CHAPTER 122

STATISTICAL PREDICTION OF HURRICANE STORM SURGE

by

C Y Yang, A M Parisi, and W S Gaither*

Abstract

High water associated with a hurricane is an important design parameter in coastal engineering Long range rational predictions can be made on the basis of Gumbel's theory of extremes and Wemelsfelder's theory respectively Fundamentals and underlying assumptions of the two theories are investigated and predictions are made for Breakwater Harbor, Lewes, Delaware, and Atlantic City, New Jersey Gumbel's theory is found satisfactory according to a criterion A crucial point, the ground rule of counting exceedances, is found to be vague in Wemelsfelder's method The ground rule must be made definite in a meaningful prediction

Introduction

In coastal protection projects, marine operations in harbors, and marine structural design, a reliable prediction of the extreme sea state associated with a hurricane is of utmost importance because of damages to lives and property [1] The engineer would want to know the answers to the following simple questions How high will the sea level rise? How often do the high water levels occur in the future? How long does each high water level last when it occurs? How high will the highest wave crest be? How often does the high waves occur and how long do they last? What are the oscillatory characteristics of the extremely strong waves? In answering these questions a large amount of research work has been conducted generally in two categories -- deterministic and probabilistic approaches In 1966 Harris investigated the characteristics of observed hurricane surges in the States [2] Bretschneider in 1959 studied local surges for the Delaware Bay [3] He made predictions of water level and waves in the bay for a given hurricane storm nearshore by a deterministic approach Such a study and similar ones as by LaSeur[4] and Moore[5] in 1966, provide useful information for short-time (days) forecast and warning systems

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[1] All superscript numbers refer to those in the Bibliography

* Associate Professor of Civil Engineering, Research Fellow of Civil Engineering and Dean of the College of Marine Studies, respectively, University of Delaware, Newark, Delaware 19711

For long-time (50 years) predictions, a deterministic approach based on laws of mechanics is too complicated and consequently the only rational approach is one based on laws of probability and statistics of past records Indeed this was recognized for quite sometime and important research work was published by Wemelsfelder in 1961, on high water levels[6], by Pierson and Marks in 1952 on wave spectrum analysis[7], and by Cartwright and Lonquet-Higgins in 1956 on high wave crests[8] More recently Frendenthal in 1969 outlined the many important aspects of probabilistic design of marine structures[9] He and Gaither further investigated the economic aspects in design[10] In a series of papers Borgman investigated wave force on piles[11] and spectral density for ocean wave forces[12]

In this paper we are concerned with the prediction of extreme mean sea levels generally associated with hurricanes near the Delaware coast by a statistical approach The term hurricane surge is used as by Weigel[13] to indicate a general association between extreme high water and a hurricane storm, though the analysis is not restricted to those caused by hurricanes This study is aimed at answering the question of how high the extreme water level will be and how often each extreme water level will occur near the Delaware coast in the future years and decades It is based on a rational analysis by Gumbel and Wemelsfelder, respectively

Gumbel's Theory

The well known statistical theory of extremes now associated with Gumbel's name was originated in the early twentieth century In the 1930's in a series of papers Gumbel presented important developments of the theory and its applications in a variety of problems -- breaking strength of materials, floods and gust winds and stock market trends[14] The fundamentals may be introduced by its application to our title problem

At Breakwater Harbor, Lewes, Delaware mean sea-level records have been obtained giving monthly maximum levels for the period 1953-1969 Our problem is to predict the occurance of high water levels in the future based on these available records and Gumbel's theory First we concerntrate our attention on the maximum height in each year of 365 days Clearly the annual maximum level is a random variable which we can not predict definitely rather only with probability statements Let the random annual maximum be denoted by X The probability that X be less or equal to a certain quantity x is the same as the probability that all 365 daily water levels are less or equal to x Furthermore, if we assume that random daily levels are independent to one another and have a common probability distribution, then

$$F_X(x) = [F_{X_o}(x)]^n$$

where X_o denotes the random daily level and n = 365 Therefore, if the probability distribution $F_X(x)$ of the random daily level X is known, the above simple relation gives the desired probability distribution of the annual maxima Since $F_X(x)$ is derived from $F_{X_o}(x)$, the latter is known as the parent distribution Now clearly the parent distribution is not known Fortunately, it has been shown that if we can assume that the number of random daily levels can be very high, then the distribution

$$F_X(x) = e^{-\alpha(x-\mu)}$$

for large n, in which α and μ are parameters This is known as the first asymptote of the extreme distribution The problem is reduced to one of determination of the parameters α and μ suitable to our particular case This may be accomplished by plotting all available data points on an extreme probability paper and then fitting the points by a straight line The two independent paramcters of the line then correspond to the desired parameters α and μ respectively So if all goes well we now find what we are looking for, namely, the probability distribution of the annual maximum water levels, $F_X(x)$ Whether all things go well or not must be pointed out so that reliable predictions can be made and the direction of future improvement can be understood These are the basic assumptions of independence among daily random levels, common parent distribution, the ground rule of plotting data points on the probability paper and the quality of fitting a straight line to these points In addition, the assumption of time invarient of the parent distribution must also be valid

