Cyclonic Storm Surge Modelling for Design of Coastal Polder

M. M. Kabir, B. C. Saha, J. M. A. Hye
Institute of Water Modelling, Dhaka, Bangladesh

ABSTRACT: Cyclones and storm surges are common phenomenon in the coastal area of Bangladesh. The area has over 700km of coastline on the main land and several offshore islands in the Bay of Bengal. 145 numbers of polders having more than 5000km of embankment were constructed in the sixties to protect the coastal low-lying area from saline inundation in order to increase agriculture production without consideration of safety against cyclonic surges. Historical record shows that more than 14 severe cyclones are generated in the Bay of Bengal in every ten years, several of which strike the coast of Bangladesh. Extremely strong storm surges with more than 10m of water elevation hit the coast of Bangladesh in the year 1970. Within the last four decades around 800,000 lives of the country have been the victims of the cyclones by overtopping or breaching of coastal embankments. Considering the complexities of the Bangladeshi coastline with numerous inlets, large estuaries, numerous polders and offshore islands use of high-resolution numerical modelling is necessary to determine the surge dynamics realistically in the shallower region. Cyclone Storm Surge Modelling has been carried out during 2000 – 2001 in connection with Second Coastal Embankment Rehabilitation Project. MIKE 21 mathematical modelling software developed by Danish Hydraulic Institute was used for the study. Under this study seventeen cyclones from 1960 to 2000 have been simulated to determine the storm surge height through out the coastal area. On the basis of the model results a statistical analysis has been carried out to determine the surge height for different return period for designing the coastal polders for providing safety against cyclonic surge.

1 INTRODUCTION

Cyclones and storm surges are common phenomenon in the coastal area of Bangladesh having coastline of more than 700km. Cyclone induced storm surges cause huge loss of human lives as well as devastating impacts to the socio-economic condition of the region. In November 1970 the most severe cyclone in the last 50 years, with respect to surge height, inundation and loss of life occurred. The cyclone caused inundation of nearly all the low coastal areas. The surge height was about 10 meters. The loss of life was estimated to 300,000-500,000.

Bangladesh Water Development Board (BWDB) and its predecessor, East Pakistan Water and Power Development Authority (EPWAPDA) constructed a series of polders (Fig.1) approximately 145 numbers with more than 5,000km in length in the coastal area from the mid-sixties to the mid seventies to protect the coastal low lying areas from saline inundation in order to increase agriculture production. Over time, those embankments proved to be very effective in protecting life and property. With the growing concerns over the protection of life and property in the coastal region, rehabilitation or construction of embankments has turned into a crucial part of coastal development.

With this end in view a large efforts have been being made for improving the embankments of the coast. Being part of these efforts "Hydraulic Modelling Study for Second Coastal Embankment Rehabilitation Project" carried out by Institute of Water Modelling (IWM) the former Surface Water Modelling Centre (SWMC) in association with DHI Water and Environment (DHI) and executed by Bangladesh Water Development Board (BWDB) represents a leap forward in the quantification of surge height.

