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Implementation of SSHAC Level 3 PSHA Project for the Ikata NPP, Japan

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ABSTRACT

This paper describes the results of the Probabilistic Seismic Hazard Analysis (PSHA) for the Ikata Nuclear Power Plant (NPP), which was conducted as the 1st implementation of Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 project in Japan. Although not a regulatory requirement, the project was conducted as part of the utilities' efforts to improve nuclear safety. The Project began in 2016 and concluded successfully in 2020. This paper presents some of the technical components of the Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) models in the project, procedural aspects in the practical application of SSHAC guidance to Japan, and directions and key challenges of future SSHAC Level 3 PSHA projects in Japan.

OUTLINE OF THE PROJECT

Background and Project Objective

The Japanese nuclear industry has mainly focused on traditional deterministic assessments of seismic hazard, but after the tragic Fukushima nuclear accident in 2011, the importance and significance of practical applications of probabilistic risk assessment (PRA) and risk informed decision making (RIDM) were identified in Japan. Under such circumstances, the Nuclear Risk Research Centre (NRRC) was established within the Central Research Institute of Electric Power Industry (CRIEPI) in October 2014 to develop the methodologies of PRA and to support the utilities' RIDM. Shikoku Electric Power Company (SEPCO) and NRRC decided to implement a SSHAC Level 3 PSHA to enhance the current PSHA in Japan and reliability of Seismic PRA according to the recommendation from the Technically Advisory Committee of NRRC. Although nearly all SSHAC projects carried out worldwide have been conducted as a regulatory requirement, this Ikata SSHAC project was conducted as a voluntary activity for the enhancement of nuclear risk evaluation in Japan. That was a highly sensible decision, despite the fact that SSHAC Level 3 PSHA requires considerable time and financial resources, because it is consistent with best international practice. Japanese regulation, which was revised after the Fukushima accident, still requires a deterministic approach.

Organizational Structure and Study Procedure of SSHAC Level 3

The first challenge of the project was developing and populating the organizational structure. SSHAC guidance, such as NUREG-2117 (2012) and NUREG-2213 (2018) describes key roles and their responsibilities including attributes required for each key participant in a SSHAC Level 3 project. For example, the Project Technical Integrator (PTI) and Technical Integrator (TI) team leads are core roles of a SSHAC project and it is preferred that the participants have experience in the SSHAC process. However, since Ikata SSHAC project was the first in Japan, there were not any Japanese experts who had experienced the SSHAC process. As a result, the Project Manager (PM) and the sponsor decided to ask the US SSHAC experts to join this project as SSHAC special advisors so that the TI team, which is composed of Japanese experts, will be provided with advice on how to conduct the PSHA according to SSHAC Level 3 appropriately. In addition to the participation of the US experts as SSHAC advisors, the PM also asked a US expert to be a member of the Participatory Peer Review Panel. Figure 1 is the organizational structure of Ikata SSHAC Project, which is the same structure as in the SSHAC guidance.

