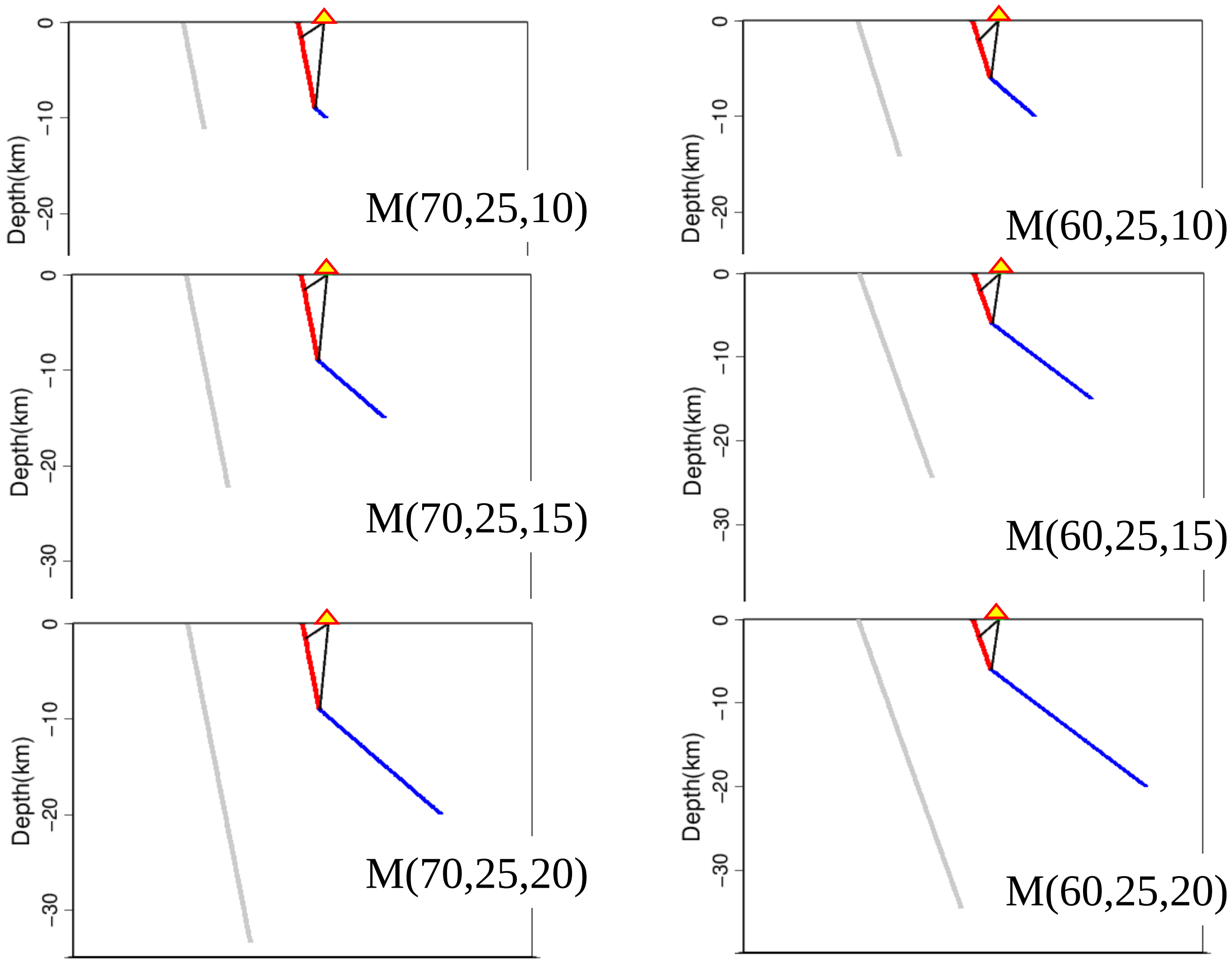



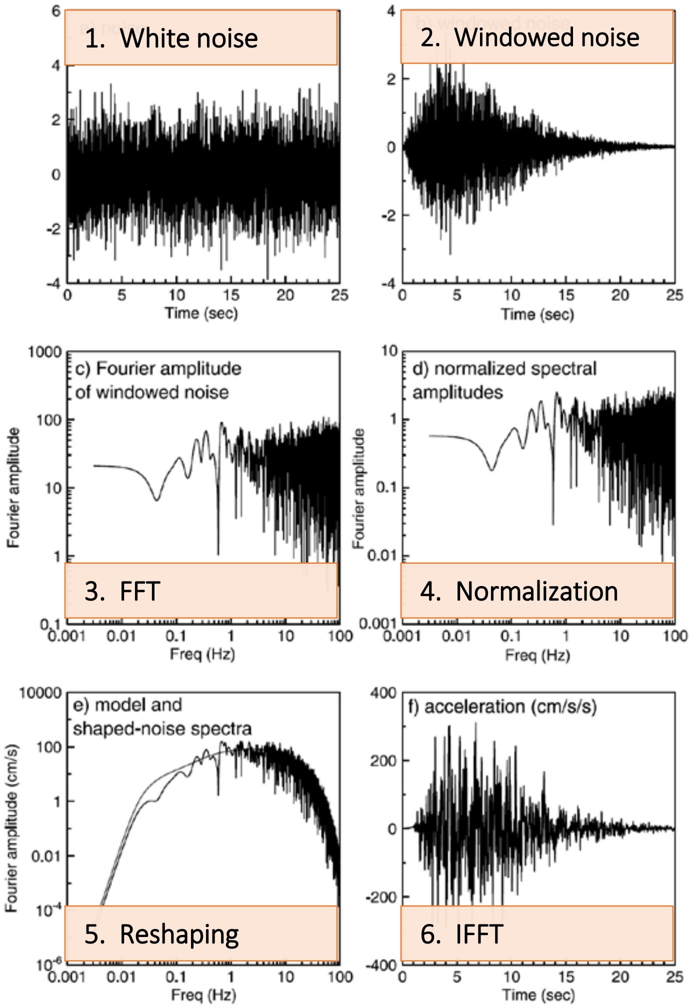

GM Estimation by Simulation

Settings of GM Simulation
(Resulting GMs are treated as REALISTIC GMs)

