Deltares

Plan for dike on peat experiment

Englisch version

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1 Background

During the five-yearly stability assessment that is required for all primary water defenses in the Netherlands, the Hoorn – Amsterdam section was found to be unsatisfactory. This was a surprising result because the design lake level is only approximately 1 m higher than normal conditions. In the past, when the Markermeer lake was still a part of the Zuyder Zee, the section in question withstood much higher water levels. This historical consideration led to very extensive mathematical analyses of the dike, which justified only very minor changes to the results of the stability assessment. In the meantime, a design has been produced for the dike upgrade. The planned upgrade is considerable, with stability berms up to 30 m in places. The plans will be difficult to implement in the various historical centres located along this section, such as Volendam, Edam, Durgerdam etc.

Debate about the results of the stability assessment and the extent of the upgrade required has focused on three issues. **The first** question to be debated is the design hydraulic load on the dike that was used in the stability assessment and for the purposes of designing the upgrade. The issue under debate here is, in particular, the duration of high water in the Markermeer lake. **The second** is the failure probability required. The situation with respect to the Markermeer dike, particularly on the North Holland side of the lake, is unusual in that the occurrence of design high water does not coincide with a design storm with the associated design wave run-up. This makes it possible to optimise the required failure probability for the stability mechanism. **The third** question being debated relates to the way in which the strength of the peat is included in the calculations. The available models used in day-to-day consultancy for describing soil strength were developed for the purposes of describing the behaviour of clay or sand. These models are not adequate for describing the behaviour of, in particular, fibrous peat. This plan and the research it describes will focus on this third issue. The first question will be elaborated in detail in another context by the Centre for Water Management. In consultation with the Centre for Water Management, discussions will take place to determine how to tackle the second question outside the context of this research plan.

The way in which the strength of peat and organic clay should be determined and included in calculations has been an issue for some years now. Questions relating to the strength behaviour of peat are important, not only for the Markermeer dikes, but also for dikes in the "rivers area" (the central part of the Rhine/Meuse delta in the Netherlands) and for the numerous secondary and peat dikes. In the cases in question, the calculated stability is less than the stability expected by engineers estimated by engineering judgment. The stability of the Markermeer dike is determined to a large extent by a layer of peat situated below the dike body and the land behind the dike. The high degree of uncertainty relating to the strength properties and the way in which they should be determined results in low calculated values for strength that are used as the basis for stability assessment and design.

In recent years, some steps have been taken towards improving our understanding of the strength behaviour of peat and organic clay. Although we now know more, this has not yet led to improvements in the calculation methods used in the guidelines or regulations for determining dike stability. The Rijkswaterstaat Centre for Water Management therefore wants to extend the research into the behaviour of peat in order to improve the calculation techniques. An experiment and field trials play an important role in this respect. The trials make clear the differences between assessment practice and the behaviour of the dike body.

This gives us an idea of the benefits that can be achieved by improving our description of the strength behaviour of peat. In the case of the Markermeer dikes, the benefits referred to here relate both to the optimisation of the design for the dike strengthening and the mitigation of the risks associated with implementation. As stated above, the problems are not confined to the Markermeer dikes. Improved calculation techniques and guidelines will, possibly after elaboration later for other locations, also lead to assessment that is more precise and improved design guidelines for dikes in the "rivers area" and for the numerous secondary and peat dikes in the Netherlands.

2 Structure of research programme

The investigation of the behaviour of peat will involve a research programme taking several years. The study programme will consist of a number of steps. The preparatory work will be done in 2011. Field measurements and field trials in the land behind the dike will play an important role during the preparatory work. The field trials will include, among other things, inducing a sliding plane through the peat. This will make a first comparison possible between the mobilised shear strength in the subsoil with the strength determined in laboratory experiments. These trials will be conducted in the land behind the dike to prevent any negative impact on the stability of the dike. An experiment will be developed, in part based on the field trials. This experiment will, if it is approved, be conducted in 2012 on a part of the Markermeer dike. It will involve loading the dike to establish a picture of the current stability of the dike. After the implementation of the field trials in 2011 and the experiment in 2012, the results will be used as the basis for regulations for determining the stability of dikes on peat for assessment purposes or for designing dike upgrades. This part of the study will be conducted as part of the Rijkswaterstaat Strength and Loading of Flood Defenses Programme (SBW). The field measurements and field trials conducted in 2011 in the land behind the dike will be conducted as preparation for the experiment and the subsequent research.

An important moment in the study will be the go/no go decision planned for mid-November / December 2011. This decision will entail deciding, on the basis of the results of the research conducted in 2011, whether it is sensible and responsible to proceed with the experiment and the subsequent research. In addition, at that point, there will also be a decision about whether it is desirable and responsible to postpone work on reinforcing the dike for five years so that the results of the study can be used to optimise the dike upgrade and to reduce the risks associated with implementation.

In summary, the research programme is structured as follows:

- 2011, implementation of field trials
- November / December 2011, go-no go decision relating to continuation
- 2012, implementation of experiment
- 2012 – 2016, elaboration of results to produce regulations and guidelines for determining the stability of dikes in the context of the SBW programme.

The work for 2011 should produce information that can be used to design the experiment in 2012, and as technical input for the go/no go decision in November/ December 2012. The go/no go decision involves the consideration of a range of factors. First of all, there will be a review of the benefits and necessity of conducting the experiment in 2012, and of the continuation in 2012 – 2016. Secondly, a decision will be taken about whether it is safe to conduct an experiment on the current dike. Thirdly, a decision will be made about the extent to which it is useful, necessary and safe to postpone the reinforcement of the dike until the results of the complete study become available in 2016 in order to take advantage of the possible optimisation of the design for the reinforcement of the dike. The go/no go decision will be taken, after consultations between the Hollands Noorderkwartier water authority and Rijkswaterstaat Centre for Water Management, by the executive board of the water authority. These consultations are not covered by this plan.

For the technical input to be delivered, the final report about the work in 2011 needs to state the study results obtained locally from the field trials in terms of the possible impact on the stability assessment of the entire Hoorn - Amsterdam section. The plan focuses principally on the work for 2011: the field trials, the extrapolation of the results to the Hoorn – Amsterdam section, and the field measurements to support this extrapolation. The plan sketches the broad outlines of the experiment and the subsequent research.

The go/no go decision will bring together the preparatory activities and the activities involved in the research programme looking at the strength of peat. This is because the go/no go decision involves deciding about the continuation of both these areas of activity. In 2011, the two activities - preparations for strengthening the dike and the research programme - can be conducted in parallel. In the period that follows, there will be some moments when the preparations for the dike upgrade can benefit from the results generated by the study programme into the strength of peat. **The first** of these will be after the delivery of the final report about the activities in 2011. **The second** will be after the completion of the analysis of the experiment in 2012. **The third** will be upon the completion of the follow-up study in 2016, when the new guideline for the stability analysis of an embankment on peat becomes available. Preparations for the strengthening of the dike will be conducted according to a specific timetable and using a specific implementation approach and will not be covered by this plan.

3 Document guide

Chapter 4 of this plan will look at the objectives formulated by the Hollands Noorderkwartier water authority ("HHNK") and the High Water Protection Programme ("HWBP"). These are mainly objectives relating to the work in 2011 and 2012, together with the objectives drafted by Rijkswaterstaat Centre for Water Management ("RWS-WD"). These objectives focus more on the follow-up research. Chapter 5 provides an overview of the work for 2011 and describes how the aims set out in Chapter 4 for 2011 will be achieved. Chapters 6 and 7 provide further details relating to the field trials and field measurements. Chapter 8 looks at the timetable. Two annexes have been included with the plan. The first annex gives an impression of the possible approach to the implementation of the experiment. The definitive design of the experiment will, if the go/no go decision is positive, be based in part on the results of the field trials. The second annex consists of a detailed timetable.