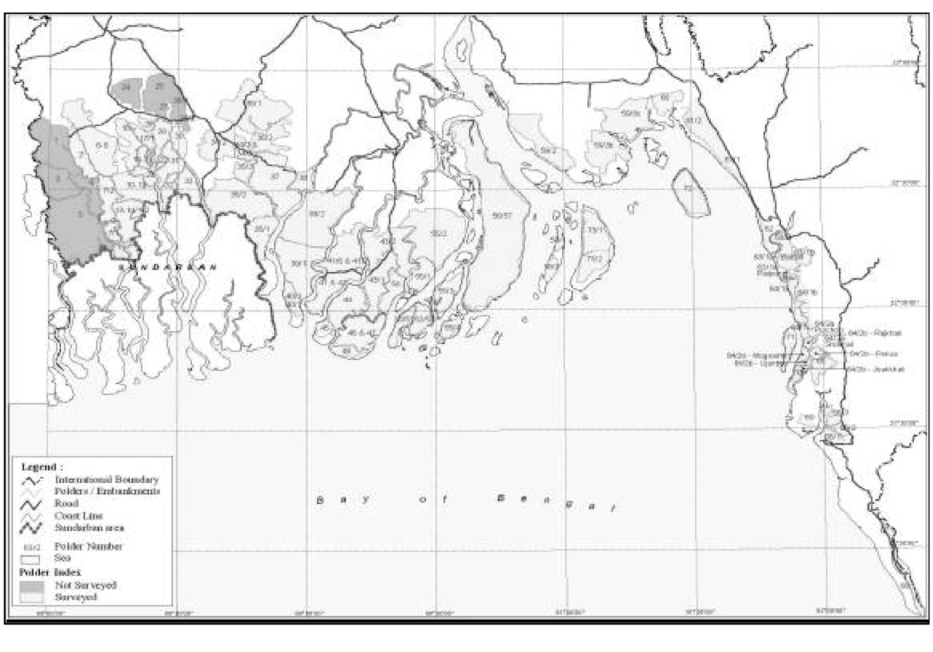

Figure 1: Coastal area of Bangladesh with polders

This paper presents the achievements of the cyclone surge modelling study in the context of assessment of surge height with an objective of designing the coastal polders.

2 CYCLONES IN BANGLADESH

About one-tenth of the global total cyclones forming in different regions of the tropics occur in the Bay of Bengal. Not all of the tropical cyclones formed in the Bay of Bengal move towards the coast of Bangladesh.

About one-sixth of the tropical storms generated in the Bay of Bengal usually hit the Bangladesh coast. Figure 2 shows the number of cyclonic storms hitting the Bangladesh coast from 1881 to 2001.

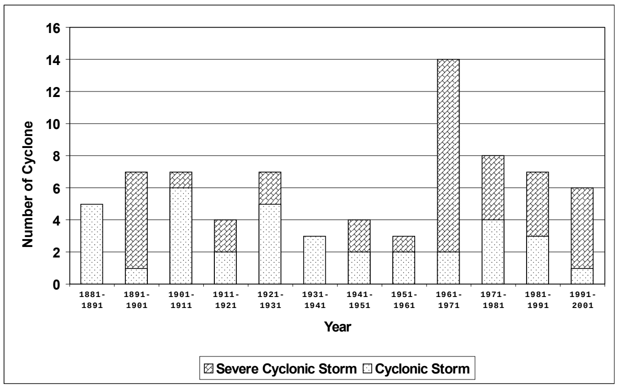

Figure 2: Number of cyclonic storms landed on Bangladesh

3. MEASUREMENTS AND METHODS

Many of the measurements used in the numerical model are already described in Jakobsen *et al.* (2001). In the following we will focus on embankment data and cyclone wind data.

The embankment data are specified on the basis of measurements as carried out under the 2nd CERP study.

Cyclone information received from Bangladesh Meteorological Department (BMD) contains time, location and classification of the cyclone. BMD classifies cyclonic disturbances according to Table 1.

The relationship between the maximum wind speed and the pressure drop in Table 1 is in accordance with Mishra and Gupta (1976). Mohal *et al.* (1998) evaluated the radius to be only 60% of the radius assumed from the BMD relationship. In the latter simulations described that the radius was reduced to only 60%, while the pressure was kept unchanged.

Table 1: Relationship between the involved cyclone parameters

Classif-ication	Pressure Drop (mB)	Max. wind speed (km/hour)	Radius to max. wind speed (km)
D	2-4	40-51	44
DD	4-6	52-61	48
CS	6-12	62-88	54
SCS	12-21	89-117	64
SCSH	≥21	≥118	≥74

Note: *D:* *Depression*
DD: *Deep Depression*
CS: *Cyclonic Storm*
SCS: *Severe Cyclonic Storm*
SCSH: *Severe Cyclonic Storm with a core of Hurricane winds*

4 METHODOLOGY

The following suite of mathematical model complex has been used for the study:

- A two-dimensional nested model of the Bay of Bengal and the coastal areas (BoBM) developed based on MIKE 21 software of DHI. In this model the surge in the Bay and the coastal areas has been simulated.
- A cyclone model developed based on the CYWIND modelling software. The CYWIND simulates pressure and wind distributions all over the model areas and provides a surface boundary condition to the two dimensional hydrodynamic model.

