Recognition and Overcome of Uncertainty in Seismic Hazard Evaluation

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Abstract

As a part of seismic probabilistic safety assessment of nuclear power plants, Japan Nuclear Energy Safety Organization (JNES) have been advancing the probabilistic seismic hazard evaluation method. The characteristic of JNES’s method is to use two ways for calculating ground motions. One is based on the empirical attenuation model. The other is based on the fault model and applied for near large active faults around a site. The uncertainty evaluation is carried out using logic tree. The procedure to elicit and integrate the expert’s opinions and to generate the logic tree was developed. Through the uncertainty evaluation in seismic hazard at several sites, important insights concerning elicitation and integration of expert opinions were obtained. JNES held the workshop on seismic hazard assessment with the focus on recognition and overcome of the uncertainties in seismic hazard evaluation on April 27, 2004. The important common recognition was obtained from the workshop. This paper describes the above contents.
1. Introduction

As a part of seismic probabilistic safety assessment of nuclear power plants, Japan Nuclear Energy Safety Organization (JNES) have been developing and advancing the probabilistic seismic hazard evaluation method. The characteristic of JNES’s method is to use two ways for calculating ground motions, based on the empirical attenuation model and the fault model for near large active faults around a site.

In JNES’s procedure for evaluating the uncertainties in seismic hazard, the uncertainty is divided into aleatory uncertainty and epistemic uncertainty. The later uncertainties are presented in a logic tree. This procedure was applied to seismic hazard analyses for several sites. In the process of determination of the analysis models and conditions, expert opinions were elicited through a series of questionnaire investigation and discussion among several experts.

JNES held the workshop on seismic hazard assessment with the focus on recognition and overcome of the uncertainties in seismic hazard evaluation on April 27, 2004. In this workshop, we had presentations of the JNES activities and by two invited experts and also panel discussion, and several important consensus and insights were obtained.

This paper describes the method to evaluate seismic hazard using attenuation and fault models and the example of evaluation result, the procedure to generate the logic tree on JNES, and the overview of the above workshop.

2. Methodology for evaluating uncertainty of seismic hazard on JNES

(1) Methodology to evaluate seismic hazard on JNES

Japan Nuclear Energy Safety Organization has been advancing the probabilistic seismic hazard evaluation method. The characteristic of JNES’s method is to use two ways for calculating ground motions as shown in Fig.1. One is based on the empirical attenuation model. The other is based on the fault model and applied for near large active faults around a site. The seismic hazard curve at a site is obtained by combining the two hazard curves which are evaluated separately based on these ways.

In this method, the fault parameters are determined by the recipe proposed by Irikura et al. (Irikura recipe), and uncertainty of these fault parameters are taken into account as a logic tree. The seismic motions for each path in the logic tree are calculated by the fault model.

(2) Classification of uncertainty factor

In JNES’s procedure for evaluating the uncertainty in seismic hazard, the uncertainty is divided into aleatory uncertainty for the randomness and epistemic uncertainty for the knowledge lack, as shown in Fig.1. The latter uncertainty is presented as branches in the logic tree.

The aleatory uncertainty is caused by the intrinsic property of the nature itself and that is generally irreducible randomness. Examples of this uncertainty and its treatment are shown in the following:

- Variability of seismic motion and size of next earthquake, etc.
- Incorporated into one hazard curve
On the other hand, the epistemic uncertainty is caused by a lack of knowledge on modeling shown as follows. That is reducible with increasing knowledge. An example of this uncertainty and its treatment are:
- Presence of a fault
- Usually shown as multiple hazard curves

The modeling of the epistemic uncertainty is most difficult and important to obtain reliable seismic hazard curves.

(3) **Procedure to evaluate epistemic uncertainty of seismic hazard using logic tree**

In the seismic hazard evaluation using logic tree as shown in Fig.1, the important parameters are identified by the sensitivity study. On these parameters, the logic tree is generated. Then the seismic hazard curves are calculated for each path in the logic tree. The fractile seismic hazard curve is estimated by statistical analysis.
3. Procedure for eliciting and integrating of expert’s opinions and generating logic tree on JNES

The procedure to elicit and concentrate the expert’s opinions and generate the logic tree consists of 11 steps as shown in Fig.2.

