Actual practices of seismic strong motion estimation at NPP sites

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Japan Nuclear Energy Safety Organization (JNES)
Seismic Safety Division

- Nuclear Safety Commission (NSC) revised “Reviewing Guide for Seismic Design of NPP” (2006.9);
  - Require risk assessment due to over design earthquake: “Residual Risk assessment”

- Atomic Energy Society developed “Standard procedure for Seismic PSA on NPP” (2007.9)
  - Adopt “Source model prediction”

Niigata-Ken Chuets-Oki Earthquake (2007.7)

Kashiwazaki-Kariwa NPP safely shut downed, but lower seismic class facilities were damaged.
Flow of Seismic ground Motion Re-evaluation According to New Seismic Regulatory Guide

Geological survey of active faults

Design basis ground motion

A
Site specific ground motion from identified earthquake sources

A1
Attenuation Equation

A2
Fault source model

B
Ground motion from defuse seismicity

C
Recognition of exceedance

D
Residual risks

Best effort of define earthquake source is encouraged; nevertheless, undefined sources may still remain. It should be guaranteed with this category as defense in depth.

Deterministic approach is still preserved. Nevertheless, state of the art PSHA is encouraged to confirm plausibility.
Empirical response spectrum by attenuation equation

Earthquake motion at site can be evaluated by empirical method using available attenuation equation in the region.

- Empirical method is that response spectrum of the site is estimated based on the earthquake magnitude (M) and hypocentral distance (X).
- In case of empirical method, earthquake sauce is regarded as point sauce.
Synthesis of Time-series Waveform by Use of Fault Model

- Fault model is composed of 16 source parameters, and characterized with the source, path and site effects.

Macroscopic parameters
- Depth of upper fault edge
- Fault length (and linkage with neighboring faults)
- Strike and dip directions of the fault plane, etc.

Microscopic parameters
- Number of asperities
- Rupture initiation point
- Dislocation and stress drop on the asperity etc.

Evaluation site

Fault plane

Fault slide

Source characteristics; \( S_A(f) \)

Propagation characteristics; \( P_A(f) \)

Site amplification characteristics; \( G_A(f) \)

Seismic motion spectrum;

\[
F_A(f) = S_A(f) \cdot P_A(f) \cdot G_A(f)
\]

Asperity: Fault rupture is inhomogeneous. High energy was released from the asperity.

Evaluation of time-series waveforms using fault model
- Fault parameters: set by the IRIKURA’s recipe etc.
Features of the Methods Using Fault Model / Attenuation Relations

Synthesized motion by Fault model (Detailed modeling)

Attenuation relations (Conventional modeling)

Source characteristics:
- Fault area, location of asperity, stress drop, rupture process, directivity, etc.
Propagating characteristics:
- Utilizing observed small event records at a site

Site characteristics $G_A(f)$

Propagation characteristics $P_A(f)$

Source characteristics $S_A(f)$

Ground motion spectra $F_A(f) = S_A(f) \cdot P_A(f) \cdot G_A(f)$

Taking into account variability in each parameter

Calculated ground motions

Probabilistic distribution of peak ground motion

Mean

Uncertainty

PGA

[Attenuation relation]

$M$ : constant

Distribution of data

Taking into account deviation around average value (attenuation rel.)

$P.G.A. \text{ cm/s}^2$

Fault distance (km)

-300.0

0.0

300.0

NEW TOKAI CASE 02 NS

MAX = 291.88

NEW TOKAI CASE 02 EW

MAX = 247.45

Magnitude (M)

Fault distance (X)

$\cdots$
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Defuse seismicity

- Short active fault
  - Surface fault rupture length < Source fault length
  - Source fault length and width ≥ Seismogenic layer

- Long active fault
  - Surface fault rupture length ∝ Source fault length
  - Source fault length ≫ Seismogenic layer

- Potential Earthquake Fault
  - Source fault of inside of seismogenic layer

We have to consider the probable faults of upper edge up to the surface.

Relationship between Earthquake Size and the Appearance Rate of Surface Fault Rupture

- Earthquake size should be estimated in the diffuse seismicity. → Probability of the surface rupture increases with M and shallow asperity.
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Seismic hazard evaluation method

Seismic hazard is defined as the relationship between the intensity of seismic ground motion and the exceedance frequency / probability at a site.

