Project Summary D2 - Modelling of sheet pile reinforced dikes in organic soils Insights from the full-scale Eemdijk test

Lengkeek, H.J.

Publication date
2022

Document Version
Final published version

Published in
Towards Improved Flood Defences

Citation (APA)
Lengkeek, H. J. (2022). Project Summary D2 - Modelling of sheet pile reinforced dikes in organic soils: Insights from the full-scale Eemdijk test. In M. Kok, J. Cortes Arevalo, & M. Vos (Eds.), *Towards Improved Flood Defences: Five Years of All-Risk Research into the New Safety Standards* (pp. 133-136). TU Delft OPEN Publishing.

Project Summary

D2 - Modelling of sheet pile reinforced dikes in organic soils

Insights from the full-scale Eemdijk test

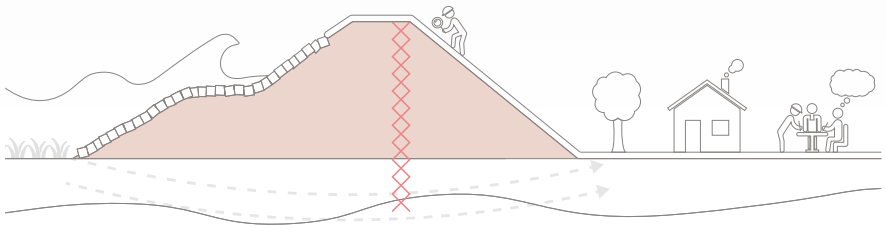
By Arny Lengkeek
Delft University of Technology

Project start: 09/2017
Project end: 09/2021

Promotors

Dr. ir. R.B.J. Brinkgreve
Delft University of Technology

Prof. dr. ir. S.N. Jonkman
Delft University of Technology



Outcome

This project developed an adjustment of the cone penetration test (CPT)-based classification chart to account for organic clays and peat. Furthermore, new CPT-based correlations are developed for geotechnical parameters of organic soils. Moreover, we developed a new model based on critical state soil mechanics, linking the effective strength parameters to undrained strength parameters, following existing approaches for slope instability analysis. Finally, we carried out a back analysis study of the Eemdijk full-scale dike failure test, consisting of three tests: (1) a ground dike, (2) a sheet pile reinforced dike and (3) pull-over tests on sheet pile panels. The interpretation of the test measurements provided valuable insights into the sheet pile performance to extreme loading conditions and beyond failure.

Figure 1: Eemdijk full-scale test; dike with sheet pile reinforcement prior to failure. Photo by Arny Lengkeek.

Motivation and practical challenge

As a geotechnical engineer with over 20 years of practical experience on hydraulic and geotechnical projects in the Netherlands and abroad, my motivation is related to better combining the theory with engineering and practice for dikes. Therefore, this project builds upon the current slope stability assessment approaches of dikes with sheet pile reinforcement and my experience in soil parameter determination, constitutive models and soil-structure interaction. This knowledge comes together in interpreting the soil investigation tests and related parameters, which are input for the advanced finite element method (FEM) models used for the stability, the strength of the sheet pile and the deformation assessment. Moreover, the Eemdijk full-scale test was a unique experiment that allowed me to validate analytical models' performance in the dike engineering practice.

Research challenge

This project answers the following research question: How does a dike reinforced by a sheet pile stability wall perform under high water conditions, and how can this be modelled? Subquestions are divided into two categories. The first category applies to parameter determination for dikes in general, and the second category to the Eemdijk experiment ("Eemdijk damwandproef") that focuses on dikes reinforced by sheet piles.

Innovative components

In the Netherlands and other deltas globally, very soft and highly organic soils are omnipresent. With the adjustment of the CPT-based classification these organic soils are better classified. Furthermore, new CPT-based correlations are developed, for example the soil unit weight for soils, ranging from sands to peat. A new theoretical model (CSR model) was developed, implementing the Limit Equilibrium Method (LEM) on slope stability analysis. The new relationship obtains the undrained shear strength based on effective strength and stiffness parameters. Finally, regarding the "Eemdijk damwandproef", two parallel 60 m long full-scale test dikes of which one was reinforced with a sheet pile were loaded until failure:

Figure 2: Eemdijk full-scale test; dike with sheet pile reinforcement after failure. Photo by Arny Lengkeek.

1. Sheet pile pullover tests consisting of 4 sheet pile configurations in length and width.
2. Ground dike stability test where the water level in the sand core of the dike is step-wise increased by infiltration.
3. Sheet pile dike stability test to create a realistic load scenario and failure mechanism.

Relevant for whom and where?

Engineers who design dikes with structural inclusions, such as sheet piles, with finite element method (FEM) models. Engineers who use CPTs

for parameter determination of soft organic soils for civil engineering projects in general.

Progress and practical application

This project developed improved CPT-based classification and correlations for the organic soils, directly applicable for Dutch dike engineering projects. The correlations are based on statistical methods and include the confidence interval.

The new developed CSR model to obtain the undrained shear strength strikes a balance between the current practice using the empirical Stress History and Normalised Soil Engineering Properties (SHANSEP) equation and the theoretical elaboration of undrained shear strength based on critical state soil mechanics. The CSR model allows for a variable spacing ratio that can be fitted to laboratory test data. The CSR model can be implemented in LEM, where it can be used for stability analysis.

