CHAPTER 55

SIMULATION MODEL FOR STORM SURGE PROBABILITIES

by

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I. INTRODUCTION

Storm surge and its impact on the coastal regions have been of interest to many researchers and engineers for a long time. Deterministic models based on classical hydrodynamics can be used for reliable predictions only for short terms, e.g. up to 24 hours for which the characteristics of the storm can be projected accurately. Long-term predictions, on the other hand, is a statistical problem due to the random nature of the storms. Such long-term prediction is becoming increasingly important as the coastal regions are rapidly developed into residential, recreational and industrial areas.

One of the first statistical studies on coastal storm surge predictions was published in 1961 by Wemelsfelder who used a Poisson probability law to fit the observed high tide data at Hook of Holland. From this fitted law, risk curves for long-term in years can be constructed for design purposes. In 1970 Yang et al applied the extreme value model to fit storm surge data for Atlantic City, New Jersey and Breakwater Harbor, Delaware. This so-called "purely" statistical method is sound in concept and simple to use. It has some serious limitations, however. First, it requires a collection of long term data (say 100 years for reliable design predictions) which is difficult to obtain in general. Secondly, the prediction for one location is not valid in general for other locations even when they are not far apart. To overcome the first limitation on the unavailability of long-term data at least partially, it is recognized that although storm tide data is limited, the general meteorological data is relatively abundant, so that more data on storm tide can be derived from meteorological data (wind field) via a hydrodynamic analysis. The analysis, of course, involves a general coastal area and consequently, the spatial variation of the storm tide can be predicted and the limitation on the location can be removed also. These observations lead to the concept of a combined statistical and hydrodynamic model which takes into account both the randomness of the long-term meteorological data and the physics of the storm surge.

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The first study known to the authors by this combined statistical and hydrodynamic approach was conducted by Bretschneider (1959) for Delaware Bay and Chesapeake Bay. In this study, the 1944 hurricane which was the most severe storm recorded along the Atlantic Coast at that time was selected as the so-called standard project hurricane. The track of this hurricane was then varied in position and orientation relative to the location in question. For each position and orientation of the hurricane, maximum storm surge height was calculated using a simplified hydrodynamic model. Following Bretschneider's study, a severe winter storm hit the Atlantic City area in 1962 and caused loss of lives and disastrous damage of properties. The following year, through an act of the Congress, the Corps of Engineers did a study for hurricane surge along the Atlantic Coast. A report was published in 1963 in which maximum surge heights were predicted for several locations based on the same standard project hurricane concept as used by Bretschneider (1959). In particular a 500 year return period was estimated for the standard project hurricane, unfortunately with little technical details. Subsequent to the 1963 study, under a contract with the Federal Insurance Administration, the Corps of Engineers in 1972 conducted a study of storm surge for the city of Rehoboth Beach, Delaware. Design surge heights of 500-year and 100-year return periods were predicted based on tide observations at Atlantic City, New Jersey and the 1963 prediction through the standard project hurricane with the estimated 500-year return period. Parallel to the studies by the Corps of Engineers (1963, 1972), Myers (1970) of the National Oceanic and Atmospheric Administration developed a refined method which he called the joint probability method to study the frequency of high tides at Atlantic City, New Jersey. It is refined in two respects. First, a thorough frequency analysis was made for the parameters of all hurricanes so that for a selected set of severe hurricanes, a frequency of occurrence can be calculated under the assumptions of independent hurricane parameters. Secondly, a refined hydrodynamic model due to Jelesnianski (1967) was used in the surge calculations from hurricane wind field. The same method was used to predict storm surge for the South Carolina coast by Myers in 1975 and for the Atlantic Coast by Ho in 1976, using a revised hydrodynamic model from Jelesnianski (1974).

The purpose of this paper is to present a simulation model which includes the generation of random artificial hurricanes and the hydrodynamic model of Jelesnianski (1974) for the long-term prediction of design storm surge. The model is then applied to the Delaware coast. Finally a comparison with other predictions and suggestions for further work are made.

