COASTAL FLOOD-RISK MANAGEMENT IN THE NETHERLANDS

MANAGEMENT DES STURMFLUTRISIKOS AN DEN KÜSTEN DER NIEDERLANDE

von

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I N H A L T

1 Introduction

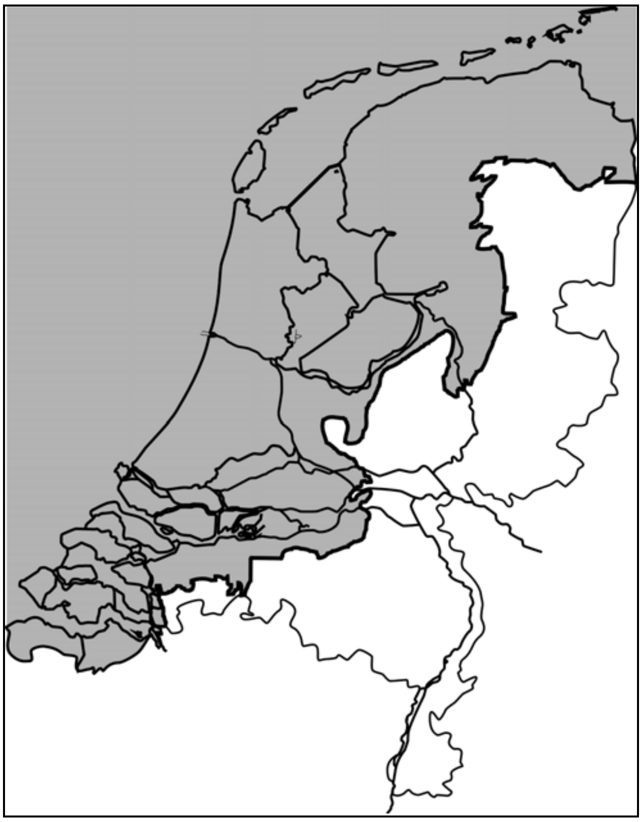


Fig. 1: The Netherlands without coastal flood protection structures

The coastline of The Netherlands is approximately 350 kilometres long. The country is densely populated with a total population over 15 million people and an average population density over 400 people per km^2.

About a quarter of the Netherlands is below mean sea level. Without flood protection structures, about two-third of the country (25,000 km^2) would be flooded during storm surges at sea or high discharges in the rivers (see figure 1). Protection against flooding is an essential condition for the country and its inhabitants. Physically, this protection is provided by an extensive system of so-called primary flood protection structures. The major part (70%) of the primary coastal defences consists of natural dunes. Dikes and barriers, like the Eastern Scheldt Barrier or the Rotterdam Barrier complete the system of flood protection structures. Furthermore, both organisational and legal measures have been taken to provide safety against flooding.

Compared to river floods the consequences of coastal floods can be devastating. The coastal area has very large and densely populated polders, which lie several metres below mean sea level. Not only does the majority of the inhabitants live in the flood prone area. Also the majority of economical activities and national infrastructure are situated in these areas as well. This paper describes the organisational, legal and technical measures aimed at providing adequate safety.

2 Organisational and legal framework

The following organisations are involved in flood protection:

- Waterboards;
- Provinces;
- Ministry of Transport, Public Works and Water Management.

In the case of disaster preparation and disaster management local municipalities play a key role as well. The municipalities are responsible for the preparation of disaster management plans and the actual management of a flood disaster. In addition to this, the municipalities are responsible for town and country planning and therefore activities of water boards and municipalities need to be co-ordinated. However, activities of municipalities will not be described further in this paper.

Water boards are a specific form of local government, a so-called functional form of government. Dating from the early Middle Ages these organisations are responsible for construction and maintenance of flood defence structures. At present, the number of water boards is about 60. They are also responsible for the water management in the polders. The costs of water management, construction and maintenance of flood defence structures are partly paid for via a system of local taxes, raised by the water boards. The additional funds, largely for (re)construction of flood defence structures are supplied by the provinces (river area) or the ministry (coastal area).

The twelve provinces supervise the water boards and are responsible for a proper interaction between the activities of water boards and local municipalities.

The Ministry of Transport, Public Works and Water Management is responsible for the supervision of both provinces and water boards. The ministry plays a central role in preparing and evaluating flood protection policy. The ministry is also responsible for the legal framework described by the Flood Protection Act of 1996. This act contains safety standards for all flood prone areas. The Flood Protection Act also describes the regular safety assessment to be performed by water boards or other managers of flood protection structures. Furthermore, the regional divisions of the ministry perform operational tasks by managing some specific flood protection structures (e.g. storm surge barriers) and preventing erosion of the coast by means of beach nourishment.

3 Maintaining safety as the present flood protection policy

In 1953 the vulnerability of the Netherlands was made clear in a disastrously painful way in the winter of 1953. A record storm surge level in the southern part of the North Sea caused the failure of many dikes and the south-western part of the country was flooded. The direct result of this disaster was 1,835 casualties and economic damages of 1.5 billion Dutch guilders (1956 price index). The indirect economic damage is estimated as a multiple of this figure.

Flooding of Central-Holland was barely avoided. Due to the concentration of economic activities in this part of the country would have led to much, much greater damages.

Immediately after the 1953 disaster the Delta Commission was installed. Based on its recommendations the coastline was shortened considerably and a more scientific approach for the design of flood protection structures was implemented. The scientific approach led to safety standards for the flood protection structures. These safety standards can be expressed as the return period of the design flood or storm surge and range from 1,250 years (river area) to 10,000 years (densely populated coastal areas).

In the following decades these safety standards have been implemented by the construction of dikes and barriers. In the coastal area the required safety has been reached. The works in the river area will be completed in 2002. Therefore the present flood protection policy is largely aimed at maintaining the acquired safety. The main purpose of the Flood Protection Act is to serve this goal. In the coastal zone the flood protection policy is based on the maintenance of two key elements :

• the coastline as it was in 1990;

• the safety of dikes, dunes and barriers.

