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PROBABILISTIC TSUNAMI RISK EVALUATION CONSIDERING UNCERTAINTY OF FAULT SLIPS

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Abstract

It is pointed out that probabilistic Tsunami Risk evaluation is useful to enterprise risk management as well as performance based design. Although a probabilistic Tsunami hazard analysis (PTHA) has been proposed for site basis hazard determination, no such study has yet been conducted in multi-Tsunami loss event simulation with shock loss considering uncertainties in the height of Tsunami wave caused by inaccurate estimation of spatial slip variability. Especially, since the uncertainty in the height of wave height caused by the inaccurate estimate of the fault slip affects the outcome of probabilistic loss evaluation, it is essential to model slip distribution. In particular, the uncertainty in the estimate of fault slips cannot be ignored, when considering a huge Tsunami source such as the Nankai Trough. In this paper, the schematic method to evaluate the uncertainty of the height of Tsunami wave on shore line is proposed. In the calculation of the height of Tsunami wave, Green Function Method is applied. The validation and calibration of wave height are also performed in order to reflect the non-linear effect in the propagation of Tsunami wave. The uncertainty in the slip distribution is approximated by the truncated Cauchy distribution considering correlation matrixes between amounts of the slip and distances between every subfault.

Keywords: Tsunami; Probable Maximum Loss; Risk Management; Uncertainty; Nankai Trough

1. Introduction

The huge loss due to earthquake and Tsunami in the 2011 Tohoku earthquake reminded us of the importance of managing the catastrophe risk. Probabilistic seismic hazard analysis began to be applied in the 1970's. Nowadays, it has been utilized as useful tools that enable them to make rational decisions in cat-risk management. Especially, the Probable Maximum Loss, PML, has been becoming a common measure in quantification of the seismic risk for lenders, insurers and investors. Although a definition of PML depends on risk management entity, definition of 90 percentile of estimated loss caused by seismic event with 10 percent chance in 50 years is common in Japan.

PML based on stochastic seismic risk evaluation is considered to be significant for the risk management toward the rational decision-making (i.e. real estate securitization and insurance). Meanwhile, damages by following Tsunami after the shock have not been considered in the PML assessment conventionally. However, for industrial infrastructure facilities located in coastal areas, damages by the following Tsunami should be key item to be taken into account in the evaluation of PML since losses resulted from the following Tsunami might be greater than losses caused by the earthquake.

Firstly, we show the outline and framework of a method of evaluation of PML by considering Tsunami loss. Losses caused by the earthquake and Tsunami are calculated based on the probabilistic multi-event model. In the second step, we describe the method to consider the uncertainty in fault slip, when we calculate the height of coastal Tsunami wave using the Green's function approach. In the Green's function approach, it is convenient to divide these uncertainties into two groups: parameter-variations that act on the Green's function level (e.g., fault geometry) and parameters that do not influence the Green's functions [1]. In this paper, uncertainties caused by the variability of spatial distribution of subfault slip amount are taken into account for the Nankai Trough. Since the Tsunami source of Nankai Trough is large, such uncertainties have marked great influences on the calculation of the height of Tsunami wave.

2. Framework

The definition of PML can be classified into several categories. The following definitions are categorized by the Architectural Institute of Japan (AIJ).

PML1 :

Seismic event loss having the exceedance probability (EP) of 10% in 50 years regarding loss defined as 90 percentile

PML2 :

Loss caused by seismic intensity that is determined according to seismic hazard at the EP of 10% in 50 years

PML3 :

Loss having the EP of 10% in 50 years

In the above-classified definitions of PML, PML2 is a definition that pays attention to the seismic hazard. On the other, PML1 and PML3 correspond to the definition that focuses on the loss. From the standpoint of practical risk management, the risk management entities tend to be considered in seismic risk evaluation as not only individual assets but also a total portfolio. The definition of PML2, which focuses on the site hazard, cannot be applied to the portfolio risk evaluation. Thus, the definition in PML1 or PML3 is generally applied to the practical risk management. Additionally, PML3 is obtained using full probabilistic exceedance probability (EP) risk curve, whereas corresponding relationship between the probabilistic loss and individual seismic event is not well-known. Therefore, PML1 is often employed in the practical risk evaluation. In this paper, new definition of PML in consideration of the Tsunami is proposed on the basis of the definition of PML1.