**Specific seismic source**
- Active fault B

**Regional seismic source**
- Seismic zone C

**Specific seismic source**
- Interplate earthquake A

**Off shore**
- Magnitude: \( M_A \)
- Occurrence frequency: \( v_A \)

**Fault Model** is applied in PSHA

**Total hazard curve**

- Frequency / probability at corresponding to intensity of seismic ground motion \( v_{total}(GM > gm; 1\ yr) \)

**Recognition of exceedance**

**Intensity of earthquake ground motion**
- Ex) PGA, Sa(T), etc

**Exceedance Frequency (n/yr)**
- Probability

**Distance**
- \( R_A \)
- \( R_B \)
- \( R_Ci \)
- \( M_B \)
- \( M_{Ci} \)

**Fault Model is applied in PSHA**
Part of Logic Tree

**Specified Seismic Source**

<table>
<thead>
<tr>
<th>Coupling Scenario</th>
<th>Seismic source location</th>
<th>Magnitude: ( M_f )</th>
<th>Length: ( L(km) )</th>
<th>Dip (°)</th>
<th>Asperity location</th>
<th>Average interval of occurrence</th>
<th>Last event (occurrence model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kakuda-Yahiko</td>
<td>TEPCO fault model</td>
<td>( M: 7.7 (L=54km) )</td>
<td>West 50</td>
<td>Top</td>
<td></td>
<td>8600 years</td>
<td>Unknown (Poisson)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>West 35</td>
<td>Middle</td>
<td></td>
<td>1300 years</td>
<td></td>
</tr>
<tr>
<td>Kehinomiya</td>
<td>TEPCO fault model</td>
<td>( M: 7.1 (L=22km) )</td>
<td>West 50</td>
<td>Top</td>
<td></td>
<td>1200 years</td>
<td>808 years ago (BPT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>West 35</td>
<td>Middle</td>
<td></td>
<td>3700 years</td>
<td>404 years ago (BPT)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bottom</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Katagai</td>
<td>TEPCO fault model</td>
<td>( M: 6.8 (L=16km) )</td>
<td>West 50</td>
<td>Top</td>
<td></td>
<td>1100 years</td>
<td>Unknown (Poisson)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>West 35</td>
<td>Middle</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Kakuda-Yahiko</td>
<td>TEPCO fault model</td>
<td>( M: 8.0 (L=76km) )</td>
<td>West 50</td>
<td>Top</td>
<td></td>
<td>1200 years</td>
<td>808 years ago (BPT)</td>
</tr>
<tr>
<td>+ Kehinomiya</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>Bottom</td>
<td></td>
<td></td>
<td>8600 years</td>
<td>Unknown (Poisson)</td>
</tr>
<tr>
<td>Kehinomiya</td>
<td>TEPCO fault model</td>
<td>( M: 7.4 (L=36km) )</td>
<td>West 50</td>
<td>Top</td>
<td></td>
<td>1200 years</td>
<td>808 years ago (BPT)</td>
</tr>
<tr>
<td>+ Katagai</td>
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<td></td>
<td>Bottom</td>
<td></td>
<td></td>
<td>8600 years</td>
<td>Unknown (Poisson)</td>
</tr>
<tr>
<td>Nagaoka-heiya-seien</td>
<td>TEPCO fault model</td>
<td>( M: 8.1 (L=91km) )</td>
<td>West 50</td>
<td>Top</td>
<td></td>
<td>1200 years</td>
<td>808 years ago (BPT)</td>
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<td></td>
<td></td>
<td>8600 years</td>
<td>Unknown (Poisson)</td>
</tr>
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Recurrence characteristic of the source is essential for PSHA and should be detected by Geol. Survey.

Most conservative case
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EQ occurrence and propagation model
Earthquake data
Active fault data

EQ occurrence and propagation model
Earthquake data
Active fault data

Response analysis
Response
Structure analysis
Shaking test data

Capacity

Fragility curves
Comp. A
Comp. B

Hazard curve

Failure probability

Ground motion acc.

Frequency

Level 1 PSA
Seismic Hazard Evaluation
Fragility Evaluation
System Analysis

Level 2 PSA (FP release rate) ➔ Level 3 PSA (Individual risk)

Analysis of Scenario
System analysis

Accident sequence freq.

Hazard
Failure prob.
Core damage
Residual risk

Ground motion acc.

Frequency
More detail in

A standard for Procedure of Seismic Probabilistic Safety Assessment (PSA) for Nuclear Power Plants 2007

The Atomic Energy Society of Japan (AESJ)
Since fault model was useful for the estimation of strong motion near fault, it was adopted in IAEA Safety Guide on Seismic Hazards in Site Evaluation for Nuclear Installations.

