Assessment using copulas of simultaneous damage to multiple buildings as a result of tsunamis

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Abstract

In this research, we target the Sagami trough earthquake tsunami that could have a big influence around the Japanese capital region and propose a method for simultaneous damage assessment using copulas that can take into consideration correlation of tsunami depths and building damages between two sites.

First, we simulated the tsunami inundation depths at two sites by using a nonlinear long wave equation. We simulated the tsunami heights by varying the slip amount (5 cases) and the depths (5 cases) for each 10 source of the Sagami Trough. Then, we constructed the response surfaces that can explain tsunami heights. Then, we conducted the Monte-Carlo simulation using copulas in order to consider correlation of tsunami heights between two sites. In this study, we used Survival Gumbel copula for the region 8 as the results of maximum likelihood estimation of bivariate copula based on the tsunami numerical simulation results. We can properly evaluate the correlation of tsunami heights by using the copula. Considering the correlation of the tsunami inundation depth at the two sites, the expected value hardly changed compared with the case of no correlation, but it was calculated largely that the damage rate of 99th percentile value was about 2 % and the maximum value was about 6 % in case of using the copulas.

① Target sources and target points

We used the Sagami trough earthquakes as a tsunami source, which was published by the study meeting for the Tokyo Inland Earthquakes of the Cabinet Office (2013) (see Fig.1). The target points for the tsunami risk assessment are located in the Sagami Bay and the entrance of the Tokyo Bay (see Fig.2).

