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Dikes on peat-soil: a strongly improved design method

The quality of over 33 kilometres of the Markermeer dikes between Hoorn and Amsterdam was found to be insufficient and need to be reinforced. Since these dikes are partly on peat soil, based on current calculation rules, relatively strong stability verges were considered. Research has shown however, that in practise dikes on peat soil are often stronger than current design calculation methods indicate. Cause for the development of an improved design method for this type of dike.

For decades now the stability of dikes has been monitored but still it appears to be difficult to establish strength parameters for especially humus clay and peat layers, in other words: layers that contain many organic substances. The discussion focuses on the question: how do laboratory tests need to be executed and interpreted to become representative for the behaviour of the ground layer the samples for these tests were taken from.

To help this discussion forward Deltares has, in close cooperation with the water board Hollands Noorderkwartier and the Department of Waterways and Public Works carried out a research titled ‘Dikes on peat’. This research focuses on the large-scale field-tests and the development of a design method for peat dikes. The field-testing was executed in 2012 in the area of Uitdam in Noord-Holland. The results have now been translated into a method specially designed for the Markermeer dikes justifying the actual peat strength in that area.

Field trial activities

In every day engineering practice strength characteristics of soil is determined with the use of laboratory tests. For all sorts of soil it applies that there needs to be a translation of the parameters that were determined in the laboratories according to small samples of the total soil layer behaviour at the location. For peat this translation is complex, due to the large heterogeneity in a peat layer, the fibre structure and the low tensions in peat. The latter requires relatively high measurement accuracy in the laboratory in order to lead to sufficient reliable results.
To acquire a better understanding of the difference between the strength measured in the laboratory and the actual strength of the peat layer in the field, five large field trial activities have been carried out in the surrounding environment of the Markermeer dikes (in the hinterland). During these trials a large part of soil was constantly being burdened up to the moment the soil collapsed (see picture). The volume of the soil part was comparable to the volume of a small dike displacement.

Prior to the field trials, thorough laboratory research had been carried out. Based on these investigations several different testing approaches, such as Direct Simple Shear DSS (see picture) and triaxle tests and interpretation methods were used to determine the parameters for the peat strength. Using both drained (presuming water drainage through pores) and undrained (presuming pore water cannot be drained) methods. For stability analysis this makes a difference according to the speed of an occurring displacement. A displacement that arises fast enough for minimal consolidation alongside the slip plane is considered to be an undrained displacement.

Subsequently these parameters have been imported in different calculation models Bishop, LiftVan, Ending Elements Method) for the forecasting of the failure mode. Providing a total of seven different approaches, each with another combination of laboratory research methods and calculation models. Besides the laboratory research also field penetration measurements (cone penetration and convex probe measurements) were performed. Results were compared to the field trials results and the laboratory tests results. Finally the different testing phases were recalculated. It was analysed which calculation model best matches the ascertained failure behaviour. All these factors together (laboratory research, field trial and calculation models) determined the strength of the peat.

Stronger than expected

Field trial results indicate that peat is stronger than accounted for in the actual reinforcement design, in accordance with the prevailing guidelines (Zwanenburg, 2013). The analysis of the field trials shows that the undrained strength characteristics are more in line with the observations from the field trials than the drained strength- characteristics. The methods emerging from the undrained approach lead to significantly more strength at low tension and are therefore more in line with the strength for peat that was detected in the field trials.
In addition the prevailing guidelines are based on triaxle tests for the determination of the strength characteristics. From the comparison of the results of the field trials and the seven procedures for the determination of the strength characteristics of peat, it appears that the DSS-trial (in combination with undrained qualities) aligns better with the results of the field trial. The prevailing method leads to a significant underestimation of the strength that has been perceived in the field trials.