Dunes are an essential element in the protection of the Netherlands against flooding. Before 1990 the safety of the dunes was under continuous threat by erosion of the coast. In 1990 the policy of maintaining the coastline was adapted. Largely by means of beach nourishment the coastline is being kept in the same position as it was in 1990.

For all dikes, dunes and barriers protecting the coastal zone against flooding safety standards have been defined. The actual safety of the flood protection structures is assessed regularly by the water board or the regional division of the ministry. In the safety assessment both developments in hydraulic boundary conditions (e.g. sea level rise) and results of ongoing research into the behaviour of flood protection structures are being applied.

4 Safety standards

Up to the floods of 1953 there were virtually no safety standards for flood protection structures. In determining the required height of dikes, the traditional method in the Netherlands used until well into this century was to take the highest known water level, plus a margin of 0.5 to 1 metre. The Delta Commission, which was set up shortly after the disastrous floods of 1953, laid down the basis in 1956 for the current safety standards with regard to protection against flooding. The starting point as proposed by the Delta Commission was to establish a desired level of safety for each dike ring area or polder.

The area which is protected by a linked system of primary flood protection structures is called a dike ring area or a polder. The flood protection structures around a dike ring area can be divided into sections, in which load and strength characteristics are comparable. These sections can consist of dikes, dunes, structures or high grounds. High grounds are areas which are high enough and thus don't need protection against flooding. Together these sections ensure the safety of the (coastal) area.

This safety level would need to be based on the costs of construction of dikes and on the possible damages which would be caused by flooding.

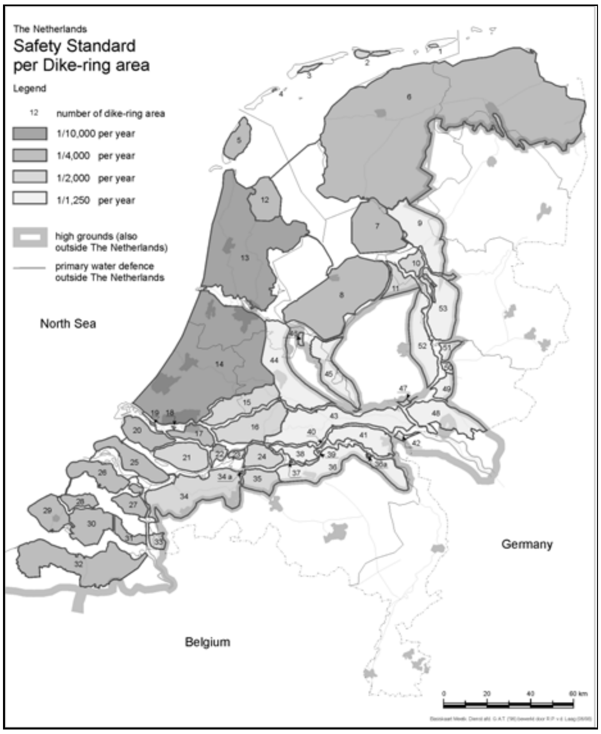


Fig. 2: Safety standards

This economic analysis led to an 'optimum' safety level expressed as the probability of failure for the coastal dikes. In practice however, the safety level was expressed as the return period of the design water level, being the most dominant hydraulic load. One of the main reasons to simplify the description of the safety standard was the lack of knowledge to describe the failure process of a dike sufficiently accurate.

The economic analysis has been used to differentiate the safety standard according to the expected damages in the various polders. A safety standard has been established for each dike ring area. This standard is expressed as the mean yearly frequency that the prescribed flood level is being exceeded. The standards vary from 1/10,000 to 1/1,250 per year (see figure 2), depending on the economic activities and size of population in the protected area, and the nature of the threat (river or sea). In 1996 these standards were laid down in legislation when the Flood protection Act came into effect. The flood levels associated to the safety standards are updated every five years to accommodate sea level rise and recent technical developments.

5 Practical application of safety standards

Hydraulic boundary conditions (flood level, wind and wave conditions) are associated to the statutory safety standards. In designing the dike, a certain margin with regard to the flood level is applied, depending on wind and wave conditions. The object of this margin is to ensure that each individual dike section is sufficiently high to withstand the prescribed flood levels and associated hydraulic loads. Technical guidelines give the engineer sufficient information to calculate the required margins and other structural aspects of the dike design.

The boundary conditions or hydraulic loads taken into account are more and more resulting from probabilistic analysis. The Delta Commission performed the first probabilistic analysis by introducing the flood level frequency curves and safety standards in terms of return periods. Following the work of the Delta Commission the (joint) statistics of flood level, wind and waves (height and period) were introduced into practice.

Theoretically the probability of failure of a coastal dikes can be calculated using the probability density functions of both the loads and strength of the dike and a limit state function which describes the failure in terms of load and strength. Appendix A contains a further elaboration of this probabilistic procedure. The maximum probability is the safety standard, prescribed in the Flood Protection Act. The complete probabilistic method is applied only in a limited number of cases. The vast majority of design procedures is carried out using design water levels and waves. Design water levels and waves are determined using the complete probabilistic method for characteristic cross-sections of the flood protection structures. Every 5 years the ministry issues the design values of these hydraulic boundary conditions for all primary flood protection structures in the Netherlands.

To illustrate the practical application of the legal safety standards two cases will be described in more detail.

- overtopping of dikes;
- excessive dune erosion.