4 Objectives of requested activities

The invitation to tender includes objectives formulated by HHNK, HWBP and RWS-WD for the study. The first objective was formulated by HHNK and HWBP and it relates to the period 2011 and 2012. The second objective, which was formulated by RWS-WD, relates to the study as a whole. The following objectives were formulated:
Objective 1: practical objective HHNK / HWBP

- The study programme will provide an answer by 31 October 2011 at the latest about the degree to which dikes on peat are stronger than indicated at present by the stability assessment models.
- The results of the study programme should enjoy broad scientific support and should be demonstrably representative for the Markermeer dikes between Hoorn and Amsterdam.
- The results of the research programme will provide the technical grounds for an administrative decision to be taken in early 2012 by the executive board of HHNK about the continuation of ongoing projects for upgrading the Markermeer dikes between Hoorn and Amsterdam.

Objective 2: scientific objective RWS-WD

- The study programme will produce new insights that enjoy broad scientific support about the strength properties, the behaviour and the failure mechanisms of embankments on peat.
- The research programme will produce new information that enjoys broad scientific support and that can be used by the Centre for Water Management as a basis for determining whether the prevailing stability assessment and design framework for dikes on peat may require amendments and whether supplementary research is required outside the scope of the planned experiments.

It should be pointed out that the go/no go decision to be taken in late 2011 will, on the basis of the research results generated in 2011, consider the extent to which it is meaningful and safe to postpone the dike upgrade for five years pending the results of the research to be conducted during that period, i.e. 2011 – 2016. The practical objective formulated above relates to this consideration.

The description of the objective states on a number of occasions that the results must enjoy broad scientific support. This plan considers this to mean, with respect to the activities in 2011 and 2012, that the Technical Committee of the Water Defenses Expertise Network ("ENW-T") will appraise and approve the results of the study.

The chapter below provides a description of how the objectives above can be achieved on the basis of the field trials. It is not the intention, as part of the research programme looking at the strength of peat, to conduct a repeat stability assessment of the entire dike between Hoorn and Amsterdam. This is a potential trap because the stability assessment also checks whether the dike will comply with the requirements over the next five years. However, there is no time, after the completion of the field trials, to assess the stability of the entire dike before the end of 2011.

5 Approach

The prevailing guidelines and technical reports identify a range of dike failure mechanisms. Dike bodies should be tested for each of these failure mechanisms. The study programme focuses on the strength of peat as a factor in the stability assessment of existing dikes with respect to deep sliding planes. During the stability assessment of the Markermeer dikes, it emerged that the safety factor for deep sliding planes in particular was inadequate. These deep sliding planes pass through both the dike body and the subsoil. In analysing this failure mechanism, the strength of the dike body and of the subsoil, the level of water in front of the dike, and the resulting pore pressure reaction in the dike body and the subsoil play an important role. When analysing for deep sliding planes, the entire system – the dike body, the subsoil, interaction between the dike and subsoil, and hydraulic boundary conditions, including the pore pressure reaction in the dike and subsoil – is important. Seen in this light, the strength of peat is a part of a larger whole, i.e. the stability of the dike body. The study should therefore focus on the complete system. This will be achieved by conducting an experiment on part of the existing dike body. Before the experiment is conducted, field trials and field measurements will take place to establish a picture of two aspects of the system. These are: (1) the strength of the peat layer and (2) the pore pressure reaction in the sand layer under design conditions. The field trials described in Chapter 6 focus on the first aspect and the field measurements described in Chapter 7 look at the second.

Objective 1, the practical objective, requires the results obtained locally to be stated in terms of the entire length of the dike. A large part of the analysis of the results will therefore concentrate on this extrapolation step. The text below describes the broad outlines of the study design and how answers to the stated questions will be arrived at. The elaboration of the study assumes that a location will first be selected for the experiment, even though the experiment will only take place later. The study comprises the following stages:

1	Choice of location	(2011)
2	Inventory of adjoining dike sections	(2011)
3	Implementation of field trials	(2011)
4	Implementation of supplementary field measurements	(2011)
5	Extrapolation of results to adjoining dike sections	(2011)
6	Preparations for, and implementation of, experiment	(2012)
7	Elaboration of general guideline for peat strength in stability analyses	(2012-2016)

In accordance with the detailed timetable described in Chapter 8 The large experiment is planned for 2012; the preparatory activities will need to start in 2011. This plan describes in detail the implementation of stages 1 through 5. This plan provides only a sketch of the possible implementation of stages 6 and 7. If the go/no go decision results in a positive decision after the activities in stages 1 through 5, a detailed plan will be drafted for stages 6 and 7.

5.1 Choice of location

Ideally, the study would have started with the second stage, the inventory of the entire Hoorn – Amsterdam dike section. On the basis of the inventory, it would then have been possible to select the optimal location. However, time restrictions as well as the limited number of available locations, together with the fact that a lot of information is already available from the tests and the preparations for the design of the strengthening of the dike, mean that the first step taken was the selection of the location. The inventory of the dike section – stage 2 – will consist of identifying differences between the different dike sections and the selected location.

The research was initiated to improve the description of the geotechnical behaviour of peat. The aim will therefore be to find a location in the Hoorn – Amsterdam dike section where there is a relatively large amount of peat in the subsoil. In addition, it will be preferable for the selected location to be such that the nuisance for the vicinity will be minimised during the experiment. There is a road on the crest of the dike or on the inner slope along almost the entire length of the dike and this will be closed during the experiment. The aim will therefore be to find a location where there are no buildings and where through traffic can be easily diverted. For the selection of the location, permission to use the land behind the dike and permits for the field trials will also be factors.

The field trials will preferably be conducted in the same location as the experiment. This will allow optimal use of the results from the field trials – the results of borings, CPT and laboratory tests, and the relationship between the laboratory results and the mobilised strength in the field – for the design and analysis of the experiment. However, the satisfactory extrapolation of the results of the field trials to the adjoining dike sections will also require measurements in a number of other locations. This is discussed in greater detail in descriptions of the following stages.

5.2 Inventory of adjoining dike sections

If the field trials show that the strength of the peat exceeds the value adopted in the stability assessment, the benefit that the study programme ultimately delivers will include a higher calculated stability factor. Consequently, the planned dike upgrade will not need to be as extensive and stability berms, for example, can be kept smaller or be dispensed with altogether. In those locations along the dike where the peat layer in the subsoil is thicker than in the test location, a comparable or larger increase in the calculated stability factor will be possible. This benefit, a higher calculated stability factor, could be offset (in whole or in part) by less favourable geometry. The geometry of the dike can be inferior to the test location due to, for example, the land behind the dike being lower, or a steeper inner slope. This can lead to a critical failure plane running mainly through the dike body and only to a limited extent through the peat layer in the subsoil. Granting increased strength to the peat layer will therefore have little effect on the calculated equilibrium factor.

