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NUMERICAL MODELING OF TSUNAMI WAVES

Book Written by:

Juan Horrillo, William Knight and Zygmunt Kowalik

REVIEW

by

George Pararas-Carayannis
President, Tsunami Society International
Editor, Science of Tsunami Hazards

The book entitled "Numerical Modeling of Tsunami Waves" by Professor Juan Horrillo, (Texas A&M University), William Knight ((National Tsunami Warning Center (retired), USA) and Professor-Emeritus Zygmunt Kowalik (University of Alaska, Fairbanks, USA), is a well-written, comprehensive treatise of the evolving science of computer modeling of tsunami waves. Their book presents an all-encompassing treatment of the subject based on research collaboration that began about 20 years ago on numerical methods to the dynamics of long-period waves, and particularly to tsunami waves. With a detailed, analytical, well-organized, orderly, and constructive approach, the authors review the basic techniques, the evolution of numerical schemes, then introduce the application of finite-methods to the study of tsunami waves, and subsequently go into the solving of more elaborate problems arising from investigations of recent tsunamis.

The 397-page monograph represents a good summation of the state of the art of numerical modeling and refinements, which encompasses all aspects and acting synergies that help understand the realities of the tsunami disaster, regardless of the source mechanism from different causes - whether by earthquakes, landslides, or massive slumps, and which can be verified by actual observations and instrumental recordings. With skillful and methodical presentation and examples - ensuring that every aspect of modeling receives appropriate consideration - the authors not only explain how the basic theory is applied, but also introduce several new important ideas, procedures and concepts in tsunami science that can be used as the fundamental basis for the simulations of long period waves.

The first chapter of the monograph provides a general introduction to the system of coordinates used in computing large-scale phenomena on the rotating Earth such as tsunami, tides, or storm surges. Specifically examined are the equations of motion and continuity, the conservation of energy, and the flow dynamics in both Cartesian and spherical coordinate systems. Subsequently described are the possible motions and the hydrostatic approximations in both vertical and horizontal directions - thus constructing energy equations, and vertically integrating them on a sphere. Furthermore, since the surface dynamics of such impulsively generated long period surface waves are affected by the ocean/sea bathymetry, consideration is given to the source mechanisms - whether involving ocean floor displacements by earthquakes, underwater landslides, or slumps. Thus, the dynamics of the two-layer fluid system involving a layer of higher density such as that of a slump, are carefully included in the solution of the equations of motion and continuity. Finally discussed carefully is the behavior of the small amplitude waves and the velocity of propagation in a channel-like sea environment, neglecting Coriolis, dissipation, and non-linear terms, However, attention is given by the authors in describing in simple terms the dispersion processes – described more analytically in Chapter 6 of the monograph.

In the second chapter of the monograph, and in a very skillful and methodical manner, the authors explain in great detail the finite difference methods of long wave propagation in one dimension, and demonstrate how the physical properties of the waves - and particularly how the phase velocity is associated with a chosen numerical algorithm. Further discussed are the computational errors of the numerical modeling methodology, the approximations of the differential equations being used for a tsunami's propagation phase, and finally describe terminal tsunami run-up.

In Chapter Three, the authors use a step-by-step approach to describe the processes of tsunami generation by both earthquakes and landslides. Subsequently introduced are the basics of Seismology, simple rheological models, a discussion of the numerical procedures, and of the general long-wave algorithms.

Chapter Four extends the description to real ocean applications to two major historical tsunamis, namely the Indian Ocean tsunami of December 2004 and the Kuril Island tsunami of November 2006. Subsequently introduced in the spherical coordinate system are: a) the construction of finite difference equations, b) the boundary conditions, and c) the source mechanisms of these two tsunami events. Verification, calibration, and refinement of the modeling methodology is obtained by comparisons between recorded observations and the numerical results, giving particular attention to the effects of scattering, diffraction, and reflection. Based on all these considerations, the energy flux is subsequently analyzed as a way for further refinement in order to determine the impact that bathymetric features may have on refraction, diffraction, scattering, pathways and terminal tsunami run-up amplification on distant shores located thousands of miles from a tsunami's source region.

Chapter Five describes the thorough transformation that tsunami waves undergo upon arriving at near-shore regions, where their amplitudes and particle velocities are greatly magnified. Explained in this chapter are the roles of the different mathematical terms in the equations of motion and continuity that contribute to such shallow water amplification. Additionally discussed are the effects of amplification due to resonance, when the already enhanced tsunami waves enter the shallower bathymetry of bays and ports, such as the ports of Skagway in Alaska and of Crescent City in California.

