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# Progress on the SSHAC Level 3 PSHA Project for the Ikata NPP, Japan

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## ABSTRACT

The progress of the Probabilistic Seismic Hazard Analysis (PSHA) for the Ikata Nuclear Power Plant (NPP) being conducted as a Senior Seismic hazard Analysis Committee (SSHAC) Level 3 project is presented. This project is the first PSHA implementation in Japan based on the SSHAC guidelines, which are stated in NUREG-2117(USNRC, 2012) and NUREG-2213(USNRC, 2018). The project started in 2016 as part of power utilities' efforts to enhance their seismic risk assessment capabilities and continuous improvement of nuclear safety. Nuclear Risk Research Centre (NRRC) and Shikoku Electric Power Company (EPCO) have been working together in this project. The project is scheduled to finish by the end of Japanese FY2019 (March, 2020). There have been three Workshops and five Working Meetings since the project started. Technical Integration (TI) teams related to Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) have already developed the final PSHA models and the project is currently conducting final hazard calculations based on them. While the TI teams were developing their preliminary and final models, several remarkable technical issues have been raised and discussed. This paper describes those technical issues which are realized and treated in the SSHAC project.

## OUTLINE OF IKATA SSHAC Level 3 PROJECT

### *MOTIVATION OF THE PROJECT*

Although Japanese nuclear regulations still require deterministic assessments even after the Fukushima nuclear accident in 2011, Japanese nuclear industry realized the importance and significance of the application of Risk-Informed Decision Making (RI-DM) in order to understand the plant's risk profile comprehensively and also make rational decisions based on them. The activity to develop RI-DM in Japan is an industrial voluntary action. NRRC and Shikoku EPCO started PSHA according to SSHAC guidelines in 2016. Development of RI-DM requires enhancement of the Probabilistic Risk Assessment (PRA) methodology and PSHA plays an important key role in the seismic-PRA as there are relatively large uncertainties inherent in natural external events hazard assessments. In other words, PSHA conducted in an appropriate study procedure based on SSHAC guidelines is an essential task for the development of seismic-PRA.

## *IKATA SSHAC ORGANIZATION*

The Organization of the Ikata SSHAC Level 3 project is shown in Figure.1. Because this is the first SSHAC project in Japan, the management team selected a few experts who had experience in the implementation of SSHAC projects: Dr.Kevin Coppersmith assumed the position of an advisor; and Dr.Martin MaCann is a member of Participatory Peer Review Panel (PPRP). Based on the experience of these individuals, the project was organized and has been progressing based on NUREG-2117/2213 and with much consideration of the scope of the roles and responsibilities of each participant.

One of the lessons learned from Ikata SSHAC level 3 project is the importance and necessity of SSHAC training including PSHA, PRA, bias consideration and so forth for all SSHAC participants. Japanese participants have already realized that there are some procedural differences between Japanese existing PSHA and to the one stated in the SSHAC guidelines. For example, Japanese seismic PRA standard allows to weigh options by using questionnaires for logic tree model. However, according to SSHAC guidelines, face-to-face discussion is required and important in the weight determination. The fact that all participants fully understand SSHAC guidelines is essential to conduct PSHA based on SSHAC guidelines.

