Improved seismic hazard assessment after the 2011 Great East Japan Earthquake

*Hiroyuki Fujiwara[1], Nobuyuki Morikawa[1], Ken Xiansheng Hao[1]

1.National Research Institute for Earth Science and Disaster Prevention

Since the 1995 Hyogo-ken Nanbu Earthquake, we have been conducting seismic hazard assessment (SHA) with National Seismic Hazard Maps for Japan under the guidance of the Headquarters for Earthquake Research Promotion of Japan (HERPJ). The National Seismic Hazard Maps for Japan summarized all of results of estimating strong motions caused by potential earthquakes that could occurring in the future. The national SHA maps consist of two kinds of maps. One is a probabilistic seismic hazard map (PSHM) that shows the relation between seismic intensity value and its probability of exceedance within a certain time period. The other one is a scenario earthquake shaking map (SESM). In order to promote the use of the National Seismic Hazard Maps, we have developed an open web system to provide information interactively, and named this system the Japan Seismic Hazard Information Station, J-SHIS.

The 2011 Great East Japan Earthquake (Mw 9.0) was the largest event in the recording history of Japan. This mega-thrust earthquake was not yet considered in the National Seismic Hazard Maps for Japan before it occur. Based on the lessons learned from this earthquake disaster, much efforts are being progressed to revise the seismic hazard assessment for Japan. We, as project staffs of the NIED, try to clarify the existed SHA problems and issues to be resolved and make proposals to improve seismic hazard assessment for Japan.

(1) Re-modeling of seismic activity with no oversight to low-probability earthquakes.
(2) Improvement of strong-motion evaluation considering low-probability earthquakes.
(3) Development of methodology for complementary use of PSHM and SESM.
(4) Improvement of techniques for prediction of strong-motion for mega earthquakes.
(5) Improvement of utilization and transmission of seismic hazard information.

We have made a series of revisions of the seismic hazard assessment based on the revised versions of the long-term evaluation of seismic activity made by HERPJ. The newer revisions of long-term evaluation for seismic activity by HERPJ are still undergoing and then, we will update and revise continuously for the seismic hazard assessment.

Keywords: National Seismic Hazard Maps for Japan, strong-motion, seismic hazard, probability, J-SHIS

Do geology and seismology tell consistent stories about earthquake rates?

*David D Jackson[1]

1.University of California Los Angeles

Evidence for quasi-periodic recurrence in California comes largely from paleo-seismic data. A team of experts compiled the most reliable data for use in the third Uniform California Earthquake Rupture Forecast (UCERF3). They reported dates of observed displacements at 32 sites on 13 named faults in California. There is a problem: recorded paleo-seismic events ceased at about the beginning of the instrumental seismic era, inconsistent with inferred paleo-event rates.

Corrected for multiple-site ruptures, the total reported paleo-event rate is about 0.04/year. Yet the most recent paleo-event date is 1916. Such a long hiatus is extremely unlikely for a Poisson process and even less probable for an ensemble of quasi-period processes.

Possible explanations for the discrepancy include (1) extreme luck, (2) unexplained regional fault interaction, or (3) mistaken identification of near-surface displacements as evidence of large earthquakes. The first can be rejected with 99% confidence. There is no evidence for the second in the pre-1916 paleo-seismic history nor in any theoretical models yet reported. The third could explain the observed quiescence because mistaken identity would be prevented by instrumental seismic data. In any case the paleo-event recurrence rates can’t be trusted for the next century because they fail the last one.

A separate problem is the assumption that seismic moment rate can be inferred from surface deformation data. Seismic moment rate depends on earthquake rate at the completeness magnitude, the b-value, and the upper magnitude limit. The earthquake rate may vary with time, and the upper magnitude limit is poorly known. The tectonic moment rate inferred from surface deformation depends on slip- or strain rate, rupture contact area, effective rigidity, and coupling, most of which are poorly known. The equality of seismic and tectonic moment rates has never been verified anywhere.