Wemelsfelder's Theory

The essential difference between Gumbel's and Wemelsfelder's theory lies in the initial manipulation of available data and in the final presentation of results Instead of picking annual maximum out of 365 daily records in a year, Wemelsfelder proposed to count the number of exceedances of high water levels in the entire period of observations Thus in any one year the number of exceedance of a level may range from 0 up to 5 or 10, and all high water occurances are to be counted in a year This is a clear distinction from the data collection method under Gumbel's theory in which one and only one high water level, the annual maximum, is considered in one year Having counted the number of exceedances of high water levels, Wemelsfelder proposed to plot the yearly rate or the number per year ν versus the corresponding level H and called such a plot a frequency curve Assuming that the high water levels are rare and independent events, he then applied the Poisson probability law [15] According to this law we can state that the probability p of no exceedance of a level in a specified period of T years is

$$p = e^{-\nu T}$$

where the parameter ν is the mean rate of exceedance This parameter can be estimated from the frequency curve Finally the probability of exceeding that level is

$$q = 1 - e^{-\nu T}$$

This probability implies a chance of failure and is therefore, defined as the risk In summary, an analytic relation is thus established among three variables, namely, the risk q, the design period T and the design water height H Recall that the mean rate ν is a function of the height H as established by the frequency curve Wemelsfelder presented the theory in a two dimensional plot, with ordinates H, abscissa T for various risks q This presentation is very appealing and different from that by Gumbel as will be shown later in applications

Applications and Results

All data used in this paper was recorded by the Coast and Geodetic Survey, Environmental Science Services Administration, U S Department of Commerce through tide gauges located at Breakwater Harbor, Lewes, Delaware, and at Atlantic City,New Jersey Highest tides above the 1929 Mean Sea-Level Datum in each month were tabulated by the Coast and Geodetic Survey for Lewes from 1953-1969, and for Atlantic City from 1923-69 These are reproduced here as Tables 1 and 2 respectively The number in parenthesis indicate estimations and the blanks indicate missing data Based on some of this data, the Corp of Engineers in 1964 made studies on hurricanes along the Atlantic Coast Delaware-Maryland line to Virginia,[16,17] and presented frequency curves* with extrapolations In our study the same frequency curves were used but were extrapolated by means of linear regression computer program where a polynomial was fitted to the curve[18] The output of the program yields a straight line for Breakwater Harbor, Lewes, Delaware, and a curve for Atlantic City These extrapolated frequency curves are shown as Figures 1 and 2

Figures 3 and 4 show the predictions of high water levels for Breakwater Harbor, Lewes, Delaware and Atlantic City, New Jersey, respectively by Gumbel's theory and with the data obtained from Tables 1 and 2 The ordinate is water height in feet the abscissa on the bottom is probability distribution of the asumptote of the annual extremes and on the top is the return period in years A fourth scale is a linear transformation

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*The references used there is Mean Low Water which is 2 5' and 4 53' above the datum of 1929, Mean Sea-Level for Lewes, Delaware, and Atlantic City, New Jersey, respectively variable which is not important in physical interpretations The plotted points are data points The theoretical prediction is represented by the central straight line A point on the line in Figure 3 for example, indicates that the height of 11 feet has a chance of 9 of not being exceeded in any one future year, and on the average it will be exceeded once in every ten years Looking at the upper portion of the line for Breakwater Harbor, Lewes, Delaware, in Figure 3, we find that a height of 12 2' has a chance of 98 of not being exceeded in one year and on an average of once in 50 years The remaining feature in Figure 3 is the two curves forming a band along the theoretical line These curves are called control curves, indicating an allowable deviation of data points from the line When all data point fall within this band, the theory is considered valid according to Gumbel Fortunately, this is the case for both Breakwater and Atlantic City Furthermore, the control curves supplement the straight line predictions For example, in Figure 3, in addition to the statement made for the point 12 2' height, we can make two more statements First, the height 12 2' will be exceeded within the interval of 18 to 160 years on the average with probability of 68 Secondly, in 50 years on the average the height will exceed 11 4' and not exceed 13 1', with a probability of 68 This fixed probability corresponds to a one standard deviation from the straight line Consequently, different control curves can be plotted for different probabilities, and standard deviations Figure 5 shows a comparative prediction for Atlantic City, New Jersey Important computations are presented in Tables 3 and 4

Now consider applying Wemelsfelder's theory to available data, monthly extremes in Tables 1 and 2, and frequency curves in Figures 1 and 2 By the method previously outlined risk curves of Breakwater Harbor, Lewes, Delaware, are constructed and shown in Figure 5 and for Atlantic City, New Jersey in Figure 6 In Figure 5 the ordinate is height of the water level and abscissa design period in years The curves indicate, for example, in 50 years a height of 13 5' will be exceeded with probability or risk of 10%, 15 3' with a risk of 1% and 17 2' with a risk of 0 1% at Breakwater Harbor, Lewes, Delaware

Conclusions and Discussions

Through the course of study, we feel that both Gumbel's and Wemelsfelder's theories are founded on rational basis and are useful in practical predictions However, it is very important to be cautious about the validity of assumptions when applied to a particular location Unfortunately, no rational method is known to the authors in case any assumption is violated Consequently, an educated guess must be made to modify the theoretical prediction in those cases As for the questions of which of these two theories is more reliable, our investigation at this point does not permit us to answer it satisfactorily However, we did find out one crucial point which must be resolved before any meaningful comparison can be made That is in the Wemelsfelder's theory, we could not find a clear ground rule for making the count of exceedances Suppose that a severe hurricane storm hits a coastal area for three days with highest water levels on the first and third day Such an event may be counted as two if the unit of time intervals is a day, counted 1 if it is a month, or counted as 1 if the entire hurricane event is considered a unit This ambiguity must be removed by a clearly defined ground rule Since we have not been able to find out the precise ground rule in Wemelsfelder's paper nor that used by the Corp of Engineers in their frequency curves, we can only assume that the count was made in a more or less arbitrary manner depending on the engineers As a result it is proposed here that a universal ground rule be established, say a daily unit so that the ambiguity can be removed and precise communication among engineers can be established

