Revision of Probabilistic Seismic Hazard Assessment for Japan after the 2011 Tohoku-oki Mega-thrust Earthquake (M9.0)

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LISBOA 2012

Hiroyuki Fujiwara & Nobuyuki Morikawa
National Research Institute for Earth Science and Disaster Prevention, Japan

Toshihiko Okumura &Yutaka Ishikawa
Shimizu Corporation, Japan

Nobuoto Nojima
Gifu University, Japan

SUMMARY:
The Tohoku-oki earthquake (Mw 9.0) of March 11, 2011, was the largest event in the history of Japan and was recorded by nearly 1200 K-NET/KiK-net stations with a peak ground accelerations of 2933 gals and more than 1g at 10 sites. This mega-thrust earthquake was not considered in the national seismic hazard maps for Japan that were published by the headquarters for earthquake research promotion of Japan. By comparing results of the seismic hazard assessment and observed strong ground motions, we understand that the results of assessment were underestimated in Fukushima prefecture and northern part of Ibaraki prefecture. Its cause primarily lies in that it failed to evaluate the M9.0 mega-thrust earthquake in the long-term evaluation for seismic activities. On the other hand, another cause is that we could not have established the functional framework which is prepared for treatment of uncertainty for probabilistic seismic hazard assessment. We consider problems and issues to be resolved for probabilistic seismic hazard assessment based on the lessons learned from this earthquake disaster and make new proposals to improve probabilistic seismic hazard assessment for Japan

Keywords: probabilistic seismic hazard assessment, strong ground motion, seismic hazard map

1. INTRODUCTION

The Tohoku-oki earthquake (Mw 9.0) of March 11, 2011, was the largest event in the history of Japan. This mega-thrust earthquake was not considered in the national seismic hazard maps for Japan that were published by the Headquarters for Earthquake Research Promotion of Japan (HERP 2009a). Based on the lessons learned from this earthquake disaster and the experience that we have engaged in the seismic hazard mapping project of Japan, we consider problems and issues to be resolved for probabilistic seismic hazard assessment and make new proposals to improve probabilistic seismic hazard assessment for Japan.

2. NATIONAL SEISMIC HAZARD MAPS FOR JAPAN

The Headquarters for Earthquake Research Promotion of Japan published a new version of the national seismic hazard maps for Japan in July 2009, which was initialized by the Earthquake Research Committee of Japan (ERCJ) on a basis of long-term evaluation of seismic activity, and on a basis of strong-motion evaluation. The National Research Institute for Earth Science and Disaster Prevention (NIED), in the meantime, also promoted a special research project 'National Seismic Hazard Mapping Project of Japan' to support the preparation of the seismic hazard maps (Fujiwara et al. 2009). Under guidance of ERCJ, we have carried out the study of the hazard maps.

The hazard 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). The examples of PSHMs are maps of probabilities that JMA seismic intensity exceeds 5-, 5+, 6- and 6+ in 30 or 50 years, and maps of the JMA seismic intensity corresponding to the exceedance probability of 3% and 6% in 30 years and of 2%, 5%, 10% and 39% in 50 years. For the PSHM, we use empirical attenuation relation for strong-motion, which follows the seismic activity model on the basis of long-term evaluation of seismic activity by ERCJ. Both of peak velocities on the engineering bedrock and on ground surface are evaluated for sites with approximately 0.25km spacing on the basis of the 7.5-Arc-Second Engineering Geomorphologic Classification Database by Wakamatsu and Matsuoka (2008). The JMA seismic intensities on ground surface are evaluated from peak ground velocity by using an empirical formula. The SESMs are evaluated for 485 scenario earthquakes of all major active faults in Japan. Selection of a specified scenario is essential to make a scenario earthquake shake map. The basic policy of the selection is that we choose the most probable case. We assume several cases of the characteristic source model and compare the results of them to show deviation of strong-motion evaluation due to uncertainties. For the SESMs, based on the source model for strong-motion evaluation we adopt a hybrid method to simulate waveforms on the engineering bedrock and peak ground velocity. The hybrid method aims to evaluate strong-motions in a broadband frequency range and is a combination of a deterministic approach using numerical simulation methods, such as the finite difference method, for low frequency range and a stochastic approach using the empirical or stochastic Green's function method for high frequency range. A lot of parameters on source characterization and modeling of underground structure are required for the hybrid method. The standardization of the setting parameters for the hybrid method is studied. We summarize the technical details on the hybrid method based on the 'Recipe for strong-motion evaluation', which are published by the ERCJ.

The national seismic hazard maps for Japan are a comprehensive integration from all of the research aspects conducted by ERCJ. It contains information of all necessary data for producing the maps. To cross-check and promote the use of the national seismic hazard maps, an engineering application committee was established by NIED. Under the committee guidance, we have developed an open web system to provide seismic hazard information interactively, and name this system as Japan Seismic Hazard Information Station, J-SHIS (http://www.j-shis.bosai.go.jp/). We aim to distribute a process of uncertainty evaluation and to meet multi-purpose needs in engineering fields. The information provided from J-SHIS includes not only results of the hazard maps but also various information required in the processes of making the hazard maps, such as data on seismic activity, source models and underground structure.