An inventory of the entire dike section will be required to extrapolate the results for the test location to the adjoining dike section. In this respect, two criteria are important: (1) the subsoil and (2) the geometry of the dike body. Geotechnical longitudinal profiles have already been drawn up for the subsoil. Cross-sections have also been established and so the geometry of the dike body is known. On the basis of this available information, an inventory can be made showing locations where the subsoil is more or less favourable than in the test location. The stability assessment looks not only at the thicknesses of the weak strata but also at possible higher pore pressure reactions in the subsoil resulting from the presence of sand layers (or sandier layers). The assessment of the geometry also distinguishes between geometries that are more or less favourable than the tested geometry. The criteria here are crest height, the steepness of the inner slope and the presence of foreland. The last of these is important in the interpretation of the pore pressure reaction in the subsoil. The following table can be drawn up on the basis of the results of the inventory.

		geometry	
		more unfavourable	more favourable
subsoil	more unfavourable	number km design cross-section	number km design cross-section
	more favourable	number km design cross-section	number km design cross-section

Table 1 Extrapolation of results to adjoining dike sections

Table 1 states the four possible categories. An indication is given for each category of how many kilometres of the Hoorn – Amsterdam dike are included in the category in question. A single design cross-section will be selected for each category. A stability calculation will be used to make clear for this design cross-section how the study results will lead to a potential improvement in the test result or the optimisation of the design. Three sources will be used for the purposes of breaking down the dike section into categories and the selection of the design cross-section. The first source is the information and experience acquired during the stability assessment. The second source is the experience acquired by the HHNK with the dike section over the years. The third source is a deformation analysis of the dike section based on satellite images. This third source will be discussed in greater detail.

An analysis will be made of the deformations in the dike body of the Hoorn – Amsterdam dike over the past 10 years using satellite images generated during that time. The results of this deformation analysis will generate extra information about the stability of the dike. Where stability is low, there will be more deformation than in places where stability is high. The dike sections can be compared with one another on the basis of the deformation analysis with the satellite images. Dike sections where there is more deformation will be less stable than dike sections where there is less deformation. The analysis includes the exclusion of other causes that result in the deformation of the dike, such as lower groundwater levels in the polder or the application of a load to the toe of the dike.

Based on the combination of the various factors affecting stability as shown in table 1, experience with the dike and the relative differences in the stability of different dike sections based on satellite images, four design cross-sections will be selected. Each cross-section is representative for one of the categories in table 1. The actual selection of the cross-sections will be based on expert judgments. The extrapolation of the local result to the adjoining dike sections will be based on these four categories. On the basis of the four categories from table 1, it will be possible to make clear to what extent the benefits at the test location can be expected to apply to the other locations as well.

By varying the structure of the subsoil and the geometry of the dike body, it will be possible to determine the sensitivity of these two variables to the benefits achieved locally. Since the length of the dike where this variation has a favourable or unfavourable effect is known, it will be possible to determine in a somewhat qualitative way the possible extent of the benefits for the various dike sections after the completion of the research programme. The satellite-image analyses also provide a link between, on the one hand, the theory (in which variations are expected on the basis of the differences in the subsoil and the geometry) and, on the other hand, the observed deformations of the dike body that indicate fluctuations in stability. In this way, the satellite-image analyses work as a "reality check" for the desk analyses.

5.3 Implementation of field trials

For the purposes of stability calculations in the day-to-day practice of designing dikes and assessing dike stability, the strength of the dike body and the subsoil is determined using laboratory experiments. The aim of the research programme looking at the strength of peat is to improve the description of the strength behaviour of peat. This requires a clear picture of the difference between the current descriptions of strength behaviour and observations in the field. It will be possible to work on improvements on the basis of the observed differences. The aim of the field trials is to determine the strength that can be mobilised over a sliding plane in peat and to compare this with the results of laboratory experiments. The field trial consists of installing a row of watertight containers. A pit will be dug in front of the row of containers. The containers will then be filled with water in stages until the subsoil collapses. The analysis of the induced sliding plane results in the mobilised resistance of the subsoil. By comparing the mobilised resistance from the field trial with the laboratory research and the basic assumptions used for testing and design, it is possible to state whether further study can result in the optimisation of the design. Chapter 6 describes the field trial in greater detail.

The strength of soil, and peat in particular, is highly stress-dependent. It is not only the stress level that is important here, but also the direction of the stresses with respect to the sliding plane. This anisotropy in strength characteristics induced by the stress can be seen, for example, in the fluctuation in strength found, on the one hand, with a triaxial compression test and, on the other, with a direct simple shear test. It can be expected that the strength that develops below a dike body that was constructed a long time ago will be different from the strength below a dike body during construction. In order to determine the impact of stress-induced anisotropy in strength characteristics, there will be a second field trial. In this trial, the containers will be filled to a level of two thirds of the level at which collapse occurred in the first field trial. Finally, the pit will be excavated and a consolidation and creep period will begin. The duration of this period will be determined in the design of the trial. Upon completion of this consolidation and creep period – two months, for example – the containers will be filled further until collapse occurs.

The first field trial will generate information about the strength of the land behind the dike. The practical application of the results of the first field trial will result in the possible optimisation of the berm. The first field trial will also generate the information required for the design of the second field trial. The second field trial will supply information about soil strength below and alongside the dike body. The difference between the results of the first and second field trials will indicate the extent to which the development in strength anisotropy in peat is important for the analysis of the stability of existing dikes.

It is important here for there to be little variation in the subsoil structure and other trial conditions between the two trials so that the difference in strength can be linked to the development of stress in the subsoil. The trials should therefore be conducted at a short distance from one another without influencing each other. This will be elaborated further in the design.

As this plan was being written, the number of supplementary field trials to be conducted after the go/no go decision was still being discussed. Firstly, the possibility has been put forward of conducting a third trial in addition to the two trials described above in which the row of containers will be left in place for a year or longer. A trial of this kind would generate additional information about the impact of time-dependent effects such as creep on the strength of the subsoil. A long trial of this kind could be initiated as early as the summer of 2011 and, in that case, be completed in the summer of 2012. The results of this field trial will then become available after the planned go/no go decision about the experiment. It is expected that a long trial of this kind will generate considerable added value for the subsequent study in 2012 – 2016. The project group has proposed discussing this after this stage has got under way and possibly carrying it out as a supplementary assignment. Secondly, during the review phase for this plan, it was pointed out that every field trial should be conducted in duplicate. This provides a better idea about the reproducibility of the trials and some indication of the spread of the results. Conducting trials in duplicate means that, if the results of the duplicate trials do not differ greatly, the conclusions in the final report on the activities in 2011 can be formulated more precisely. More precisely formulated conclusions make it possible to improve the formulation of the recommendation about the go/no go decision relating to the experiment and the possible postponement of the work on strengthening the dike.

The further elaboration of the plan assumes a set-up with two field trials. If it is decided to conduct duplicate trials, they will not take place at the same time but in succession, making it possible to use the experience from the successive trials.

5.4 Implementation of field measurements

The response of the potential head in the underlying sand layer has a major effect on the stability of the dike. It is expected that this response will be minor. There is a thick relatively impermeable layer on the bed of the Markermeer lake, limiting the response of the potential head in the sand layer. If the experiment planned for 2012 is to be adequately representative, the level of the expected rise in the potential head in the sand layer should be known and integrated in the experiment or the analysis. Because a possible rise in the potential in the sand layer has major consequences for the analysis of dike-body stability, this information is also needed for the extrapolation of the local results to the adjoining dike sections. During the testing and the set-up of the design for strengthening the Markermeer dike, extensive studies have already taken place to determine of the design potential head in the underlying sand layer. As this plan is being written, the results of those studies are only available to a limited extent. As the work is being conducted, there will first be a review of the information that is already available and subsequent activities will be elaborated on that basis. In the remainder of this plan, it is assumed that a few pump tests and associated field measurements will be needed to establish a proper link between a potential change in the water level in the Markermeer lake and the associated response in the potential in the sand layer. The pump tests and associated field measurements are described Chapter 7.