A conceptual diagram of a PML, which considers effects by Tsunami on the basis of PML1, is shown in Fig. 1.

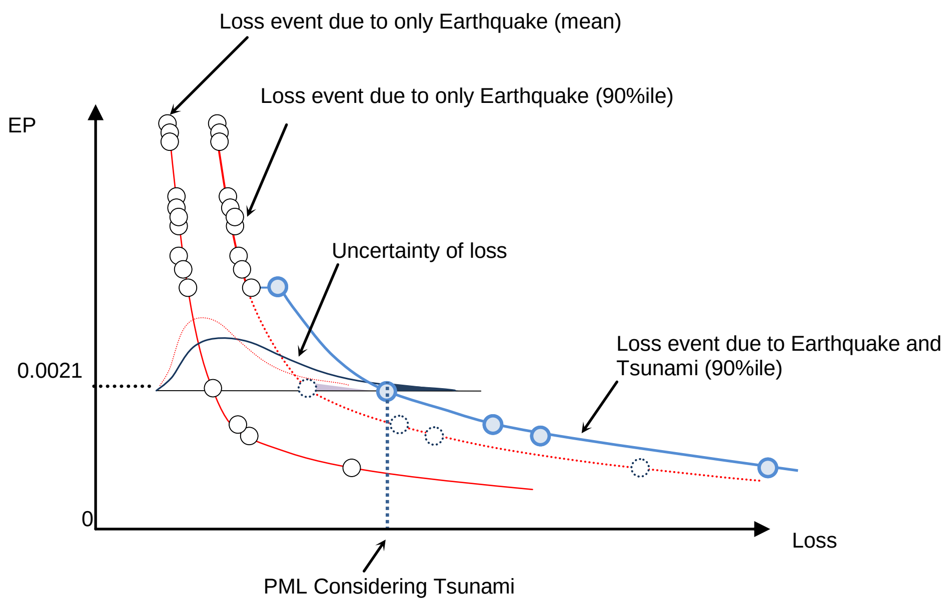

Fig. 1 Conceptual diagram of a PML in consideration of Tsunami

3. Methodology of Considering Uncertainty of Fault Slip

Tsunami sources in our probabilistic model are illustrated in Fig.2. One step of the calculation of Tsunami inundation height is divided into several procedures, namely, set of fault parameters, calculation of initial displaced sea-water-level, wave propagation analysis and run-up evaluation. The height of coastal wave is calculated for most of Tsunami sources by solving the non-linear wave propagation equation from rectangular modeled Tsunami sources. As mentioned above, the uncertainty in fault slips of the Nankai Trough (Fig. 3, Table 1) should be considered because the uncertainty in the fault slip has marked great influences on the accurate calculation of the height of Tsunami wave.

Freund and Barnett [2] pointed out that the height of Tsunami wave is underestimated when calculations of Tsunamis are performed with not the heterogeneous slip distributions but the uniform slip distributions. Geist [3] calculated Tsunami wave height uncertainty along the Pacific coastline of Mexico using a trench fault with 100 cases of random slip. Based on numerical results, he confirmed that random slip distribution of a trench fault significantly affected the height of localized coastal wave. Recently, there are some studies that focus on considering spatial slip distribution of fault plane to evaluate Tsunami hazard or risk assessment. Many of those studies (e.g. Fukutani *et al.* [4]; Goda *et al.* [5]) adopt a method based on the stochastic earthquake source model (e.g. Mai and Beroza [6]; Lavallée *et al.* [7]), which uses the spectral analysis of slip heterogeneity in an inverted source model.

In this study, we, however, developed a new method from a different perspective by considering slip heterogeneity of fault plane by using slip correlation coefficient in accordance with distance among all subfaults. The fault targeted in this study is the Nankai Trough, which has the vast source area, so that the effects by spatial slip distribution cannot be negligible. In order to carry out the stochastic Tsunami evaluation that takes into account the uncertainty in the fault slip (slip and slip distribution), we adopt Green's function approach.

