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TEMPORAL CHANGE OF SEISMIC LOAD BY PROBABILISTIC SEISMIC HAZARD ANALYSIS WITH RENEWAL PROCESS

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ABSTRACT: Probabilistic seismic hazard analysis (PSHA) is carried out during the seismic design of structures, and a seismic load corresponding to a certain return period is calculated. In PSHA, there are cases where a renewal process is adopted for some large specific earthquakes. When the probability of the occurrence of an earthquake increases within a certain period, the seismic load based on PSHA also increases. Here, we study the temporal change of the seismic hazard and the influence of the epistemic uncertainty on the occurrence probability of a large earthquake around Japan. When calculating the occurrence probability of earthquakes around the Nankai Trough and the Sagami Trough, the occurrence history is not clearly known, hence, a large epistemic uncertainty arises about the parameters of the Brownian Passage Time (BPT) distribution, such as the average recurrence interval, and the aperiodicity parameter alpha. In order to consider such uncertainty, we employ the Monte Carlo method with a large number of input parameters to grasp the temporal change of the occurrence probability. In addition, the calculated occurrence probability is incorporated into the seismic hazard analysis. Here, we conduct a risk assessment for sample sites and discuss the notion that the influence of the epistemic uncertainty on seismic loads varies greatly from one region to another.

Keywords: Probabilistic seismic hazard analysis, Earthquake occurrence probability, Temporal change, Renewal process, Epistemic uncertainty

1. INTODUCTION

Seismic ground motions, calculated with a certain probability from the seismic hazard curve, are usually adopted as the seismic load in the seismic design of structures based on the probabilistic seismic hazard analysis (PSHA). In Japan, the Headquarters for Earthquake Research Promotion (hereinafter called HERP), established by the government, conduct PSHA with a spatial resolution of 250m mesh all over Japan and have released a Japanese National Seismic Hazard Map (hereinafter called the Japanese NSHM)[1]. In this Japanese NSHM, the probability of earthquake occurrences in the next 30 or 50 years from a reference date and their seismic intensity or peak ground velocity with respect to a certain probability value are made open to the public through a website on the Internet. This period of 30 or 50 years is considered long enough to account for earthquake risks, the service life of structures, and the lifetime of humans. The Japanese NSHM is updated every year with new information about the probabilities of earthquakes. Unless a large earthquake occurs in a certain year, the hazard at the same site in the next year increases each year. Therefore, the building load guidelines by the Architectural Institute of Japan [2] suggest that the seismic load for structures is calculated on the basis of the time-dependent seismic hazard curve according to the Japanese NSHM. However, it is not practical from the seismic design point of view that the load value changes depending on the reference date and the period to be considered.

Meanwhile, the US seismic hazard map that was published by the United States Geological Survey shows long-term and short-term models [3, 4]. The long-term model is characterized by the earthquake occurrence probability being given by the Poisson process and considering the epistemic uncertainty for some parameters and equations. Since the Poisson process is adopted, the seismic load value does not change at any time in the long-term model. The short-term model takes into account one-year seismic activities such as cascading earthquakes. Therefore, structural designers can set the seismic load considering the structural performance while comparing loads of the long and short-term models. When using the two models in this way in Japan, the occurrence period of a large earthquake is estimated as a few hundreds of years, which is relatively small, so it is important to capture the time change of the seismic load by PSHA.

In this report, we adopt a renewal process using the Brownian passage time (BPT) distribution and evaluate the temporal change of the time-dependent hazard curve by analyzing a sample site. In this study, the epistemic uncertainty of the parameters of the BPT distribution seems to have a large influence on the result. Therefore, we derived the time-dependent occurrence probability of earthquakes at the sample sites from their occurrence year using the Monte Carlo method with many input parameters for the BPT distribution and incorporated it into the seismic hazard analysis. We then analyzed the seismic hazard of the sample sites and discussed the temporal change of the seismic load. Furthermore, the results are compared to the seismic load calculated using the time-independent hazard curve with the Poisson process.