Finally, we wish to point out that neither of the two theories take into account the important parameter of the time-span of an occurance of high water Since this parameter is obviously significant in the characterization of the damaging effect of a storm, even a crude modification of the two theories for this effect is extremely useful Also, we wish to mention that during the conference presentation of the paper Lee Harris raised an important question He argued that the astronomical tides should be substracted from the total water heights to get that part of the height due to hurricane surge alone This question was responded by both J B Schijf and C L Bretschneider The general agreement is that in a location where the water heights are governed by a non-linear law and sufficiently large quantity of records are available, then the separation of the astronomical tide and hurricane surge is neither possible nor useful However, if a linear law prevails then the separation is justifiable

Acknowledgement

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TABLE 1

Monthly Extreme Tides for Breakwater Harbor*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug	Sep.	Oct	Nov.	Dec
1953	8.3	8 9	7.9	8.5	8 6	8.3	7.8	8.5	8 2	10 1	9 5	7.8
1954	8.2	8.2	7.4	7 9	8.9	8.4	7.7	(8.0)		8.7	8 2	8 5
1955	8.2	7.6	8.1	9.0	7 9	9.2	8 2	8.5	8.2	9.2	8 8	8 0
1956	9.8	7.8	8.3	8.8	8 3	8.7	8.5	9.0	9 7	8 7	9 2	8.2
1957	8 4	8 8	8 6	7 6	7 8	8 3	8.1	8.6	7.9	9 1	8 4	8 7
1958	8.0	8 6	9.0	9.2	8 7	8.1	7 9	8.2	8 7	8 7	8 2	8 9
1959	8.3	7 6	8 9	8 3	8 3	8 3	8.0	8.3	8 2	8 5	8 3	8 9
1960	8 3	8.4	8.9	8 0	8 4	9 0	8 1	8 4	9 2	9 2	8 6	9 7
1961	9.7		8.8	8.5	8 1	8.0	8 5	7.9	8 8	10 5	8 8	8 7
1962	8.0	8.1	12.0	7.5	8 3	8.2	8.3	8 1	8 4	8 8	10 2	8 6
1963	8.4	7.7	7 9	8 6	8 2			7 6	9 0	8.2	8 8	8 0
1964	10 0	9 1		8.6	8.5	8 6	8.6	8 5	8 7	8 1	8 6	8 5
1965	9.4	8.2	8 4	7 9	7 8	8 5	8.4	8 3	8.1	8 2	8 3	8 2
1966	9.4	8.0	8.5	7 9	7 8	7 9	8.4	8 1	8 9	7 7	8 7	8 5
1967	8 6	9 6	8.5		9 7	9 0	8.0	8 0	9.6	8 6	8 7	8 7
1968	8.8	8 5	8 4	8 4	8 7	9.1	8 2	8.4	8 3	8.8	9.4	8 7
1969	8 9	8.7	9 2	8.4	8 4	8.6	8.7	8.9	8 7	8.5	9 9	8 8

* The height above the 1929 Mean Sea-level Datum is listed according to U S. Coast and Geodetic Survey tables

TABLE 2

Monthly Extreme Tides for Atlantic City*

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep	Oct	Nov	Dec.
1923	10.2	9.9	10.6	10.3	9.8	10.2	9.7	9.3	9.5	10.9	10.5	11.0
1924	9.6	10.6	11.1	9.9	9.9	10.1	9.8	9.9	9.6	10.6	9.9	9.4
1925	10.5	9.6	9.1	9.5	10.1	10.1	9.7	10.2	9.9	9.9	9.8	10.6
1926	9.9	10.5	9.6	9.1	9.6	9.6	10.0	10.2	10.1	10.1	9.6	9.5
1927	9.8	11.2	10.6	10.7	10.2	9.9	10.1	10.5	9.8	10.3	9.9	10.7
1928	9.5	9.8	10.6	10.6	10.2	10.1	10.1	10.5	10.9	10.4	9.7	10.1
1929	9.9	9.7	9.3	10.6	9.4	10.6	9.7	9.6	9.9	10.9	10.5	10.4
1930	10.6	9.6	10.2	9.6	9.9	9.8	9.8	11.2	9.6	10.0	10.4	10.3
1931	11.0	9.4	11.5	10.5	9.7	9.9	10.0	10.6	10.1	10.0	9.8	9.7
1932	10.5	9.9	10.9	9.6	9.4	10.4	9.7	9.6	11.0	9.5	(11.8)	10.2
1933	11.8	9.4	10.1	10.2	10.2	10.2	11.0	11.2	10.4	10.4	9.8	10.2
1934	9.8	9.7	(9.8)	10.1	10.0	(9.8)	9.8	9.8	9.9	10.7	9.9	10.4
1935	9.9	10.0	9.9	10.2	9.6	10.5	9.8	9.9	11.8	9.8	11.5	10.3
1936	9.9	9.9	10.3	9.6	9.4	9.9	9.9	9.7	10.9	10.6	9.7	10.3
1937	9.7	10.8	10.5	11.1	10.2	10.0	9.8	9.8	10.2	11.0	10.6	10.7
1938	10.6	10.3	10.0	9.6	10.7	10.6	10.0	10.0		(10.5)	10.0	10.3
1939	10.2	10.2	10.2	9.9	11.6	10.2	10.2	10.2	9.9	10.5	10.5	10.2
1940	11.3	10.5	(10.3)	10.6	10.9	10.0	9.6	10.3	10.5	11.4	10.7	10.7
1941	10.7	10.2	10.2	9.7	10.2	10.3	9.9	10.2	10.2	10.2	9.9	9.9
1942	10.2	10.3	11.4	9.9	10.8	10.2	10.3	10.1	10.5	10.8	10.2	10.8
1943	9.9	10.8	10.0	10.5	10.4	10.4	10.4	10.3	11.1	11.7	10.4	10.2
1944	11.1	10.2	10.0	9.9	10.2	(10.5)	10.1	10.6	(13.8)	11.1	12.0	10.1
1945	10.9	10.5	9.8	9.7	10.2	10.8	10.6	10.8	10.7	11.1	10.6	11.4
1946	10.5	9.8	9.9	10.5	10.9	10.9	10.2	10.2	10.5	10.7	10.8	10.3
1947	10.4	10.5	10.0	10.8	10.0	10.6	10.2	10.6	10.3	11.1	12.1	9.9
1948	10.4	10.6	10.5	9.9	10.2	10.3	10.7	10.5	10.1	11.5	11.0	10.8