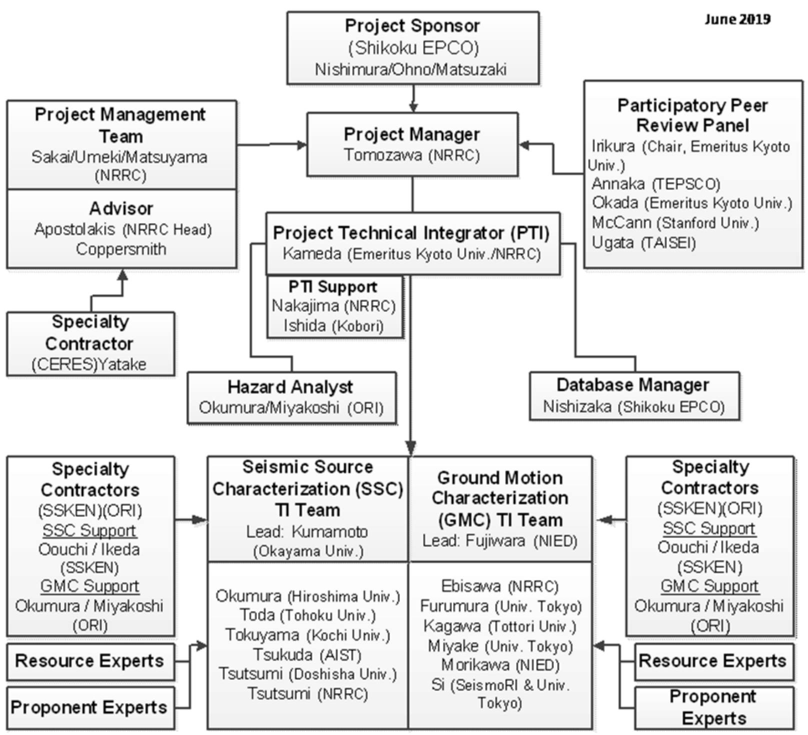


Figure 1. Organizational Structure of Ikata SSHAC Project

The study procedure of this project is based on a SSHAC guidance as shown in Figure 2, with the study divided into three stages. The first stage is "Evaluation", where the TI team evaluates the quality and reliability of the data, methods and models that can be used for the PSHA. Accordingly, the TI team invites external experts, referred to as resource experts (RE), at Workshop (WS) #1 to explain usable data and methods. In addition, the TI team invites proponent experts (PE) at WS #2 to explain and advocate specific models, thereby conducting direct discussions between the TI team and PEs. During the "Integration" stage, which follows "Evaluation", the TI team builds SSC and GMC models that capture the Centre, Body, Range of Technically Defensible Interpretations (CBR of TDI), which is a fundamental concept of SSHAC process. During this stage, preliminary SSC and GMC models are first created and a hazard analysis is conducted.

These results and the comments relating to the preliminary model from the PPRP are used as feedback at WS#3 and, after the workshop, to create a final model. All study contents are documented completely in the final “Documentation” stage.