2. CALCULATION OF THE EARTHQUAKE OCCURRENCE PROBABILITY WITH A RENEWAL PROCESS

In this paper, we conduct PSHA using the seismic source model of the Japanese NSHM. The seismic hazard curves are calculated for some sample sites in the regions of Kanto, Tokai, and Kinki, as described in the next section. Earthquakes in the Nankai Trough and Sagami Trough (class M8), for which the renewal process in this seismic source model is adopted, are major earthquakes around Japan and have a significant effect on the results of these regions.

According to the long-term evaluation of the Sagami Trough earthquake reported by HERP [5], the earthquake occurrence sequence was generated using the Monte Carlo method, with the average occurrence interval and the variation value as the sample value, assuming that the earthquake occurrence interval follows the BPT distribution. The data series satisfying the past earthquake occurrence histories were selected, and the time-dependent occurrence probability was calculated from this data. Stein et al. also proposed the same calculation method in [6]. We adopted a similar procedure in this study. When calculating the probability according to the unique probability distribution and the parameter pair consisting of the average occurrence interval and the variation value, the result may be dominated by the shape of the tail of probabilistic distribution in an extremely low probability range.

Our proposed method aims to address this issue by considering the epistemic uncertainty using several parameters. The occurrence probabilities for all other earthquakes in the seismic source model are calculated using the same method as the Japanese NSHM

2.1 Nankai Trough Earthquake

The parameters for calculating the occurrence probability of Nankai Trough earthquakes are determined on the basis of the reference report detailing the past earthquake occurrence history [7]. First, referring to the past earthquake occurrence history from [6], pairs of these two parameters are generated as uniform random numbers with an average recurrence interval of 50-300 years and an aperiodicity parameter α of 0.1-0.5. Using these parameter pairs, we then generate the earthquake occurrence year series with the Monte Carlo method dating back to the latest earthquake occurrence year. We then select 3,000 pairs of the parameters where the year sequence satisfies the past historical earthquake sequence. Since the 1605 Keicho earthquake was a tsunami earthquake, it is not clear whether it was an earthquake around the Nankai Trough. Therefore, as shown in Table 1, we consider two cases: Case 1, where the 1605 Keicho earthquake is considered, and Case 2, where it is not. When calculating the hazard curves to be described later, these cases are considered with equal weights in the logic tree. Parameters are selected out of the 3,000 pairs for each case. The latest earthquake occurrence year was 1944.9 on average for the Showa Tonankai and the Showa Nankai earthquakes. When selecting a parameter pair for the BPT distribution satisfying the earthquake history sequence, it is difficult to generate samples with the year that completely matches the time history. Therefore, the data where the earthquake samples occurred in the five years before or after the past earthquake occurrence year is judged to satisfy the condition. This is because the confidence interval of the sample occurrence is about 5%. Next, using the BPT distribution of the pair of selected parameters, 1,000 samples of occurrence years of the next future earthquake are generated for each case using the Monte Carlo method. As a result, we obtained 3,000,000 samples of the occurrence years of the next earthquakes. Figure 1 shows the flow chart of this calculation.

Table 2 shows the results of parameter generation. In Case 1, the average occurrence interval is about 125 years, whereas in Case 2, the Keicho earthquake was not considered, and hence the average occurrence interval was about 151 years, which is about 20% larger than in Case 1. In addition, α tends to be slightly larger in Case 2. The average of the coefficient of variation is about 0.14 and 0.15 for each case, respectively. Figure 2 shows the sampling results of the occurrence year of the next future earthquake, generated using the Monte Carlo method with these parameters. The probability of the earthquake occurrence in each year as of January 1, 2018, is shown in Table 3. The probability of earthquake occurrence is 0.65% in 2018, but it greatly rises over time and becomes about 1.17% after 30 years. Case 2 also has an occurrence probability more than twice as much as 30 years later.

2.2 Sagami Trough Earthquake

The occurrence probability of the Sagami Trough earthquake is calculated using the parameters provided in the report by HERP [5]. First, referring to the result of the Monte Carlo simulation in [5], parameter pairs are generated using uniform random numbers similar to the Nankai Trough earthquake case that was presented in the previous section. The range of the average recurrence interval is from 50 to 300 years and α range from 0.1 to 0.8. The history of the Sagami Trough earthquake, which is used for selecting the samples, is shown in Table 4. The latest Sagami Trough earthquake occurred in August 1923. We generated next earthquake year samples of 1,000 after selecting 3,000 pairs for the BPT distribution parameter. Furthermore, the earthquake history is the same as the condition reported in [5], and the 1703 Genroku Kanto earthquake is excluded from the time series.

