Coastal Engineering Technical Note

ESTIMATION OF ECONOMIC LOSSES FROM TRANSMITTED WAVES COMPUTER PROGRAM BWLOSS2 (MACE-16)

PROGRAM PURPOSE: The microcomputer program BWLOSS2 fits a long-term cumulative probability distribution to transmitted wave height data and estimates expected annual economic losses due to wave attack after a protective breakwater has been built. The program is intended to aid in the definition of incremental economic benefits attributable to a breakwater design, not to estimate potential damages to the breakwater itself. The detailed technical basis for application of BWLOSS2 in a systematic optimization procedure for design of rubble-mound breakwater cross sections is discussed by Smith (1985).

PROGRAM CAPABILITIES: Estimation of incremental economic benefits directly attributable to rubble-mound breakwaters built for wave protection requires that the costs to the beneficiaries with the breakwater in place be determined. A breakwater built such that no waves are transmitted during the worst conceivable conditions is seldom affordable. It is often more cost effective to accept a small amount of risk that waves from a very severe storm will be transmitted and cause losses. The damage caused by these transmitted waves is assumed to follow a previously derived economic loss function of wave height:

$$\$L(H_s) = \$L_{max}(1 - \exp[A(H_s - H_{Lo})]) \quad \text{for } H_s \geq H_{Lo}$$

where

$\$L(H_s)$ = the economic losses caused by a storm of significant wave height H_s;

$\$L_{max}$ = the maximum conceivable loss due to wave attack;

H_{Lo} = the maximum wave height for which losses can be neglected;

A = a site specific coefficient determined by regression of historical $(H_s, \$L(H_s))$ data.

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The MACE program BWLOSS1, CETN-I38 is available to derive this economic loss function for the site of interest, given $\$L_{max}$, H_{Lo} and historical economic losses with the associated significant wave heights. BWLOSS2 requires that L_{max}, H_{Lo}, and A be input.

A long-term extremal cumulative probability distribution of incident significant wave heights, $F(h_s)$, assumed to define the wave climate on the seaward side (incident) of the breakwater is specified in one of the following three forms:

(1) Extremal Type I $F(h_s) = Pr(H_s < h_s) = \exp\{-\exp(-[h_s - \varepsilon]/\Phi)\}$

(2) Weibull $F(h_s) = Pr(H_s < h_s) = 1 - \exp[-(h_s/B)^{\alpha}]$

(3) Log-Extremal $F(h_s) = Pr(H_s < h_s) = \exp(-[B/h_s]^{\alpha})$

The long-term cumulative probability distribution of transmitted wave heights, $F(h_t)$, defines the wave climate on the landward side of the breakwater. The wave height H_t is taken to represent the domain of irregular transmitted wave heights in the same manner that H_s represents the domain of incident wave heights. $F(h_t)$, in each of the above forms, is calculated by the method of least squares from user inputted transmitted wave height versus incident return period data. Given the incident return period denoted by RT, $F(h_t)$ can be estimated as follows:

$$F(h_t) = 1 - 1/\lambda RT$$

where λ is specified by the user as the average number of storms per year, also termed the Poisson lambda parameter (Borgman and Resio, 1982). The method of least squares is then applied to estimate the parameters for $F(h_t)$. Four measures of statistical confidence are computed: the non-linear correlation, the sum of the square residuals, the standard error of the estimate, and the mean square deviation. A residual table for each distribution is optionally printed. The transmitted wave heights during any storm represented by h_s are probably not Rayleigh distributed, but the transmitted wave height associated with a given incident significant wave height is assumed to be at the 13.5 percent exceedance level among all transmitted waves (including those of zero height). This is the same exceedance level as the significant wave height in a Rayleigh distributed sea state. The methods of Andrew and Smith (1985) can be applied to estimate the transmitted wave heights at other exceedance levels during a specific transmitted sea state.

The program BWLOSS2, in a manner similar to its sister program BWLOSS1, computes an expected annual economic loss due to transmitted waves $E(\$L(H_t))$ by the following formula:

$$E(\$L(H_t)) = \lambda \int_{-\infty}^{\infty} \$L(H_t) \; d/dH_t[F(H_t)]dH_t$$

The program assumes that the number of extremal events per year is a random variable best modeled by the Poisson distribution, which is independent of H_t and can be characterized by its mean value of λ. This factor is necessary to present the expected economic losses as an annual average. $\$L(H_s)$ is also taken to describe $\$L(H_t)$ since the transmitted waves are now the incident waves to facilities and operations incurring losses. Since no losses are caused by transmitted waves of intensity H_{Lo} or less, the expected annual losses can be rewritten as:

$$E(\$L(H_t)) = \int_{H_{Lo}}^{\infty} \$L(H_t) \; d/dH_t[F(H_t)]dH_t$$

The numerical inegration is accomplished by Simpson's rule using 100 intervals.

PROGRAM AVAILABILITY: BWLOSS2 is available in Microsoft BASIC and FORTRAN for the IBM PC. A FORTRAN IV version is also available, as implemented on the WES Honeywell DPS-8 mainframe system. The program is available on a 5 1/4-in. diskette or as a printed program listing and may be obtained from Ms. Gloria J. Naylor at (601) 634-2581 (FTS 542-2581), Engineering Computer Programs Library Section, Technical Information Center, U.S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180-0631. Questions concerning the applications of BWLOSS2 can be directed to Mr. Orson P. Smith at (601) 634-2013 (FTS 542-2013) or Mr. Robert B. Lund at (601) 634-2068 (FTS 542-2068), both of the Coastal Design Branch, CERC.