Keywords: seismic moment, earthquake rate, forecast, paleo-seismology, recurrence

Long-term Probability of the Kanto M8 Class Earthquake along the Sagami Trough, Central Japan

*Masajiro Imoto[1], Nobuyuki Morikawa[1], Hiroyuki Fujiwara[1]

1.National Research Institute for Earth Science and Disaster Prevention

We discuss the uncertainty of the long-term probability of the Kanto M8 earthquake along the Sagami trough, central Japan, which has been reported by the Earthquake Research Committee, the Government of Japan. First, we propose a Bayesian method to use a prior distribution consistent with a historical sequence in estimating the probability based on earthquake sequences to match geological and geomorphological evidences, where origin times of nine paleoearthquakes are given with large uncertainties. Next, we examine earthquake sequences generated with the Poisson distribution. Results suggest that the epistemic uncertainty of the Meio Kanto earthquake leads to an uncertainty of 0.7% to 5.3% for 30 yr probability, where the Poisson distribution becomes more likely than the Brownian passage time distribution in the case of the Meio earthquake being one of Kanto M8 earthquakes. Finally, we discuss on the frequency distribution of inter event times in the simulated sequences. It is a notable feature that a histogram of the inter event times exhibits a bimodal distribution. This feature is explained by the evidence that the peak at the longer interval consists of the former five inter event times and the other peak at the shorter interval does of the later three inter event times. This suggests missing earthquakes in a former part of the paleoearthquake series. Consequently, it is likely that the current long-term probability of the Kanto earthquake is underestimated based on an incomplete earthquake series.

Keywords: Kanto M8 Earthquake, Probability, Uncertainty, Inverse Gaussian distribution, Poisson distribution

Insights into data-driven tectonic regionalisation in seismic hazard analysis

*Yenshin Chen[1,2], Graeme Weatherill[2], Marco Pagani[2], Fabrice Cotton[3]

1.ROSE Programme, UME School, IUSS-Pavia, Italy, 2.Global Earthquake Model Foundation, Italy, 3.GFZ German Research Centre for Geosciences, Germany

In seismic hazard analysis, it is frequently assumed that specific assumptions relating to the modelling of ground motion and the characterisation of the seismogenic sources may apply to regions of the globe displaying similar tectonic characteristics. This process, called regionalisation, is frequently an essential component of a seismic hazard analysis either because local data is insufficient to characterise fully the source and propagation-path characteristics or because it is necessary to organise the information into few big categories considered homogeneous from a tectonic point of view. Examples of this operation can be found in methods and studies performed for the selection and the application of ground motion prediction equations in probabilistic seismic hazard analysis, real-time hazard and loss estimates such as ShakeMap and, characterisation of earthquake recurrence and maximum magnitude (Mmax) in low seismicity regions. A key concept that is common to all these analyses is the definition of tectonic similarity and, therefore, of the criteria adopted for the definition of ‘tectonically uniform’ areas. However, previous regionalisation works, have mainly been created by subjective judgements, thus, the process for the delineation of zones remains hardly reproducible. Clearly this makes difficult updating, reviewing and replicating regionalisation results across the globe.
These drawbacks can be overcome with the use of more objective and replicable data-driven methodologies for defining tectonic regions using global seismotectonic information. The regionalisation process can be implemented in an automatic computational scheme which is reproducible, comprehensible from a geophysical rationale, and capable of revision or refinement when new data is introduced database. However, tectonic regionalisation in seismic hazard, as in many other problems in earth system science, is a complicated problem, owing to the variety of parameters and uncertainty as well as to the vague definition of the ‘tectonic homogeneity’.
In this work we test a classification-scheme based on fuzzy logic that allows dealing concepts that are approximate rather than precise;. Since it is able to quantify and manipulate uncertainty with mathematical rigour, it represents a suitable, feasible and effective tool to deal with tectonic regionalisation issues. Moreover, it supports the incorporation of the expert judgement into the classification process (e.g., with higher seismic moment and lower quality factor, it suggests a higher degree of belief to be a tectonic active region). The proposed regionalisation methodology accounts for uncertainty by assigning to each point within the classified area a membership degree to the tectonic regions considered; this result can be incorporated into logic-tree models, a widely used tool for quantification of epistemic uncertainties in probabilistic seismic hazard assessment.
We describe a global tectonic regionalisation model for use in seismic hazard applications using a data-driven fuzzy regionalization methodology that largely relies on global seismotectonic databases and models (e.g., seismic moment rate, quality factor, shear-wave velocity), and its potential application.

