INSHORE TSUNAMI HAZARD INCLUDING BATHYMETRIC AND EPISTEMIC UNCERTAINTY – A DESIGN METHODOLOGY

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CONTEXT

Probabilistic Tsunami Hazard Analysis (PTHA), as detailed by Thio et al (2005) amongst others, can be considered a conceptually standard approach to assessing tsunami hazard, as discussed by Geoscience Australia in the Tsunami Hazard Modelling Guidelines (2018). Typically, hazard curves of a hydrodynamic parameter such as surge level are produced at an offshore location.

A hazard curve is produced by aggregating the hydrodynamic modelling results of a large number of tsunami source scenarios propagated to the area of interest. Aleatory uncertainties relating to tsunami source are mapped by assigning probability distributions or employing logic trees, while epistemic uncertainty (relating to model uncertainty) may also be included. This approach is typically reliant on a numerically tractable representation of the hydrodynamics, such as the linear shallow water equations (SWE), for which source solutions can be stored and combined using linear superposition.

Nearshore hazard is more difficult to assess due to the hydrodynamic non-linearities associated with tsunami wave shoaling, and fine modelling resolution required to capture processes (including long-wave resonance) in a study area. Typically, nearshore hazard might be assessed by employing a simplified representation of inshore transformation, or reverting to the selection of a subset of design scenarios for detailed nearshore modelling, based on offshore hazard results. As such, a problem of translation exists; computation tractability prevents the production of an inshore hazard curve that preserves both complex inshore hydrodynamics and offshore hazard information.

This study presents a methodology which facilitates the production of inshore hazard curves which retain and account for complex hydrodynamic interactions, in addition to allowing uncertainty in bathymetry and model capture of seiching in local embayments. The methodologies are demonstrated through a case study of American Samoa, for which detailed bathymetry is available in the public domain, and high-resolution tsunami observations have been previously captured.

BATHYMETRIC UNCERTAINTY

Bathymetric uncertainty includes both random (stochastic) measurement errors, and systematic errors or bias; the latter is more relevant in this context.

Bathymetric uncertainty is represented by borrowing from spatial correlation approaches employed in geotechnical analysis. A stochastic model for bias was combined with scale of fluctuation representations to produce a large set of bathymetries, used as input to the hydrodynamic modeling process.

RESONANCE

Resonance of local embayments (seiching) is difficult to capture (refer Roeber et al, 2010) due to the sensitivity of modelled resonant frequencies and mode shapes to input bathymetries, in addition to non-linear effects.

In this study, key resonant modes were assessed through eigenvalue analysis of the linearized shallow water equations. For resonant modes, mesh sensitivities were assessed, and used to produce perturbed bathymetries to distort resonant frequencies over a range consistent with epistemic uncertainties (based on past observations in the literature).

An ensemble of input bathymetries was generated by combining the perturbed bathymetries with bias maps produced by considerations of bathymetric uncertainty.

HYBRID MODELLING

A paired modelling approach was applied to quantify inshore hazard transformation. For the purpose of this study, a single far-field tsunami event was considered, the 2009 Samoa tsunami. Linear SWE based modelling was initially applied to assess the hydrodynamic response to the ensemble of input bathymetries. The database of results was partitioned using k-means analysis to identify a spanning subset of input scenarios for further detailed analysis.

The subset of scenarios was subsequently analysed using TUFLOW FV (detailed modelling), which applies the non-linear SWEs. The results from the detailed modelling were used to formulate a transfer function, in turn enabling the inshore transformation of the larger ensemble of bathymetry scenarios.

RESULTS

The results demonstrate a process for transforming offshore tsunami hazard results to an inshore location which accounts for non-linear hydrodynamics, and uncertainties in bathymetry and model capture of resonant processes. The approach lends itself to production of nearshore hazard curves using the full set of tsunami scenarios providing input to the usual offshore hazard assessment, and as such, represents a step forward from the scenario based approach.

REFERENCES

Thio, Ichinose, Somerville (2005); Probabilistic tsunami hazard analysis, Risk Frontier, vol 5(1). Pp. 1-4.
Roeber, Yamazaki, Cheung (2010); Resonance and impact of the 2009 Samoa tsunami around Tutuila, American Samoa.