TABLE 2 (Continued)

Year	Jan.	Feb.	Mar.	Apr	May	June	July	Aug	Sep	Oct.	Nov	Dec.
1949	10.2	10.2	10.1	10 5	10.9	10.1	10 0	10.1	10 4	11 0	9.9	9.6
1950	9.3	10 5	9.7	10.0	10.2	10 2	9 8	9.7	11 2	10.2	13 2	11 1
1951	10.3	10 0	10.7	9.8	10 8	10 5	10 5	10 3	9 8	10 7	11 4	10 4
1952	10.6	10.5	10.0	10 1	10 6	10 2	10 2	10 0	10.3	10 1	10 8	11 0
1953	10.6	10 6	9.8	10 1	10 3	10 1	9 8	10 1	10 1	12 3	11 2	9 8
1954	10 4	10 1	9 2	9 8	11 0	10.5	9 7	10 6	10 8	10 8	10 1	10 3
1955	10 3	9.5	10.3	11 1	9 9	11 1	10 2	10 2	9 7	11 2	11 0	10 0
1956	11 4	9 8	10 4	10 6	10 2	10 7	10 5	11 2	11 1	10 5	10 6	10 1
1957	10 5	10.9	10 6	9.9	9 7	10 3	10.0	10.7	10 2	10.8	10 3	10 3
1958	10.4	10 7	11 1	11 3	10 6	10 0	9 9	10 0	10 5	10 5	10 2	(10 8)
1959			10.7	10 4			10 1	(10 3)	10 0	10 5	10 1	11 5
1960	10.4	10.8	10 2	9 9	10.6	11 1	10 0	10 5	12 2	10 8	10 6	10 4
1961	11.6	(11 2)	11 2	10.8	9.9	(10 3)	10 8	10 6	11 0	12 2	10.1	10 3
1962	10.0	10.3	13 4			10 2	10 4	10 2	10 3	10 3	11 2	10.7
1963	10.6	9.9	9.9	10.6	10.3	10.4	10 8	9 8	11 1	10.4	11 1	10 2
1964	11 0	11.0	10 5	10 4	10 3	10.4	10 4	10 3	10 5	10 2	10.3	10 6
1965	11.1		10 3	9 8	9.9	10.8	10 4	10 4	10 2	10 2	(10 5)	10 4
1966	12.1	(10 3)	10.4	9 9	9 8	10 0	10 3	10 4	10 6	9 9	10 5	10 9
1967	10.7	11 3	10 4	11.3	11 3	11 0	9 8	9 9	10 9	10 8	11 0	11 1
1968	10.7	10.7	10.3	10 5	10 8	11.2	10.4	10 3	10 3	11.0	11 9	11 0
1969	10.3	10.9	11 0	10 1	10 5	10 7	10.8	11 0	10 7	10.5	11 7	

* The height above the 1929 Mean Sea-level Datum is listed according to U S. Coast and Geodetic Survey Tables

