Probabilistic Risk Analysis and Safety Evaluation of Dikes

Case study: Structural Safety assessment with Multi-criteria evaluation on Anqing Dikes in China

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Preface

This research is done for the partial fulfilment of requirements for the co-operation project between Directorate-General Rijkswaterstaat (RWS) of the Ministry of Transport, Public Works and Water Management in the Netherlands, represented by Road and Hydraulic Engineering Institute in Delft (DWW), and the Flood and Drought disaster Research Center in Beijing (RCDR) of the Ministry of Water Resources in China.

Within the cooperation between two sides some new technologies can be applied and exchanged. The Dutch's experience has been used for reference in the development of China probabilistic risk analysis system involved the whole report.

According to the proposal by DWW, there is also special interest to learn from Chinese experiences. Since it is a continuation of the previous studies, some conclusions from preceding reports of our research in Chinese also were translated and presented in this report as possible as I can.

Since my colleague MS Wang will concentrate on the economic analysis to assess damage that would result form flood. At that moment it will also be possible to calculate the costs and benefits of some alternative mitigating measures. For this case, some section of this report is empty for her study.

Abstract

What are the new mechanisms of inundation of an embanked area? Flooding may not only occur because of too high water levels, but also because of a collapse of a dike when its revetment is damaged, when a slope slide occurs, or when water seeps through or under a dike and thereby weakening it. When determining the probabilities of flood, all these failure mechanisms have to be taken into consideration. In addition, the flood probability is calculated for an entire dike ring area and not for a single dike section only. In this way, a better insight into the protection level of the area can be obtained, Weak links in the dike ring become apparent and bottle-necks can be ranked from large to small. Uncertainties due to lack of knowledge can also be made explicit.

In this reports, the following contents have been involved:

(1) A typical dike with inclined impermeable facing is selected to investigate its safety against piping. A comparison of the Sellmeijer's method, the Chinese method and the Bligh's method, respectively, shows that the Sellmeijer's requires shorter seepage length and hence, a more economical design for water retaining structures against piping. A sensitivity analysis was performed by using the various geometrical variables and geotechnical parameters to investigate the different model's compatibility and accuracy. These parameters include thickness of clay layer and sand layer, width of foreland and cross dike crest and piping-berm, height of water level, slope ratio, permeability coefficient of sand and clay layer.

(2) A brief introduction on the reliability theory has been given, such as the limit state equations for different failure mechanisms, their solving approach, and fault tree. And then, some soil strength parameters of levee and its foundation are taken as random variable, limit state equations of overtopping, piping and sliding of two typical dikes with inclination watertight facing and the homogenous embankment are formulated, and the influences of various factors such as geotechnical statistic parameters and geometry of dikes on reliability index or structure risk degree for these failure modes, have been investigated systematically.

(3) Some functions and features of two software system on the structural safety assessment used in the Netherlands and China have been discussed.

(4) Description of Anqing dike system has been given. Emphasize on discuss of the geological condition and historical yearly maximum water levels of the pilot has been made. The large-scale reinforcement project on this dike since 1998 has been discussed.

(5) A case study on risk assessment has been carried out for the pilot area. The safety factor, probability of failure, probability of flooding of various failure modes for each individual section and a whole dike section have been given at different water levels. A risk map of structural safety and some multi-evaluation indices along the whole dike has been achieved. The combination probability has been presented for each failure mode and every individual section and a whole section, some valuable remarks and conclusions will be helpful to understand the weakest compartments. The total probability of failure of the dike ring has been obtained, which will be employed in a further calculating of the risk of flooding including the economic loss.

Based on the research, a new approach is under development to implement the methodology in China. However, there are still a number of known limitations for which additional research and development appear warranted.

Contents

Chapter 1 Problem Analysis, Project Objective and Working-method

1.1 Necessity for this study

The objective of this study is to apply reliability analysis on the Anqing' flood defence system in China in order to support an evaluation of the appropriateness of these methods.

Construction of dikes is the most important structural measure of flood protection in China and the Netherlands. China has about 250,000 km of dikes, among which the main dikes have a total length of 65,700km. In the Yangtze River, all classes of dikes together take 30,000 km, of which 3,600 km are main dikes. According to the kind of resisted floodwater, there are two categories of dikes: river levees and see dikes. Each category can be divided into some grades on the basis of the importance of a dike (for example, the Yangtze River dikes include three grades).