Table 5 shows the result of the parameter generation. The average of the recurrence interval of all data is about 356 years, and the average of the coefficient of variation α is 0.35, resulting in a large uncertainty. The latest interval is 220 years between the Genroku Kanto earthquake in 1703 and the Taisho Kanto earthquake in 1923. Since this was excluded from the condition, the result is larger than the generally known recurrence interval. There is room for further discussion on adding the Genroku Kanto earthquake to the time series, but since the elapsed time from the latest earthquake occurrence is still short and the probability is small during the period of several decades from the present time, we think that this result is sufficient for subsequent studies.

Figure 3 and Table 6 show the calculation results for the occurrence of the next earthquake, which is most likely to occur around 2250 AD. As of January 1, 2018, the probability of the earthquake occurred in the next 30 years is 0.53%. HERP's report says that the occurrence probability of the Sagami Trough earthquake of magnitude 8 is approximately 0–5% in the next 30 years, which is consistent with our result. Although the probability in 2018 is 0.008%, it rises with time, and after 30 years, it will be quadrupled to 0.030%. We think that these probabilities have no significant effect on the seismic loads in PSHA for extremely low probabilities.

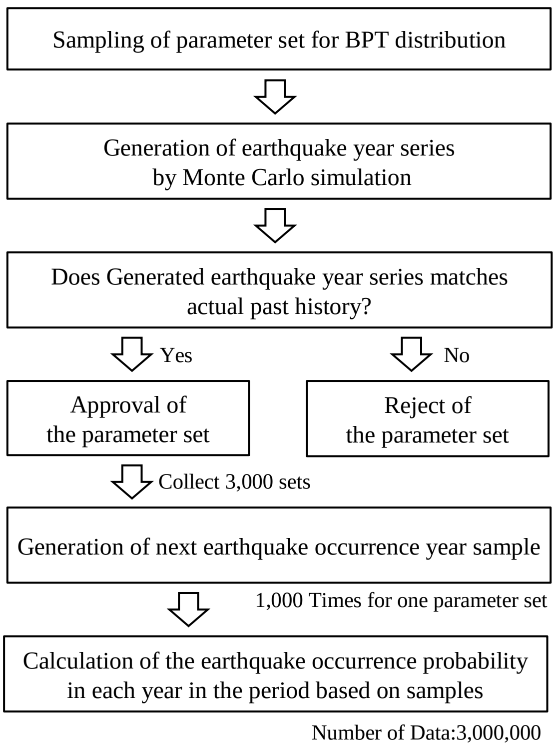

Fig.1 Flowchart of the calculation of earthquake occurrence probability

Table 1 Historical Nankai Trough earthquakes

No.	Date	Name	Case 1	Case 2
1	Jun., 1361	Shohei	*	*
2	Jul., 1498	Meiou	*	*
3	Jan., 1605	Keicho	*	-
4	Aug., 1707	Houei	*	*
5	Dec., 1854	Ansei	*	*
6	Aug., 1944	Showa	*	*

*: included, -: excluded

Table 2 Samples Obtained for the BPT distribution parameters: the Nankai Trough earthquake (N =6,000)

Samples	Case 1		Case 2	
	t	α	t	α
Average	125	0.32	151	0.33
Standard deviation	17	0.05	22	0.05
Max.	194	0.46	251	0.50
Min.	75	0.16	92	0.16

t: recurrence interval year, α: aperiodicity parameter

Table 3 Earthquake probability in each occurrence year as of January 1, 2018: the Nankai Trough earthquake

Year	Occurrence probability	
	Case 1	Case 2
2018	0.65%	0.29%
2023	0.79%	0.38%
2028	0.90%	0.46%
2033	1.02%	0.55%
2038	1.09%	0.63%
2043	1.14%	0.69%
2048	1.17%	0.75%