3. COMPARISON BETWEEN THE STRONG-MOTIONS OF TOHOKU EARTHQUAKE AND THE SEISMIC HAZARD MAPS

The Tohoku-oki earthquake was the first M9-class earthquake that is closely recorded by dense seismograph network. The ground motions were recorded at more than 1200 K-NET (Fujiwara et al. 2007) and KiK-net (Aoi et al. 2011) stations (Fig. 1(a)). The peak ground accelerations (PGA) exceeded 1g at 20 sites and the largest PGA, 2933 gals (2933 cm/s^2), was observed at the K-NET Tsukidate station (MYG004). Fig. 1(b) shows a comparison between the observed JMA (Japan Meteorological Agency) seismic intensities of the Tohoku-oki earthquake and JMA seismic intensity distribution for 2% probability of exceedance in 50 years, which is one of the probabilistic seismic hazard maps. In the probabilistic seismic hazard map, the seismic intensity of 2% probability of exceedance in 50 years has been evaluated as 6- or 6+ in Miyagi prefecture and in the southern Kanto region, which covers almost the observed ground motion for the Tohoku-oki earthquake. However, in the northern area of Ibaraki Prefecture and in Fukushima Prefecture where large earthquakes with high probability of occurrence had not been expected, the seismic intensity 6+ was observed at the points where seismic intensity 5- or 5+ was expected in the seismic hazard map. As observed in this comparison, predicted ground motion level in the probabilistic seismic hazard map was clearly underestimated in Fukushima Prefecture and the northern part of Ibaraki Prefecture for the Tohoku-oki earthquake (M9.0). This is primarily because, in the long-term evaluation that has been the basis of the seismicity model for the probabilistic seismic hazard map, the occurrence of great earthquakes M9.0 has not been evaluated. On the other hand, the cause of underestimate also lies in the inability to establish well the whole framework of probabilistic seismic hazard assessment methods under the circumstances that many issues are left unresolved in seismology.

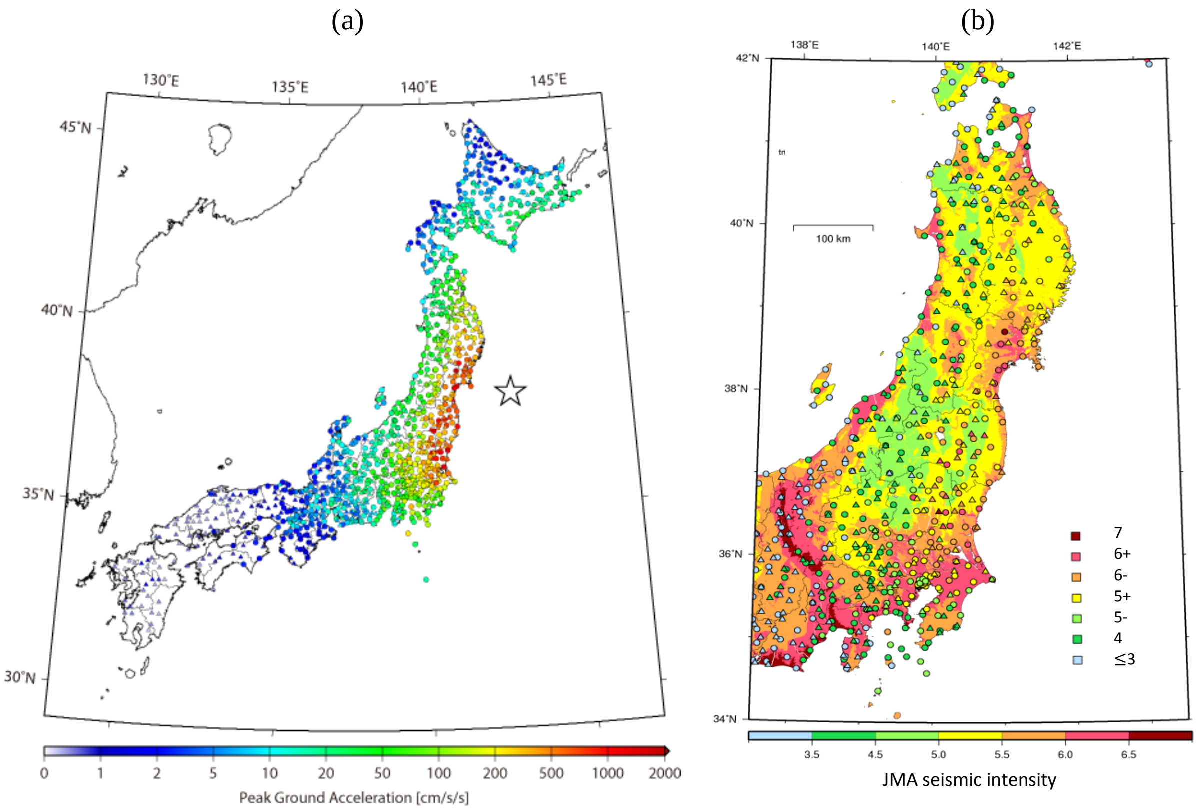

Figure1. (a) The peak ground accelerations recorded at K-NET (○) and KiK-net (△) stations. (b) Comparison between the observed seismic intensities（○ : K-NET, △ : KiK-net）of the Tohoku-oki earthquake and seismic intensity distribution for 2% probability of exceedance in 50 years, which is one of the probabilistic seismic hazard maps.