Our increased prosperity means natural threats can cause a great deal of damage. And bearing in mind there is less willingness to accept it, citizens are changing the demands they set on government. People want to live their lives without feeling threatened by the water. But more importantly, the manner in which the land is used means that the consequences would be far greater now than they were a few centuries ago. The rise in population meant that increasing numbers of lower-lying areas were taken into use.

This study is one of the first attempts towards a new safety philosophy based on risk approach, a calculation method for probabilities of flooding and its consequences.

The aim of this study is:

(1) To analyze / understand and to apply the probabilistic design method and risk assessment to the improvement of safety evaluation of river dike systems.

(2) To apply this knowledge in the Chinese situation and to extend it to other locations.

(3) To appraise the present state of the Yangtze river dike system by probabilistic approach and risk analysis in order to give technical authorities a clearer picture of the water defense system.

In China, the strategy of hydraulic modernization by information technology driving is being put forward, which is aim to improve the decision-making technique on flood defence system and disaster reduction by using high and new technology. In order to intensity of flood prevention and rush to deal with an emergency during flood period, it is necessary to present or employ new approach of safety assessment on dike engineering, which will become a useful tool to carry out the safety management and risk assessment for engineers and mangers.

In addition, our government has poured much money into the strengthening of the main dike, to a flood water level with a return period of 1000 year height. What are the new mechanisms of inundation of an embanked area? Flooding may not only occur because of too high water levels, but also because of a collapse of a dike when its revetment is damaged, when a slope slide occurs, or when water seeps through or under a dike and thereby weakening it. The flood probability is calculated for an entire dike ring area and not for a single dike section only. In this way, a better insight into the protected area should be obtained. The question as to whether the dike is safe enough, which standard should be maintained, and whether the current safety approach still meets current standards, will have to be answered at political level.

With this study, some new knowledge and ideals should be functional in answering these questions and to support an anticipating approach to the safety discussion.

1.2 The art-of-review on safety evaluation of flood defences in the netherlands and china

1.2.1 Dutch risk assessment method for flood defences

Before 1953 the risk estimates (safety definitions) were either formulated on the basis of intuition or experience. The 'highest known water level' on site played a crucial role. The flood defence was designed at that level plus a certain margin. If a flood defence proved too low for a new and higher water level, then this automatically became the highest known water level and the dike was raised.

After the 1953 disaster the need for a more unambiguous approach, along the lines of the section above was adopted. The safety requirements in the prevailing guides placed on the flood defences have their origins in the Delta Committee’s body of ideas, collated in its 1960 report. An econometric view was set up for Central Holland. The econometric optimum safety level was fixed at approximately 1/125,000 per year, assuming a complete loss of capital goods. The loss of human life and the breakdown of society was not collating in this view.

Assuming a flood probability of 1/125,000 per year this would mean about the same collapse probability for the flood defence. However, it was impossible to determine the probability of collapse of a dike with any precision due to insufficient numeric insight into the collapse mechanisms. As a result, partly in light of the other uncertainties, another approach was chosen. The requirement was that it must be possible to ‘completely retain’ a water level with an exceedance frequency of 1/10,000 per year (the design level, the Normative High Water, MHW). That was considered to be true when only 2% of the accompanying waves running up the dike were exceeding the crest of the dike.

For Hoek van Holland it was determined that a level of NAP +5m has an exceedance frequency of approximately 1/10,000 per year, the so-called base level of the Delta Committee. For Central Holland the design level (MHW) is the same as the base level. For other locations along the coast the base levels have been determined by assuming conditions with the same exceedance frequency. For the MHW along other parts of the coast an economic reduction was applied however, varying from 0.2 to 0.6m. The accompanying exceedance frequency of the MHW along the coast varies from approximately 1/4000 to approximately 1/1500 per year. The economic reduction was motivated by the fact that the consequences in the case of dike collapse are less serious than in Central Holland.

For the upper rivers area the River Dikes Committee (the Becht Committee) recommended an exceedance frequency of the design discharge (to which the MHW is linked) in 1977 equal to 1/1250 per year. The ‘extenuating circumstances’ in the rivers area in relation to the coast included: fresh versus saltwater and in the long term forecasting river floods versus in the short term forecasting of sea floods. The loss of Nature values also played a role in the choice of this number. The Boertien Committee made a similar choice in 1993, the result of which was the same exceedance frequency of 1/1250 per year. This number was chosen in spite of the fact that a material risk consideration would lead to a lower frequency.