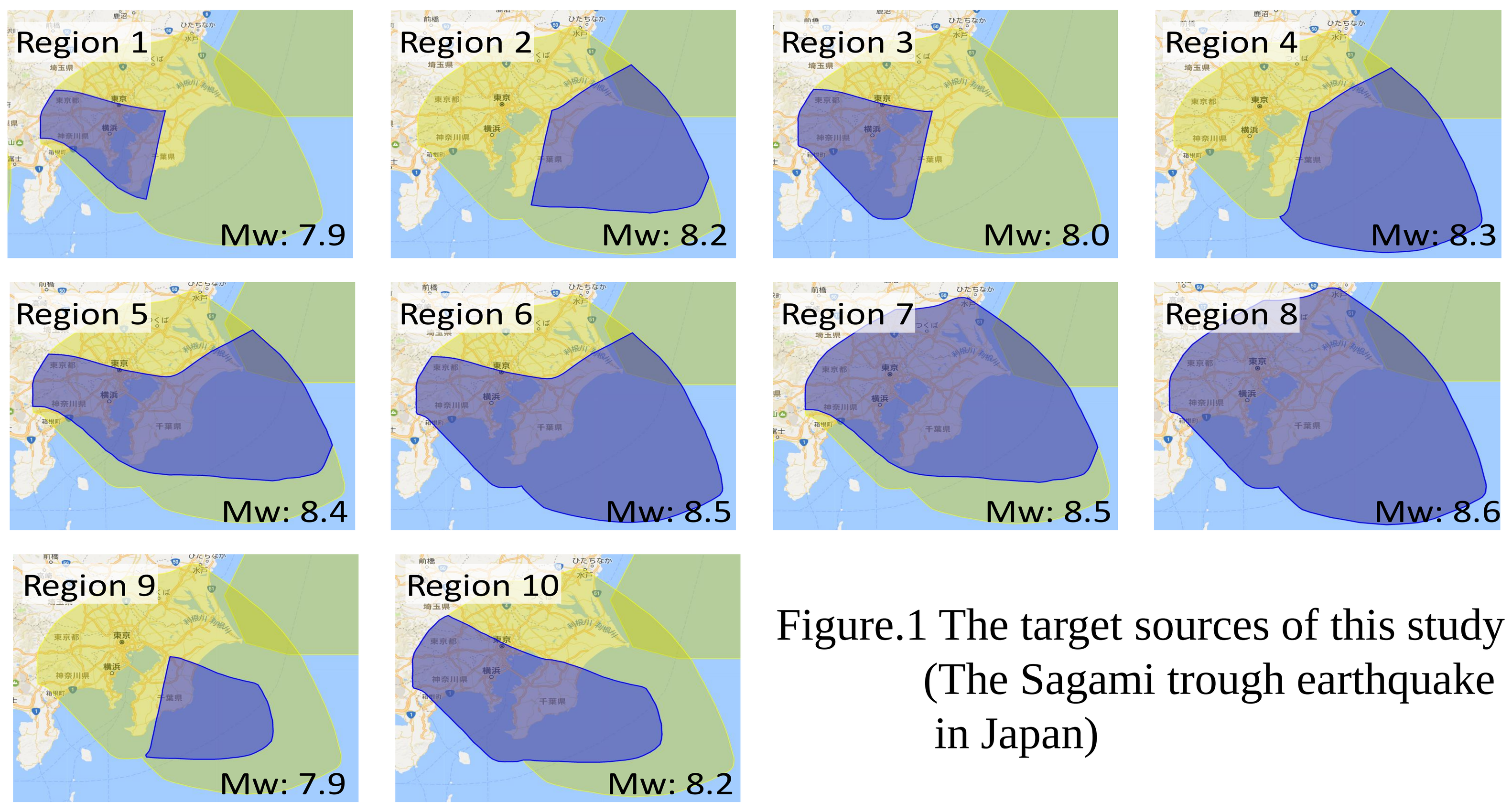

Figure.1 The target sources of this study (The Sagami trough earthquake in Japan)