6 Coastal dikes

The structural design of a coastal dikes can be characterised mainly by determining the required crest level, stability of the revetments, geotechnical stability and the reliability of movable objects intersecting the dike, such as sluices. Although the crest level is not the single required safety feature of the dike, the example is limited to this aspect. The crest level of the dikes needs to be sufficient to prevent too large quantities of water overtopping the structure. Two conditions may be of importance :

- overtopping without failure of the dike, leading to too large quantities of water in the polder;
- overtopping leading to failure of the dike due to erosion or geotechnical instability (infiltration) of the inner slope.

Whether the first condition is of importance depends very much on the local situation. The example is focused on the second condition which has a general character. In the design procedure several design criteria can be used, depending on the local situation and structural aspects of the dike. The design criteria used for overtopping depend on the quality of the inner slope. Critical discharges are :

- 0.1 l/m/s, with no specific demands to the inner slope with regard to erosion or infiltration
- 1 l/m/s, which requires good quality clay and grass cover with a slope not steeper than 1:2
- 10 l/m/s, which requires excellent good quality clay and grass cover with a slope not steeper than 1:3.

For coastal dikes the application of 10 l/m/s is being considered at present. This criterion is used for river dikes where wave periods are typically 3 to 4 seconds. For coastal dikes with wave periods up to 10 seconds and more this criterion may lead to enormous volumes of overtopping during shorter periods. Therefore it is considered to limit overtopping rates for coastal dikes to 1 l/m/s. The traditional 2% wave run-up criterion leads to overtopping rates of 3 to 5 l/m/s. Using the traditional 2% wave run-up criterion the following procedure is applied :

- crest level = design water level + wave run-up + additional margins;
- the design water level is the flood level with the legally prescribed return period;
- wave run-up : $z_{2\%} = 8*Hs*\tan\alpha$

$z_{2\%}$	=	2% wave run-up (m)
Hs	=	significant wave height (m)
$\tan\alpha$	=	steepness of the outer slope (-)

- additional margins are to compensate for sea level rise, settlement and seiches
  - sea level rise = 20 cm per century
  - settlement = based on geotechnical calculation
  - seiches = depending on local situation, ranging from 10 cm to 80 cm

As an example the required crest level of a coastal dike called the Pettemer Zeewering has been selected. This dike is situated on the Dutch shore in dike ring area 13 as shown in figure 2. For this dike ring area or polder the safety standard is 1/10,000 per year. The prescribed hydraulic boundary conditions for this location are :

- flood level : MSL + 4.70 meter;
- wave height : 4.70 meter.

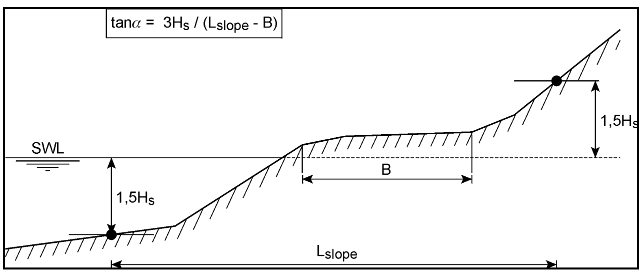


Fig. 3: Cross section of the Pettemer Zeewering

These boundary conditions are only partially probabilistic derived. The flood level has a return period of 10,000 years. The wave height is the expected wave height associated to this water level. It is not a design combination derived using joint statistics. The wave height is the wave at the toe of the dike. The Pettemer Zeewering has a berm in the outer slope with different slope angles above and below this berm. For this situation an equivalent slope is determined, as explained in figure 3.

The cross-section of the Pettemer Zeewering is similar to figure 3. Above the berm the outward facing slope is 1:3.19 and below the berm the slope is 1:4.12. The berm is approximately at storm surge level. This leads to an equivalent slope of 1:4.95. Using this slope and the prescribed boundary conditions the required crest level is :

- hcrest = h+8*Hs*tan α
- h-crest = 4.70 + 8*4.70*(0,202) = 12.3 m.

The additional margins for sea level rise, land subsidence (0.1 m) and seiches (0.15 m) lead to a required crest level of MSL+12.55 meter. The present crest level is MSL+12.75 meter, which seems to be sufficient for the moment. As an illustration the required crest levels using different overtopping criteria are given :

- 0.1 l/m/s: h-crest = 4.70 + 12.43 + 0.25 = 17.38 m.
- 1.0 l/m/s: h-crest = 4.70 + 9.82 + 0.25 = 14.77 m.
- 10 l/m/s: h-crest = 4.70 + 7.22 + 0.25 = 12.17 m.

7 Dunes

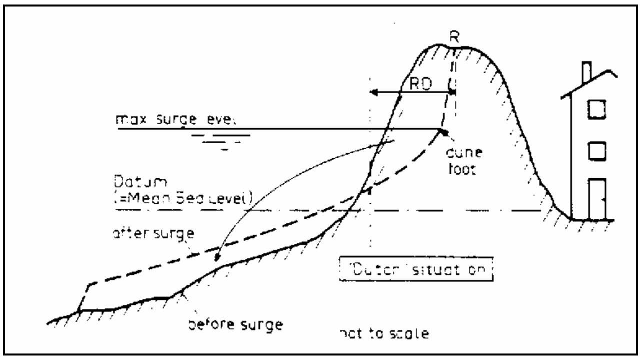


Fig. 4: Typical Dutch dune cross section

A typical Dutch dune cross-section is shown in figure 4. During a storm (surge) offshore will occur and the safety of the polder may be threatened. For the safety assessment of a dune the design levels associated to the safety standards serve as a basis. However, compared to dikes there is a significant difference. Dikes in the Netherlands have to be designed in such a way that they can withstand a design storm surge. In such cases the dikes must still have some residual strength. Consequently, the frequency of exceedance of the design level may not be interpreted as a frequency of failure. The design method used in the Netherlands for dunes does not account for any residual strength. Consequently, dunes designed using this method should be able to withstand a storm surge with a lower probability of occurrence. The required safety margin during the occurrence of a water level equal to the design level is expressed by a factor with which the frequency of exceedance of the design level must be multiplied so as to arrive at a normative probability per year of collapse for a dune profile. This factor is set at 10^{-1}. For Central Holland, for instance, this implies a normative probability of failure per year of 10^{-5}. The actual amount of erosion during a storm surge is affected largely by the following factors:

- maximum storm surge level
- significant wave height
- sand diameter
- initial dune profile
- storm surge duration.