The considerations of the Delta Committee and its elaborations have since formed the core of the safety requirements. The exceedance frequencies of the MHWs form at this time the most tangible expression of the degree of protection against high water, offered to various areas.

The concept 'completely safe' is worked out in the design rules. It should include a margin due to uncertainties in such matters as water levels, wave attack, soil & material characteristics and behaviour of the water retaining structures. The Delta Committee chose the freeboard for this margin, the difference between the crest height of a dike and the design level. This difference is decided in the design by such factors as the wave run-up, any fluctuations in the water level due to wind, estimated settlement of the flood defence and such like. The Delta Committee recommended that the freeboard, even when there is no wave attack to speak of, should be at least a couple of decimetres.

In The Netherlands a similar development with respect to risk-based design and maintenance of flood defence systems has taken place. Until recently the Dutch flood defences were expected to be able to withstand a water level with a certain frequency of exceedance. The accepted frequency of exceedance has been established for different areas. These standards of safety are mainly based on the consideration that everyone has equal rights to the same level of safety.

In the last few years the emphasis in safety approaches with regard to flood defences has shifted from the frequency of exceedance approach to a risk-based approach. To support this risk-based approach, software called PC-Ring has been developed to calculate the probability of inundation of flood defence systems. These calculations are based on certain failure modes. These failure modes take both the strength of the flood defence and the local loading conditions into account. Besides the total probability of inundation the output of PC-Ring consists of the probabilities of failure of the included cross sections and the contributions of the uncertainties of random variables to the total uncertainty of reliability functions representing the failure modes. The knowledge of these probabilities provides the possibility to spot the weak elements in the flood defence system. Knowledge of the mentioned contributions indicates how the system can best be improved.

The exceedance frequency is a standard for a high water level that a dike section should be able to withstand. The flood probability of an area is that the entire area will be flooded due to failure of one or several water defence works of that protected area. The differences between the proposed method to determine probabilities of flooding from the current approach (exceedance) is at three levels:

(1) The analysis of an entire dike ring instead of individual dike sections. In this way, the strength of a dike ring as a whole (consisting of dikes, structures and dunes) is determined.

(2) Taking various types of failure mechanisms of a dike ring mutually into account. This is different from the current approach, in which the type of failure is dominated by the failure modes “overtopping” and “overflow of water”.

(3) Systematically and verifiably discounting all uncertainties in advance when calculating the probabilities of flooding. In the current approach, uncertainties are for the greater part

discounted afterwards by including an extra safety margin.

1.2.2 Review of safety management and risk assessment of the Yangze River dike

Chinese dikes were gradually formed in the past. The initial Jingjiang dikes of the Yangtze river date from AD 300, so they have a history of over 1600 years. All these dikes are proof of the struggle of the Chinese people against flood for thousands of years. Because dikes were constructed, damaged, and rebuilt repeatedly, there are some potential dangerous occurred during the flood period.

In China, the safety management is based on the experience and judgment of engineers at some extent, despite the reference to the existing codes and monitoring results and a few years operating status. In 1998, BBC reported that "The decisive battle to beat the flood has begun, and danger may appear at any time, especially around the inland lakes, above the warning level. Some 3,500 local people are now defending the dikes while soldiers and armed police officers are on standby for rescue work". Figure 1.1 gives the picture of local residents have been organized to detect the potential emergency on the dike at higher water level. In Yangtze river basin, during the rainy season most warnings of an imminent failure come from the thousands of dyke inspectors living and working 24 hours per day in inspection shelters on the dykes. They observe weaknesses of the dyke and try to warn as early as possible. The same as for construction techniques holds for maintenance techniques and emergency relief. Age-old methods are used to prevent the dyke of failure. While the techniques are usually successful, the rates of productivity of the repairs are low, despite of the thousands of people working on the dyke.

Figure 1.1 Local residents have been organized to detect the potential emergency on the dike

In the past 100 years, engineers have summarized the experience to find the rational and scientific and effective method for safety design and assessment. The notion of safety factor or safety margin has been updated many times, and it achieves a rather credible grade up to the middle of 20th century. Although safety factor is an empirical coefficient, it generalizes the factors of disadvantage and advantage of effects of structural safety and their combined action. It includes the potential over loading and inhomogeneous of material strength and man-made error occurred during the design or construction or operating. So, this is the reason that safety factor was used to verify and calibrate the other design methods.