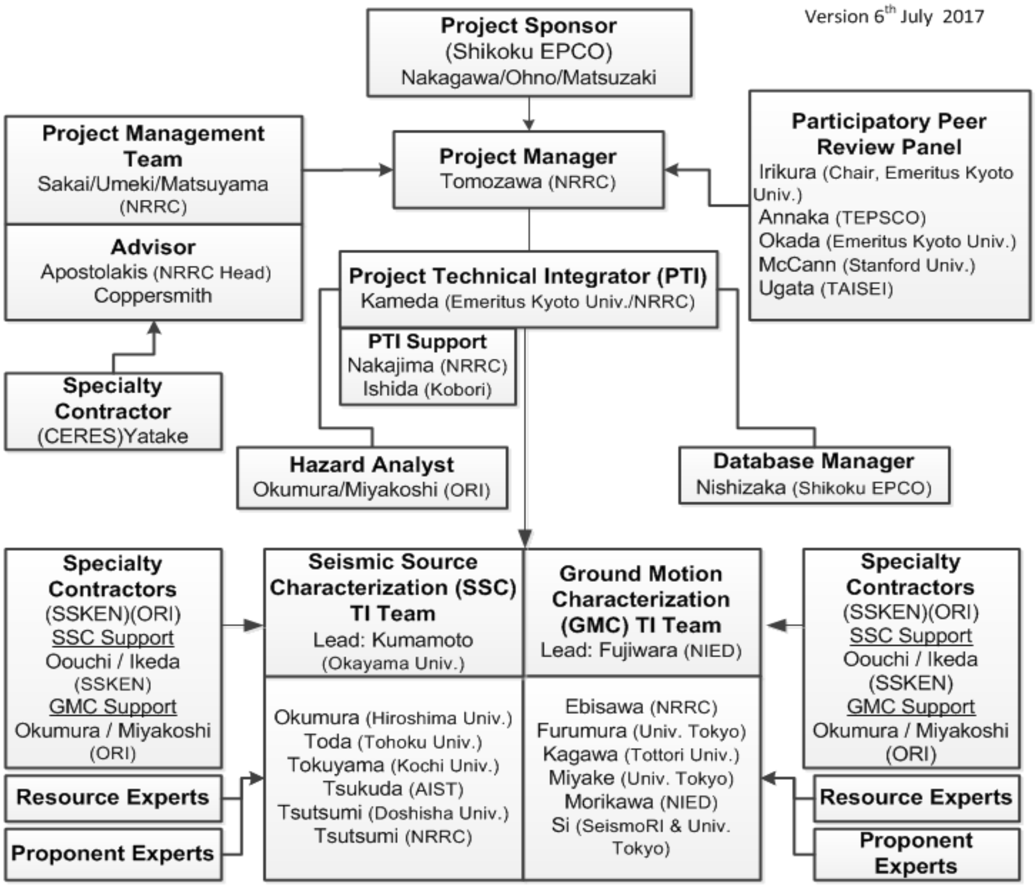


Figure 1. Ikata SSHAC Level 3 PSHA Project Organization

## SEISMOLOGICAL ENVIRONMENT OF IKATA NPP SITE

Figure 2 shows the location of Ikata NPP site and distribution of active faults around the site. Ikata NPP site is located in the north western of Shikoku-island in the western region of Japan. One of the most remarkable seismological characteristics of Ikata NPP is that one of the longest active fault systems in Japan named Median Tectonic Line (MTL) is located nearby Ikata NPP site. The shortest distance between MTL and Ikata NPP is about 8km. During the permission stage of restarting Ikata NPP after the Fukushima nuclear accident, MTL was evaluated as 54km long active fault in basic scenario and 480km long in the most conservative scenario based on deterministic approach. Because of its long length, evaluation of uncertainty of fault segmentation and earthquake occurrence probability of the MTL was identified as a likely hazard-significant issue from the beginning of the project.

