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FORECAST ALGORITHM FOR INTERPLATE GENERATED TSUNAMIS CALIBRATED BY DRAG FORCE TRANSPORT OF EASTER ISLAND MONOLITHS

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ABSTRACT

Forecast estimated synthetic tsunami arrival heights and times are numerically computed, every 10 kilometers along the coast, from groups of impulse functions of a collection of segmented rupture area tsunami sources of prototype interplate earthquakes. The algorithm is tested and calibrated with data and information from the transoceanic tsunami of may 22 1960, generated by an estimated M_w = 9.5 earthquake with an 800 km length rupture area along the southern coast of Chile. The best fit for rupture area extension, segmentation and fault slip of the dislocation are determined from an inverse analysis of numerous tsunami observations abroad, but specifically from the impact in Easter Island located just along the path of maximum energy propagation. Run-ups in such place were estimated from the tsunami wave hydrodynamic drag force induced transport in the archeological monolithic structures. In real cases, for preparedness planning and early warnings, the earthquake parameters are adjusted as time progresses from an inverse analysis of early observations of the tsunami in the vicinity of the generation area.

Introduction

The issue of effective and reliable early tsunami warnings depends on the rapid detection an analysis of seismic and sea level data. Although Mexico does not have in operation a national warning system for its Pacific coast highly threatened by local and remote source tsunamis, several research institutions and government agencies are working in the implementation of key elements of a National Program on Tsunami Detection, Monitoring and Warning. The federal Scientific Research and Higher Education Center of Ensenada (CICESE) with the support of the National Research Institute for Earth Science and Disaster Prevention (NIED) from Japan, developed a robust and low cost high frequency sea level tsunami gauge, sampling every minute and equipped with 24 hours real time transmission to the Internet. All the ground components of the system (solar panel, transmitter, and antenna) are located at the top of a 10 meter height strong pole, to make it capable to withstand the tsunami attack. A prototype of this instrument is

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currently in operation at the port of El Sauzal (31° 55’ N, 116° 42’ W) and the signal can be viewed permanently at the http://observatorio.cicese.mx Internet site. It is intended to establish a network of these real time sea level sensors with one instrument installed every 100 kilometers covering the Pacific Ocean coast of Mexico, Central and South America, under the auspices of the local government agencies.

Simultaneously, to increase the effectiveness and reliability of this early warning system, an algorithm to predict the wave heights and arrival times of synthetic tsunamis is under development.

Forecast Algorithm

A universe of forecast estimated arrival heights and times were computed from wave forms of synthetic tsunamis. These tsunamis, numerically computed by solving the shallow water long wave equations, were generated from groups of impulse functions of a collection of segmented rupture area sources of prototype earthquakes along the coast of Central and South America. The predicted height and time arrivals were so obtained from a linear superposition of the specific group of Green’s functions corresponding to the segments of the rupture areas (Aste 2002).

In a real case, for a rapid estimation of a tsunami occurrence, the magnitude of the coseismic dislocation and the location of the rupture has to be evaluated from early determinations of the earthquake parameters (i.e. USGS, Harvard) and/or from an inverse analysis of early observations of the tsunami in the vicinity of the generation area, adjusted as time progresses.

Calibration

For the algorithm test and calibration purposes, the huge transoceanic tsunami of may 22 1960, generated by an estimated Mw = 9.5 earthquake was selected. To determine the best fit for a rupture area extension, segmentation and fault slip of the dislocation, an inverse analysis of the numerous tsunami observations abroad needs to be performed. Two alternatives were considered: a) the homogeneous (Kanamori and Cipar 1974) which suggest that the earthquake originated in a single 800 km length rupture area along the southern coast of Chile with a best fit dislocation of 24 meters, and b) the heterogeneous one (Aste 2002) which considers four 200 km each length rupture zones with best fit dislocations of 19.0, 6.0, 3.5 and 17.6 meters from north to south respectively.

