

# INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



*This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:*

<https://www.issmge.org/publications/online-library>

*This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.*

# Strength conditions of Dutch dikes

## La puissance naturelle d'une digue Hollandaise

A. Bizzarri, P. Blommaart & M. Ketelaars – Ministry of Public Works, Delft, the Netherlands

**ABSTRACT:** The natural strength of a dike is often higher than the strength determined by means of numerical or Finite Elements models. In The Netherlands the river dikes have withstood the high floods in 1993 and 1995 while they should have failed according to the theoretical predictions. In this paper two case studies are described in which an attempt is made to determine the actual strength of a dike. In the first case study, historical data are used to determine the "proven strength" of a dike. The second study consists in three field tests which will be performed on a real dike. A description of tests is presented in this paper.

**RÉSUMÉ:** La puissance naturelle d'une digue est souvent plus haute que la puissance déterminée au moyen de modèles numériques des éléments finis. En Hollande les digues de fleuve ont la tenue que les hautes inondations dans 1993 et 1995 tandis qu'ils devraient avoir échoué selon les prédictions théoriques. Dans cet article deux études sont présentées dans lesquelles une essai est faite de déterminer la puissance réelle d'une digue. Dans la première étude des données historiques sont employées pour déterminer " la puissance prouvée" d'une digue. La deuxième étude consistait en trois essais sur le terrain qui seront exécutés sur une vraie digue. Une description des essais est présentée dans cet article.

### 1 INTRODUCTION

Since the early middle age dikes were built in The Netherlands to protect the country from the threat of flooding. The design of dikes was based on experience and on the principle of trial and error. Dikes were reinforced as a consequence of an observed loss of stability or higher storm surge levels. In the last 50 years, the knowledge of the extreme hydraulic conditions (loading) and of the different mechanisms which lead to the failure of a dike has been considerably increased. Nevertheless it is still difficult to determine exactly the strength of the dikes. This difficulty also emerged during the high water period of 1993 and 1995. In both occasions, the experts had predicted by means of the theoretical models, that several dikes would have failed as a result of the high water level in the rivers. As a consequence of these predictions, ten thousand of people were forced to evacuate the regions behind these dikes. Actually the dikes did not fail and the commotion induced in the local community as well as the high cost of the evacuation could have been avoided.

The Dutch safety philosophy is based on the probability of exceeding a storm surge level. Design and test methods have been developed and described in several guidebooks in order to guarantee a level of protection according to the legally prescribed safety standards. These technical requirements are concerned with geometrical design (shape/height of the dikes) as well as the stability criteria for slope protection and are related to the possible failure mechanisms.

The determination of the strength of a dike against failure is based on computational models in which the physical behaviour of soils is often highly schematised. Furthermore, the determination of the geometry and of the geotechnical properties of the different subsoil layers is based on soil investigation results. The natural heterogeneity of soil and the discrete nature of the in-situ soil investigations results in a fairly large uncertainty in the calculations. Therefore, in order to compensate for this uncertainty, safety margins are used in the calculations. This means that the "actual strength" of a dike is possibly larger than the "theoretical strength". This is in particular true for the old dikes.

An insufficient knowledge of the actual strength of dikes can lead to unnecessary or expensive reinforcements of a dike, or to

measures, such as evacuation during extreme water level, which could be avoided.

During the last few years, the Dutch Ministry of Public Works has been leading a research program which will result in a better determination of the actual strength of a dike. In order to reach this goal the following possibilities have been studied:

- the use of archival data and experience in the determination of the strength parameters;
- decreasing the uncertainties in the determination of the strength parameters by performing more local soil investigation;
- decreasing the uncertainties in the used physical models by performing field tests in real scale.

The first two possibilities have been combined in the methodology of "proven strength". This methodology has been applied in the case study "Markermeer".

Due to the large risks involved, it is normally difficult to perform failure tests on real dikes. However an unique possibility has recently arisen. As a consequence of the widening of the bed of the river, a dike along the river Lek (location Bergambacht) has become unnecessary and therefore suitable to be used as location for field tests. The tests are in the preparatory stage and will be performed between April and July 2001.

