Risks and safety of flood protection structures in the Netherlands

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ABSTRACT

This paper gives an overview of risks and safety issues with respect to flooding hazards in the Netherlands. In the Netherlands flood protection structures against sea, rivers and lakes are constructed in a probabilistic way. Discussed will be the flood frequency models which form the basis of the probabilistic design methods of flood protection structures, as well as measures for reduction of flood-related risks.

1 Introduction

The Netherlands is a low-lying country which has to protect itself against flooding from the sea and its rivers. Reliable flood defences are essential for the safety of the country. Without the dikes and dunes, more than half of the Netherlands would be regularly inundated. So the extensive system of dikes and dunes is essential to the safety and habitability of the country and an absolute precondition for healthy economic development. In a country like the Netherlands, flood protection must never be neglected. The management and maintenance of flood defences must always be a top priority. Climate changes may soon lead to higher design water-levels. Our water systems need room to evolve if they are to cope with uncertain and unforeseen future developments. For the rivers, this means water conservation throughout the entire catchment area and enlarging the flow area of the river rather than embarking on a further round of dike strengthening. Where the coast is concerned, it means extensive sand nourishment instead of “hard” engineering structures. Room for water also means that we may sometimes need to take a step back and, for instance, stop building in the winter flood plains of the rivers, on the beaches and in the dunes facing the sea. And reserve land now for possible future use to maintain flood protection.

2 Flood protection structures

The flood protection structures in the Netherlands are the dikes against the sea, lakes and rivers and the dunes and storm surge barriers against the sea. In Fig. 1, a topographical map of the Netherlands with its main rivers Rhine, Meuse, Waal and Ijssel and the sea Noordzee is shown. River – and sea dikes are shown in red and black. In red are drawn the dikes which are too low (800 km in length). The costs of reinforcement are approximately 2 billion ECU. In black are drawn the safe dikes (1700 km in length).

Especially in the south-western part of the Netherlands (the estuary of the Rhine River; Fig. 2), as part of the Delta Plan, quite some storm surge barriers have been built. One of the most complicated works is the building of the Rotterdam storm surge barrier (Fig. 4). The storm surge barrier alone is unable to guarantee the safety of South Holland, as seawater can enter the Europort area freely through the seaports. For this reason a supplementary dike reinforcement programme is implemented, with a further barrier. This runs through the Europort area and is known as the Europort Barrier. Thanks to the New Waterway Rotterdam Storm Surge Barrier the chance of exceeding in Rotterdam a water level of 3,60m above

Amsterdam Ordnance Datum (NAP) is reduced from once every 100 years on average to once every 10,000 years on average. The failure risk of the barrier itself is only once in 10,000,000 years.

Figure 1: Dike Map of the Netherlands

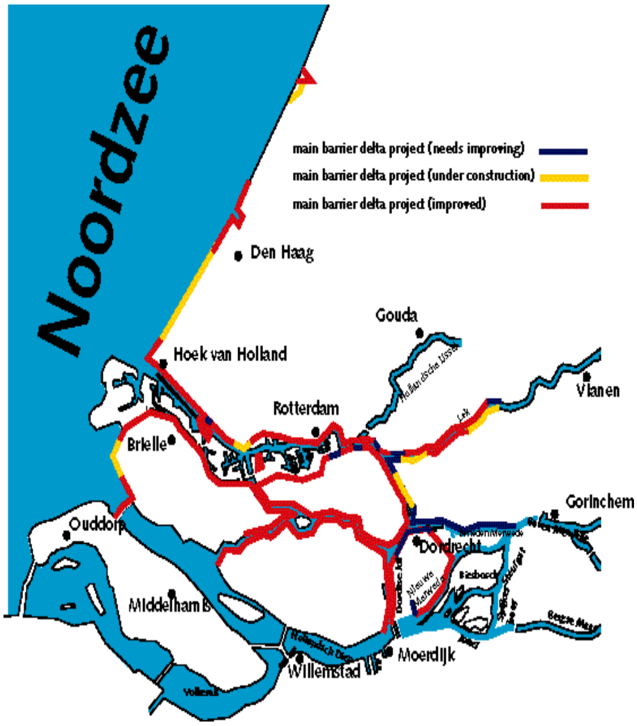

Figure 2: South Holland

Figure 3: River dike “in action”

