Proposal of a method for evaluating tsunami risk using response-surface methodology

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Abstract

Information on probabilistic tsunami inundation hazards is needed to define and evaluate tsunami risk . Several methods for calculating these hazards have been proposed (e.g. Løvholt et al. (2012), Thio (2012), Fukutani et al. (2014), Goda et al. (2014)) . However, these methods are inefficient, and their calculation cost is high, since they require multiple tsunami numerical simulations, therefore lacking versatility.

In this study, **we proposed a simpler method for tsunami risk evaluation using response-surface methodology.** Kotani et al. (2016) proposed an evaluation method for the probabilistic distribution of tsunami wave-height using a response-surface methodology. We expanded their study and developed a probabilistic distribution of tsunami inundation depth. **We set the slip (*x1*) and the depth (*x2*) of the Sagami trough earthquake fault as explanatory variables and tsunami inundation depth (*Y*) as an object variable**. We implemented a regression analysis based on the results of 25 tsunami numerical calculations for on the coast of Tokyo Bay and **developed a response-surface, which was defined as *Y*(*x1*, *x2*) = 6.744**x1* + 0.069* *x1***x2* – 2.025**x1* **x1* – 3.210.** Based on the analyses, We clarified that the expected damage probability of the steel building located in the target area is 49.6%, assuming that an earthquake occurs.

① A target source and a study area

We used the Sagami trough earthquake (Mw 8.5) as a tsunami source, which was published by the study meeting for the Tokyo Inland Earthquakes of the Cabinet Office in Japan (2013) (see Fig.1(a)). The target point for the tsunami risk assessment in this study is located in the Hakkei-jima island, Yokohama-city, Kanagawa prefecture (see the red points in Fig.1 (a) and (b)). The Hakkei-jima island is a welfare facility of the Yokohama City Port Plan. Hakkeijima Sea Paradise, Yacht Harbor are in the place and it is a place for relaxation for the citizens in Yokohama city.

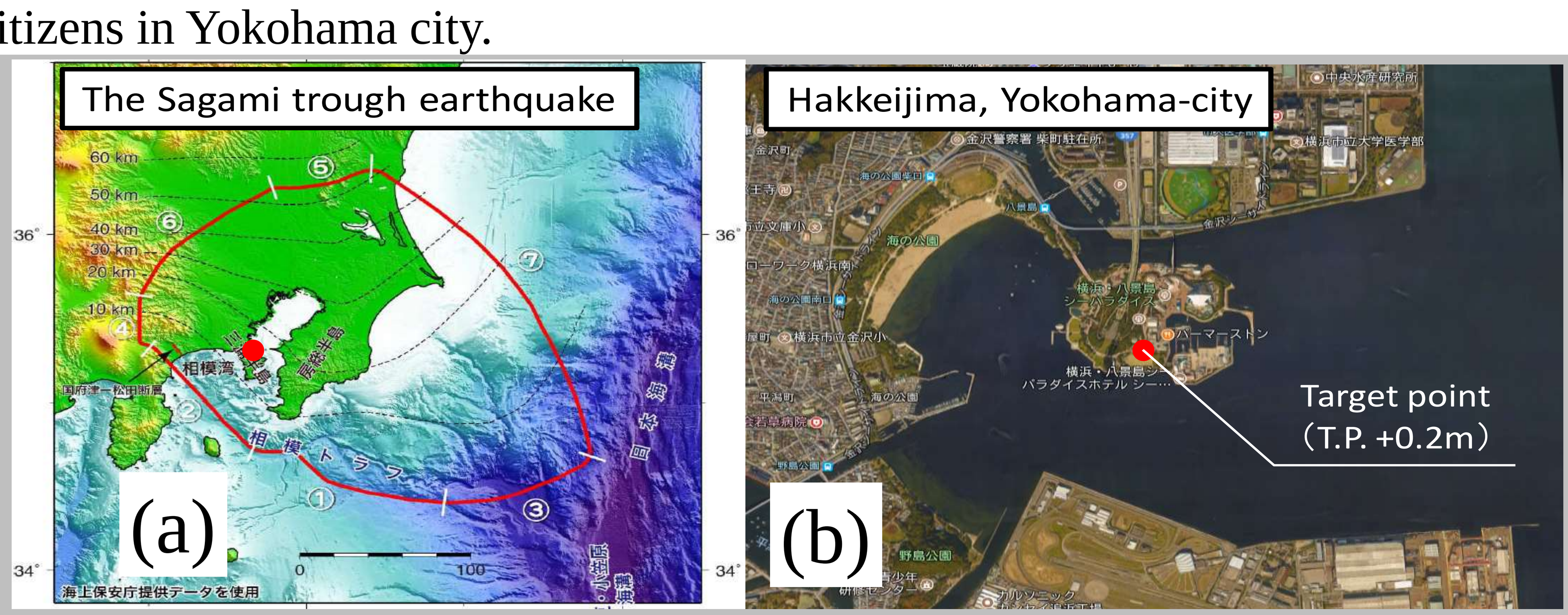

Figure.1 (a) The source area of the Sagami trough earthquake (Mw 8.5)
(b) Target point for tsunami risk assessment

Using the fault parameters of the Sagami trough earthquake, we calculated the initial displacement of tsunami by Okada's equation (see Fig.2(a)) and simulated tsunami wave by non-linear long wave equation (TUNAMI model by Tohoku University in Japan). Figure.2 (b) shows that max tsunami wave height around coastal area of Kanto-region in Japan.