INPUT:

1. $\$L_{max}$, H_{Lo}, and A for the economic loss function
2. The incident Poisson lambda parameter (λ)
3. A set of transmitted wave heights and return period data points

OUTPUT:

1. Parameters for each form of $F(h_t)$, its mean, variance, the non-linear correlation, and the sum of the square residuals

2. A residual table for each form of $F(h_t)$ (optional)

3. A return period table for each form of $F(h_t)$

4. The expected annual economic losses from wave attack with the breakwater in place

SAMPLE PROBLEM: The maximum conceivable loss due to wave attack is 20 million dollars. Losses are negligible for significant wave heights up to 2 ft. The regression coefficient, A, for the economic loss function is -0.086. There are an average of 4 extremal events per year. The transmitted wave heights and corresponding incident wave condition return periods in feet and year are: (2.6, 20); (3.2, 30); (3.6, 40); (3.9, 50); (4.5, 75); and (5.0, 100). What is the expected annual loss in millions of dollars with the breakwater in place?

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RUN
ESTIMATION OF ECONOMIC LOSSES FROM TRANSMITTED WAVES
BWLOSS2
VERSION 11-85
*************************************************************
* BWLOSS2 IS A PROGRAM WHICH FITS LONG-TERM CUMULATIVE      *
* PROBABILITY DISTRIBUTIONS TO TRANSMITTED SIGNIFICANT      *
* WAVE HEIGHT DATA TO ESTIMATE EXPECTED ANNUAL ECONOMIC     *
* LOSSES DUE TO WAVE ATTACK AFTER A BREAKWATER HAS BEEN     *
* BUILT.  THE PROGRAM REQUIRES DATA ON A PREVIOUSLY         *
* DEFINED LOSS .VS. SIGNIFICANT WAVE HEIGHT FUNCTION        *
* (REF. PROGRAM BWLOSS1) AND AT LEAST 2 POINTS OF           *
* TRANSMITTED WAVE HEIGHT, RETURN PERIOD DATA.  THE         *
* DISTRIBUTIONS OF TRANSMITTED WAVE HEIGHTS ARE CALCULATED *
* BY THE METHOD OF LEAST SQUARES.  A RESIDUAL TABLE CAN BE *
* OPTIONALLY PRINTED.                                       *
*************************************************************

INPUT $Lmax FOR LOSS CURVE: $L(Hs)=$Lmax(1-EXP(A(Hs-Hlo)))
? 20
INPUT Hlo, THE MAXIMUM WAVE HEIGHT FOR WHICH LOSSES ARE NEGLIGBLE
? 2
INPUT A, THE REGRESSION COEFFICIENT
? -.086
INPUT AVERAGE NUMBER OF EXTREMAL EVENTS PER YEAR,
THE POISSON 'LAMBDA' PARAMETER
? 4
INPUT THE NUMBER OF TRANSMITTED WAVE HEIGHT,
RETURN PERIOD DATA POINTS YOU HAVE
? 6
INPUT THE DATA POINTS-ONE AT A TIME
INPUT TRANSMITTED WAVE HEIGHT, COMMA, THEN RETURN PERIOD IN YEARS
? 2.6,20
? 3.2,30
? 3.6,40
? 3.9,5-0
? 4.5,75
? 5.0,100
PRINT RESIDUAL TABLES(Y/N)?
? Y
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WEIBULL

```
F(ht)=Pr(Ht<ht)=  1-EXP(-(ht/BETA)^ALPHA)
ALPHA        =  0.485
BETA         =  0.125
MEAN         =  0.129
VARIANCE     =  0.000
```

XVALUE	YVALUE	YEST	DIFF
2.6	.9875	.9872	.00034
3.2	.9917	.9919	.00024
3.6	.9938	.9939	.00015
3.9	.9950	.9950	.00002
4.5	.9967	.9966	.00007
5.0	.9975	.9975	.00003

```
NON-LINEAR CORRELATION IS       0.9969684
SUM SQUARE RESIDUALS IS         0.0000002
STANDARD ERROR IS               0.0002262
MEAN SQUARE DEVIATION IS        0.0577878
```

RETURN PERIOD TABLE

YEAR	HS
5.0	1.20
10.0	1.85
25.0	2.92
50.0	3.89
100.0	5.02

```
SELECT A DISTRIBUTION
EXTREMAL TYPE I...1
WEIBULL..........2
LOG-EXTREMAL......3
SELECT 1, 2, OR 3
? 2

EXPECTED ANNUAL LOSS IN MILLIONS OF DOLLARS IS       0.1785565
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REFERENCES:

Andrew, M.E. and Smith, O.P. 1985. "Revised Method for Estimating Irregular Runup on Rough Slopes and Wave Transmission by Overtopping," CERC Miscellaneous Paper (in preparation), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Borgman, L. And Resio, D. 1982. "Extremal Statistics in Wave Climatology," Topics in Ocean Physics, Soc. Italiana di Fisica, Bologna, Italy.

"Computer Program BWLOSS1: Estimation of Economic Losses as a Function of Wave Height," CETN-I-38 U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

"Computer Program WAVDIST: Extremal Significant Wave Height Distributions," CETN-I-40 U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smith, O.P. 1985. "Cost Effective Optimization of Rubble-mound Breakwater Cross Sections," CERC Technical Report 86-2 U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.