Annual Meeting of Korean Society of Coastal and Ocean Engineers
Sung Kyun Kwan University, 6-7 October 1995

EXTENDED ABSTRACT

THE STORM SURGE PROBLEM IN THE BAY OF BENGAL

Gary Watson

Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji, Kyoto 611, Japan

gary@rs01.dpri.kyoto-u.ac.jp

INTRODUCTION

Every few years the low-lying coastal plains of Bangladesh are seriously flooded by storm surges, in which fierce cyclones develop in the Bay of Bengal and then move towards the coast, pushing large masses of sea water onto the land. The coastal areas are densely populated and the combination of high winds and deep floods invariably kills thousands of people. In recent years the two most severe disasters occurred in 1970 (200,000-300,000 deaths) and 1991 (about 130,000 deaths). In addition to the death toll, millions suffered the loss of their homes, livestock, crops and hence their whole livelihood. Depite relief efforts, further loss of life results from disease and starvation in the aftermath. India and Burma also suffer from major disasters of this type, although not on quite the same scale as in Bangladesh.

In rich countries, such losses would prompt substantial resources to be committed to finding ways of reducing the impact of these disasters. Several countries subject to less severe storm surge problems have major ongoing research programs devoted to measuring and predicting the surges (for example, Japan, UK, Netherlands and USA), alongside existing operational warning systems.

A significant amount of relevant expertise has accumulated from the research in developed countries, but in order to be useful it must be applied to the specific conditions in the Bay of Bengal. A certain amount of work has been published in which numerical models of storm surges have been developed and applied to the Bay of Bengal. However, this has been sparsely funded and is far less than what is necessary if the best possible operational warning system is to be developed.

One important way of reducing the death toll, and in Bangladesh perhaps the only feasible one, is to build elevated shelters into which the people can be directed when flooding is expected. All those who have published work on this subject are agreed on the importance of having accurate and reliable advance predictions of flooding. Currently, an empirical relationship between cyclone parameters and surge heights is used, so that at least some kind of flood warning is given whenever a severe cyclone is expected. However, use of a coastal numerical model has the potential to greatly improve the accuracy and detail of these warnings.

A major hindrance to this is the paucity of quantitative measurements of past surge events, and the continuing lack of an effective network of instruments to monitor future surges as they occur. The problem with the existing tide gauges is that they are not intended to measure surges. During a cyclone and the accompanying surge, most of them give no useful data. Most still rely on measurements being noted manually in books. When the cyclone comes, the station has to be abandoned and no data are recorded. Others may go off the top of the scale.

Bangladesh is a poor country (GNP $180 per capita, compared with $9,500 for Korea, a factor of more than 50). Since there are also many other pressing and immediate needs, it is not realistic to expect Bangladesh to be able to fund enough research and development on surge prediction. One purpose of this paper is thus to stimulate new interest in making a serious attempt to address this problem. It must be emphasized that such an undertaking as this will inevitably require much time and will progress slowly. It is impossible to predict when there will be another surge as large as that which occurred in 1991. It is important that before it happens, the monitoring network is installed and working, and that the predictive models have been tested against smaller events in order to make them as effective as possible. It will be a number of years before they will be good enough to be used in an operational warning system, but the sooner the work begins, the sooner that will be possible.

This paper briefly reviews the history of storm surge events in the Bay of Bengal, summarizing what few quantitative data are available. The development of numerical models is then summarized, and limited conclusions are drawn from the few comparisons that have been made with data. Suggestions for future progress are then discussed. The review is primarily concerned with oceanographic aspects of the problem, but the meteorological issues are equally or even more important.

PREVIOUS WORK ON THE PROBLEM

The problem of storm surges in the Bay of Bengal has been usefully reviewed by Murty et al. (1986) and Murty & Flather (1993). These papers include a useful historical survey of past surge events and the associated casualties, a discussion of the essential physics and a review of the modelling that has been done. Much of the material in the present review was covered in these papers.