As for the coastal dikes a simplified safety assessment method has been developed, based on probabilistic calculations. The safety assessment method comprises a number of computational rules for the determination of that degree of dune erosion. The values, to be used in the calculations, are determined in such a way by probabilistic numerical techniques, that the thus calculated degree of dune erosion has a probability of exceedance equal to the required maximum accepted probability of failure. For some coastal sections, an additional amount of dune erosion, due to a gradient in the longshore transport, is still to be taken into account. The long-term development of a dune profile is of great importance, especially in case of an eroding coast. The safety assessment method has been developed in such a way that also a good impression can be obtained of the point in time when loss of the required safety of the dune profile might occur. Hence measures can be taken in time. It is assumed that a series of profile measurements over the past 15 years or more is available. The yearly coastal measurements included in the data files of the automated processing system of the ministry can be advantageously used. The availability of such a time series is not only imperative for assessing the safety in the future, but also for the processing of the influence of the profile fluctuations on the safety. These fluctuations must be taken into account because it is not exactly known which profile is present just before the storm surge.

The procedure of the safety assessment method has the following six steps :

1. An **erosion analysis** under design conditions is made for each profile from the series of profile measurements with the aid of the computational model (figure 5).

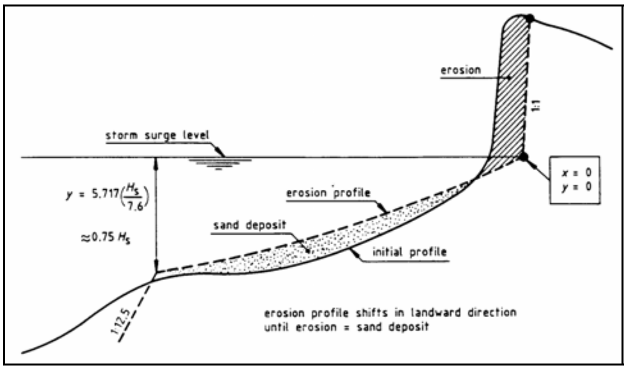


Fig. 5: Safety assessment of dunes, erosion analysis

2. For each erosion analysis, the calculated amount of dune erosion above storm surge level (A) is augmented with a **surcharge** (T) to take account of:

- the influences of the inaccuracy of the computational model;
- oscillations;
- uncertainties, such as the storm surge duration.
- The effect of this surcharge is expressed in an additional recession of the steep dune front. Point P is the intersection of this shifted dune front with the storm surge level (see figure 6).

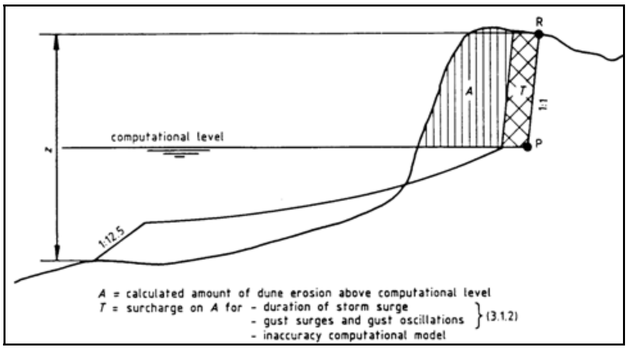


Fig. 6: Safety assessment of dunes, surcharge

3. The above calculations yield a time series for the position of point P. These positions can be plotted in a diagram as a function of time (see figure 7). It can be easily induced from the position whether there is question of a stable, eroding, or progressing coast. The trend of the position of point P as a function of time can be estimated by means of regression analysis. A linear approximation will usually do. The **profile fluctuations** are expressed in the scattered position of the points P around this regression line.

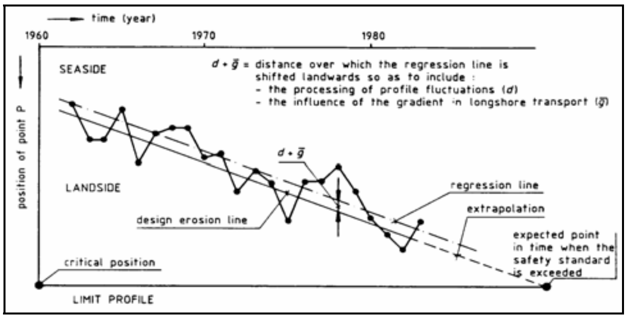


Fig. 7: Safety assessment of dunes, profile fluctuations

4. The influence of the uncertainty of the profile position is now taken into account by shifting the regression line over a certain distance (d), dependent on the magnitude of the profile fluctuations, in a landward direction. The shifted regression line, the design erosion line, yields the position of the design erosion point as a function of time. The design erosion point is the intersection of the steep dune front and the storm surge level here, the position of which has a probability of exceedance which is equal to the considered maximum permissible probability of collapse. In case of the straight coast of Central Holland, for instance, this probability is 10^{-5} per year. So far, the influence of a gradient in the longshore transport on the dune erosion has not been taken into consideration.

5. For coastal profiles whereby account must be taken of the net loss of sand from the profile due to a gradient in the **longshore transport**, the final design erosion line is obtained by shifting the in the foregoing obtained shifted regression line over an additional distance ( ) in landward direction.

6. In case a minimum profile, **the limit profile**, no longer exists landwards of the design erosion line, the remaining profile no longer satisfies the established safety standard. Hence this limit profile does not offer a safety margin, but represents the situation just before collapse (limit state).

