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Observational method for dike management

Méthode d'observation pour la gestion des digues

R.A.J. van de Kamp & E.H. Rob
Department of hydraulic and geotechnical engineering, Witteveen+Bos Consulting Engineers, Deventer, Netherlands

ABSTRACT
An observational method for dike management is proposed in this contribution. Due to several causes, dikes in The Netherlands are exposed to an increase in and variation of loads. Though many dikes have sufficient safety, the safety of a significant number of dikes is classified as doubtful. Since large-scale dike strengthening is undesirable, a search for new methods for dike management has been initiated. The proposed observational method uses monitoring of relevant parameters to assess the safety of dikes under actual circumstances, by comparing measurement results with predefined boundary values. As soon as the boundary values are exceeded, dike managers are expected to undertake measures. In this way, dike strengthening is limited to those locations for which it is truly necessary.

RÉSUMÉ
Le présent article propose une méthode d'observation pour la gestion des digues. Sous l'influence de plusieurs causes, les digues aux Pays-Bas sont exposées à un nombre croissant de dangers graves et nouveaux. Bien que de nombreuses digues soient suffisamment sécurisées, la sécurité d'un nombre considérable de digues est classée douteuse. Un renforcement à grande échelle des digues n'étant pas souhaitable, des mesures ont été mises en œuvre pour rechercher de nouvelles méthodes de gestion des digues. La méthode d'observation proposée s'appuie sur le contrôle de quantités pertinentes visant à évaluer la sécurité de digues dans des conditions réelles, en comparant les résultats de mesure à des valeurs limites prédéfinies. Les gestionnaires de digues sont sensés prendre des mesures dès que les valeurs limites sont dépassées. De cette manière, le renforcement des digues est limité aux emplacements pour lesquels il est vraiment nécessaire.

1 INTRODUCTION

Events in recent years revealed that dikes in The Netherlands are exposed to an increase in and variation of loads. On the one hand it is expected that river discharges will strongly increase during wet periods, which results in increased hydraulic loads. On the other hand several dikes failed, due to drying out of dikes during dry summers. How critical this situation really is, is illustrated by the consecutive high waters of 1993 and 1995 and by the failures of secondary dikes in the dry summer of 2003. The causes of the increase in loads are often imputed to climate changes, but this falls outside the scope of this contribution.

In this article an observational method for dike management is proposed. The use of this method is illustrated by an example of failure due to high water pressures underneath a dike.

1.1 *Safety assessment of dikes in The Netherlands*

At present the safety of dikes in The Netherlands is assessed every five years. For the assessment a step by step method is in use, known as the Regulations for Safety Checks. The first step of the method comprises a global analysis of the geometry of the dike. Some dikes are classified as safe in this step, based on the proven strength of their geometry. If the safety of the dike is classified as doubtful or insufficient, the next step has to be performed. The next step comprises an advanced analysis of for example the stability by using the common Bishop method. Depending on the outcome of this second analysis, the safety is again classified as sufficient, doubtful or insufficient. The final step comprises detailed analyses, for example by performing Finite Element calculations.

Using this system, many dikes are classified as safe. There are however also a significant number of dikes, of which the safety is considered to be doubtful. From a safety perspective it is advisable to strengthen these dikes. However, large-scale dike strengthening is considered to be unfavourable due to the economical, environmental and social-cultural impacts. Therefore a large-scale search for new methods to strengthen and manage dikes with a doubtful safety has been initiated.

2 THE OBSERVATIONAL METHOD

2.1 *Principles of the observational method*

The observational method in geotechnical engineering (Peck, 1969; Nicholson & Powderham, 1996) is defined as an integrated process of design, construction and management. The method provides a powerful tool for managing uncertainties related to subsoil conditions and soil-structure-interaction. The method is characterised by rather accepting uncertainties and trying to manage them, than trying to eliminate them. In this way it is attempted to handle uncertainties in such a way, that an economically optimised structure is realised.

The observational method uses monitoring of the behaviour of the soil and structure to ratify decisions concerning the construction and management process. The method has several variations of which the "best-way-out" and "ab initio" are the most common. The "best-way-out" method is used when failure is imminent and applying monitoring to evaluate the success of countermeasures is considered to be the only way out of trouble. When using the "ab initio" method, monitoring is completely embedded in the design and construction process from the start of a project.

An example of the "best-way-out" observational method in dike management is the installation of sandbags on dikes with doubtful safety in order to increase the stability during high water. This method is at present applied in dike management. Examples of the "ab initio" observational method in dike management are however rare. A possible use of a variant of the "ab initio" method is proposed in this article.

2.2 *Proposed observational method*

The proposed observational method uses monitoring by two different systems (figure 1). The first one is an Early Warning System (EWS), the second one is a Close Monitoring System (CMS). The EWS serves to automatically inform dike managers on the fact that the loading or resistance of the dikes for which they are responsible, is changing. At this moment one can decide to take no further action or to install the CMS. The CMS provides reliable and detailed information on the behaviour of the dike under extreme conditions. Based on the comparison of the measurement results with pre-defined boundary values, one can decide to take countermeasures or to take no further action.

The EWS has to satisfy a number of requirements. Next to the more obvious demands as being reliable and able to measure relevant quantities, the system also has to be able to provide a manageable amount of data, and to withstand erosion and vandalism. In addition, the system should preferably conduct continuous measurements of a parameter (as opposed to discontinuous measurements like daily inspections).

The CMS is important in situations in which the safety of a dike is truly critical. The system has to provide highly detailed measurements on for example displacements, before the soil has collapsed. The CMS may be composed of a total station with mirrors, as applied in tunnelling in urban environments (e.g. Kaalberg, 2001).