Since the great disaster of 1970, at least nine different researchers or groups have produced numerical models of storm surges in the Bay of Bengal. Representative of each of these researchers' work are the papers by Das, 1972; Dube et al., 1986; Subramanian et al., 1989; Rugbjerg & Basse, 1991; Johns and Lighthill, 1992; Katsura et al., 1992 (model by Yamashita); Murty & El-Sabh, 1992; Flather, 1994; and Nakagawa et al., 1995. The fundamental equations used in these models are all roughly the same: depth-averaged shallow-water equations, with slight differences between the wind stress and bottom-friction terms. Since the shallow-water approximation is very good for such long-period phenomena, three-dimensional models have been found not to give significantly different results to those of depth-averaged models (Johns et al., 1983; Sinha et al., 1986).

These models have been used to make various investigations into the effects of different cyclone parameters (size, strength, speed, landfall) on the surge. However, there have only been a very limited number of comparisons against real data.

The two most important factors in determining the height of a surge are the properties of the cyclone and the coastal topography near landfall. Accurate data for both must be used if an accurate prediction is to be made. The time of landfall relative to high tide is also vitally important, since this determines the tidal phase at which maximum surge occurs and hence whether there is serious flooding or not. For example, Flather (1994) found that a five-hour error in the predicted time of landfall resulted in flooding occurring in a completely different location. In an operational model therefore, an accurate forecast of flooding depends on having an accurate prediction of both the time and location of the cyclone's landfall.

Interactions between surge and tide cannot be neglected; the two cannot be treated independently and accurate tidal forcing at the deep-sea boundary must be included

(Johns, 1985; Flather, 1994). Johns noted that in 1985, the tides in the Bay were not know sufficiently accurately for the purpose.

Early models used a vertical coastal boundary, with no representation of coastal flooding. When later models began to incorporate the flooding effect, significant differences in results were obtained (e.g. Johns et al., 1982, Dube et al., 1986), demonstrating the importance of having a good inundation routine in the model. This part of the problem is one that is still under development. Flather (1994) began to include the effect of rivers into the coastal boundary condition.

Since similar models have already been verified in other surge-prone regions, the essential physics should by now be reasonably well understood. The Bengal surges have their own unique features however, and it cannot be taken for granted that applying the same equations here will produce accurate results. The models need to be tested against field measurements, yet very few data are available for this purpose. The comparisons with real data which have been made in the literature only use a small number of individual sea level measurements. Such comparisons can only confirm that the models are not producing wildly inaccurate answers; they are not sufficient for a useful assessment of accuracy, or for identifying sources of error that can be corrected.

FUTURE DIRECTIONS

The lack of sufficiently accurate tidal information for use on the ocean boundary of the model can now be improved. In the last few years, greatly improved global ocean tidal models have been possible thanks to increases in computer power, and these have been verified with the aid of data from satellite altimeters. These new results should be able to improve the tidal boundary contition for the Bengal surge models. In addition, the interactions between surge and tide in this region should be investigated more thoroughly.

Another subject that should be given further attention is the generation of edge waves by surges. Johns and Lighthill (1992) recently drew attention to this phenomenon, which is potentially capable of causing a flood wave to travel along the coast, a long way from the point of cyclone impact.

In terms of model development, the greatest potential for improvement is in the modelling of inundation. Ultimately it is the flooding of coastal land which is the result of real importance. Progress here requires much better coastal topography data. However, another question that remains open is how best to represent the influence on the water of different kinds of terrain, and of buildings. This is a fundamental question that is applicable in all geographical locations and for other kinds of flooding such as tsunami.

A small research project is in progress at the Disaster Prevention Research Institute, Kyoto University to investigate some limited aspects of the problem. One aim is to develop a coastal shallow-water model that is able to predict whether a surge can form into a breaking wave or bore. If so, its destructive capacity is likely to become greatly increased and it is important to know where and under what circumstances this could occur. It is also anticipated that this model should be useful for improving inundation procedures.