II. SIMULATION MODEL

A Monte Carlo simulation model (see for example, p. 124, Benjamin and Cornell, 1970) is developed to predict storm surge probabilities. This model consists of six essential parts: (1) estimating the statistical distribution of historical hurricanes and hurricane parameters, (2) generating artificial hurricanes associated with the set of random hurricane parameters, (3) computing the surge heights in each artificial hurricane by a suitable hydrodynamic model, (4) combining the hurricane surge with astronomical tide, (5) generating random winter total tide (storm plus astronomical) and (6) constructing extreme value distribution based on yearly maxima.

A flow chart is shown in Figure 1 for the simulation and combination of the hurricane storm surge, astronomical tide and winter tide in a year. This chart is explained in the following steps.

(1) Generate a uniformly distributed random number, U, between 0 and 1.

(2) If U<P (the probability of occurrence of a hurricane in the area during one year), a hurricane occurs; otherwise it does not.

(3) If a hurricane occurs, then generate a set of hurricane parameters, center pressure drop ΔP, radius R, forward speed V and direction θ, consistent with their distributions.

(4) Generate another uniformly distributed random number, U, to compare with P_L (the probability of a landfalling hurricane) and decide whether it is a landfalling hurricane or one moving parallel to the coast.

(5) Calculate temporal surge profile due to the artificial hurricane.

(6) Generate random amplitude and phase for astronomical tide.

(7) Calculate the combined maximum tide S_H (hurricane surge plus astronomical tide). If a hurricane does not occur, set $S_H = 0$.

(8) Generate a total winter tide S_W (storm plus astronomical) based on the distribution of observed total winter tide.

(9) Take the larger of the two values, S_H and S_W, and set it as the extreme event of the year.

(10) Plot the extreme events on extreme value probability paper.

III. APPLICATION TO DELAWARE

For Delaware coast, data source and input data to the simulation model consists of (1) hurricane occurrence frequency and hurricane parameters for 70 years from Bretschneider (1972), (2) amplitudes of astronomical tide in September from Myers (1970) and (3) total winter tide (1953-1974 storm plus astronomical) from U. S. Geological Survey. These raw data were first analyzed to obtain statistical distributions for use in the model as explained in the previous section. It should be pointed out, however, that due to the inefficiency of the computer available, the cost in running the hydrodynamic model of Jelesnianski (known as SPLASH II) was found to be prohibitive when hundreds of runs are needed in the simulation process. Accordingly, only four runs of the SPLASH II were made to furnish the needed information (the shoaling factor) in the simplified analysis based on Jelesnianski's monographs. This known crudeness and other major assumptions such as the independence of random parameters of a hurricane indicates the approximate nature of the final result.

A total of 792 sample years were used in the final simulation analysis from which key values of the total tide (either hurricane surge plus astronomical tide or winter storm surge plus astronomical tide) together with their frequency of occurrances are sorted out. To facilitate design application, these values are plotted on extreme value probability paper as shown in Figure 2, where the abscissa on the bottom of the figure is the probability distribution function, i.e. the probability that the yearly extreme is equal or less than the indicated tide; and that on the top of the figure is the so-called return period in years. The return period in years means that on the average, the indicated tide level will be exceeded at least once in these many years.

IV. COMPARISON AND DISCUSSION OF RESULTS

In Figure 2, a comparison is presented among the predictions by Yang et al (1970) for Breakwater Harbor, Delaware, by Myers (1970) for Atlantic City, New Jersey, by Corps of Engineers (1972) for Rehoboth Beach, Delaware and by the present simulation model for Breakwater Harbor, Delaware (1976). Although the present analysis is admittedly crude in many aspects, the large discrepancies among these four sources indicate that the prediction by the Corps of Engineers in 1972 based on the concept of a standard project hurricane of 500 year return period and by Myers in 1970 for Atlantic City, New Jersey are probably overly conservative for the Delaware coast. This comment is based on the seemingly lack of technical basis for the assessment of the 500 year return period for the Corps study and the result by Ho (1976) which indicates a higher tide at Atlantic City, New Jersey than at Delaware. To be more specific than this requires further improvement of the simulation analysis on at least the following aspects: (1) a more complete hydrodynamic model taking into account the effect of the Delaware Bay should be used in place of Jelesnianski's (1974) SPLASH model which considers a straight coastline only; (2) the correlation among the hurricane parameters should be taken into account; (3) amplitudes of astronomical tide should be analyzed for all the hurricane season rather than the month of September only; (4) all of the raw data used should be constantly updated and examined for accuracy; (5) a hydrodynamic model for winter storm needs to be developed to improve the prediction reliability particularly for locations like Delaware where winter storms are perhaps more important in the sense of severity than hurricane storms.