4. SEISMIC ACTIBITY MODEL BEFORE THE TOHOKU-OKI ERATHQUAKE

The methodology of probabilistic seismic hazard assessment was used for preparing the probabilistic seismic hazard maps for Japan. Probabilistic seismic hazard assessment method is a technique that has been developed in order to set ground motion level corresponding to certain probability of exceedance. In probabilistic seismic hazard assessment, the uncertainty for occurrence of earthquake and level of ground motion are considered. In the national seismic hazard maps for Japan, the map that shows the probability of exceedance for a certain level of ground motion has been used as a typical map. To prepare probabilistic seismic hazard maps, seismic hazard assessment methods described below have been adopted. In seismic hazard assessment, we analyze the relationship between the following three parameters: the ground motion intensity that occur in the future at a given site; the target period; and target probability. The brief outline of the procedure of seismic hazard assessment in preparation of the probabilistic seismic hazard maps is shown below.

(1) Model the earthquake activities around a target site according to the ERCJ's earthquake classification.
(2) For each modeled earthquake, evaluate the probability of the earthquake magnitude, the probability of the distance from the target site, and the probability of earthquake occurrence.
(3) Set a probability model for presuming the ground motion intensity for an earthquake of a given magnitude and distance. For each modeled earthquake, evaluate the probability of the intensity of the ground motions caused by that earthquake within the target period exceeding a certain value. Use empirical attenuation relations for strong motion evaluation. Specifically, first derive the peak velocity on the engineering bedrock based on an attenuation relation using the shortest distance from the target site to the fault plane, then multiply the derived value by the site amplification factor to obtain the peak velocity, and finally use the relation between the peak velocity and the JMA instrumental seismic

intensity to evaluate the seismic intensity on the ground surface.
(4) Repeat the operation above for all modeled earthquakes, and sum up the results to obtain the probability of the intensity of the ground motions occurring within the target period exceeding a certain value by at least once, when all earthquakes are taken into consideration.

In this manner, seismic hazard assessment is conducted for each site, and by fixing any two parameters of the ground motion intensity, period, and probability, the value of the remaining parameter are obtained. The probabilistic seismic hazard maps show the distribution of such values.

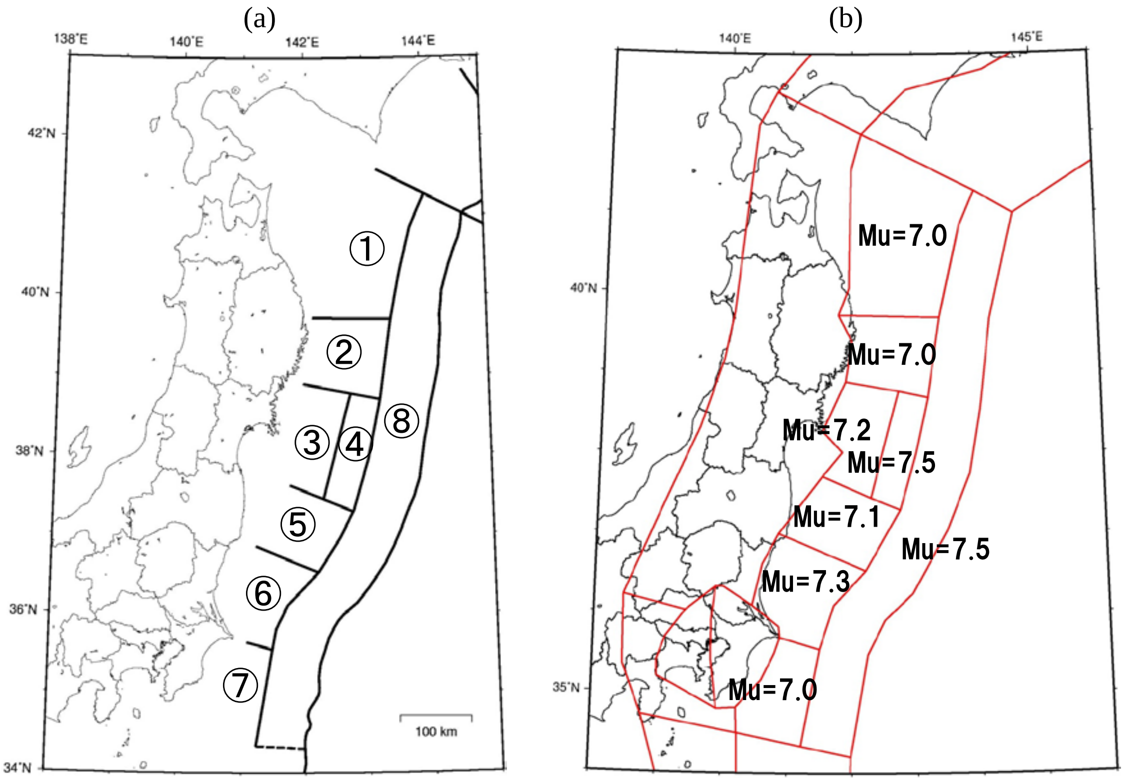

Figure.2 (a) Target areas for "Long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso". (b) Upper limit of magnitude Mu for of background earthquakes for the Pacific plate.

