CHAPTER 84

APPLICATION OF RISK CRITERIA IN COASTAL ENGINEERING

ASIT K. BISWAS

Resources Research Centre, Policy & Planning Branch, Department of Energy, Mines & Resources, and Visiting Professor of Civil Engineering, University of Ottawa, Ottawa, Canada

INTRODUCTION: A design of any engineering structure may be said to be optimum when it can meet all the necessary requirements at a minimum possible cost. In all cases there is a probability, however slight (sometimes even incalculable because of lack of data), that the design load can be exceeded and, thus, damages could occur. Obviously, lower the design load, higher would be the cost of anticipated damages and vice versa. Thus, from economical standpoint alone, the ideal solution would be when the total cost of construction and anticipated damages is at its minimum. Very often, however, other factors like social, political, etc., have to be considered, and this makes the whole process a complex decision making problem - sometimes completely out of the jurisdiction of the engineers.

GENERAL CONSIDERATIONS: Risk is inherent in any structure, and those in coastal engineering are no exception. But very often this simple fact is overlooked. With our present state of knowledge (1968) it is impossible to determine the upper limit of any natural phenomenon, and design wave is no exception (for general discussion on the subject see refs. 1, 2, 3). If this concept is not accepted, one has to seriously consider the possibility that a wave height of x ft is possible (a maximum height) but a height of $x + 0.001$ ft is physically impossible. If the physical upper limit concept is abrogated, as is advocated by the author, then it becomes evident, as a corollary, that any design value of wave height, however high, is associated with some probability of occurrence, however small, and thus some degree of risk, however slight. This does not mean that risk in such a design is automatically increased; all it means is that if the probability of occurrence of a design wave x is P, then a higher value of $x + dx$ reduces the corresponding probability to $P - dP$.

RISK CRITERIA: It is not politically much expedient to use the word risk which, at least to the layman, immediately brings unfortunate connotations to mind. An attempt would be made herein to suggest two simple procedures for evaluating risk for design waves by using (i) return periods, and (ii) 'damage' functions.

RETURN PERIOD: If a series of n Bernoulli trials are considered, each of which culminate in either a success or a failure having p and q as their respective probabilities, then the interval between the successes (or failures) may be defined as "recurrence interval", "return period", or "waiting time", and:

$$p + q = 1 \qquad \text{........... (1)}$$

Let the hazard event have an intensity X (a random variable) with a cumulative probability function F(x). The failure of a future event may be said to have occurred when X has a value equal to or less than x, i.e.,

$$F(x) = P(X \leqslant x) = q = 1 - p \qquad \ldots\ldots\ldots\ldots (2)$$

Let T(x) be the random variable which expresses the time interval between two successive 'exceedence' events (higher than x). The return period of a success in years is defined by (ref. 4):

$$\bar{T}(x) = 1/p = 1/[1-F(x)] \qquad \ldots\ldots\ldots\ldots (3)$$

Now if exceedance occurs for the first time at the ith trial, it means that it must have failed in the previous (i-1) trials. Hence, the probability P(i) is given by:

$$P(i) = p.q^{\,i-1} \qquad \ldots\ldots\ldots\ldots (4)$$

As the variable takes only integral values, the left limit will be given by $i > 1$, but it will obviously be unlimited to the right as the event need not occur. It can be easily shown that the distribution function of T in the present discrete case is geometric (it is exponential in the continuous case); and hence the cumulative probability $P(t \leqslant i)$ that the event occurs before or at the ith trial is given by:

$$P(T \leqslant i) = p(1+o+q^2+ \ldots. +q^{i-1})=1-q^i \qquad \ldots\ldots\ldots\ldots (5)$$

Hence, $$P(i) = 1 - \left[1-1/\bar{T}(x)\right]^{i} \qquad \ldots\ldots\ldots\ldots (6)$$

If encounter probability E is defined as the probability of occurrence of an event of higher magnitude than x within the designed life of the structure of L years, then:

$$E= 1 - \left[F(x)\right]^{L} = 1- \left[1-1/\bar{T}(x)\right]^{L} \qquad \ldots\ldots\ldots\ldots (7)$$

Equation (7) shows the relationship between return period, encounter probability, and the life of the structure. Figure 1 shows the relationship between the return period and the designed life period for various fixed risk criteria.