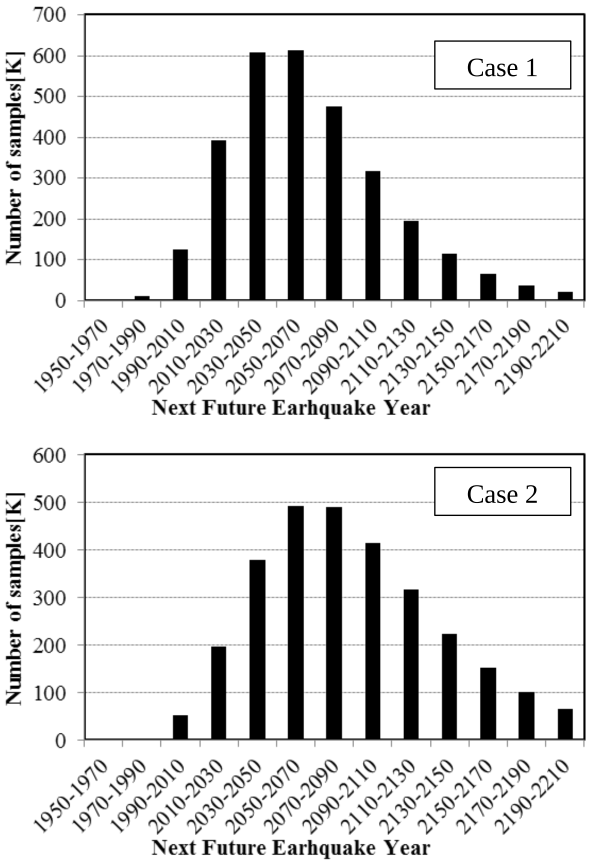

Fig. 2 Samples of the occurrence year of the next earthquake for the Nankai Trough earthquake

Table 4 Historical Sagami Trough earthquakes

No.	Earthquakes occurrence history
1	5400-5300 BP
2	5000-4800 BP
3	4800-4250 BP
4	4250-3950 BP
5	3800-3600 BP
6	3300-3100 BP
7	3050-2850 BP
8	2750-2700 BP
9	2500-2400 BP

Table 5 Samples Obtained for the BPT distribution parameters: the Sagami Trough earthquake (N =6,000)

Samples	t	α
Average	366	0.36
Standard deviation	36	0.10
Max.	510	0.73
Min.	249	0.11

t: recurrence interval year, α: aperiodicity parameter

Table 6 Earthquake occurrence Probability in each year as of January 1, 2018: the Sagami trough earthquake

Year	Occurrence probability
2018	0.008%
2023	0.011%
2028	0.015%
2033	0.017%
2038	0.021%
2043	0.027%
2048	0.032%

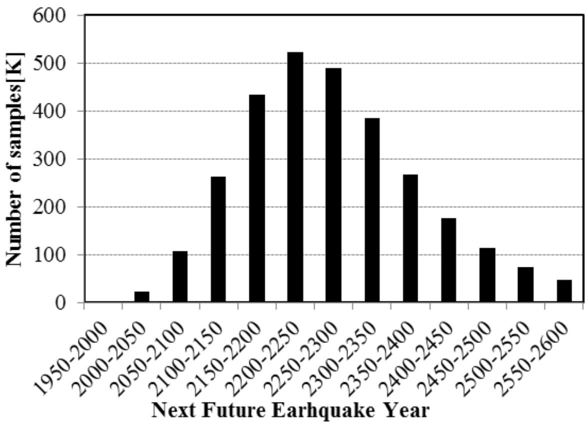

Fig.3 Samples of the occurrence year of the next earthquake for the Sagami Trough earthquake

3. PROBABILISTIC SEISMIC HAZARD ANALYSIS

3.1 Application to PSHA

PSHA is carried out according to the studies reported in [8, 9]. We calculated the peak ground acceleration (PGA) at the engineering bedrock defined as shear wave velocity, Vs= 292m/s, by ground motion prediction equation (GMPE) of Kanno et al. (2006)[10], and did not consider the amplification of the ground motion by the soil surface. The seismic source model is also in accordance with [9]. However, we used the occurrence probabilities as established in the previous section for major earthquakes around the Nankai Trough and the Sagami Trough. The time-dependent earthquake probabilities are calculated as of January 1, 2018. The target sites are the locations of the prefectural government office in Tokyo, Kanagawa, Shizuoka, Aichi, and Osaka. From the viewpoint of the relation between the evaluation site and the epicenter location, Shizuoka, Aichi, and Osaka are affected by the Nankai Trough, whereas Tokyo and Kanagawa are in the areas where the Sagami Trough has a great influence. Figure 4 shows the source area of Nankai Trough earthquake and Sagami Trough earthquake and the target sites for PSHA.