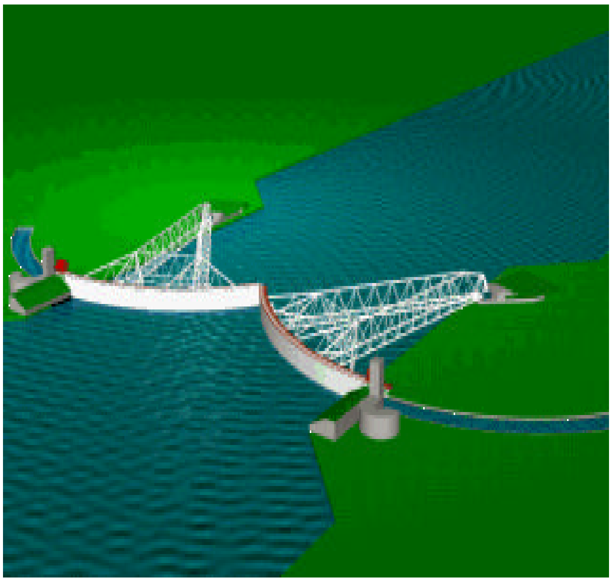

Figure 4: Rotterdam surge barrier

3 Reduction of flood-related risks

Where flood defences are concerned, measures relating to the sea defences have the highest priority (risk to human life, little advance warning of flooding), followed by those in the diked sections of the rivers (risk to human life, more advance warning). Measures along the undiked sections of the rivers have a lower priority because they present no risk to human life. But there is no such thing as absolute safety. Whatever we do, we may at some time face a water-level which our flood defences are simply not designed to withstand. We must learn to live with the awareness of that residual risk and be prepared to cope with such circumstances if they occur.

During the floodings of 1993 and 1995, many cities along the Rivers Rhine, Waal, Ijssel and Meuse were threatened by high water (Fig. 3). In 1995 dikes were at risk of bursting in the Netherlands. As a matter of precaution, several hundreds of thousands of people were evacuated. Damages were estimated to several billion ECU.

Therefore, the Ministers of Environment of France, Germany, Belgium, Luxembourg and the Netherlands declared on February 4, 1995 in Arles that they deemed necessary to reduce flood-related risks as rapidly as possible. It was not acceptable to them that situations as came up at that time put people’s lives and property and the environment at such great risks.

Floodings are natural phenomena. The natural variation of water levels is part of the feature of rivers. It is the basis for river flow dynamics and the development of a typical floodplain profile. Extreme floodings occur when intensive precipitation falls on soils, which are already saturated due to former precipitation or which are frozen and can thus not absorb any water. Extreme floodings may only be influenced to a limited extent. Various human interferences have clearly altered the river regime. Thus, the starting point is to take back these human interferences with the river regime, as far as possible. This means above all to increase water storage on the surfaces and in the floodplains, but also to reduce the damage risks in flood-prone areas.

Flood damages are created by the interplay of two independent mechanisms. Nature – supported by man – gives the high-water levels. At the same time, man increases the values along the river and the damage risks. At a given time, the combination of floodings and the accumulation of values in areas at risk create a more or less great damage.

Measures that can be taken to reduce the risks can be subdivided into contributions of water management, spatial planning, nature protection, agriculture and forestry.

