The influence of measurement density on micro-instability testing

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ABSTRACT

Protection from water flooding by dikes is an important issue in the Netherlands. Therefore dikes have to be regularly tested for possible failure, for example caused by micro-instability. Micro-instability occurs in the upper layer of the dike, due to water flowing through it. The goal of this research was to determine the influence of the measurement density on safety assessment of river dikes for micro-instability and in addition to give a confidence interval for these assessments. This paper shows that uncertainty in cover layer thickness has the largest effect on the reliability of dike safety assessment in relation to micro-instability.

Keywords

Dikes, failure mechanism, micro-instability, measurement density, statistical analysis, measurement simulation

INTRODUCTION

In 2014 the KNMI introduced four climate scenarios that we should bear in mind for the future (NOS, 2016b). These climate scenarios predict the rise of the sea level and increase in the intensity of extreme precipitation. We already encountered this increase in intensity of precipitation this year (NOS, 2016a). In June parts of Europe, including the Netherlands, encountered heavy rainfall which lead to possible dike breaches. Luckily this could be prevented, but it shows how important well maintained dikes are these days and will be in the future, in particularly because over a quarter of the Netherlands lies below sea level and more than half is at risk of flooding. Dikes can fail in many ways and one of them is through micro-instability. Micro-instability is the failure of the upper layer of the dike, due to water flowing through the dike. This makes a dike unstable and not suitable to protect the hinterland from water.

To prevent this, dikes are tested in the Netherlands every 5 years (Ministerie van verkeer en waterstaat, 2007). Depending on the result of the test a dike will be rejected or accepted. There are two undesirable outcomes that can occur. The first outcome is that a dike will be rejected while this is not necessary. The second outcome is that a dike is accepted wrongly. In the first situation the dike will be reinforced while this was not necessary and so there will be less budget for a dike that does need to be reinforced. In the second case the dike will not be reinforced while this is necessary, which produces possibly dangerous situations.

Since testing of dikes involves soil properties from randomly taken samples there is a certain amount of uncertainty in the interpretation of test measurements. This uncertainty makes it harder to evaluate the safety with required reliability and to maintain dikes cost efficiently. This leads to the following research question: what is the influence of measurement density on the reliability of the test results of dikes on micro-instability?

TYPES OF TESTING

To test for micro-instability there are two types of testing, depending on the dike geometry. In case a dike has a cover layer of clay it needs to be tested for shearing and heaving. A dike made of sand needs to be tested for shearing and scouring (TAW, 2001). The processes that take place during micro-instability are shown in Figure 1. For these tests different parameter values are necessary and will be discussed later in this paper.

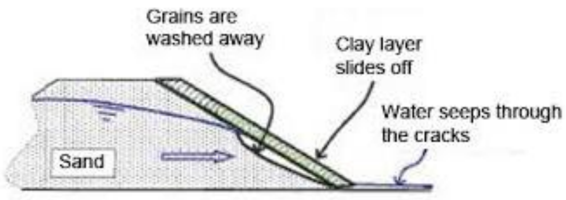

Figure 1: Processes occurring during micro-instability

GEOMETRY OF A TYPICAL DIKE

To perform this research a dike was modeled. This was a fictitious dike representative for dikes in the Netherlands. The choice of dike was based on the suitability for testing on micro-instability. The case used for the dike build-up is the design of a dike used in a project of Room for the River. for this project a dike was relocated between Cortenoever en Voorsterklei (Oudkerk, 2011). Based on this design two schematisations were made: one dike with a layer of clay and a core of sand, see Figure 2.

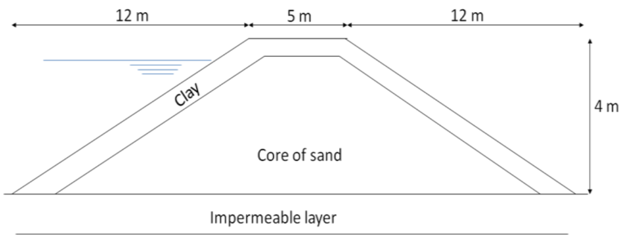

Figure 2: Schematization of a sand dike with clay cover layer

The other schematisation was a sand dike without a clay cover layer, see Figure 3.