The result of the seismic hazard curve considering the time change is shown in Fig. 5. The dotted curves are time-dependent, adopting the average probability of Case 1 and Case 2, and the solid curve is time-independent, using the Poisson process. The obtained hazard curves show that the hazard risk increases with the passage of time, depending on the imminent earthquake at every site. The probability of the Nankai Trough earthquake rises within the estimated period. Therefore, the hazard risk rises, especially in Aichi and Shizuoka that are close to the source area of the Nankai Trough earthquake. In Shizuoka, Aichi, and Osaka, the time-dependent curve exceeds the non-time-dependent curve within the considered period. The temporal change of the PGA with a 10% annual exceedance probability in the next 50 years is shown in Table 7. Shizuoka has the largest PGA, followed by Kanagawa and Tokyo. Shizuoka also has the highest rise in the hazard risk within this period, and the PGA increases by about 32% for Shizuoka and about 24% for Aichi. In Tokyo and Kanagawa, the probability of the Sagami Trough earthquake does not rise so much, so the increase in the PGA after 30 years is relatively small.

3.2 Discussion

From the above results, we discussed the method of setting the seismic load on the basis of the stochastic approach. The time dependence of the hazard curve is strongly related to on the imminent earthquake and the distance from its source area. As time passes and the occurrence probability of a major earthquake rises, an earthquake will constitute a greater hazard risk. The earthquake will

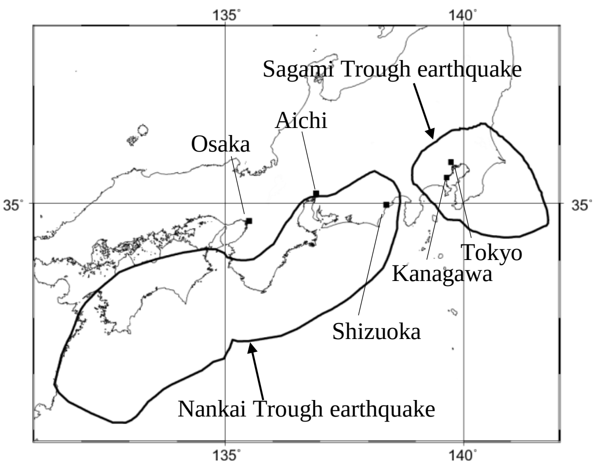

Fig. 4 Target sites and source areas of the Nankai Trough and the Sagami Trough earthquake