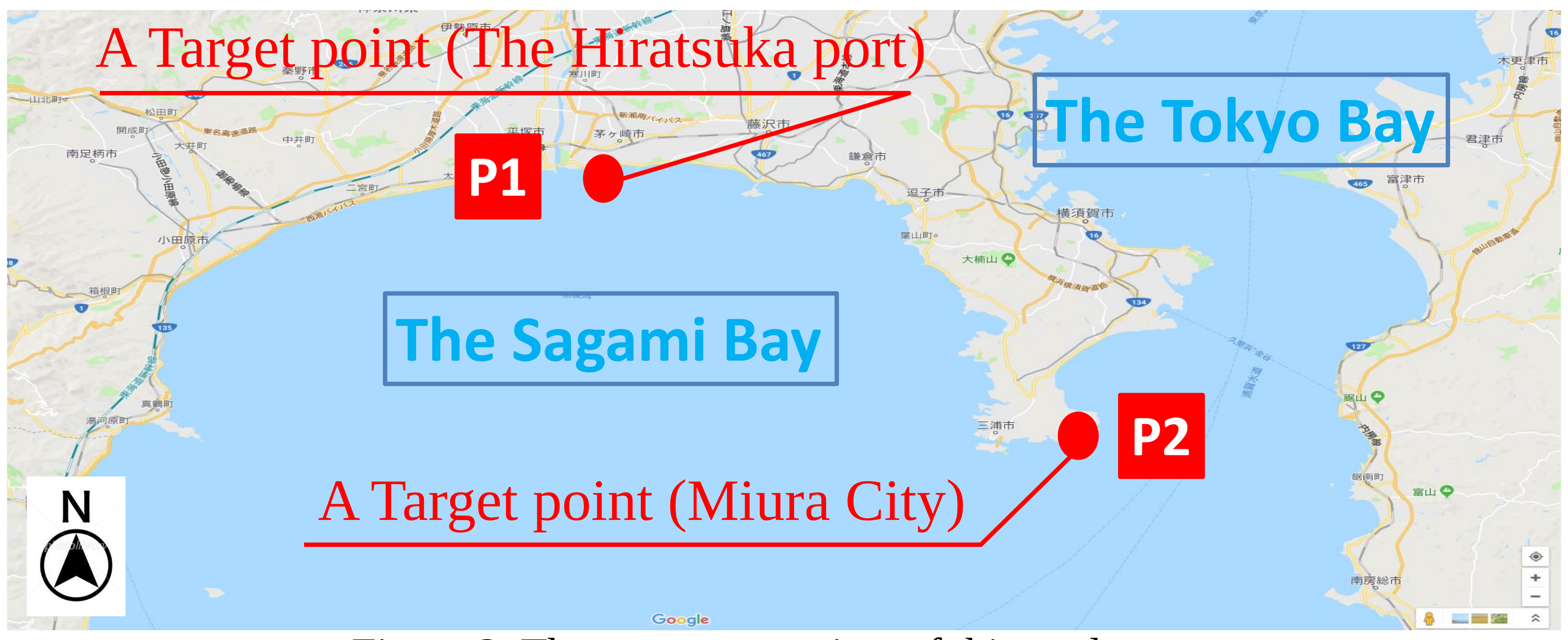

Figure.2 The two target points of this study

② Constructing response surfaces for the target points

Using the fault parameters of the Sagami trough earthquake, we calculated the initial displacement of tsunami by Okada's equation and simulated tsunami wave by non-linear long wave equation (TUNAMI-N2 model by Tohoku University). In order to consider uncertainties of tsunami wave, the tsunami simulations were conducted with changing slip rate and fault depth. The slip were changed from 0.7 times to 1.4 times (5 cases). The fault depth were changed from -1.0 km to +2.0 km (5 cases). Then, we conducted regression analyses using below equation and developed a response surface for tsunami inundation depth.

