Coastal Engineering Technical Note

ESTIMATION OF LONG TERM DAMAGE TO RUBBLEMOUND BREAKWATERS COMPUTER PROGRAM: BWDAMAGE (MACE-18)

PURPOSE: A key step in the identification of an optimum among all possible rubblemound breakwater plans is to estimate the expected damages and life cycle costs of related maintenance and repairs. The following discussion reviews an analytical technique that has been proposed for making these predictions. A more comprehensive discussion is available in Smith (1986).

BACKGROUND: Scale model studies at the US Army Engineer Waterways Experiment Station have addressed, to a limited degree, the level of damage to breakwater trunk armor layers experienced when the design wave height is exceeded. The reserve stability trends or tendency for damage levels to increase with design wave exceedance ratio can be characterized by a function of the form:

$$\%D(H) = \%D(H_d)\exp[S_r(H/H_d - 1)] \quad (1)$$

where:

$\%D(H)$ = the percent damage experienced by a particular armor type from an incident wave height H.

$\%D(H_d)$ = the percent damage when the incident wave height $H = H_d$, the design wave height.

S_r = an empirical coefficient fit to the scale model test results for a particular armor unit type

A higher S_r coefficient means that an armor unit type experiences higher damage levels for the same increase in H. Table 1 gives values of $\%D(H_d)$ and S_r for various armor units and wave conditions.

Table 1

Coefficients for Analytical Prediction of Breakwater Damage

Armor Unit Type (1)	Wave Condition (2)	$\%D(H_d)$ (3)	S_r (4)
Quarrystone (rough)	Nonbreaking	3.0	6.95
Quarrystone	Breaking	2.0	3.65
Quadripods	Nonbreaking	3.0	6.00
Tribars	Nonbreaking	3.0	4.87
Dolosse	Nonbreaking	2.0	1.68
Dolosse	Breaking	2.0	3.55

These coefficients should be used with caution in Equation 1 above to predict breakwater damage. The variation in $\%D(H_d)$ between armor unit types reflects improved accuracy of damage measurements, as well as damage trends which may be related to armor unit characteristics. The damages predicted by Equation 1 at selected levels of design wave exceedance and the associated upper 95 percent statistical confidence limit are presented in Table 2. Equation 1 predicts the statistical mean trend of the experimental data, and since this is the most probable damage level for a given H/H_d ratio based on the empirical evidence available, it is appropriate for application in estimates of expected (long term average) damage. Designers should also be sure to consider the damage predicted by the upper 95 percent confidence limit of the pertinent model test, as shown in Table 2, and report these predictions in their documentation of the design analysis.

Table 2

Damage Level Predictions at Selected Design Wave Exceedances in Percent displacement of the Armor Layer (Mean Trend/95 Percent Confidence Limit)

Armor Unit Condition (1)	H/H_d 1.00 (2)	1.05 (3)	1.10 (4)	1.15 (5)	1.20 (6)	1.25 (7)	1.30 (8)	1.35 (9)	1.40 (10)
Quarrystone (Nonbreaking)	3.0/24.7	4.2/25.7	6.0/27.2	8.5/29.6	12.1/33.1	17.1/38.2	24.2/45.5	34.2/55.8	48.4/70.4
Quarrystone (Breaking)	2.0/10.2	2.4/10.6	2.9/11.0	3.5/11.6	4.1/12.2	5.0/13.0	6.0/14.0	7.2/15.2	8.6/16.7
Quadripods (Nonbreaking)	3.0/18.6	4.0/19.5	5.5/20.7	7.4/22.6	10.0/25.1	13.4/28.6	18.1/33.3	24.5/39.8	33.0/48.5
Tribars (Nonbreaking)	3.0/10.4	3.8/11.1	4.9/12.1	6.2/13.4	7.9/15.1	10.1/17.3	12.9/20.1	16.5/23.7	21.0/28.4
Dolosse (Nonbreaking)	2.0/4.3	2.2/4.5	2.4/4.6	2.6/4.9	2.8/5.1	3.0/5.3	3.3/5.6	3.6/5.9	3.9/6.3
Dolosse (Breaking)	2.0/7.4	2.4/7.8	2.9/8.2	3.4/8.7	4.1/9.4	4.9/10.1	5.8/11.1	6.9/12.2	8.3/13.6

Note: Displacement of more than 30-40 percent of the armor layer will often involve erosion of underlayers, which in practice requires a repair effort of greater scope than replacement in kind.