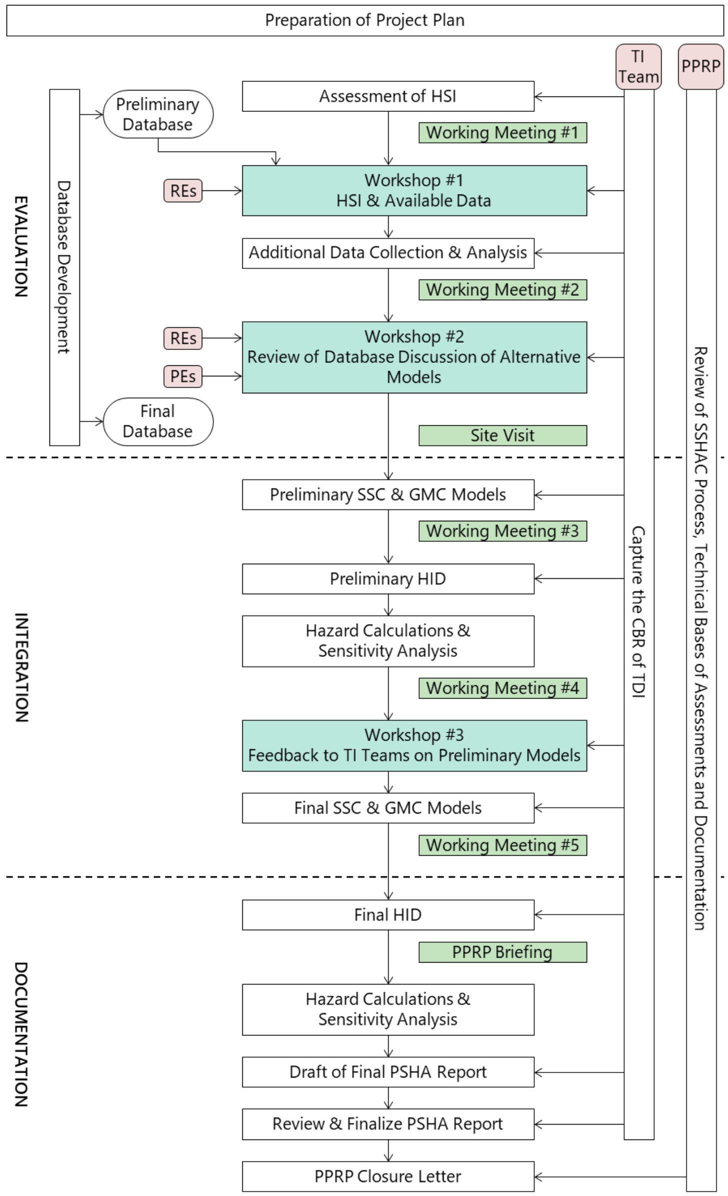


Figure 2. Project Study Procedure

SEISMOLOGICAL ENVIRONMENT OF THE IKATA NUCLEAR POWER PLANT

The Ikata NPP is located in the north western part of Shikoku-island in the western region as shown in Figure 3. The owner of Ikata NPP is SEPCO, which is the sponsor of this project. Figure 3 also shows the distribution of active faults. One of the longest active fault systems in Japan named the Median Tectonic Line (MTL) is located close to the Ikata NPP. The shortest distance between MTL and Ikata NPP is 8km. Based on the seismological environment, the TI team identified characterization of the MTL, such as fault segmentation, occurrence probability, estimation of seismic motion in the immediate area of the seismic source, etc. as hazard significant issues. In addition to the considerations of the MTL, intra/inter plate boundary earthquakes along the Nankai Trough subduction zone were also considered. Nankai Trough is a subduction zone between the Philippine Sea plate and Eurasian Plate. Historically, the maximum magnitude along the Nankai Trough was about M8.7. The Japanese government re-evaluated the probable maximum magnitude earthquake as M9.0 after the occurrence of the Tohoku mega-earthquake in 2011. Consequently, the TI team considered that geometry, location, and occurrence probability of Nankai Trough earthquakes as also one of the other important hazard significant issues.

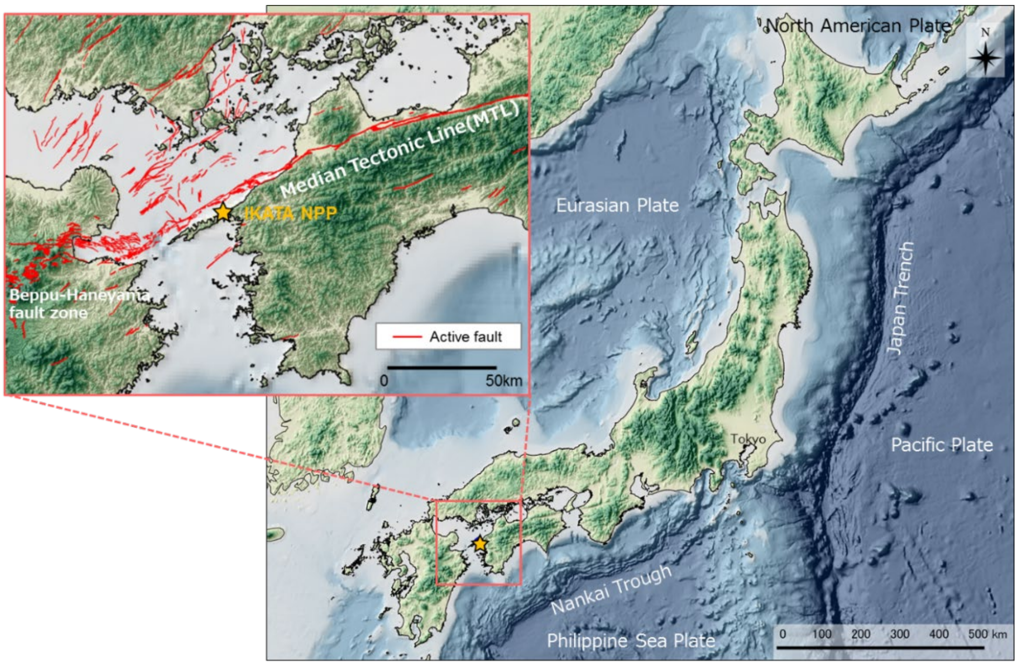


Figure 3. Location of Ikata NPP

TECHNICAL STUDIES OF THE PROJECT

The SSC TI team characterized all seismic sources that have the potential to contribute to the hazard at the Ikata NPP. Source characteristics include source locations and geometries, maximum magnitude and recurrence intervals. The TI team is in charge of capturing the CBR of TDI, which includes all uncertainties. The SSC TI team also developed a model for the segmentation and recurrence characteristics of the MTL. Development of site specific Ground Motion Prediction Equation (GMPE) and application of fault rupture model in PSHA are the major important technical issues in GMC TI team. A full application of fault rupture model is being conducted to augment empirical observations and this represents considerable advancement for PSHA. The empirical observations of the GMPEs for nearby seismic sources need to be supplemented with a physical model. GMC TI team realized that the application of fault rupture model is essential for the PSHA of Ikata NPP because the MTL is located only 8km away from the site.