DAMAGE FUNCTIONS: In certain cases the above procedure may not be advisable as it gives no information about damages. If it is assumed that (i) the process is stochastic with stationary independent increments and has time-independent average, (ii) 2 or more events cannot occur simultaneously, and (iii) damages are restored to the original level after the hazardous events, then the process becomes a compound Poisson one (ref. 5), that is:

$$L(t) = \sum_{n=1}^{N(t)} D_n, \text{ for } t \geqslant 0 \qquad \ldots\ldots\ldots\ldots (8)$$

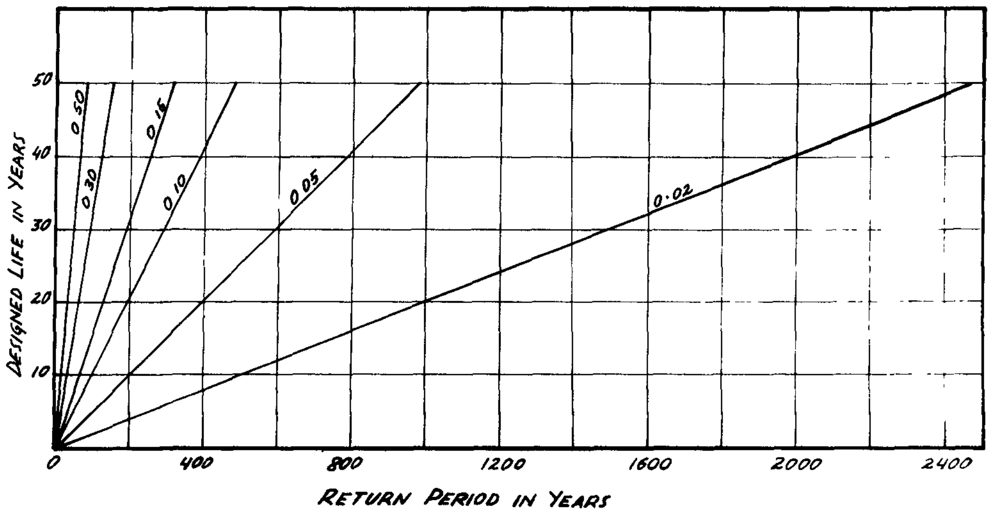

Figure 1. Relation between return period and life of structure for various risk criteria

where, $\{N(t),\ t \geq 0\}$ = a Poisson counting process (number of hazardous events of unspecified magnitudes occurring during the interval o to t)

$\{L(t),\ t \geq 0\}$ = stochastic process of accumulated damage from time o to t

$\{D_n, n=1,2, \ldots N(t)\}$ = family of independent random variables identically distributed as a random variable D, and

n = number of waves exceeding the intensity x_o within the time interval.

From the properties of a compound Poisson process $\{L(t),\ t \geq 0$ the first and second moment functions will be as follows:

Mean : $E\left[L(t)\right] = \nu t\ E\left[D\right]$ .... (9)

Variance : $Var\left[L(t)\right] = \nu t\ E\left[D^2\right]$........... (10)

Covariance : $Cov\left[L(s),\ L(t)\right] = \nu E\left[D^2\right] \min\{s, t\}$.... (11)

where, $E\left[\cdot\right]$ = mathematical expectation,
ν = intensity of the process, and $t > s > 0$.

The relation between variance, mean, and $E\left[D^2\right]$ is given by:

$$Var\left[D\right] = E\left[D^2\right] - E^2\left[D\right] \qquad \text{........... (12)}$$

Equations (9) and (10) may give sufficient information about the loss at any time by its mean and variance, and it may not be necessary to estimate entire distribution of damage.

CONCLUSION: For economical as well as practical reasons it is not possible to design a structure which can withstand all the critical conditions acting on it at the same time. Thus, if a risk is necessarily being taken, it is essential that the designer should know the extent of the risk, and if possible, it should be kept consistent from one place to another (other things being equal) in keeping with sound engineering practice. Unfortunately very little research has been done in this highly complex field of risk criteria which sometimes includes the process of decision taking. It is high time to start intensive research programs in this important direction.

ACKNOWLEDGMENT: Preparation of this paper was supported by the National Research Council of Canada's research grant No. A-4359.

REFERENCES

1. Gumbel, E.J. "The Calculated Risk in Flood Control" Scientific Research, Section A, Vol. 5, 1955, pp. 273-280

2. Biswas, Asit K. "Risk Criteria And Flood Estimation" Hydrology Lecture Note No. 1, Queen's University, Kingston, 1967

3. Biswas, Asit K. "The Philosophy of Estimating Spillway Design Flood" 82nd Annual Meeting, Engineering Institute of Canada, Halifax, May, 1968

4. Gumbel, E.J. "Statistics of Extremes" Columbia University Press, New York, 1958, p. 22

5. Parzen, E. "Stochastic Processes" Holden-Day, Inc., San Francisco, 1962, pp. 128-131