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THE FLORIS-2 PROJECT

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ABSTRACT:

The Floris–2 project consists of two phases. In the first phase of the project various applications of the flood risk software package are developed, improved and tested. This software package will be used in the second phase of the project where the flood risks for all dike ring areas in the Netherlands will be calculated. A thorough analysis and comparison of the calculated flood risks will help evaluate the current safety policy. Will the actual approach survive, where the safety against flooding is based on the current five-yearly safety assessments, or is it possible and desirable to have a risk-based safety approach?

In the Floris-2 project the software application PC-Ring is used to calculate the probability of flooding of a dike ring area. Failure mechanisms for dikes, hydraulic structures and dunes can be calculated with PC-Ring. For dikes the failure mechanisms overflow/overtopping, revetment and erosion, sliding or uplifting and piping are implemented. The failure mechanisms of hydraulic structures that are taken into account are overflow/overtopping, non-closure, piping and constructive failure. Dune erosion can also be calculated.

At the beginning of 2008 the flood risk instrument was extensively tested on three dike-ring areas. This “system-test” was not only a test of the instruments, applications and available data. It was also a test for the engineers that have tendered for the production phase of the project and will use it in the next phase of the project. They are challenged to perform the following activities: (1) schematizing the dike-ring into quasi-uniform dike sections, (2) constructing probabilistic input for PC-Ring, out of the rough data (3) calculating the probability of failure for dikes, dunes and hydraulic structures and analyzing the results, (4) calculating the flood scenario probabilities and finally (5) calculating the flood risk of the dike ring area in terms of economic risk and casualties.

Key Words: risk based safety approach, probability of flooding, flood risks, flood risk-instrument

1. INTRODUCTION

The Netherlands is a low-lying area in the delta of the Rhine, Meuse and Scheldt rivers. The principal threat comes from high water levels, along the coast of the North Sea and the Waddenzee caused by storm surges, and in the Delta region caused by large river discharges and storm force waves. The Netherlands is protected by an extensive system of primary water defences. These have been built, mainly in the form of dikes, along the major rivers, the Wadden coastline, the Zeeland sea arms and the IJssellake coast. Along the North Sea coast the water is mainly held back by dunes. Large dams and special structures such as the Storm Surge Barriers in the East Scheldt (Oosterschelde) and the New Waterway (Nieuwe Waterweg) form part of the system of primary water defences. The complete system of primary water defences has a length of more than 3500 km. Hundreds of locks, pumping stations and discharge sluices are part of the water defence system as well as the high grounds in some areas. An area that is protected by a system of primary water defences is called a dike ring area. The Netherlands counts 55 of these areas, which vary in size, population, economic value and land use (Figure 1).