V. ACKNOWLEDGMENT

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VI. REFERENCES

Benjamin, J. and Cornell, C. A., Probability, Statistics and Decisions for Civil Engineers, McGraw-Hill, 1970.

Bretschneider, C. L., "Hurricane Surge Predictions for Delaware Bay and River," U. S. Army Corps of Engineers, Miscellaneous Paper No. 4-59, November 1959.

Bretschneider, C. L., Revision to "Hurricane Design Wave Practices," Proceedings of the 13th Coastal Engineering Conference, ASCE, Vol. 1, pp. 167-196, 1972.

Corps of Engineers, Philadelphia District Report, Hurricane Study, Delaware River and Bay, Pennsylvania, New Jersey and Delaware, 1963.

Corps of Engineers, Philadelphia District, Elood Insurance Study, City of Rehoboth Beach, Delaware, June 1972.

Ho, Francis S., "Hurricane Tide Frequencies on the Atlantic Coast," Abstract, Proceedings of the 15th Coastal Engineering Conference, ASCE, 1976.

Myers, V. A., "Joint Probability Method of Tide Frequency Analysis Applied to Atlantic City and Long Beach Island, New Jersey," U. S. Department of Commerce, Weather Bureau, ESSA, Technical Memo WBTM HYDROII, April 1970.

Myers, V. A., "Storm Tide Frequencies on the South Carolina Coast," National Weather Service, NOAA, Technical Report NWS-16, June 1975.

Jelesnianski, C. P., "Numerical Computation of Storm Surge with Bottom Stress," Monthly Weather Review, Vol. 95, No. 11, November 1967.

Jelesnianski, C. P., "SPLASH II (Special Program to List Amplitudes of Surges from Hurricanes), "General Track and Variant Storm Conditions," NOAA, Technical Memo NWS-TDL-52, 1974.

Wemelsfelder, P. J., "On the Use of Frequency Curves of Storm Floods," Proceedings of the 7th Coastal Engineering Conference, ASCE, 1961.

Yang, C. Y., Parisi, A. M. and Gaither, W. S., "Statistical Prediction of Hurricane Storm Surge," Proceedings, 12th Coastal Engineering Conference, ASCE, pp. 2011-2030, September 1970.

