Abstract

Tsunami wave trains generated by in-ocean earthquakes can induce undesirable oscillations inside harbors. The wave amplitude of some certain periods is magnified due to the local responses. These responses, known as harbor resonances, include wave diffractions, refractions, and multiple boundary reflections. A numerical model incorporating these effects is built to study response characteristics of American Samoa Pago Pago Harbor. The discrete Fourier transform algorithm is applied to verify the computational results and explore the influence of the tidal level variation on the tsunami response at Crescent City Harbor.

Background: Tsunami as a Natural Hazard

Introduction of the Governing Equation

Mild Slope Equation: \( \nabla \cdot (C_x C_y \nabla \eta) + k^2 C_x C_y \eta = 0 \)

\( \eta \) is the complex-valued amplitude of the free surface elevation; 
\( C_x \) is the phase speed; 
\( C_y \) is the group speed of the waves; 
\( k \) is the wave number; 
\( \nabla \) is the gradient operator; 
\( \nabla \cdot \) is the divergence operator.

Wave Oscillations in American Samoa Island

Response curves associated with the tidal gauge station for 8 directions as shown are obtained. They illustrate the dominant wave period of Pago Pago Harbor is 18.0 min. This fundamental mode has been verified by energy spectral density of tidal gauge records. The amplification factor at the pumping mode is as high as 9.0 and almost the same for all 8 directions of incoming waves. In addition, another notable mode is 4.7 min. with the amplification factor of 4.3.

The mode shape contour illustrates the amplification factor throughout the harbor particularly for one direction and one wave period. The mode shapes of different wave periods and directions show different distributions of the amplification factor magnitude.

The first fundamental mode of 18.0 min. has only one nodal line located at the boundary of the outer region. However, other two modes have more than one nodal lines within the calculation domain. It is clear that the amplification factor is greater at the most inside area for all different modes.

Effects of the Tidal Level Variation

The local response characteristics to incident waves at Crescent City Harbor have been studied by Lee, Xing and Magoon and the dominant response wave period has been proven to be 22.0 min. inside the harbor. Wave spectrum analyses of four tsunami events clearly show the natural period is quite close to 22.0 min.

On February 26th, 2010, at 22:34 PST, a magnitude 8.8 earthquake struck south-central coastal region of Chile. A large tsunami was generated and propagated throughout Pacific Ocean and hit California coast. Intensive wave oscillations are shown by the marigram. Additionally, the tidal level varied from 0.6 meters to 3.9 meters during this event.

The wave spectral density image presents distinctive behaviors from previous cases. Numerous spikes on a wide frequency range can be detected besides the dominant wave period of 22.0 min. This multiple-peak phenomenon is attributed to the tidal level variation. The presence of energy distributions on other frequencies is the manifestation of the first fundamental mode for Crescent City Harbor at different water depths.

Concluding Remarks

This study demonstrates a harbor with a certain shape and topography responses to the incident tsunami waves through a predictable pattern. The effect of the local response is embodied by the amplification of the incoming waves with some modes. The characteristics of the local response are also affected by the water depth which changes due to the tidal level variation. Therefore, it is essential to analyze the wave motion as a function of the dimensionless wave number.