Table 1. Long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso before the Tohoku-oki earthquake.

Earthquake	Magnitude	Occur. prob. within 30 years
Characteristic earthquake in ①	Approx. M8.0	0.2%～10%
Interplate earthquakes other than characteristic earthquake in ①	M7.1～M7.6	About 90%
Earthquakes in ②	Unknown	Unknown
Miyagi-ken-oki earthquake in ③	Approx. M7.5	99%
Interplate earthquakes in ④	Approx. M7.7 (M8.0 for correlated with Miyagi-ken-oki earthquake)	80%～90%
Interplate earthquakes in ⑤	Approx. M7.4 (Successive occurrence of multiple earthquakes)	About 7% or less
Interplate earthquakes in ⑥	M6.7～M7.2	About 90% or more
Earthquakes in ⑦	Unknown	Unknown
Tsunami earthquakes in ⑧	Approx. Mt8.2	About 20%
Intraplate earthquakes (normal fault type) in ⑧	Approx. M8.2	4%～7%

For probabilistic seismic hazard assessment, it is necessary to model all the earthquakes that may occur in the future. Basically, based on the results on long-term evaluation by HERP, we construct a model of seismic activity. However, long-term evaluation is intended to be used for general disaster prevention activities and it was focused to assess the earthquakes that are considered likely to occur. Therefore, the earthquakes that had been evaluated are only part of future earthquakes that may occur. To construct the model needed to evaluate the probabilistic seismic hazard, it becomes necessary to fill the gap and a model for background earthquakes is required. In probabilistic seismic hazard assessment, it has become essentially important and difficult issues to model earthquakes that are low probability of occurrence and have not been assessed in the long-term evaluation by HERP.

In the following, in order to examine more specific issues, we summarized the seismic activity model that was used for the probabilistic seismic hazard maps. For the source fault regions of the Tohoku-oki earthquake, the model had been implemented based on the "Long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso" (HERP 2009b). In the long-term evaluation, the entire area is divided into eight regions and the evaluation for seismic activity had been conducted in each region (Fig. 2 (a)). The results of the long-term evaluation are summarized in Table 1. For each region, based on the records for earthquakes occurred in the past, by analyzing the pattern of occurrence, the presence of characteristic earthquake was evaluated. For the regions where the presence of a specific size earthquake was observed, the size of earthquakes and the interval between earthquakes have been evaluated. Typical examples include the Miyagi-oki earthquake.

On the other hand, in areas that were difficult to evaluate because no sufficient data were obtained, probability of earthquake occurrence was calculated by assuming a Poisson process without specifying where they occur. In addition, for the region where clear evidence of past earthquakes had not been obtained, for example, the off Boso area, no specific assessment was made and as the evaluation results, "Unknown" had been shown. Thus, in the long-term evaluation that was conducted before the Tohoku-oki earthquake, evaluation had been made by the idea that large earthquakes of same size occur repeatedly in the same area, based on the observed records, historical documents and the results of geomorphological and geological surveys. If there was insufficient evidence and data, no assessment done and "Unknown" had been shown.

A significant point in "Long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso" is that magnitude 8.2 tsunami earthquakes had been expected to occur with probability of 20% in the next 30 years in the region near the Japan trench from the northern off Sanriku to off Boso. If measures had been taken for tsunami earthquakes based on the evaluation, we might have been able to reduce some of the victims of this earthquake, especially in south region from Fukushima prefecture.

In preparation of the probabilistic seismic hazard maps, in addition to the above mentioned long-term evaluation, earthquakes that are not even mentioned there are considered as "background earthquakes". The background earthquakes of the Pacific plate are shown in Fig. 2 (b). In these regions, interplate earthquakes that occur on the upper boundary of the Pacific plate and intraplate earthquakes in the Pacific plate have been considered. The upper limit of magnitude of the background earthquakes has been set for each region. This upper limit is determined by the maximum size of the historical earthquakes that occurred in each area before the Tohoku-oki earthquake, excluding the large earthquakes that are considered in the long-term evaluation. In this regard, it had been pointed out that to use the previous maximum value for each region might lead to an underestimate as a result. However, there were many opposing views for setting an upper limit exceeding the previous largest event.

