Available online at www.sciencedirect.com
ScienceDirect
Journal of Hydrodynamics
2017,29(3):377-392
DOI: 10.1016/S1001-6058(16)60747-3
www.sciencedirect.com/science/journal/l0016058

Characteristics of wave amplitude and currents in South China Sea induced by a virtual extreme tsunami*

Zhi-yuan Ren (任智源)[1,2], Xi zhao (赵曦)[1], Ben-long Wang (王本龙)[1], Frédéric Dias[3], Hua Liu (刘桦)[1]
1. *MOE Key Laboratory of Hydrodynamics, School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China*
2. *National Marine Environmental Forecasting Center, Beijing 100081, China, E-mail: zhyren@foxmail.com*
3. *School of Mathematics and Statistics, University College Dublin, Dublin, Ireland*

(Received March 12, 2017, Revised April 14, 2017)

Abstract: This paper investigates the potential extreme tsunami hazards of the worst case scenario of the magnitude $M_w = 9.30$ in South China Sea (SCS) as the Manila Trench is becoming one of the most hazardous tsunami source regions. Using nonlinear shallow water equations model, the time series of surface elevation, arrival time, spatial distributions of maximum wave amplitude and velocity distribution are presented. The characteristics of wave and currents are analyzed. The numerical results indicate that most of the energy of tsunami wave distributes in central and north part of SCS. The offshore regions around SCS will be influenced significantly by the tsunami currents generated by an earthquake in the Manila subduction zone. The maximum wave amplitude near Guangdong Province, Hainan Island, and Taiwan Island exceeds 4 m and velocities at the majority of measured locations near coast exceeds 2 m/s. Nested grid with high resolution is used to study the impacts of the tsunami on Hainan Island, Taiwan Island, and Lingding Bay. The regions with high hazard risk due to strong currents are identified. Finally, a fast tsunami warning method in SCS is developed and discussed, which can provide tsunami warning information in 5 min.

Key words: Tsunami, South China Sea (SCS), worst case scenario, wave characteristic, fast tsunami warning

Corresponding author

Prof. Hua Liu is the director of MOE Key Laboratory of Hydrodynamics, Ministry of Education of China, at Shanghai Jiao Tong University. He received his first degree and Master degree at Hohai University in 1984 and 1987. Since 1991 when he graduated from Shanghai Jiao Tong University with Ph. D. degree in fluid mechanics, he has been a faculty member at Department of Engineering Mechanics at (Shanghai Jiao Tong University) SJTU. His main research interests cover hydrodynamics at high speed, water wave mechanics and tsunami, estuarine and coastal hydrodynamics. He has published around 120 journal papers. Dr. Liu serves as member of IUTAM Symposia Panel for Fluid Mechanics, co-chair of the executive committee of International Conference on Hydrodynamics, the chair of Fluid Mechanics Division of Chinese Society of Theoretical and Applied Mechanics, and associate editor of Journal of Hydrodynamics.

* Project supported by the National Natural Science Foundation of China (Grant Nos. 11632012, 51379123).
Biography: Zhi-yuan Ren (1986-), Male, Ph. D.
Corresponding author: Hua Liu, E-mail: hliu@sjtu.edu.cn

Introduction

Two extreme tsunamis have produced devastating damage around the Indian and Pacific Oceans over the last decade. The 2004 Indian Ocean tsunami, which generated from north of Sumatra of Indonesia, attacked many countries around Indian Ocean (India, Bangladesh, Indonesia, Thailand, Sri Lanka, etc.), and led to death of more than 200 000 people[1,2]. The 2011 Tohoku tsunami brought huge damage to Japan, with a death toll of 15 000 or higher and extensive coastal infrastructure damages, such as Sendai Airport and Fukushima Daiichi nuclear power plant[3-5]. The past extreme tsunami events become the motivation for the investigation on the extreme tsunami hazards in South China Sea (SCS), as the Manila subduction zone is becoming the most hazardous tsunami source region[6,7].