1. Collection of related seismic information
2. Identification of important issues
   To identify the important issues within the epistemic uncertainties based on the above results
3. Selection of experts
   To select the experts concerning the above important issues
4. Selection of technical integrator
   To select the technical integrator to elicit and integrate the expert’s opinions
5. Selection of methods to elicit the expert’s opinions
   The methods to elicit the expert’s opinions are as follows.
   - Questionnaire
   - Interview
   - Exchange of opinions within group
   - Workshop
   - Combination of the above methods

Fig.2 Procedure for evaluating uncertainty of seismic hazard on JNES
6. Elicitation of expert’s opinions based on questionnaire investigation
   In order to elicit the expert’s opinions, the following devices need to be included.
   - To set up the concrete questions
   - To offer the results of sensitivity analyses
   - To set up the answer columns including answers of weighting for each model and
     parameter and free discussion
7. Exchange of expert’s opinions among experts
   To repeat about 2 or 3 times the exchange of expert’s opinions and to integrate them
8. Generation of tentative logic tree
   The tentative logic tree is generated by the following ways.
   - That is generated by the technical integrator.
   - That is generated through the exchange of expert’s opinion.
9. Review of tentative logic tree among experts
10. Generation of final logic tree
11. Review of final logic tree among experts

4. Examples of uncertainty evaluation of seismic hazard and knowledge obtained through evaluation

(1) Example of uncertainty evaluation of seismic hazard using attenuation model

a. Evaluation conditions

A site located at east Japan was selected to estimate. The important items were identified based on
sensitivity analysis results for the factors of epistemic uncertainties as shown in Table 1. They are the
following four items.
   - Item 1: Modeling of seismic zone and source depth
   - Item 2: Length, magnitude and frequency of specific fault
   - Item 3: Selection of attenuation model, setting of deviation and upper limit of seismic motion
   - Item 4: Combination of historical earthquake data and active fault data

The experts were selected from committee members of Seismic Hazard assessment WG (11 persons of
JNES. Their specialty field and organization are as follows.
   - Specialty field: Geology, topography, seismology, earthquake engineering and reliability
     engineering etc.
   - Organization: University, research organization and utility

The team was set up as follows.
   - Team for modeling seismic source: 7 persons
   - Team for modeling seismic motion propagation: 5 persons
b. Evaluation results

As example of uncertainty evaluation of seismic hazard using attenuation model, the examination process concerning item 2 is shown in Fig.3. In this figure, the first questionnaire was carried out to the experts with the introduction of specific active fault data and seismic zone map etc. The results of questionnaire were integrated into the following four opinions.

- Opinion 1-1: Length (l)- 80 km, magnitude prediction equation (M)- Utsu equation , average slip rate (V)- no description
- Opinion 1-2: L- 30 km, M- Matsuda equation, V- S1
- Opinion 1-3: L- 21 km, M- Matsuda equation, V- S2 or S3
- Opinion 1-4: L- 18 km, M- Matsuda equation, V- S4 or S5

After the discussion was carried out among the experts based on the above four opinions, the second questionnaire was carried out again. The results of questionnaire were integrated into the following two opinions.

- Opinion 2-1: L- 70 km, M- Matsuda equation, A- S1
- Opinion 2-2: L- 18 km, M- Matsuda equation, A- S2 or S3 or S4 or S5

The discussion was carried out among the experts about the details of reference materials and sensitivity analysis results for the above two opinions.

The technical integrator finally estimated the following weight taking account of the above discussion.

- Opinion 2-1: weight -0.2 for L- 70 km, M- 7.9 by Matsuda equation, A- 1/11300 years