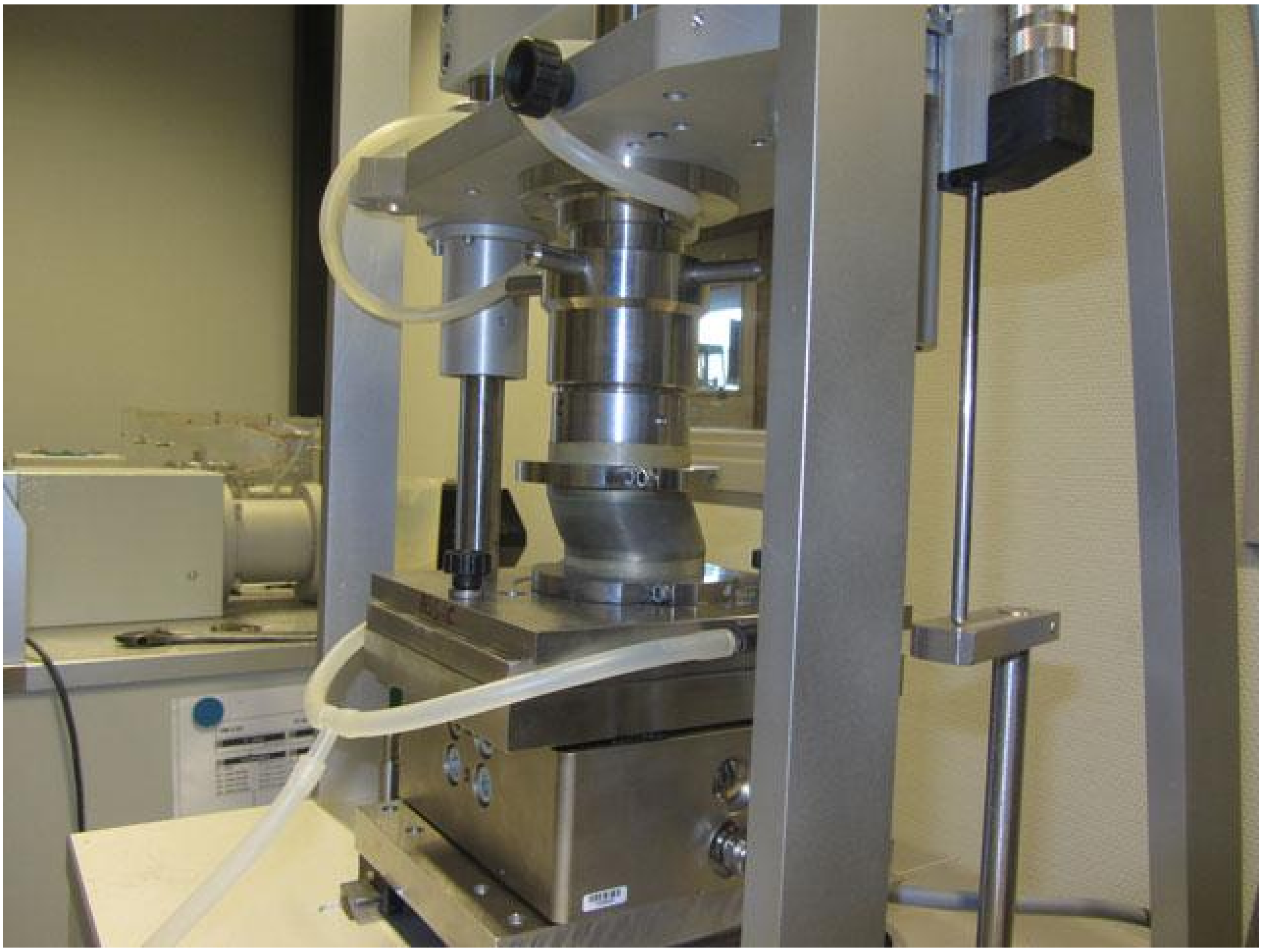

Field

trial: peat is being increasingly burdened until collapsing

Analysis of the failure cause shows that peat acts differently from the way actual calculation models for determining stability suppose. Such as the manifestation of the straight slip planes, instead of the curved planes most models calculate with (Zwanenburg, de Bruijn & de Vries 2012). Therefore besides the calculation models LiftVan and Bishop the model Spencer-Van der Meij was applied as well. The Spencer-VanderMeij method acknowledges the straight slip plane and is therefore best capable of finding the determinative slip plane. Calculating with use of the Spencer-Vander Meij method is considered to be a refinement of the calculation results of the methods Bishop and LiftVan.