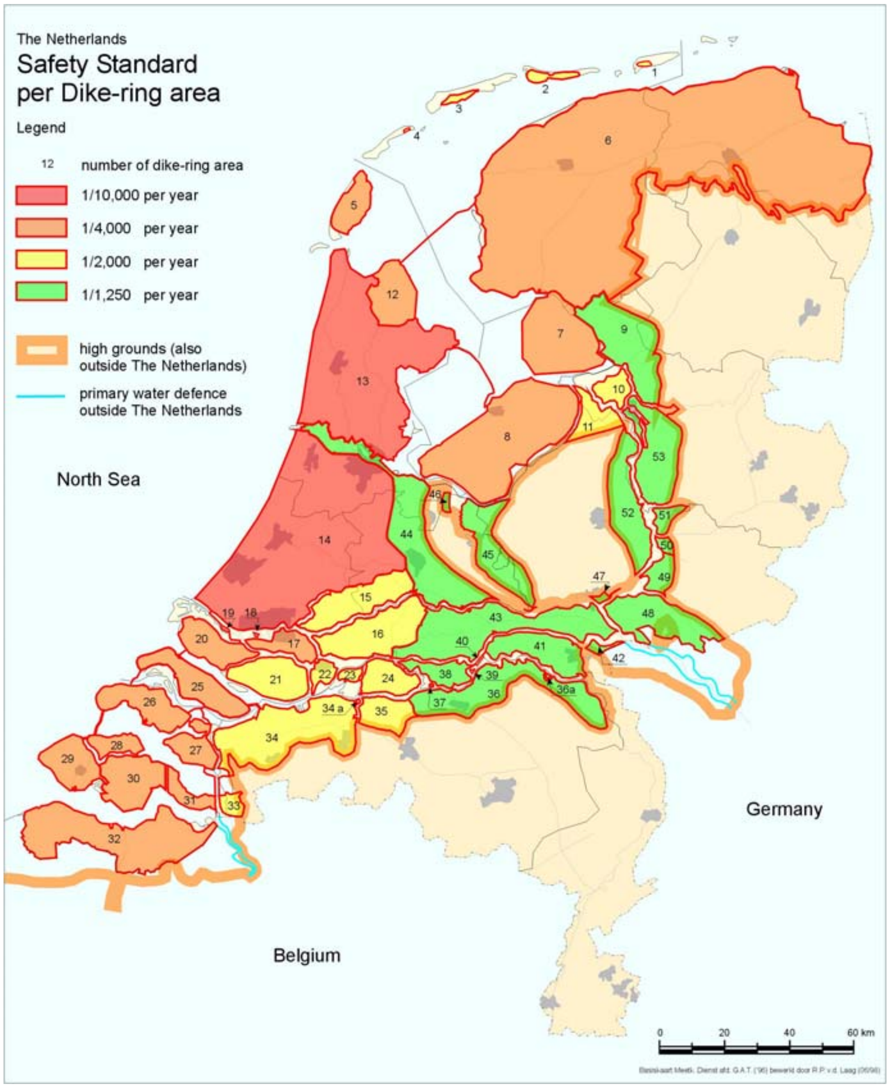

Figure 1: Dike ring areas in the Netherlands

2. FROM EXCEEDANCE FREQUENCY TO FLOODING RISK

The Delta Committee (1960) developed the foundations of the current safety approach. For each dike ring area a minimum safety level has been set, based on the exceedance frequency of extreme water levels, an estimation of the potential damage of flooding and a cost-benefit study of the central part of the Netherlands. The Water Defences Act (1996) provides these standards of minimum safety levels for all dike ring areas (Figure 1). According to the present safety approach this standard is the probability of the water level exceeding the level, which the dike section should withstand. In 1992 the Technical Advisory Committee on Water Defenses (TAW) started the research program ‘Flooding risks: a study of the probabilities and consequences’. This study was followed by the Floris 1 project in 2001 and the Floris 2 project in 2006.

The research program was the result of the advisory report of the Delta Committee (1960). This committee noticed at the time that a safety approach should preferably be based on estimates of the flooding risks. In doing so the probabilities and consequences of flooding would have to be considered together and in coherence.

While an exceedance frequency is a measure of a water level that should safely be held by a dike section, the probability of flooding of an area is that it will overflow due to the collapse of one or several water defenses around the area. The method to determine probabilities of flooding is distinguished from the current approach at three levels:

1. The transition from an individual dike section to a dike ring approach, with which the strength of a dike ring (consisting of dikes, hydraulic structures and dunes) can be calculated as a whole.

2. Taking equal account of various types of failure mechanisms of a dike ring. This is different from the current approach, in which overtopping and overflow of water dominate the type of failure.

3. Taking a probabilistic rather then a deterministic approach. This means discounting in advance, in a systematic and verifiable way, all uncertainties when calculating the probabilities of flooding. In the current approach uncertainties are for the greater part discounted afterwards by building in an additional safety margin.

3. THE PROJECT ORGANISATION

This large and complex project is being managed by a management group, existing of delegates of the three partners in the project (Ministry of Public Works, the Association of Water Boards and provinces). Based on information delivered by the project managers, the management group decides on project planning, budget and quality of the instrument and the results. The Centre for Water Management is executing the project. This in contradiction with the Floris-1 project (van Westen and de Leeuw, 2005), where the water boards and the provinces had a less active role. Their role is necessary because of their knowledge of the local water defences and the protected area. These organisations are not only represented by employees in the project organisation, but also have an active role in collecting the data for the risk assessments. The water boards provide data (strength parameters) of the water defences and the provinces are responsible for delivering hydraulic calculations in which various floods have been simulated. A number of consultancies and large technology institutes (GTI’s) have developed the risk instrument. In case the present safety assessment is replaced by a risk-based assessment, the consulting engineers should get experience with this new method. For this reason they have been asked to perform the calculations, analyse the results and report their findings. The Expertise Network for Flood Protection (ENW) has been asked to provide an independent quality audit of the methods used and the results achieved.

