Ground motion intensity for a given exceedance probability

Exceedance probability for a given ground motion intensity

Probabilistic Seismic Hazard Assessment in general issues

確率地震予測評価之課題

Ken XS Hao (郝憲生) 独立行政法人 防災科学技術研究所
National Research Institute for Earth Science & Disaster Prevention
The big quakes might be considered “black swans”, for they are rare, had an extreme impact on society. But being rare is not the same as being an outlier that invalidates a particular probability model or overturns a methodology. Consequently, it is not obvious that our models and methods are in need of repair (Ellsworth, 2012).

1. Seismic activity in Island arc of Taiwan and Japan

2. Probabilistic Seismic Hazard Assessment
   - Modeling of Seismic Activity
   - Classification into 3 category
   - EQ without specified source faults
   - Uncertainty
   - Reality on East Japan

3. Cooperative works on PSHA
   - Historical records
   - Sharing EQ database
   - Person exchange
convergent ISLAND ARC OF TAIWAN AND JAPAN

divergent

Ma Kuo-Fong, 2011, GEM
Four Plates of Eurasia, North American, Pacific and Philippines joined in Japan with 4,000 km of subduction zones
Bathymetry and Tectonic Setting near Taiwan

Ma Kuo-Fong, 2011, GEM
2. Probabilistic Seismic Hazard Assessment

- Modeling of Seismic Activity
- Classification into 3 category
- EQ without specified source faults
- Uncertainty
- Reality on East Japan
National seismic hazard maps for Japan

Long term evaluation

Strong-motion evaluation

Probability of occurrence, magnitude, location

Strong-motion, underground structure

Probabilistic Seismic Hazard Maps

- Strong-motion intensity with a given probability, or the probability with a given intensity.
- Considering all possible earthquakes.

Scenario Earthquake Shaking Maps

- Strong-motion intensity around the fault for a specified earthquake.
System for the national seismic hazard mapping project

- Surveys for active faults
- Surveys for underground structure

Long-term evaluation

- Study on methods to make probabilistic seismic hazard maps
- Study on methods to make scenario earthquake maps

Evaluation of Strong-motion

National Seismic Hazard Maps for Japan

Japan Seismic Hazard Information Station (J-SHIS)

NIED

ERC

Advanced maps
Table of Contents

1. Introduction
   Outline

2. Seismic Source Fault Models for Characteristic Earthquakes in Long-Term Evaluation (pp 41)
   2.1 Major Active Fault Zones
   2.2 Subduction-Zone and Eastern Margin of the Japan Sea

3. Probabilistic Seismic Hazard Maps (PSHM) (pp 357)
   3.1 Evaluation Procedure and Its Result Representation
   3.2 Area Covered by the PSHM and Map Specifications
   3.3 Seismic Activity Evaluation Models
   3.4 Earthquake Category
   3.5 Ground Motion Evaluation Models
   3.6 Change Logs for the Used Parameters of Probabilistic Seismic Hazard Maps
   3.7 Evaluation Results

Technical reports on National Seismic Hazard Maps for Japan (2009)
Table of Contents (Continued)

4. Seismic Hazard Maps for **Specified Seismic Source Faults**
   (pp 36)
   4.1 Procedure and Results of Evaluation & Presentation Method
   4.2 Areas Covered by the SHM and Its Specifications
   4.3 Determination of **the Inner Source Parameters and Others of Characteristic Earthquakes** Occurring in Major Active Fault Zones
   4.4 Subsurface Structure Models
   4.5 Method of Strong Motion Simulation relation
   4.6 Evaluation Results

5. **Japan Seismic Hazard Information Station (J-SHIS)** (pp 19)
   5.1 Outline
   5.2 Objectives
   5.3 Technical Background
   5.4 J-SHIS System
   5.5 **Toward Sending Information on Earthquake Risk**

6. Toward the Future
   (pp 3)

7. Closing Remarks

Acknowledgments

Appendix **Strong Ground Motion Prediction Method ("Recipe") for Earthquakes with Specified Source Faults**
   (pp 50)
Modeling of seismic activity

Earthquakes of which the seismic source fault is specified
(earthquakes occurring in major active fault zones, subduction-zone earthquakes, and earthquakes at any other active faults)

Earthquakes without specified source faults

For known faults:

Unknown faults:

Target site

Evaluation of the probabilities of magnitude, distance and earthquake occurrence (frequency)

- Probability function of the magnitude $P_k(m_i)$
- Probability function of the distance where the magnitude is $m_i$ $P_k(r_j|m_i)$
- Earthquake occurrence probability $P(E_k;t)$ or occurrence frequency $v(E_k)$
- Poisson G-R relation

BPT distribution based on a renewal process

Stationary Poisson process

Magnitude $i$, distance $j$
Probability that the ground motion intensity exceeds a certain level where earthquake $k$ has occurred:

$$P(Y > y \mid E_k) = \sum_{j} P(Y > y \mid m_i, r_j) P_k(m_i) P_k(r_j \mid m_i)$$