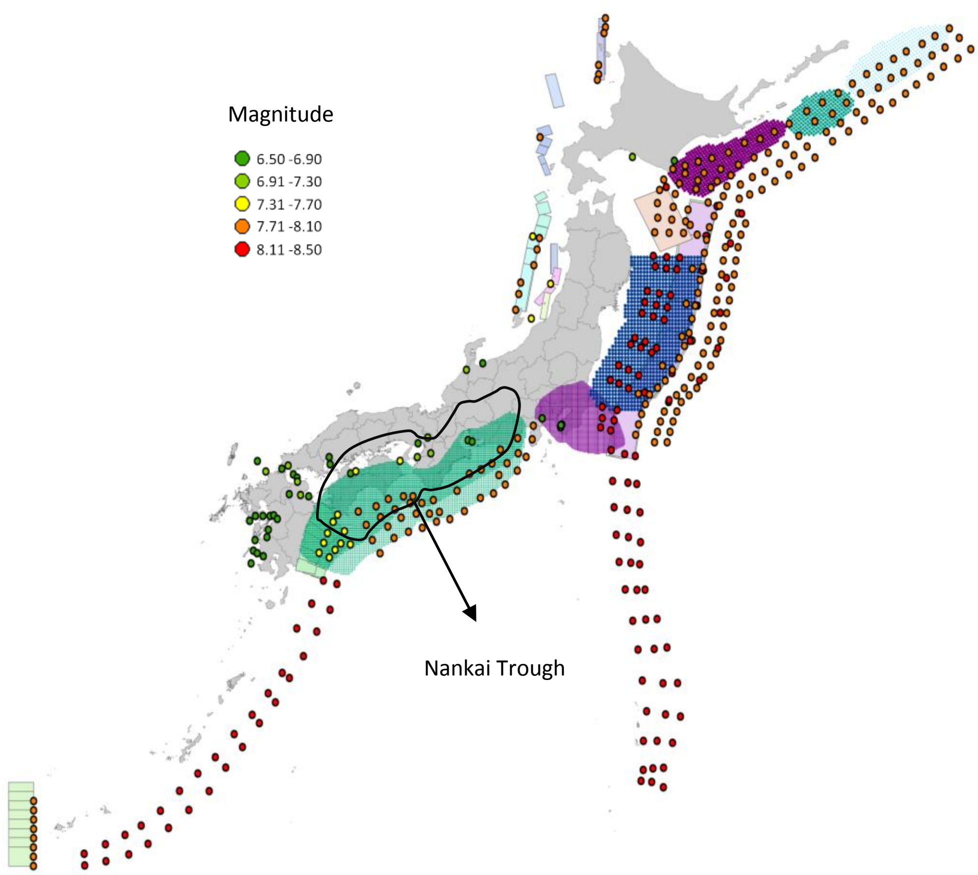

Fig. 2 Possible Tsunami sources around Japan

Procedures to obtain slip heterogeneity of the Nankai Trough are as follows (see Fig. 5):

1. The Nankai Trough source is divided into 397 subfaults that corresponds to 20km × 20km rectangular area (see Fig. 4). At each point of the Pacific Ocean off the coast, Tsunami waveforms caused by the unit slip are calculated in advance.
2. Based on the distance matrix and the slip amount among each subfault, we calculate a correlation coefficient of the slip amount in accordance with the distances among all subfaults (see Fig.6).
3. In each 397 subfault, normal random numbers are generated on the basis of above correlation matrix.
4. By using NORTA method (Cairo and Neilson [8]), we convert the random numbers into one-dimensional truncated Cauchy distribution, which demonstrates the slip distribution of the fault and obtain a slip pattern of each 397 subfault.
5. Various slip patterns on the fault plane can be obtained by changing the random numbers.

Fig. 7 shows an example of slip distributions for the Nankai Trough. This example indicates slip heterogeneity of the fault plane well. It is noted that the parameters such as the geometry and magnitude in the Nankai Trough are based on those in the publication by the Headquarters for Earthquake Research Promotion (HERP). Fig. 8 shows the numerical results of the height of Tsunami wave on the basis of the proposed method that enables us to handle and consider the uncertainty in spatial fault slip in evaluation of the PML considering Tsunami, accurately.

4. Conclusions

We proposed a numerical method to calculate the height of the Tsunami wave by considering the uncertainty in the spatial fault slip whose occurrence is predicted in the Nankai Trough earthquake. Using our method, it is possible to make a rational decision in regard to the seismic risk by considering the damages via in the following Tsunami of the shock. In particular, our numerical method has the advantage for the accurate estimate of risk with risk management entity that are composed of critical facilities near the coast.