SSC Model

A logic tree model relating to the scale of the MTL is shown in Figure 4. Note that the MTL is evaluated on the basis of historical earthquakes based on ancient documents, events history from paleo-earthquake surveys, geometrical characteristics of fault system such as the step width of fault segments, etc. The SSC TI team evaluated that MTL are divided into eight segments.

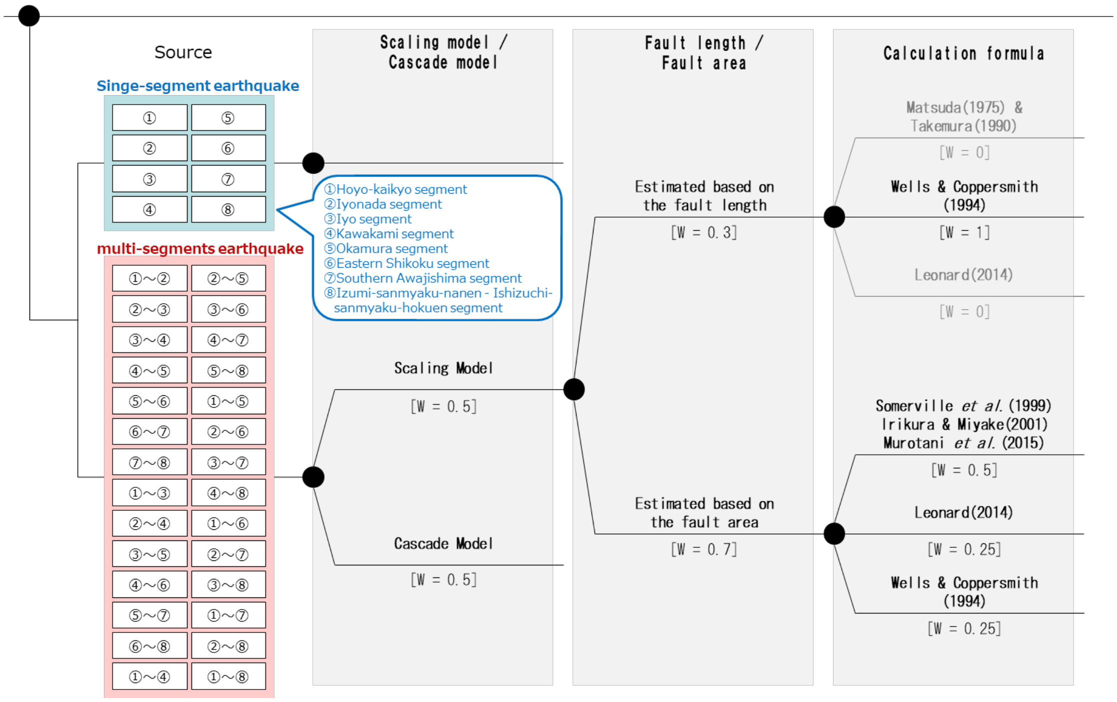


Figure 4. Logic Tree Model of Scale of MTL

GMC Model

As for the MTL, which seems dominant to Ikata NPP, both GMPE and fault rupture model are utilized to estimate site ground motions. The GMPEs support high reliability within the range of the dataset, whereas the fault rupture model supports high applicability near the seismic source in terms of setting weights. Considering that both the empirical and physical methods have numerous application examples in Japan and are equally defensible, the weights were determined to be equal and set as 0.5:0.5. Figure 5 and Figure 6 show the logic tree model for ground motion of the MTL using GMPE and the fault rapture model, respectively. When the TI team decided to apply the fault rupture model, they examined uncertainties systematically and comprehensively. Figure 7 shows the comparison between Japanese methodologies (Empirical Green's function (EGF) and Stochastic Green's function (SGF)) and methodologies in South California Earthquake Centre, Broadband Platform (SCEC BBP), that is, methods of Song, CSM, EXSIM, SDSU, UCSB, GP. Based on these studies, the TI team concluded the uncertainty range of the median value is about 1/1.5 to 1.5.

HAZARD ANALYSIS RESULTS

As shown in Table 1, combining all seismic sources results in a number of branches on the order of 10^{25} and 10^{26} for the horizontal and vertical motions, respectively. Therefore, fractile hazard curves were first calculated for each seismic source and then combined to calculate the overall hazard curves, which reduced the amount of calculations. All hazard curves are shown in Figure 8. Figure 8(1) shows fractile hazard curves and Figure 8(2) shows hazard curves from each seismic source. In the relatively high frequency range, the Nankai Trough earthquake is dominant, whereas MTL is dominant in the low frequency range.