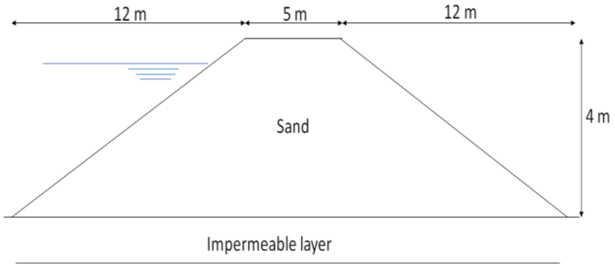

Figure 3: Schematization of a sand dike

Within this research it was chosen to do the testing using the local level approach. This means that there is a minimum of 1 measurement every 150 meter of dike (Drenth, 2015). According to the "Technisch Rapport Waterkerende Grondconstructies" at least 4 measurements are necessary to be able to say statistically relevant things about the test result (TAW, 2001). However, to get a clearer idea of the effect of measurement quantity on test results also a simulation of 3 measurements was performed. This means that for local testing the modeled dike cannot be longer than 450 meter.

REPRESENTATIVE PARAMETER VALUES

To carry out the tests a number of parameter values was necessary. Most of these parameters follow from dike characteristics and regulations of the Technische Adviescommissie voor de Waterkeringen (TAW, 2001).

Dike with a cover layer of clay

In case of the dike with a cover layer of clay three parameter values are unknown. One of these unknown parameters is the groundwater level at the landside dike toe. This parameter depends on the exit point of the phreatic line which is defined as the top surface of a freely moving groundwater table. This exit point was determined using the Casagrande-method (Casagrande, 1937). Besides the phreatic line, also the thickness and the volumetric mass of the cover layer needed to be determined. This was done by simulating soil measurements.

Sand dike

In case of the sand dike only the angle of internal friction and volumetric mass of the soil are unknowns, both of which are affected by the unknown amount of contained clay. Besides this, the internal angle of friction also depends on the degree of saturation of the soil (fvb-ffc Constructiv, 2012).

Representative values

The used parameter values are given in Table 1. Most of these values are obtained from regulations and dike characteristics (TAW, 1989, 2001). The other parameter values are acquired from literature (CUR, 1993; GWWmaterialen, 2014).

α, angle of slope	18,43°
γ_d, model factor	1,1
$\gamma_{m,p}$, soil factor	1,0
$\gamma_{m,\phi}$, soil factor	1,1
γ_n, safety factor	1,12
ρ_w, water density	1000 kg/m³
$\rho_{g,clay}$, clay density	1600 - 2000 kg/m³
$\rho_{g,\ sand}$, sand density	1500 - 1750 kg/m³
φ, angle of internal friction	27,5° - 37,5°
d, thickness of cover layer	0,5 - 2 m
g, gravitational acceleration	9,81 m/s^2
h, water depth	3,5 m
z, reference level	0 m

Table 1: Overview used parameter values

UNCERTAINTIES AND VARIATION OF THE PARAMETERS

In this study, four parameters are set as random variables, namely the volumetric weight of the sand and clay, the angle of internal friction of the sand and the thickness of the cover layer. The others are assumed deterministic. Each of the four random parameters were log-normally distributed to prevent negative values. To find out how much uncertainty lies in the various parameters, measurements were simulated in MatLab using the bootstrap principle and the Monte Carlo analysis. For every measurement density from 3 up to and including 30 measurements a repetition of 2000 times was done. After sampling values for the various unknown parameter histograms were made as shown in Figure 4.