Both alternatives agree reasonably in their predicted maximum tsunami wave heights when compared with the observations from 5 tidal gauge records of coastal locations in Chile, north and along the major axis of the rupture area, as provided (Servicio Hidrográfico y Oceanográfico de la Armada de Chile 2000). However the homogeneous alternative predicts wave heights double in size to the heterogeneous one along the path of maximum energy propagation, roughly normal to the major axis of the rupture area, where nearby records are not available.

The 22 May 1960 Tsunami in Easter Island

Easter Island is a 12 x 22 kilometers triangular shaped volcanic island located in the Pacific Ocean 3700 km east of the coast of Chile, just along the path of maximum energy propagation, roughly normal to the major axis of the rupture area of the 1960 tsunami. No tidal gauges were in operation in the island by that time. The tsunami impacted the southeast coast of the island, carrying 150 meters inland the 15 "moai" archeological monumental statues of the Tongariki "ahu" ceremonial altar (Cristino and Vargas 2002). The altar stands 6 meters above mean sea level near the coast of Hotuiti Bay. Maximum tsunami wave heights were estimated by visual observations to be in between 6 to 8 meters, without giving reference to mean sea level, ground level or any other datum. Maximum horizontal extension of the tsunami inundation at the site was also roughly estimated as being 500 meters inland from the coast line.

Tsunami Impact Forces in the Structures

The maximum 1960 tsunami wave height at Easter Island coast, needed for the appropriate calibration of the forecast algorithm and the selection of the best fit alternative, as described above, can be evaluated from an estimation of the tsunami wave forces necessary to start the motion and carry the archeological massive structures horizontally inland, against the friction forces with the ground.

Most of the existing guidelines for design tsunami forces in onshore structures consider the following loads: 1) hydrostatic force, 2) buoyant force, 3) hydrodynamic drag force, 4) surge inertial force, 5) debris impact force, and 6) wave breaking force (Yeh, 2007). Federal Emergency Management Agency 2008) considers also the following loads: 1) impulsive forces, 2) debris damming forces, and 3) additional gravity loads from retained water on elevated floors.

Parameters needed for the force evaluations and subsequent wave height estimations are: legth, width, and height of each of the 15 statues of the "ahu", and the density of the volcanic andesite material from which they were built. Sources for this information were: (Heyerdahl *et al* 1961), (Cristino and Vargas 2002) and notes provided in his web home page by Tadano Ltd. from Japan about the Tongariki Moais Restoration Project, which took place in 1993. Static and dynamic friction coefficients were estimated.

Calculations and Results

From the 9 design tsunami forces in onshore structures described above, only the following loads: hydrostatic force, buoyant force, hydrodynamic drag force, and surge inertial force, acting against the friction forces with the ground, were considered. Others were neglected.

Averaging the results for the 15 statues considered individually, gives a minimum wave height of water of 6.1 meters above the base of the altar to start the motion and carry the statues 150 meters inland, and consequently a tsunami wave height of 12.1 ± 0.3 meters above mean sea level at the shoreline. This result agrees reasonably with the documented 6 to 8 meters height estimated by visual observations if the ground base of the altar is considered as the vertical reference level. Initial undisturbed sea water level at Hotuiti bay was evaluated by harmonic analysis of the tidal components at the time of the tsunami arrival.

After inverse analysis is performed, the heterogeneous dislocation hypothesis (Aste 2002) which considers four 200 km each length rupture zones for the may 22, 1960 Chilean earthquake gives a much better fit with the calculated tsunami wave height at Easter Island than the homogeneous hypothesis (Kanamori and Cipar 1974) which considers a single 800 km length rupture area.

Conclusions

When neither sea level records nor field survey measurements are available, evaluation of tsunami wave forces in nearby coastal structures along the path of maximum energy propagation, roughly normal to the major axis of the earthquake rupture area, can provide valuable information to help determine the segmentation and extension of the dislocation, by inverse analysis. This tsunami inversion process could be particullarly valuable for past centuries earthquakes when recorded information is insufficent or incomplete.

Forecast algorithms to estimate synthetic tsunami arrival heights and times from rapid detection an analysis of seismic rupture zone information can be an important tool to help the issue of effective and reliable early tsunami warnings for coastal communities.

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