It is emphasized again that in order to objectively study the surges and improve our ability to forecast them, a permanent and comprehensive monitoring network is required. Data are necessary on sea-surface elevation and currents at the coast and offshore, on the wind and pressure distribution in the cyclone, on the track and speed of the cyclone, and on the extent of inland flooding. Comprehensive and continuously-updated surveys of the constantly-changing coastal land and ocean topgraphy are also required. Without such data, any work on developing predictive models is of limited use because the predictions cannot be objectively tested, sources of error cannot be identified and the models cannot be improved. In contrast, good operational models have been possible in other countries because sufficient historical data from tide gauge networks and meteorological observations were available.

Although various ideas have been suggested for reducing the amount of flooding in a storm surge, it is likely that the most effective means of reducing the loss of life is by enabling the population to take refuge. There is an ongoing program of building surge shelters, and this should continue. In order for these to be effective, accurate and timely warnings and an efficient system for conveying them to the people are of utmost importance. It is also important to continually educate the population about cyclones and surges, and about appropriate action to take when a warning is issued.

REFERENCES

Das P.K. Prediction model for storm surges in the Bay of Bengal. *Nature* **239**, 21-213, 1972.

Dube S.K., Sinha P.C., Roy G.D. The effect of a continuously deforming coastline on the numerical simulation of storm surges in Bangladesh. *Mathematics and Computers in Simulation* **28**, 41-56, 1986.

Flather R. A storm surge prediction model for the northern Bay of Bengal with application to the cyclone disaster in April 1991. *J. Phys. Oceanog.* **24**, 172-190, 1994.

Johns B., Dube, S.K., Sinha P.C., Mohanty U.C. and Rao A.D. The simulation of a continuously deforming lateral boundary in problems involving the shallow water equations. *Computers and Fluids* **10**, 105-116, 1982.

Johns B., Sinha P.C., Dube S.K., Mohanty U.C. and Rao A.D. Simulation of storm surges using a three-dimensional numerical model: an application to the 1977 Andhra cyclone. *Quart J. R. Met. Soc.* **109**, 211-224, 1983.

Johns B., Rao A.D., Dube S.K. and Sinha P.C. Numerical modelling of the tide-surge interaction in the Bay of Bengal. *Phil. Trans R. Soc. Lond.* **A 313**, 507-535, 1985.

Johns B. and Lighthill J. Modelling of storm surges in the Bay of Bengal. *Proc. ICSU/WMO Int. Symp. Tropical Cyclone Disasters*, Beijing, Oct. 1992.

Katsura J. et al. Storm surge and severe wind disasters caused by the 1991 cyclone in Bangladesh. *Res. Rept. on Natural Disasters, Supported by Jp. Min. Ed. Sci. Cult., Jp.Group for the Study of Natural Disaster Science, No. B-2.* 101pp. March 1992.

Murty T.S., Flather R.A., Henry R.F. The storm surge problem in the Bay of Bengal. *Prog. Oceanog.* **16**, 195-233, 1986.

Murty T.S. and El-Sabh, M.I. Mitigating the effects of storm surges generated by tropical cyclones: a proposal. *Natural Hazards* **6**, 251-273, 1992.

Murty T.S. and Flather R.A. Impact of storm surges in the Bay of Bengal. *Unpublished Manuscript*, 1993.

Nakagawa H., Inoue K. and Tanino T. Flooding in Sandwip Island in the 1991 storm surge disasters. *Unpublished Manuscript*, 1995.

Rugbjerg, M. and Basse P. Protection against cyclonic surges in Bangladesh. *Proc. COPEDEC III*, Mombasa, Sept. 1991.

Sinha P.C., Dube S.K., Roy G.D., Jaggi S. Numerical simulation of storm surges in Bangladesh using a multi-level model. *Int. J. Num. Meth. in Fluids* **6**, 305-311, 1986.

Subramanian V., Mahadevan B and Srinivasan D. Effect of the open sea boundary conditions on storm surge simulations, *Coastal Engineering* **13**, 293-302, 1989.