5 BAY OF BENGAL MODEL

5.1 Hydrodynamic Model

The model is two-way nested as shown in Figure 3 and includes four different resolution levels (grid sizes) in different areas. The Meghna Estuary is resolved on a 600m grid. Information on the grids is given in Table 2.

Table 2: model grid specifications

Model	Origin (degree)	Orien-tation (deg.)	Grid spacing (m)	Grid nos.
Coarse grid	Lon = 84.6400 Lat = 18.9100	-1.74	Dx = 5400 Dy = 5400	180× 111
Interme-diate grid	Lon = 86.7500 Lat = 20.8100	-1.06	Dx = 1800 Dy = 1800	321× 153
Fine grid	Lon = 89.9712 Lat = 21.3393	+0.11	Dx = 600 Dy = 600	396× 357
Local Sandwip	Lon=91.0776 Lat=22.3400	+0.652	Dx=200 Dy=200	375× 270

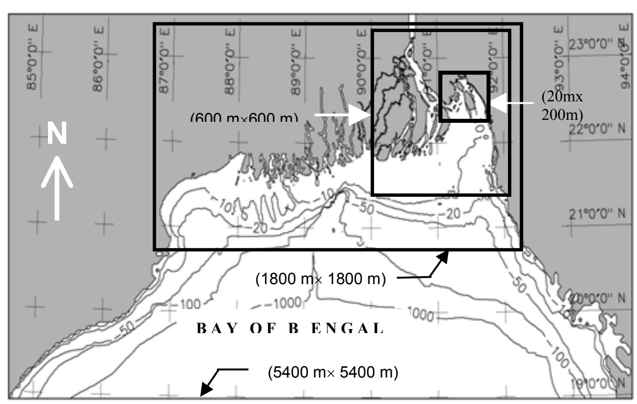

Figure 3: Nesting of the model

The model has a wide, deep and open ocean boundary in the south. Predictions on water levels have been made for the two extreme points along this boundary, Baruva in India and Searle Point in Myanmar (Fig. 3). A linear interpolation between the water levels has been made to define the southern boundary. The northern boundary has been specified by adequately adjusted water level that was measured at the nearest station, Chandpur.

The model has been calibrated and validated against measured water levels and discharges for different hydrological conditions.

5.2 Cyclone Model

A proper cyclone description together with information of land levels is important and essential in order to simulate realistic flood depths. Simulation of cyclone model has been done to create the pressure and wind field required for the storm surge and wave simulations. For the description of the wind field and the pressure field, cyclone model needs information on:

- Radius to maximum winds
- Maximum wind speed
- Cyclone tracks, forward speed and direction
- Central pressure
- Neutral pressure

The developed Cyclone Model has been calibrated and validated for different cyclones. Figures 4 and 5 show the validation results against against wind speed and pressure. The validated models have been simulated for the seventeen major cyclones from 1960 to 2000. Figure 6 presents the cyclone wind and pressure field for 1970 cyclone at landfall time.

The validated cyclone wind model has been applied in simulating the wind and pressure fields for the seventeen cyclones from 1960 to 2000.