Table.1 shows the tsunami inundation depths simulated from tsunami numerical simulations for the target point. Tsunami numerical simulation was conducted with changing slip rate and fault depth. The slip were changed from 0.8 times to 1.2 times. The fault depth were changed from -1.0 km to +2.0 km.

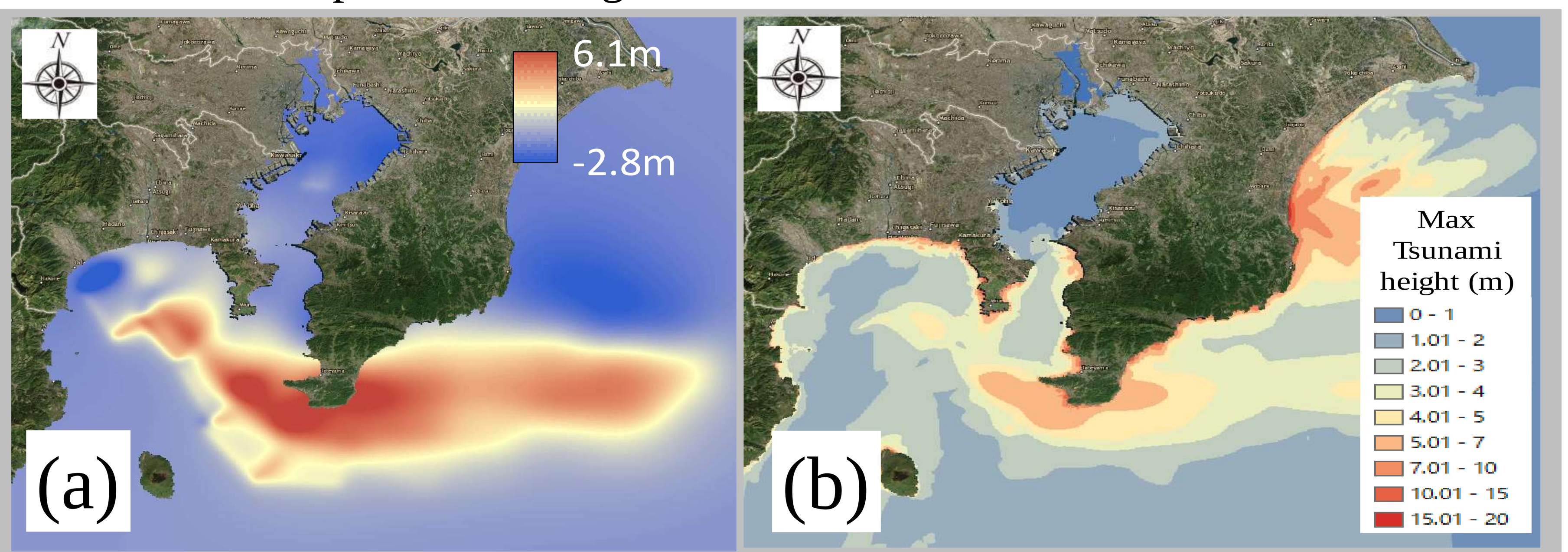

Figure.2 (a) Initial displacement of tsunami estimated from Okada's equation
(b) Max water height simulated by non-linear long wave equation

Table.1 The tsunami inundation depths from tsunami numerical simulations

	+1.0 km	+ 0.5 km	0 km	- 0.5 km	- 1.0 km
1.2 times	2.05 m	2.01 m	1.97 m	1.94 m	1.90 m
1.1 times	1.87 m	1.85 m	1.81 m	1.78 m	1.73 m
1.0 times	1.58 m	1.55 m	1.48 m	1.44 m	1.39 m
0.9 times	1.28 m	1.25 m	1.23 m	1.20 m	1.15 m
0.8 times	0.99 m	0.99 m	0.97 m	0.94 m	0.91 m

We conducted regression analyses using below equation and developed a response surface for tsunami inundation depth.

$$Y\,(x1,x2) = a*x1 + b*x2 + c*x1*x2 + d*x1*x1 + e*x2*x2 + f$$

x1: Slip rate of the earthquake, x2: Depth of the earthquake

② Response surface for the target point

As the result of regression analysis, the following response surface was selected.

$$Y\,(x1,x2) = 6.744*x1 + 0.069*x1*x2 - 2.025*x2*x2 - 3.210$$

Figure. 3 (a) shows the simulation results (Blue point) and the response surface (Red area). The developed response surface can explain the simulation results well. Then, we conducted monte-carlo simulation using the surface considering uncertainty of slip and depth of the earthquake (see Table.2). Figure. 3 shows the histograms of tsunami inundation height as the results of mote-carlo simulation.

