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Coastal Hazards

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COASTAL HAZARDS

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Preface

Intensive development in the coastal zone has placed more people and property at risk to coastal hazards. The needs for coastal hazard mitigations provide many challenging topics for scientific research. This book, an expanded conference proceeding, on Coastal Hazards collect sixteen papers covering different topics of coastal hazard, including tsunami, hurricane winds, storm surge, oil spills, waves, river inflow effects on estuarine and coastal salinity, wave-structure interactions, pollutant spills, and coastal flood and erosion. Practical and advanced research methodologies and technologies have been introduced by those papers, which include field measurements, laboratory experiments, and integrated numerical modeling. Most of the papers have been presented in the ASCE Engineering Mechanics Institute Conference held during August 8-11, 2010 in Los Angeles, California. A few papers without presentations in the conference have also been invited because of their relevance to coastal hazards. The papers presented in this expanded conference proceeding provide good references for researchers, coastal engineers, and the coastal management community. The editors are thankful for the support by the Board of the ASCE Engineering Mechanics Institute, the Turbulence Committee, and the Fluids Committee.

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THE MYSTERY OF 2010 CHILEAN EARTHQUAKE GENERATED TSUNAMI WAVES AT CRESCENT CITY HARBOR

Jiin-Jen Lee[1], Ziyi Huang[1] and Xiuying Xing[2]

ABSTRACT

The tsunami generated by the 2010 Chilean earthquake was recorded at several tide gauge stations along the Pacific coast from 02/27/2010 to 03/02/2010. The marigram at the tide gauge station in Crescent City Harbor in Northern California is analyzed in detail because Crescent City is well known for its tsunami vulnerability. The energy spectrum as a function of frequency has been found to contain several spikes corresponding to the frequency range of $3\times10^{-4} \sim 8\times10^{-4}\,Hz$. This behavior is different from several prior tsunamis observed and analyzed for Crescent City Harbor. A finite element numerical model has been used to compute the resonant response at Crescent City Harbor to incident waves with different wave directions. It is found that the spectral spikes are associated with the first fundamental mode of oscillation at the dimensionless wave number $kl = 1.10$ for different water depth due to the varying tide levels (0.6 to 3.9 meters). A closer view of the spectral density curves found that everyday tide gauge record also contained the same multi-spectral-spikes because of the significant variation of water depth from low tide to high tide. In order to correctly decipher the resonant response characteristics to incident wave the response curve plotted as a function of the dimensionless wave number is essential.

Keywords: resonant response, Chilean earthquake tsunami, mode of oscillation, dimensionless wave number, fundamental resonant mode, Crescent City Harbor

1. INTRODUCTION

On February 26th, 2010, at 22:34 PDT, a magnitude 8.8 earthquake occurred in south-central coastal region of Chile approximately 300 km north of the site of the massive 1960 Chile earthquake (M_w=9.5). The 02/26/2010 earthquake was generated along the plate boundary where the Nazca Plate is being subducted under the South American Plate. A large tsunami was also generated causing severe damage to coastal towns and harbor facilities along Chilean coastal region.

The generated tsunami waves propagated throughout Pacific Ocean. They arrived at California coast about 12 ~ 13 hours later. The wave trains had been recorded at several tidal gauges located along the California coast. The tide gauge record from 02/27/2010 13:00 PDT to 03/01/2010 13:00 PDT at Crescent City Harbor is shown in Figure 1. Crescent City harbor located in Northern California is well known for its tsunami vulnerability due to its location and topography. Consequently, many authors have described the harbor as a "sitting duck" for tsunami waves originated from the Pacific Ocean (See Magoon, 1965; Powers, 2005).

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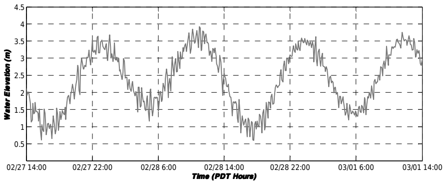

Figure 1. Crescent City Harbor marigram recorded by tide gauge for Chilean earthquake event

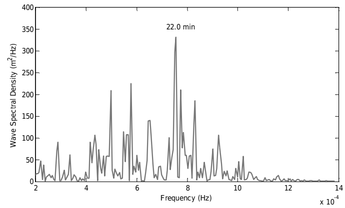

Figure 2. Wave spectral density at Crescent City Harbor tide gauge location for Chilean earthquake event

The energy density spectrum as a function of the wave frequency based on the time series shown in Figure 1 after separating the tide is presented in Figure 2. Numerous peaks in the spectral density for the range of frequency between $3\times10^{-4} \sim 8\times10^{-4}Hz$ can be seen in Figure 2. A casual look at the energy spectrum of Figure 2 would lead one to believe that the response to this Chilean tsunami wave at Crescent City Harbor is very different from the numerous prior tsunamis that were recorded at Crescent City Harbor and analyzed by Lee, Xing and Magoon (2008).