# Simulation Model defined - M(Dip1, Dip2, Depth$_{seis}$)



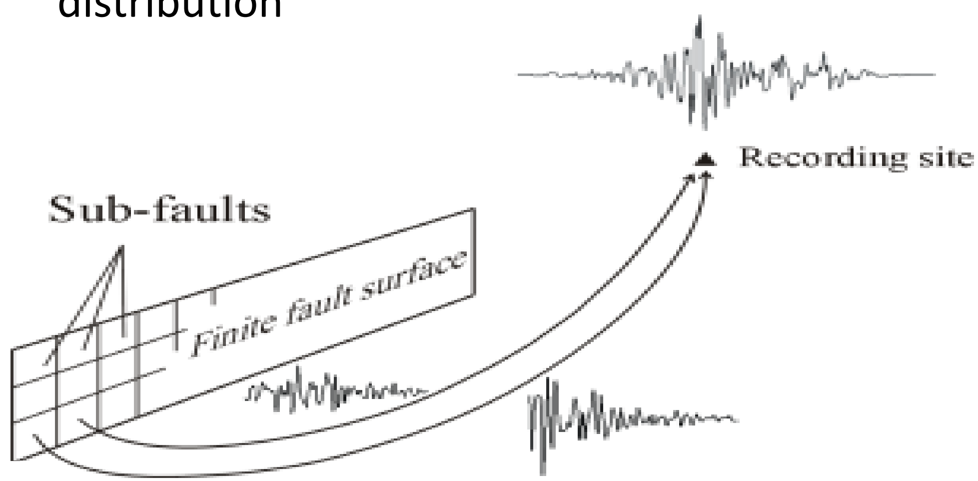
# Ground Motion Simulation Using EXSIM




Point-Source Synthetic

## Modeling of finite-fault effect using EXSIM

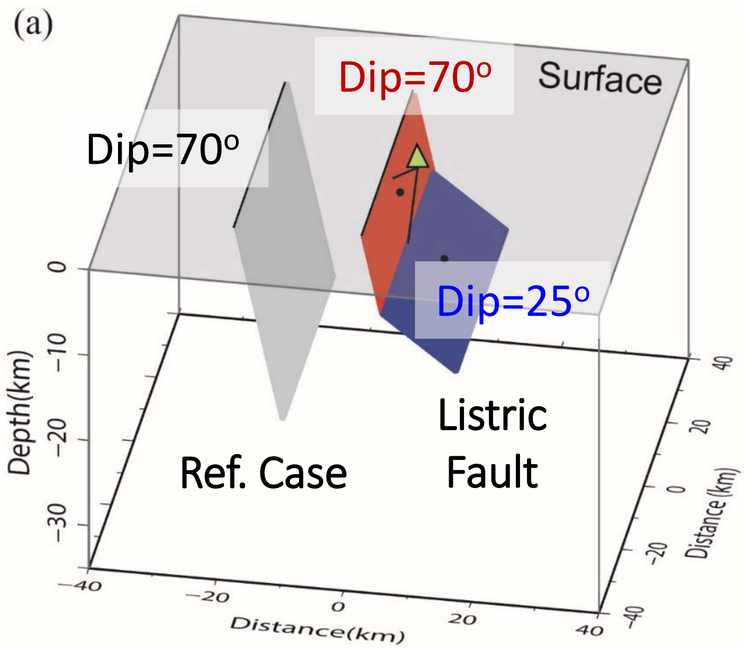
- Each subfault is considered as a point source
- Energy release of each subfault is triggered by rupture front (=rupture delay time)
- Seismic waveforms at a specific station is obtained by summing responses of all subfaults in time domain
- Accounting for GM variations by randomizing slip distribution



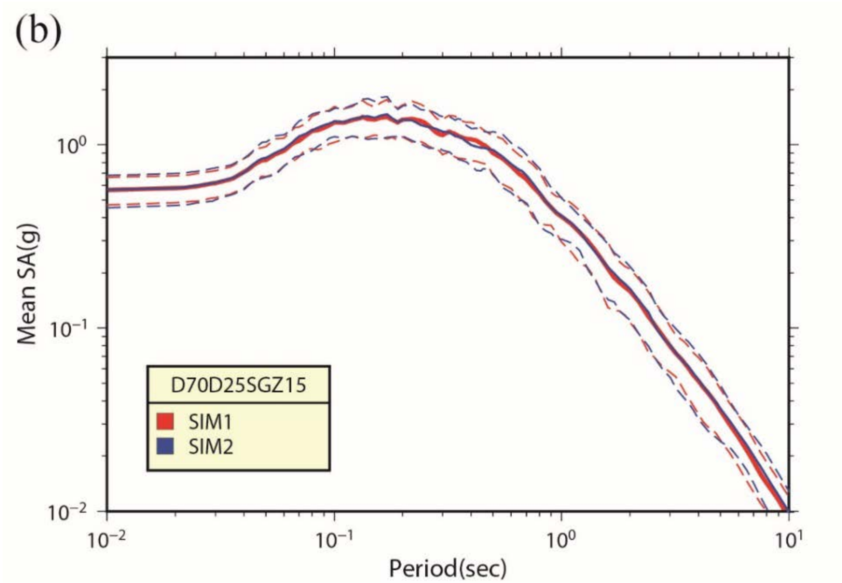

Finite-Fault Synthetic

# Ground Motion Simulation of Listric Fault

- Preserved total moment of two segments is same as reference case
- Hypocenter is located at the center of each plane
  - **SIM1**: rupture propagates from the **shallow** to the **deep** segment (30 simulations)
  - **SIM2**: rupture propagates from the **deep** to the **shallow** segment (30 simulations)
- Mean response spectra (SA) are averaged from all simulated spectra