### 2 PROVEN STRENGTH: CASE STUDY "MARKERMEER"

As time goes by, the strength of a dike increases due to consolidation and aging of the soil. Therefore, a dike which has withstood an extreme loading situation in the past, will, in similar conditions, do it again. This "proven strength" can be established if the sustained extreme load is comparable to the present design load and if the geometry of the dike at the time of the historical situation is similar to the present geometry. When these conditions are fulfilled then it is possible to conclude that the strength of the dike is sufficiently great to guarantee resistance against loss of stability.

The "Markenmeer" belonged before 1932 to the "Zuiderzee". Before the construction of the "Afsluitdijk" (closing dike) and successively the "Houtribdijk" dike, several storms have taken



Figure 1. Zuiderzee (1681) and IJsselmeer / Markermeer (present).

place during which the water level was higher than the actual design level.

In the study *Markermeer II 2000*, the methodology of “proven strength” is used to investigate the dikes along the coast of the former “Zuiderzee”. This investigation has become necessary because of the introduction for this region of stricter safety standards. According to these standards, most of the dikes would have failed the safety test in spite of the fact that the sustained water level is much higher than the present design level (MHW).

The case study concerns the resistance against high water-level in relation to the failure mechanisms: stability of the inner slope, up-lifting and piping.

The duration and the high water-levels along the analysed dike’s sections have been reconstructed by means of archival data. The actual designed water level has also been defined. As shown in Figure 2, the resulting designed water level is lower than the highest historical water level.

The actual geometry of the different dike’s sections were compared with the profiles before 1932 in order to determine the influence on the geotechnical stability of the modifications that occurred. It could be concluded that 62 of the 78 analysed profiles can be considered comparable to the historical profiles and therefore, according to the methodology of “proven strength”, the geotechnical stability can be considered sufficient.

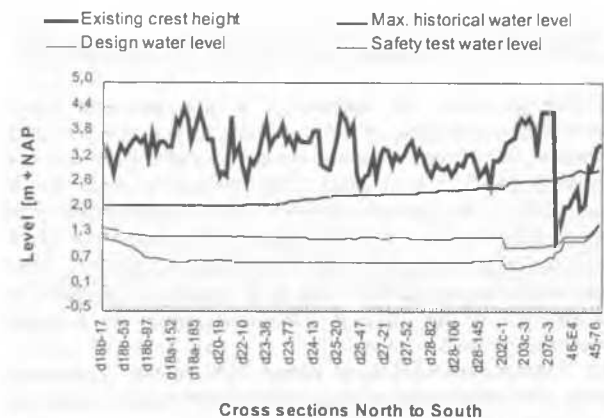


Figure 2. Levels along the former Zuiderzee coast of the Markermeer.

For 12 of the remaining profiles a further study would probably lead to the same conclusion. These conclusions can be used for the estimation of the cost of improvement of the dikes along the “Markermeer”. The use of the methodology of “proven strength” for the investigation of the dike’s stability would lead to a saving of about 45 million Euro in comparison with the estimation resulting from a standard analysis.

### 3 ACTUAL STRENGTH: TEST FIELD “BERGAMBACHT”

In order to widen the bed of the river, a turn of the river Lek, nearby the village Bergambacht, has been cut by building a new dike behind the old one (Fig. 3). Because the protection of the region behind the dike is now guaranteed by the new construction, the possibility has arisen to use the old dike to perform several tests in prototype scale. The purpose of the experiments is to investigate the “actual strength” of real dike and increase knowledge about the behaviour of dike under conditions which are comparable to the design conditions. In particular three tests will be performed:

- Phreatic line test: the development of the water level in the dike due to a high water level in the river.
- Deformation test: the development of slope instability due to high pore water pressure in and under the dike.
- Wave overtopping test: the development of the phreatic line by infiltration due to overtopping waves.

During these tests the dike will be loaded to conditions similar to real extreme conditions. A monitoring program by means of accurate instrumentation has been set up to follow the different processes. At the same time, predictions will be made by means of numerical and finite element computer programs. The comparison of the predictions with the test results will lead to a validation of the computer models and of the test method concerning the related failure mechanisms.

The possible risks which could compromise the tests have been inventoried and analysed in order to be able to take appropriate preventive measures.



Figure 3. Test bank along the river Lek.