5. PROBABILISTIC SEISMIC HAZARD ASSESSMENT AFTER THE EARTHQUAKE

Based on the lessons learned from the Tohoku-oki earthquake, the revision of methodology for the long-term evaluation has been promoted in HERP. In previous long-term evaluation, based on observation data, historical records and the results of geological and topographic survey, earthquakes have been evaluated by assuming that earthquakes of similar size occur repeatedly in the same area. In next long-term evaluation in the future, by improving the methodology, it has been aimed to take into account not only earthquakes that can be estimated from seismic data obtained in the past, but also earthquakes that have not been confirmed by historical records and observations, based on scientific evidence. After the techniques of long-term evaluation have been improved, we hope that many of the earthquakes that may occur in the future will be covered by new long-term evaluation.

Table 2. Seismic activity model based on the revision of long-term evaluation.

Region No.	Earthquake type	Previous model	Revised Model 1	Revised Model 2	Revised Model 3
※	Repeating Eq.	None	M=8.4～9.0 P30=0%	M=8.4～9.0 P30=0%	G-R model with Poisson process for total area Interplate Eq. Mu=9.5 Intraplate Eq. Mu=8.2
①	Repeating Eq.	M=8.0 P30=6.3%	M=8.0 P30=7.3%	M=8.0 P30=7.3%	
	Other Eq.	M=7.1～7.6 P30=93%(P)[1)]	M=7.1～7.6 P30=88%(P)	M=7.1～7.6 P30=88%(P)	
	Background Eq.	Mu=7.0	Mu=7.0	Mu=7.0	
②	Repeating Eq.	None	None	None	
	Other Eq.	None	None	None	
	Background Eq.	Mu=7.0	Mu=8.0/7.5[2)]	Mu=8.2/8.2	
③	Repeating Eq.	M=7.5 P30=100%	M=7.4 P30=55%(P)	None	
	Other Eq.	None	M=7.0～7.3 P30=61%(P)	None	
	Background Eq.	Mu=7.2	Mu=8.0/7.5	Mu=8.4/8.2	
④	Repeating Eq.	M=7.7 P30=81%	M=7.9 P30=0	Combined with ③	
	Other Eq.	None	M=7.2～7.6 P30=51%(P)		
	Background Eq.	Mu=7.5	Mu=8.0/7.5		
⑤	Repeating Eq.	M=7.4 P30=7.2%(P)	M=7.4 P30=14%(P)	None	
	Other Eq.	None	None	None	
	Background Eq.	Mu=7.1	Mu=8.0/7.5	Mu=8.2/8.2	
⑥	Repeating Eq.	M=7.0 P30=99%	M=7.0 P30=95%	None	
	Other Eq.	None	M=6.9～7.6 P30=69%(P)	None	
	Background Eq.	Mu=7.3	Mu=8.0/7.5	Mu=8.3/8.2	
⑦	Repeating Eq.	None	None	None	
	Other Eq.	None	None	None	
	Background Eq.	Mu=7.0	Mu=8.0/7.5	Mu=8.3/8.2	
⑧	Repeating Tsunami Eq.	M=8.2(6.8) P30=20%(P)	Mt=8.6～9.0 P30=25%(P)	Mt=8.6～9.0 P30=25%(P)	
	Repeating Eq. (Normal fault)	M=8.2 P30=5.1%(P)	M=8.2 P30=5.1%(P)	M=8.2 P30=5.1%(P)	
	Other Eq.	None	None	None	
	Background Eq.	Mu=7.5	Mu=8.0/None	Mu=8.0/None	

※ Source fault area for the Tohoku-oki earthquake type.

1) (P) shows that occurrence probability is calculated assuming Poisson process.

2) Mu is the upper limit of magnitude. Mu= Interplate Eq. / Intraplate Eq.

On the other hand, it may be difficult to completely evaluate all possible earthquakes in the future by using the techniques of long-term evaluation that are based on the scientific methodology and the scientific knowledge, such as, observational records, historical records and the results of geological and topographic surveys. In probabilistic seismic hazard assessment, a framework for considering the uncertainty of the phenomenon itself and the limits of scientific knowledge, has been prepared using the stochastic and probabilistic method. It becomes a problem to establish a methodology to make the framework effectively work. In order to construct a probabilistic seismic activity model that encompasses the seismic activity of all possible earthquakes, it is necessary to establish a new methodology from that of the conventional long-term evaluation. To achieve this, it is necessary to evaluate objectively the property of long-term evaluation in the modeling of seismic activity based on the long-term evaluation for the seismic hazard assessment. Also, it may be necessary to promote proper modeling of background earthquakes that encompasses all earthquakes that are not considered in the long-term evaluation. For example, it may be possible to evaluate the magnitude of earthquakes from the area of the plate boundary that can be considered to cause earthquakes, and to assess the frequency of occurrence of earthquakes by using the Gutenberg-Richter formula that shows the relationship between the number of earthquakes and their magnitude. In its revision, it is essential to consider a new method of setting the scale for earthquakes, not limited by the idea of using the historical largest event for each small region.

After the Tohoku-oki earthquake, HERP had been reviewing the long-term evaluation for the area in which the Tohoku-oki earthquake occurred and released the revised version of the "Long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso" in November 2011. In this revision, although the revision of the methodology of the long-term evaluation itself has not yet been made and the most part has remained a traditional evaluation, a new assessment has been made of the Tohoku-oki type earthquake. Based on this evaluation, we have made a revision of the seismic hazard assessment. In Table 2, we show the parameters of the seismic activity model for the revision of the probabilistic seismic hazard maps. In this revision, not only results of the long-term evaluation have been revised, but also the upper limits of background earthquakes have been revised. In addition, here we propose three models in order to consider uncertainty of seismic activity.

