CHAPTER 159

Breach Growth Research Programme and Its Place in Damage Assessment for a Polder

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<u>Abstract</u>

In the Netherlands the Technical Advisory Committee on Waterdefences (TAW) is developing a new safety philosophy, in which safety levels will be expressed in terms of risk of flooding. At present safety levels are expressed in terms of probability of exceedance of a certain water level. Risk is here defined as the product of probability of failure and expected damage. In order to be able to assess the expected damage, the flooding discharges in case of a dike failure have to be determined. These flooding discharges largely depend on the process of breach growth. The TAW has started a study on the breach growth mechanism, which is carried out by means of a step by step approach. Firstly laboratory experiments have been carried out to investigate the essential features of the total process. Mathematical models have been developed that describe the different phases of the breach growth process as observed in the laboratory. Recently a large field experiment has taken place in order to validate the mathematical models. So far, all research on breach growth has been focussed on sand-dikes and dunes, which implicitly means that the models are upper bound approaches. In next phases of the research programme breach growth in dikes containing less erosive materials such as clay will be investigated.

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Introduction

The research described in this paper has been carried out for the Technical Advisory Committee on Water Defences (TAW). This committee is a permanent adivisory board for the Dutch Minister of Transport, Public Works and Water Management on all technical aspects of flood defences in the Netherlands. Research is carried out by order of the Road and Hydraulic Engineering Division of the Ministry. The results are supportive to the advises of the TAW. The gained knowledge is published in technical reports and guides with practical design standards.



Fig. 1. The Netherlands.

A large part of the Netherlands is several meters below mean sea level, lake level and flood levels of the rivers Rhine, Meuse and IJssel [fig. 1]. To protect the Netherlands from flooding, a system of 53 so-called dike ring areas has been defined. Each dike ring area is in fact a polder protected by flood defences such as dikes, dunes and special constructions (for instance sluices and storm surge barriers). About 1600 km of dikes, 300 km of dunes and hundreds of special constructions protect the low lying country.

History of design standards

In Dutch flood protection history the 1953 disaster plays a crucial role and marks a change in approach to flood defence standards. Before 1953 dikes were built based on a level of 0.5 meter above the highest known flood level with a surcharge for wave run-up. This experienced based approach became fatal in 1953. A major part of the south-west of the Netherlands was flooded due to a unexpected high flood level with a return period of 300 years. The damage was enormous: 1853 people were killed; direct economical loss was approximately 14% of the Dutch GNP. Flooding of the economical more important and more densily populated central part of Holland could just be avoided. Directly after this disaster the government installed the so-called Delta-committee which had to recommend about measures to avoid such a disaster in the future. Partly based on an analysis of the economical values of the dike ring area of the central part of Holland, the committee concluded that a design water level with a frequency of exceedance of once in 10,000 years should be appropriate. Under design conditions each dike section should be absolutely safe. Since absolute safety is per definition not achievable, this absolute criterion was translated in a criterion for overtopping: less than 2% of the number of incoming waves were allowed to cause overtopping. For the rest of the Netherlands similar safety levels were derived: depending on the relative economical importance flood defences of other dike ring areas should have a design water level with a frequency of exceedance of 1/4000 or 1/1250 per vear.

Present approach

The present approach is based on the work of the Delta-committee. The safety standards in terms of a certain water level exceedance frequency are still up to date. However throughout the years several adaptations have been made, especially to the design methods. The 2% run-up criterion for instance has been translated unto an equivalent overtopping criterion of 0.1, 1.0 or 10 l/m/s depending on the expected strength of the inner slope. For other mechanisms such as geotechnical failure, additional design criteria have been developed. All criteria are related to individual cross section of the dike. No correlations are considered. Only for certain dike ring areas which are situated in the transition regime where a combination of high tides and river discharges cause design water levels, an approach has been followed in which for the overtopping mechanism correlations between individual dike sections are dealt with [TAW/CUR, 1991]. For dunes it was noticed that an

overtopping criterion based on a certain water level was not appropriate. For the determination of the safety of dunes a totally different approach has been chosen for that reason. A probabilistic design standard has been developed in which several stochastic parameters, such as water level, wave height and grain size were taken into account. The safety level has been expressed in terms of probability of failure per dune section. This probability was chosen to be a factor 10 smaller than the water level exceedance frequency of 1/10,000 per year [TAW/CUR 1988].

In general the present approach is not a uniform design method and can be referred to as a 'dike section overloading approach'. In fig. 2 this approach is indicated. On the vertical axis the load S_0 (for example the overtopping discharge) is given. On the horizontal axis the strength (for example expressed in terms of resistance to erosion of the inner slope). In general failure will occur if the load exceeds the strength.



Fig. 2. Overloading approach.

This is the area above the diagonal line. The horizontal line refers to the overloading approach in which the probability that the strength is smaller than an expected value R_0 is not considered.

Thus, features of the present approach are:

- safety levels are partly based on economical analysis (1953 situation);
- probabilistic description of the hydraulic load only (water level

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exceedance frequency);

- deterministic approach of the strength in terms of allowable overtopping rates (0.1, 1.0 or 10 l/m/s);
- a dike section approach: no correlations between dike/dune sections are considered;
- several kinds of merely deterministic approaches for other failure mechanisms like geotechnical failure;
- probability of failure approach for dune sections.