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

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

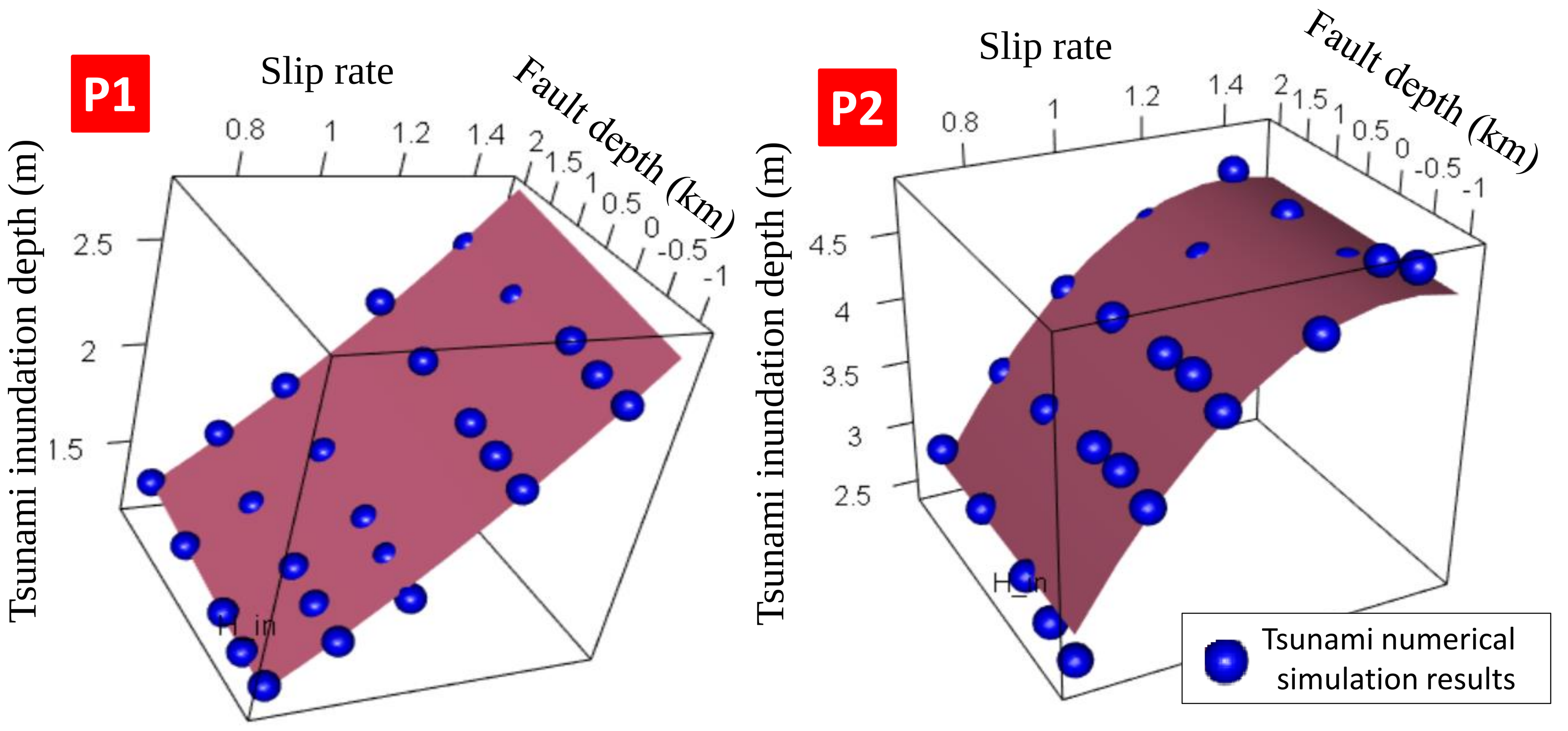

Figure.3 The constructed response surfaces at each point (P1, P2) **for the region 8**

③ Tsunami risk assessment using Monte-Carlo simulations and copulas

We conducted Monte-Carlo simulation (N=10,000) using the response surface considering uncertainty of slip and depth of the earthquake (see Table.1).

Table.1 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)

Figure.4 (a) is the Monte-Carlo simulation results (Black points) of **the region 8** without considering correlation of tsunami height between two sites. The red points are the tsunami simulation results. The black points cannot not be considered the correlation. Based on the tsunami numerical simulation results (25 cases), we conducted maximum likelihood estimation of bivariate copula, then selected Survival Gumbel copula because AIC is minimum (AIC = -49.54). Figure.4 (b) is the results of Monte-Carlo simulation results considering the correlation using Survival Gumbel copula.