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Table 1 Pattern of the Nankai Trough by the HERP

No.	Segmentation	Mw
No.1	ZYXE	8.8
No.2	ZYXEd	9.0
No.3	ZYXEs	9.0
No.4	ZYXEsd	9.1
No.5	YXE	8.7
No.6	YXEs	8.9
No.7	ZYX	8.8
No.8	ZYXs	9.0
No.9	YX	8.7
No.10	YXs	8.9
No.11	s	8.4
No.12	ZY	8.7
No.13	XE	8.3
No.14	Y	8.5
No.15	X	8.2

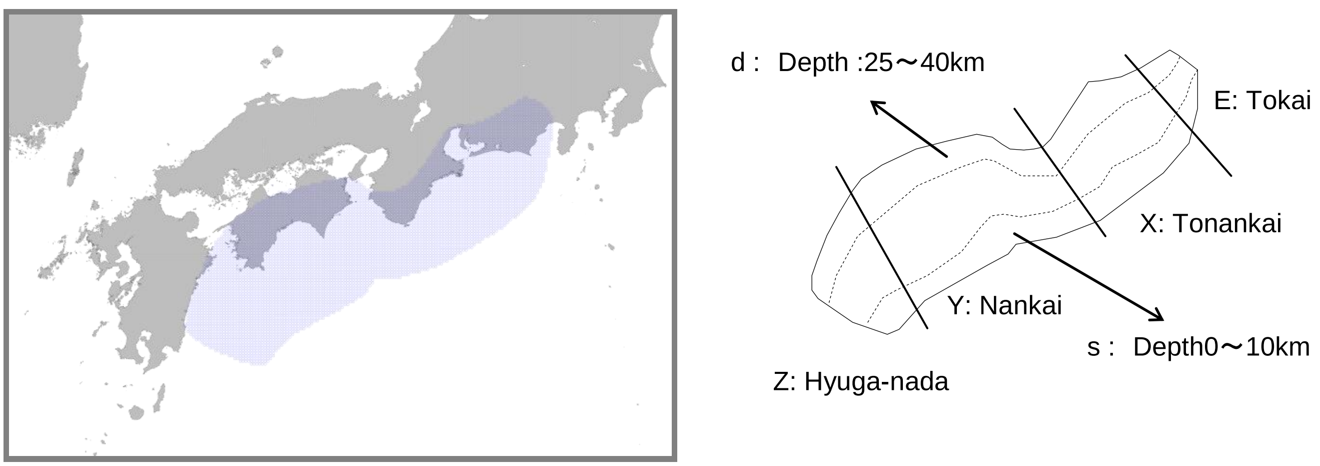

Fig. 3 Location and Segmentation of the Nankai Trough

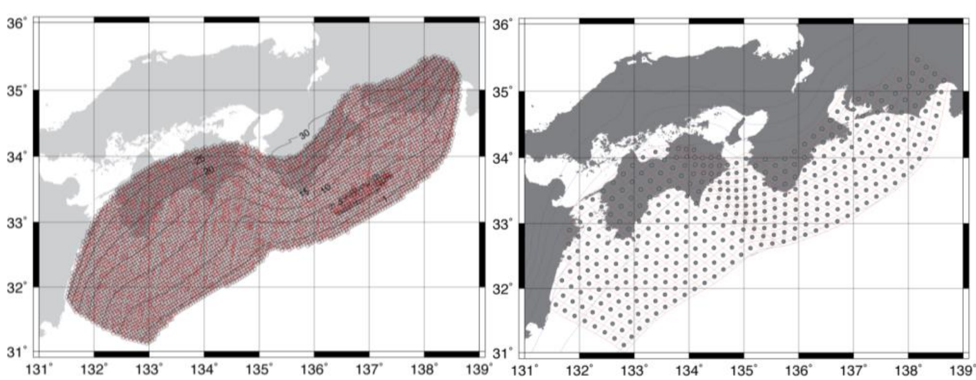

Fig. 4 Subfault of the Nankai Trough

To make approx. 400 subfaults that is 20km×20km rectangular

↓

To calculate tsunami wave height for each subfault

↓

To build correlation matrix regarding slip according to distance among each subfault