Because the pump tests are important for the extrapolation of the results to the remaining sections of the dike, they have been planned at several locations. One of these locations is the test location; the tests will also be conducted at another two sites.

5.5 Extrapolation of result to adjoining dike sections

On the basis of the field trials, the maximum load that can be applied to the peat layer using the containers can be determined. This maximum load will then be compared with the maximum load that the subsoil can manage according to the available calculation techniques. A range of calculation techniques are available for this comparison. In addition, there are a range of possibilities with each calculation technique for determining the parameters by conducting different laboratory experiments or by interpreting a laboratory experiment differently. Several combinations are possible for the purposes of analysing the field trial, with the calculation techniques being combined with different types of laboratory experiments and interpretation methods. In what follows, combinations of this kind are referred to as working methods. A working method therefore consists of a selected calculation technique, a laboratory experiment and the associated interpretation method. Seven working methods were adopted beforehand for the analysis of the field trials. The working methods adopted have been set out in table 2. The working methods were selected on the basis of current consultancy practice, the results of the "actual strength" SBW study, and the discussion relating to the determination of parameters for dike upgrade projects for which preparations started recently. Each working method in table 2 is therefore an available option at present.

Table 2 makes a distinction between two calculation methods: analytical stability analysis and the finite element method, FEM. Two analytical methods have been adopted for conducting the analysis: the LiftVan and Spencer methods. The prevailing guidelines and technical reports require the Bishop method to be used when there is no uplift, with the LiftVan method being used when uplift does play a role. The current formulation of the LiftVan method means that it converges with the Bishop method in situations where circular sliding planes are the determinant pattern, such as situations in which uplift does not play a role. It was therefore decided to use the LiftVan method in order to match current testing and design practice. The Spencer method also focuses on straight sliding planes. Because there is generally a horizontal component in sliding planes in peat, the Spencer method is also used in the analytical calculations. The FEM calculations are used to improve the approach to calculating the impact of stress and strain on the development of peat strength. During the follow-up in 2012 – 2016, the use of FEM calculations for determining the stability of dikes will be elaborated further.

The first working method in table 2 is the working method used for the stability assessment of the Markermeer dike and the design of the dike upgrade. Where the potential benefits of an improved description of peat strength behaviour are discussed, the calculation results from working methods 1 will serve as the reference.

working method	calculation technique	Parameter identification / laboratory experiments
1	LiftVan / Spencer	Current working method with drained strength parameters from multistage triaxial tests
2	LiftVan / Spencer	Current working method with drained strength parameters from isotropic consolidated single-stage triaxial tests
3	LiftVan / Spencer	Drained strength properties at 2% strain from anisotropic consolidated single-stage tests
4	LiftVan / Spencer	Drained strength properties based on peak and residual strength from anisotropic consolidated triaxial tests
5	LiftVan / Spencer	Undrained strength properties as elaborated in the "actual strength" SBW study. DSS tests are used in peat, and anisotropic consolidated single-stage triaxial tests for clay. In addition, the development of pre-consolidation stress with increasing depth is determined using a number of compression tests.
6	LiftVan / Spencer	Undrained strength properties determined on the basis of field probe measurements, for example with a ball probe, CPT etc.
7	FEM	Strength and stiffness are determined on the basis of the tests conducted for working methods 4 and 5.

Table 2 Description of various working methods for conducting the analysis

The results of the field trial are compared with the results of these seven methods. Because of the relatively limited sizes of the containers, the size of the induced shear plane will also be relatively limited. The analysis of the resulting sliding plane will have to do include 3D effects, and in particular friction at the end faces. In order to establish a picture of the role played by the 3D effect, exploratory calculations will be with FEM.

The first results of the analysis of field trials will be the comparison of the results of the calculations using the seven working methods with the observations from the field trial. This will show which working method provides the closest match with the field trial. In addition, on the basis of the difference between the calculated result using the working method upon which the stability assessment of the Markermeer dike is based and the observed slide, an impression can be established of the potential benefit that can be expected from the follow-up research.

In order to achieve the objectives formulated in chapter 4, two extrapolation steps are required. **The first** is the step in which the results and the conclusions of the field trial conducted in the land behind the dike at the test location are applied to the dike at the test location. **The second** step is the extrapolation of the results for the test location to the remainder of the Hoorn – Amsterdam dike section.

Each of the working methods, including the adjustments required for the proper calculations pursuant to the field trial, will be used to calculate the stability of the dike body at the test location. Here, the results of the pump tests will be important for a proper estimate of the geohydrology of the subsoil. During the appraisal of the calculated stability factor, the required safety levels should be taken into account. Usually, in assessment and design practice, in accordance with the prevailing guidelines, partial safety factors are used to discount the required safety level. However, the results of the field trial can only be compared with the expected strength values and they supply little information about the spread of the strength properties. That makes it difficult to determine the design values for strength on the basis of the field trial.

In the past, the calculated equilibrium factor, determined on the basis of a conservative approach to the mean value for strength, was tested using a required safety factor of 1.4. Compliance with the standard was considered to be achieved if the calculated equilibrium factor was larger than or equal to 1.4. Compliance was not achieved if the calculated equilibrium factor was less than 1.3 and a probabilistic stability calculation was required if the value was between 1.3 and 1.4. The extrapolation of the results from the field trial to the stability of the dike will fall back on this approach. Using the seven working methods referred to above, stability will be calculated using the mean value, including any optimisation based on the results of the field trial, and tested against a value of 1.4. In addition, probabilistic calculations will also be conducted using the analytical methods. The probabilistic methods will produce a failure probability. The calculated results, consisting of a calculated equilibrium factor and failure probability, can be compared with one another and with the results found earlier. However, this comparison cannot be made directly since the stability assessment was conducted on the basis of design values for the strength parameters, including the partial safety factors. The calculations carried out at the time for the purposes of the stability assessment will therefore be made again in such a way that the same basic assumptions are used, enabling direct comparison.

In addition to current stability, potential improvements in the dike are also an important area of attention. The analysis will make calculations for strengthening the dike with a stability berm. The required berm length will be calculated using the optimised mean values, with the calculated stability factor being tested for a required value of 1.4. If the calculated stability factor in the first analysis, in which the stability of the current profile is determined, is already greater than or equal to 1.4, no berm length will be determined.

Table 1 will be used for the purposes of the extrapolation of the results for the test location to the adjoining dike sections (see page 6). Four cross-sections result from this table that are characteristic for the Hoorn - Amsterdam dike section and which are each representative for a part of the dike section. During the implementation of the field trial, the strength of the subsoil was also determined with field probes (method 6). The laboratory tests can be used to determine the correlation between the field probe measurements and the undrained shear resistance. This correlation is then calibrated using the results of the field trial. By conducting the field probe measurements at the locations of the four cross-sections in table 1 in conjunction with the optimised correlation, the strength of the subsoil can be determined at those locations. It is then possible to determine the stability of the dike at those locations. Because the correlation is linked to the mean value for strength, the calculated stability factor here will also be tested against the value 1.4. If a lower value is calculated, the berm length will be determined that is required to comply with the stated requirement.