Currently, most researchers adopted the shallow water equations or Boussinesq equations to simulate the tsunami propagation. The main difference of the two kinds of numerical models is that the Boussinesq model can reproduce the dispersion effects of the tsunami, because the dispersion effects can play a significant role for long distance propagation of co-seismic tsunami, smaller scale earthquake tsunami, or landslide-induced tsunami[8,9]. Kirby et al.[9] and Grilli et al.[10] reported that the dispersion effects in the 2011 Tohoku tsunami became significant when it propagated across Pacific Ocean. Zhao et al.[11] and Ren et al.[12] carried out numerical experiments on the dispersion effects of tsunami wave in SCS by the Boussinesq equations[11]. Through numerical simulation by one-dimensional Boussinesq equations, Zhao et al.[13] reported that the initial N-shape tsunami waves could evolve into long wave trains, undular bores or solitons near the coastal area owing to long distance propagation over the continent shelf of SCS. Matsuyama et al.[14] did an experiment on tsunami wave fission in a large wave flume. Tissier et al.[15] reproduced tsunami-like undular bores in coastal region using a Boussinesq model. Even though the different wave patterns should be considered to study the runup and effects of tsunami on coastal structures[16], it is acknowledged that, for the worst case scenario, the dispersion effect on tsunami propagation in the deep region of SCS is not significant. The shallow water equations can be used to analyze the characteristics of tsunami wave in the deep region of SCS.

Fritz et al.[17] developed a method to calibrate and analyze the videos recorded from building rooftops at Kesennuma Bay along Japan's Sanriku coast using LiDR and presented the measured maximum tsunami height of 9 m in the Kesennuma Bay narrows and the maximum tsunami currents of 11 m/s. Lynett et al.[18] carried out numerical simulation of the hydrodynamic flows in the Port of Oarai and in Pillar Point Harbor-during the 2011 Tohoku tsunami event and the 2004 Indian Ocean tsunami in Salalah, Oman which shows that the simulation predicts maximum flood speeds of 3 m/s-6 m/s around the breakwater gap. Lynett et al.[19] compared the maximum speeds computed by the method of splitting tsunamis (MOST) to that computed by the Boussinesq equations and noted that MOST can reproduce the MOST tsunami model satisfactorily reproduces measured tsunami-induced current speeds. Admire et al.[20] reported comparisons between the measured and computed currents from the Tohoku-oki, Japan and other recent tsunamis in northern California which confirms that the MOST numerical model works well for reproducing the tsunami currents. Arcos and Leveque[21] adopted the shallow water equations to compute the distribution of velocity around Hawaii Island induced by the 2011 Tohoku tsunami and concluded that the GeoClaw numerical tsunami model can accurately predict current velocities at the nearshore locations. Reviews on the history of tsunami current observations in ports and the recent advances in numerical methods for tsunami modelling can be found in Borrero et al.[22] and Behrens and Dias[23] respectively.

Since 2004 Indian Ocean tsunami, the significant advancements of tsunami warning system and methodology had attracted more attention. Early works were carried out to focus on the early tsunami warning system in SCS. Liu et al.[7] developed an early warning system in SCS based on COMCOT model and buoy inversion method. Ren et al.[24] extended this method to be a multi-buoy inversion method, and gave the priority of buoy arrangement in SCS. One optimization method based on reaction time and the population centers is proposed by Liang et al.[25]. Lin et al.[26] developed a tsunami warning method without DART measured data, which is implemented in COMCOT model. Considering the potential impacts of currents in ports, it is necessary to predict the tsunami-induced currents for the worst case scenario in the SCS region.

In this study, the nonlinear shallow water equations based tsunami numerical model is used to simulate the virtual extreme tsunami in SCS. The analysis of characteristics of wave amplitude and currents induced by the tsunami is carried out. The impacts on Hainan Island, Taiwan Island, and Lingding Bay are computed numerically with finer grids. A fast tsunami warning method in SCS developed with GeoClaw model is presented.

1. Numerical model

The numerical model GeoClaw is used to simulate the generation and propagation of tsunami. Okada model[27] is adopted to compute the deformation of sea bottom in a subduction zone and provide the initial