The contribution of water management

- Reduce discharge peaks by improving the soil seepage capacity, by storing water and by reactivating flood zones
- Ensure runoff capacities and – where required – increase them by river development
- Reduce the flow velocity by re-naturation measures in streams in the catchment area
- Flood defence by dikes and walls
- Prolong early warning times by improved forecasting

The contribution of spatial planning and urban development

- Preventive consideration of flood aspects when fixing land development and spatial planning
- Protection of existing and potential runoff and storage areas

- Limit damage risks by keeping areas at flood risk free of unsuited uses and by increasing risk awareness
- Integrate streams into urban development; storage and seepage of precipitation in urban settlements
- Reduce discharge peaks by protecting and developing free areas and equivalent land development

The contribution of nature protection

- Reduction of discharge peaks by reactivating floodplains and re-naturing water bodies
- Reduction of discharge peaks by preserving and restoring wetlands capable of storing water in the entire catchment area

The contribution of agriculture and forestry

- Reduce discharge peaks by improving the seepage capacity of agricultural areas
- Reduce discharge peaks by opening areas for flooding
- Reduce erosion by suitable forms of agriculture
- Reduce discharge peaks by natural forest development and afforestation

4 Predicting river flooding

Floods can be such devastating disasters that anyone can be affected at almost anytime. In order to reduce the risk due to floods, three main approaches are taken to flood prediction. Statistical studies can be undertaken to attempt to determine the probability and frequency of high discharges of streams that cause flooding. Floods can be modelled and maps can be made to determine the extent of possible flooding when it occurs in the future. And, since the main causes of flooding are abnormal amounts of rainfall and sudden thawing of snow or ice, storms and snow levels can be monitored to provide short-term flood prediction.

Food frequencies are determined for any given stream if data is available for discharge of the stream over an extended period of time. Such data allows statistical analysis to determine how often a given discharge or stage of a river is expected. From this analysis a recurrence interval can be determined and a probability calculated for the likelihood of a given discharge in the stream for any year. The data needed to perform this analysis are the yearly maximum discharge of a stream from one gauging station over a long enough period of time.

In order to determine the recurrence interval, the yearly discharge values are first ranked. Each discharge is associated with a rank, m, with m = 1 given to the maximum discharge over the years of record, m = 2 given to the second highest discharge, m = 3 given to the third highest discharge, etc. The smallest discharge will receive a rank equal to the number of years over which there is a record, n. Thus, the discharge with the smallest value will have m = n.

The number of years of record, n, and the rank for each peak discharge are then used to calculate recurrence interval, R by the following equation, called the Weibull equation:

$$R = (n+1)/m$$

A graph is then made plotting discharge for each year of the record versus recurrence interval. The graph usually plots recurrence interval on a logarithmic scale. An example of such a plot is shown below for the Rhine river of the Lobith gauging station.