The project approach can be described with the next steps:

1. Development or preparing phase
2. Ongoing development of a risk-instrument
3. Test of the total system (GO/NO GO decision)
4. Production phases 1 and 2

The 1st phase has been ended at the beginning of this year. The activities carried out to develop the risk instrument have been finalized. These activities are:

- Development of a user-friendly application on a central server and a user-friendly interface for PC-Ring;
- Improvement of the piping mechanism in the PC-Ring model;
- Development of failure mechanisms that describe the behavior of hydraulic structures;
- Development of tools that calculate the steps from flood probabilities to flood risks;

A number of activities have been started in the first phase but are ongoing activities that will end at the moment that the start of the calculation for the specific dike ring areas are planned. These activities are:

- Collecting data on water defenses by the water boards;
- Collecting results of flood simulations by the provinces;
- Collecting geotechnical data for a nationwide database ‘DINO” at the central server

Further, an ongoing development phase will start at the time the first productions phase starts. In this development phase a general improvement of the total risk-instrument will be achieved. The goal is to develop a robust, complete and user-friendly instrument at the end of the project, which can be used by the Ministry, the water boards and the provinces. In this way the users have the possibility to get familiar with the instrument. It is also a tool to help set priorities for improvement measures of their water defenses.

The first phase has ended in 2007. At the beginning of 2008 a test of the total system has started. This phase is planned for the first half year of 2008. In this phase, the flood risks for three dike ring areas will be calculated by the consultancies that have been selected for the production phase. The goal of this “system test” is not only to find out if the risk-instrument and the manuals fulfill the criteria. The system test will also give answers to questions about the quality of data, the organization and the people that work for the project. If the answers meet the criteria as expressed by the management group, they will decide to go on with the production phase.

The production phase comprises the calculation of the risk of flooding of all the dike ring areas (55) in the Netherlands. The selected consultancies will carry out the calculations. To control the time and budget of the project, this phase is divided in two parts. After the first phase an evaluation moment can be planned for the first phase, leading to a decision on the second phase.

4. DATA MANAGEMENT

As mentioned in paragraph 3, the water boards have been asked to give access to their data of water defenses. For various reasons however, the required data for a full probabilistic analysis is not always available. First of all, the water boards and the Ministry of Public Works who are responsible for the maintenance of the dikes don't collect the data of all possible failure mechanisms as stochastic values but mostly as deterministic values. This is mainly due to the fact that the obligated five yearly safety assessments only requires deterministic data.

Secondly, most water boards have a long history of scale increase. They merged from 3500 water boards at the beginning of the 20th century to 26 in 2007. This means that a lot of the archived data has been lost in the process of moving or cannot be traced because people have left the organization. And even if the archives are still intact, different archiving-philosophies make a uniform approach to disclose the necessary data extremely difficult.

In order to be able to carry out risk assessments by comparing the outcome of all dike rings, the Floris-2 project has set up a system to collect the deterministic data from the water boards and produce the necessary probabilistic input for PC-Ring:

- The water boards are asked to check their archives for all relevant data.
- A general method to schematize a dike into input for PC-Ring is developed.
- A dedicated user-interface is developed.
- Input and output are stored on a central located server.

Since the start of the Floris-1 project in 2001, the water boards have started to give access to their data and to digitalize them as much as they can. It appears that in fact three categories of data can be distinguished:

1. Sufficient available data to construct a stochastic value
2. Insufficient available data in a section classified as 'strong'
3. Insufficient available data in a section of unknown strength

The 2nd Category is expected not to contribute to the probability of flooding. The 3rd category cannot be taken into account, the impact on the probability of flooding is not known. As a consequence this will have an impact on the flood probabilities and the way to deal with this problem in the calculations. The 1st category will lead to a high quality result of the calculation. For the 2nd category of data no calculations will be made. In a risk assessment however, a result is necessary. Therefore we assume for this category that the probability of flooding equals zero. The 3rd category requires the most attention. Two ways are distinguished to get a result. If only few data is missing, assumptions are made, based on expert judgment. The data can for example be taken equal to adjacent dike sections. If more data is missing, safe assumptions will not lead to a reliable answer. In that case the dike section is omitted but notice will be made of this fact while presenting the calculated flood risk of the dike ring area.

The amount of available data differs. Cross section-data (dike profiles) is mostly available in large quantities. The water boards have this information for at least every 100 m. In case of Flimap data the information is almost infinite, what has its advantages for a stochastic approach.