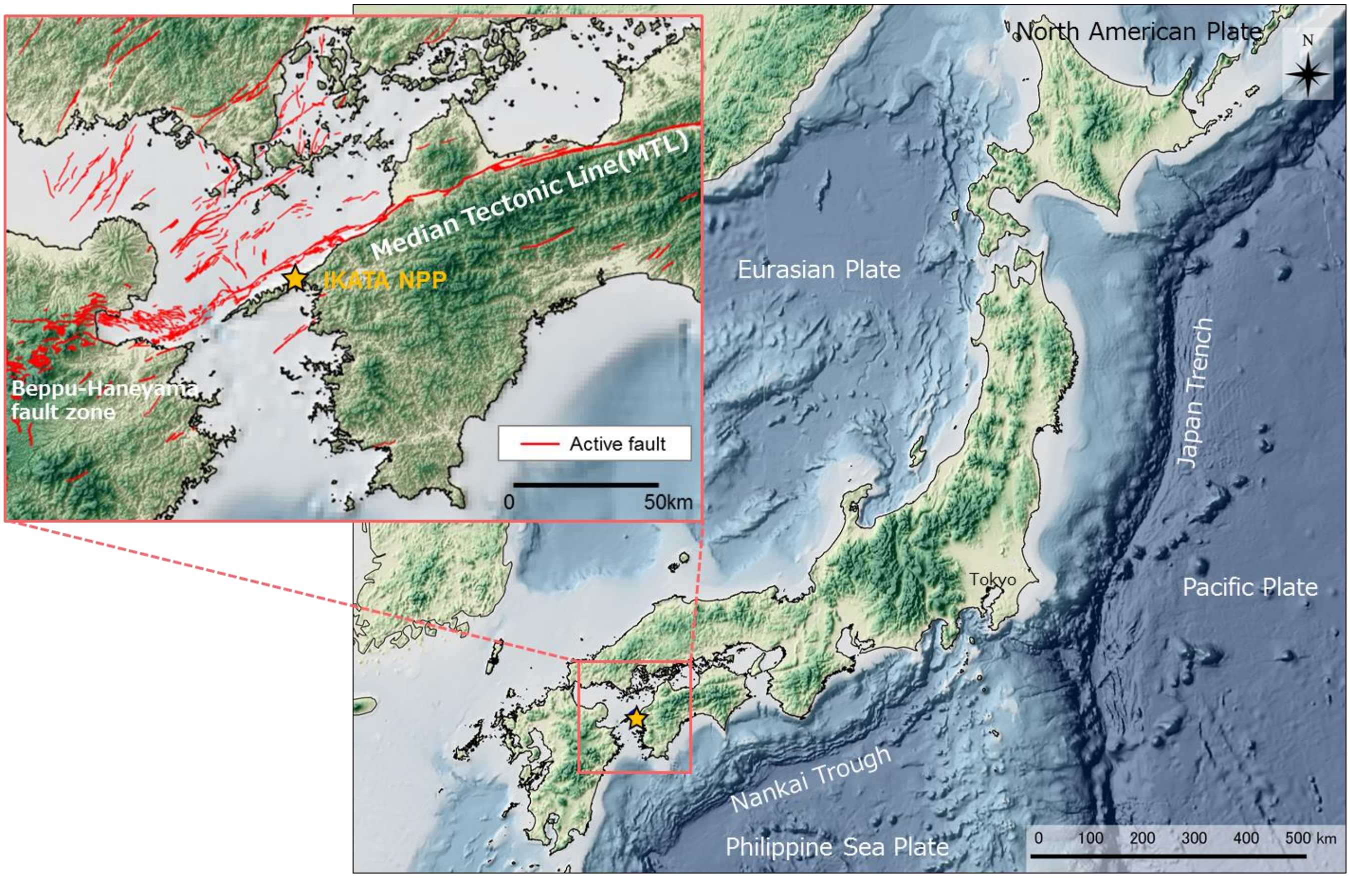


Figure 2 Site Location

In addition to the MTL evaluation, intra/inter plate boundary earthquakes along the Nankai Trough subduction zone have also been considered. Nankai Trough is a subduction zone between the Philippine Sea plate and the Eurasian Plate. The plate interface is located 30-40km beneath the Ikata NPP site. Historically, the maximum magnitude along the Nankai Trough is about Mw=8.7. Preliminary calculations show that maximum magnitude estimates for the Nankai Trough are generally one of the hazard-significant issues. As a matter of fact, after the M9 earthquake in 2011 in Tohoku region, the Japanese government evaluated the maximum magnitude of earthquakes along the Nankai Trough as M9. Consequently, TI teams considered that geometry, location, and occurrence probability of Nankai Trough earthquakes as one of the most significant hazard issues.

Other than MTL and Nankai Trough, earthquakes occurring within the local area source, especially zoning of area source and magnitude-frequency distribution, were also pointed out among TI-teams as hazard-significant issues.

## TECHNICAL STUDIES RELATED TO IKATA SSHAC LEVEL 3 PROJECT

### *OUTLINE OF THE TECHNICAL STUDIES*

The SSC TI team has characterized all seismic sources that have the potential to contribute to the hazard at the Ikata site, including both crustal sources and subduction zone sources. Source characteristics include source locations and geometries, maximum earthquake magnitudes, and earthquake recurrence. The TI team is in charge of capturing the Centre, Body, Range of Technically Defensible Interpretation (CBR of TDI), which is the key concept of SSHAC. The SSC TI team has 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 major important technical issues in GMC TI team. A full application of fault rupture models is being conducted to augment empirical observations and this represents considerable advancement for PSHA. The empirical observations of the GMPEs nearby seismic sources need to be supplemented with a physical model. It was realized that application of fault rupture models is essential because MTL is located only 8 km away from Ikata NPP site. Various studies regarding methods, models, setting branches and weights have been conducted by GMC TI team to ensure the capture of the CBR of TDI.

### *OUTLINE OF SENSITIVITY ANALYSIS BASED ON THE PRELIMINARY MODELS*

Final hazard calculations are being conducted based on the final SSC/GMC models, which were constructed after the 3rd Workshop. During the 3rd Workshop, TI teams obtained feedback from the discussion with PPRP from capturing CBR of TDI and hazard calculations including hazard sensitivity studies based on preliminary models. There were several suggestions for the evaluation of uncertainty based on hazard sensitivity studies. Figure 3 is a tornado plot that shows the contribution to uncertainty from each branch of the logic tree for the MTL. Positions of each rectangle in the figure are the calculated PGA (Peak Ground Acceleration) associated with each branch of the logic tree. The broader the range of calculated results, the larger the contribution to the uncertainty in the mean hazard. The size of each rectangle scales with the weight assigned to each branch by the TI teams. Figure 3 shows that uncertain factors related to GMC are relatively dominant compared to the ones of SSC. Especially, it is easy to understand that selection of GMPE and single station sigma are key factors to be studied for building logic tree model.

Similarly, Figure 4 shows contribution of each uncertain factor to Nankai Trough earthquake. In addition to some GMC factors, magnitude determination affects the level of seismic hazard in this case. In other words, there seems to be a debate regarding the maximum magnitude of earthquakes along the Nankai Trough. After the M9.0 earthquake occurrence in 2011, pessimistic estimation has become common in the seismic academy in Japan. Risk assessment such as PRA and PSA aims basically for the best estimate solution, but also accounts for recurrence rates and uncertainties. However, realization of conservatism in hazard assessment is difficult to evaluate. SSC TI team has discussed maximum magnitude very carefully through evaluation and integration stages, but it can be seen that other GMC related factors are equally or even more important to hazard than the magnitude.

TI teams examined these hazard sensitivity studies and also considered various and useful comments and recommendations from PPRP based on CBR of TDI and helpful information based on SSAHC advisor’s experiences through previous SSHAC projects. The TI teams put all of these information together and developed the final SSC/GMC models.