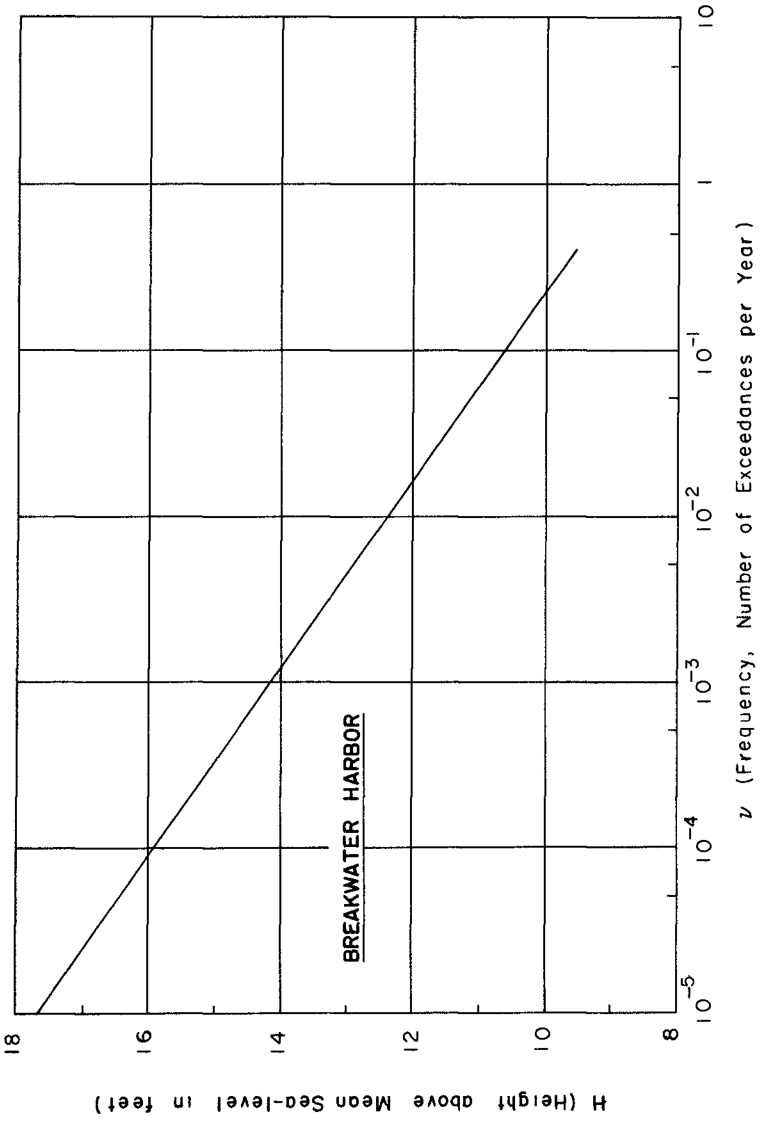

FIGURE 1 Frequency Curve far Breakwater Harbor

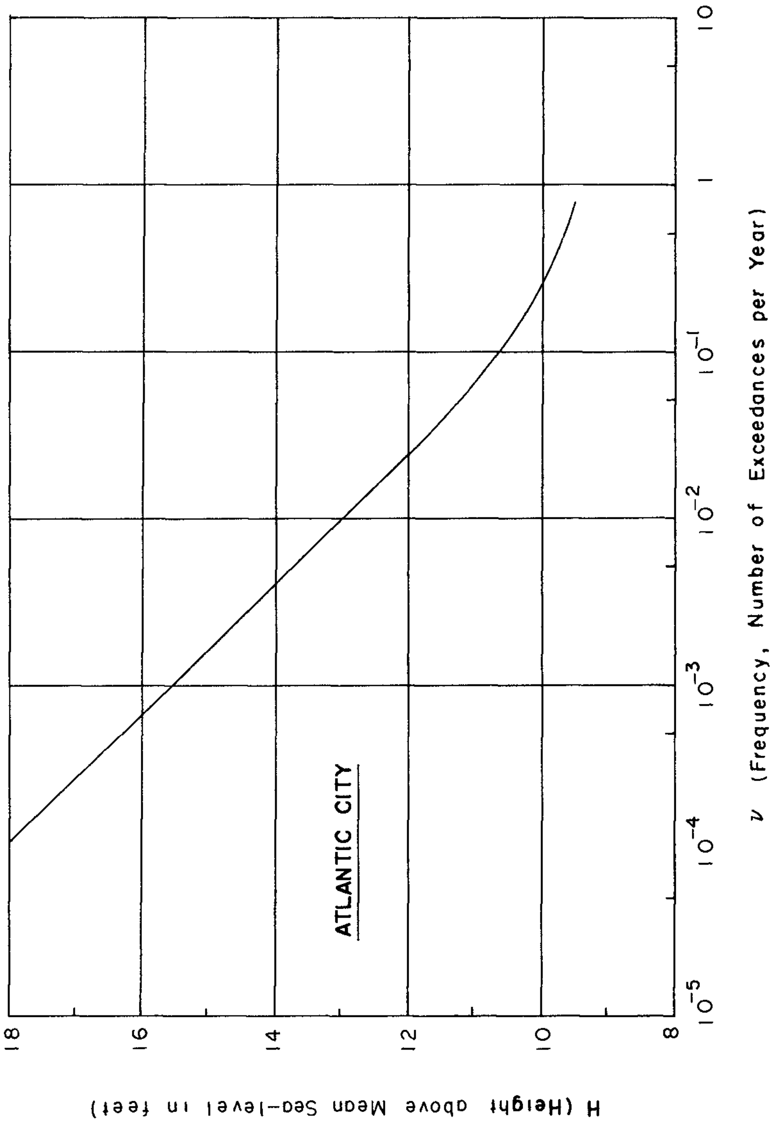

FIGURE 2 Frequency Curve for Atlantic City

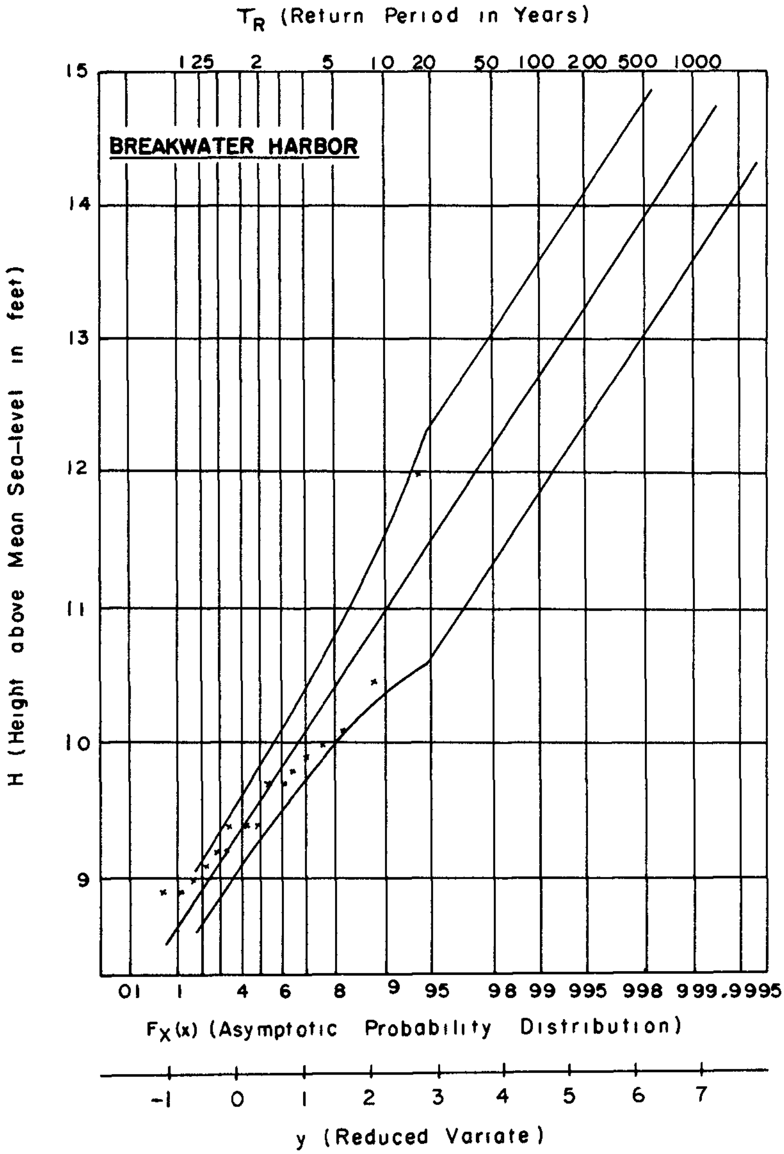

FIGURE 7 Gumbel Analysis for Breakwater Harbor

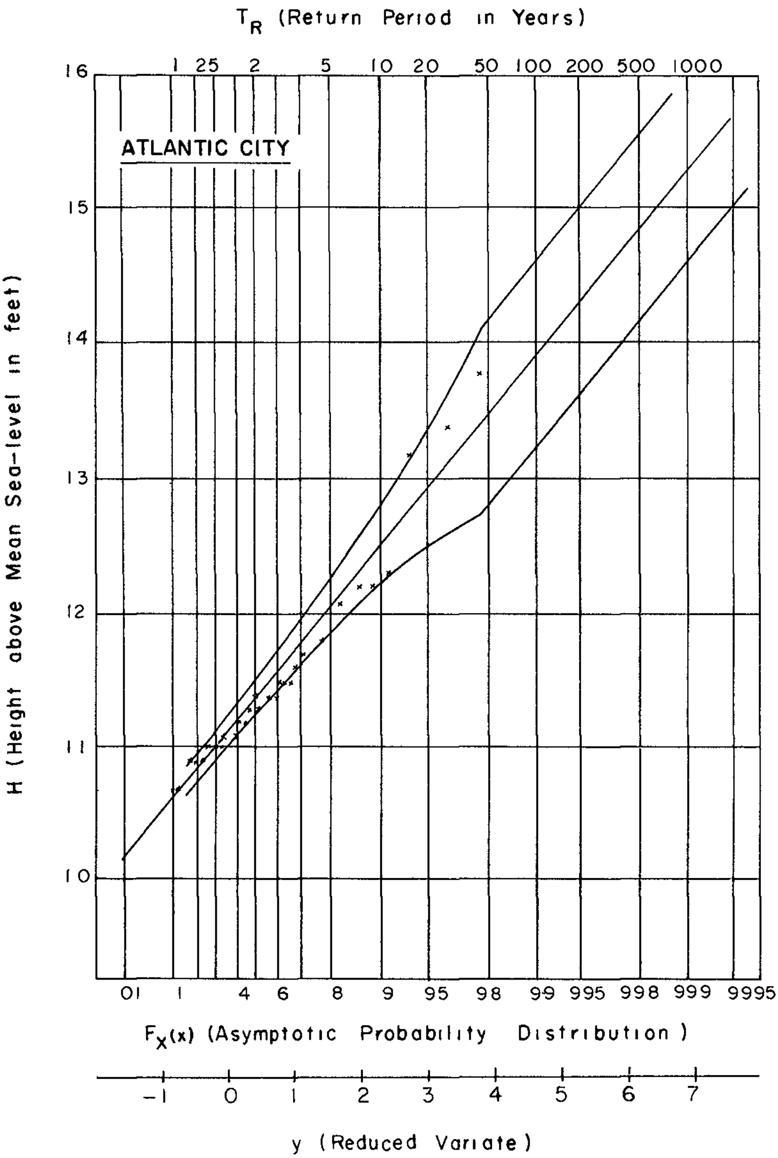

FIGURE 8 Gumbel Analysis for Atlantic City

TABLE 7

Gumbel Analysis of Breakwater Harbor Data

i	H*	H^2	$\frac{i}{N+1}$	y
1	8.9	79.21	0.056	-1.059
2	8.9	79.21	0.111	-0.788
3	9.0	81.00	0.167	-0.582
4	9.1	82.81	0.222	-0.409
5	9.2	84.64	0.278	-0.247
6	9.2	84.64	0.333	-0 095
7	9.4	88.36	0.389	-0.057
8	9.4	88.36	0.444	+0.208
9	9.4	88.36	0.500	0.366
10	9.7	94.09	0 556	0 533
11	9.7	94.09	0.611	0.708
12	9.8	96 04	0.667	0.904
13	9.9	98.01	0.722	1.122
14	10.0	100.00	0.778	1.382
15	10.1	102.01	0.833	1.700
16	10.5	110.25	0.889	2.140
17	12.0	144.00	0.944	2 854

$\Sigma H = 164.2$ $\Sigma H^2 = 1595.08$

$\bar{y}_N = 0.5181$ $\bar{H} = 9.65$ $\overline{H^2} = 93.828$

$\sigma_N = 1.0411$ $\bar{H}^2 = 93.292$

$s_H^2 = 0.535$ $s_H = 0.731$