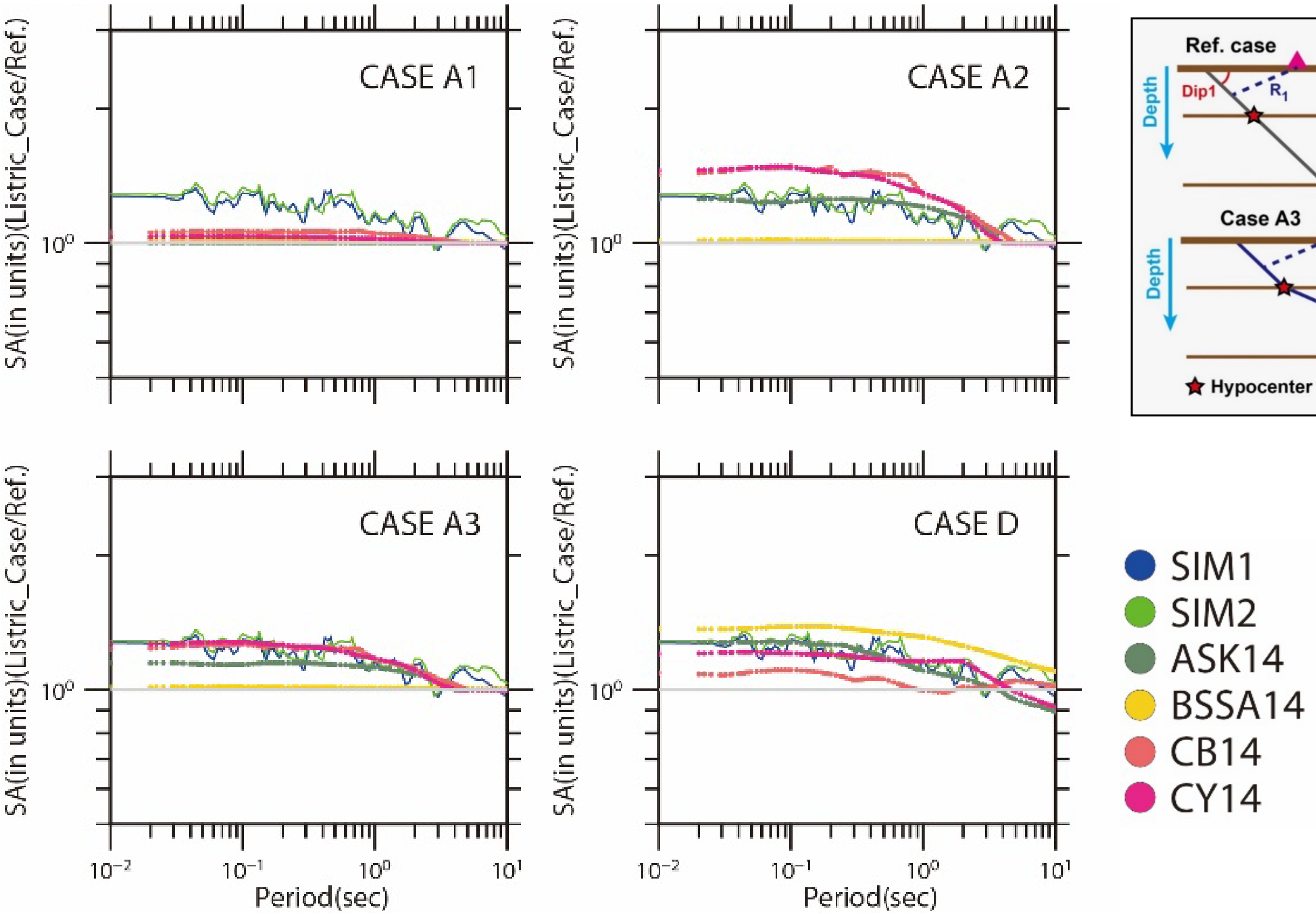


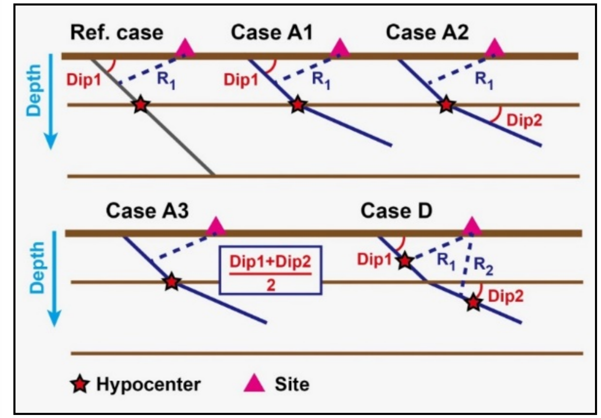

Schematic Plot of the Ref. Case & the Listric Fault Case




Simulated Spectral Acceleration Response Spectra & mean spectra

# Ground Motion Simulation of Listric Fault



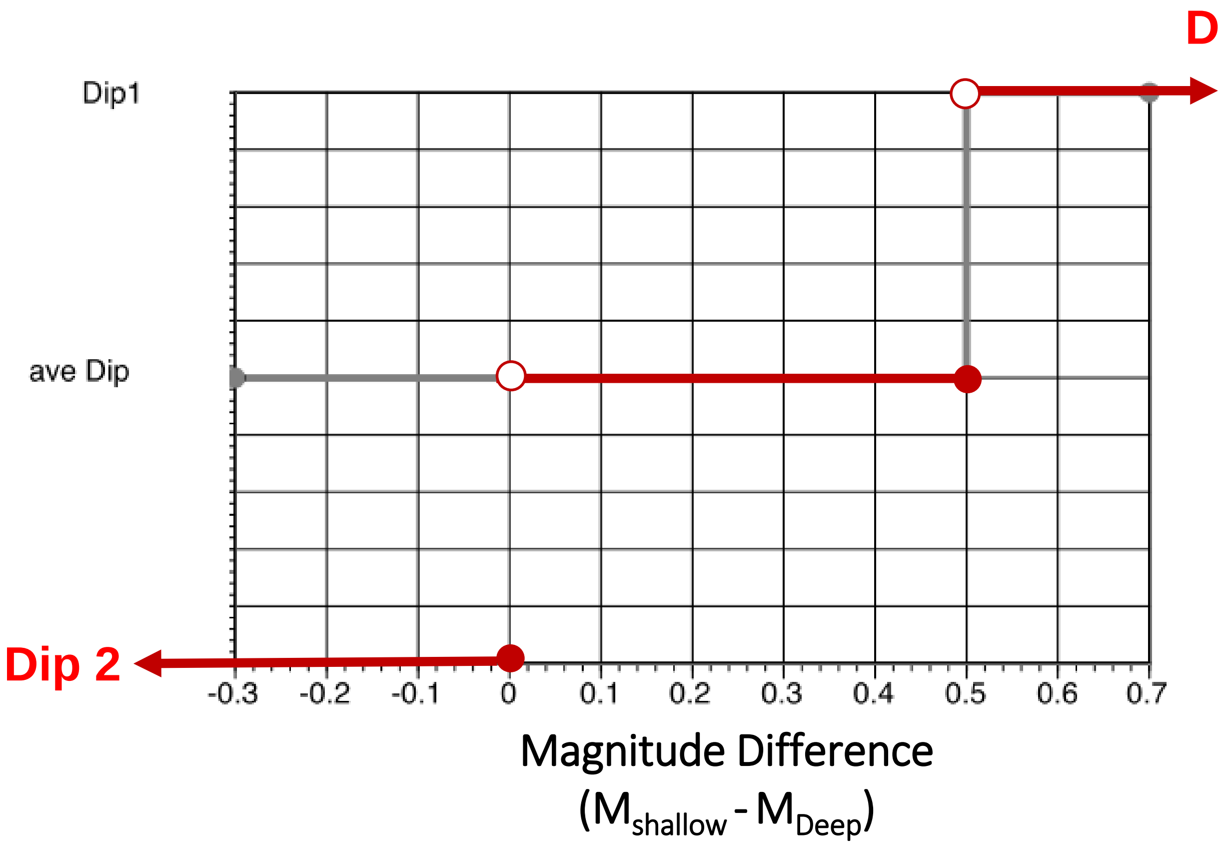




M(70,25,15)

**Comparisons of Spectral Acceleration Ratio at Each Period**

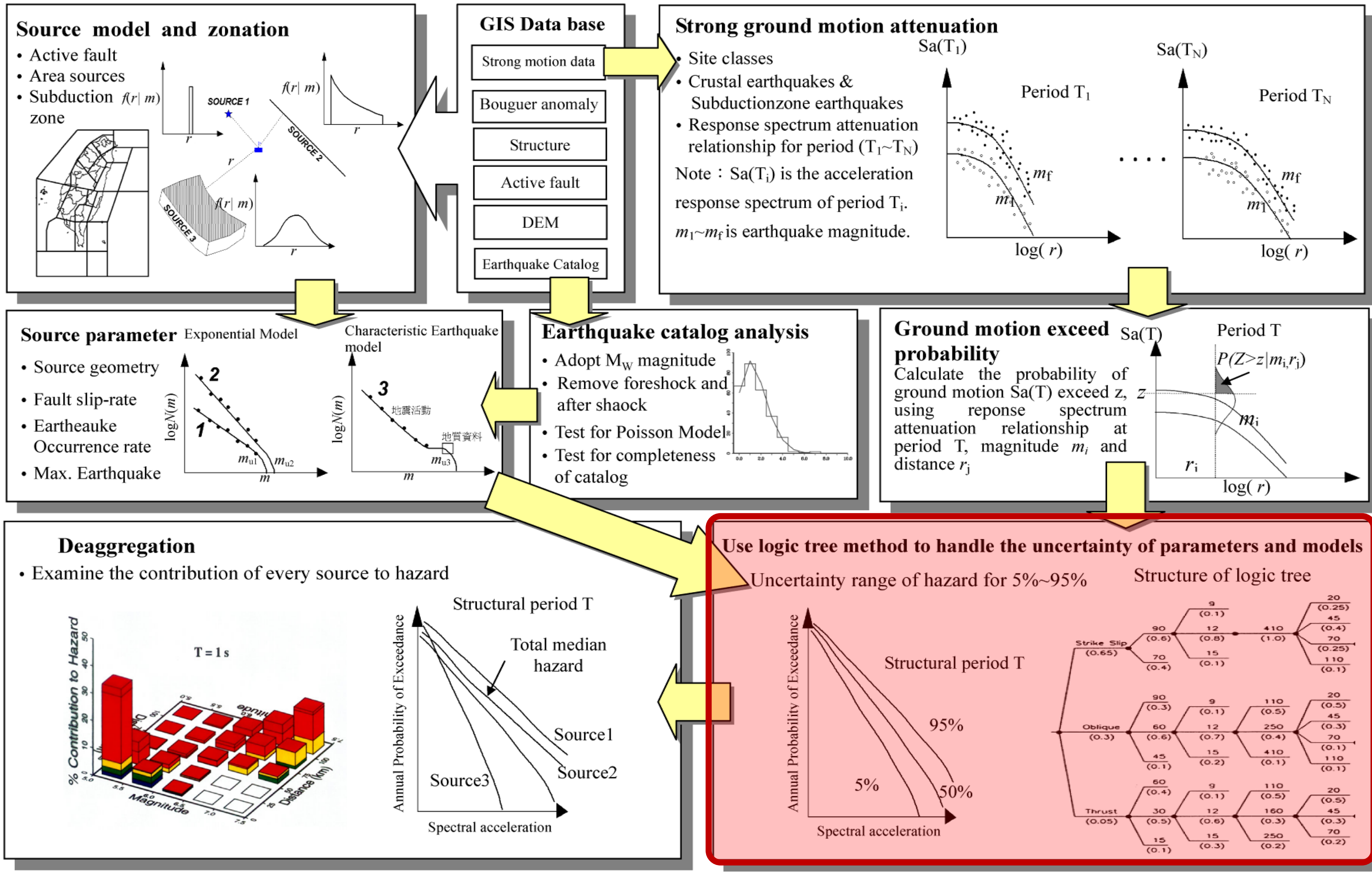
# A suggestion model to Listric Fault

Then we can choose a proper input of DIP ANGLE to GMPE for predicting GM & even hazard calculation!