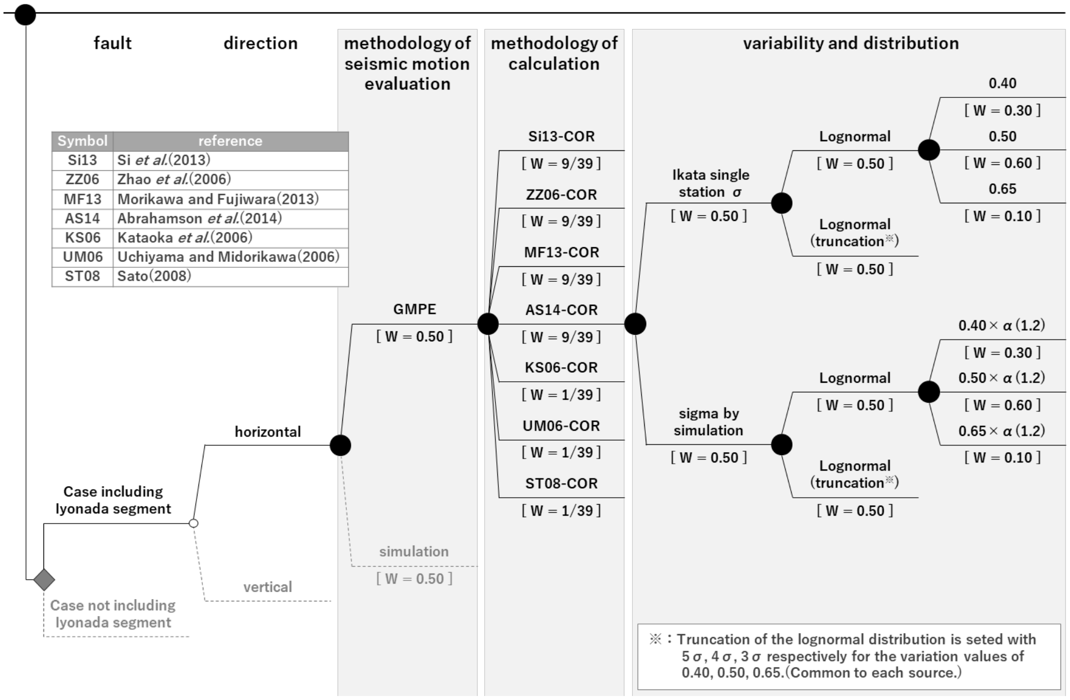


Figure 5. Logic Tree Model of Ground Motion of MTL (GMPE)

