Tsunami flow parameters influencing port damage: A case-study of the 2011 Tohoku tsunami

Constance Ting Chua, Nanyang Technological University, constance.chua@ntu.edu.sg
Kwanchai Pakoksung, Tohoku University, pakoksung@irides.tohoku.ac.jp
Anawat Suppasri, Tohoku University, suppasri@irides.tohoku.ac.jp
Adam Switzer, Nanyang Technological University, aswitzer@ntu.edu.sg

INTRODUCTION

In the past decade, tsunami fragility models have emerged as a common way of quantifying the relationship between tsunami flow characteristics and structural vulnerability. Fragility functions describe the probability that a structure exceeds a prescribed damage threshold for a given tsunami intensity. Tsunami flow characteristics are represented by tsunami intensity measures (hereafter referred to as TIM) in fragility modelling. The use of an appropriate TIM is imperative to deriving models with as much accuracy as possible. This aspect of research is still an area of debate. In this study, the aim is to assess TIMs that are most optimal for the estimation of structural fragility of port structures. The 2011 Tohoku tsunami was selected as our case study, and we use the damage data for port structures obtained from Chua et al. (2021).

METHODOLOGY

We investigate the relationship between three TIMs – depth, velocity and hydrodynamic drag force, and structural response (Table 1). Within these TIMs, we consider not only equivalent and non-equivalent maximum values of force but we also introduce new definitions of TIMs – instantaneous values of force corresponding to maximum depth and velocity. “Equivalent” here follows the definition provided by Macabuag et al. (2016) where hydrodynamic force values are calculated using separate non-coincident maximum values of depth h_{max} and velocity v_{max}. In this study, non-equivalent maximum force values are calculated directly from numerical simulation as total peak force at any one point. Instantaneous values here refer to force values captured in the numerical simulation when depth or velocity are at their maximum values.

Table 1. Tsunami intensity measures used in this study

Flow characteristics	TIMs considered	Expression
Inundation depth	1. Simulated max. depth	h_{max}
Velocity	2. Simulated max. velocity	v_{max}
Hydrodynamic force	3. Non-equivalent hydrodynamic force	$\frac{1}{2}\rho g h v^2$
	4. Equivalent hydrodynamic force	$\frac{1}{2}\rho g(h_{max})(v_{max})^2$
	5. Hydrodynamic force at max. depth	$\frac{1}{2}\rho g(h_{max})(v_{hmax})^2$
	6. Hydrodynamic force at max. velocity	$\frac{1}{2}\rho g(h_{vmax})(v_{max})^2$

We performed tsunami numerical simulation of the 2011 Tohoku tsunami to reproduce flow values for each port structure. Tsunami generation, propagation and its resulting coastal inundation were calculated using TUNAMI-N2 model. We employed the composite fault model (Tohoku University Model version 1.2) proposed by Imamura et al. (2012) to set up our initial water level condition for simulation.

The damage data used in this study relies on the damage database developed in Chua et al. (2021), where damage data for ports structures including buildings and non-building infrastructure were collected from eight port industries, across six affected ports located in coastal plains within the Tohoku region of Japan. Because of the ordered nature of damage data, a proportional odds model – an ordinal logistic regression model, was used in this study to investigate the most appropriate TIM(s) for the estimation of tsunami fragility. A 10-fold cross-validation technique was applied to assess the classification accuracies of each model.

CONCLUSION

We set out in this study to identify tsunami intensity measures which provide the best damage estimates of damage. Our main findings are as follows:

1. Non-equivalent maximum values of force are more realistic representation of force measures and are found to provide better estimates of damage as compared to maximum force values calculated from non-coincidental maximum depth and maximum velocity values.
2. Damage is likely to have occurred before maximum depth or maximum values, which suggest that using non-coincident maximum depth or maximum velocity values is highly unrealistic.

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