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| Table 1 Uncertainty factors in the case estimated seismic hazard using attenuation model |
|-----------------------------------|-----------------------------------|
| Special hypocenter                | Area hypocenter                   |
|                                   |                                   |
| Maximum moment model             | Maximum moment model              |
| R                                 | R                                 |
| U                                 | U                                 |
| Hypocenter model                 | Hypocenter model                  |
| ○                                 | ○                                 |
| 1) Selection of active fault data catalogs | 1) Selection of historical earthquake data catalog |
| 2) Set up of active fault in catalogs based on area around site (longitude, latitude) | 2) Set up of historical earthquake in catalogs based on area around site (longitude, latitude) |
|   - based on confidence (I, II, III) of active fault |   - set up of historical time and magnitude |
|   - Avoidance of double count fault and historical data |   - Avoidance of double count fault and historical data |
| 3) Magnitude, location, frequency | 3) Magnitude, location, frequency |
|   - Magnitude (M) |   - Magnitude (M) |
|   - Set up of fault length (way of segmentation) |   - set up of Magnitude |
|   - Selection of fault length --magnitude equation |   - location (epicenter, depth) |
|   - Plain (longitude, latitude): uniform distribution |   - frequency (\(\nu\)) based on non-poison process |
|   - Depth: \(\alpha\) times for fault length |   - Selection of non-poison model |
|   - Frequency (\(\nu\)) based on non-poison process |   - set up of mean return period (T=D/Vs) |
|   - Selection of non-poison model |   - set up of Average slip rate (Vs) and displacement (D) |
|   - set up of Average slip rate (Vs) and displacement (D) |   - set up of last occurrence time (T0) |
|   - set up of mean return period (T=D/Vs) |   - set up of Minimum magnitude |
| 4) Set up of seismic zone         | 4) Set up of seismic zone          |
| ○                                 | ○                                 |
| Seismic motion propagation model  | Seismic motion propagation model   |
| ○                                 | ○                                 |
| 1) Selection of attenuation model | The same as left contents          |
| 2) Set up of logarithmic standard deviation | The same as left contents          |
| 3) Selection of truncate deviation | The same as left contents          |
The fractile of seismic hazard of before and after the opinion exchange among experts is shown in Fig.4.

- Opinion 2-2: weight 0.8 for L-18 km, M-6.9 by Matsuda equation, A-1/6000 years

The fractile of seismic hazard of before and after the opinion exchange among experts is shown in Fig.4.

Fig.3 Process concerning Location, length, magnitude and frequency of the specific fault (items 2)

Fig.4 Comparison of hazard curve before and after opinion exchange
The method to evaluate the uncertainty of seismic hazard using fault model was applied to a site in Japan. The hypocenters around a site consist of those based on (1) historical earthquake, (2) active fault data and (3) near large active fault. The seismic hazards of the hypocenters based on (1) and (2) were evaluated using attenuation model. The hypocenters of (3) were defined as the fault parameters; asperity, stress drop, etc., determined by the Irikura receipt. The variability of these fault parameters was considered by referring expert opinion and the probable combinations of their parameters were represented as a logic tree. The seismic motions for each path in the logic tree were calculated using fault model and the hazard of (3) was evaluated as shown in Fig.5. The seismic hazard curves of (1), (2) and (3) were combined as shown in Fig.6.
(3) knowledge obtained through evaluation

Through carrying out such trial process, the following important consideration items were identified concerning elicitation of expert opinions and integration of discussion points.

a. Selection of expert
   - To select from various specialty fields and organizations
   - To select the experts for important items

b. Concerning Technical Integrator (TI)
   - To maintain the fairness
   - To avoid the compulsory opinions
   - To maintain the fairness in management
   - To promote the positive discussion

c. Questionnaire investigation
   - To offer the high qualities information
   - To avoid the vogue answer by showing suitable sentence
d. Concerning elicitation of expert pinions
   - To carry out the opinion exchange several times by suitable members (5-6 persons),
   - To delete the unimportant opinion based on the results of sensitivity study,
   - To carry out the opinion exchange under no compulsion,
   - To agree the process of technical decision making based on scientific information,
   - To maintain the transparency of opinion exchange process and
   - To clarify the items on which the opinions are not in consensus finally.

4. Overview of international seismic hazard workshop organized by JNES

(1) Program of workshop

JNES held the workshop on seismic hazard assessment with the focus on recognition and overcome of the uncertainties in seismic hazard evaluation on April 27, 2004. The program of this workshop is shown in Table 2.

In this workshop, the above JNES's activity was introduced. Then the presentations of Dr. Leon Reiter (U.S. Nuclear Waste Technical Review Board) and Dr. Paul G. Somerville (URS Corporation) invited from U.S.A. were made. Furthermore the panel discussion with the title of recognition and overcome of uncertainty in seismic hazard evaluation was carried out. Several important insights were obtained at the workshop.