DS422 → NS-G-3.3
Fault model was essential to resolve factor of extreme amplitude.

Micro parameters

<table>
<thead>
<tr>
<th>Strike</th>
<th>Dip</th>
<th>Rake</th>
<th>$S$</th>
<th>$M_o$</th>
<th>$\Delta \sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asp 1</td>
<td>40</td>
<td>40</td>
<td>90</td>
<td>$5.6 \times 5.6$</td>
<td>$1.33 \times 10^{18}$</td>
</tr>
<tr>
<td>Asp 2</td>
<td>40</td>
<td>40</td>
<td>90</td>
<td>$5.6 \times 5.6$</td>
<td>$2.00 \times 10^{18}$</td>
</tr>
<tr>
<td>Asp 3</td>
<td>40</td>
<td>40</td>
<td>90</td>
<td>$5.6 \times 5.6$</td>
<td>$2.00 \times 10^{18}$</td>
</tr>
</tbody>
</table>

Comparison between synthesized and observed time history at KK1 base

High stress drop about x1.5 times

Rupture velocity: 2.7 km/s

Fault model was essential to resolve factor of extreme amplitude.

SEISMIC ISSUES IN VIETNAM

- Active faults may exist near site.
- Strong motion estimation by fault model will be useful.

Conclusion

• Active faults may exist around future NPP sites.
• Strong ground motion estimation with fault model can contribute significantly to seismic hazard assessment near by the fault.
• Therefore it has been adopted in DS422(NS-G-3.3)/IAEA.
• In order to apply the fault model scheme, input parameters will be desired.
• Seismological and Geological investigations are quite essential to estimate the parameters, as well as, their uncertainties.

Cảm ơn
Strong ground motion by the fault source model

Simulation Method by Fault Model is also adopted to estimate earthquake motion, more precise method than empirical method.

- Fault is treated as a plane divided small elements in fault model analysis.
- Earthquake motion is analyzed by compose of waves propagated from every element.
Irikura’s Recipe

1. Fault rupture area \((S = LW)\)
2. Seismic moment \((M_0 = \mu SD)\)
3. Mean stress drop \((\Delta\sigma_C)\)
4. Total area of asperity \((S_a)\)
5. Stress drop of asperity \((\Delta\sigma_a)\)
6. Number \((N)\) and location of asperities
7. Average slip rate of asperity \((D_a)\)
8. Effective stress of asperity \((\sigma_a)\) and of background domain \((\sigma_b)\)
9. Setting of slip rate function

Geological investigation is quite essential!
Seismic Hazard Evaluation Result (2/2)

Region of specific source

Fault A
Fault B
Regional source

Site

Fault A
Fault B
Seismic zone 1
Seismic zone 2
Seismic zone 3
Seismic zone 4
Total seismic zones

Exceedance Frequency (n/yr)

PGA

0 500 1000 1500

10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}
The logic tree is a tool of dealing with possible models derived by experts for uncertainties in seismic hazard evaluation.

Modeling of seismic sources A, B
Modeling of ground motion propagation C

\[ \begin{align*}
A_1(\alpha_1) & - B_1(\beta_1) - C_1(\gamma_1) \\
A_2(\alpha_2) & - B_2(\beta_2) - C_2(\gamma_2) \\
A_2(\alpha_2) & - B_3(\beta_3) - C_1(\gamma_1)
\end{align*} \]

\[ \begin{align*}
A_1 & - B_1 - C_1 & \alpha_1 \times \beta_1 \times \gamma_1 \\
A_1 & - B_2 - C_1 & \alpha_1 \times \beta_2 \times \gamma_1 \\
A_1 & - B_3 - C_1 & \alpha_1 \times \beta_3 \times \gamma_1 \\
A_2 & - B_1 - C_1 & \alpha_2 \times \beta_1 \times \gamma_1 \\
A_2 & - B_2 - C_1 & \alpha_2 \times \beta_2 \times \gamma_1 \\
A_2 & - B_3 - C_1 & \alpha_2 \times \beta_3 \times \gamma_1
\end{align*} \]

\[ \sum \alpha_i = 1, \ \sum \beta_j = 1, \ \sum \gamma_k = 1 \]

\[ \sum \sum \sum \alpha_i \beta_j \gamma_k = 1 \]