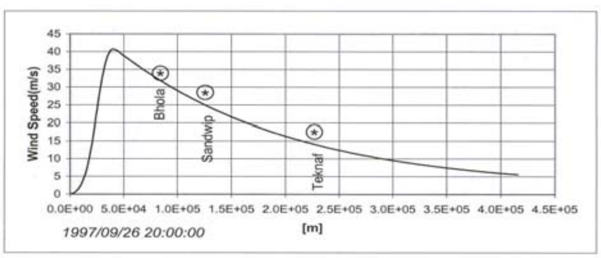

Figure 4: Comparison of simulated and observed wind

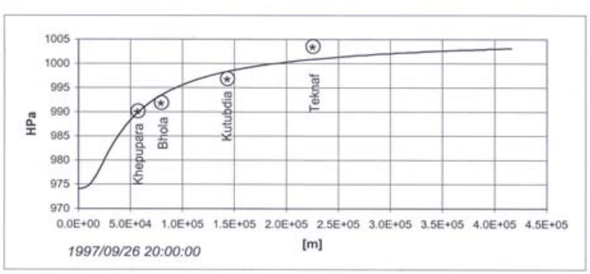

Figure 5: Comparison of simulated and observed pressure

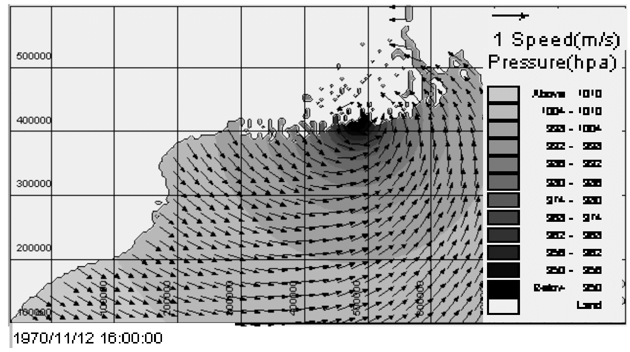

Figure 6: Wind and pressure field at landfall for November 1970

5.3 Storm Surge Model

The surge model has been developed on the basis of the calibrated hydrodynamic model and cyclone model. Prior to its application the surge model has been calibrated and validated against surge levels. Sample plot of comparison between simulated and measured surge levels is shown in Figure 7 for Dasmunia. A good agreement has been achieved between observed and simulated ones.

The calibrated and validated model has been applied for simulating the seventeen major cyclones from 1960 to 2000.

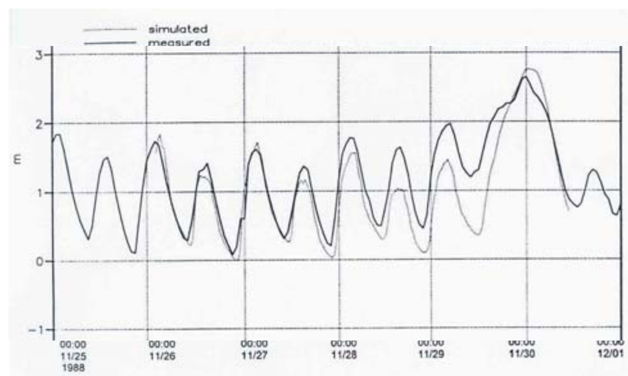

Figure 7: Comparison of simulated and observed surge levels at Dasmunia

6 STATISTICAL ANALYSIS FOR DESIGN SURGE LEVELS

In order to compute the design surge levels corresponding to different return period the highest simulated surge levels during the 17 cyclones covering the period from 1960 to 2000 (40 years) have been fitted to an exponential frequency distribution as shown in Figure 8.

All points in the model area have been considered, but only computational points with at least 13 simulated maximum water levels have been analysed. In other words, the land areas, which are not often inundated has been disregarded, and the fitting has been done based on only the 13 highest water levels also in sea areas where 17 water levels have been obtained (the difference was not important in the sea areas). The simulated water levels have been ranked and given the return periods T=40 years/(n-½), where n is the number in the ranking (the plotting position formula). The result from the 1876 cyclone surge was successfully used to validate the statistical model.