Keywords: seismic hazard, regionalisation, fuzzy logic

Towards harmonized seismic hazard assessment in the Asia Pacific region

*Ken Xiansheng Hao[1,2], Hiroyuki Fujiwara[1], Marco Pagani[2]

1.National Research Institute for Earth Science and Disaster Prevention(NIED), 2.Global Earthquake Model Foundation(GEM)

Nowadays –even in developed countries –earthquake occurrence is causing surprise and showing the necessity of introducing risk reduction policies, which should be instead part of enduring initiatives. Promoted by OECD, since 2009 the Global Earthquake Model initiative (GEM) is trying to raise awareness and promote a collaborative assessment of earthquake risk. The GEM Foundation is currently a growing public-private partnership, including over 10 private companies active in the financial and engineering sector, and more than 20 public organizations and associate members encompassing international organizations such as the UN International Strategy for Disaster Reduction. GEM released the OpenQuake-engine in 2013 and OpenQuake Platform in 2015, the latter providing access to seismic hazard and risk models (SHA), datasets and tools (http://www.globalquakemodel.org/openquake/about/platform/). One of GEM's main targets is to work together with local communities on building a global SHA mosaic of hazard and risk models within 2018.

Appointed as the organization in charge of developing national SHA in Japan, NIED is fully committed with GEM and is working at the national and regional level to promote GEM principles. NIED joined in 2012 GEM as a representative of Japan to strength the public part of GEM's partnership and to share with the global community the Japanese experience gained during the recent destructive events, particularly on hazard modeling. The lessons learned after the 2011 Tohoku-oki for example are particularly relevant. In the new hazard models created by NIED after a four years effort, various changes and improvements have been introduced to address the lack of large earthquakes along the main subduction structures particularly along the east coast. For example, in the case of the Nankai Trough the 2014 model contains a set of 15 mutually exclusive occurrence cases where each case may contain independent ruptures is used to model the occurrence of the largest events. The Openquake-engine, GEM's core technology, has recently adapted the unique idea and supported its modeling approach, which might be also used now for other subduction interface sources.

In the last decade NIED carried out a series research cooperation projects with neighboring regions and distance countries particularly after the 2008 Wenchuan earthquake. Examples of these collaborations are the JST-MOST-NRF strategy SHA program which involved Japan-China-Korea between 2010 and 2013, the series of Japan-Taiwan-New Zealand SHA workshops, as well as interaction exchanges with numerous professional and organizations. With most open databases, open-source software and state-art technology, and professional and leading organization, GEM supports NIED in these international collaborations aiming at exchanging experiences and to the promotion of common standards and model in the East Asia region, the Asia Pacific region, as well as global region.

Keywords: Global Earthquake Model (GEM), Seismic Hazard Assessment (SHA), Japan China Korea SHA program, Japan Taiwan New Zealand SHA workshop

Applicability of NGA-West 2 GMPEs to Japan: how to evaluate models using correlated observations

*Sum Mak[1], Danijel Schorlemmer[1]

1.Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ

We compared the performance between the newly developed NGA-West 2 GMPEs and native Japanese GMPEs. The dataset set we used was the most comprehensive among similar studies, consisting of 16 earthquakes of Mw 5.5-6.9, each producing at least 8 records within 40 km to the epicenter. The observations were not used in creating the GMPEs under evaluation, so the test was truly prospective and assessed directly the predictive power of the models. The NGA-West 2 GMPEs was found to perform better than older models.
We emphasize two issues of GMPE evaluation that have been less explored in the literature. Firstly, observed ground motions are believed to be correlated, and are modelled to be correlated. Such a correlation should be duly respected in the evaluation. Secondly, the observation can be considered as a realization of some random process, and so the performance metric, whatever it is, is also a random variable. Such uncertainty should be considered when assessing whether one model is better than the other. We handled the data correlation by treating the observed ground motions as one multivariate random variable. We assessed the uncertainty of evaluation by a cluster bootstrap.