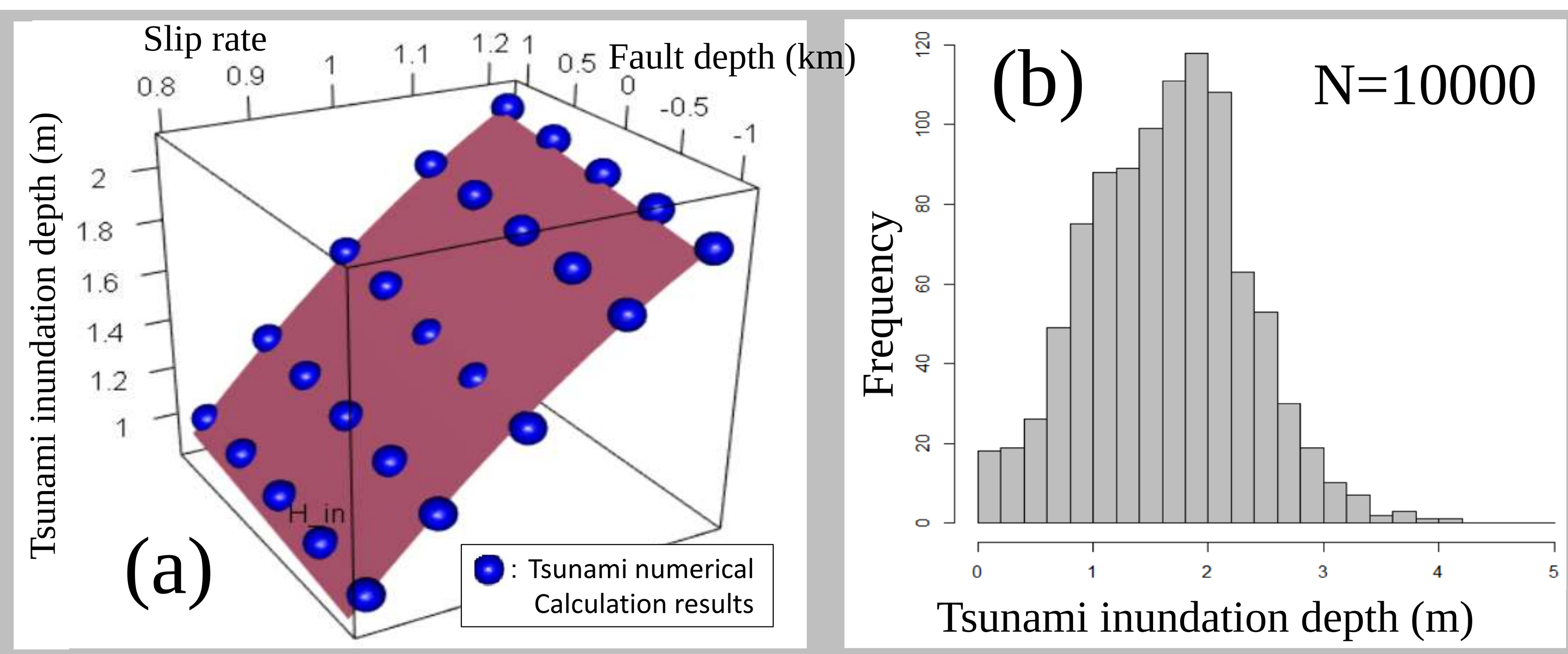

Figure.3 (a) The simulation results (Blue point) and the response surface (Red area)
(b) The histograms of tsunami inundation height

Table.2 Uncertainty of slip rate and fault depth

Variables	Average	Standard deviation	P.D.F	Reason for the variation
Slip rate	1.00	0.10	Normal Distribution	The Nuclear Civil Engineering Committee, Japan Society of Civil Engineers (2016) indicated that there can be a variability of ±0.1 Mw considering same fault area. In this case, a variation range of slip is from 0.7 times to 1.4 times.
Fault depth [km]	0.12 (log average)	0.65 (log standard deviation)	Log normal Distribution	This variability was calculated based on the observation errors of fault depths, which are listed in the seismic source list of JMA (Data period: 2016/10-2017/10)

Next, we estimated the histograms of damage probability of steel building (see Fig.4 (a)) by using the tsunami inundation deptns generated from monte-carlo method. In evaluation of the damage probability, we used the fragility curve of steel building developed by Suppasri et al.(2013). Finally, we can evaluate exceedance probability of damage probability when the Sagami trough earthquake occur (see Fig.4 (b)). From this results, we can estimate the expected value and the percentile value of damage probability (49.6%) , although it is conditional.