Appendix B contains a detailed example of this safety assessment procedure.

8 Maintaining safety

The key item of the Dutch flood protection policy is maintaining the safety provided by present the flood protection structures. The Flood Protection Act enforces a regular safety assessment. The manager of a flood protection structure is obliged to perform such a safety assessment every 5 years. The assessment report has to be submitted to the responsible province, which will report to the ministry. The ministry will present a national report on the safety of the primary flood protection structures to parliament. In addition to the traditional design guidelines a specific guideline for this safety assessment has been prepared.

The safety of each structure has to meet the legally prescribed safety standard. The safety standards, expressed as return periods, are transferred into structural design criteria for practical application. For the safety assessment a similar procedure has been adopted with slightly less stringent criteria. The guideline contains three functional quality scores :

- good : the structure meets the design standard;
- sufficient : the structure doesn't meet the design standard, but under design conditions no failure will occur;
- insufficient : the structure will (start to) fail under design conditions.

In order to limit the effort for the safety assessment the assessment procedure has a three-stage approach. To begin with, a simple procedure requiring little information is applied. Both the very good and the very poor structures need no further attention (during the assessment). The intermediate structures are studied using a detailed assessment procedure and again the good and poor structures can be discerned. Finally, an advanced method (state of the art) is applied to study the remaining structures.

Since the Flood Protection Act dates from 1996, the first round of safety assessments will be completed in 2001. So far, the experience with the safety assessment procedure shows that the structural information on many flood protection structures was not readily available. A lot of effort has been put into acquiring this information during the first round of safety assessment. However, it is expected that only the second round of safety assessment (2002-2007) will give an complete overview on all Dutch flood protection structures.

9 Developments

The situation described is largely based on the standard of practice in the Netherlands. The state of the art however shows a number of developments which may be introduced in the standard of practice in the near future. In some cases, mostly large scale flood protection projects like storm surge barriers, these developments have been introduced already. The Delta Commission introduced a one-dimensional probabilistic approach. The flood level was the only parameter considered to be a stochastic variable. The other parameters were treated in a deterministic way. In general, the other hydraulic loads like wind and waves were taken into account as expected values. At that time (1960) these expected values were 'best' or 'educated' guesses. The strength parameters were treated in a deterministic way too, but given the safety philosophy (to withstand the prescribed hydraulic loads) now conservative values or design criteria were used. In the decades following the report of the Delta Commission the hydraulic loads have been modelled in a more sophisticated manner:

- joint probability distributions of flood level, wave heights and wave periods have been derived for the coastal and lake areas
- joint probability distributions of flood level and wind velocities have been derived for the river deltas.

The results of these studies are slowly but steadily introduced into practice. The safety standard (expressed as a return period) is applied to a combined hydraulic load parameter (e.g. overtopping discharge) instead of a flood level only.

The introduction of these developments however is always associated with a fierce discussion in which the focal issue seems to be : are we still in line with the principles of the Delta Commission?. In recent years it has been shown that the technical elaboration as mentioned above of the safety standards leads to higher hydraulic loads, which again may lead to massive reconstruction works. On the other hand, probabilistic techniques are very much welcomed if traditional conservatism of certain design rules is replaced with a modern, but cheaper variety.

One major issue in the discussion on probabilism is the way we deal with **uncertainties**. Uncertainties can be classified in three categories :

- implicit uncertainties, because the variable studies has a stochastic nature;
- model uncertainties, because our description of natural phenomena is always insufficient;
- statistic uncertainties, because the number of observations of extreme events is too small.

The Delta Commission introduced the implicit uncertainties. This has been extended in recent year to other hydraulic load parameters. Model uncertainties are not taken into account if hydraulic load models are considered. Strength models or design criteria do include a safety factor, although this factor is mostly based on experience or engineering judgement. Statistical uncertainties, like the accuracy of the design water levels (with a return period of 10.000 years !!!) are not taken into account. Some recent studies on uncertainties have shown that all uncertainties mentioned above can be incorporated into our design procedures. However, if these uncertainties are just treated as additional stochastic variables and the safety level is kept at the same level, this will lead to enormous increases in required crest levels. These increases may vary from 1.0 to 2.0 meters. Appendix C contains some examples.

Another major issue is the **quantitative flooding risk analysis**. The present safety standards are expressed as (return periods of) extreme water levels. These return periods and water levels are only indirectly related to the potential flooding risks, which were calculated in 1960. Technical uncertainties, like the behaviour of dikes during extreme conditions, prohibited a more direct link between economical damages or casualties and the technical requirements for flood protection structures. Since the report of the Delta Commission the issue of the calculation of flooding risk (probability of flooding times the consequences) has been a popular research item. Within this item many research topics can be discerned :

- geotechnical or structural modelling
- strength parameters
- hydraulic modelling
- hydraulic parameters

- statistical parameters, including correlation between various loads and events
- modelling of failure or collapse of flood protection structures (breaching)
- damages due to flooding
- effectiveness of measures to prevent damages.
- In the following years flooding probabilities and flooding risks will be calculated for the entire country. These results can be used for the following purposes :
- to assess the actual flooding risks (damage potentials) related to the present safety standards;
- to optimise the present design methods within the existing framework of safety standards;
- to compare flooding risks with the societal risks associated to other events (e.g. traffic);
- to start a discussion on acceptable flooding risk levels in relation to acceptable risk levels of other events.

The aim of this effort is to devise a new safety philosophy based on a quantitative flooding risk approach. With this, safety is related to the risk of flooding in terms of multiplying the probability of flooding with its consequences, expressed in damage and victims. This safety approach offers the possibility to consider and assess measures in the entire risk chain (extreme water levels, the probability of a dike breach and the consequences of flooding) and to make an optimal choice. Through measures which reduce the probability of high water or which limit the damage caused by a dike breach, just as great a contribution can be made to protection as with raising the height of the dike itself. Figure 8 shows how the risk-concept and the regular safety assessment of dikes may interact. The present flood protection policy and the risk-concept are shown as two circles above each other. The lower circle is the present policy of safety assessment aimed at maintaining the prescribed safety standard. The upper circle at the left side represents the future risk-assessment.