$1/\alpha_N = 0.761$ $u_N = \bar{H} - (1/\alpha_N)\bar{y}_N = 9.264$

Φ	0.150	0.200	0.300	0.400	0 500	0 600	0.700	0 800	0 850
$\sigma(y)\sqrt{N}$	1.255	1.243	1.268	1.337	1.443	1.598	1 835	2.241	2 585
$\sigma(H)$	0.232	0.230	0.234	0.247	0.267	0.295	0.339	0.414	0 478

$\Delta_{H\ N} = 0.869$ $\Delta_{H,N-1} = 0.578$

* Yearly Extremes from Table 1

TABLE 8

Gumbel Analysis of Atlantic City Data

i	H*	H^2	$\frac{i}{N+1}$	y
1	10.5	110 25	0.021	-1.35
2	10.6	112.36	0 043	-1 14
3	10.7	114.49	0.064	-1.01
4	10.7	114.49	0.085	-0.90
5	10.7	114.49	0.106	-0.80
6	10.9	118.81	0.128	-0.72
7	10.9	118.81	0.149	-0.64
8	10.9	118.81	0.170	-0.57
9	10.9	118.81	0.191	-0.50
10	10.9	118.81	0.213	-0.44
11	11.0	121.00	0.234	-0.37
12	11.0	121.00	0.255	-0.31
13	11.0	121.00	0.277	-0 25
14	11.0	121.00	0.298	-0.19
15	11.0	121.00	0 319	-0.13
16	11.1	123.21	0.340	-0.08
17	11.1	123.21	0 362	-0.02
18	11.1	123.21	0.383	+0 04
19	11.1	123.21	0.404	0 10
20	11.2	125.44	0.426	0.16
21	11.2	125.44	0.447	0.22
22	11.2	125.44	0.468	0.28
23	11.3	127.69	0.489	0.33
24	11.3	127.69	0.512	0.40
25	11.4	129.96	0.532	0.46