Future approach

The TAW has decided to aim at a general overall consistent design philosophy. This new approach is referred to as the inundation risk approach. In this approach safety levels will be expressed in terms of risks. Risk is here defined as the value of probability of inundation times the expected damage in case of inundation:

$$R = P_f * D$$

- R = risk
- P_f = probability of failure (inundation)
- D = damage in case of failure

Risk can be expressed in for instance monetary units and/or loss of lives. Load as well as strength will be dealt with in a probabilistic way. Correlations between dike sections will be accounted for. Polders with high values at risk should have a relatively lower probability of inundation than others. In this approach two seperate tracks of development have to be distinguished. The first one is the assessment of the risk itself. The other one is the assessment of an acceptable risk level. The former is discussed here.

Several issues have to be investigated. In general the following steps can be distinguished:

- estimation of the probability of failure of the flood defence system;
- estimation of the inundation proces in case of failure;
- analysis of the expected damage (material and immaterial) in case of inundation.

For the estimation of the probability of failure all possibly known (physical) causes of failure have to be gathered and arranged

systematically in a so-called fault tree. The top event of the tree is inundation. The branches are all possible failure mechanisms such as overtopping, sliding, erosion of revetments, piping etc. For each mechanism a mathematical model is developed. By means of either Monte Carlo analysis, other level III or level II analysis, the probabibility of the top event (inundation) is estimated. Of course for the parameters which are involved in the several models statistical information has to be gathered to estimate the distribution function and values for its parameters such as mean value and standard deviation. Much knowledge is allready developed on this aspect of the inundation risk approach. Several mathematical models for the description of the failure mechanisms are available now [TAW/CUR, 1990].

For the analysis of the expected damage in case of failure floodings of the past have been analysed. This information is reproduced in mathematical relationships of the inundation parameter (such as inundation depth) and the expected damage as a percentage of the total value of an object. In fig. 3 such a relation is shown for damage to households in relation to inundation depths. In fig. 4 a similar curve is shown for casualties [TAW/CUR, 1990]. It is obvious that for the use of this type of relations a good estimate of the inundation parameters is important. These parameters depend heavily on the flood discharges in case of dike failure. However, knowledge of the flood discharges as a result of dike breaching is poor. Most information is based on eyewitness reports of breach growth events in the past. This information is very difficult to gather and also difficult to relate to the hydraulic and geotechnical conditions of the dike itself. Indeed, this kind of data is extremely unreliable. An example of the result of eve-witness information of the past is shown in fig. 5. From this and other similar figures it can be estimated that the velocity of the widening of a breach, ranges from 0.5 m to 50 m per hour [TAW-C/Delft Hydraulics, 1993b]. From sensitivity analysis it is known that an uncertainty of a factor 10 in the breach widening velocity gives at least a factor $\sqrt{10}$ in uncertainty of the water level inside the polder and in the time that certain waterlevels are reached [TAW-C/Delft Hydraulics, 1993c]. This leads to an overall uncertainty in the expected damage. This uncertainty in the process might also influence disaster management strategies in which evacuation of inhabitants of a polder is an essential part.

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Fig. 3. Damage factor (1.0=100%) for houses and farms as a function of the inundation depth [TAW/CUR, 1990].



Fig. 4. Percentage of persons drowned (proportion of the population) as a function of the inundation depth [TAW/CUR, 1990].



Fig. 5. Development of the breach width as a function of time, based on eye-witness reports.

Set up of research programme

To overcome this lack of knowledge the TAW decided in the late eighties to develop a breach growth model which determines flood discharges as a result of initial failure of a flood defence (dunes and dikes). In 1989 an unexpected oppertunity occurred to observe a breach growth process in a sand-dike, which was temporarily built in a small tidal inlet (het Zwin) in the Netherlands [Visser et al. 1990]. There was hardly any time for preparation, so the experiment didn't provide many data. However, photographs and video provided sufficient information to start modelling and were helpful in setting up laboratory test series on breach growth. Being aware of the complexity of the process it was decided to start with sand-dikes first. This would provide an upper bound of the process as other materials are expected to be less erosive. It would also provide a good estimation of the processes expected in case of breaching of dunes.

From the Zwin experiment in 1989 it was learned that the process could well be seperated in some typical phases. The first phases are described

as the erosion process of the inner slope and the lowering of the crest of the dike, which are two-dimensional processes [Steetzel et al1992]. This was investigated first in the Schelde-flume at Delft Hydraulics [TAW-C/Delft Hydraulics, 1993a]. After these experiments it was decided to investigate the so-called isolated widening of the breach in the Scheldebasin of Delft Hydraulics. This provided information on the stepwise sliding of the edges of the breach [TAW-C/Delft Hydraulics, 1993b]. During this series an additional experiment was done to investigate the fully three dimensional process. However, this provided only little information because of the limitation of the basin bottom. Mainly for this reason, and also to verify the results obtained in small scale situations, an other prototype experiment was carried out in October 1994 in the Zwin. This time more preparation time was available and extensive measurements were carried out on all relevant aspects of the breach growth process, such as current velocities, waterlevels, scour hole dimensions and of course the development of the breach itself.

Future research

In 1995 much effort wil be put into the finishing of the mathematical modelling for breach growth in sand-dikes and dunes [Visser,1994]. By means of a sensitivity study, it will be decided which aspects have to be investigated in more detail and which priorities have to be given. Future research will at least be focussed on breaching in dikes composed of less erosive materials.

Conclusions

As a conclusion it can be pointed out that:

- 1. Breach growth development is an essential factor in an inundation risk analysis.
- 2. Breach growth research by means of step by step approach turned out to be an effective way to unravel the complex process.
- An upper bound model, directly applicable for sand dunes, will be available in the near future (1995)
- Future research will be focussed on dikes containing less erosive materials.

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