The risk-assessment circle includes the socio-economic effects and the evaluation. This evaluation will not remain confined to flooding risks, other sources of risk will be taken into account as well. The risk-assessment will give information on expected damages in case of a flood. The damage of a flood by the sea will differ from the damage caused by water from the rivers: the water is or is not salt, announcement on long versus short term. A small polder will inundate more quickly than a large polder, through which the people get less time to evacuate. In a deep polder more damage will occur than in a shallow one. In a dike ring area where many people live and work, the damages will be higher than in an area with a sparse population. And last but not least, the damage depends on the people being prepared to evacuate, and how effective this evacuation takes place.

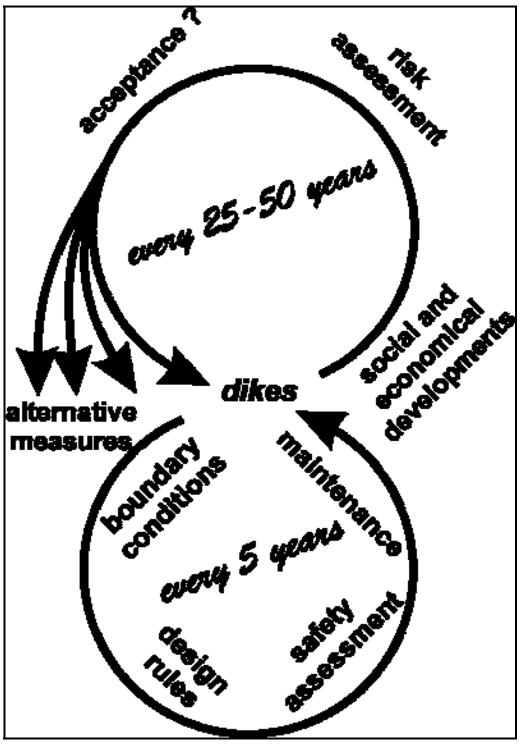


Fig. 8: Present flood protection policy and the risk-concept

The amount of damage may be accepted or rejected, given other sources of risk and the effort required to reduce the flooding risk. To reduce the flooding risk several strategies and measures can be considered. One of the alternatives is to heighten or strengthen the river dikes, which can be expressed as a higher safety standard. This safety standard can be maintained again using the lower circle, which is the core of the present flood protection policy. Given the time-scale of the processes involved the interaction between the both circles should not be frequent (safety assessment once in five years, safety philosophy once in 25-50 years) .

10 Research activities

Research is necessary to make the changeover from the current safety philosophy to the safety philosophy based on a flooding approach. The research programme of the aims to make this changeover possible. In order to achieve an accurate safety philosophy based on the risk of flooding, it is essential that the probability of flooding and its consequences can be calculated sufficiently accurately. It is also important to establish what is felt to be an acceptable level of risk.

The **probability of a dike breach** is not adequately established under the current safety standards, while the probability of a dike breach followed by flooding is the most tangible measure of danger. After all, flooding results in economic damage and, depending on the situation, victims.

Merely measuring dike height provides insufficient information where it concerns protection from flooding. Two technical arguments can be cited for this: the **geotechnical stability** of dikes and the **correlation between the failure of**

different dike sections. If for example, during periods of high water, the dikes lose their resistance to sliding, a dike breach can occur without the water flowing over the crest of the dikes. This contributes to the probability of a dike breach or flooding. The required resistance to these largely geotechnical failure mechanisms cannot be expressed in terms of a hydraulic load standard or crest height. In the present situation, additional requirements are laid down for the probability of a dike breach occurring at water levels below the prescribed water level.

The larger the polder, the more dikes sections are needed to protect the area. If these sections together with the hydraulic load on these sections are fully correlated, the safety of the area can be expressed as the safety of a single dike section. In practice, this is not the case. Both the strength of and the load on the dike sections around the area are not fully correlated. Other types of constructions, such as discharge sluices, are to a large extent responsible for this. The probability of a dike breach in an arbitrary dike section, followed by flooding, is thus always greater than the probability of a breach in a single dike section.

Flooding usually results in extensive material damages. The extent of the damage depends on the nature of the threat (sea water or fresh water, short or long period of flooding, expected or unexpected) and the characteristics of the flooded area (depth, built-up areas, industry, exact location of the dike breach). In particular, deep floods or fast-flowing water can have serious consequences in the form of victims, extensive damage, and disruption to normal life and infrastructure. In calculating the **consequences of flooding**, the research is concentrating on developing an instrument by which damage and victims for each dike ring area can be calculated in a uniform and practical manner. Warning and information systems contribute in taking the right measures at the right moment, by both government and the individual citizen. Applying these types of instruments influences the consequences of flooding in a positive way. A Flood Information System is currently being developed. This can be used before and during floods for predicting the way in which any flooding will take place, monitoring water levels, waves, the condition of the dikes and the availability of the road network, determining the effects of any measures taken, announcements and communication.

The present **standards** laid down in the Flood Protection Act date from 1960 and only indirectly related to the flood damages. Whether these standards are still sufficient is a matter of social and political debate. To support this debate tools will have to be developed to answer questions like :

- what is an acceptable risk ?
- can such an acceptable risk be expressed in (a) quantitative measure(s) ?
- is it possible and meaningful to compare flooding risks with other societal risks ?
- what is the role of economic optimisation ?