2. NUMERICAL MODEL AND SIMULATION RESULTS

To discover the mystery of this recorded tsunami of 02/27/2010 ~ 03/01/2010, the numerical model used in Lee, Xing and Magoon (2008) is reexamined closely.

The numerical model used is a hybrid finite element model. The governing equation is the Mild Slope Equation first derived by Berkhoff (1972):

$$\nabla\cdot\left(CC_g\nabla\phi\right)+\frac{C_g\omega^2}{C}\phi=0 \qquad (1)$$

in which $\phi=\phi(x,y)$ is the velocity potential, $C=\dfrac{\omega}{k}$ is the wave celerity, $C_g=\dfrac{C}{2}(1+G)=\dfrac{C}{2}\left(1+\dfrac{2kh}{\sinh 2kh}\right)$ is the group velocity and $G=\dfrac{2kh}{\sinh 2kh}$, k and ω are the wave number and the wave frequency, h is the water depth (which is a function of x and y).

The numerical model incorporates the effects of variable water depth, wave refraction, wave diffraction, wave reflection from partial or fully reflecting boundaries, entrance energy dissipation, as well as wave transmission through porous breakwaters. For a more detail presentation of the numerical model used in this study see Lee and Xing (2010).

Figure 3(left) shows the model region for the computer model (only the major grid blocks are shown). The numerical model contains 9,709 finite elements and 39,688 nodes with eight incident wave directions (indicated as direction #1 to #8). Crescent City Harbor is shown in Figure 3(right) with five locations of interest denoted as A, B, C, D, and E with the tide gauge location noted.

Figure 4 presents the computer simulation response curves with the two distinct resonant periods at the tide gauge station of Crescent City Harbor under different scenarios of assumed wave directions. The ordinate is the amplification factor defined as the wave height at the tide gauge station divided by the incident wave height. The abscissa is the dimensionless wave number kl (where k is the wave number, 2π divided by the wave length l, and l is the characteristic length of the harbor which is the length from the outer harbor entrance to the facing coastal line about 4.363 feet in the present model). It clearly shows that 22.0 min and 10.3 min resonant periods (based on the average water depth) existed at the tide gauge station.

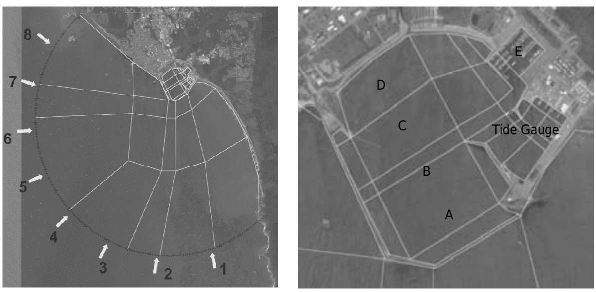

Figure 3. Simulation domain for Crescent City Harbor (left) and locations of special interest as A, B, C, D, E and the tide gauge (right)

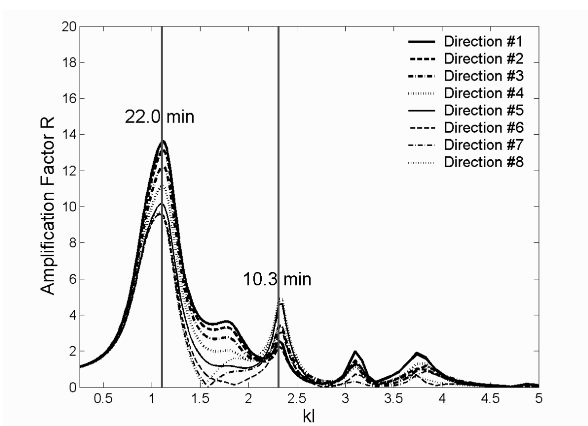

Figure 4. Response curves at tide gauge location for different incoming wave directions