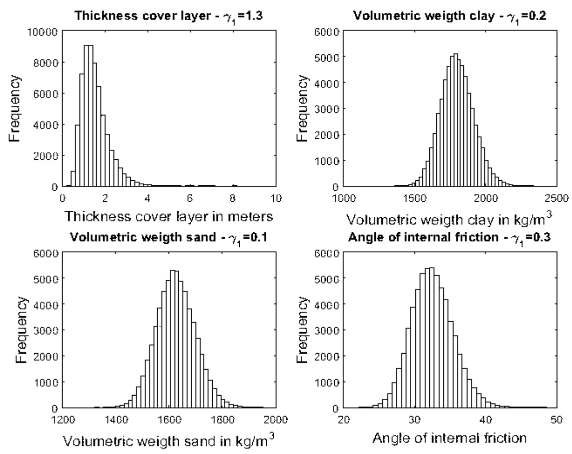

Figure 4: Histograms for the various unknown parameters

From these histograms we can see that the thickness of the cover layer is not normally distributed, but is more skew towards the right and has values up to and including 8 meter. Since a clay layer of 8 meter can hardly be called a cover layer of a dike, the different unknown parameters were sampled again, but this time under a uniform distribution to determine the influence on the uncertainty of the parameters. The numbers that came out of both of these samplings are shown in Table 2.

	Lognormal distribution		**Uniform distribution**	
Parameter	Max.	Min.	Max.	Min.
Volumetric volume of clay	6%	2%	5%	1%
Thickness of the cover layer	45%	15%	30%	6%
Volumetric volume of sand	4%	1%	4%	1%
Angle of internal friction	8%	2%	7%	1%

Table 2: Overview of uncertainty in the parameters

The uncertainties are found by taking the 95% confidence interval for each measurement quantity. The uncertainties are expressed as the deviation in percentage from the mean. The maximum deviation always occurs at a measurement quantity of 3 measurements and the minimum at a measurement quantity of 30 measurements. The exact course of the uncertainty differs for the parameters. The angle of internal friction of the sand and the volumetric weight of the sand and clay have a course in the uncertainty that is fairly similar. The decrease of the uncertainty is largest until 10 to 15 measurements, after this the decrease smoothens. The thickness of the cover layer however still decreases with entire percentage points at a measurement quantity of 30 measurements. On top of this, the uncertainty of this parameter is the largest uncertainty. The uncertainty of the other parameters can almost be neglected compared to the thickness of the cover layer.

THE EFFECT OF MEASUREMENT DENSITY ON THE TEST RESULTS

Model results of the different tests were visualized in figures like Figure 5. In this figure the relative test result (results normalized to one) is shown in combination with the lower and upper limits of the 95% confidence interval around this relative average result.

	Lognormal distribution		**Uniform distribution**	
Test	Max.	Min.	Max.	Min.
Heaving	48%	16%	53%	14%
Shearing of the cover layer	48%	16%	53%	14%
Scouring	7%	3%	7%	2%
Shearing of the dike	12%	2%	11%	3%

Table 3: Overview of uncertainty in the test results

In Table 3 an overview of all the uncertainties in the test results is given. Again this uncertainty is given in a percentage deviation from the mean value. From the

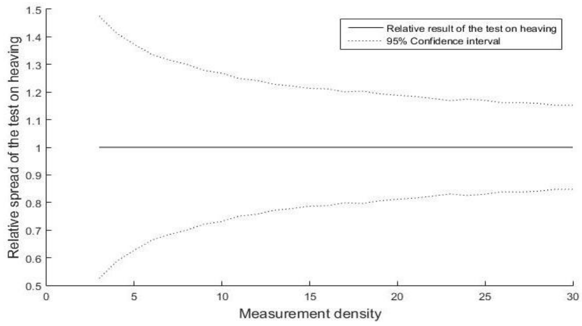

Figure 5: Relative spread of the test results on heaving

table it is clear that the largest uncertainty is in heaving and shearing of the cover layer. This uncertainty is mainly caused by the uncertainty of the thickness of the cover layer. To reduce this uncertainty it is best to invest in reducing the uncertainty of the cover layer. This can be done by increasing the measurement density.