Keywords: Ground motion prediction equation

Probabilistic seismic hazard analysis on long fault source

*ChengYu Pan[1], YuanChei Wu[1]

1.INER

When we are defining the geometry of a long fault source in PSHA, we seek for the geological or geophysical evidence. In a complex tectonic environment such as plate boundary region, the defining of the fault is important, thus logic tree combining the evidence of existing geological or geophysical survey is added in. We then use these facts to divide a fault system into several segments or defining two faults individual even though they are close to each other. But we often face a situation that the earthquake does not always occur on existing fault. And sometimes the magnitude of an earthquake does not go with the length of a fault as we expected. It seems like the applying of logic tree may still miss some of the possibility of one source due to the incompleteness of field survey. However, as we know that the principle of PSHA already considered the possibility of different size of length and magnitude of a fault. So, another way to describe a long fault source is to consider the fault system as a whole and setting up a range of length and magnitude.

In this study, we apply both method mentioned above to two cases in Taiwan. One is on the east boarder of Taiwan, the Longitudinal Valley fault. The other located in Taiwan Strait is called Binhai fault. And the comparison of these two methods will be shown as result.

Keywords: Probabilistic Seismic hazard analysis

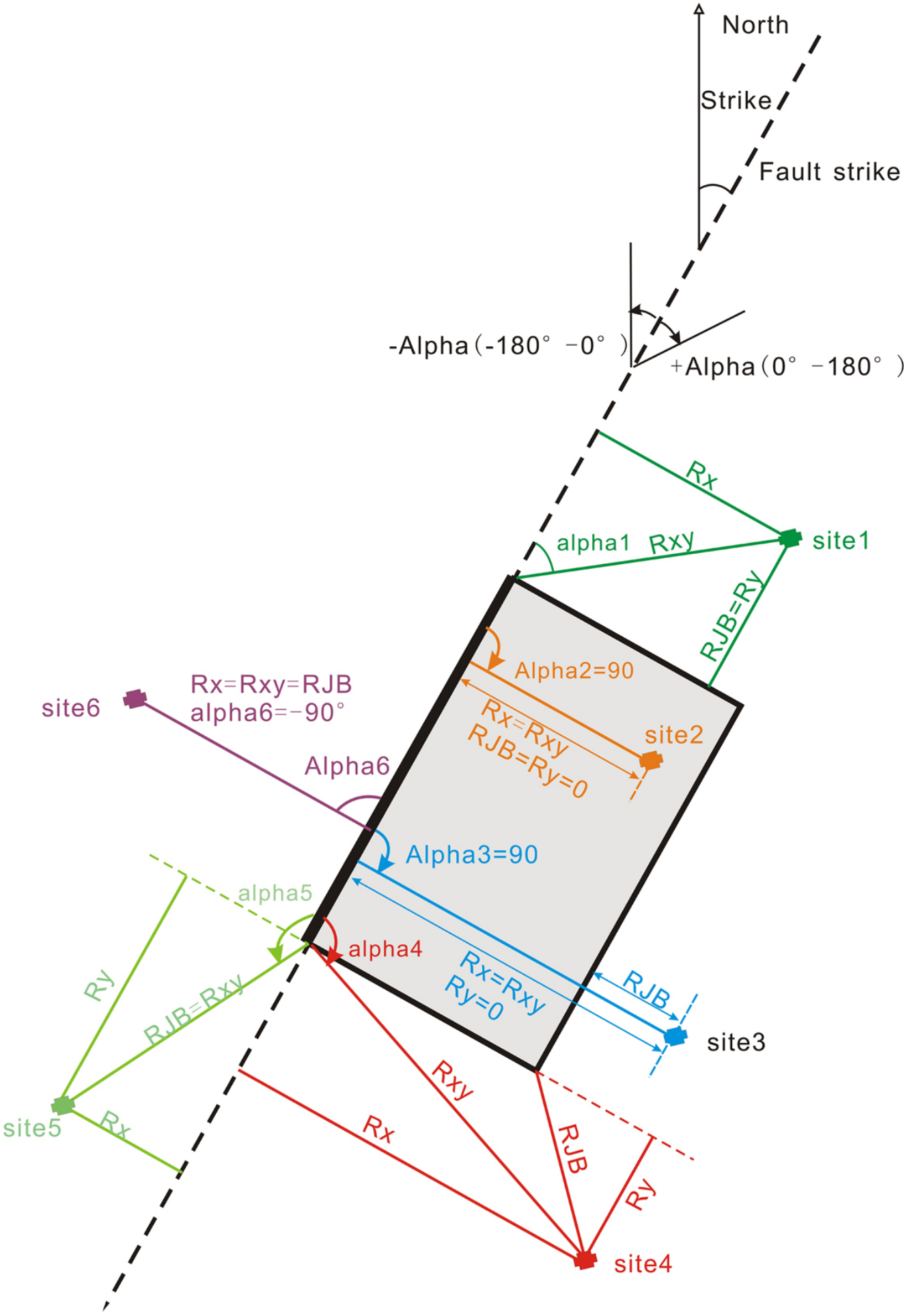
Physical equations for calculating fault-to-site distances used in NGA GMPEs based on earthquake source geometry