Chapter Six presents the influence dispersion has on transoceanic long wave propagation, energy flux, pathways, time of travel, and probable synergistic impact on tsunami run-up at a distant shoreline, in contrast to previously-considered tsunami models which are based on the shallow water approximation which ignores the effects of wave dispersion. In describing in greater detail dispersion in this chapter, a term is included in the equation of motion, which represents the sum of both hydrostatic and non-hydrostatic components, and uses as descriptive examples the transoceanic propagation of recent events, namely the Japan (Tohoku) Tsunami of 2011, and the Indian Ocean Tsunami of 2004 – both demonstrated by previous studies as generating long period waves that were particularly dispersive (Kulikov 2005; Horrillo et al., 2006; Saito et al., 2011). Based on these considerations, the equation for the energy flux is developed.

Chapter Seven of the monograph addresses and details the three-dimensional (3D) methods that are being used for applications of numerical modeling, particularly because the initial tsunami generation phase where the prevailing domain is compact, or when high initial speeds are triggered. Additionally explained in this chapter is the numerical methodology of connecting the 3D generation domain to 2D depth averaged equations which are being used for the tsunami's transoceanic propagation, with the numerical method applied to the Gulf of Mexico.

Chapter Eight of the monograph emphasizes and describes the guidelines used by developers of tsunami hazard mitigation maps, formulated by the National Tsunami Hazards Mitigation Program (NTHMP). Such mapping work has been carried out for the Gulf of Mexico but expected to be similarly applied to other vulnerable regions threatened by comparable tsunamigenic sources and regional climatology and geomorphological features.

A final discussion in the monograph includes several of the computational programs related with the individual chapters, and additionally provides the Internet link to the Texas A&M University at Galveston Tsunami Research Group (TRG) Internet page where the Fortran Codes can be found (https://www.tamug.edu/tsunami/Tsunami-Codes.html).

CONCLUSION

In a very skillful and methodical manner - the authors provide in the reviewed monograph, new insights on the subject of numerical modeling, its gradual upgrading, and updates with what is being done presently with state-of-the-art, high-performance computers, which allow for even more accurate simulations of tsunami waves generated from a variety of source mechanisms - whether from earthquakes, landslides, or other sources.

The eight chapters of the monograph, include thorough reviews of theoretical principles and of the development of codes for specific applications to computer modeling of real and theoretical data sets, as well of examples from the literature specific to the methodology used. These new codes allow the rapid solution of highly complex equations that describe tsunami wave generation, tsunami wave energy propagation, dispersion, and allow the prediction of near and far field wave characteristics. These characteristics relate to the unique mechanisms of wave generation from different sources and the effects on the distribution of wave energy and its attenuation across a body of water. The modeling is based on finite discretization in space and time, using structured rectangular meshes with codes and using finite difference schemes. However, the codes that are used for the calculations have been modified or extended to allow for mesh refinements.

Finally, and in addition to validating the results with historical data, the monograph provides several conclusions concerning the effects of various source characteristics on wave generation, propagation and termination – all of great importance in both understanding these processes, but also of being of significance to Tsunami Warning Systems in issuing more accurate predictions, and thus enabling Civil Defense Authorities to evaluate the tsunami risks and take measures that will protect human lives, properties and important infrastructure.

In summary, the monograph entitled "Numerical Modeling of Water Waves" by Juan Horrillo, William Knight and Zygmunt Kowalik represents an outstanding work of scholarship and a valuable reference for any researcher involved in numerical modeling.

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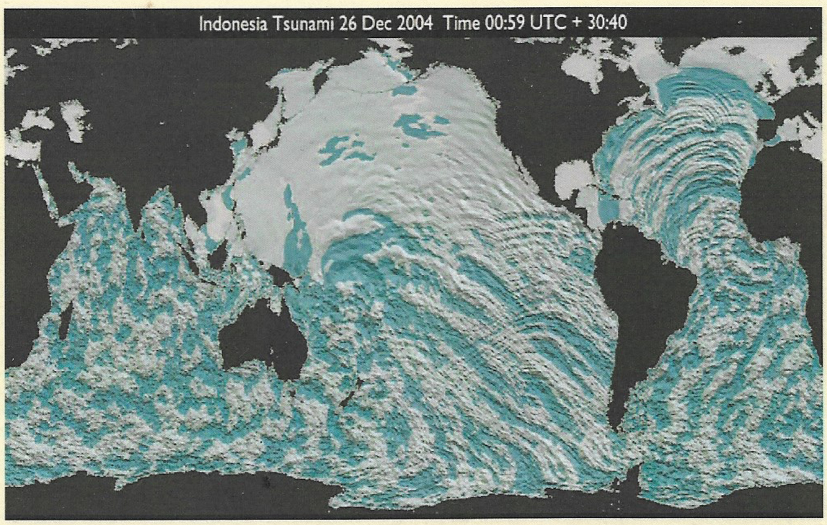
Numerical Modeling of Tsunami Waves



Juan Horrillo, William Knight
and **Zygmunt Kowalik**

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