**GMPEs**

**lnY (…, dip,…..)**


Source model and zonation
• Active fault
• Area sources
• Subduction zone
f(r| m)
SOURCE 1
SOURCE 2
SOURCE 3
r
GIS Data base
Strong motion data
Bouguer anomaly
Structure
Active fault
DEM
Earthquake Catalog
Strong ground motion attenuation
• Site classes
• Crustal earthquakes & Subductionzone earthquakes
• Response spectrum attenuation relationship for period (T1~TN)
Note：Sa(Ti) is the acceleration response spectrum of period Ti.
m1~mf is earthquake magnitude.
Sa(T1)
Period T1
Sa(TN)
Period TN
log( r)
Source parameter
• Source geometry
• Fault slip-rate
• Eartheauke Occurrence rate
• Max. Earthquake
Exponential Model
Characteristic Earthquake model
logN(m)
m
地震活動
地質資料
Earthquake catalog analysis
• Adopt MW magnitude
• Remove foreshock and after shaock
• Test for Poisson Model
• Test for completeness of catalog
Ground motion exceed probability
Calculate the probability of ground motion Sa(T) exceed z, using reponse spectrum attenuation relationship at period T, magnitude mi and distance rj
Sa(T)
Period T
P(Z>z|mi,rj)
log( r)
Deaggregation
• Examine the contribution of every source to hazard
T = 1 s
% Contribution to Hazard
Magnitude
Distance (km)
Structural period T
Total median hazard
Source1
Source2
Source3
Annual Probability of Exceedance
Spectral acceleration
Use logic tree method to handle the uncertainty of parameters and models
Uncertainty range of hazard for 5%~95%
Structure of logic tree
Structural period T
95%
50%
5%
Strike Slip (0.65)
Oblique (0.3)
Thrust (0.05)

# 「A scenario earthquake on the Shanchiao fault」

# A pilot project on the Shanchiao Fault

- Central Disaster Prevention and Response Council, Executive Yuan
- **Combine「scenario simulation」、「loss estimation」、「response plan」**

科技部
Ministry of Science and Technology

# Strong Motion Simulation for the Shanchiao fault

**Fault parameters**
**（length、strike and dip angle、segmentation etc.）**

↓

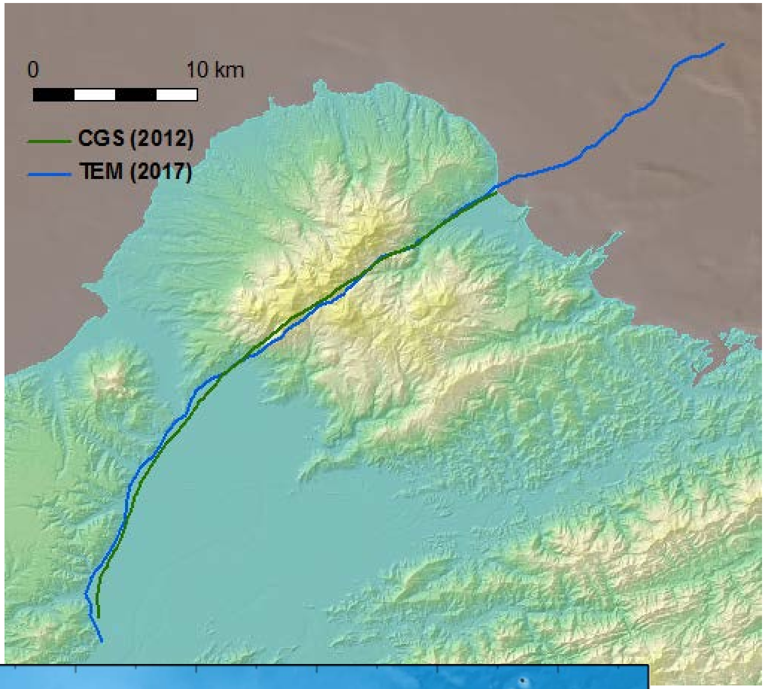
**Scaling relation of source parameters**