Hazard curve for each earthquake:

$$P_k(Y > y) = P(E_k) P(Y > y \mid E_k)$$

or

$$P_k(Y > y) = 1 - \exp\{-v(E_k) P(Y > y \mid E_k) t\}$$

Hazard curve integrating the results for all earthquakes:

$$P(Y > y; t) = 1 - \Pi\{1 - P_k(Y > y; t)\}$$

Ground motion intensity for a given exceedance probability:

Exceedance probability for a given ground motion Intensity:

$$P(Y > y) = 1 - \prod\{1 - P(Y_i > y)\}$$

Exceedance Prob. of an intensity level $P(Y > y \mid E_k)$

Prob. for each earthquake $P(Y > y) = P(E_k) P(Y > y \mid E_k)$

Prob. for all Eqs $E_k$ $P(Y > y) = 1 - \prod\{1 - P(Y_i > y)\}$
Classification into Earthquake category

EQ category I
EQ category II
EQ category III

Characteristic Subduction-zone Earthquakes
Fused Subduction-zone Earthquakes
Crustal Earthquakes
3.3.3 Earthquakes occurring on Active faults

- Determination of the earthquake occurrence probability
- $R$ (year) : Mean recurrence interval
- $R = \frac{D}{S} \times 1000$
  - Where, $D$ (m) = displacement per event;
  - $S$ (mm/year) = average slip rate
- $\log R = \log L / S + 1.9$
  - Where, fault length $L$
- $\log L = 0.6 M - 2.9$; (Matsuda, 1975)
- $\log D = 0.6 M - 4.0$
- For the unknown of average slip rate,
- activity levels are grouped as
  - Class A: 1 mm/y
  - Class B: 0.25 mm/y
  - Class C: 0.047 mm/y

EQ category III

Technical reports on National Seismic Hazard Maps for Japan (2009)
3.3.4 Earthquakes without specified source faults

The Earthquake Occurrence Ratio

- $R = \text{between Interplate and intraplate}$

All earthquakes are regarded as interplate earthquakes unless they are deeper than the line marked on the map. Earthquakes deeper than this line are regarded as intraplate earthquakes.

EQ category II

Technical reports on National Seismic Hazard Maps for Japan (2009)
(a) Shallow earthquakes in the vicinity of Nansei-shoto islands

Upper surface of the Philippine Sea plate

Evaluated as earthquakes at the Philippine Sea plate
(Relatively deep earthquakes from Kyushu to the vicinity of Nansei-shoto islands)

Data for this area is included in shallow earthquakes.

(b) Earthquakes in the vicinity of Yonaguni-jima

Since relatively deep earthquakes have been modeled in the vicinity of Yonaguni-jima, earthquakes shallower than 100 km are treated collectively.
Technical reports on National Seismic Hazard Maps for Japan (2009)

Figure 3.3.4.10-2 Occurrence frequency of earthquakes without specified source faults in the Philippine Sea plate (Total for interplate and intraplate earthquakes)

2009 version (data: - Dec. 2007)  
Rate of change = (2009-2008)/2008  
2008 version (data: - Dec. 2006)
Uncertainty: \( U = U_r + U_k \)

1. **Ur: Aleatory (Random) Uncertainty**

- Time of EQ occurrence
- Location of EQ occurrence
- Source properties (e.g. M) of EQ occurrence
- Ground motion at a site
- Given the median value of motion
- Inner Source parameters, fault rupture process (e.g., direction of rupture)
2. Uk: Epistemic (Knowledge) Uncertainty 情報不足→不確定性

• Geometry of seismotectonic and seismo-genic zones
• Distributions describing source parameters  (e.g., rate, b value, maximum M)
• Median value of ground motion given the source properties
• Limits on ground shaking
Common logarithm standard deviation $\sigma$

$\sigma = 0.23$

$\sigma = 0.15$

Seismic intensity in 3% exceedance probability within 30 years
Random phenomenon (Aleatory uncertainty) was considered in hazard curve calculation.

Reduce uncertainty by using variance $\sigma$ depending on Velocity amplitudes.

- Conventional value (0.23)
- Value to be used for the National Seismic Hazard Maps for Japan

Estimated value of the peak velocity (cm/s) on the engineering bedrock ($V_s = 600$ m/s)
3.3.2 Subduction-zone Earthquakes

We did pointed out that a M7.4 to 8.0 earthquake in Miyagi-ken-Oki, area A, with probability of 99%, would be occur within 30 years.

However, the ruptures trigged areas A, E, D, F, G and C simultaneously, over a region of 500km x 200km, which was far beyond our considerations. The maximum M was underestimated.
Major earthquakes on active faults and subduction zone with low-probability.

Regarding the PSHA for low probability, at present it is insufficient to evaluate the uncertainty for low probability of M8-class earthquakes and it is necessary to improve techniques for them.
Preparation for the next M9
3. Cooperative works on PSHA

- Historical records
- Sharing EQ database
- Person exchange
What lessons we have learnt from the Tohoku earthquake?

“The borderless world of Science” → enabling knowledge and data exchange each others.

Subduction zones → Crossing border connect the world
Earthquakes without specified source faults in the vicinity of Ryukyu islands

W.-J. Huang, et al, 2010
Subduction zones for Island arc
Internaional Cooperation

Trilateral cooperative program enabling knowledge data exchange

Approved and supported by each individual counties

SHA for Next Generation

Welcome to Cooperation with TEM