The Model 1 is compliant with the revised long-term evaluation. Regarding background earthquakes for the regions ②~⑧ in Fig. 2(a), the maximum magnitude (Mu) of interplate earthquakes is 8.0 and Mu of intraplate earthquakes is 7.5. The Model 2 is a simplified one of Model 1. In Model 2, for background earthquakes, Mu of interpolate earthquake is the maximum magnitude that is calculated from the size of the area and Mu of intraplate earthquakes is 8.2. In Model 3, without using the results of long-term evaluation, the GR model is applied for one large area for all the combined area of ①~⑧ in Fig. 2(a). Mu for interplate earthquake is 9.5 and Mu for intraplate earthquake is 8.2. To see the impact of the earthquake of Tohoku-oki type that is considered in the Model 1, we also make a map as of January 1, 2011 when is just before the earthquake occur. For the Tohoku-oki type, the probability of occurrence over the next 30 years is approximately 15%, assuming the average occurrence interval 600 years and 561 years from the latest activities and α=0.24 for BPT model. Fig. 3 shows a comparison of the 2011 version and the modified 2011 version with the earthquake of Tohoku-oki type. The maps show distribution of exceedance probability within 30 years for JMA seismic intensity 6-. Fig. 4 shows a comparison of the 2011 version and Model 1 of the 2012 version. Fig. 5 shows a comparison of Model 1, Model 2 and Model 3. On the basis of seismic hazard assessment that is averaged over a long period of time, we make maps showing the distribution of seismic intensity corresponding to long return period. To accomplish this, we evaluate the hazard by using a Poisson process for all the seismic activity. We carry out the calculation for return period of 1,000year, 10,000 year and 100,000 year. In Fig. 6, as maps for distribution of seismic intensity corresponding to return period of 1,000 year, we show (a) map evaluated by using a BPT model and (b) map evaluated by using a Poisson model. In Fig. 7, we show maps for distribution of seismic intensity for (a) return period of 10,000 year and (b) that of 100,000 year. The map for return period of 1000 year indicates the degree of shaking mainly caused by subduction zone earthquakes. The map for 10,000 year indicates the degree of shaking caused by not only subduction zone earthquakes but also earthquakes in major fault zones. The map of 100,000 year shows the degree of shaking for most of the shallow inland crustal earthquake, including background earthquakes. For long return period, we can understand that it could be hit by the shaking of seismic intensity 6- or more in almost all regions of Japan.

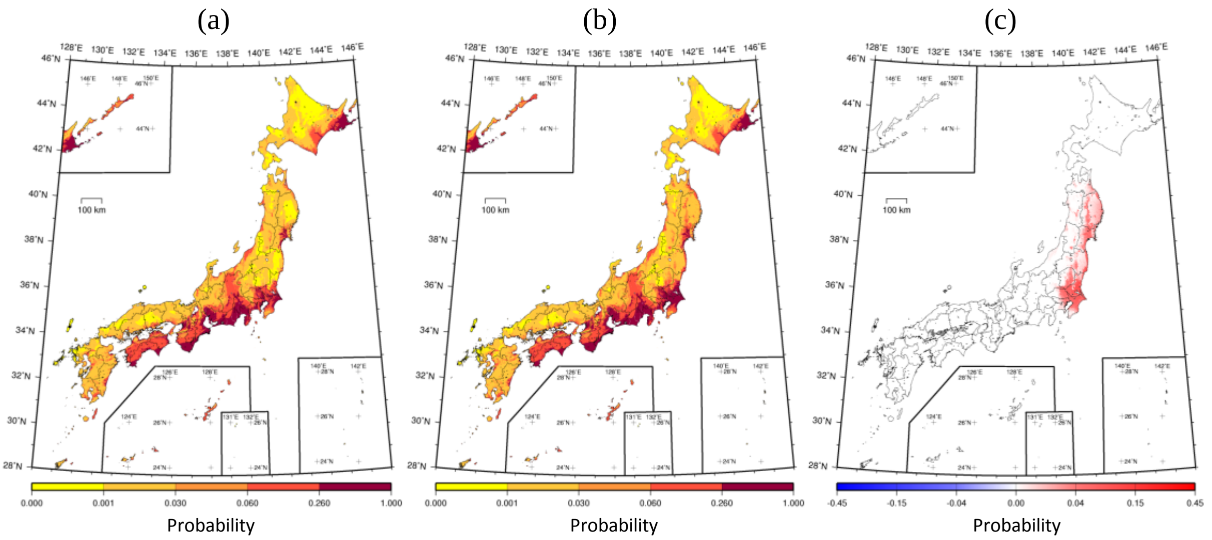

Figure 3. The maps show distribution of exceedance probability within 30 years for JMA seismic intensity 6-. (a) The 2011 version. (b) The modified 2011 version with the earthquake of Tohoku type. (c) The difference between (a) and (b).

