The integration of Ground-Motion Prediction Equations and Ground Motion Simulations

Y.T. Yen, M.C. Hsieh, P.S. Lin

Disaster Prevention Technology Research Center, Sinotech Engineering Consultants, Inc., Taipei, Taiwan
Flowchart of Probability Seismic Hazard Analysis

**Flowchart:**

1. **Source**
   - Active faults
   - Area sources
   - Subduction sources

2. **Recurrence**
   - Earthquake occurrence rate
   - Max. Earthquake
   - Earthquake catalog analysis

3. **Ground Motion**
   - Site class
   - Crustal & Subduction
   - Period of response acceleration

4. **Hazard**
   - Total median hazard
   - Contribution of every source to hazard

**Notes:**
- $f(r|m)$: Probability density function of distance and magnitude
- $r$: distance
- $m$: magnitude
- $T$: period
- $Sa(T)$: Acceleration response factor

**Legend:**
- 1. Exponential Model
- 2. Characteristic Model
- 3. Number of quakes vs. magnitude
- Contribution Hazard
- Structural Period $T = 1.0$ sec
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
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
Significant concern: lack of observed seismic data
Application of the GMPEs to Listric Fault

What the basic condition is the similar ground motion level from GMPEs and Simulations for the Ref. case.

A scheme of listric fault

Dip: 70°/25°

Approach setting
Introduction of the EXSIM method

Extended to finite-fault model:

• Subfaults are considered as point sources
• Rupture front arrival excites subfaults
• Time series of subfaults are properly delayed and summed in time domain
• Random slip model as a realization
Fault geometry and parameters setting

- Hypocenter is located at the center of each plane (two rupture types)
- Preserved total moment of two segments is same as reference case

M1 (75, 25)  M2 (60, 20)
Ground motion character of the listric fault

- SIM1: propagation from shallow to deep
- SIM2: propagation from deep to shallow
- Mean spectra are considered from 30 realizations

M1 (75, 25)
Sketch for comparison between Response spectra of simulation and GMPE

Variables are only the dipping angles of a lystirc fault.
Simulation Model defined - $M(\text{Dip}_1, \text{Dip}_2, \text{Depth}_{\text{seis}})$

- $M(70,25,10)$
- $M(70,25,15)$
- $M(70,25,20)$
- $M(60,25,10)$
- $M(60,25,15)$
- $M(60,25,20)$
## Input parameters of four GMPEs

### Four GMPEs used in the base case of HCT

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ASK14</th>
<th>BSSA14</th>
<th>CB14</th>
<th>CY14</th>
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<tbody>
<tr>
<td>Magnitude</td>
<td>M_w</td>
<td>M_w</td>
<td>M_w</td>
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<tr>
<td>Top of Rupture (km)</td>
<td>Z_{tor}</td>
<td>-</td>
<td>Z_{tor}</td>
<td>Z_{tor}</td>
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<tr>
<td>Style of faulting</td>
<td>F_{RV,F_{NM},SS}</td>
<td>U, F_{RV,F_{NM},SS}</td>
<td>F_{RV,F_{NM},SS}</td>
<td>F_{RV,F_{NM},SS}</td>
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<td>Dip (deg)</td>
<td>Dip</td>
<td>-</td>
<td>Dip</td>
<td>-</td>
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<tr>
<td>Down-dip rupture width (km)</td>
<td>W</td>
<td>-</td>
<td>W</td>
<td>-</td>
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<td>Closest distance to rupture (km)</td>
<td>R_{rup}</td>
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<tr>
<td>Hor. dist. to surface proj. (km)</td>
<td>R_{JB}</td>
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<td>Hor. dist. from edge of rupture (km)</td>
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<td>-</td>
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<td>R_{x}</td>
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<tr>
<td>Hor. dist. off end of rupture (km)</td>
<td>R_{y0}</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>Hanging wall model</td>
<td>F_{HW}</td>
<td>(R_{JB})</td>
<td>F_{HW}</td>
<td>F_{HW}</td>
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<td>V_{S30} (m/s)</td>
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<td>V_{S30}</td>
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<td>V_{S30} for reference rock (m/s)</td>
<td>1100</td>
<td>760</td>
<td>1100</td>
<td>1130</td>
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<tr>
<td>Depth to Vs (km)</td>
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<td>Z_{1.0} (dz_{1.0})</td>
<td>Z_{2.5}</td>
<td>Z_{1.0}</td>
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<td>Hypocentral depth (km)</td>
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<td>Z_{hyp}</td>
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<td>Directivity term</td>
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<td>-</td>
<td>(Z_{hyp})</td>
<td>DDPP</td>
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<td>Regional variations</td>
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<td>Aftershock factor</td>
<td>F_{AS}</td>
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M(70,25,15)
A suggestion model to Listric Fault

A scheme of listric fault

Dip: 70°/25°
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)
Conclusion

- Physics-based ground motion simulation is a powerfully alternative way to help to figure out what trend of ground motion.

- We have successfully carried out ground motion simulations to justify GMPEs for the uses of seismic hazard assessment:
  - Implementation of GMPEs in the case of listric-fault
  - Address reduction factor of the edge effect from off-end subduction-zone earthquakes in large magnitude

- Limitation of various simulation methods should be identified carefully for applying their results into evaluation of GMPEs.

- Further GMPE improvements, simulation techniques could consider for the directivity effect, fault geometry effect (hanging-wall and footwall), etc.
Thank you for your attention
Background

• The U.S. Actions Following Fukushima Daiichi Accident
  – The Nuclear Regulatory Commission (NRC) established the NTTF in response to the Fukushima Daiichi nuclear power plant accident.
  – The NTTF provided a series of recommendations which resulted in a 10 CFR 50.54(f) letter to all U.S. plants.

• The Post-Fukushima Implementations in Taiwan
  – The Atomic Energy Council (AEC) required Taiwan Power Company (TPC) should follow NTTF 2.1: Seismic to reevaluate seismic hazard and review the seismic design basis of nuclear facilities in Taiwan.

• TPC Launched “Seismic Reevaluation of Nuclear Facilities” Project to:
  – Develop Hazard Input Document for Taiwan using SSHAC Level 3 Methodology
  – Develop GMRS of Nuclear Facilities and Study Sites in Taiwan
SSHAC Processes - II

- Gather data and information from literature
- TI makes assessments including uncertainty
- TI confers with members of technical community to understand alternative viewpoints
- Workshops are held to discuss:
  - Significant issues and available data
  - Alternative hypotheses
  - Feedback and documentation
- Participatory peer review of process and technical
- TI team responsible for technical assessments
- Expert panel responsible for making technical assessments
- TFI facilitates expert interactions and aggregates expert assessments

(Coppersmith, 2012)
M(70,25,10)
M(70,25,20)