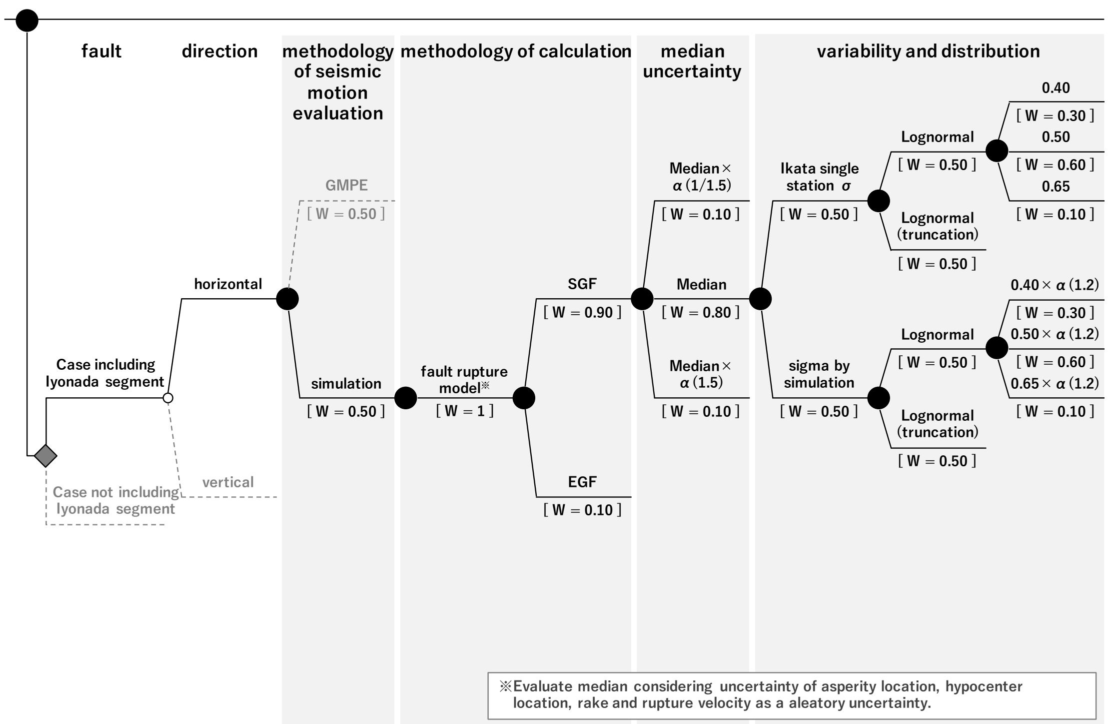


Figure 6. Logic Tree Model of Ground Motion of MTL (Fault Rupture Model)

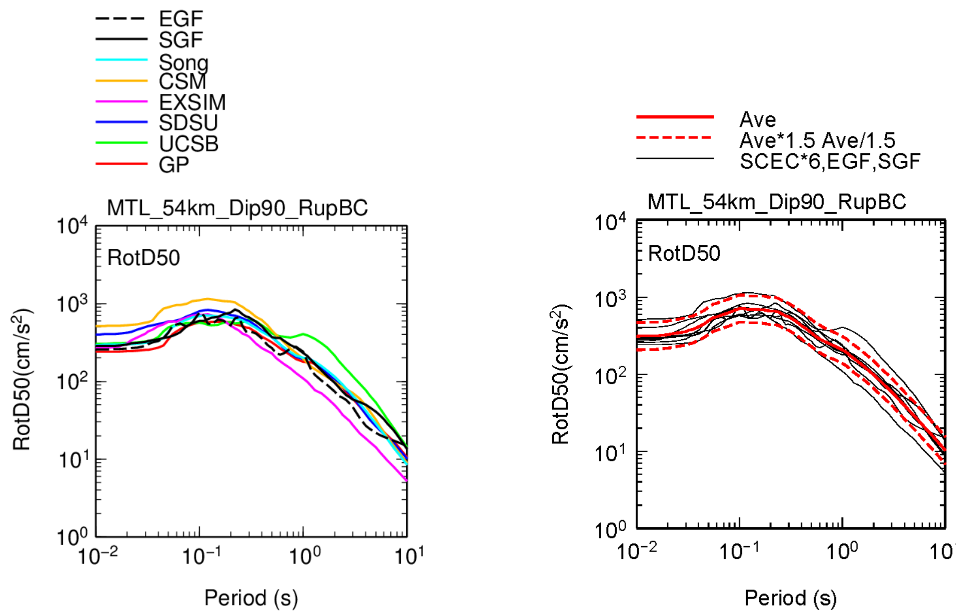
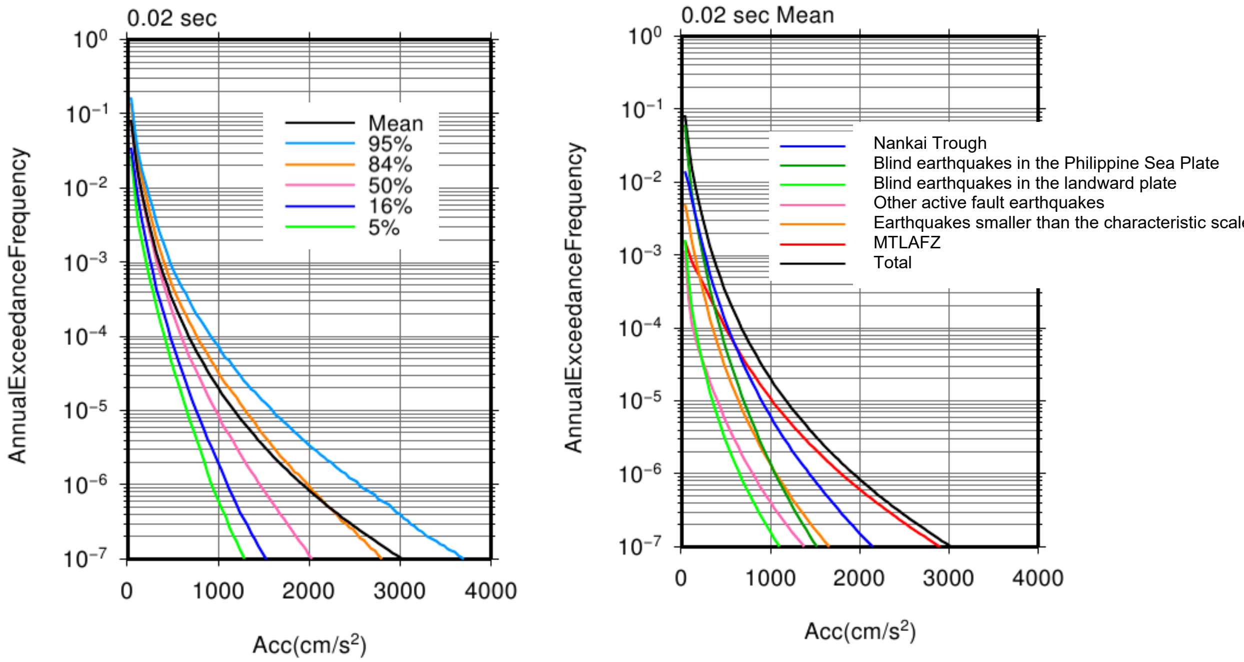