*xiaoliang zhang[1], yushan zhang[1]

1.China earthquake disaster prevention center

NGA GMPEs (NGA-West1, 2008 and NGA-West2, 2014) are beginning to be widely used in seismic hazard analyses. However, these new models are considerably more complicated than previous GMPEs, and they require several more input parameters. Users are faced with the challenge of estimating unknown input parameters when implementing NGA models.
In this paper, we are interested in fault-to-site distances parameter. Scherbaum *et al*. (2004) (termed “SSC04”) ever developed empirical expressions for converting source-to-site distance measures using simulated source geometries. The conversion equations are in the form of polynomial functions of M, R_{JB}, and style of faulting. Kaklamanos *et al*. (2011) (termed “KBB11”) derived physical equations relating the three distance measures (R_{JB}, R_{RUP}, and R_X) found in the NGA 2008 models using various geometric principles. KBB11 used the Joyner-Boore distance (R_{JB}) as the primary distance measure to compute other distances ($R_{RUP,}$ R_X) by characterizing the earthquake source by the geometric parameters down-dip rupture width *(W)*, depth-to-top of rupture (Z_{TOR}), fault dip (), and source-to-site azimuth (*alpha*). When R_X is also needed (as in the AS08 and CY08 models), KBB11 method is advantageous, because R_X cannot be estimated using the SSC04 relationships (because R_X had not yet been introduced as a distance measure in 2004). One other potential issue is that the SSC04 equations are technically only applicable for R_{JB}<100 km, whereas KBB2011 equations are physically derived and are applicable for any distance range at which the flat-earth assumption is valid (typically, several hundred kilometers).
KBB11 used the Joyner-Boore distance (R_{JB}) as the primary distance measure to compute other distances ($R_{RUP,}$ R_X). But in one situation R_{JB} is equal to zero, which means the site is located directly above the ruptured area; either R_X or R_{RUP} must be specified in order to calculate the third distance parameter using KBB11. In some other situations, when the fault trace and site location is known, we need to simulate the ground motion caused by different segment rupture of the whole entire fault. In these cases, the R_X and R_{XY} are easily measured by GIS tools but the R_{JB} is dependent on the down-dip rupture width *(W)*. In this paper we introduce a new distance measure R_{XY} (the closest distance from top of rupture) which is used to estimate source-to-site azimuth *alpha* (sin(*alpha)*= R_X/ R_{XY}) and R_Y (R_Y= R_{XY}·cos()). Based on KBB11 we derived distance equations using the R_X and R_{XY} to compute R_{JB}, R_{RUP}, R_X, and R_{Y0}.

