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Tsunami Risk Assessment Considering Tsunami Wave Correlation Using Copulas

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Abstract

It is necessary to consider simultaneous damage to multiple buildings when performing probabilistic risk assessment for a portfolio of buildings. In this study, we demonstrate tsunami risk assessment for two buildings using copulas of tsunami hazards that consider the nonlinear spatial correlation of tsunami wave heights. First, we simulated the wave heights considering uncertainty by varying the slip amount and fault depths. The frequency distributions of the wave heights were evaluated via the response surface method. Based on the distributions and numerically simulated wave heights, we estimated the optimal copula via maximum likelihood estimation. Subsequently, we evaluated the simultaneous distributions of the wave heights and the aggregate damage probabilities via the marginal distributions and the estimated copulas. As a result, the aggregate damage probability of the ninety-ninth percentile value was approximately 1.0 % higher and the maximum value was approximately 3.0 % higher while considering the wave height correlation. We clearly showed that the usefulness of copula modeling considering the wave height correlation in evaluating risk of building portfolio. We only demonstrated the evaluation method for two buildings, but the effect of the wave height correlation on the results is expected to increase if more points are targeted.

① Target earthquake 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).

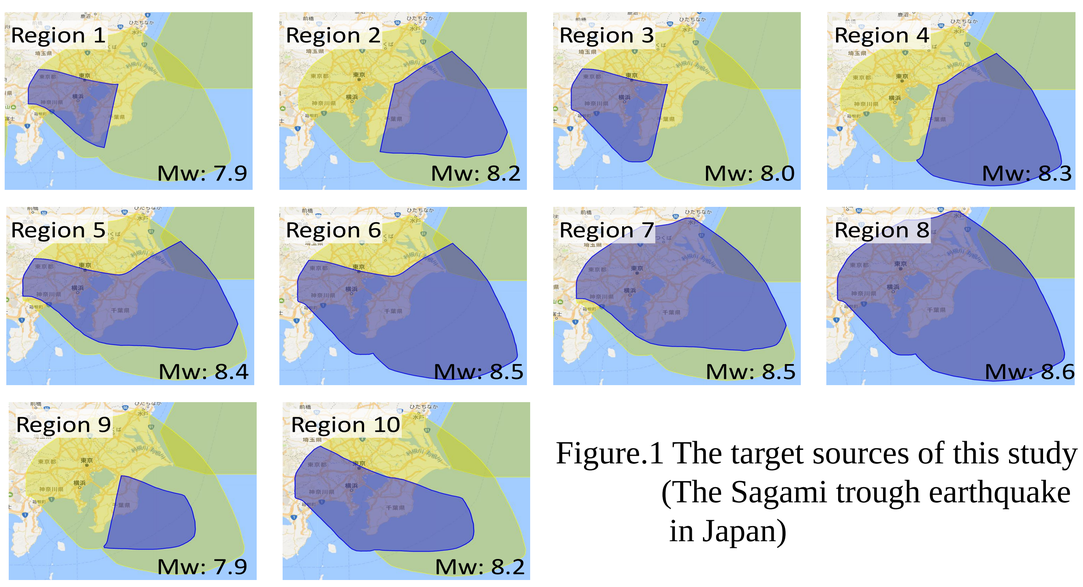


Figure.1 The target sources of this study (The Sagami trough earthquake in Japan)