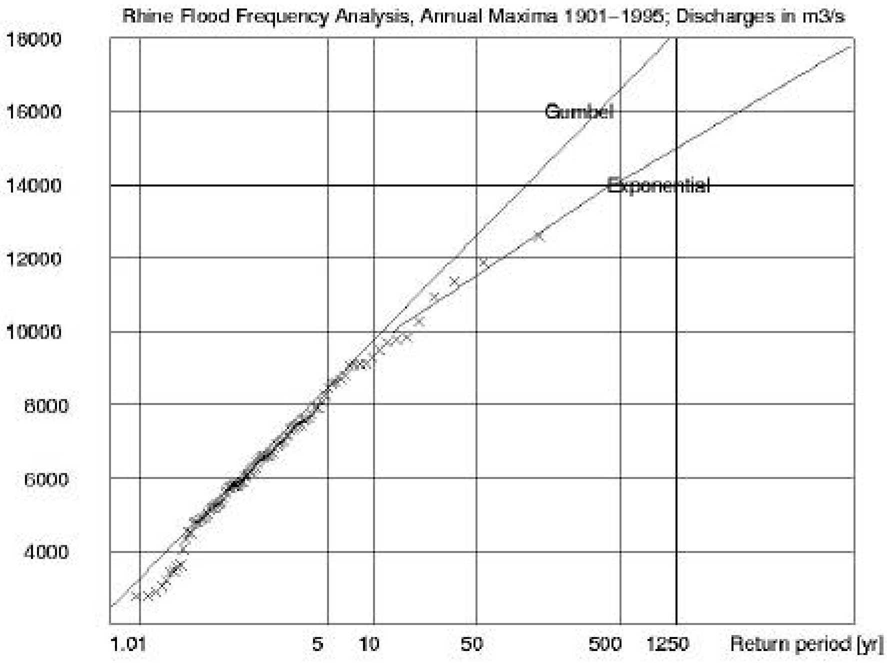

Figure 5: A flood frequency analysis of the river Rhine

The Dutch river dikes are designed to withstand floods with a discharge that can occur once every 1,250 years, called the design discharge. In Fig. 5 the results of a frequency analysis of the year maxima of discharges at the location where the river Rhine enters the Netherlands, Lobith, is given. The Boertien Committee made an analysis where they used as data sets the year maxima and peaks over threshold data of the Rhine discharges. As distributions they used Gumbel, Pearson III (shifted Gamma), Lognormal and Generalised Pareto. They suggested to use the exponential distributions for the frequency analysis of the discharges. Boertien's advise is adopted by the politics and nowadays used to determine the design discharges. As a comparison the Gumbel fit is also shown in Fig. 5. The dots show the annual maxima of the past 100 years as the empirical distribution form. Notice that the 1/1,250 years discharge level is estimated by the exponential distribution about 2000 m^3/s lower than with the Gumbel distribution. This corresponds with a few decimetres lower design level for the height of the river dikes.

Note that for the Rhine river data, shown above, the 1926 flood had the highest discharge of 12,600 m3/sec, which is equivalent to a 150-year flood. Also note that two floods that reached a similar stage occurred on the Rhine river in the years 1995 and 1993. Does this make the statistical analysis unreliable? The answer is no. As we shall see, it is possible to have two 50-year floods occurring 100 years apart, 50 years apart, or even 2 in the same year.

The probability, Pe, of a certain discharge can be calculated using the inverse of the Weibull equation:

$$Pe = m/(n+1)$$

The value, Pe, is called the annual exceedence probability. For example, a discharge equal to that of a 10-year flood would have an annual exceedence probability of 1/10 = 0.1 or 10%. This would say that in any given year, the probability that a flood with a discharge equal to or greater than that of a 10 year flood would be 0.1 or 10%. Similarly, the probability of a flood with discharge exceeding the 100 year flood in any given year would be 1/100 = 0.01, or 1%.

Note that such probabilities are the same for every year. So, for example, the probability that discharge of the Rhine river at Lobith will exceed 12,000 m3/sec (the discharge of the 100-year flood) this year or any other year would 1%. You can think of this in the same way you would think about rolling dice. The probability on any roll that you will end up with a six, rolling only on die, is 1 in 6 or 16.67%. Each time you roll that one die the probability is the same, although you know that it is possible to roll two or three sixes in a row.

Thus, it is important to remember that even though two 50-year floods occurred in the Netherlands just a few years ago, there is still a probability that such a flood, or one of even greater magnitude, will occur this year.

If factors such as amount of rainfall, degree of ground saturation, degree of permeable soil, and amount of vegetation can be determined, then these can be correlated to give short-term prediction, in this case called a forecast, of possible floods. If a forecast is issued, then a flood warning can be communicated to warn the public about the possible extent of the flood, and to give people time to move out of the area. Such forecasts are very useful for flooding that has a long lag time between the storm and the peak discharge. Flash floods, which characteristically have short lag times, are more problematical. Thus, in some areas known to be susceptible to flash floods, a flash flood warning is often issued any time heavy rainfall is expected because there is always the chance of a flash flood accompanying heavy rainfall.

Conclusions

- Floodings are natural events, which must be periodically reckoned on.
- Man has aggravated the maximum flood level and the travel time of floods by land development in the catchment area, by river development and by reducing natural flood storage areas,
- Embankments and other flood protection structures along the rivers cannot grant absolute protection,
- Settlements and other uses in flood-prone areas present a particular damage risk.

Recommended literature

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