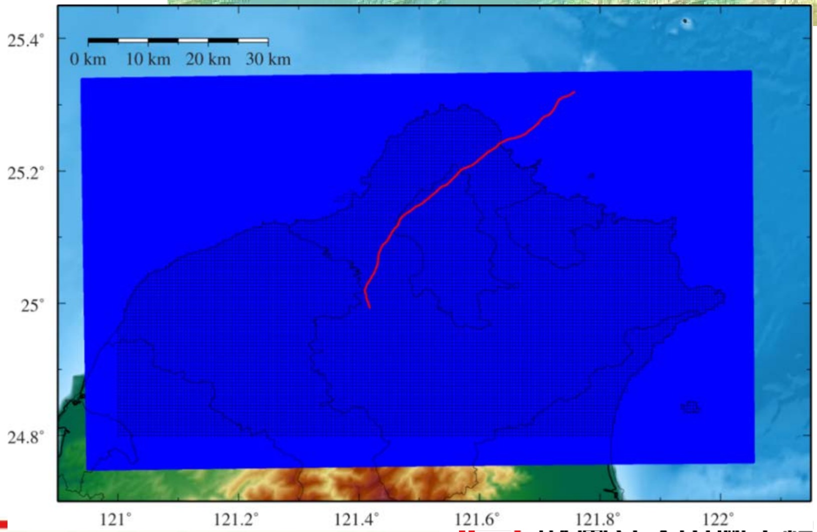
↓

**Characterized source model**

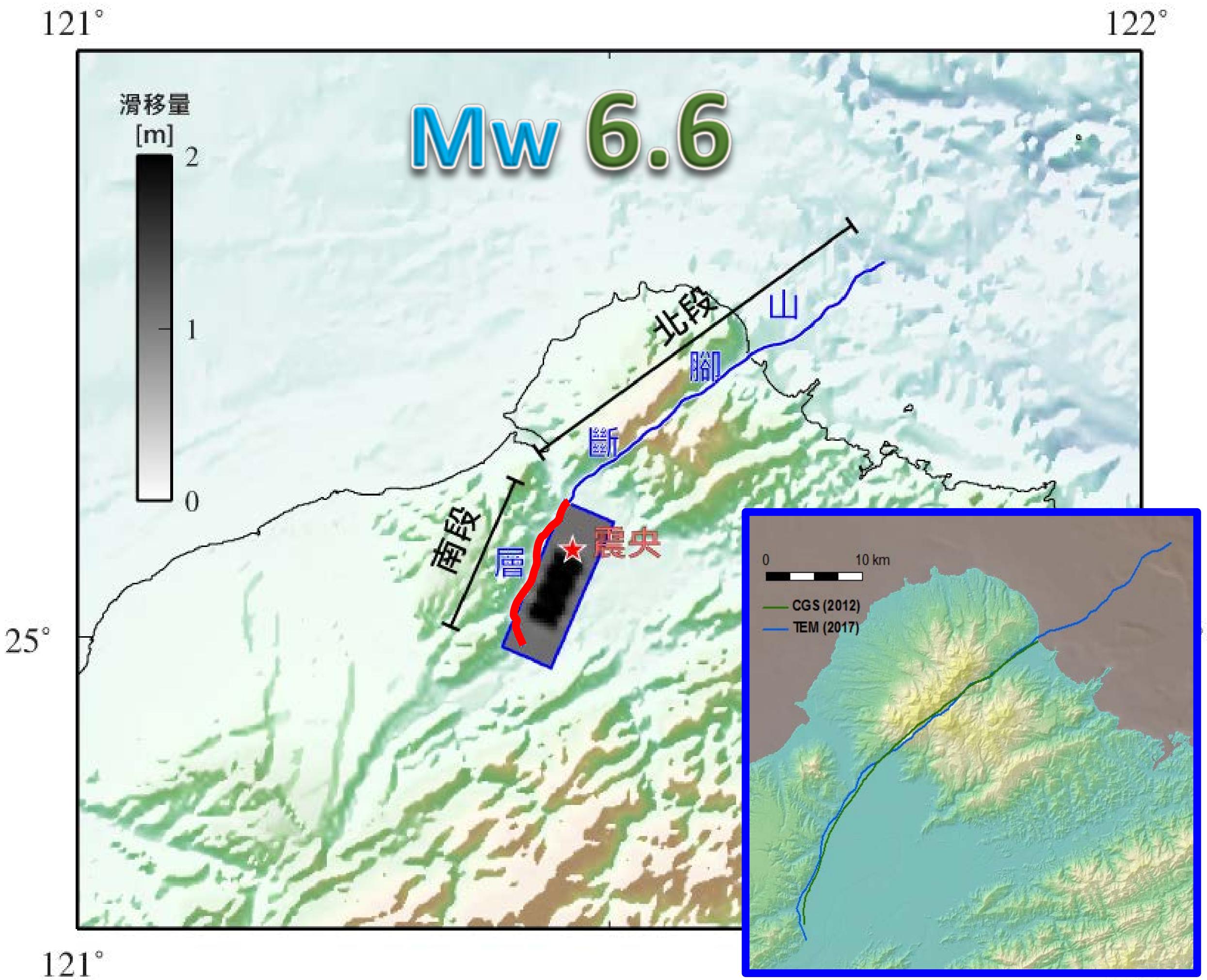
↓

**Scenario Shaking Map**



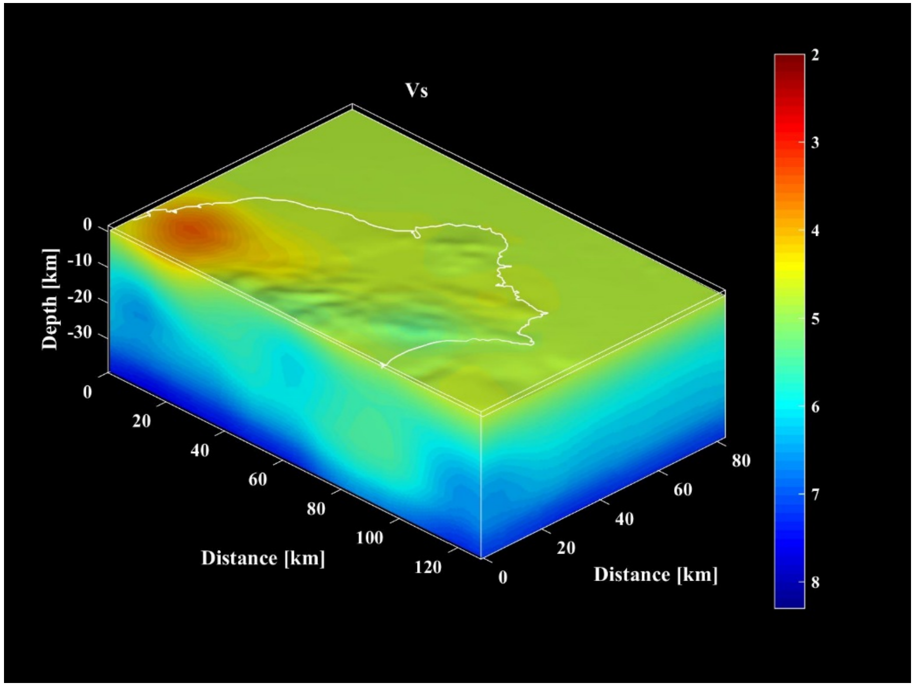
# Scenario earthquake – south segment



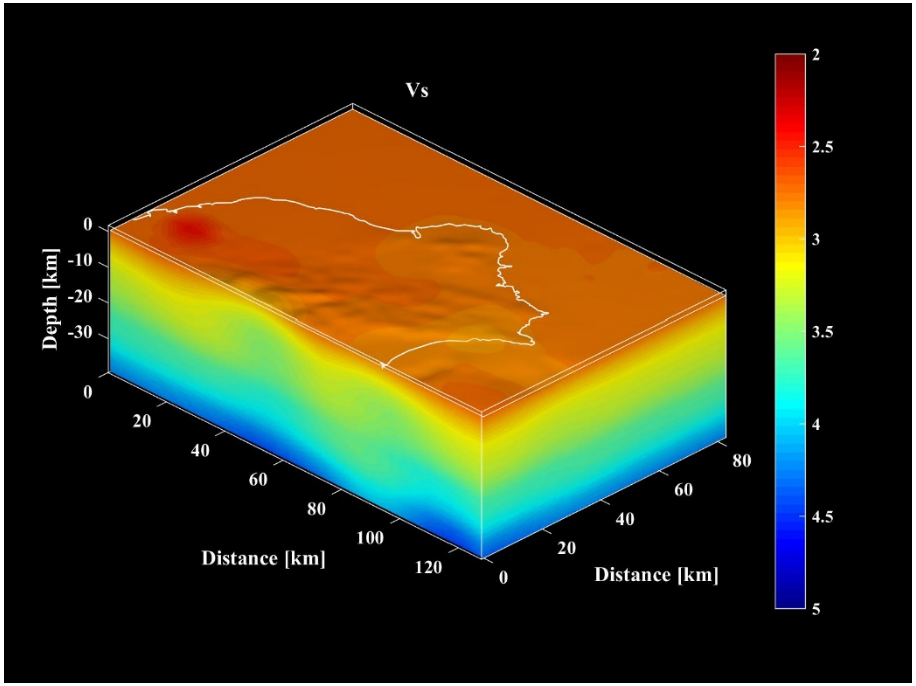

- Taipei metropolitan
- Seismogenic structure from Taiwan Earthquake Model
- Executable case, not a extreme case

# Scenario earthquake – south segment

- Velocity Structure (Kuo-Chen *et al.*, 2012) and Topography Model
- High Performance Computing, HPC