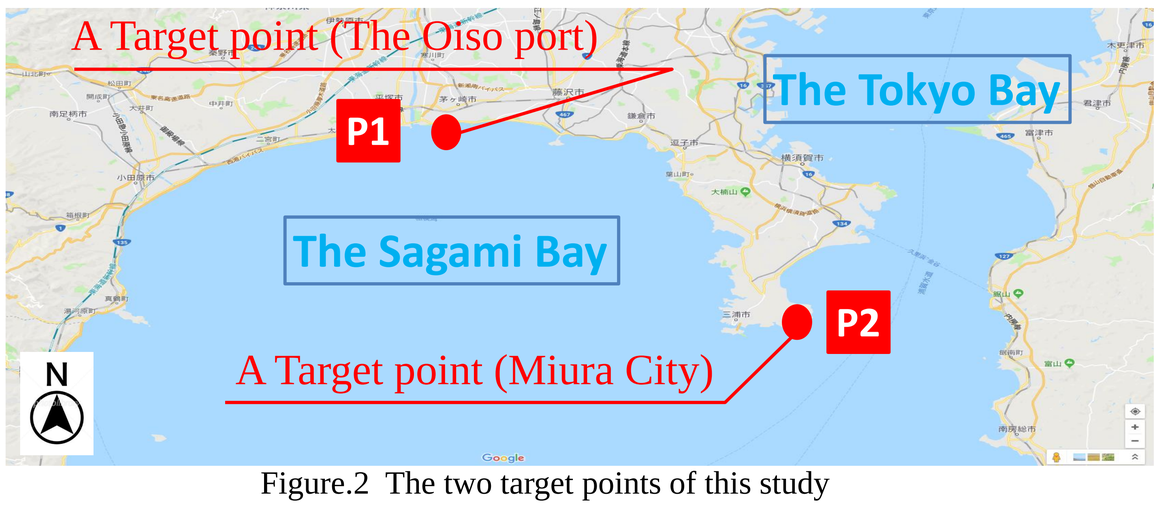


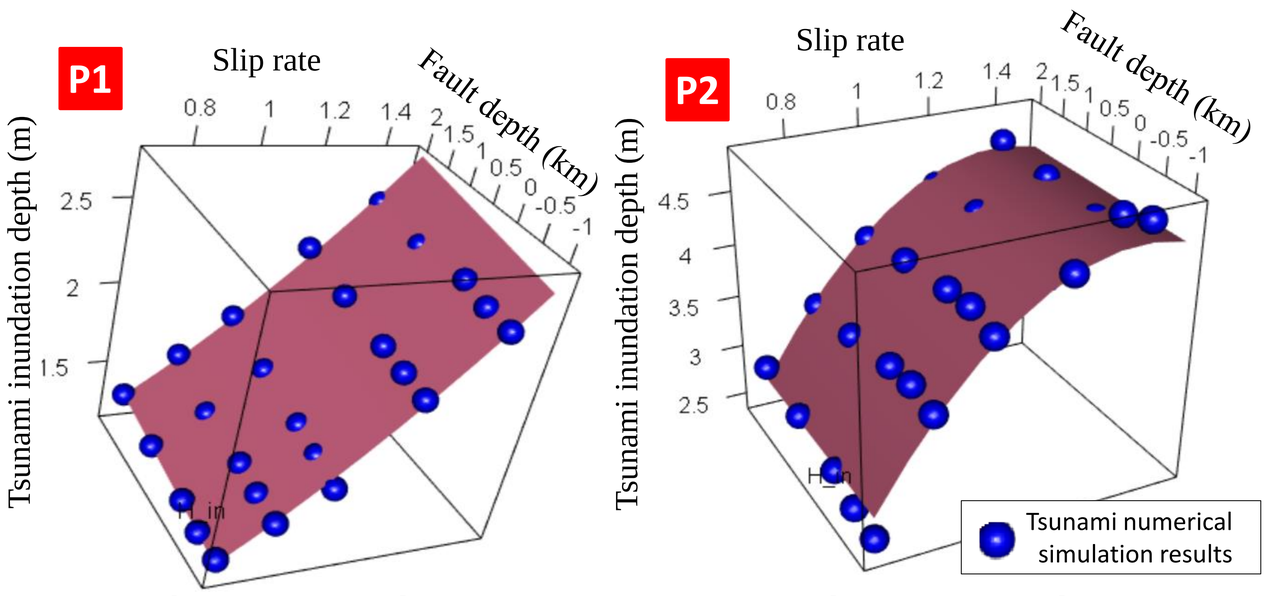
Figure.2 The two target points of this study

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 nonlinear 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



a= 0.66, b=0.05, c=0.00, d=0.52, e=0.51 *a= 11.11, b=0.00, c=0.00, d=-4.02, e=-3.13*

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 (*x1*)	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 (*x2*) [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 be considered the correlation. Based on the tsunami simulation results (25 cases), we conducted maximum likelihood estimation of bivariate copula, then selected Frank copula because AIC is minimum (AIC = -49.11). Figure.4 (b) is the results of Monte-Carlo simulation results considering the correlation using Frank copula. The Monte-Carlo simulation results agree well with the tsunami simulation results.