Tables 1 and 2 include predictions for only four types of armor units, two of which do not include breaking wave conditions. This is unfortunate but leaves the designer with no option but to apply subjective judgment to choose damage coefficients which are close to those of the most similarly shaped armor unit in the same wave conditions. Slender concrete armor units, including nearly all concrete types more complex than plain cubes, are subject to breakage in place from impacts between individual units in the armor slope. This breakage would presumably be accompanied by displacement of the broken pieces during an extreme storm. An increase in S_r of 50-100 percent would provide some allowance for this likelihood, but there are no data currently available with which to more precisely predict breakage or its effect on overall breakwater reserve stability. Analytical predictions of breakwater stability and functional performance should always be confirmed by scale model testing prior to construction.

PROGRAM CAPABILITIES: The microcomputer program BWDAMAGE applies an Extremal Type I, Weibull, or Log-Extremal probability distribution of extreme wave heights to estimate the expected annual damage to the breakwater. The cumulative distribution functions have the following forms:

(1) Extremal Type I $\quad F(h) = P_r(H \leq h) = \exp(-\exp-(h-\varepsilon)/\phi))$

(2) Weibull $\quad F(h) = P_r(H \leq h) = 1 - \exp(-(h/B)^{\alpha})$

(3) Log-Extremal $\quad F(h) = P_r(H \leq h) = \exp(-(B/h)^{\alpha})$

where P_r [·] denotes the probability of the event in brackets, H denotes a random variable wave height, and h denotes a specific wave height. The parameters of these distributions can be derived from Computer Program WAVDIST (CETN-I-40). The expected (long term average) annual percent damage, E(%D(H)/yr), is estimated as:

$$E(\%D(H)/yr) = \lambda \int_{-\infty}^{\infty} \%D(H)\lfloor d/dh(F(h))\rfloor dh$$

where λ = the average number of extreme events per year. The number of extreme events occurring per year is assumed to be a random variable best modeled by the Poisson distribution, which is independent of the random variable H. Since little damage is caused to the breakwater by waves of height less than H_d, the expected annual percent damage can be rewritten as:

$$E(\%D(H)/yr) = \lambda \int_{H_d}^{\infty} \%D(H)\lfloor d/dh(F(h))\rfloor dh$$

BWDAMAGE accomplishes this integration by Simpson's Rule with 100 intervals. The upper integration limit is taken as the h value such that F(h) = .99999. The maximum error in E(%D(H)/yr) due to ommission of the upper tail is .001 λ percent. The expected annual percent damage per unit length is converted to expected dollars damage through input of the breakwater dimensions and cost of the armor unit (see sample run).

The time interval in which a specified level of damage will occur is estimated in two ways. The first simply divides the specified level of unacceptable damage by the expected annual rate to give a repair interval in years. This method includes an account of the accumulation of damage from successive storms. The other method involves solving the %D(H) function for the wave height h which would cause the specified level of damage. The Long-Term

Distribution, F(h), is then applied to determine the return period, RT(h), of the event as governed by the following equation:

$$RT(h) = [\lambda(1-F(h))]^{-1}$$

This method is much less conservative and will predict a repair interval on the order of λ times as long as that predicted by the first method.

PROGRAM AVAILABILITY: The program 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. A 5-1/4-in. diskette or a printed program listing 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 BWDAMAGE can be directed to Mr. Doyle L. Jones at (601) 634-2069 (FTS 542-2069) of the Coastal Design Branch, Coastal Engineering Research Center.

INPUT:

1. Design wave height H_d
2. Name of armor unit
3. $\%D(H_d)$ and S_r for the armor unit (optional; for any not listed in Table 1)
4. Wave height distribution type and parameters
5. Average number of storms per year λ
6. Volume of armor layer in cubic feet per linear foot
7. The cost of the armor in dollars per cubic foot
8. Percent damage to armor layer allowable before repair would be accomplished (optional)

OUTPUT:

1. Expected annual percent damage to the structure
2. Expected annual repair costs to the structure
3. A repair interval for a specified percentage of armor layer damage.