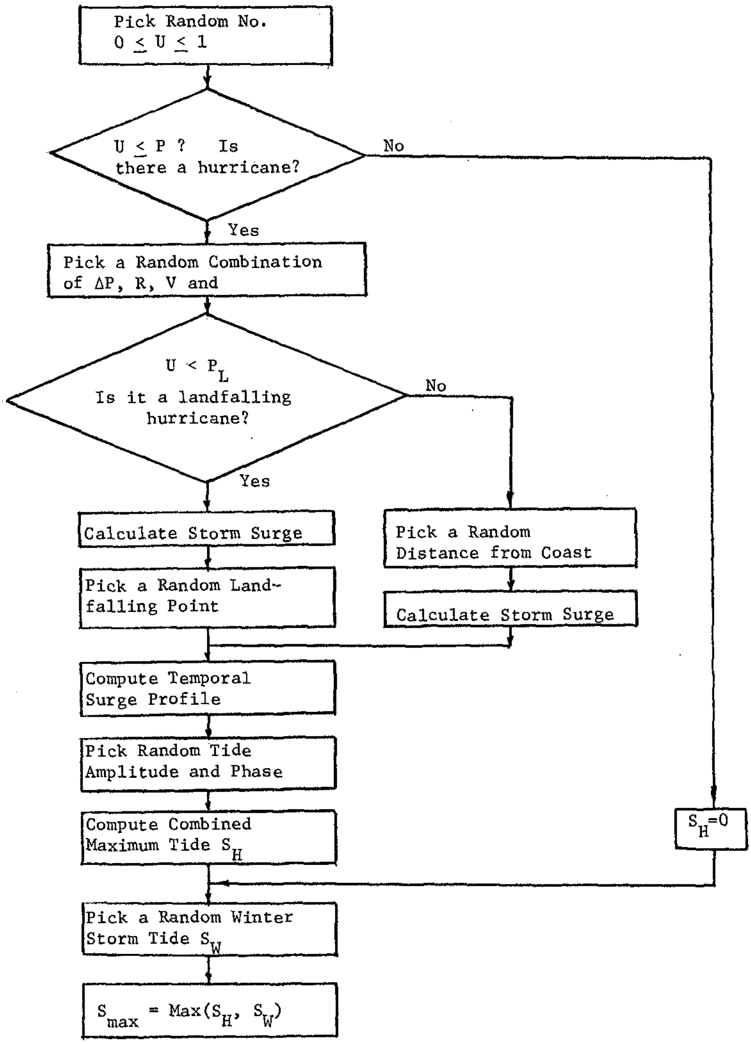

Figure 1 Flow Diagram for Simulation of Maximum Combined Tide in One Year

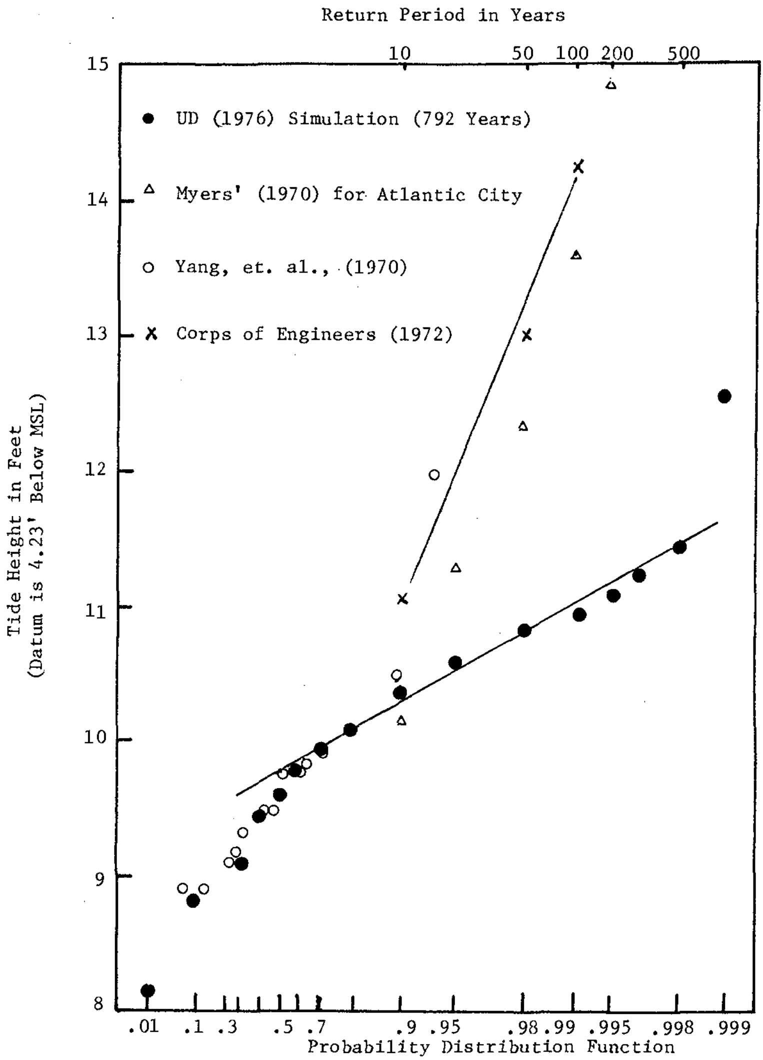

FIGURE 2 Comparison of Extreme Tide Distribution from Simulated Model for Breakwater Harbor with Yang, et al. (1970) Result Based on Historical Tide Record at Breakwater Harbor and with Vance Myers' (1970) Result for Atlantic City Based on His Combined Statistical Model. and with the Corps of Engineers (1972) for Rehoboth Beach, Delaware Based on the Standard Project Hurricane and Tide Data for Atlantic City.