The Eemdijk full-scale test gave insight into the soil-structure interaction of the structurally reinforced dike on soft soil, loaded by high water and uplift conditions. The capacity of sheet piles complies with the Eurocode and even shows robustness after failure for a less

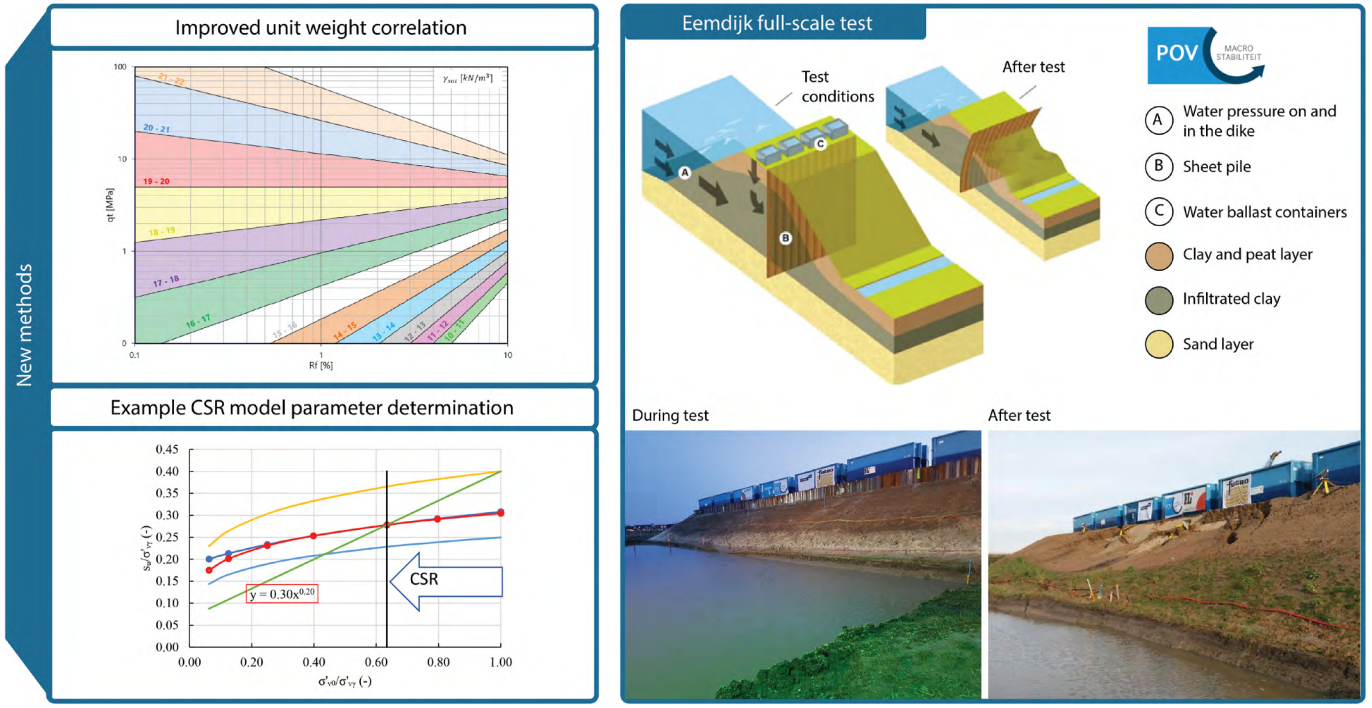


Figure 3: Components of the research relating the new methods and the Eemdijk full-scale test including an illustration and photo impressions during and after the test. Sources: Illustration and after test photo by POV macrostabiliteit. During test photo taken by Arny Lengkeek.

conservative approach than in the current guidelines. The sheet piles contribute to the dike's water-retaining capacity after structural failure and prevent breaching. For a detailed description of each finding, **please check the project outputs below**.

Recommendations for practice

- Consider using the updated CPT based classification given its improvements compared to previous methods for the sedimentary deposits found in the Netherlands.
- Consider using the new CSR model to compare effective strength and undrained strength parameters and reduce uncertainties in parameter determination and stability analysis.
- The back-analysis of the Eemdijk confirms that despite the complex soil-structure interaction, the FEM models perform well. The strength and deformations are underestimated due to anisotropy and 3D effects. The reduction of stiffness parameters is not required for advanced models as the reduction in strength parameters already covers this.

Key project outputs

Lengkeek, H.J., Jonkman, S.N., & Kanning, W. (2021). Application of geo-statistics and pairwise established CPT-based correlations for line infrastructure. http://isc6.org/images/Cikkek/Sessions/ISC2020-487.pdf

Lengkeek, A., Naves, T., Post, M., & Breedeveld, J. (2019). Eemdijk full-scale field test programme: sheet pile pullover tests. Doi: 10.32075/17ECSMGE-2019-0456

Breedeveld, J., Zwanenburg, C., Van, M., & Lengkeek, A. (2019). Impact of the Eemdijk full-scale test programme. Doi: 10.32075/17ECSMGE-2019-0398

The components of this research are developed for a range of typical dike sections for the Dutch riverine area, and for a case study of a full-scale test embankment in Eemdijk.

Photo © NOS / Eric Feijten.