SAMPLE PROBLEM: With an average of 4 extreme events per year, a design wave height of 10 feet, tribar armor units, 213.7 cubic feet of armor per linear foot of trunk, and the cost of the armor at $165 per cubic foot, what is (a) the expected damage per linear foot per year in percent, (b) the expected cost per linear foot per year, (c) the average repair interval for 5 % damage based on the expected damage per linear foot per year in percent (found in part (a) above), and (d) the return period of the storm causing 5 % damage? Use F(h) as Extremal Type I with $\varepsilon = -2.270$ and $\phi = 3.261$.

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RUN
ESTIMATION OF RUBBLEMOUND BREAKWATER ARMOR LAYER EXPECTED DAMAGES
BWDAMAGE
VERSION 1-86

UNITS USED SHOULD BE CONSISTENT WITH THOSE USED IN BWLOSS1 AND
BWLOSS2 - OTHERWISE THE EXTREMAL DISTRIBUTION PARAMETERS MUST BE CHANGED

SITE OF DATA OR PROJECT NAME? SAMPLE RUN OF BWDAMAGE

ENGLISH OR METRIC UNITS (E OR M) ? E

INPUT HEIGHT OF DESIGN WAVE IN FEET? 15

ARMOR UNITS IN CATALOG

 1   QUARRYSTONE (NON-BREAKING WAVES)
 2   QUARRYSTONE (BREAKING WAVES)
 3   QUADRIPODS (NON-BREAKING WAVES)
 4   TRIBARS (NON-BREAKING WAVES)
 5   DOLOSSE (NON-BREAKING WAVES)
 6   DOLOSSE (BREAKING WAVES)
 7   OTHER

INPUT NUMBER OF ARMOR UNIT ? 4

SELECT AN EXTREMAL DISTRIBUTION
EXTREMAL TYPE I...1
WEIBULL..........2
LOG-EXTREMAL......3

SELECT 1, 2, OR 3? 1

INPUT EXTREMAL TYPE I EPSILON AND PHI? -2.27,3.261

INPUT THE AVERAGE NUMBER OF EXTREMAL EVENTS PER YEAR, THE 'POISSON'
LAMBDA PARAMETER? 4

INPUT THE VOLUME OF ARMOR LAYER IN CUBIC FEET PER LINEAR FOOT? 213.7

INPUT THE COST OF THE ARMOR IN DOLLARS PER CUBIC FOOT? 165
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ESTIMATION OF RUBBLEMOUND BREAKWATER ARMOR LAYER EXPECTED DAMAGE
                        SAMPLE RUN OF BWDAMAGE
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COST OF ARMOR (DOLLARS PER CUBIC FOOT) =  165
VOLUME OF ARMOR LAYER IN CUBIC FEET PER LINEAR FOOT =  213.7
DESIGN WAVE HEIGHT =  15 FEET
EXPECTED DAMAGE PER LINEAR FOOT PER YEAR FOR TRIBARS (NON-BREAKING WAVES) IS
 .3 %
EXPECTED REPAIR COST PER LINEAR FOOT PER YEAR IS $  106

WOULD YOU LIKE TO PREDICT A REPAIR INTERVAL (Y OR N) ? Y

INPUT % DAMAGE TO ARMOR LAYER AT TIME OF REPAIRS? 5

THE AVERAGE REPAIR INTERVAL FOR  5 % DAMAGE
BASED ON .3 % PER YEAR EXPECTED DAMAGE IS  16.67  YEARS

THE RETURN PERIOD OF THE STORM CAUSING 5 % DAMAGE IS  80.9 YEARS
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ANOTHER RUN (Y OR N) ? N
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REFERENCES:

Smith, O. P. 1986. "Cost Effective Optimization of Rubblemound Breakwater Cross-Sections," CERC Miscellaneous Paper (in preparation), U. S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U. S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, "Extremal Significant Wave Height Distributions Computer Program: WAVDIST", CETN-I-40, 1985, Vicksburg, MS.