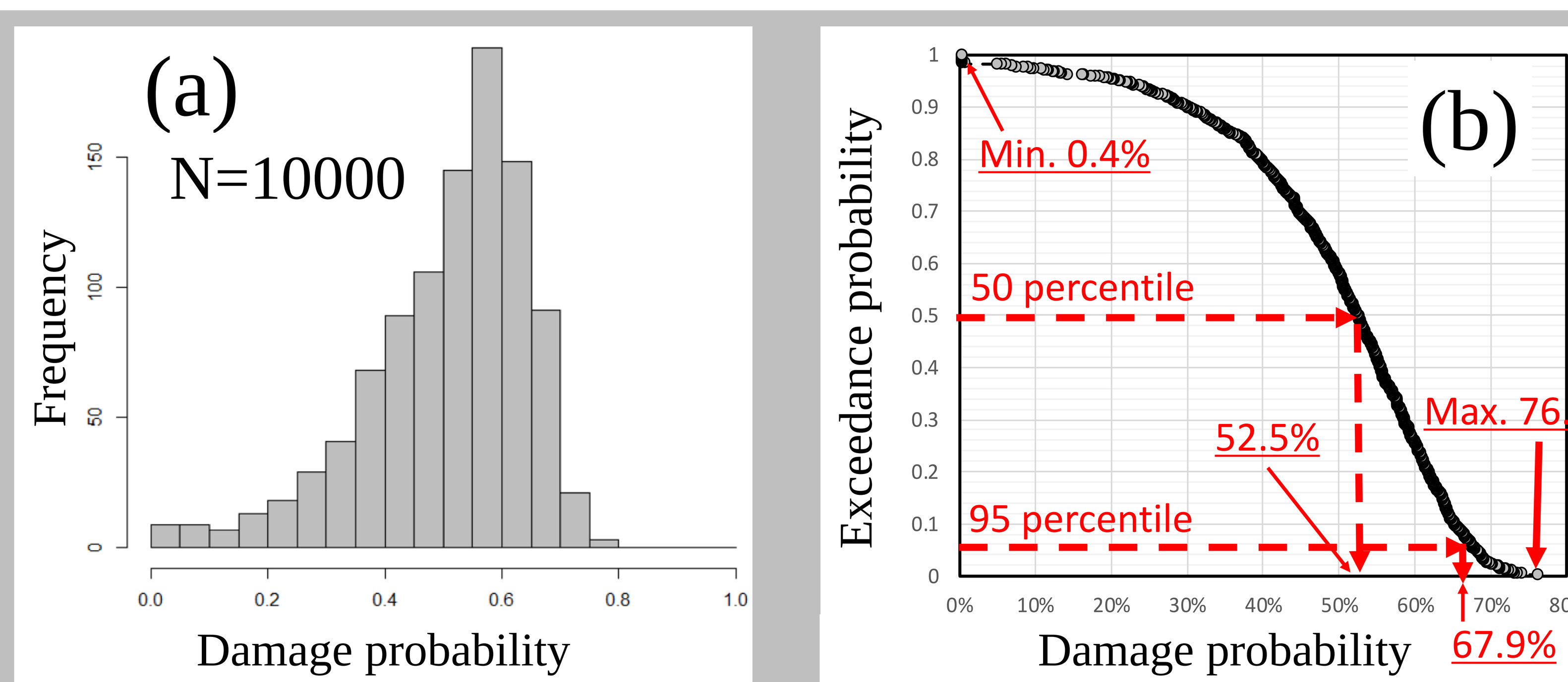

Figure.4 (a) Initial displacement height of tsunami estimated from Okada's equation
(b) Max water tsunami height simulated by non-linear long wave equation

③ Summary

We proposed tsunami risk evaluation using response-surface methodology. The proposed method is a useful and simple way to evaluate tsunami risk using response-surface without conducting multiple tsunami numerical simulations.

Reference

Takuma KOTANI, Shinsuke TAKASE, Shuji MORIGUCHI, Kenjiro TERADA, Yo FUKUTANI, Yu OTAKE, Kazuya NOJIMA, Masaaki SAKURABA (2016), Numerical-Analysis-Aided Probabilistic Tsunami Hazard Evaluation Using Response Surface, Journal of Japan Society of Civil Engineers, Ser. A2 (Applied Mechanics (AM)), Vol. 72 (1), pp.58-69. (in Japanese)