Keywords: NGA GMPEs, source-to-site distances, RJB



A comparison of USGS National Seismic Hazard Maps with observed ground motions

*Sum Mak[1], Danijel Schorlemmer[1]

1.Helmholtz-Zentrum Potsdam Deutsches GeoForschungsZentrum GFZ

People's confidence to scientific models accumulates through continuously validating the models's predictions by observations. We compared the seismic hazard forecasts of the four published versions of USGS National Seismic Hazard Maps with the observed ground motions since 2000, which are largely prospective to the models. We verified that the observed seismic hazards computed from macroseismic intensity records were comparable to those from instrumental records. This provides a usable source of data for model testing for the Central and Eastern United States, where instrumental records are almost nonexistent. The observed hazards were found to be generally consistent with the forecasted ones for peak ground acceleration. The forecasted hazards for spectral acceleration at 1 s for California appeared to be conservative. Recent versions of the model were often in better agreement with the observations. Small earthquakes, as expected, were found to have insignificant impact on spectral acceleration at 1 s. Induced earthquakes showed an obvious impact to seismic hazard for short return periods, while that for long return periods was less clear. We examined the sufficiency of data amount by computing the statistical power of tests.

Keywords: Probabilistic seismic hazard assessment

A study on introducing epistemic uncertainties to National Seismic Hazard Maps for Japan

*Nobuyuki Morikawa[1], Hiroyuki Fujiwara[1], Jun'ichi Miyakoshi[2], Mitsutaka Oshima[2], Takeshi Morii[2]

1.National Research Institute for Earth Science and Disaster Prevention, 2.Shimizu Corporation

After the 2011 great Tohoku earthquake, consideration of epistemic uncertainties in seismic hazard assessment has been one of the most important problems in Japan. In this study we show an example of the probabilistic seismic hazard assessment which considered epistemic uncertainty.
In National Seismic Hazard Maps for Japan published by Earthquake Research Committee of Japan (ERCJ), epistemic uncertainties such as probability of earthquake occurrence, modeling of fault geometry, modeling of earthquake activity are partially taken into consideration, in accordance with the long-term evaluation. If enough information is lack in long-term evaluation, then certain measures should be taken against epistemic uncertainties, by taking complementary information into account. However, the current seismic hazard assessment does not meet such demands. In our study, we show an example of treatment of such uncertainty in modeling the probability of simultaneous activity of multiple segments and resultant seismic hazard.
In the new version of long-term evaluation of active faults by ERCJ, probability of earthquake occurrence caused by simultaneous activity of multi-segment faults are indicated as “unknown”. As to these multi-segment faults events, two models shown below are proposed (Oshima et al., 2015).
Model1: Assign probability of earthquake occurrence for each segment's independent activity to multi-segment faults events.
Model2: Assign occurrence frequency of each segment estimated by average slip velocity to multi-segment faults events.
The model1 takes into account the long-term evaluation saying that “the probability of earthquake occurrence does not become larger than that of each segment’s independent activity”. Thus, the probability for multi-segment faults events that contain the segment with zero-probability of occurrence are also set to zero. However, the activities of neighboring segments have the potential to trigger the event at the segment where the possibility of independent activity is evaluated as “almost zero”. In model2, probabilities for such events are not set to zero.
As to the results of hazard analysis for aforementioned two models, the difference in hazard curves can be seen only in quite low probability range (e.g., exceedance probability of 0.1% in 30 years). Because information on rare events tend to be short and indicated as “unknown” in long-term evaluation, modeling with consideration of epistemic uncertainty is essential to take aim at hazard analysis that calls extremely rare events into account.

Keywords: Probabilistic seismic hazard assessment, Epistemic uncertainty, Seismic activity model, National Seismic Hazard Maps for Japan

