

Improved seismic hazard assessment after the 2011 Great East Japan Earthquake

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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?

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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

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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

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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 (M_{max}) 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

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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

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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