Communication will be a vital item to be addressed. The general public is hardly aware of flooding as an actual risk. Therefore it is extremely difficult to raise the flood protection issue in a public debate without taking people by surprise. Furthermore, the technical scope of the flood protection issue is very wide and very complicated at the same time. Because of this, the participation of the general public has been very limited so far. It is a challenge for the responsible authorities and researchers to developed a well balanced communication strategy. This strategy should be aimed at clarifying the main problems we are facing now and in the future. Once the public has become aware of potential flooding problems, the communication may be focused on the full range of possible solutions, their effects and proposed strategies.

11 Conclusions

Today, the Netherlands are quite well protected against flooding. Following the flood disaster of 1953 a massive programme for dike (re)construction has been started using nationally prescribed safety standards. In the coastal area these safety standards - expressed as return periods of the design flood level - range from 10,000 years to 4,000 years.

From 1990 the attention of the authorities responsible shifted towards maintenance of the flood protection structures. The regular safety assessment is a vital tool in this maintenance process. Amongst other issues, the effects of sea level rise are included in the safety assessment.

In addition to maintenance on a structural level the safety on a more conceptual level needs to be maintained as well. The potential damages due to flooding have increased dramatically over the last decades, during which period all flood protection structures were (re)constructed. It is a matter for debate whether the present safety levels are still adequate. Quantitative risk analysis and a well balanced communication strategy can be used to support this debate.

Given the large return periods, the uncertainties of hydraulic loads (amongst others) are significant. These uncertainties need to be addressed and dealt with both in the quantitative risk analysis and the communication strategy. Furthermore, the state of the art in some specific topics (geotechnical (in)stability, breaching process, statistical aspects, flooding damages) needs to be improved.

Appendix A Probabilistic calculations

Let the strength be : R (in French : résistance)

Let the load be : S (in French : sollicitation)

The limit state function can be defined as : $Z = R-S$. The structure is considered to be in a limit state (on the edge of failing) if Z equals to 0 :

- $Z > 0$ safe area
- $Z = 0$ limit state

- $Z < 0$ unsafe area.

The load and strength of a coastal dike can be expressed in so-called basic variables. These variables can be stochastic or deterministic. For a coastal dike the required crest level can be calculated using the following procedure:

- crest level = design water level + wave run-up
- wave run-up : $z_{2\%} = 8 \cdot Hs \cdot \tan\alpha$

$z_{2\%}$ = 2% wave run-up (m)

Hs = significant wave height (m)

$\tan\alpha$ = steepness of the outer slope (-)

Using this design formula the limit state function can be expressed as : $Z = (hcrest) - (h + 8 \cdot Hs \cdot \tan\alpha)$

The crest level (hcrest) is either a running variable (while designing) or a deterministic parameter (while assessing the actual safety). In both cases this parameter can be treated as a deterministic parameter. The load is the combination of flood level (h) and significant wave height (Hs). The parameters h en Hs are stochastic variables in this case. The probability density functions of these variables can be described by :

- f(h)
- f(Hs).

If the variables are not correlated, the joint probability density function can be calculated quite simple :

- f(h)*f(Hs).

This joint probability density function can be shown in a graph using iso-density charts in the h-Hs space (see figure 9).

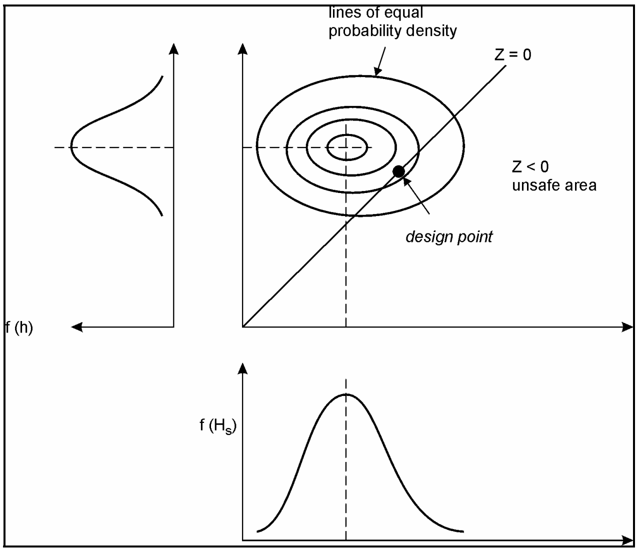


Fig. 9: Probabilistic procedure

The probability of failure is the content of the joint probability density function in the unsafe area.

The maximum probability P is the safety standard, prescribed in the Flood Protection Act. The combination of h-Hs with the maximum probability density is called the 'design point'. In practice this design point will be used by engineers or authorities to design a dikes or to assess the safety.

The number of basic variables can be extended according to the specific situation and design procedure. Correlation between basic variables can be introduced. But basically the probabilistic procedure remains the same. This means that for every situation simple design points (combinations of basic variables) can be given. In most cases these simple design points or design loads are sufficient. Only for specific situations (e.g. cost optimisation or tailor made design structures) the probabilistic procedure is carried out in the design process.

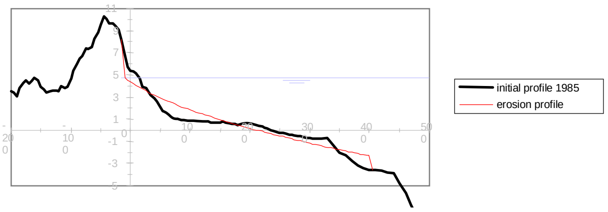
The probabilistic procedure described before has become more or less general practice in designing flood protection structures. However, probabilism is still largely confined to the hydraulic loads. The strength of the structure and design criteria are mostly taken into account in a deterministic way, using a safety factor which is largely based on practice and engineering judgement. Also the uncertainty of loads, strength, criteria, models and so on is not taken into account as well.