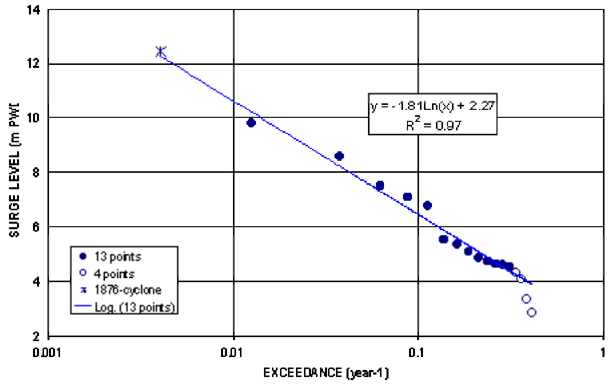

Figure 8: Analysis of 17 maximum surge levels from 1960 – 2000

On the basis of the analysis surge levels of the study area have been computed for 10, 20, 50 and 100 year return period. Figures 9a and 9b present the surge levels for 10 and 100 year return period.

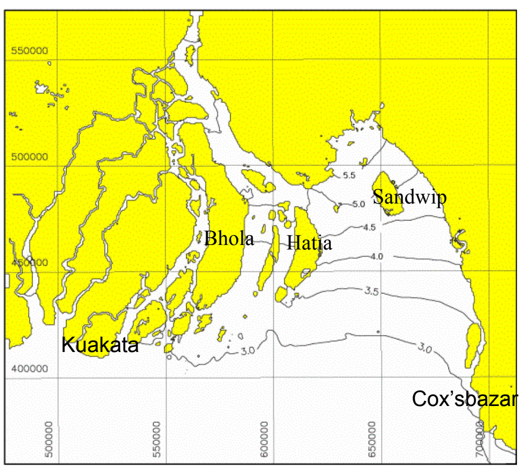

Figure 9a: 10 year return period surge levels

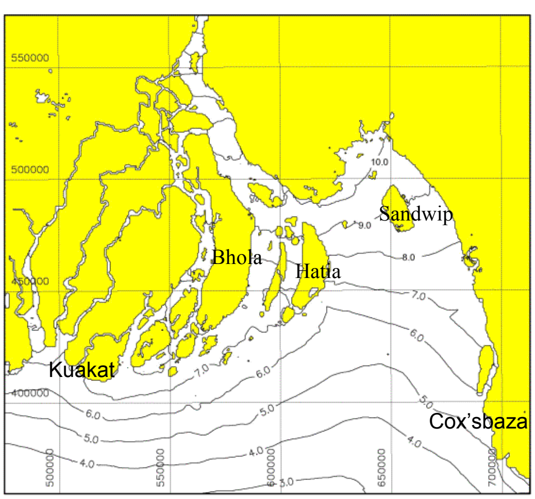

Figure 9b: 100 year return period surge levels

The figures show that the region at the north of Sandwip Island is the zone of intense surge attack. The surge level exceeds 10m level (PWD) against 100 year return period and even rises more than 6m for return period of 10 years. Kuakata, the area western side of the estuary and Cox's Bazar, the south western coastline, are almost equally endangered in terms of surge height for all return periods. Surge elevations in these regions are relatively low, less than 3m for 10 year and about approximately 6.5 to 7.0m for 100 year return period.

7. CONCLUSION

The two-dimensional calibrated and validated Bay of Bengal Model has been applied in simulating the cyclone induced surge levels for seventeen major cyclones from 1960 to 2000 (40 years). Statistical analysis has been done for the simulated maximum surge levels corresponding to the mentioned cyclones to compute surge levels for 10, 20 50 and 100 year return period. The analysis shows that the most sensitive region is the northern corner of the bay that covers the region around the Sandwip Island and the Meghna River mouth. The surge level in this region exceeds 10m level (PWD) against 100 year return period and even rises more than 6m for return period of 10 year. Funneling effect and sudden change in depth close to the coast causes such amplification of surge height. The findings of the study can be applied in designing the coastal polders.

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