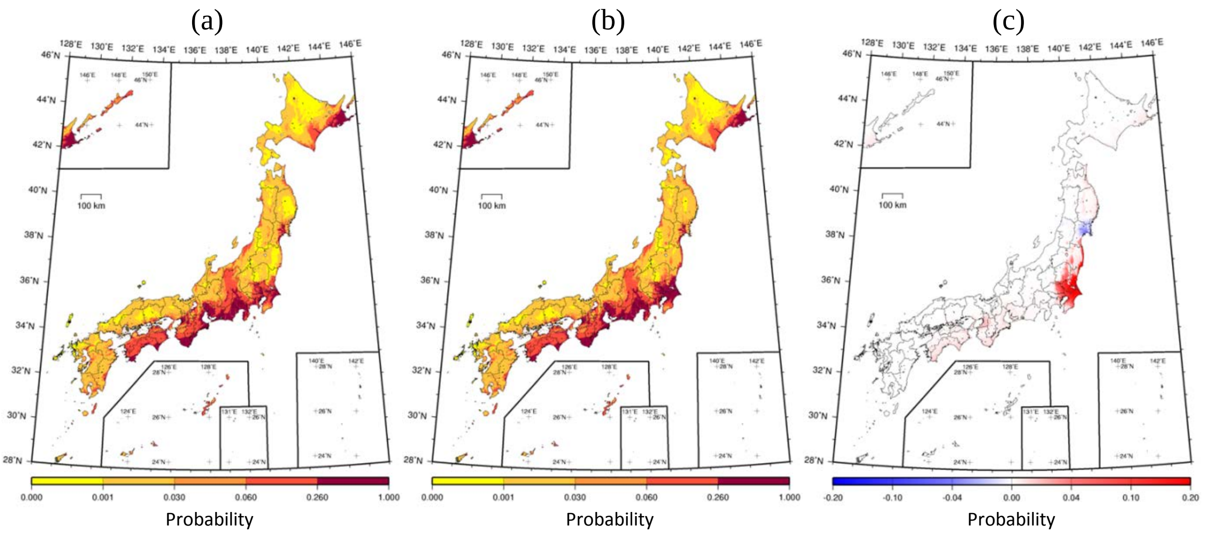

Figure 4. (a) The 2011 version. (b) Model 1 of the 2012 version. (c) The difference between (a) and (b).

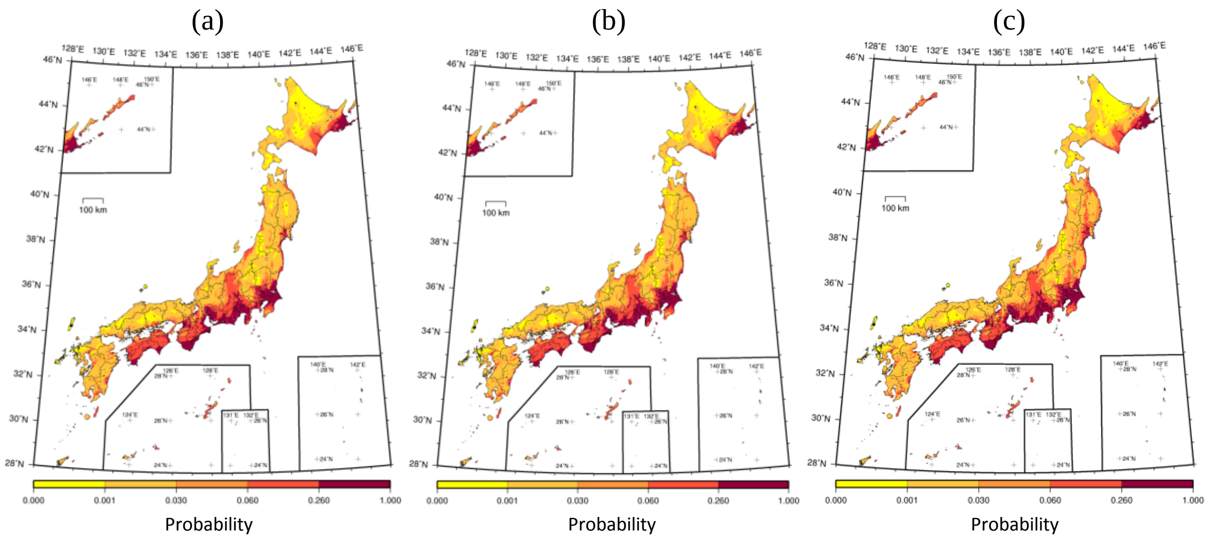

Figure 5. Comparison of (a) Model 1, (b) Model 2 and (c) Model 3.