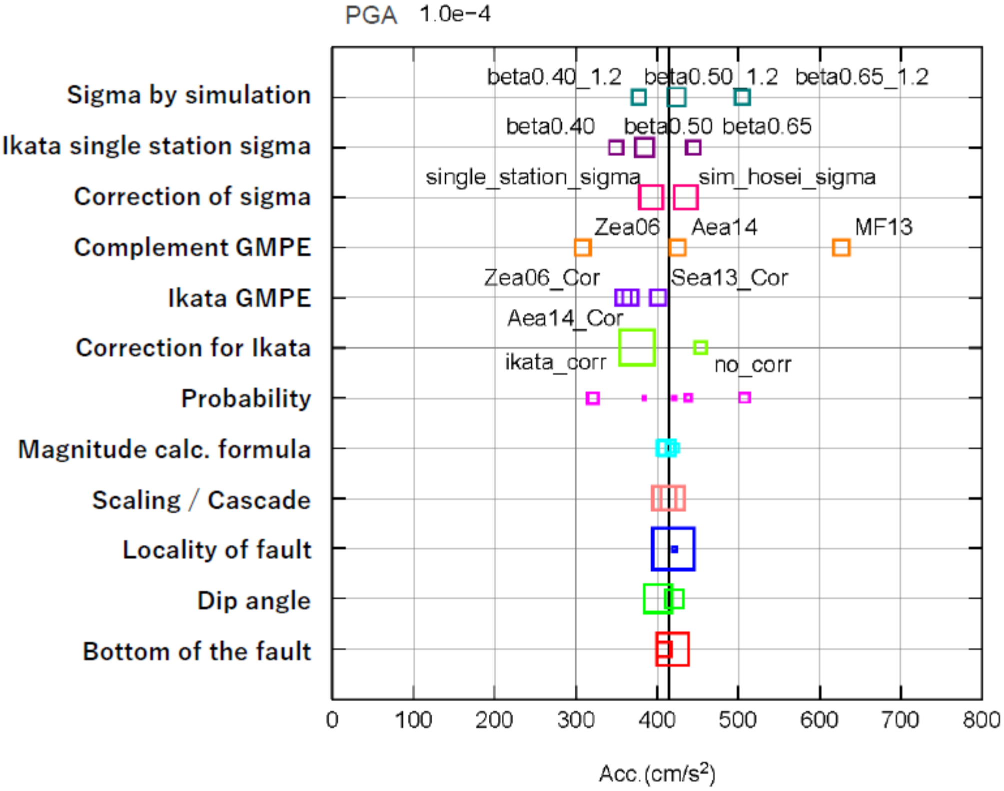


Figure 3. Tornado Plot (MTL: PGA (Horizontal): $10^{-4}$/y)

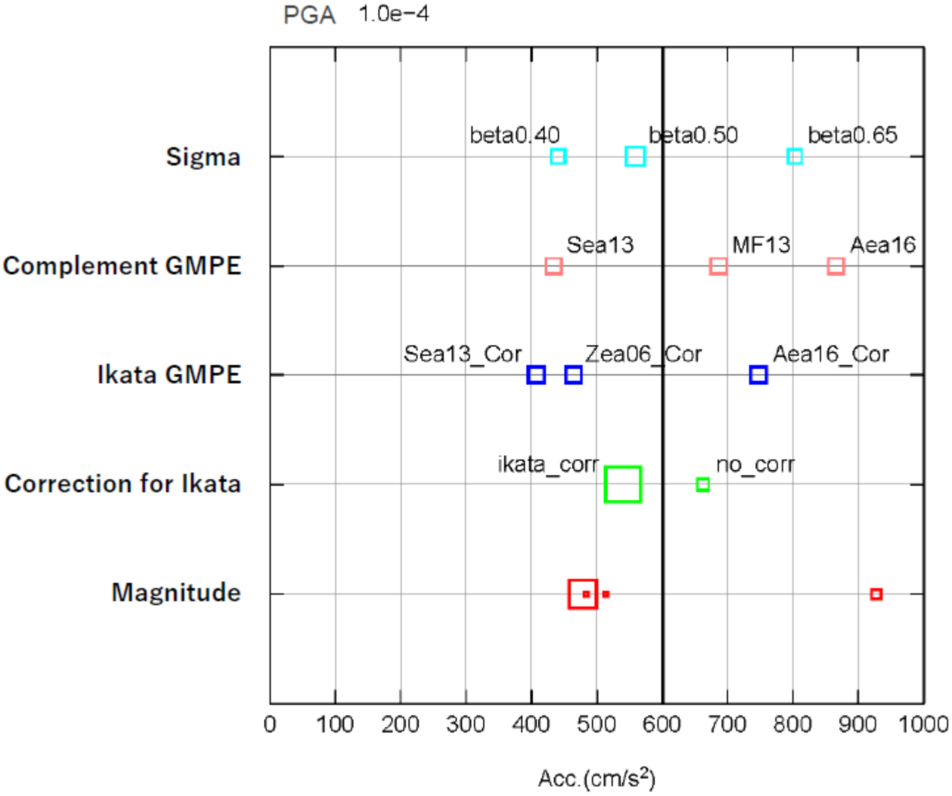


Figure 4. Tornado Plot (Nankai Trough: PGA (Horizontal): $10^{-4}$/y)

## *SPECIFIC TECHNICAL STUDIES IN IKATA SSHAC LEVEL 3 PROJECT*

Because of the importance of the selection of GMPE, the GMC TI team considered the treatment of GMPE as the final GMC model very carefully. GMC TI team decided to develop site specific GMPE based on the Japanese and international GMPE according to the comments and recommendations of SSHAC advisor and PPRP.