Since the 1980's, the probabilistic design method based on the stochastic theory has been employed design code and standard of building in China. The resistance and loading effect of structure should be taken to be random variables, then the reliability index and failure probability of structure can be calculated according to the probability density distribution curve. But the preconditions of correct and reliable distribution curves should be imposed. In fact, there are many factors of effect on resistance and loading.

In this case, it is a difficult task to transform and extend the new method. It is no doubt that the non-deterministic associated with the deterministic method will be rather scientific methods and means to assess the safety of dike. Thus, the traditional deterministic method and probabilistic method will be involved in this study.

In addition, the development of the software system for safety assessment of dike is helpful to the design, maintenance, safety management of river levee and revetment in China. It is an effective tool to transfer the professional knowledge to engineers. In recent years, some tentative research work aiming at the improvement of the safety management and assessment has been carried out.

In China, the risk analysis of overtopping and slope stability and seepage stability by the reliability method have been studied, but the computation of failure probability taking in account all relational factors are imperfect. The structure risk models of slope stability and seepage stability have been proposed by Wang Zuofu. Using the input-output investment decision-making method, the decision-making model of dike strengthening has been suggested by Zhang Junzhi. The correlation of these failure mechanisms and feasibility of generalized analysis are deserved in further study. A practical software system has been developed by using the conventional procedure and probabilistic risk method---SADSS. According to the process for flood prevention, a model and its solution method of structure risk on dike were put forward. Some computing results of whole dike sections can be real-time displayed, and this system has been applied successfully to the modern management on dike of Anqing city.

Based on these results, some design guides and handbooks of this method applying for China can be presented in the near future.

1.3 Traditional method for safety evaluation

The assessment aspects as included in the guide relate to height, stability, means of closure and limit profile. The manager begins with general monitoring on the basis of simple calculation rules and goes into greater detail if such proves necessary. On the basis of monitoring a qualification is given per flood defence element of 'good', 'satisfactory' or 'poor'. A design profile is usually laid down in the data-base corresponding to the assessment level 'good'.

In the classic deterministic approach fixed calculation values are used for the load and the strength, with a safety coefficient in between: Strength = F *Load, with F > 1.

As every parameter shows a specific spread, F does not say anything about the failure probability. A completely different probability can accompany the same 'safety coefficient' so that the load exceeds the strength. The probability that the strength is smaller than the load, in other words $Z < 0$, is much smaller in the upper case than in the lower case, while the 'safety coefficient' in relation to the average is the same. This is also true if other calculation values are assumed, with a smaller probability of occurrence than the average value for the definition of the safety coefficient.

In a deterministic design the selection of F is based on experience or intuition. The aim is to prevent failure or collapse, in other words to prevent $Z < 0$. An experienced designer will select a larger F as the spread of the parameter increases or the design model is less accurate, but F still says nothing about the failure probability.

1.4 Probabilistic risk analysis

The protection against flooding by flood defences is never absolute. Upper limits of natural phenomena like wind and rain are not known. Instead it must be assumed a certain exceedance-probability of these phenomena. Under extreme conditions flood defences can collapse and the land behind it will flood. Under less extreme conditions the behaviour of the flood defence cannot always be predicted, so there is always a (small) probability of collapse.

In recent years, a number of flooding events occurred in some countries in the last decade has caused an increasing interest in risk-based safety approach of flood defences. Probabilistic risk analysis is the up-to-date research field of safety assessment techniques of dike. It is well-known that the experience of the design and maintenance and assessment of embankment and revetment engineering in the Netherlands is worth to referring.

In this approach, the various uncertainties of the loading and strength variables are expressed in terms of probabilities. The probabilistic approach aims to estimate, on the one hand, the failure probability of a flood defense system and on the other hand, the expected damage according to that failure during the lifetime of the system. The design is based on a risk analysis with regard to safety and economy.