Geotechnical data however is much less available. For the Floris-2 project this has been a reason to develop a nationwide database 'DINO'. In this database all available piping data is collected and made suitable to calculate the probabilities of piping. Data of dunes is already available at the Ministry. Every year numerous dune profiles along the Dutch coasts are measured. This data is stored on the central database that is used in the Floris-2 project and can be used in the calculations of the failure mechanism, dune erosion immediately. In most cases, data of hydraulic structures is available in good quality. For historical structures this is often not the case, especially not for the constructions in the subsoil. In this case an approach is suggested to consider “proven strength” of the construction. In this way by making use of expert judgment, a probability of flooding is estimated.

5. DEVELOPMENT OF A FLOOD-RISK INSTRUMENT

In the Floris-1 project the first steps to a risk-instrument have been made. The major attention was however focused on the probabilities of flooding. In the evaluation of the Floris-1 project three goals according to the method have been addressed:

1. Improve the piping mechanism
2. Make the failure mechanisms for the hydraulic structures available in PC-Ring
3. Develop user friendly tools and improve the data management

The last goal was described in paragraph 3. The first two goals will be described in the next two paragraphs.

5.1 The piping mechanism

The results of the Floris-1 project showed high probabilities of flooding for a large number of dike ring areas (Havinga and Kok, 2005). In most of these cases, the mechanism piping caused these high values.

The calculated probabilities of flooding however did not correspond with the results of the five-yearly safety assessments of the dikes and were not recognized by the water boards. Therefore it was decided to improve the piping-module. The ENW came with the following advise:

- Improve the piping-module in PC-Ring that calculates the probabilities of piping
- Develop an Artificial Neural Network (ANN) for piping and implement it in PC-Ring
- Given a positive result of the feasibility-study, a nationwide subsoil-model must be developed

The first improvement to the piping-module was the addition of a second layer to the existing 1-layer module. Piping mainly occurs in the top layer. Many parameters of the subsoil however, like the permeability or the thickness of sand bed, were derived from the deeper layers in the subsoil. The two-layer model based on the equations of Sellmeijer (ref) give much better results. By combining a great number of piping calculations, an ANN has been set up. This ANN (Mpiping) calculates very quickly the critical head for piping of any given situation, using its database of existing piping-cases. Mpiping has been tested and tuned with four existing piping-cases and the results are very encouraging

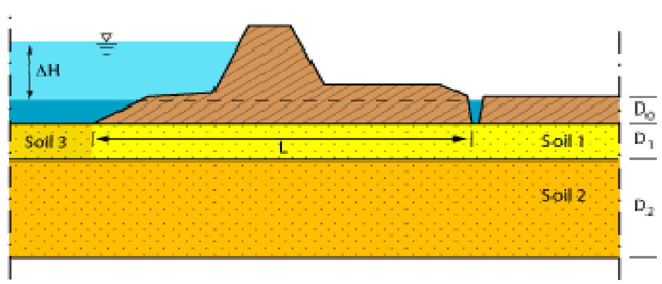

Figure 2: Schematization of the piping mechanism for the Floris-2 project

One of the main reasons to develop this subsoil database is the lack of sufficient geotechnical data at the water boards. The water boards do have geotechnical data, but only if they needed the information for the design or five-yearly safety assessment and this appeared to be not enough to construct stochastic values throughout the dike ring area. Furthermore, a lot of the historical data has been lost.

The Dutch research institute TNO has gathered geotechnical data for many years and stored it in the DINO-database. Although the data is often not near-dike data, it is very useful to construct an image of the subsoil. In the feasibility study it appeared that the Netherlands could be divided into four more or less homogeneous parts. For each area the subsoil has been schematized into input for Mpiping. It appeared that different combinations of subsoil could be distinguished. For any location, the probability of a number of sub soils can be given. Apart from some parts in the North and South, this database covers the entire area of the Netherlands.

5.2 Hydraulic structures in PC-Ring

The various failure mechanisms of hydraulic structures as a result of extreme high water levels or ship collision have been described in probabilistic terms. In general, there are three categories of failure mechanisms as a result of extreme high water levels:

- Insufficient height
- Not closing the hydraulic structure
- Insufficient strength (failure of closure-means, macro-instability of the structure, piping)

In the Floris-1 project, the method to determine the probability of failure was only based on a probabilistic approach of water level exceeding-frequencies. All other elements like strength and subsoil parameters were deterministic values.