The GMC TI team developed site specific GMPE utilizing correction methodology based on the original GMPE and compatibility between observation data and estimated value. However, there are only a few observation records at Ikata NPP site. The TI team also considered observed seismic motion data which are recorded in Japanese network systems of seismic motion, such as K-NET and KIK-NET. The TI team selected 8 basic GMPE based on clear criteria such as a shear velocity of the ground, considering the fact that shear velocity of the foundation ground of Ikata NPP is about 2.6km/s. Figure 5 shows one of the study examples of comparison between pre-correction and post-correction for each 8 GMPE. 8 GMPE were mostly proposed by Japanese experts except for one from the US. Finally, GMC TI team assigned the weight based on the general considerations on credibility of original GMPE, adaptability and others.

The GMC TI team has also adopted the latest methodology in estimation of ground motion. That is full-dressed application of fault rupture simulation in PSHA. Fault rupture model has been common in estimation of ground motion in Japan not only for the nuclear industry but also for government studies regarding earthquake damage prevention. The fundamental reason for the development of fault rupture model in Japan is that there are only a few observation recorded ground motion data nearby seismic source even in Japan where seismicity is very high, even though there are many specific active faults. That means credibility of GMPE nearby seismic source is not believed as high as it is commonly considered internationally.

However, practical applications in the past of fault rupture models have been limited to deterministic assessments. Therefore, the GMC TI team had to study the application of fault rupture model in PSHA including examination of the accuracy of the fault rupture model and determination of epistemic uncertainty comprehensively. Figure 6 is one of the study examples related to fault rupture simulation. Figure 6 shows the comparison between Japanese methodologies (EGF (Empirical Green's Function), SGF (Stochastic Green's Function)) and methodologies in SCEC BBP (South California Earthquake Centre, Broadband Platform/Song, CSM, EXSIM, SDSU, UCSB, GP). Based on these studies, the TI-team determined the weights of fault rupture model and their range of epistemic uncertainty in logic tree model. The GMC TI team concluded that the uncertainty range of mean value is about from 1/1.5 to 1.5 as shown on the right part of Figure 6.

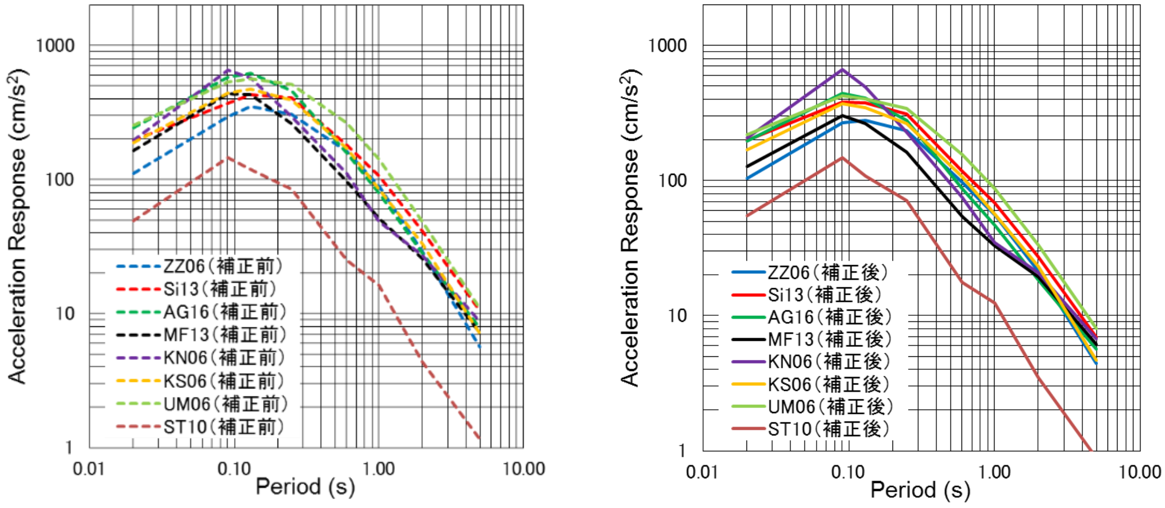


Figure 5. Comparison of pre-correction and post-correction for GMPE selection
(Ex. Mw=7.0 Distance=50km)
(Left: Pre-correction /Right: Post-correction)