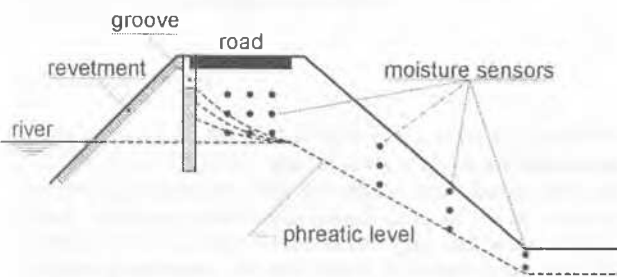


Figure 4. Phreatic line test.

### 3.1 Phreatic line test

The development of the water pressures inside a dike during high water level has a great influence on the determination of the stability of the dike. For this reason a research study has been initiated in which all the available field measurements in The Netherlands have been inventoried and they will be compared with results of calculations with theoretical models. This comparison will lead to a validation of the computer models used in the calculations. The test field in Bergambacht gives a ulterior possibility, by performing a controlled experiment, to study the behaviour of the phreatic line under extreme conditions and calibrate the theoretical models. The achieved knowledge would also lead to clear directives in the determination of the phreatic line for the designing and testing of dikes, and to better founded long-term research proposals.

The relation between the pore water pressure during extreme (design) conditions and the initial position of the water table inside the dike as well as the water content in the region above the phreatic line will be studied. The amount of rain and the water content in the dike have been measured during 8 months to determine the relation between the rain and the initial soil saturation.

The following matters will be investigated:

- influence of the high (prolonged) river water level on the stationary position of the phreatic line
- fall of the high water level and influence on the phreatic line
- the determination of the phreatic surface from a phreatic zone

A schematic view of the phreatic line test is shown in Figure 4. A groove will be dug along the outer border of the crest and filled with coarse material. The influence of the high water level in the river on the position of the phreatic line will be simulated by increasing the water level in the groove. The monitoring will take place by means of water pressure sensors which will be placed at different heights in the dike profile.

### 3.2 Deformation test

The purpose of the test is to study the development of the shear band during failure. The process of failing takes a certain amount of time. This means that by recognising the different signs which precede the final failure of a dike, it would be possible to take the adequate measures.

The deformation test is shown in Figure 5. During the test the dike will be forced to deform according to the up-lift mechanism. Like many river dikes in the Western part of the Netherlands, the dike in Bergambacht is build on a soft soil layer of about 13 m thick on top of a sand layer. Under normal conditions with average water level, the dike is partially supported by the soil behind the dike. The horizontal force resulting from the sliding soil mass in the active zone will partially be transferred to the sand layer by shear in the passive zone and partially to the ground beyond the passive zone by horizontal pressure. At high water level in the river, the ground water head in the deep sand layer increases, causing a reduction of the effective stress and therefore also of the shear stress at the boundary between the sand and the soft soil layer. This process can lead to local uplift of the soft soil layer and a reduction of the shear stress to zero. The soil in the up lift zone will then act as a horizontal compression bar in order to transfer the horizontal force resulting from the sliding soil mass to the confining zone. This mechanism will induce failure of the dike according to a deep slip surface.

During the test, water will be pumped into the deep sand layer to produce the high water head. In order to induce the loss of stability, the first 1.5 m of the clay layer will be removed in the region behind the dike at a distance of 8 m from the toe. Because of the high estimated strength of the dike, it will be probably necessary to add a load on the crest to induce failure.

The test will be monitored by measuring the water pressures and the deformations. The position of the phreatic line inside the dike as well as in the region behind the dike is very important for the analysis of the test. The monitoring of the horizontal as well of the vertical deformations will be performed on the surface and inside the body of the dike. Different techniques will be applied including image processing. In order to be able to follow the development of the shear band, the measurements have to be performed at regular interval.

The predictions will be performed by means of analytical and finite element computer models. The soil parameters which are necessary for the calculations must be determined by means of field measurements and laboratory tests. A better description of the soil shear strength can be achieved by taking into account anisotropy in the analysis. This can be obtained by means of undrained stability analysis: the ADP (Active, Direct, Passive) method.