This means that the field probe measurements will be given an important role in the extrapolation of the results from one cross-section to the entire Hoorn – Amsterdam dike. The grounds for the working method with field probe measurement have been set out in the SBW research but this working method is not yet a component of Dutch day-to-day engineering practice. The working method has therefore not been included in the prevailing guidelines and technical reports in the Netherlands. However, this is an efficient working method that can be used to extrapolate local results to the entire dike section within the time available. Using other working methods for the extrapolation of the study results would involve extra laboratory work. The tight schedule means that there is no opportunity for extra laboratory work in the period after the completion of the field trials and before the delivery of the final report. The time available for the completion of the field probe measurements is much shorter, so that the use of working method 6 for the extrapolation of the results can be completed within the time available. It should be pointed out that SBW research programme and Delft Cluster research programme have already looked at the use of field probe measurements for the purposes of dike stability analyses. This also included an examination of, for example, the spread in the correlation between the field probe measurements and the laboratory experiment results.

During the completion of stage 5, the final report will be delivered on the activities in 2011. The report is scheduled for delivery on 31 October 2011. The report provides an interim description of the status at that time of the study programme looking at the strength behaviour of peat. The final report describes the results of the field trials and provides an indication of the possible expected benefits for strengthening the Hoorn - Amsterdam dike assuming the further full development of the experience acquired. Here, benefits will not only be expressed in terms of potential savings during the strengthening of the dike but also in the limitation of operational risks. The potential benefits of the study programme will be elaborated on the basis of the classification in table 1. This results, for four cross-sections, in the potential benefits and the associated length of the Hoorn – Amsterdam dike section for which the individual cross-sections are representative. From this, it is possible to derive the level of potential benefit that can be expected for the different dike sections.

In addition, the final report will state recommendations about postponing the dike upgrade so that the research results can be used in 2016 for the optimisation of the design for strengthening the dike. It should be emphasised that this report will not include the elaboration of a new and full stability assessment of the Hoorn – Amsterdam dike. Instead, the recommendations will be based upon the stability calculations for five cross-sections. These are the 4 cross-sections described in table 1 and the cross-section at the test location. When considering the question of whether to postpone the strengthening of the dike, the potential expected benefits and the safety of the hinterland during the study period play an important role. The final report on the work in 2011 provides the technical input for the administrative decision about the extent to which it is useful, necessary and responsible to postpone the dike upgrade pending the final results of the research programme looking at the strength behaviour of peat that will become available in 2016.

5.6 Preparations for, and implementation of, experiment (2012)

The field trials and field measurements covered a number of components of the entire dike, including the subsoil. The entire system also needs to be tested, primarily for the purposes of the second objective, as described in chapter 4. Testing the entire system – the stiff dike on the soft subsoil – rather than individual components makes it possible to demonstrate that the conclusions of the examination of the individual components also apply to the system as a whole. For this purpose, an experiment will be conducted on part of the existing dike. An important factor during the testing of the system as a whole is the interaction between the stiff dike material and the soft peat. On the basis of the review by ENW and the project group, it is expected that additional field trials will be conducted in this phase.

The design of the experiment will be produced after a positive go/no go decision in November/ December 2011. The design will be based on the results of the field trials and field measurements. To give an impression of what may be expected, an indication of the set-up and implementation of the experiment has been included in the annexes.

5.7 Elaboration of general guideline for peat strength in stability analyses (2012-2016)

After the field trials have been conducted in 2011, a picture will be established of the potential improvement in the description of the strength behaviour of peat. Completion of the experiment in 2012 will lead to an understanding of how this improvement in the description of the strength behaviour will contribute to an improvement in the assessment of the stability of the dike section where the experiment takes place. However, the aim is to arrive at a generally applicable improvement in the description of the strength behaviour of peat for the purposes of assessing dike stability and designing dike upgrades. The study that follows in 2012 – 2016 should look at the extent to which more advanced models provide a better description of peat behaviour, how the associated parameters should be determined, the extent of the associated uncertainty, how the associated partial safety factors should be determined and, finally, how all these things come together in stability assessments or the design of a dike upgrade. The answers to these questions will be set out in 2016 in a new technical report about the strength behaviour of peat. The technical report will be drafted as part of the SBW programme.

6 Detailed description of implementation and analysis of field trial

The research has been split up into the following stages:

1 Site investigation
2 Laboratory research
3 Drafting of design
4a Implementation of first field trial including prediction for second field trial
5a Analysis of first field trial and design, including prediction for second field trial
4b. Implementation of second field trial
5b. Analysis of both field trials

In the analysis of the two field trials, post-calculations of the failures that actually occur play an important role. The calculations will be conducted using the usual analytical models. These models conform to the assessment regulations and design guidelines and make it clear to what extent, on the basis of the results, optimisation of the design can be expected. In addition, finite element models will be used for post-calculations of the actual shear events. The central focus in this analysis will be on strength anisotropy. In addition, the finite element calculations will establish a picture of the role played by 3-D effects, which will be a major factor in the expected sliding planes in the container experiments. The different stages are elaborated one by one below.

Stage 1, site investigation
The site investigation serves to:

- establish a good picture of the strata in the subsoil to supplement the available data
- to supply enough sample material for the laboratory studies
- to generate an impression of the strength of the subsoil using field probes

The field research will be conducted at eight locations, four per field trial, around the containers. Figure 1 shows the planned locations a) through h. The following tests have been planned for each location for in-site testing (there are eight of these locations in total):

- 1 CPT down to – 15 m below the surface (conventional)
- 1 CPT, calibrated for soft soil measurements down to the pleistocene sand (approx. – 12 m below the surface)
- 1 ball probe measurement down to the pleistocene sand (approx. – 12 m below the surface)
- 1 Begemann boring down to the pleistocene sand (approx. – 12 m below the surface)
- A vane test at 3 depths

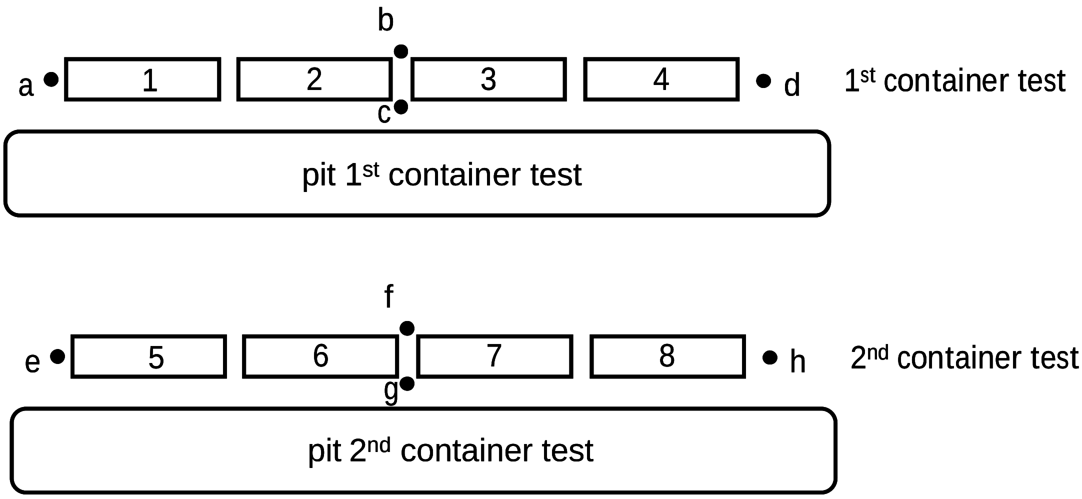

Figure 1 Soil investigation location, before the positioning of the containers

Stage 2, laboratory research
It is expected that the field trial will affect the top 5 to 6 m of the subsoil. The available geotechnical longitudinal profiles show that, at this depth, the subsoil consists primarily of a top clay layer and a peat layer. Below the peat layer, there is a silty clay layer. For the purposes of the design of the research, it is being assumed that there are three layers: the top clay layer, a peat layer and a third layer that still has to be determined. This third layer could be the underlying silty clay layer. However, it may also be decided to split up the peat layer into two layers if this proves relevant.