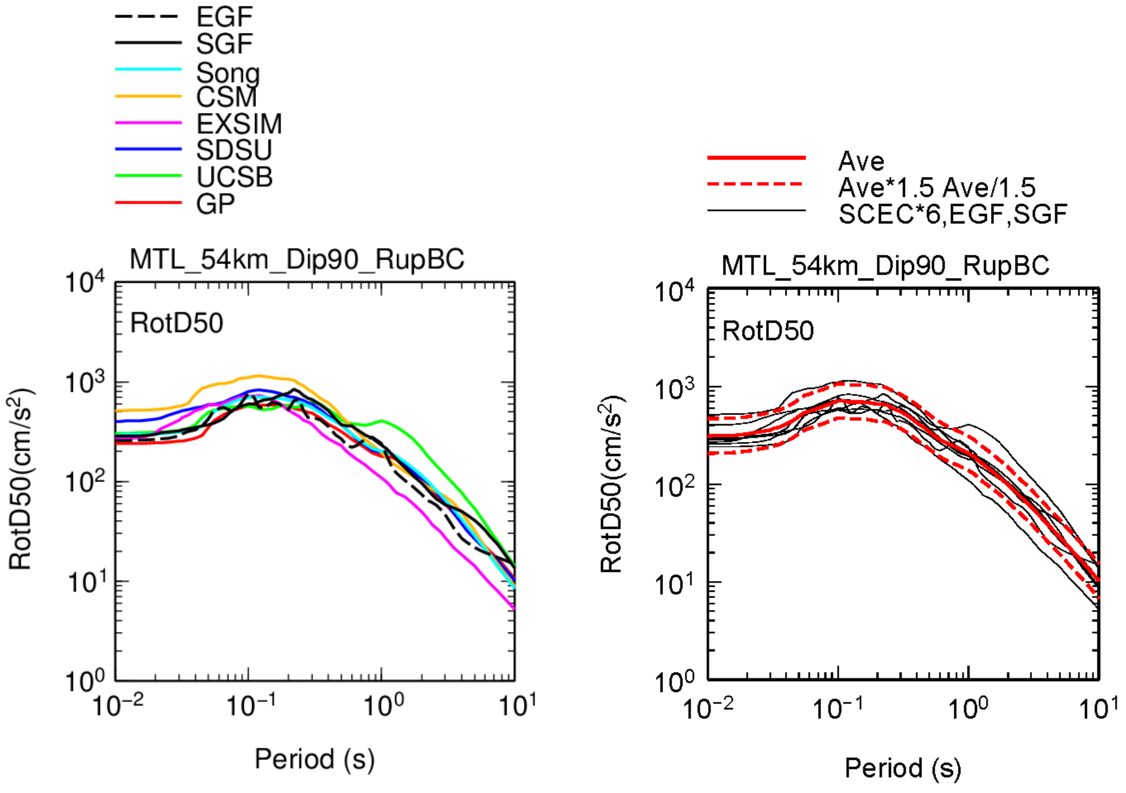


Figure 6. Comparison of fault rupture model simulation
(Source: MTL (Fault Length: 54km, Distance: 8km)

## OUTLINE OF FINAL SSC/GMC MODEL

SSC/GMC TI teams have developed their final PSHA models based on comprehensive assessments related to seismic source and ground motion characterization. Figure 7 and Figure 8 show typical examples of logic tree model of SSC and GMC respectively. Figure 7 shows a logic tree model regarding a scale evaluation of the earthquake caused by MTL considering fault segmentation.

Figure 8a shows ground motion estimation utilizing GMPE. The TI team selected 8 corrected GMPE as site specific GMPE and also considered Ikata single station sigma as the variability of GMPE. Because of the lack of observation records nearby seismic source, it is fundamentally difficult to estimate the variability of GMPE nearby seismic source. Therefore, the GMC TI team considered another branch related to variability of GMPE, that is, variability which is estimated by numerical simulation utilizing fault rupture model.

Figure 8b is also a logic tree model for ground motion estimation. Figure 8b is the utilization of fault rupture model. Estimation of uncertainty in fault rupture model simulation is one of the key challenges. The TI team determined the branch and weights based on the review of numerical simulations regarding recent earthquakes and comparison among various methods including SCEC-BBP in the US.