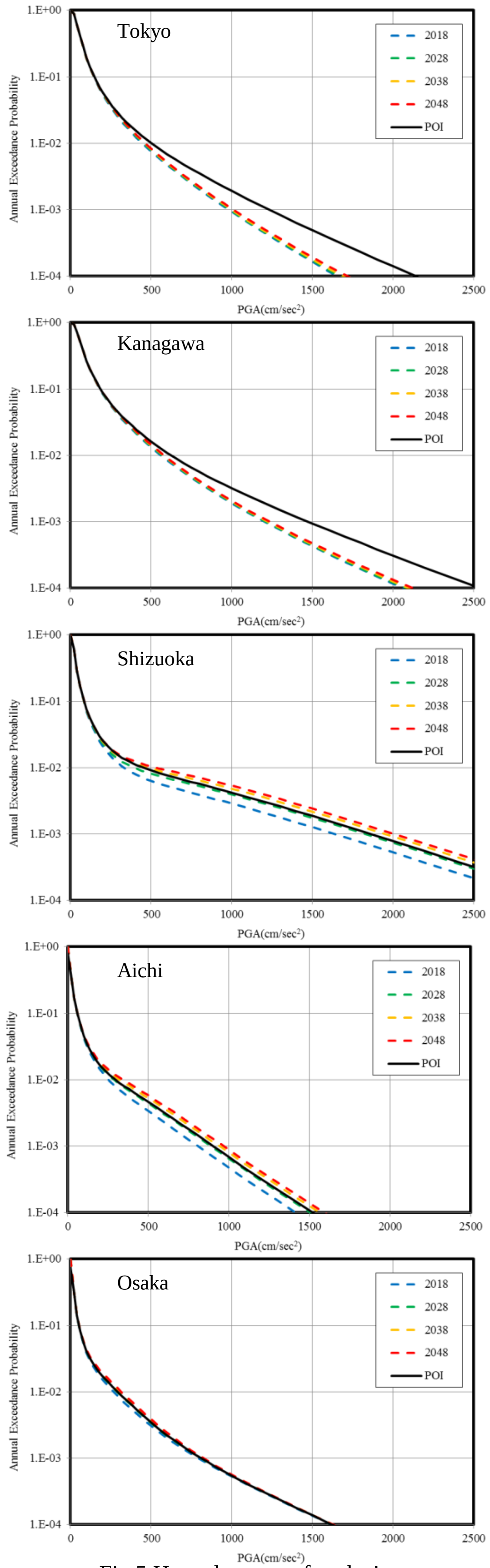

Fig.5 Hazard curves of each site

dominate the hazard risk greatly. Therefore, when setting seismic load, it is necessary not only to examine seismic loads only from the hazard curve but also to disaggregate the hazard curve and grasp the contribution of each earthquake and its characteristics such as the magnitude, epicenter distance and occurrence probability. Then, it is important to comprehensively consider both the deterministic and the probabilistic approaches.

4. CONCLUSION

In this paper, we studied the temporal change of the earthquake hazard around Japan and the epistemic uncertainty about the earthquake occurrence probability for major earthquakes. We also conducted a seismic hazard analysis for some sample sites, and quantitatively showed that the seismic hazard greatly changes with time.

5. REFERENCES

[1] Headquarters for Earthquake Research Promotion, National seismic hazard Maps for Japan (2017 Edition), 2017. (in Japanese)

[2] Architectural Institute of Japan, AIJ Recommendations for Loads on Buildings (2015 Edition), 2015. (in Japanese)

[3] Petersen, M.D., Moschetti, M.P., Powers, P.M., Mueller, C.S., Haller, K.M., Frankel, A.D., Zeng, Yuehua, Rezaeian, Sanaz, Harmsen, S.C., Boyd, O.S., Field, Ned, Chen, Rui, Rukstales, K.S., Luco, Nico, Wheeler, R.L., Williams, R.A., and Olsen, A.H., 2014, Documentation for the 2014 update of the United States national seismic hazard maps: U.S. Geological Survey Open-File Report 2014–1091, 243 p., https://dx.doi.org/10.3133/ofr20141091.

[4] Petersen, M.D., Mueller, C.S., Moschetti, M.P., Hoover, S.M., Kenneth S. R., et al., 2018 One-Year Seismic Hazard Forecast for the Central and Eastern United States from Induced and Natural Earthquakes, Seismological Research Letters, No.89(3), pp.1049-1061, https://doi.org/10.1785/0220180005

[5] Headquarters for Earthquake Research Promotion, Long term evaluation for the earthquakes around Sagami Trough (2nd Edition), 2014. (in Japanese)

[6] Stein, R.S., Toda, S., Parsons, T., & Grunewald, E., A new probabilistic seismic hazard assessment for greater Tokyo, Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, Vol.364(1845), 2006, pp.1965-88, https://doi:10.1098/rsta.2006.1808.

[7] Headquarters for Earthquake Research Promotion, Long term evaluation for the earthquakes around Nankai Trough (2nd Edition), 2013. (in Japanese)

[8] Hiroyuki F., Shunichi K., Shin A., Nobuyuki M., et. al., A study on National Seismic Hazard Maps for Japan, Technical Note of the National Research Institute for Earth Science and Disaster Prevention, No.336, 2009. (in Japanese)

[9] National Research Institute for Earth Science and Disaster Resilience, Japan Seismic Hazard Information Station (J-SHIS), http://www.j-shis.go.jp, 2017 (online)

[10] Kanno, T., Narita, A., Morikawa, N., Fujiwara, H., Fukushima, Y., A new attenuation relation for strong ground motion in Japan based on recorded data, Bulletin of the Seismological Society of America, Vol. 96, No.3, 2006, pp.879-897.