Chapter 5: SUMMARY AND CONCLUSIONS

The dissertation describes a numerical model for calculating long-wave evolution over complex bathymetry and the associated inundation of coastlines with realistic topographies. The main goal of the study is to develop and comprehensively test a numerical algorithm that is robust and applicable to simulations of field events. The shallow-water wave approximation is chosen as the model equation, because many nearshore processes are described by these equations and can also be considered as possible application of the model. The main engineering application assumed in this study is the simulation of tsunami waves. The numerical solution of the equations uses an explicit second-order finite-difference scheme, a splitting method is then applied for development of the 2+1 numerical algorithm to model three-dimensional long waves. An absorbing boundary condition was derived for the open-sea boundaries and moving-shoreline algorithm was constructed to model the run-up process.

Two separate numerical algorithms are described and tested in this study, one for plane 1+1 waves and another for three-dimensional 2+1 waves. While it may seem superfluous to include a 1+1 algorithm, when the entire 2+1 problem has been solved, there are two main reasons for including the 1+1 algorithm and separate descriptions for the two models. One, it was found to be occasionally useful to apply a combination of the 1+1 and 2+1 models to simulate field events, when high resolution bathymetric data are not available for the entire area of interest in the simulation. This approach permits the study of the dynamics of the wave runup in specific places of interest where the beach-profile transects have been measured directly during post-event surveys, or to specify where profiles should be measured when predictions of higher order of accuracy are required for zoning studies. Two, the process of solving the 2+1 problem involves splitting the solution into two 1+1 problems. Given the number of laboratory and field data available for validation of 1+1 problems, it was felt that the validation of the 1+1 code was of paramount importance in setting up the validation of the 2+1 code, which was carried anyway using the small number of available large-scale 2+1 laboratory experiments.

Chapters 2 and 3 describe the finite-difference model developed for the solution of the field equations for 1+1 and 2+1 cases, respectively, and the testing of the numerical algorithm. The numerical tests show that the method is robust enough to model not only non-breaking waves, but also the runup of mildly plunging waves for both 1+1 and 2+1 models. It should be noted that the laboratory wave parameters used for the tests correspond to very extreme cases in nature. For example, the 0.3 solitary wave used in chapter 2 for the model comparison would have had the same dimensionless parameters as a 1,200*m*-amplitude wave propagating in the 4*km*-deep open ocean, or the same as a 60*m*-amplitude wave approaching a coast from the 200*m*-deep continental shelf which would lead to a 100*m*-high vertical runup on a natural beach resulting into horizontal inundation ranging from 3*km* to 10*km*. Even the smallest dimensionless amplitude 0.1 wave used for the validation corresponds to a prototype wave with expected vertical runup of about 60*m* on a plane beach. Clearly, these are very extreme cases. The model performed well simulating these extreme waves, which suggests strongly that for the typical range of the field wave parameters, the model should perform at least as well or better, since these prototype waves are more linear in behavior.

The main contribution described in these two chapters is the development of the shoreline algorithm. The calculation of the moving shore-boundary even for the 1+1 evolution has been a classic problem of coastal hydrodynamics. It is a process involving air, water, and beach-surface interactions with thin jet-like flows which often become supercritical; finite difference solutions have to rely on the introduction of additional grid-points inside the computational domain, at a hefty price; before the writing of this thesis, all existing algorithms used friction factors or artificial viscosity terms to slow-down the shoreline evolution and stabilize the computations. Even thought the choice of these fudge coefficients have been ad-hoc, the numerical algorithms have performed well, except when modeling extreme events. The shoreline algorithm developed here, just as the entire evolution algorithm, it uses no friction factors or any other ad-hoc coefficients. It was found to predict extreme inundation heights such as the 30m runup observed in the 1993 Hokkaido-Nansei-Oki tsunami correctly.

After extensive verification of the numerical algorithm against laboratory experiments, analytical and numerical solutions, the model was applied to simulate several historic tsunamis, as described in chapter 4. The goal of these numerical experiments was not only to further test the numerical algorithm, but also to understand its limitations in simulating realistic events and to gain a new knowledge about the simulated tsunamis.

The Nicaragua and Peru models showed that important dynamic characteristics of the tsunami wave can be learned from the 1+1 runup computations combined with the 2+1 model. The Kuril tsunami calculation demonstrated that a “slow” tsunami with a large wave period can be modeled without inundation computations to predict the runup distribution, to first order, particularly if there are no unusual topographic features.

A complete 2+1 model with runup computations around all shoreline boundaries demonstrated the ability to reproduce most of the important characteristics of the tsunami wave such as runup heights, flow velocities, offshore time history of the wave amplitude and the inundation zones. This model was applied for simulation of the Hokkaido-Nansei-Oki and Mexican tsunamis where bathymetric and topographic data of sufficient resolution was available. The spatial grid resolution analysis performed for the Hokkaido-Nansei-Oki model demonstrated that using 150*m* grid is sufficient to reproduce overall runup heights distribution along coastlines. The Manzanillo tsunami simulation also showed that such resolution appears to be enough to simulate the complicated nearshore wave dynamics, that was recorded by the offshore gages during this tsunami. At the same time to model important local effects of the tsunami such as overland flow, inundation velocities and local runup maxima, the local bathymetric and topographic data with high horizontal resolution are essential. Although the minimum resolution for a grid for correct predictions must be such that it resolves the smallest essential bathymetric features, it was found that a 50*m* grid was sufficient to reproduce extreme inundation heights. In practice the grid resolution depends only on the resolution of the available data; increasing the grid resolution through interpolation does not appear to improve predictions, as long as the “coarse” grid is sufficient to resolve the wavelength. In general, it appears also that without sufficient grid resolution, the inundation computations do not improve the predictions, and they can often vary by a factor of two or more from the field measurements.

The numerical model which was described, tested and applied for studying historical tsunamis appears to be a powerful numerical instrument for studying the evolution of long waves and tsunamis. The model proved to be a robust enough to simulate realistic events without preliminary calibration of any model parameters, such as friction factors or artificial viscosity. The validation of the model demonstrated that the shallow-water approximation simulates adequately those tsunami-wave characteristics that are essential for the tsunami hazard mitigation. The model can be used both for various studies of long wave evolution, and for practical applications of the tsunami-hazard reduction programs.

Remaining unresolved issues at least from the point of view of coastal hydrodynamics include the quantification of the effects of wave breaking in velocity estimation in both 1+1 and 2+1, the quantification of bottom friction effects particularly for very gentle beaches, the determination of the relative effects of the different fault parameters in defining the ground deformation, the effects of time-dependent ground deformations in the computation and the quantification of minimum practical resolution limits for useful predictions and for maximum resolution limits beyond which no further improvements are possible. Although VTCS-3 can be used in real time, its capability to “absorb” real time data from bottom pressure transducers or satellite images and correct the real time evolution calculations during an actual tsunami event remains to be developed. The rapid progress of tsunami science in the past 5 years promises that these issues will be successfully addressed in the next decade.