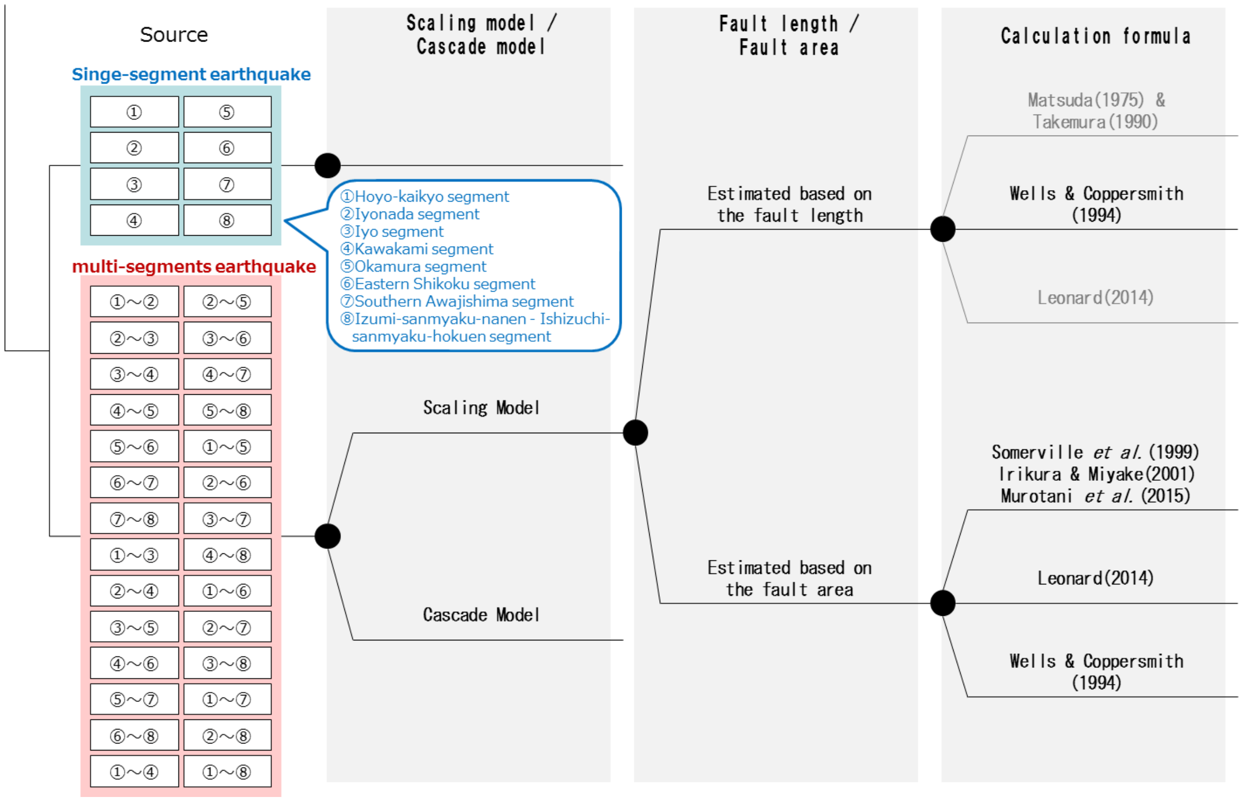
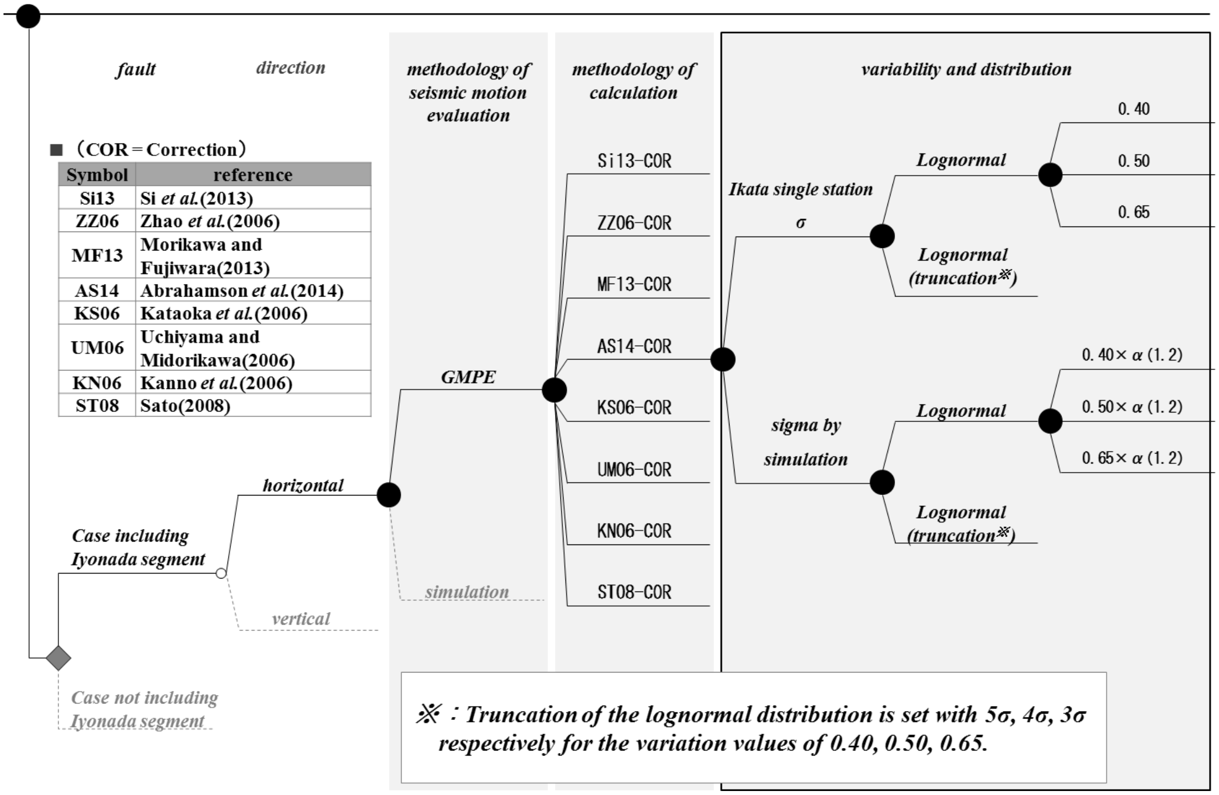