An important reason for the trials is the discussion about the way in which the strength of the subsoil has to be determined. The analysis of these trials therefore uses different methods to determine strength. The results of these different working methods will be juxtaposed in stage five and compared with the field trial. A total of seven methods have been defined for which the analyses will be conducted (see chapter 5, table 2). The laboratory research should produce enough parameters for each method to conduct the research.

In addition to the tests for determining strength, a number of supplementary tests will be needed for classification purposes. This is primarily of importance for the peat study that will start after the experiment.

Stage 3, Design
Figures 1, 2 and 3 have been included only as an indication. This indicative sketch was drawn up on the basis of the favourable experience acquired in the IJkdijk ("Smart Dike") project with field trials of this kind. The actual dimensions of the row of containers, the distance to the test pit and the dimensions of the test pit (depth, pit slopes on either side and the length of the pit) should be based on design calculations. Important elements during the design of the field trial are:

- number of containers, length of the row
- deciding whether a single row will suffice or whether a double row is needed
- dimensions of the test pit
- distance from the row of containers to the pit
- size of the loading steps for filling the containers.

The design of the first field trial will be based on the DSS tests. The design of the first trial will also serve as the prediction for the first test. After the 1st trial has taken place, work will start on a detailed prediction based on the seven methods referred to above.

The predictions will be conducted prior to the second field trial. Before the first field trial, a design will be drawn up on the basis of DSS tests. For the first field trial, the design will also be the prediction. The decision to conduct DSS tests is based on experience with the "IJkdijk" stability test.

The analyses to be conducted have been summarised in the table below.

analysis	working method***
prediction 2nd field trial	all 7 working methods
optimisation parameters on the basis of result of field trial	all 7 working methods
impact of 3D effect	working method 7
impact of stress and strain on development of strength in subsoil	working method 7
Stability of dike at the test location on the basis of optimised mean values	all 7 working methods
probabilistic analysis of dike stability	working methods 1 – 6
determination of berm length given current SF* < 1.4	all 7 working methods
Determination of equilibrium factor for 4 cross-sections** spread along the dike	working method 6
determination of required berm length given current SF* < 1.4 for 4 cross-sections** spread along the dike	working method 6

Table 3 Overview of analyses to be conducted,
** $SF_{current}$ = calculated safety factor for the current cross-section based on optimised mean values for the strength characteristics.*
*** = these are the four cross-sections from table 1,*
**** for an explanation of the working methods, see table 2.*

Stage 4, Monitoring
Figures 2 and 3 provide a sketch of the monitoring arrangements. A monitoring array will be set up in the middle of the row of containers. The monitoring array consists of 7 pore pressure meters at different depths and an inclinometer located at the front of the first container. In addition, inclinometers are located to the front of the row of containers between containers 1 and 2 and between containers 3 and 4. The containers and instrumentation are installed one week before the experiment takes place. Once proper records have been made of the initial situation, the experiment can start. The experiment starts with the excavation of the test pit. During the excavation of the pit, horizontal deformation is measured in real time using the inclinometers. Once the subsoil is at rest, and horizontal deformations has ceased, the containers can be filled in stages. This will be decided on the basis of the deformation rates and pore pressure criteria in the subsoil. The exact criteria will be determined later during the drafting of the measurement and monitoring plan. The amount of water to be added in each stage will depend on the design calculations. The following steps will all be taken on the basis of the measured horizontal deformations. The next step in the loading will be taken only once the subsoil has settled down enough. Criteria for this purpose will be set out in the operational plan. The containers are linked so that the level in each container is the same. The water

levels in the containers will be measured to ensure that this is the case and to determine the size of the load.

Increasing the load in stages will make it possible to determine precisely at what load collapse occurs. After the conclusion of the test, once the containers have been removed, the sliding plane will be described by determining the top, bottom and internal apex of the sliding plane, if possible.

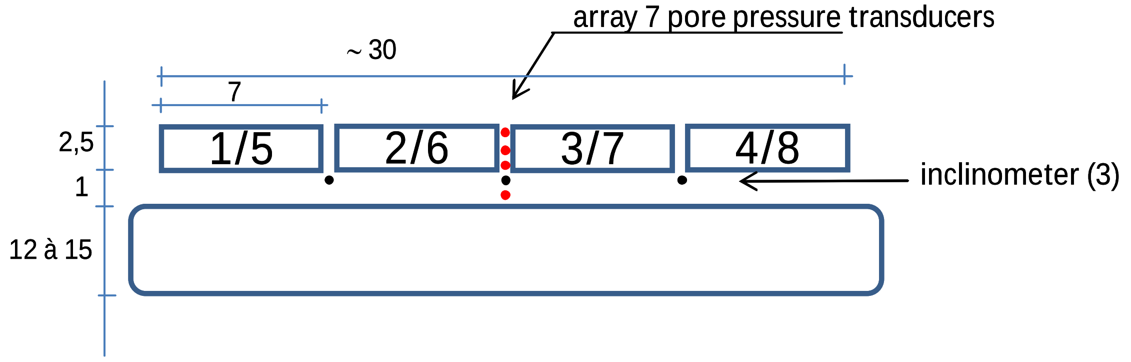

Figure 2 Top view of measurement configuration, dimensions in [m], indicative

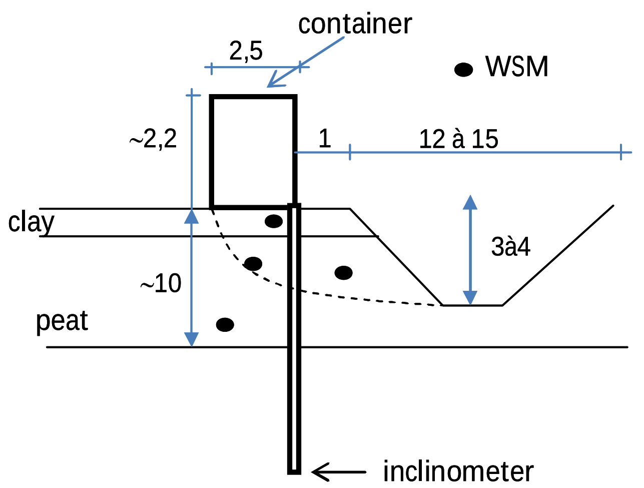

Figure 3 Cross-section of monitoring array, dimensions in [m], indicative

Stage 5, Analysis
The mobilised shear resistance will be determined by post-calculation of the trials. Post-calculation of the results will draw on both the usual analytical methods and on finite element calculations. The analysis using the analytical methods is necessary to link up with present stability assessment regulations and design guidelines. The added value of the finite element calculations is that they make it possible to include anisotropy and also the 3D effect. The pressure conditions below and alongside the dike have a major impact on the maximum strength of the subsoil that can be mobilised. This is a question not only of the stress level, but also the direction, of the stresses. This stress-induced anisotropy in strength can only be described properly using finite element calculations. Recently developed models that describe this anisotropy well will be used in the analysis alongside the Mohr-Coulomb model and the Hardening Soil Model. It is expected that this area in particular will result in improvements to the description of the behaviour of peat.