Implementation

With the use of the field trial results the method of transforming relatively small-scale laboratory test results to the behaviour of a total soil layer has been validated and improved. However, the results of the field trials are not necessarily practical applicable.



DSS-test part of determination of strength and behaviour of the peat in the new designing method

First of all, the range of strength characteristics and soil heterogeneity must be taken into account. A transformation of characteristics that were locally found to other, not sampled cross sections and embankment extension must take place.
A secondly important reservation relates to the accuracy of the DSS-testing: the low pressure in peat imposes high demands to the accuracy of the execution of the DSS testing. Not only regarding to measurement accuracy, but also to the influence of for instance sample disturbance.

These comments are included in the development and foundation of the improved design method for dikes on peat-soil (Zwanenburg 2014). Protocols for the execution of DSS-testing on peat and correlations based on four calibration locations alongside the Markermeer dike were composed, for the transformation of the locally found strength features to other cross sections.
These correlations have specifically been composed for use during the calculation of the stability of the Markermeer dikes. The method describes the full design line from parameter determination up to composition of the dike reinforcement design and is made up of eight steps. The first seven steps determine the 0-variety: the calculated stability of the current situation. In case of insufficient stability, the dike reinforcement is designed subsequently.

Step 1 - Choose profiles
Step 2 - Carry out field activity
Step 3 - Carry out laboratory tests
Step 4 - Compose correlations
Step 5 - Determine calculation parameters
Step 6 - Determine other starting points
Step 7 - Design 0-version
Step 8 - Design dike reinforcement

The essence of the method consists of carrying out field penetration measurements in each of the cross sections that are to be calculated. Within the calibration fields' comparisons between the field penetration measurements and the completed laboratory research were drawn. Based on results here, correlations were composed. Measurements from each profile must be made available to reduce uncertainty elements in the determination of the peat soil strength features. With the use of the correlations the field penetration measurements are translated to strength profiles in the depth. The strength profiles are then used in the stability analysis for dike reinforcement design.

With regard to the current design calculation methods the method is innovative on a number of points. Most important the parameter determination (DSS-test and undrained shear strength) of the peat layer and the additional use of the design model Spencer-Vander Meij for the stability analysis. Finally, in view of a certain spread in soil characteristics and uncertainties in model calculations, a safety margin for the design calculations has been determined.

Impact of new knowledge

With the improved design method for dikes on peat soil the strength and the behaviour of peat can be calculated appropriately. The design method is in line with the developing Legal Test Instrument (WTI) that will become effective in 2017 in the Netherlands. More insight in the peat strength can lead to less expensive and less radical reinforcement measures. It is to be expected that at some places a leaner reinforcement could suffice. Potential savings that will result are still difficult to predict.
The team working on the reinforcement of the Markermeer dikes uses the improved design method dikes on peat for new dike reinforcement design calculations. The calculation results are expected in the winter of 2015.

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Background picture:
Part of the Markeermeer dikes between Amsterdam and Hoorn, that need reinforcement. But how? And at what costs?

Summary

Over 33 kilometres of Markermeer dikes between Hoorn and Amsterdam have found to be insufficient and in need of reinforcement. These dikes are partly grounded on peat soil. Geotechnical expertise and area experience suggest that dikes on peat-soil are in practise stronger than current design calculation methods indicate. This suspicion was approved by practical research, which shows that the strength of the peat is stronger than can be analysed from the prevailing guidelines for strength characteristics determination. Field trial results have been transformed into a design method focussing on the Markermeer dikes in compliance with the peat strength. Regarding the current calculation rules, the method is innovative on several points. Most important are the parameter determination (DSS-test and undrained shear strength) of the peat-layer and the complementary use of the calculation model of Spencer van der Meij in the implementation of stability analyses.

Literature

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