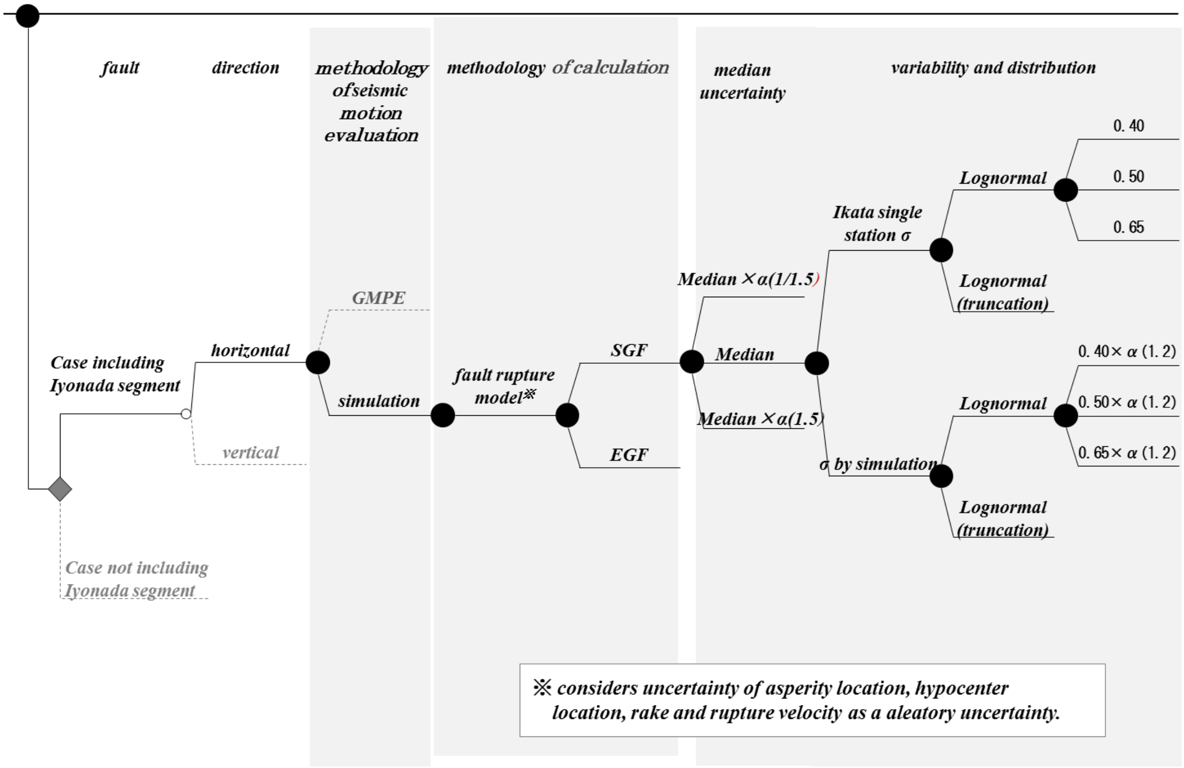
Figure 7. Logic tree model (SSC)



| Symbol | reference |
|---|---|
| Si13 | Si *et al.*(2013) |
| ZZ06 | Zhao *et al.*(2006) |
| MF13 | Morikawa and Fujiwara(2013) |
| AS14 | Abrahamson *et al.*(2014) |
| KS06 | Kataoka *et al.*(2006) |
| UM06 | Uchiyama and Midorikawa(2006) |
| KN06 | Kanno *et al.*(2006) |
| ST08 | Sato(2008) |

*※：Truncation of the lognormal distribution is set with 5σ, 4σ, 3σ respectively for the variation values of 0.40, 0.50, 0.65.*

Figure 8a. Logic tree model (GMC: GMPE)



*※ considers uncertainty of asperity location, hypocenter location, rake and rupture velocity as a aleatory uncertainty.*

Figure 8b. Logic tree model (GMC: Fault rupture model)

## CONCLUSION

Described in this paper is the progress of the first SSHAC level 3 PSHA implementation in Japan. We have discussed the key technical issues that have been studied, discussed and adopted in the Ikata SSHAC project. Because of the limitations of the length of this article, the detailed elements of the seismic source characterization model have not been fully described herein and in this paper we mainly focused on ground motion characterization as a general technical issue.

We are currently conducting final hazard calculations, so no hazard calculation result is yet available. The final SSHAC report including hazard calculations will be released at the end of the project.

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 procedure can be readily adopted for use in Japan and is an effective mechanism for capturing the current knowledge and uncertainties related to seismic hazard analysis. In turn, the results of the Ikata SSHAC Level 3 PSHA will provide high-quality and technically defensible results for use in PRA/PSA at the plant.

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