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Energy Grade Line Analysis of Tsunami run-up on the Sendai Plain after the 2011 Tohoku earthquake

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ABSTRACT

Energy Grade Line Analysis (EGLA) of tsunami run-up has been proposed as a simple tool to predict inundation heights and tsunami loads. A large database of more than 500 inundation measurements collected on the Sendai Plain on the east coast of Japan after the Tohoku earthquake of 2011 provided the writers the opportunity to evaluate the accuracy of the general EGLA method and to make adjustments to fit the model to the Sendai Plain. Refinements to the EGLA model included a correction for the influence of large linear topographic obstructions on tsunami flows in order to achieve better agreement with measured inundation heights. The study illustrates that inundation height predictions are sensitive to the choice of Froude number parameter and land use roughness coefficients. An important outcome of this study is a site-specific tool for probabilistic prediction of inundation heights over the Sendai Plain that is of value for tsunami counter measure planning including design of tsunami resistant structures.

1. Introduction

Tsunamis can cause significant loss of life and property. During the 2011 Tohoku earthquake[2] tsunami, more than18,000 persons were lost. The total land area along the Pacific coast of Japan affected by the tsunami was 561 km^2 and much damage was done to industrial installations, power and transportation infrastructure (The, 2011 Tohoku Earthquake Tsunami Joint Survey Group, 2011; Mori and Takahashi, 2012; Mori et al., 2011). One area that was damaged was the Sendai Plain. This event has put renewed focus on tsunami countermeasure strategies to minimize property loss and to protect human life (Coleman et al., 2011; Monastersky, 2012). Countermeasures that have been discussed include establishment of warning and evacuation systems, and land use control (FEMA P-646, 2012). Disaster prevention/mitigation schemes based on “multiple defense” have also been proposed (Cyranoski, 2012; Central Disaster Management Council of Japan, 2011). These multiple defenses consist of a seawall followed by restricted land use, strengthened buildings and elevated embankments. Tsunami-proof structures used as evacuation facilities are also part of the planning. A necessary prerequisite for effective tsunami counter measure planning, including design of tsunami-resistant structures, is satisfactory predictions of the flooded area, inundation heights and tsunami loads. This is the motivation for the current study.

2. Background and objectives

The general approaches for tsunami inundation prediction are based on 1) analytical or semi-analytical solutions and 2) numerical hydrodynamic models. The former offer the advantage of simplicity at the cost of accuracy and range of application as a result of the simplifying assumptions required to obtain an analytical solution (Peregrine and Williams, 2001; Carrier et al., 2003; Yeh, 2006). The latter approaches offer better accuracy and wider range of application. Titov and Synolakis (1998) developed a numerical simulation method that was va1idated against large-scale laboratory experimental data. Their method was used for run-up analyses of the 1993 tsunami in Okushiri (Japan), the 1994 tsunami in the Kuril Islands (Russia) and the 1996 event in Chimbote (Peru). Goto et al. (2013) carried out a preliminary survey of the Sendai Plain shortly after the 2011 tsunami and compared measured run-up data to predictions using a 2D numerical model. The disadvantage of numerical hydrodynamic models is that they require initial and boundary conditions, such as wave source characteristics, friction between tsunami and the land surface, and land boundary geometry.

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[2] official name given by the Japan Meteorological Agency (JMA) is "2011 off the Pacific Coast of Tohoku Earthquake".