The main advantages of a risk-based safety approach are: (1) It is based on the concept of risk and therefore considers all the aspects related to failure of a flood defence system: the strength and the loading conditions of the flood defence system as part of the probability of inundation as well as the consequences of inundation in case of failure of the flood defence system. (2) It supports the process of decision-making with respect to maintenance of a flood defence system as a risk-based analysis of flood defence systems points out the system's weakest links and enables the decision-maker to target maintenance activities. (3) In case of large scale flood defence improvements the decision-maker can compare different design options in terms of the actual risk reduction and the costs which are associated with the improvement option.

The main steps of this approach are as followings:

(1) The first step in the reliability analysis is the definition of the system. This step points out the relevant defence length for the calculation of the probability of inundation and the area which suffers consequences in case the flood defence system fails.

(2) The second step is to define the system's components, or the defence types that occur

in the flood defence system. Part of the second step is to determine the different failure modes which can cause failure of the components.
(3) The third step is to select for each failure mode the cross sections in the flood defence system that are regarded as the weakest compartments. These cross sections represent the flood defence system and contribute most to the total system's probability of failure.
(4) After this last step the flood defence system has been translated from reality into a model, the model has been expressed into data and the data can be used to calculate the probability of failure with some programs or softwares. These results point out the weakest links in the system and which random variables contribute most to the variance of the total probability of failure. (add determine consequeses of failure; determine of risk level) relate failure to the consequences of flooding).
(5) Based on the results the evaluation can be made whether reliability methods for flood defence are appropriate to serve as a detailed level methodology in the risk-based assessment of flood defence systems.
More and more, the interest in risk-based design and maintenance of flood defences has grown in other countries, for instance USA, Australia, England, Canada.

1.5 Relation between the traditional method and probabilistic method

In fact, the probabilistic design approach is a logical extension of the traditional method. As we known, the deterministic method has been using in the active code of designing of dikes and revetments. Probabilistic calculation techniques are more laborious and complicated than deterministic ones, but correspond better with the aim to produce sophisticated structures and have insight into the actual risks. The 'safety coefficient' used in deterministic practice actually says little about safety: the same value means something completely different depending on the mechanism.
The difference between a deterministic approach and a probabilistic one is good expressed in the determination of the necessary dike height.
The predominantly deterministic determination assumes the normative high water level (MHW) that the dike must be able to retain. This MHW includes a rise in sea level in the plan period (up to now 0.1m for 50 years) and wind effects on the local water level. In addition, the wave run-up is the most important parameter in the determination of the crest height. The wave run-up is calculated on the basis of a certain wind at MHW and the corresponding waves (bearing in mind the geometry of the foreland and the outside slope). This is expressed in the level that is exceeded by 2% of the waves or a certain overtopping discharge. The so-called crest reference height is therefore equal to this level.
Settlement of the soil body over a certain maintenance period is also taken into account to avoid a situation in which the height of the dike is lower than the crest reference level needed. That results in the so-called construction level. The difference between crest reference level and MHW is called the freeboard. At least 0.5m is usually maintained for that, also when the calculated wave run-up is lower. This is in connection with uncertainties in the determination of the MHW's among other things, and to ensure that the crest is easily passable in the case of extremely high water levels.
In a probabilistic approach, as in the inundation probability calculation, the result of the

above-mentioned approach can still be used as an initial estimate. The probability that the defence will fail must subsequently be calculated. That may be due to a defence that is too low or too weak. The inundation probability is studied after integration with all failure mechanisms. The whole range of combinations of water levels and waves are included. A lower defence may then be possible than would follow from a deterministic approach, because other dike sections or mechanisms contribute less to the failure probability. The determination of the ultimate dike height is therefore much less direct than in the deterministic method. MHW plus a few decimetres is however retained for the time being for the dike height.

1.6 Structure of this report

In chapter **1** the background leading to the initiative of this project, the definition of the problem and the objective of this study is given. This chapter closes with a description of the safety assessment method in main lines. Chapter **2** provides an overview of the deterministic safety assessment method on dike. Chapter **3** contains the comparison study of the different models on piping between China and the Netherlands. Chapter **4** provides an overview of the reliability methods and risk assessment for flood defence systems, especially for Dutch method. These methods are the tools which are used to perform the probabilistic risk analysis. Chapter 5 gives an outline of safety evaluation technical standard and risk level, and decision-making after a risk analysis. Chapter **6** discussed the function and feature of the practical software system for structural safety assessment. In chapter **7** the boundaries of the Anqing city flood defence system are defined together with the main components or defence types occurring in the system. In chapter **8** contains a description of the choices which have been made with respect to the data requirements in general and specifically connected to the separate failure modes. In chapter **9** main failure mechanisms and their probability functions and random variables concerned with this case study have been discussed. Chapter **10** the results of the calculations on Anqing river dikes are presented. Finally, in chapter **11**, the conclusions and recommendations are given.
Therefore, the whole report can be subdivided on the basis of the related contents into three parts: Traditional deterministic method (Chapter 2, 3); theory description of probabilistic risk assessment (Chapter 4, 5, 6); case study for Anqing dike ring system (Chapter 7, 8, 9, 10).