### 3.3 Wave overtopping test

As in the phreatic line test, the purpose of this experiment is to study the influence on the pore water pressure during extreme (design) conditions of the initial position of the water table inside the dike as well as the water content in the region above the phreatic line. The development of the water level inside the dike is in this test due to overtopping of the crest by high waves. The influence of the unsaturated region will be studied.

Water will be forced to flow over the crest of the dike to simulate overtopping by waves. The test is depicted in Figure 6. The deformation of the inner slope and the pore pressure inside

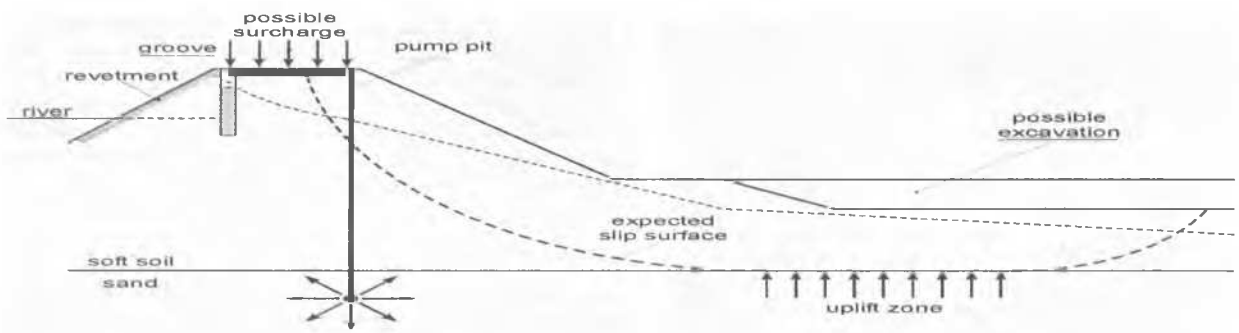


Figure 5. Deformation test.

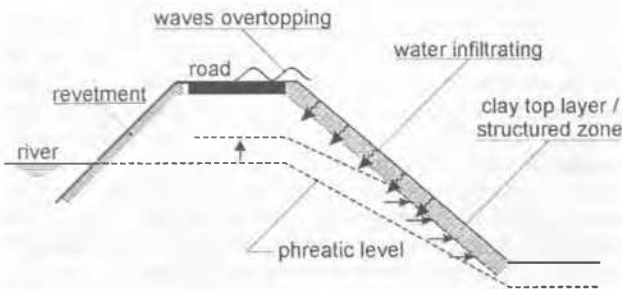


Figure 6. Wave overtopping test.

the dike will be measured. Additionally to the test with a constant water flow, it will be possible to vary the flow to simulate the stochastic character of a wave overtopping.

#### 4 CONCLUSIONS

This paper gives a description of a project which has been started in order to determine the actual strength of a dike. Two research lines have been followed. The first one is based on the use of the historical data to determine the "proven strength" of a dike. The use of this method in the stability analysis of the "Markermeer" dikes, in the former "Zuiderzee" would bring a saving in the estimated costs of the dike's improvement. The second research line consist in the possibility to perform field test on real scale in order to gain insight into the strength of a dike. This study is still in the preparation stage. The three tests will be performed in the spring of 2001.

#### 5 REFERENCES

Blommaert, P.J.L. 1997. Inner Slope Stability Analysis of Dutch River Dikes. *Proc. Young Geotechnical Engineer's Conference, Madrid 24-27 September*

Pilarczyk, K.W. (ed.) 1998. *Dikes and Revetments. Design, Maintenance and Safety Assessment*. Rotterdam: A.A. Balkema.

Van der Meer, J.W., Wouters, J. & Schouwstra, L.P. 2000. *Markermeer II. Proven strength in relation with geotechnical stability*. INFRAM report i221 (in Dutch)

Van Duin, T.A. 2000. *Test field Actual Strength. Analysis of field measurements in dikes* GeoDelft report CO-710301/65 (in Dutch)

Van Duin, T.A. 2000. *Test field Actual Strength. Analysis of field measurements in dikes* GeoDelft report CO-710301/134 (in Dutch)

Zwanenburg, C. 2000. *Tests in the test location Actual Strength*. GeoDelft report CO-710301/9 (in Dutch)