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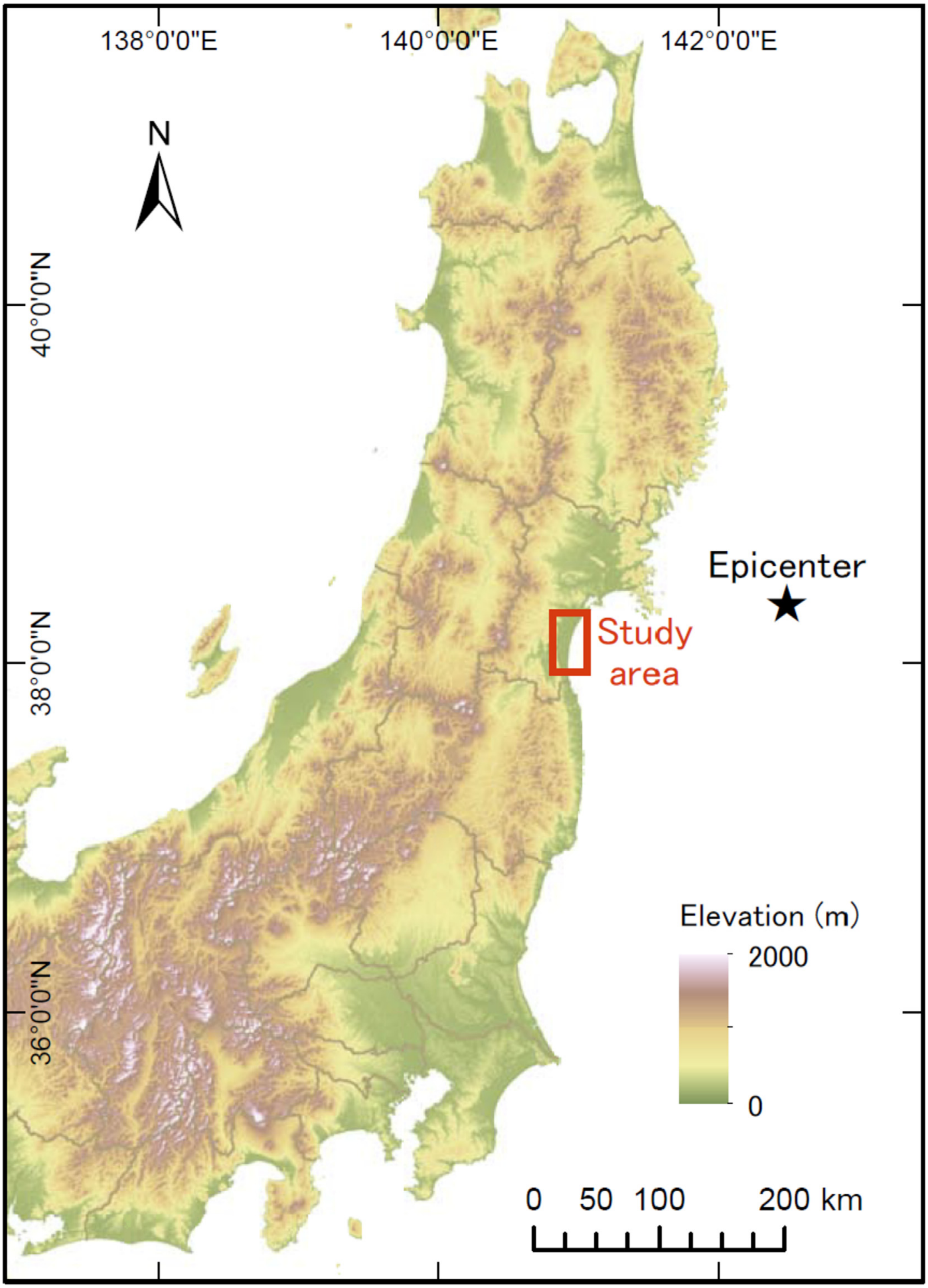

Fig. 1. Location of Sendai Plain study area.

However, for the design of a multiple defense systems extending over large urban areas located on tabular topography a simple analytical model with a minimum number of input parameters is likely the only practical methodology. Such an approach is the Energy Grade Line Analysis (EGLA) method that is described in Chapter 6 of ASCE standard ASCE/SEI 7-16 (2017). Greater detail and explanation of the general approach can be found in the paper by Kriebel et al. (2017) where the EGLA approach is called the Energy Method (EM).

Earlier efforts to calibrate and investigate the accuracy of the EGLA based on numerical modelling have been described by Weibe (2013) and Naito et al. (2016) using sites in Oregon and Hawaii, respectively. Kriebel et al. (2017) compared predictions using EGLA with the results of Monte Carlo simulations using the program COULWAVE (Lynett et al., 2002; Park et al., 2013). Kriebel et al. (2017) concluded that the EGLA approach is conservative (i.e., overestimates maximum inundation depth and maximum velocity). The need to investigate the veracity of the EGLA method against real-world scenarios with physical data was noted by Naito et al. (2016). Carden et al. (2015) compared EGLA predictions against measurements of flow depths and velocities recorded at five different locations in the Tohoku area after the 2011