Chapter 11 Conclusions and Recommendations

11.1 Conclusions

In order to transform the traditional empirical methods of safety evaluation and management of dike to foreseeable risk management mode, it is important to predict and evaluate the categories of potential dangers, cause of danger occurring and consequences of accidents through more reasonable numerical models and calculation approaches. Probabilistic risk analysis approach is the up-to-date research field of safety assessment techniques of dike. Based on the theory framework of reliability analysis and risk assessment, the interactive software system of dike risk analysis operating on the Windows platform has been developed and used in a pilot area. Some conclusions can be drawn:

(1) A comparison has enn given of the piping method. The comparison of the Sellmeijer's method with the empirical methods of Bligh showed that the Sellmeijer's method requires a shorter seepage length and produces a more economical design for water retaining structures. Chinese method also can give a reasonable design within a certain range, and the safety factor by this model is not very sensitive with some variables than the one by other models. An increasing curve, safety factor increase with the permeability coefficient of sand layer, has been gained by Bligh model, which is unreasonable.

(2) Some soil strength parameters are taken as random variable, two typical dikes, an inclination watertight facing dike, and the homogenous embankment have been employed in the studying of individual dike section, and the influences of various factors such as geotechnical statistic parameters and geometry of dikes on reliability index or structure risk degree for overtopping and piping and sliding, have been investigated systematically. Some numerical models and solving approach have been testified.

(3) The case studies are an important part of this research. They are initially oriented to obtaining information to increase insight into the flood risk of the whole dike section. Subsequently, the spatial distribution of multi-indexes, for instance, safety factor, probability of failure and probability of flooding along the entire dike has been obtained at a specified water level. The probability of flooding of potential damage is considerable little, especially in seepage instability. The safety factor and reliability index of dike stability increase as the decreasing of the water level, but the risk degree of instability decrease. The safety indexes of outer slope stability are lower than the one of inner side, so the monitoring of the revetment or bank collapse in outer side should be enhanced during the flood season. According to the distribution of evaluation indexes for a whole dike at different water levels, the sliding failure mode plays a principal role for the overall failure probabilities. The Section No. 05+687~08+687, and No. 40+439~40+687 turn out to be the weakest link regarding to the sliding results. These sections can be selected as the breach spot employed in flood simulation and damage assessment. the overall probability of flooding of the entire section is 0.4382 at design water level. In addition, the relation between the various evaluation indexes and different water levels shows that the flood water level has a great influence on the indexes, but not linear. The adjustment and modification on the flooding-protection water level can be proceeded for some subsections, since some larger safety margin in some sections has been checked.

(5) The new calculation method and software system SADSS were tested for the pilot, and it

shows that the method, works. In brief, risk analysis associated with traditional method used to find weak spots in the dike ring seems to be a very powerful tool. This method also shows the effect of gaps in our knowledge on water defences.