26	11.4	129 96	0.553	0.52
27	11.4	129.96	0.574	0.59
28	11.4	129.96	0.596	0 66
29	11.4	129.96	0.617	0.73
30	11.5	132.25	0.638	0.80
31	11.5	132.25	0 660	0.88
32	11.5	132.25	0.681	0.96
33	11.6	134.56	0.702	1.04
34	11.7	136.89	0.723	1 13
35	11.8	139.24	0.745	1.22
36	11.8	139.24	0.766	1.32
37	11.8	139.24	0.787	1.43
38	11.9	141.61	0.809	1.55

TABLE 8 (Continued)

i	H*	H^2	$\frac{i}{N+1}$	y
39	12.1	146.41	0 830	1.68
40	12.1	146.41	0.851	1.82
41	12.2	148.84	0.872	1.99
42	12.2	148.84	0.894	2 19
43	12.3	151.29	0.915	2.42
44	13.2	174.24	0.936	2.72
45	13.4	179.56	0.957	3.12
46	13.8	190.44	0.979	3 85

$\Sigma H = 526.7 \quad \Sigma H^2 = 6053.03$

$\bar{y}_N = 0.5468 \qquad \bar{H} = 11.45 \qquad \bar{H}^2 = 131.103$

$\sigma_N = 1.1538 \qquad \overline{H^2} = 131.588$

$s_H^2 = 0.485 \qquad s_H = 0.697$

$1/\alpha_N = 0.604 \qquad u_N = \bar{H} - (1/\alpha_N)\bar{y}_N = 11.120$

Φ	0.150	0.200	0.300	0.400	0.500	0.600	0 700	0.800	0 850
$\sigma(y)\sqrt{N}$	1.255	1.243	1.268	1 337	1.443	1.598	1.835	2.241	2.585
$\sigma(H)$	0.112	0.111	0 113	0.119	0.128	0.142	0 163	0.199	0.230