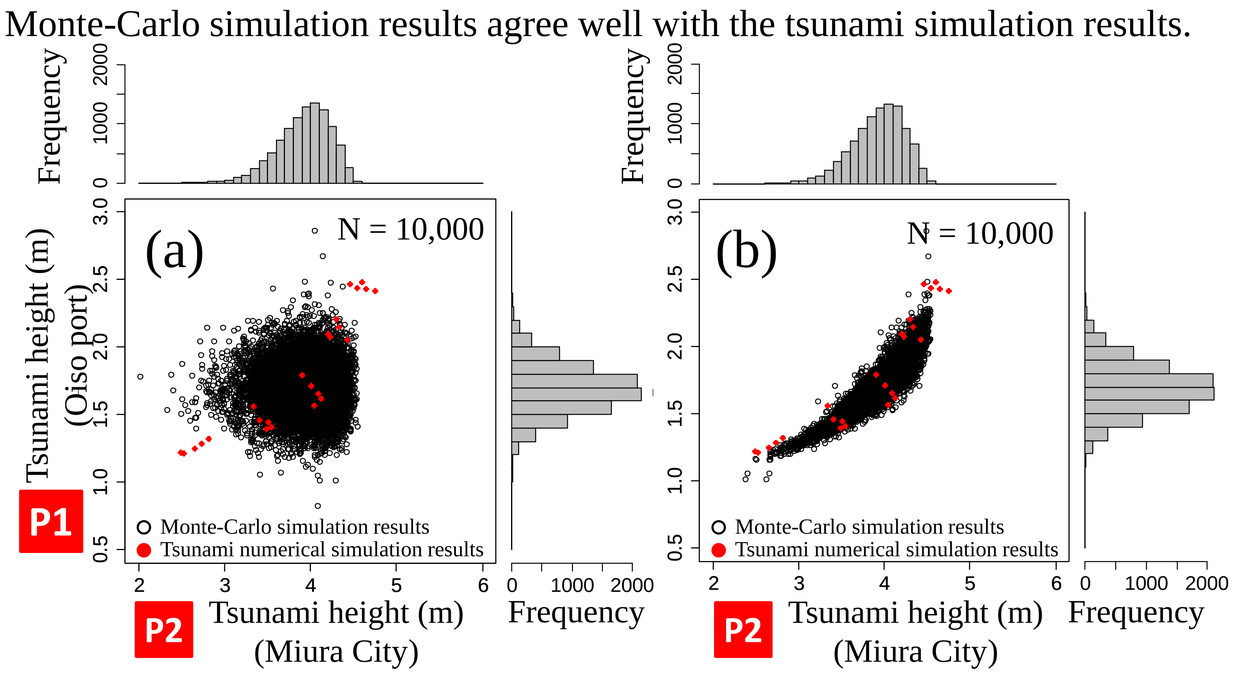


Figure.4 Monte-Carlo simulation results (a) without and (b) with Frank copula

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 95/99th percentile value was about 1 % and the maximum value was about 3 % in case of using the copulas (see Table.1).

Table.1 Aggregate Damage probability

	Aggregate damage probability of two buildings		
	No correlation (A)	Correlation (B)	Difference (B-A)
Average	58.8%	58.8%	0.0%
95 percentile	66.2%	67.0%	0.9%
99 percentile	68.9%	69.7%	0.8%
Maximum	73.5%	76.7%	3.1%

④ Summary

We proposed tsunami risk evaluation using response-surface method and monte-Carlo simulation technique considering correlation of tsunami heights 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)