Vp

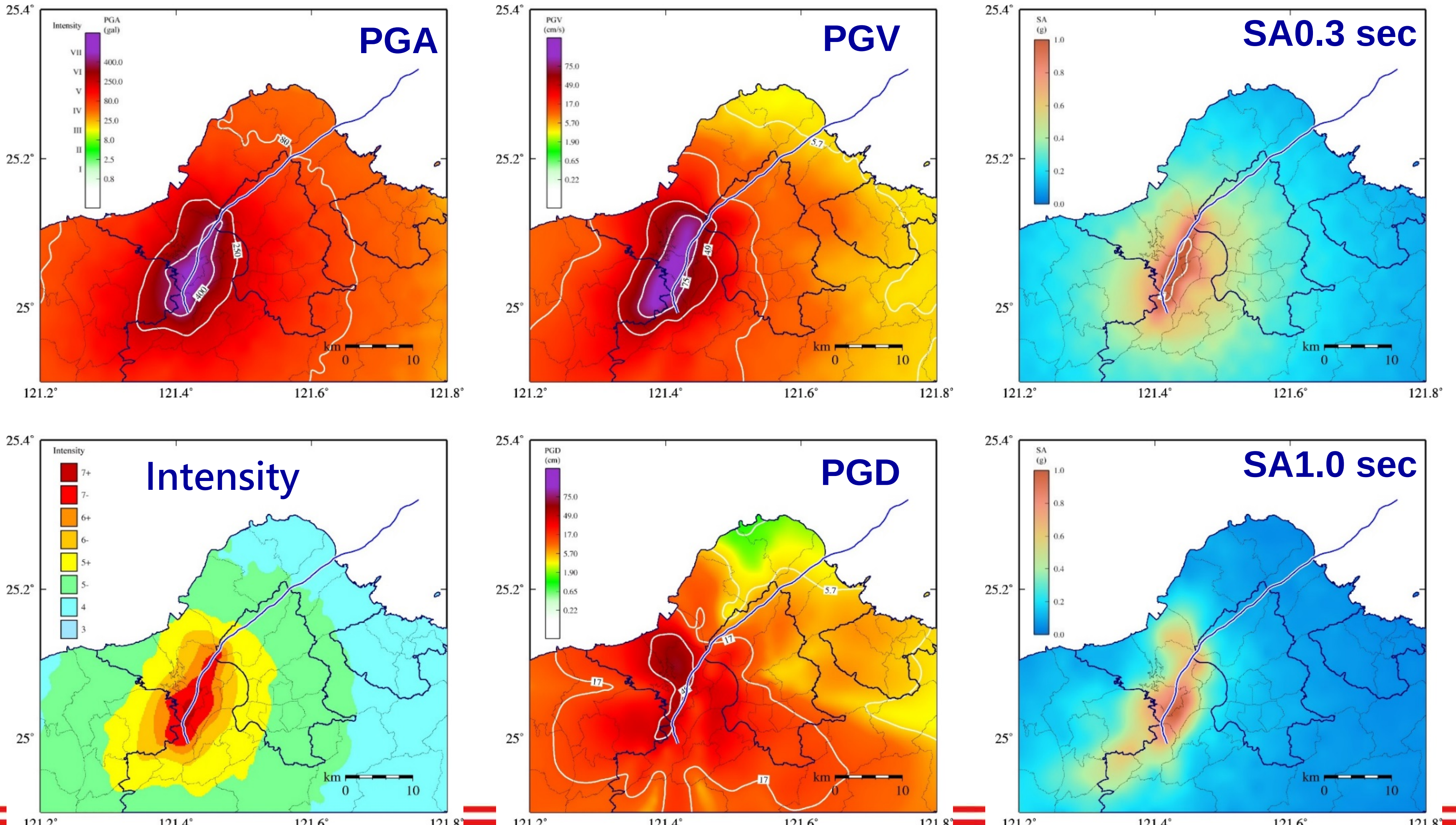



Vs

# An animation of ground motions for Shanchiao Fault

# Parameters for loss estimation

**Bedrock (Vs = 760 m/s)**



# Loss Estimation

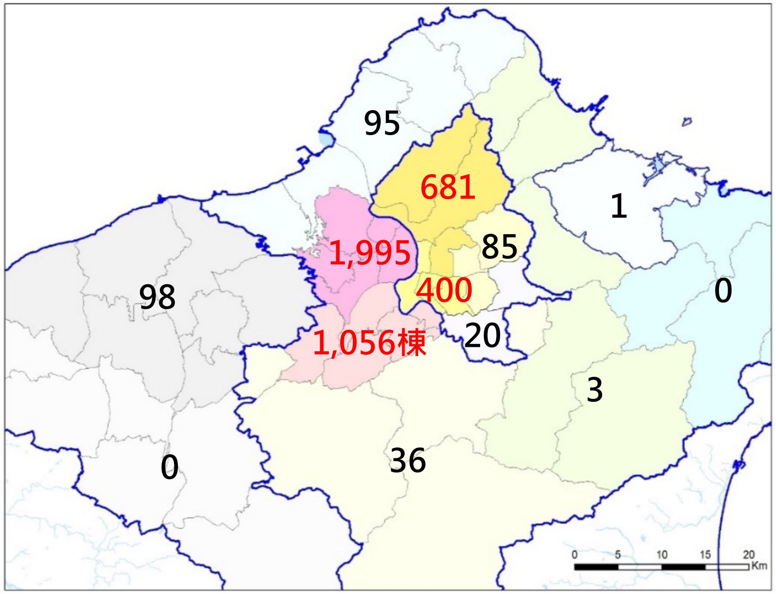
## National Center for Research on Earthquake Engineering (NCREE)

(Taiwan Earthquake Loss Estimation System, TELES)

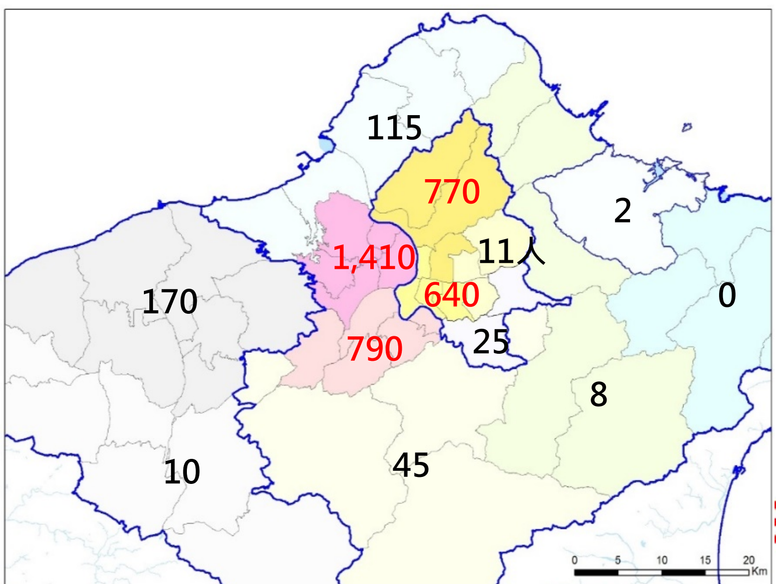
## National Science and Technology Center for Disaster Reduction (NCDR)

(Taiwan Earthquake impact Research and Information Application platform, TERIA)

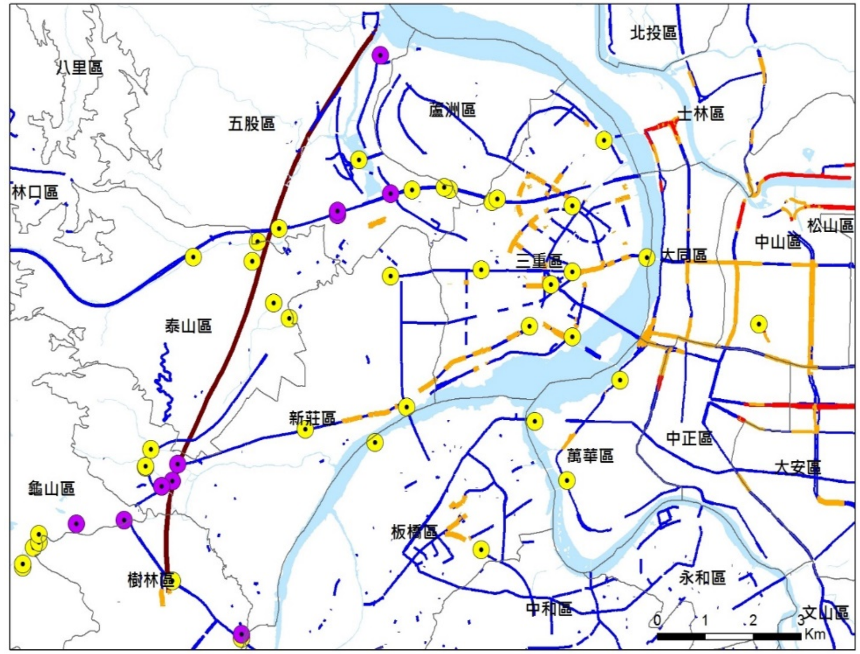
# Building damage




# Casualties




# Road and Bridge damage




Emergency Rescue Road (width > 20 m)

**Risk of road closure**

**Medium**

**High**

**Risk of bridge closure**

**Medium**

**High**

## Water & Power supply

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# Response Plan

## National Fire agency, Ministry of the interior

Earthquake drills conducted around Taipei on National Disaster Prevention Day (2018/09/21)