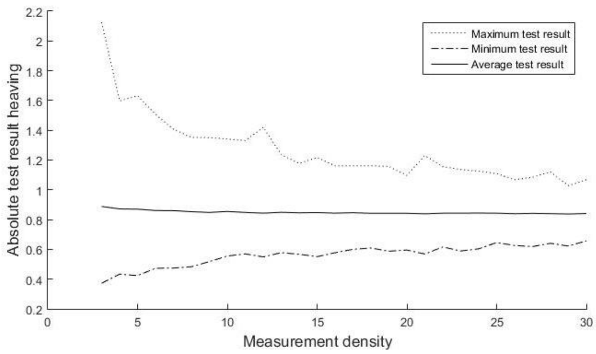

Figure 6: Absolute test results on heaving

Figure 6 shows the absolute (non normalized) results. All the average test results meet the standards that are given by the TAW. The maximum values of the test result for heaving, scouring and shearing of the cover layer are above one, which means that the dike would not meet the standards for micro-instability. From a measurement quantity of 10 to 15 measurements the maximum value of the test results is smaller than one and thus meets the standards regarding micro-instability.

DISCUSSION

The aim of this research was to determine the influence of the measurement density on the test results of river dikes for micro-instability and besides that give a confidence interval for these test results. This is done by using a hypothetical dike with characteristic values representative for a Dutch dike.

In this research a constant water level is assumed and a phreatic line that is in balance. The unknown values remained to be the volumetric weight of the sand and clay, the internal angle of friction of the sand and thickness of the cover layer. The unknown parameters were sampled using a lognormal distribution. This seemed a logical choice since it makes sure that there will be no negative values, but it turned out that the thickness of the cover layer produced unrealistically high values. Therefore the simulation was repeated using a uniform distribution for all parameters. This made sure that the values stayed within the given interval and reduced the variation in the thickness of the cover layer, however it remained the dominant parameter regarding the uncertainty in the test results.

According to TAW (2001) a distinction can also be made in a sand dike where the inner bank is under water and above water. In this research only the sand dike with the inner bank above water was investigated. However, the uncertainties found in the parameters can be used to determine the uncertainty in the test results on a sand dike where the inner bank is saturated.

The relative results found in this research are applicable for every dike that has the same geometry as used in this case. The further dimensions of the dike do not influence the relative results. This makes the results useful for situations in practice.

CONCLUSION

As stated in the introduction it is important to minimise the risk of a wrong conclusion regarding dike safety. Therefore the uncertainty of the actual test results need to be reduced. This research describes the influence of the measurement quantity on the uncertainty of the test results on micro-instability. Micro-instability appears when the cover layer collapses. This can happen in different ways, depending on the type of dike. In case of a sand dike with a cover layer of clay heaving and shearing can occur. In case of a sand dike without a cover layer of clay scouring and shearing can occur.

For all parameters it was shown that the uncertainty decreases as the measurement density increases. This means that when more measurements are taken, this results in a better insight in the true strength of the dike. The point where an extra measurement has no significant influence on the test result lies for most of the tests between the 10 and 15 measurements.

By establishing the point of intersection of the lower or upper limit (depending on the test) of the test result and the fail limit, it is possible to determine the number of measurements needed to reject or accept a dike with a sufficiently high reliability. This number of measurements is different for every dike, since the dimensions of the dike play a part in this. Moreover, the results show that dikes with a cover layer of clay require a higher number of measurements to reach a reliable conclusion regarding their safety with respect to micro-instability.

Recommendations

Every test result regarding soil contains a certain uncertainty. From this research it can be concluded that the uncertainty of test results of a dike with a cover layer of clay is the largest. This is mainly because of the uncertainty in the thickness of the cover layer. So to reduce the uncertainty in the test results it is most effective to reduce the uncertainty in the thickness of the cover layer. This can be done by increasing the measurement density. Reducing the time to by using new techniques can help with this. The applicability and implementation of these techniques need to be researched.

Besides this it was chosen to use a constant water level with an equilibrium phreatic line. In practice this is not always the case, especially in case of a sea dike. What the influence of the changing phreatic line is on the uncertainty can be further researched.

ROLE OF THE STUDENT

Last year I did this research at BZ Innovatiemanagement, at Deventer. I was supervised by Wouter Zomer from BZIM and Jord Warmink from the University of Twente. The topic was proposed by Wouter Zomer and the execution, including the formulation of the research questions, the approach, the processing of the results and the formulation of the conclusion were done by myself.

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