↓

To generate normal random parameter having above correlation matrix

↓

To make the pattern of slip spatial distribution by using NORTA method

↓

To generate of tsunami waveform based on the Green's function approach

↓

To integrate the waveform and calculate wave height

Fig. 5 Step of considering slip uncertainty of the Nankai Trough

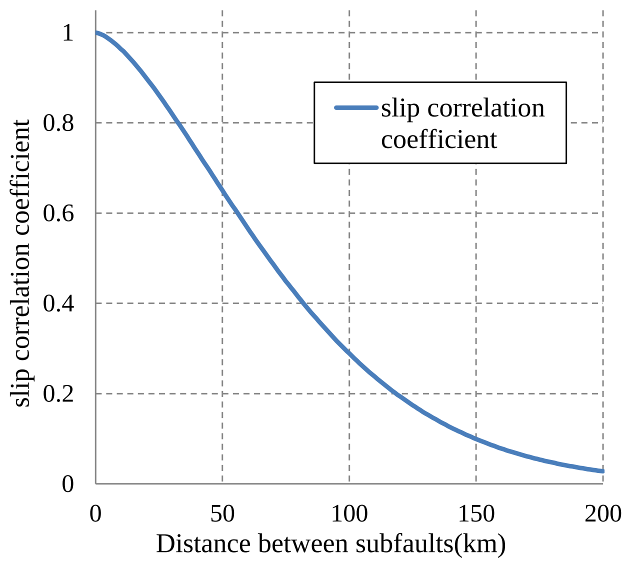

Fig. 6 – Slip correlation coefficient versus Distance between subfaults

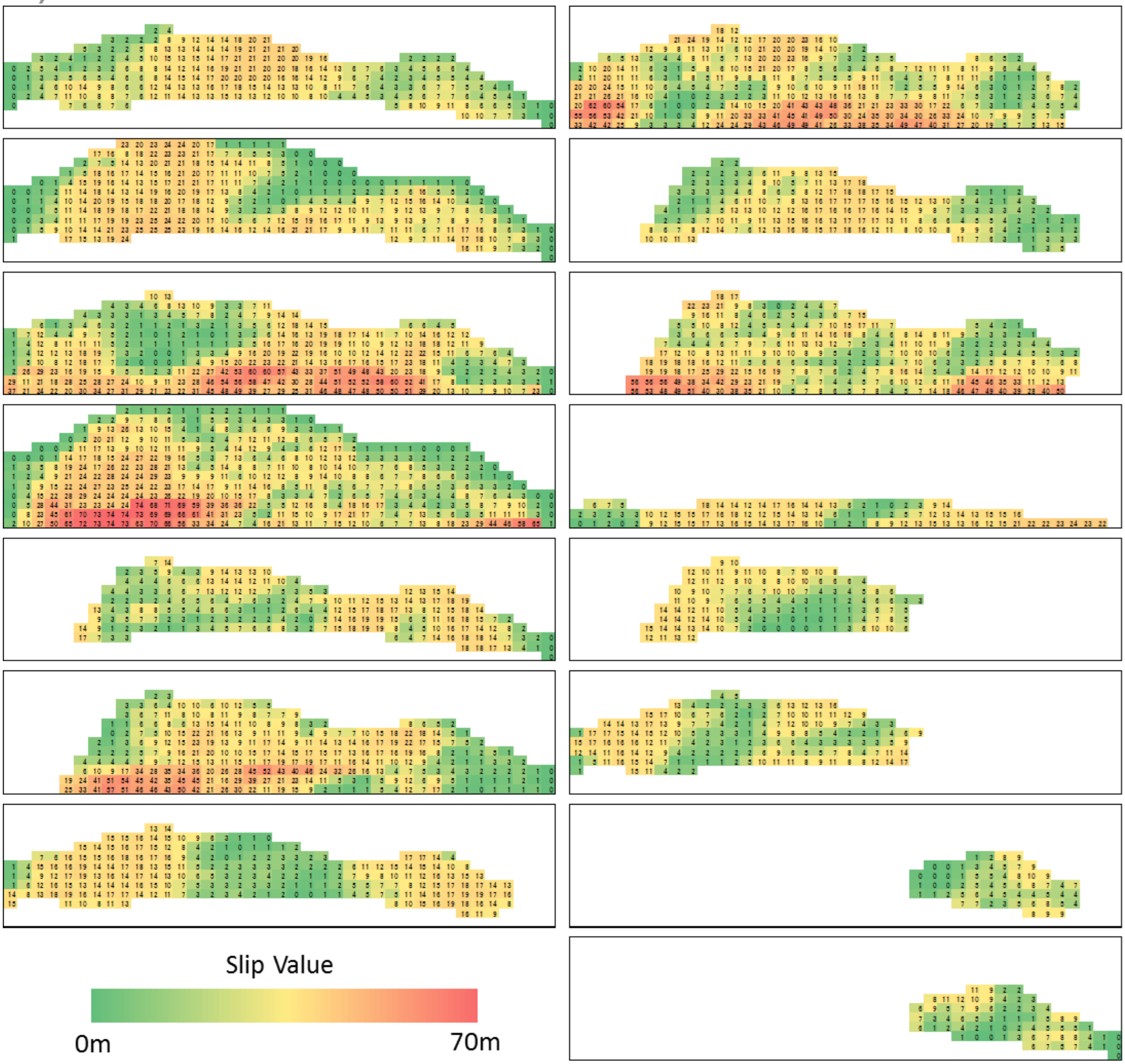

Fig. 7 Example of slip distribution of the Nankai Trough

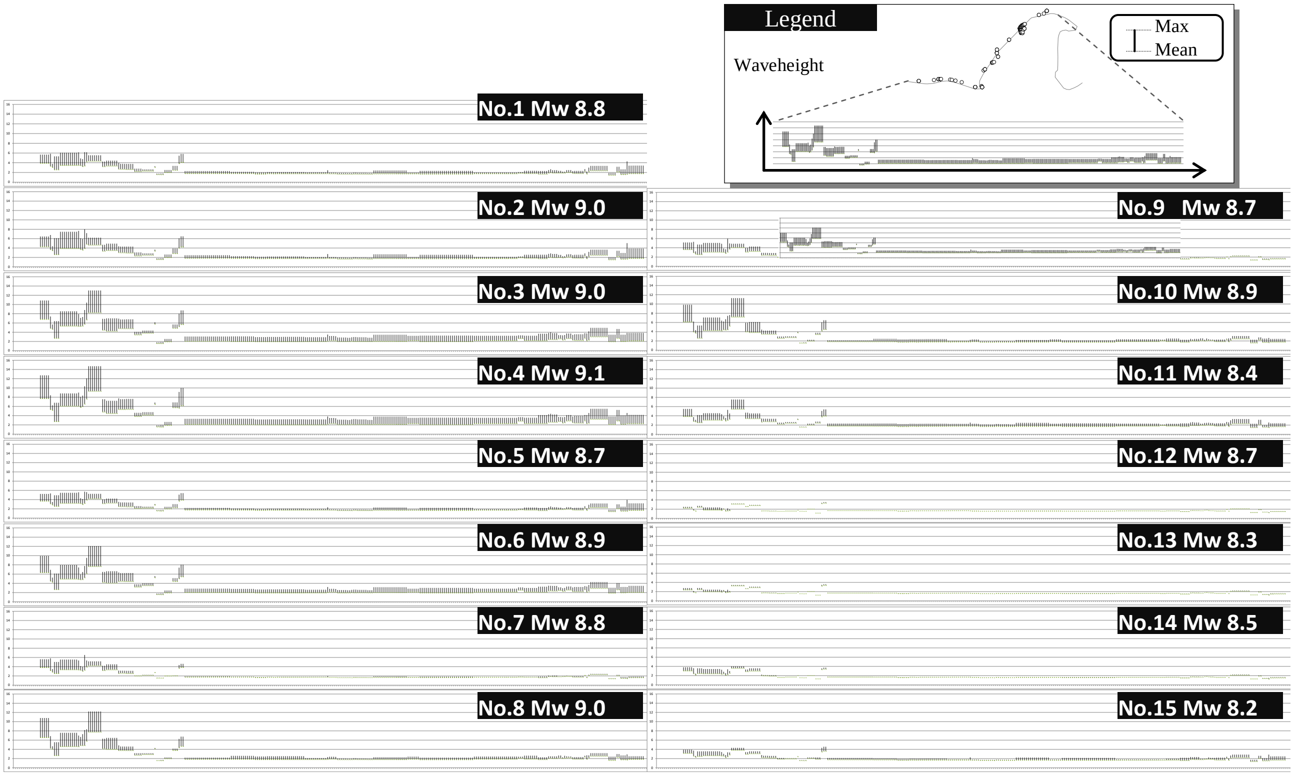

Fig. 8 Coastal Tsunami Wave height due to the Nankai Trough considering uncertainty of slip distribution