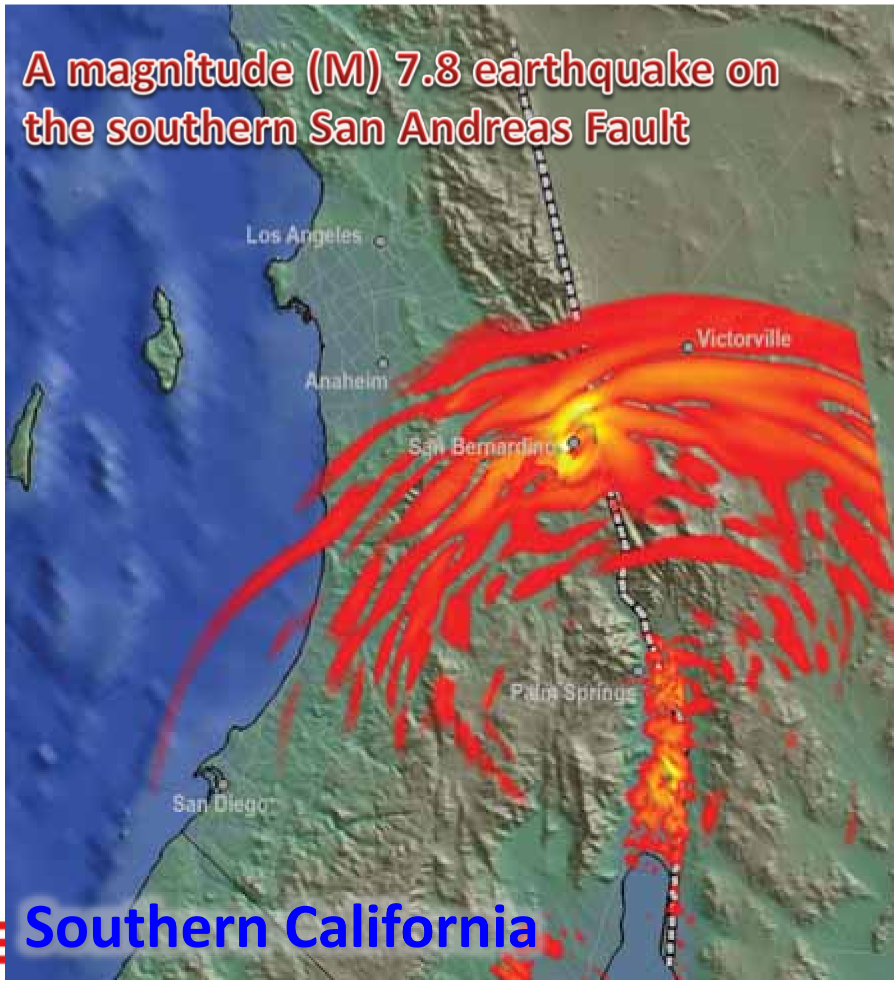
# Key items

| Building damage | Casualties | Evacuation | Lifelines |
| --- | --- | --- | --- |
| • Retrofit<br>• Building Damage Inspection<br>• continuity management of school<br>• continuity management of government<br>• Insurance payment | • Rapid damage assessment<br>• Search and rescue<br>• Emergency medical care<br>• The provision of emergency shelter for victims | • safe evacuation space<br>• shelters(operating, dispatch, arrangement…)<br>• Volunteer management<br>• public order | • electricity and water supply<br>• electricity and water backup |

**Preparedness – Emergency response -Recovery**

# ShakeOut Earthquake Scenario (2008)

**Earth Science:** Design earthquake → **Engineering:** Estimate physical damage → **Social Science:** Estimate impact on social systems → **Policy:** Actions that could reduce losses




**Earth Science in the ShakeOut**

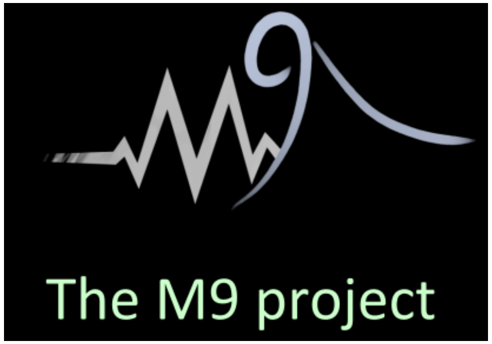
- Scenario
- The EarthquakeSource
- Ground Motions
- Fault Offsets
- Secondary Hazards
- Aftershocks

**Engineering in the ShakeOut Scenario**

- Buildings
- Non-structural and contents damage
- Utilities, Lifelines, and Infrastructure
- Fire Following Earthquake

**Social Science in the ShakeOut Scenario**

- Emergency Services
- Mortality and Morbidity
- Business Interruption
- Movement of Goods


- Tradition is a single idealized scenario for an M9 earthquake.
- We'll make multiple realizations for a scenario, framed probabilistically.
- Engineering, Social, Behavioral, and Economic, Sciences.

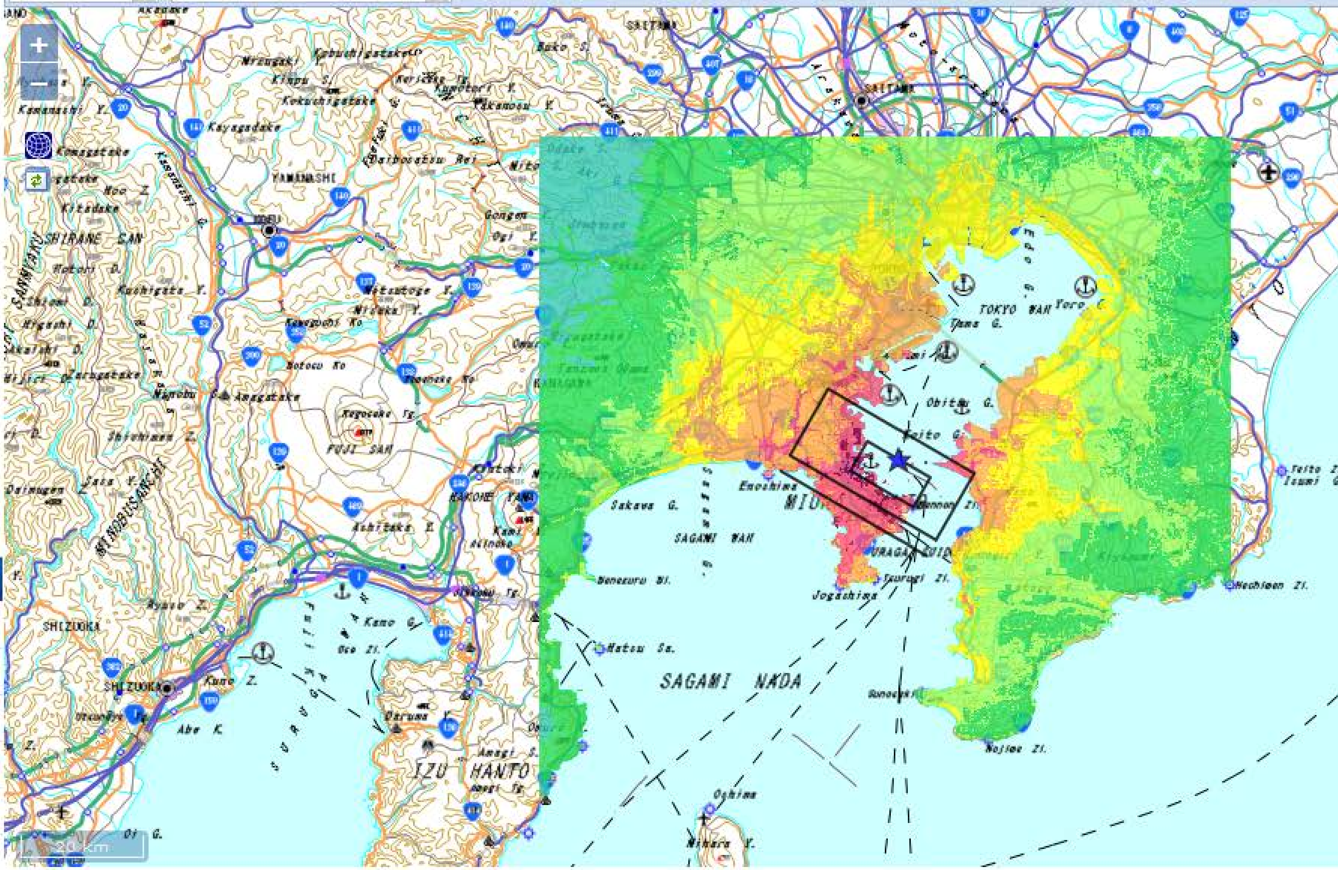
[>>>J-SHIS Japan Seismic Hazard Information]

▸ Japanese NIED

# Tokyo area

PSHM | Averaged Hazard | PSHM by EQ Cat. | CPE | **SESM** | Site Amp. | Subsurface Structure | Exposed Pop.