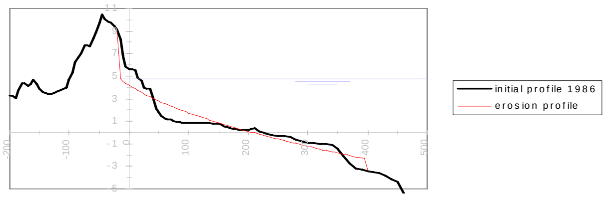
Appendix B Safety assessment of a dune - Example Texel

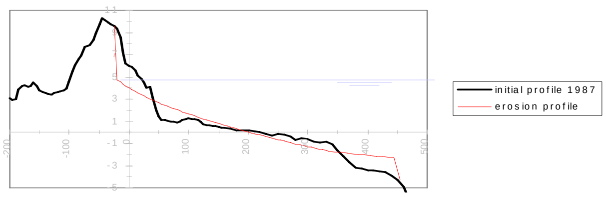
As an example of the safety assessment a dune cross section on the island of Texel (dike ring area 5 in figure 2) has been selected. For this dike ring area or polder the safety standard is 1/4000 per year. The prescribed hydraulic boundary conditions for this location are:

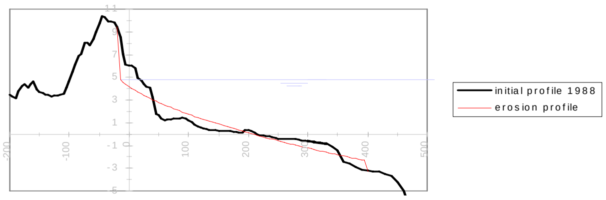
- flood level: MSL + 4.30 meter
- wave height: 9.35 meters
- peak period: 12 seconds

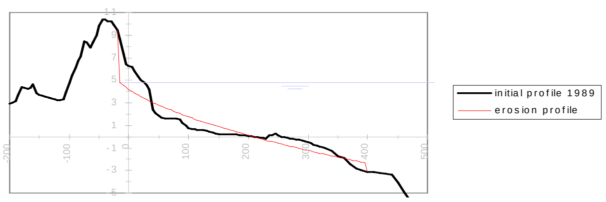
An erosion analysis under design conditions is carried out for each profile from the available series of profile measurements (1985 to 1989). The results of the erosion analysis are given in the following figures:











The amount of erosion A (m^3/m) and the surcharge T (m^3/m) is calculated and given in the following table for each of the five profiles:

Profiles (year)	A = calculated amount of dune erosion above computational level (m³/m)	T = surcharge on A (m³/m)
1985	20	25
1986	46	31.5
1987	79	39.75
1988	55	33.75
1989	63	35.75

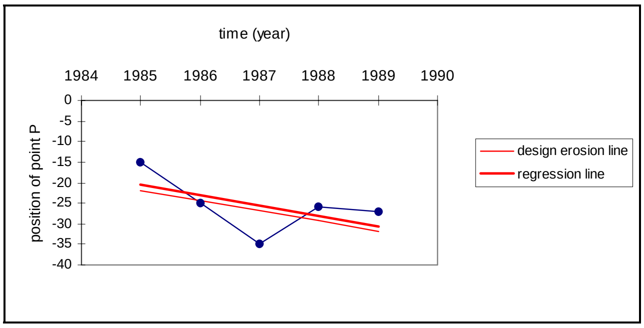


Fig. 10: Profile fluctuations

A linear regression line for the position of point P in time can be determined from this diagram, as well as the standard deviation of the position of the calculated points P from this line. The design erosion line is obtained by shifting this regression line landwards over a distance d:

The design erosion line is seaward from the critical position of the limit profile. Therefore from this calculation it can be concluded that the dune in Texel is safe and is expected to be safe at least for the next 5 years.

Appendix C Effect of uncertainties

The example of the Pettemer Zeewering may be extended a little bit in order to explore the effect of additional stochastic variables and uncertainties. For this purpose several probabilistic calculations are made, according to the following scenarios

Scenario	Water level	Wave height	Wave period	Crest level
Reference	deterministic[1]	deterministic[2]	deterministic[2]	12.55
A) Stochastic water level	stochastic	deterministic[2]	deterministic[2]	12.55
B) Stochastic, uncertain water level	stochastic uncertain[3]	deterministic[2]	deterministic[2]	13.12
C) Uncertain water level and wave height	stochastic uncertain[3]	stochastic[4]	deterministic[2]	13.76
D) All hydraulic loads uncertain	stochastic uncertain[3]	stochastic[4]	stochastic[4]	14.57

1) Deterministic means that the water level with a return period of 10,000 years has been calculated separately. This value is used in a deterministic fashion to calculate the required crest level.

2) Deterministic means that the expected values of wave height and wave period are used to calculate the required crest level.

3) Stochastic and uncertain means that both the probability distribution function of the water level and its uncertainty are taken into account.

4) Stochastic means that the uncertainty of the expected values of wave height and wave period are taken into account.

As shown in the table the reference scenario leads to an almost identical crest level as the scenario A. This is also to be expected because the water level is the only stochastic variable in which case the design point for a deterministic calculation can be derived very easily. Increasing the number of stochastic variables however leads to increased crest levels :

- a statistical uncertainty (μ = 0.0 and σ = 0.35 meter) of the water level probability density distribution leads to an increase of the required crest level of approximately 0.50 meter;
- adding the uncertainty of the wave height (μ = 1.0 and σ = 0.20) leads to yet another increase of over 0.6 meter;
- finally, including the uncertainty of the wave period (μ = 1.0 and σ = 0.10) leads to the largest increase of over 0.80 meter;

- comparing with the reference scenario the added uncertainties leads to a total increase of the required crest level of 2 meter.

Basically for this reason the model (hydraulic) and statistical uncertainties are not yet taken into account in the standard of practice. The discussion on further application of probabilistic methods including uncertainties will be taken along in the research programme and policy preparation plan on flooding risks.