Figure 7. Comparison among Various Methods of Fault Rupture Model

Table 1: Number of Logic Tree Branches

Earthquake type category	Horizontal	Vertical
MTLAFZ earthquake		
GMPE including Iyo-nada Segment	88,704	152,064
Simulation including Iyo-nada Segment	76,032	114,048
Total	164,736	266,112
Iyo-nada Segment not included	44,352	76,032
Earthquakes smaller than the characteristic scale	84	144
Other active intraplate fault earthquakes		
Other than Gotanda fault	168	288
Gotanda fault GMPE	588	1 008
Gotanda fault simulation	252	504
Total	840	1,512
Blind earthquakes in the landward plate	672	1,152
Blind earthquakes in the Philippine Sea Plate	336	336
Nankai Trough Megathrust Earthquake	1,512	1,512
Total	2.96E+25	7.43E+26



(a) Fracrile Hazard Curves (b) Hazard Curves of Each Seismic Source

Figure 8. Hazard Curves (Horizontal/0.02s)

As an example of the hazard sensitivity analyses conducted, Figure 9 shows the variance contribution plot of Nankai Trough earthquake source characteristics. The plot shows the relative contribution that each characteristic of the Nankai source makes to the total variance in the hazard results. This allows an understanding of dominant contributors to the hazard uncertainty and variability. As shown in Figure.9, GMPE selection is the dominant uncertainty for the hazard curves. There are several GMPEs in the logic tree model (Figure.5) and each model is associated with parameters that include significant aleartory variability. It is suggested that considerations on selection and site correction of GMPEs are one of the biggest challenges in PSHA.

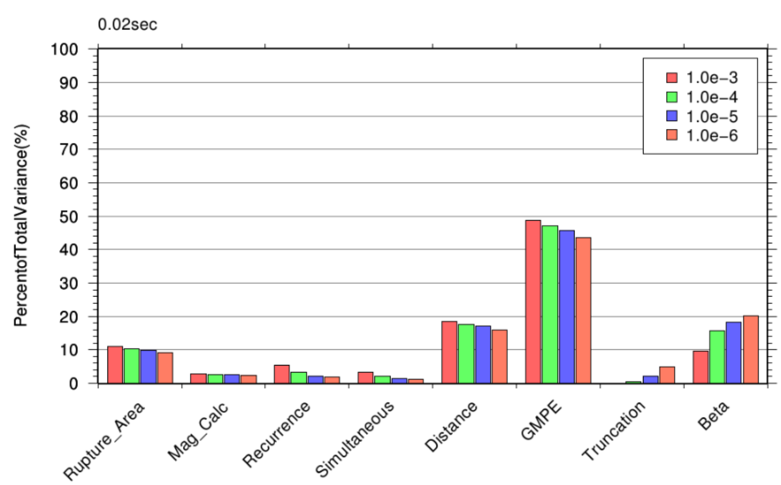


Figure 9. Variance Contribution of Nankai Trough Earthquake

PRACTICAL ARRANGEMENTS

Since there are some cultural and institutional differences, we arranged practical modifications on the actual SSHAC guidance. We obtained the approval of SSHAC advisors for those modifications in order to avoid any violations in the appropriate SSHAC process. The followings are such modifications.