In the Floris-2 project the probability of failure of hydraulic structures has been determined by means of a desk study. After analyzing the results of numerous hydraulic structures, the method has been extended with a stochastic approach of all strength-parameters.

This stochastic approach already existed for the determination of failure probabilities of dikes and dunes. This approach is described in the computer model PC-Ring. PC-Ring determines and combines in a scientifically way the probability of failure of mechanisms of cross sections into the probability of failure of an entire dike ring. The effects of correlation of strength and solicitation parameters are taken into account. The failure mechanisms of hydraulic structures are described as the so-called Z-function in which strength and solicitation parameters are described as stochastic values. The failure mechanisms, described as Z-functions have been added to the PC-Ring program.

A failure mechanism only leads to collapse of a hydraulic structure when the incoming water has enough power to erode the subsoil thus causing instability of the hydraulic structure. Some failure mechanisms cause immediate instability like the collapse of the door of a lock that opposes a great head. It is also possible that the head needs to increase in order to cause the erosion that leads to collapse of the structure. In case of the latter, the probability of collapse of the hydraulic structure is less than the probability of failure of the door of the lock because a higher water level has a smaller probability of occurrence. Inconvenience due to the inflow of water is however expected.

6. DIAGNOSTIC INSTRUMENT FOR FLOOD RISKS

When all data has been used to produce the probabilistic parameters, PC-Ring will produce the probability of flooding. These values will be discussed with the local area manager in order to check the figures with the maintenance experience and expert-judgment. If the figures match this judgment, the schematization process stops. If not, another round of tuning the probabilistic parameters will start by checking the used data and finding additional data until a satisfying and reliable answer is found.

For the impact of a flood, the intensity and type (sea, lake or river) determine the hydraulic characteristics of a flood. Therefore the flood probabilities calculated for the dike sections are combined into probabilities of flood scenarios. The provinces have calculated the consequences of the flood scenarios on loss of life and damage. Multiplying the probability of a flood scenario by the consequences, gives us the flood risk in the dike ring area.

The flood risk in the dike ring area is not just a number. It is composed of contributions of dike sections, dunes, and hydraulic structures to the probability of flooding. It is also composed of different failure mechanisms. These mechanisms give information about the hydraulic loads and individual strength parameters. In this way we can analyze which elements contribute most to the flooding probability. For the impact of a flood, we can again analyze where the flood has the largest contributions in terms of loss of life or damage to buildings and infrastructure (Figure 3).

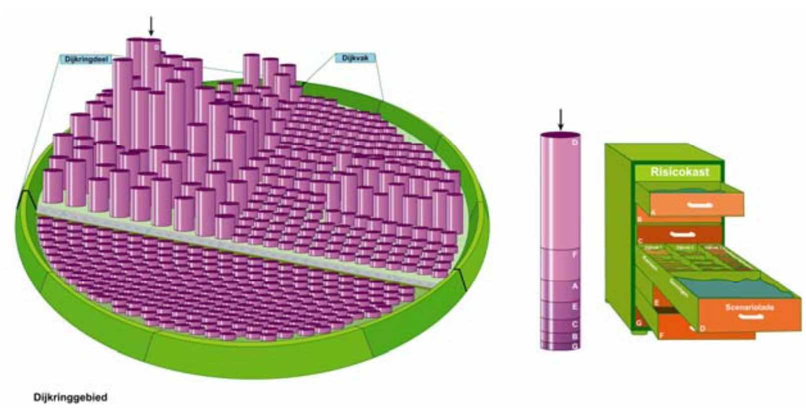

Figure 3: Diagnostic instrument for flood risks

After the diagnostic instrument has been applied, decision makers of the water boards can plan reinforcement measures for their water defenses in a cost-effective way. For the Floris-2 project however the results of the analyses will lead to recommendations on the used flood risk instrument and more over to recommendations on applying the five-yearly safety assessments on a risk-based way.

7. REFERENCES

Towards a new safety approach. A calculation method for probabilities of flooding Technical Advisory Committee on Water Defenses (TAW), June 2000

Havinga F.J. and Kok M. Flood Risks and Safety in the Netherlands (Floris). Floris Study – Full Report. November 2005. DWW-2006-014. ISBN 90-369-5604-9.

Sellmeijer, J. B; Proceedings International Conference on Scour and Erosion, November 2006, Amsterdam