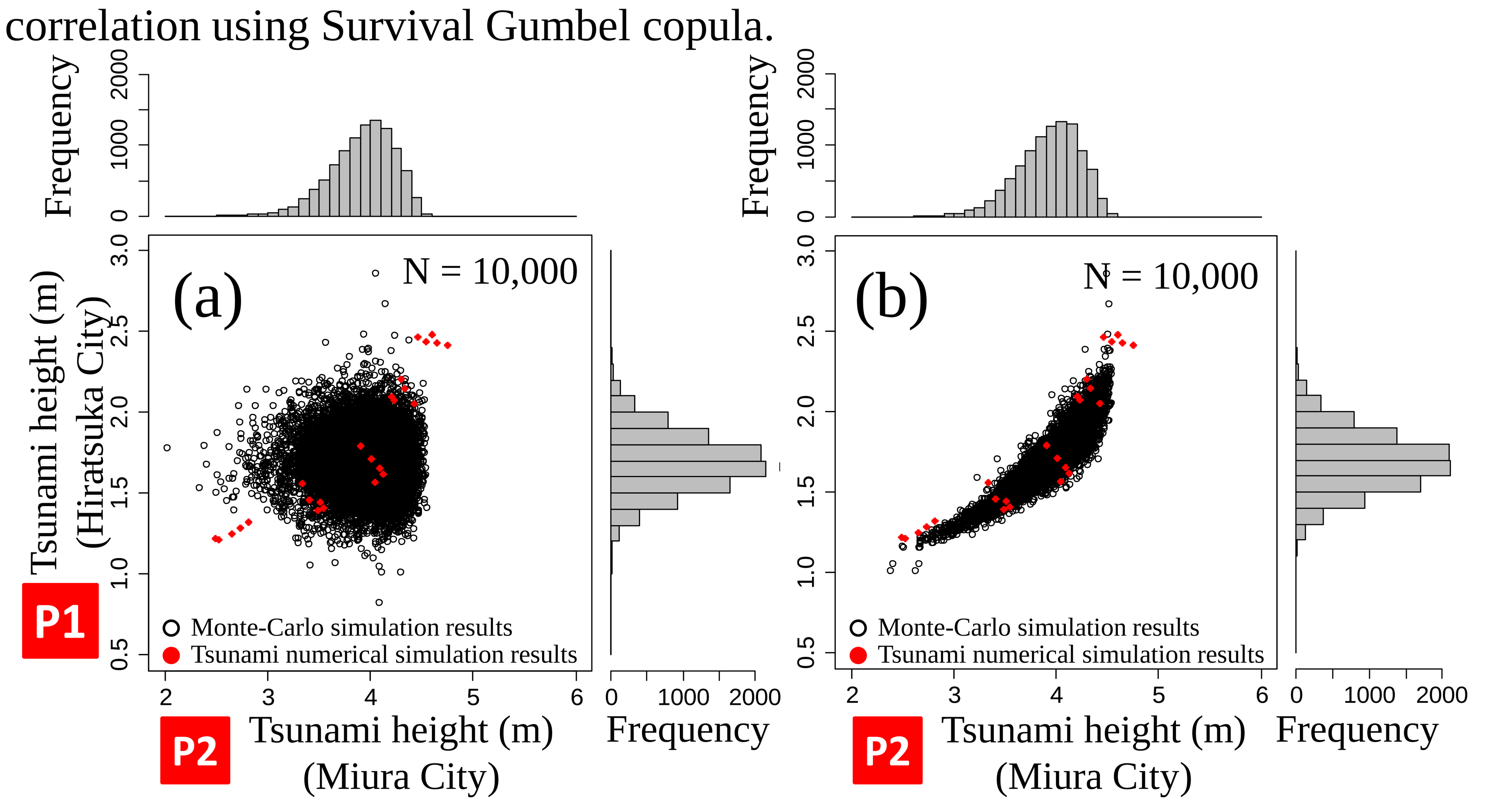

Figure.4 Monte-Carlo simulation results (a)without and (b) with Survival Gumbel copula

For all regions of the Sagami trough, we conducted same statistical simulations using above method. Then, we converted the tsunami heights to the damage probability of steel building at two points using fragility curve. Compared with the case of no correlation, the expected value of the damage probability hardly changed, but it was calculated largely that the damage rate of 99th percentile value was about 2 % and the maximum value was about 6 % in case of using the copulas (see Fig.5).

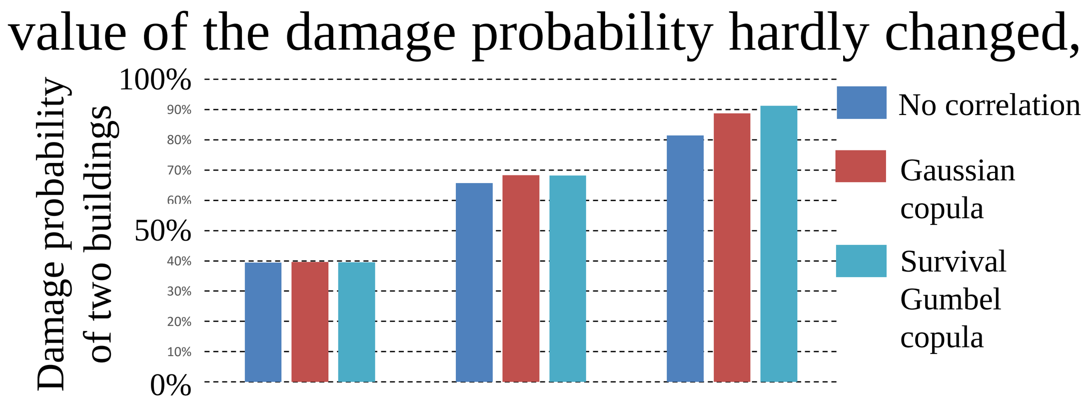

Figure.5 Damage probability in case of using each copula

④ Summary

We proposed tsunami risk evaluation using response-surface method and monte-Carlo simulation technique considering correlation of tsunami depth using copulas. The proposed method is a useful and simple way to evaluate tsunami risk without conducting many tsunami numerical simulations.

Reference

Yo FUKUTANI, Shuji MORIGUCHI, Takuma KOTANI, Kenjiro TERADA (2018), PROBABILISTIC TSUNAMI LOSS ESTIMATION USING RESPONSE-SURFACE METHOD -APPLICATION TO SAGAMI TROUGH EARTHQUAKE-, Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), Vol. 74(2), pp.I-463-I-468. (in Japanese)