- Use of a "TI support team"

Japanese experts in universities and public institutions are subject to restrictions on side jobs. Therefore the time that TI Team members can spend on the Ikata SSHAC project is limited. The PM and the sponsor set the "TI support team" which is composed of speciality contractors and SEPCO technical staff to solve the situation. However, the responsibilities of the TI support team was just to prepare documents, data and others to be discussed in the TI team. TI support team did not play a role in decision making for PSHA modelling nor did they provide direction of study items. In other words, all decision makings were done by the TI team according to the SSHAC guidance. Due to the restrictions, it was also difficult to hold the Workshops, Working Meetings and TI team internal meeting, so WSs and WMs were often held on the weekends and TI meetings were held in the evenings. These are the practical obstacles for Japanese experts to join the SSHAC project.

- Obtaining various advice from the SSHAC advisor and repeated trainings

It was observed that TI members of some SSHAC projects outside of the US were composed of US experts and experts from relevant countries. However, the PM and the sponsor decided to compose the TI team with Japanese experts in order to increase the number of experts who experience the SSHAC process for future SSHAC-based PSHAs in Japan. To compensate for the lack of SSHAC experience, Dr. Kevin Coppersmith who is one of the co-authors of this paper played a role of special advisor. Project participants such as TI team, PPRP, project management team received various useful advice from him and were able to keep the quality of SSHAC Level 3. Similarly, Japanese experts are not accustomed with probabilistic analysis much because deterministic approach is widely applied in Japan as a whole. SSHAC advisors and other relevant experts conducted SSHAC procedural training to TI members to ensure that all SSHAC processes were understood.

- Participation of regulators

In most SSHAC projects, regulators observe the SSHAC workshops because the SSHAC project is implemented to fulfil regulatory requirements. However, the Ikata SSHAC project was not implemented as an activity of regulatory requirement, but rather as utility's voluntary activity for the improvement of nuclear safety. The PM informed Nuclear Regulatory Authority (NRA) of the Ikata SSHAC project, then the NRA staff observed workshops and working meetings of this project.

DIRECTIONS AND KEY CHALLENGES OF FUTURE SSHAC-BASED PSHA DEVELOPMENT IN JAPAN

One of the lessons learned from the Ikata SSHAC project is that the SSHAC process requires significant funding and is time consuming. How to develop and implement SSHAC Level 3 based PSHA to a whole country of Japan is a challenging issue. Repeated implementations of site specific SSHAC projects as Ikata SSHAC project in Japan is not realistic considering the budget, study period, and limitation of experts. Instead, a multi-site SSHAC process is one of the feasible options. There are two different types of study procedures for the multi-site SSHAC process according to the NUREG-2213: a "phased" study and an "integrated" study. One is the phased multi-site SSHAC study which is composed of two stages. The first stage is the regional study including multi-sites. The second stage is site-specific refinements at each site based on the results of regional study. The CEUS-SSC project for the NPP sites in the central and eastern US was a phased multi-site SSHAC process (USNRC 2012a). The other is an integrated multi-site SSHAC process which conducts regional study and site specific study in a single SSHAC project. The SSHAC process for the NPP sites in Spain used this integrated SSHAC process. Specific plans for PSHA development in Japan will be studied through some technical surveys and studies. Because the seismicity of CEUS and Spain mentioned above is lower than Japan, it is necessary to consider the feasibility before we make up the concrete plan for SSHAC Level 3 based PSHA development in Japan. Meanwhile, we understand it is also important to share various study contents during Ikata SSHAC project with utilities and PSHA conductors. So, we are currently creating the "Practical PSHA guide based on lessons learned from Ikata SSHAC project". The character of this guide is designed to make the PSHA study process efficient by providing useful information.

CONCLUSION

This paper described the motivation, technical contents, and results of the Ikata SSHAC project, which was the first implementation of SSHAC Level 3 PSHA study in Japan. In addition, practical considerations for SSHAC guidance application to Japan was also described. Finally, directions and challenges for future SSHAC Level 3 PSHA development in Japan were also presented. The SSHAC Level 3 process has been used to conduct PSHA for nuclear facilities in several countries, including the United States, Spain, Switzerland, Taiwan and South Africa. The Ikata SSHAC Level 3 project clearly shows that the SSHAC process should be adopted in Japan and is an effective mechanism for capturing the current knowledge and uncertainties. The results of the Ikata SSHAC Level 3 project will be used in PRA/PSA at the site with high reliability.

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