The Orissa super cyclone which crossed the Orissa coastal region near Paradip on October 29, 1999 proved to be disastrous. The strong winds, torrential rains with heavy rainfall and high storm surge associated with the cyclone caused havoc that resulted in the death of thousands of people, cattle and extensive damage to agricultural land, paddy crop, transmission lines, power supply, roads and buildings. In the present study, a fine resolution finite element model is used to simulate surges due to this super cyclone. The model results are compared with observed surges available from post-storm survey reports. Comparison of results show that they are in good agreement with the observed surges, and the finite element model can be used for real time surge forecasts.

Keywords Cyclone · Finite element modeling · Paradip

1 Introduction

The super cyclonic storm that traveled over the Bay of Bengal before reaching the Orissa coast on 19 October 1999 was the most intense cyclone recorded in Orissa for 14 years. It produced a huge storm surge and catastrophic floods that caused severe damage to the coastal districts of Orissa. Paradip is the most vulnerable place for landfall of cyclones along the Orissa coast, and the 1999 super cyclone hit the coast at Paradip. The damage caused by surges that result from severe cyclones can be
minimized if they are forecast well in advance. The National Institute of Ocean Technology (NIOT) has developed a real time storm surge prediction model for the East Coast of India (Latha and Mahadevan 2000) and calibrated the model using data of past cyclones and surges over the east coast (Latha et al. 2002). In this paper, we present a fine resolution grid generated for the Orissa coast and the surge simulations that are carried out using the NIOT model for the 1999 Orissa super severe cyclone. The objective of our analysis was to compare the results from the model with those of observed surges (Kalsi et al. 2004), so that this model can be used for operational level forecasts.

2 NIOT storm surge model

We have simulated surges along the coast of Orissa using the storm surge model developed by NIOT. The mathematical formulation of vertically integrated forms of shallow water equations for simulating the cyclonic wind-induced flow in the ocean and the numerical method using a finite element scheme for solving the equations are presented in Latha and Mahadevan (2000). In the scheme presented in this article, nine-noded Lagrangian isoparametric elements are used to discretize the flow variables in the problem.

The use of Lagrangian interpolation functions in combination with Simpson’s rule of integration of dependent variables over an element makes the coefficient matrices of the flow variables diagonal as opposed to a banded matrix, which normally results from other forms of finite element schemes. This leads to an explicit time integration scheme which avoids matrix iterative solvers and hence a reduction in computation, which is a primary requirement in real time storm surge prediction. Due to its explicit nature this scheme is comparable to the Finite Difference Method (FDM) scheme in terms of computational effort and has the flexibility of the Finite Element Method (FEM) schemes to incorporate irregular boundaries and bathymetry of the shelf region, which are important features of the study area. The main input to this model are the bathymetry of the study domain at these grid points and the cyclone data.

3 Governing equations

The vertically integrated forms of the shallow water equations governing the ocean flow field in an ocean shelf, in a Cartesian co-ordinate frame fixed to the rotating earth, are the continuity equation:

\[ q_{x,x} + q_{y,y} + \zeta_t = 0, \]  

and the momentum equations in the \( x \) and \( y \) directions:

\[ q_{x,t} + H^{-1} q_{x} q_{x,x} + H^{-1} q_{y} q_{x,y} - f q_{y} = -\rho^{-1} H p_{a,x} - g H \zeta_{x,x} + \rho^{-1} (\tau_{ax} - \tau_{bx}), \]  

\[ q_{y,t} + H^{-1} q_{y} q_{y,y} + H^{-1} q_{x} q_{y,x} - f q_{x} = -\rho^{-1} H p_{a,y} - g H \zeta_{y,y} + \rho^{-1} (\tau_{ay} - \tau_{by}). \]