CASE1 | IJMA



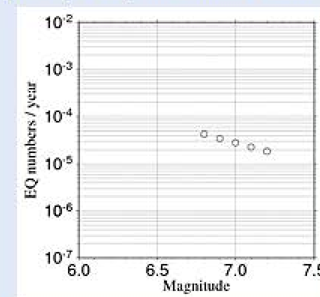

Seismic Activity Model -Average Case-,2017

[Miura-hanto fault group (Main part/Kinugasa /Kitatake fault zone)]

| | |
|---|---|
| Magnitude | 6.7(Mw) |
| Probabilistic Model | BPT |
| Mean Recurrence Interval[Years] | 3400.0 |
| The Latest Event[Years ago] | 1417.0 |
| Probability of Occurrence in 30 years[%] | 0.01 |
| Probability of Occurrence in 50 years[%] | 0.01 |

[Fault Parameter] [Display 3D faults]

EarthQuakes whose Traces are Hardly Recognized (EQTHR) from surface evidences




Close

Only [ ] Major Active Fault Zones are selectable in SESM

3 or under | 4 | 5 Lower | 5 Upper | 6 Lower | 6 Upper | 7 (IJMA)

**三浦半島断層群主部 Miura Peninsula Faults(main part)**

衣笠・北武断層帯 **Kinugasa/Kitatake fault Zone**

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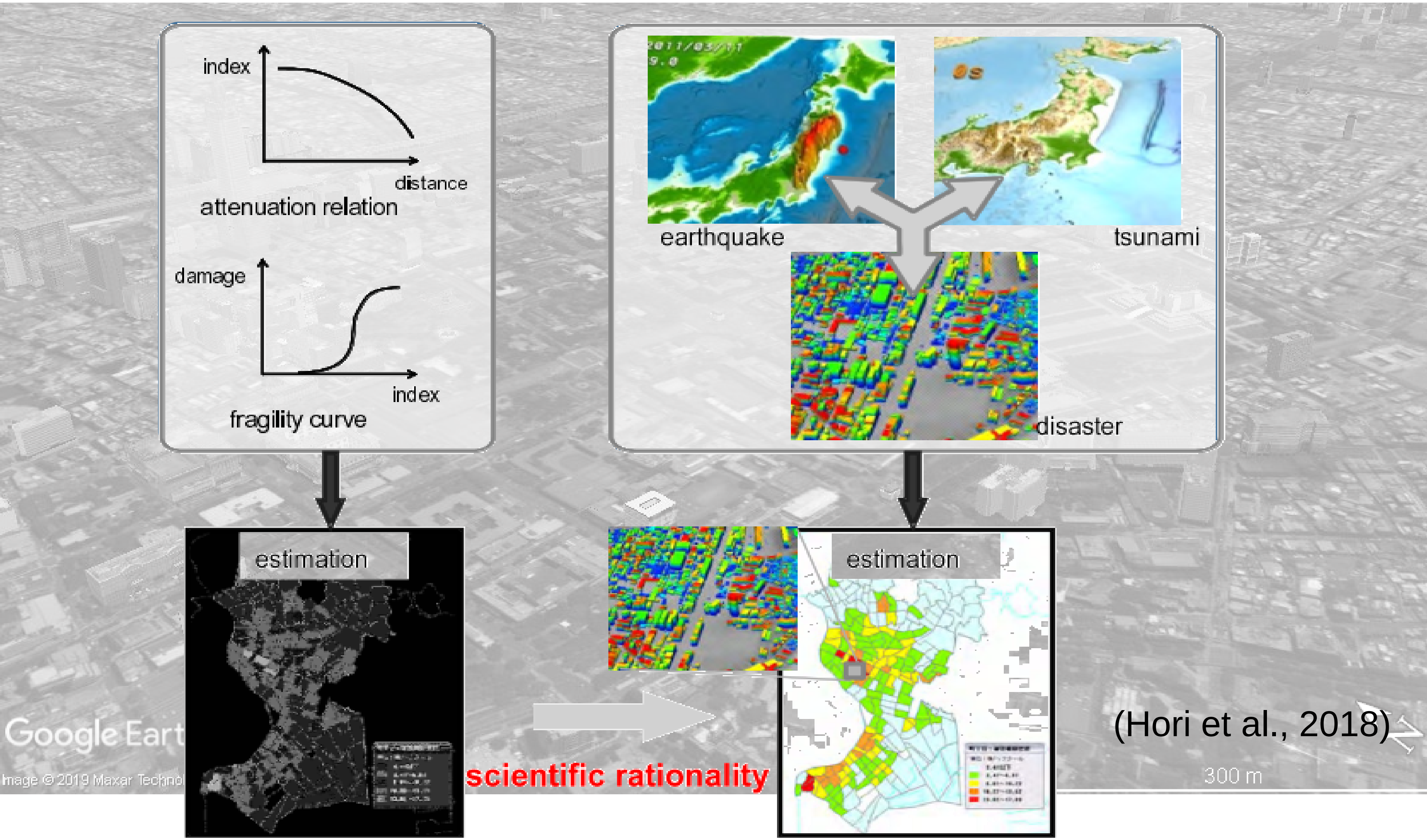
**CURRENT**
**empirical**

**FUTURE**
**simulation**



# Earthquake Disaster Simulation of Civil Infrastructures

(Lu and Guan, 2017)

# Needs for use of ground motion simulations for engineering application

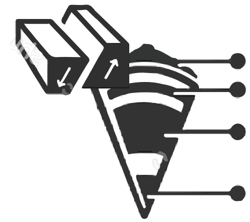
- **Validation :** Quantitative evaluation of the accuracy of the simulation methods
- **Robustness :** Similar results using different simulation methods
- **Transparency :** Someone other than the author can run the simulation
- **Reproducible Results :** Fixed versions of simulation software that are readily available
- **Easy operation for professional experts :** Efficiency and universality in practical applications

(Extended from Abrahamson in the 15th WCEE, 2012)

# What else ?

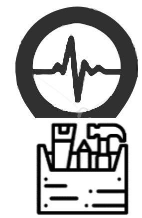
- **Model development**

  - Fault, Site and Path



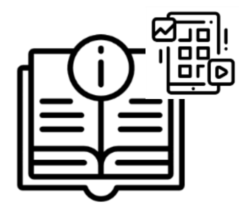
- **Combination of methods**

  **-** Efficient and Systematic



- **Speculation or Regular guide**

  **-** A standard to be followed



# Summary

- Ground motion simulation can be a powerfully alternative way to help to figure out what trend of ground motion and variation pattern.
- Scenario earthquake simulation for future events is helpful for revealing shaking level and for hazard mitigation and prepareness.
- Ground motion simulation will play an creative role in engineering application in the future.

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# Thank you for your attention

Q&A

Thanks all coworkers and collaborators involved

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