The sliding plane that will be generated in the field trial is expected to be relatively small. As a result, the usual plane strain approach will not be correct. Using the recently developed PLAXIS 3D it will be possible to establish an idea of the size of the impact of the 3D effect on the strength found. The 3D calculation approach will be tested using Plaxis 2D calculations. It was decided to adopt this approach in order to keep the resolution of the 3D calculations comparable with the 2D calculations.

The mobilised shear resistance found over the sliding plane will then be compared with the various methods used to establish the strength properties in the laboratory experiments by using field probes.

7 Detailed description of field measurements

To reduce the location-specific uncertainties in the increase of the pore pressure in the sand layer in response to the variations in the water level of the Markermeer lake, pump tests will be conducted. In this way, geohydrological parameters such as the permeability and the storage coefficient of the aquifer can be determined, as can the hydraulic resistance to vertical flow through relatively impermeable layers. During the experiment, changes in groundwater levels will be measured in wells at different distances from the pumping well. Using the drop in the observation wells, it is possible to determine the geohydrological properties.

The design and elaboration of the pump test involves the following basic assumptions:

- Summer level of Markermeer lake NAP – 0.20 m;
- Winter level of Markermeer lake NAP – 0.40 m;
- Stability assessment level 2006 NAP + 0.70 m for Hoorn – Amsterdam section (a few local exceptions near Hoorn, NAP + 0.80 m);
- Design lake level, planning period of 50 years, = NAP +0.97 m;
- Design duration, 30 days build-up, 10 days constant, 30 days rundown.

The experiment includes the following stages:
1. Site investigation
2. Laboratory research
3. Design
4. Implementation
5. Analysis

1. Site investigation
The supplementary site investigation for each pump well consists of 1 CPT and a Begemann 29 mm boring including sand sampling. In addition, five observation wells per pump well will be placed in the first aquifer and two pore pressure meters will be placed in the Holocene stratum near the pump well.

2. Laboratory research
The laboratory work will consist of processing the Begemann 29 mm borings and three grain distribution tests on the sand to estimate the permeability of this sand using the Den Rooyen method.

3. Design
The location of the other two well tests (the first will be at the test location) will be determined on the basis of the interpretation of the soil investigation conducted along the Amsterdam-Hoorn dike for the purposes of the stability assessment.
For the purposes of the pump test, a well will be drilled that will contain an extraction pump. The water from the well will be discharged into the surface water. Depending on the amount discharged, a permit will be required. The five observation wells will be installed in and around the well. One observation well will be located in the well, one will be more than 200 m away from the pump well (depending on the predictions) for reference monitoring purposes and three will be located in between. On the basis of the amount of the extracted water, the fall in the potential head found with the observation wells and the size of the reaction in the

observation wells and the water level in the well, it will be possible to give answers to the questions under investigation.

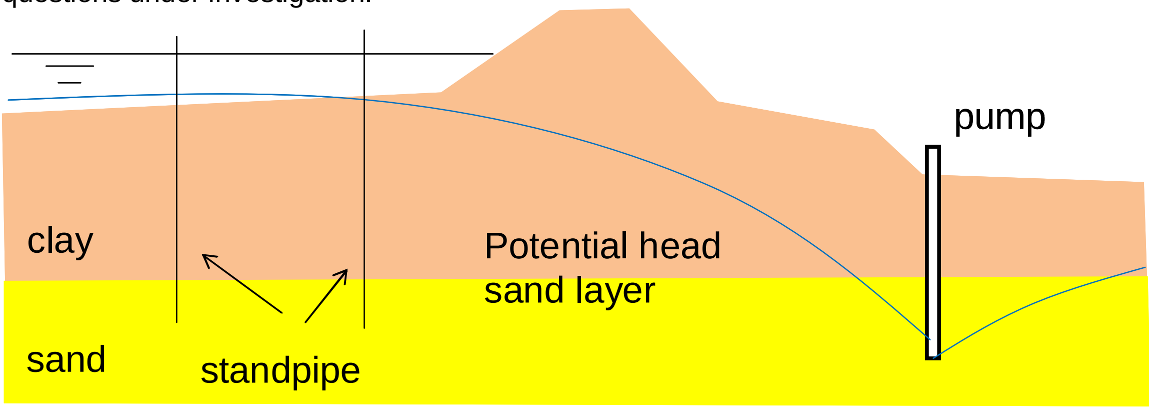

Figure 4 Indicative sketch of pump test, only two of the five planned observation wells are shown.

That is why, for the purposes of the experiment, the following are important:

- The pump well;
- Extraction pump with flow meter registering continuously;
- The monitoring network of observation wells and water-pressure meters, equipped with divers and log boxes that register at minute intervals.

It was decided to conduct an extraction test because this is easier to carry out than an infiltration test and it also provides clear answers to the questions being researched.

4. Implementation
The planned duration will be based on the predictions and the future operational plan but it will be a maximum of one week including the baseline measurements. A range of approaches to loading the dike can be devised, depending on the geohydrological conditions. The actual extraction of the water from the well is not expected to take more than one working day. The experiment will include the extraction phase and then the infiltration phase. The extraction phase will continue until, at a certain flow, the water levels no longer fall. The exact location of the pump test in the cross-section of the dike depends on the interpretation of the research that has already been conducted, the availability of the plots of land and the authorisation procedures. At present, consideration is being given to a location in the berm of the dike or just behind that location in the surface inside the dike.

5. Analysis
The analysis consists of entering the observation well readings in graphs by setting out the drop in the water levels in the observation wells over time. In this way, it is possible to determine the transmissivity, the *KD* value, the elastic storage and damping.

Both in the prediction and analysis phases, the results will be reviewed with geohydrologists from Deltares and the Centre for Water Management.

To ensure that the results are representative for the Markermeer dikes between Hoorn and Amsterdam, three pump tests will be allocated to different locations along the dike (with one of them at the location of the container experiments). The phased plan described above will be the same for all three tests.

8 Timetable

Chapter 5 provides a summary of the work in 7 stages. After stage 5, there will be an important go/no go decision. Stages 1 through 5 will take 30 weeks. If the work up to and including stage 5 has to be completed on 31 October 2011, the work needs to start in the first week of April. This means that this plan must be approved before then and that a location will have to have been selected. If, for example because of the selected location, agreement from the land owner or authorisation procedures, the work starts later, the time required for the work will remain the same (30 weeks) and the completion date will therefore be later. An important assumption here is that there will be no problems acquiring the required authorisation.

It is important for the field work, CPTs and borings to start quickly, so that the design for the experiment and the laboratory work can get started.

Assuming commencement in the first week of April, it will then be possible to start setting up the test location in the last week of April and the first field trial can take place in the last week of May. The second trial can then be set up and conducted in the last week of August.

In the interim, the laboratory experiments will be conducted and the predictions for the second trial will then be drawn up. In addition, in the interim, the pump tests will take place and the preparatory work for the extrapolation of the local results to the adjoining dike sections will be done.

The analysis of the container experiments will take place in September 2011. Following on from this, in October, the local results will be extrapolated to the adjoining dike sections. This extrapolation will result in the recommendation about the implementation of the experiment in stage 2 of the study.

A Indicative set-up of experiment

A.1 Indicative description of experiment

At the time of the current plan being written, the exact details of the experiment were not yet known. The drafting of a preliminary design, including an operational plan, is a part of the work to be conducted in 2012. The design of the experiment will be based on the results from phase 1. The test set-up below was used during the drafting of this plan.