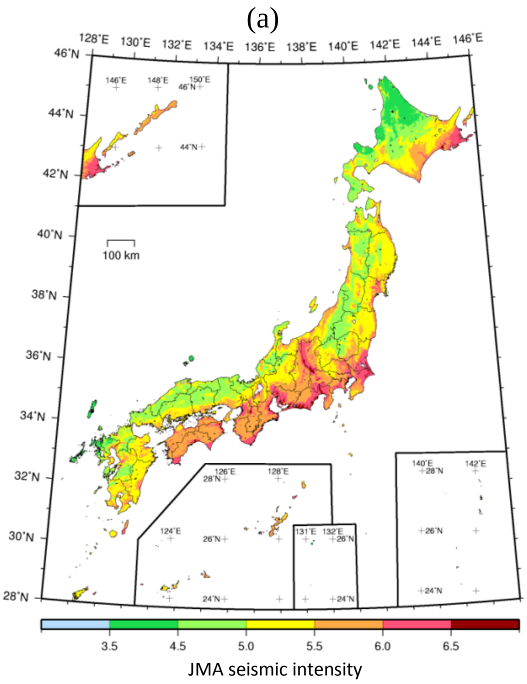

Figure 6. Maps for distribution of seismic intensity corresponding to return period of 1,000 year. (a) The map evaluated by using a BPT model and (b) the map evaluated by using a Poisson model.

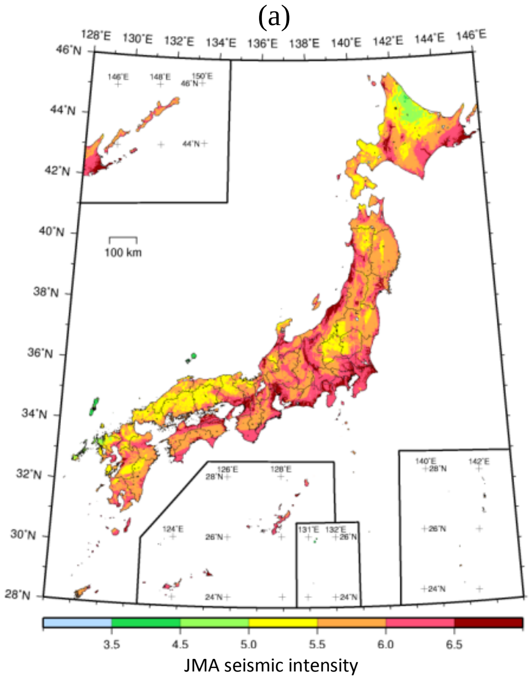

Figure7. Maps for distribution of seismic intensity corresponding to (a) return period of 10,000 year and (b) that of 100,000 year. The map for 10,000 year indicates the degree of shaking caused by not only subduction zone earthquakes but also earthquakes occur in major fault zones. The map of 100,000 year shows the degree of shaking for most of the shallow inland crustal earthquake, including background earthquakes.

6. CONCLUSION

We have made a revision of the seismic hazard assessment based on the revised version of the "Long-term evaluation of seismic activity for the region from the off Sanriku to the off Boso" by the ERCJ. Revision of seismic activity model for other regions of Japan has been undergoing. After the revision of long-term evaluation for whole of Japan, we will recalculate seismic hazard. The followings are problems to be solved in the future.

(1) Modeling of seismic activity with no oversight to low-probability earthquakes
For both subduction zone earthquakes and earthquakes at active faults, it is necessary to aim to model seismic activity that can be considered to events about once several thousands or several tens thousands of years. To achieve this goal, we need to model background earthquakes that include a low probability of earthquakes by using the Gutenberg-Richter formula or other statistical techniques to compensate the long-term evaluation.

(2) Preparation of strong ground motion maps considering low-probability earthquakes
In addition to emphasize the urgency of the earthquake occurrence by showing the probability, by going back to the original purpose of the evaluation of probabilistic seismic hazard, we should prepare the maps that show the strong-motion level for earthquake preparedness. For example, based on the averaged long-term seismic hazard assessment, evaluating strong-motion level for about 10,000-100,000 years return period, we should prepare the maps that show the distribution of strong-motion level. Regarding the seismic hazard assessment for low probability, at present, it is insufficient to evaluate the uncertainty of ground motion prediction for low probability M8 class earthquakes and it is necessary to improve techniques for them.

(3) Development of methodology for selecting appropriate scenario earthquakes from probabilistic seismic activity model
In the seismic activity model considering low-probability earthquakes, not only earthquakes with specified faults, but also earthquakes without specified faults are included. From the seismic activity model, it is necessary to establish a methodology that can be selected as appropriate scenario earthquakes for purposes of earthquake preparedness.

(4) Development of methodology for prediction of strong ground motions for mega earthquakes
In order to perform seismic hazard assessment considered the low-probability events, it is necessary to predict strong ground motions for large earthquakes that have not been recorded by the modern seismic observation network. For the "Method for prediction of strong ground motion for earthquakes with specified faults (recipe)", which is currently being used for strong motion prediction, the subduction zone earthquakes up to about M8 and earthquakes on active fault up to about 80km in length are only verified its scope. The sophistication of techniques that can be applied to the prediction of strong ground motions for super large earthquakes are required.

AKCNOWLEDGEMENT
This study was conducted as a part of the research on advanced seismic hazard assessment for the National seismic hazard maps for Japan.

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