$\Delta_{H,N} = 0.689 \qquad \Delta_{H,N-1} = 0.458$

* Yearly Extremes from Table 2

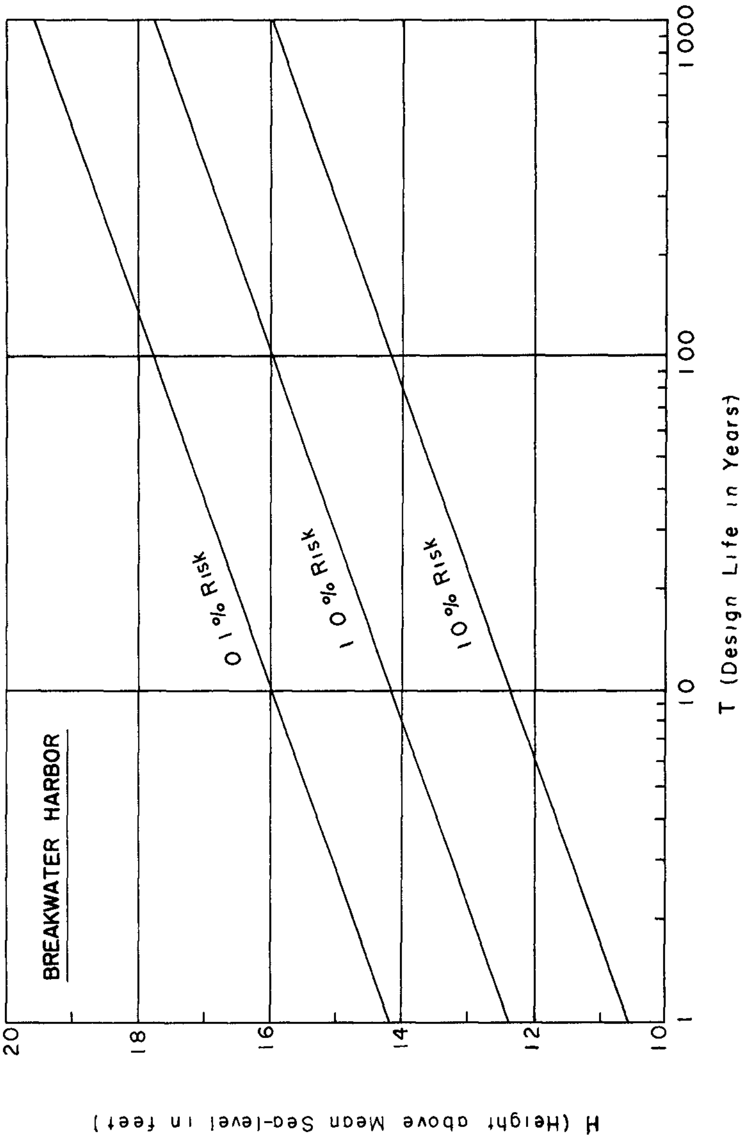

FIGURE 5 Wemelsfelder Risk Curves

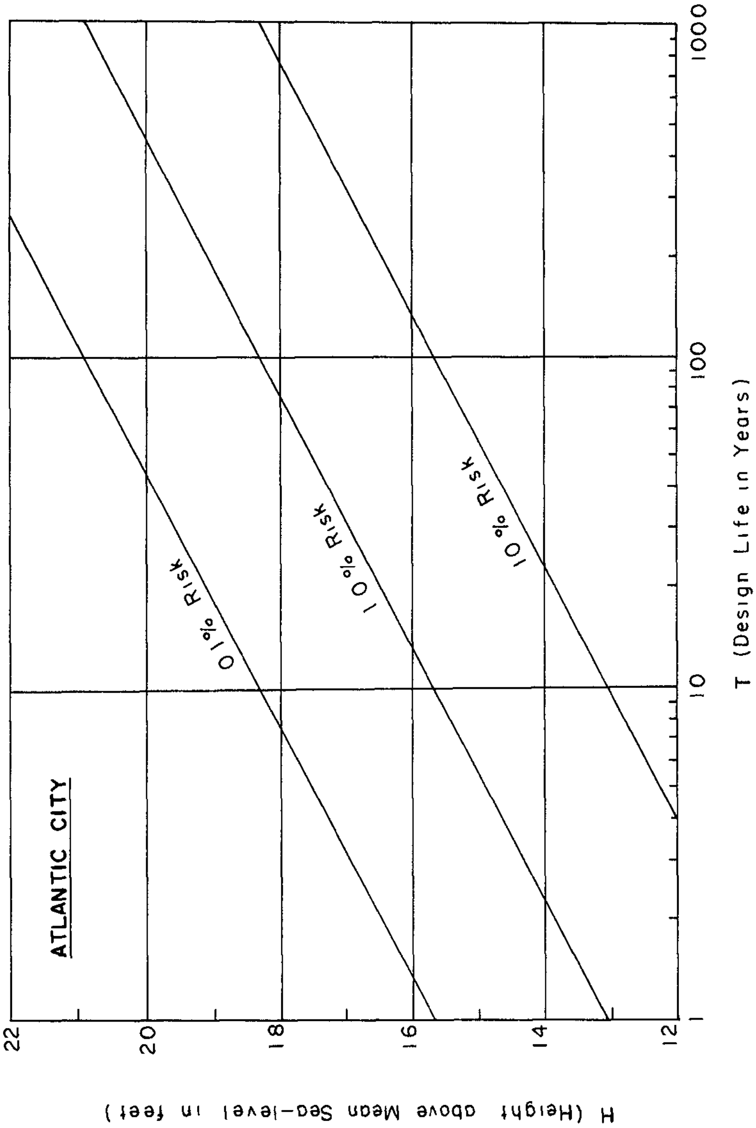

FIGURE 6 Wemelsfelder Risk Curves

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