(2) Important common consensus obtained by workshop

The important common consensus obtained from the workshop is as follows.
   - Seismic PSA is effective method to evaluate the seismic safety of nuclear plants and to identify their weakness.
   - The factors of uncertainty in seismic hazard are divided into the aleatory and epistemic uncertainties.
   - The elicitation and integration of various expert opinions concerning the epistemic uncertainties are very important in order to utilize the logic tree. In the same way, the transparency and accountability are also very important.
   - The practical experiences of logic tree have to be accumulated.
   - It is important to approach from both science and technology sides and to promote the mutual cooperation and understanding
   - It is also important to study based on the analyses with taking account of new knowledge.
### Incorporated Administrative Agency
Japan Nuclear Energy Safety Organization (JNES)

**Workshop on How to Overcome Uncertainties in Seismic Hazard**  
- Application of Logic Tree -

**Agenda**

| Time/Date | 9:30 – 18:00 / April 27 (Tuesday), 2004 |
| Place | Tokyo Palace Hotel |
| Contents | |
| * Opening Address (9:30 ~ 9:45) | Hideki Nariai  (President, JNES) |
| * Introduction — Purpose of the WS — (9:45 ~ 10:00) | Hiroyuki Kameda  (National Research Institute of Earth Science and Disaster Prevention) |
| * Presentation on Seismic Hazard Evaluation Methodology in JNES — Logic Trees — (10:00 ~ 11:00) | Katsumi Ebisawa  (JNES) |
| * Invited Presentations (11:00 ~ 13:00) | |
| * Uncertainty in Seismic Hazard Analysis: Some Lessons Learned | Dr. Leon Reiter  (U.S. Nuclear Waste Technical Review Board) |
| * Treatment of Uncertainty in Earthquake Source and Strong Ground Motion Characteristics at Yucca Mountain | Dr. Paul G. Somerville  (URS Corporation) |
| < Lunch (13:00 ~ 14:00) > | |
| * Panel Discussion (14:00 ~ 17:30) | |
| * Title: Recognition and Overcome of Uncertainty in Seismic Hazard Evaluation | |
| * Coordinator | Tsuyoshi Takada  (University of Tokyo) |
| * Panelists: | Yoshihiro Kinugasa  (Tokyo Institute of Technology)  
Takashi Kumamoto  (Okayama University)  
Hiroyuki Fujiwara  (National Research Institute of Earth Science and Disaster Prevention)  
Takao Kagawa  (Geo Research Institute)  
Shizuo Noda  (Tokyo Electric Power Company)  
Tadashi Annaka  (Tokyo Electric Power Services Co., Ltd.)  
Dr. Leon Reiter  (USNWTRB)  
Dr. Paul G. Somerville  (URS Corporation)  
Katsumi Ebisawa  (JNES) |
| (1) Short Presentations (6 Panelists) and Discussions | < Coffee Break (20 minutes) > |
| (2) Discussions including floor | |
| * Summary (17:30 ~ 17:55) | Masaharu Sakagami  (JNES) |
| * Closing  (17:55 ~ 18:00) | Mitsumasa Hirano  (JNES) |
5. Summarization and future plan

(1) Summarization

The main examination results are summarized as follows.
- The characteristic of the method to evaluate seismic hazard by JNES is to use two ways for calculating ground motions. One is based on the empirical attenuation model. The other is based on the fault model and applied for near large active faults around a site.
- In the method of uncertainty evaluation on JNES, the uncertainty is divided into aleatory uncertainty and epistemic uncertainty. The later uncertainty is presented in the logic tree. The procedure to elicit and integrate the expert’s opinions and generate the logic tree was developed.
- This method was applied to the evaluation for several sites. Through the evaluation, the important consideration items concerning elicitation and integration of expert opinions were identified.
- JNES held the workshop on seismic hazard assessment with the focus on recognition and overcome of the uncertainties in seismic hazard evaluation on April 27, 2004. The important common consensus was obtained from the workshop. The main items are as follows.
  - Seismic PSA is effective method to evaluate the seismic safety of nuclear plants and identify their weakness.
  - The elicitation and integration of expert opinions related the epistemic uncertainties are very important in order to utilize the logic tree. In the same way, the transparency and accountability are also very important.
  - It is important to approach from both science and technology sides and to promote the mutual cooperation and understanding

(2) Future plan

In order to advance the method of seismic hazard evaluation, the following issues will be carried out.
- To examine the factors of the uncertainty and to set up the appropriate standard deviation by considering that the deviation depends on the amplitude of seismic motion.
- To examine the limited value of seismic motion and to set up the truncation value such as 3 standard deviation.
- To generate the standard manual of logic tree considering the elicitation and integration of expert’s opinions, which is suitable to our country.

References

*: In Japanese