The experiment will involve placing a design load on the dike body and measuring the resulting response of the dike body. In accordance with the "Technisch rapport waterkerende grondconstructies" (*Technical report for water retaining soil structures*), and the underlying reports, three load effects will be taken into consideration. The first is the water against the dike body. The second is the load imposed by traffic on the dike body. The third is the decline in the strength of the subsoil and dike body as a result of water infiltration, pushing up pore pressure in the dike body and subsoil and reducing granular stress and therefore the strength of the dike. These three factors play an important role in the practice of designing and assessing dike stability and should therefore be included in the experiment.

To raise the water level in front of the dike body, a test pit will be made on the side of the Markermeer lake by installing a sheet pile wall at some distance from the dike body. The area between the sheet pile wall and the dike body can be filled with water. It is important here for the area within the pit to be adequate to generate a realistic infiltration pattern in the dike body and the subsoil. For the time being, a length of 300 m and a distance to the dike of 50 m is being assumed.

The traffic load is a temporary load that results in an increase in pore pressure in the subsoil but not in an increase in the effective stress, and therefore in an increase in strength. The reaction of the subsoil to traffic load is undrained. Because the development of pore pressures in the subsoil play an important role and the design duration of the design lake level covers a period of several weeks, the traffic loads should not be included in the experiment as a permanent factor. The traffic load should be activated at a given moment during the experiment. The traffic load should be simulated only after the high water level in front of the dike body is already in place. It would be preferable for the traffic load to be activated remotely, with consideration being given in this respect to filling containers with water.

The pore pressure reaction in the subsoil is the result of the higher water level in front of the dike body. The design of the experiment can make a distinction between water that infiltrates directly into the dike body, and increasing pore pressure in the sand layer below the dike body. The sheet pile wall in front of the dike body can be used to raise the water at the front of the dike for good simulation of infiltration in the dike body. It is difficult to create an increase in potential in the subsoil. Because the underlying sand layer is thick and very permeable, the planned approach using a sheet pile wall will not be adequate to simulate a representative situation in this respect. The studies for the purposes of assessment and the design of the upgrade of the Markermeer dike have shown that the bed of the Markermeer lake is impermeable. In addition, there are deep polders behind the dike body, and that means that high potential in the sand can easily seep away. At the time of the current plan being written, these studies have not yet been examined and it is not yet known to what extent they will be used for the elaboration of the experiment. These studies will be used in the design of the experiment. In addition, the work for 2011 also includes field measurements. These field measurements based on pump tests are intended, among other things, to determine the extent to which a raised potential in the underlying sand layer can be expected and the extent to which it will be important for the representativity of the experiment. If it should emerge from the measurements that the effect of a raised potential in the sand layer is not negligible and that it is required for the implementation of the experiment, the potential in the deep sand will have to be raised artificially. This will make the experiment considerably more complex.

The implementation of the experiment focuses on the relationship between, on the one hand, the loads placed on the dike body and, on the other, the deformation of the dike body and subsoil. Both need to be monitored closely during the experiment. During the design of the experiment in 2012, an extensive measurement and monitoring plan will also be drawn up. That plan will draw on the experience acquired during the "IJkdijk" project. The size of the external load, the level of water in the sheet pile pit and the applied traffic load can be determined accurately. To determine the levels of pore pressures in the subsoil, a number of monitoring arrays will be used. Pore pressure meters will be installed along the length of these arrays in the dike body and the subsoil at various depths. Deformations of the dike body and subsoil will be measured using both inclinometers and glass-fibre technology. The reasons for the locations selected for the instruments in the dike body or subsoil will be stated in the measurement and monitoring plan.

The installation of a sheet pile wall has been planned during the execution of the experiment. Sheet piling will be positioned in the foreshore for this purpose. After completion of the experiment, this sheet piling will preferably be removed. During this operation, it is conceivable that a connection will be established between the water of the Markermeer lake and the deep sand layer. At present, trials are being conducted on behalf of Waternet looking at how sheet piling can be removed without this happening. During the drafting of this plan, it was assumed that the results of this study can be used during the design of the experiment.

A.2 Load size

During the experiment, a design load on the dike body will be simulated over a small distance and the response of the dike body will then be measured. In daily engineering safety margins will be applied in the design calculations. Calculations demonstrate that the calculated cross-section complies with the required safety margin. For the stability assessment of existing dikes an equivalent procedure is followed. The interpretation of the experiment should comply with this procedure. However, analysis of (only) one experiment in which the dike is loaded to its design load will not provide information about the required safety margin.

In the past, the stability of dikes was calculated using the mean value for the strength of the subsoil and dike body, and the results of the calculations were tested against an equilibrium factor of 1.4. (If an equilibrium factor between 1.3 and 1.4 was found, a probabilistic analysis had to be conducted). The safety factor, SF, is defined as follows:

$SF = \frac{\sum R}{\sum S}$, where *S* represents the load and *R* the maximum resistance to slide. The load is determined by the design high water level, the effect of the design high water level on the potential heads in and under the dike body, and the traffic load. The resistance to slide consists of the strength of the soil.

The current guidelines and technical reports prescribe a working method based on partial safety factors. For the purposes of elaborating a working method with partial factors, it was decided to adopt a partial factor for the load of 1.0. In other words, no uncertainty was taken into account in the load. The partial safety factor for the strength was then broken down into a schematisation factor, model factor, material factor and damage factor. For the determination of the values of these parameters, it was decided to avoid any break with the past. In other words, the required level of safety, which originally resulted in an equilibrium factor of at least 1.4, has been expressed as a reduction in strength *R*, via the partial safety factor for the strength, that is such that the calculation result does not change substantially. During implementation, the actual behaviour will be measured that has to be compared with the mean value for the strength properties. The impact of the model and damage factors on that behaviour is awkward to determine. In order to nevertheless establish a link with the required safety level, it has been decided to fall back on the original requirement: SF $\geq$ 1.4. Here, the uncertainty in the calculation is expressed as an increase in the load of 40%. The benchmark for the experiment will therefore be a load that is 40% higher than the design load. If the dike body can cope with this load without a sliding plane being induced, the stated safety requirement will have been met.

In short, the implementation of the experiment consists of the following stages:

1. raise water level in pit to design level, NAP + 0.97 m
2. keep water level constant until a stationary situation is reached
3. if there are no signs of any loss of stability, raise water level to NAP + 1.52 m (design level + 40%)
4. keep water level constant until a stationary situation is reached
5. add traffic load
6. lower water level in pit to surrounding level of lake, wait until pore pressures in and under the dike body have returned to original values.

It has been assumed here that the initial situation corresponds to the winter level of NAP – 0.40 m.

A.3 Safety

In 2011, only small field trials have been planned in the area behind the dike. The implementation of these field trials will not endanger the stability of the dike in any way whatsoever. In 2012, after the go/no go decision in late 2011, an experiment will be conducted on the existing Markermeer dike. Failure of the dike body is not expected during the experiment. If there is any failure, the inner slope will slide, resulting in a crack in the crest bridging a height of a few decimetres. No water will flow into the polder after this slide.

If, contrary to every expectation, water does flow into the polder, the presence of the sheet pile wall will limit the amount of water. During the experiment, the sheet pile wall will act as a temporary replacement dike. The dimensions of the sheet pile wall will be planned accordingly. If, after the completion of the experiment, it emerges that the dike has been so weakened that its water-defense capacity is inadequate, the sheet pile wall will be kept in place until the dike has been repaired again during the next summer season.

Despite the considerations listed above with respect to the safety of the local inhabitants, a soil depot will be put into place near to the test location so that soil can be brought in quickly to build a stability berm. If the slope does slide, it may be desirable to put a berm of this kind into place in order to minimise the damage to the dike body.