Dicea Risk analysis in the design of coastal structures

Henk Jan Verhagen

Associate professor in coastal engineering
Head of the Hydraulic Engineering Department

Awareness of the possible risks is essential for every design in Coastal Engineering. The design engineer has to face several questions, like:

What design frequency for the boundary conditions has to be used
What will be the Achilles’ tendon of the structure and how to minimize that

The basis for the choice of the design frequency is the Poisson relation:

\[ P = 100 \left( 1 - \exp \left[ - f \times T \right] \right) \]

in which:
P = chance (or probability) of exceedance (%)
f = average frequency of exceedance (number / year)
T = considered period (year)

Example 1: A tidal current of 1.5 m/s is exceeded twice a year on the average. The chance that this value will be exceeded in a certain year is then: 100 \left( 1 - \exp \left[ - 2 \times 1 \right] \right) = 86 %.

Example 2: A wave height of 1.2 m is exceeded once per 100 year on the average (or better: has an average frequency of 0.01 / year). The chance that this value will be exceeded in a year is 100 \left( 1 - \exp \left[ - 0.01 \times 1 \right] \right) = 1 %. In general it can be said that for small frequencies (compared to the considered period, so better: for small values of \(f \times T\)), the chance is equal to the frequency.

In practice, the chance P and the period T have to be chosen before f (and the accompanying values for the boundary conditions) can be determined. This can be done by rewriting the formula above:

\[ f = - \ln \left( 1 - P / 100 \right) / T \]

Example 3: An accepted chance of 10 % and an inspection period of 1 year leads to \( f = - \ln(1-0.1)/1 = 0.105 \) or a return period of about 10 years. (Here again can be seen that for small P, f is almost equal to P).

Accepted chance

The choice of an acceptable chance depends on the consequences. Risk is usually defined as:

\[ \text{Risk} = \text{chance} \times \text{effect} \]

So one has to have an idea about the effects. A damage that is partial and which can easily be repaired allows a much higher chance than a damage which threatens a whole structure or
which leads to damage in a whole area or to casualties. In an economic analysis one can say that the extra costs to reduce the risk should be lower than the extra costs of the risk itself. To get a very rough idea one could say that a 10 - 20 % chance is acceptable for damage that can easily be repaired, 1 % for an essential part of a structure and 0.1 % for damage that leads to large social and/or economic consequences.

The behaviour of a structure or material can play a role in the intuitive choice of an acceptable chance (of course in a formal economic analysis this is automatically being taken care of). The figure shows two completely different behaviours. The first two lines show a relative decrease of the damage with an increasing number of waves. The third line shows a strong increase of the damage, so-called progressive failure. The first behaviour is e.g the case for a rip-rap slope, while the second is valid for a pitched block revetment. So, for rip-rap an accepted chance of exceedance of the boundary conditions of e.g. 10 % could be used, while for the pitched blocks one could think of 1 %.

Considered period

The choice of the period in the Poisson relation is just as essential as the accepted chance of exceedance. It has very much to do with the maintenance strategy. If inspection and repair is not envisaged, the whole lifetime of a structure has to be taken for the period T. When inspection (and repair!) is done on a yearly basis, 1 year can be taken for the period T. Example: With an accepted chance of 10 % the design frequency for a structure that is being inspected and repaired every year will become about 1 / 10 year (or 0.1 / year or a return period of 10 year). For the same structure not being inspected and with a wanted lifetime of 30 years this will become 1 / 300 year. This gives a heavier load and hence a more expensive structure. This illustrates the use of inspection and repair. Some parts can not be inspected, for instance because it is hidden behind the structure or covered under the seabed. In that case there is no choice and the lifetime has to be taken for the period T.
Fault trees

A structure can fail in different ways. It is the responsibility of the designer to recognize these failure mechanisms.

The figure shows the most important failure mechanisms for a revetment. A critical analysis of possible failure mechanisms is crucial for every design. Structures usually do not fail because of underestimation of loads, but mostly due to not recognizing or neglect of a failure mechanism. In a probabilistic failure analysis, all possible failure mechanisms are combined in a fault tree.
On top of the fault tree, the worst event is placed, in this case the total failure of the slope. There are several ways to get to this top event. For a so-called parallel system, two (or more) partial failures are necessary. In the figure of the fault tree of the revetment this is the case for overall instability. Both erosion of the foreshore AND instability of the toe are necessary to cause overall instability. So, this is an AND gate in the fault tree where the chances of both partial events are multiplied to get the chance of the subsequent event. In a series system, one partial failure is enough to cause instability. In the figure this is the case for local instability which can be caused by instability of top layer elements OR instability of filter elements OR uplift of the top layer etc. This is an OR gate in the fault tree where the chances of the partial events are added to get the chance of the subsequent event. Even when it is impossible to get accurate figures for the various chances it is good to think about the possible failure mechanisms and to draw a fault tree. It always contributes to a better understanding and a better tuning of the total design.