11.2. Recommendations

(1) The combination between more reliability functions should be made in the near future. Since the coefficients of influence in combination with the reliability functions point out what kind of maintenance activities are expected to be most effective, some results of this should be submitted in the further research. The method of combine the different components of a flood defence system should be further study and implement in the practical project.
(2) Some levees may be subjected to significant water heights for many months. When this occurs, the phreatic surface within the levee will rise, increasing pore pressures and increasing the risk of failure due to through-seepage, underseepage and slope stability. This is acknowledged in a rudimentary way by reducing the crest width when the levee is exposed to flood heights for only a limited time. If we can use some time-dependent analyzing model, especially for the seepage simulation, and nonsaturation slope stability, in the real-evaluating of the dike safe, it will be an essential development in this field and deep in diagnose of the disease of the dike during the flood season.
(3) As soil is a continuous medium, the appropriate characterization of uncertainty in a two-dimensional slope or seepage analysis is dependent on the size of the modeled area and free body. Application of spatial correlation theory to soil parameters in SADSS should be taken into account. Similarly, real levees may be many miles in length. Intuitively, a long levee is less reliable than a replicate shorter one.
(4) Computer programs like PC-Ring, SADSS are in single-machine mode, in some extent, there will be in trouble with updating and sharing of data-base and developing of flood emergency action and so on. Therefore, web-based or GIS-based software system would be promising. In addition, these program is “tailor-made”, in which the defence types and failure modes are fixed. Each time when the program is applied to a flood defence system with different defence types, the new failure modes must be imbedded in the program code. “one-size-fits-all” computer program should be set up.
(5) The failure modes are related to structural failure and are limited to the components in this case study: embankments without additional structures, and three failure modes with respect to structures. The failure modes of the wave return wall and relief-wall and anti-seepage wall and sluice should be added to the report.
(6) When the engineers proposes improvement of existing levees (typically raising the height), economic studies are required to assess the benefits and costs. My colleague MS Wang will concentrate on the economic analysis to assess damage that would result form flood according to some computing results mentioned-above. At that moment it will also be possible to calculate the costs and benefits of all alternative mitigating measures.
(7) To support a wide application of risk methodologies in flood defence an overarching risk-based framework is being developed that integrates decisions on different levels (e.g. national, large-scale, strategy, scheme, etc) and across differing functions (local authorities, flood warning, operation and maintenance, etc.). The flood probability is calculated for an entire dike ring area and not for a single dike section only, which can meet the demand in

some extents. In this way, a better insight into the protected area can be obtained, weak links in the dike ring become apparent and bottle-necks can be ranked from large to small. So our government should further carry out and support this kind of research work, especially in research from probability of exceedance to probability of flooding.

(8) If the risk analysis has to be improved, efforts have to be focused on gathering more, and more accurate data as input to the probability calculations. Especially the probability of failure of structural artifacts in the earthen dike, e.g. sluices, was based on possibly inaccurate assumptions. Although usual amount of information is available, lack of information occurs with respect to the following: the original experiment data of the geotechnical parameters, especially in the strength parameters and seepage coefficient. Thus, a number of basic variables with statistical distribution functions and correlations can be gained.

(9) As we known, the safety evaluation and risk analysis can be proceeded after gathering some first-hand materials, such as safety monitoring, Combining the monitoring data with evaluation models is a promising research field.

(10) Finally, as mentioned above, the guideline for dyke safety assessment is a very necessary tool for a dyke owner manager therefore it highly recommended organize a project to build up the legal guideline in China. However, an assess work can be taken a lot of money, thus depend on Chinese’s economy condition at present then might be applying for each 5 coming years or 10 coming years for instance. As the Netherlands, they assess the safety of dyke once time in five years. In this way, the specific guides and reports published by the TAW provide the information will be used and recommended.

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Curriculum Vitae

Xingzheng WU was born in ShanDong province of China on February 29, 1972. In 1990 he finished his high school education at Lianshan high school, Jining, Shandong. In the same year, he entered ShanDong University, Jinan, ShanDong. After four years of study, he got his B. Sc. in 1994. In 1997, he obtained his M.Sc. from the same university with Solid mechanics. The title of his master thesis is "Study of Geosynthetic Reinforced Soil Embankment". In 2001, he got his Ph.D degree from Dalian University of Technology, Dalian, Liaoning province, China. The title of his doctor thesis is "Constitutive Models of Coarse-grained Soils with Static and Dynamic Loading and Their Applications in High Concrete Faced-slab Rockfill Dam". In parallel to his study, he worked as a research assistant in the National Science Foundation project of China from 1997 to 2001 and in the 9th Five-Years Plan Project from 1999 to 2000. In these projects, he was active on constitutive model and numerical approach in 3-D finite element analyses.

At the beginning of 2001, he started working towards new research field in the probabilistic design and risk assessment of flood defences at China Institute of Water Resources and Hydropower Research (IWHR), (Research Center of flood and drought disaster reduction of Ministry of Water Resources). And in the subproject of WORLD BANK and Youth Acceleration Fund of National Electric Power Corporation project and some practical engineering projects, he developed the software system of safety evaluation with multi-indexes on flood defences.