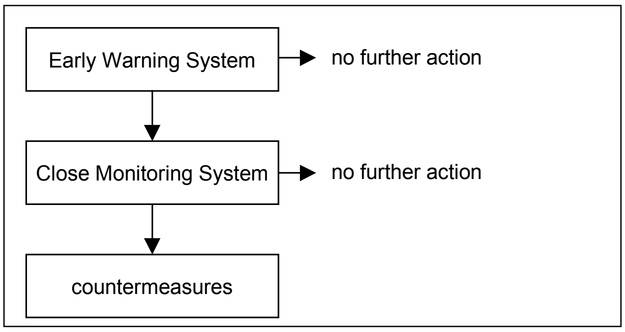

Figure 1. Scheme of the proposed observational method for dike management

2.3 *Advantages and disadvantages of the proposed method*

This section discusses the most important advantages and disadvantages of the use of an observational method for dike management. The main advantage is that dike managers gain an improved insight into the condition of the dike under extreme circumstances. This improved insight enables them to take better decisions on the initiation of countermeasures. Also, the engineering judgement of experienced dike managers can be formalised by the determination of boundary values for the relevant parameters.

The second advantage of the method is that dike strengthening can be optimised, by restricting it to those sections for which it is really necessary. The risk of failure of dikes with doubtful safety can be controlled by the observational system and therefore it is not necessary to perform large-scale dike strengthening of these dikes.

Naturally, the method also has some disadvantages. It may for example turn out to be very difficult to determine relevant measurement parameters for some failure mechanisms. Another concern is the reliability of the monitoring systems. Natural wear, vandalism and unintended damage can seriously reduce the reliability of a permanent monitoring system (Morgenstern, 1994). For this reason an observational method with two different monitoring systems is proposed (EWS and CMS), of which the first one is considerably robust and the second is relatively vulnerable.

Finally the relation of the method to safety regulations plays an important role. At present it is very difficult to determine probabilities of failure for processes with an observational method (Hachich & Vanmarcke, 1983), which may be unacceptable for administrations.

3 CASE STUDY: UPLIFTING OF A RIVER DIKE

3.1 *Introduction to the case*

The use of the observational method for dike management is explained by a case study of a situation that frequently occurs in the Netherlands. The dike for this case study is a typical dike in the Netherlands (figure 2), with a river on the one side and a polder on the other side. The geological profile of large parts of the Netherlands is characterised by layers of peat and clay overlaying a stratum of Pleistocene sand (the so-called Hollandprofile).

The groundwater potential in the sand stratum depends on the transmissivity of the sand stratum and riverbed and the duration of a high water in the river. The surface water level inside the polder is maintained at a continuous level by pumping stations.

At the inner toe of the dike the soil is subject to a phenomenon called uplifting. Uplifting occurs if the groundwater potential in the sand stratum is greater than the weight of the overlaying soils. The result of this is a strong reduction of the inward macro-stability.

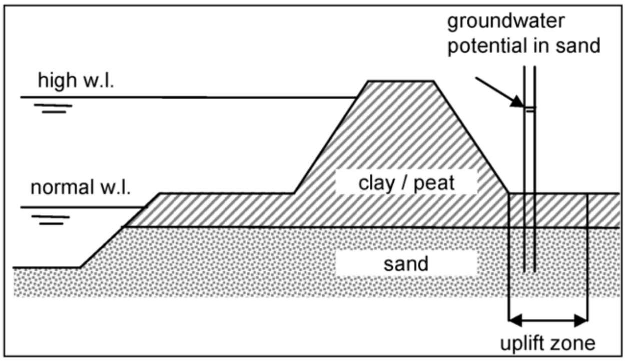

Figure 2. Typical dike section for Hollandprofile

3.2 *Observational method for the case study*

The observational method for the presented case is based on measurements of the groundwater potential in the sand stratum. This parameter is easily measured by using electronic float gauges, which can send their data automatically to the dike manager. If desired, the method can be extended with a close monitoring system to register the displacements of the soil at the inner toe of the dike.

The factor of safety of the inner bank of the dike is calculated using the Uplift Van-method of the program MStab (e.g. Koelewijn et al., 2002), which incorporates uplifting. This calculation is performed for different groundwater potentials in the sand stratum. The boundary values are determined by the required factor of safety for inward stability as prescribed in national regulations (for this example a safety factor of 1.10 is assumed to be sufficient).

If the safety factor decreases for example beneath 1.40 (see paragraph 3.3), the dike management will have to increase the frequency of measuring and to start the preparation of countermeasures. These countermeasures in this case consist of the installation of an additional berm with a height of 1 m and a width of 25 m at the toe of the embankment.

3.3 *Calculation results*

Figure 3 shows an example of calculated effective stresses and an inward sliding plane for the riverdike. Figure 4 presents the calculated stability factors for different groundwater potentials in the sand stratum. The dashed line shows the effects of the countermeasure on the stability of the dike.

As can be seen in figure 4 the critical boundary value of 1.10 is reached if the groundwater potential increases to about 2.2 m. By applying the countermeasure, the stability factor increases to a value of about 1.80 at the same groundwater potential.

The time available for applying countermeasures equals the time during which the stability factor decreases from 1.40 to 1.10. This is consistent with an increase of the groundwater potential of 1 m (from 1.2 to 2.2 m). Under normal circumstances this will leave dike managers enough time to apply countermeasures. Of course an increase in water levels must be foreseen, before applying countermeasures.

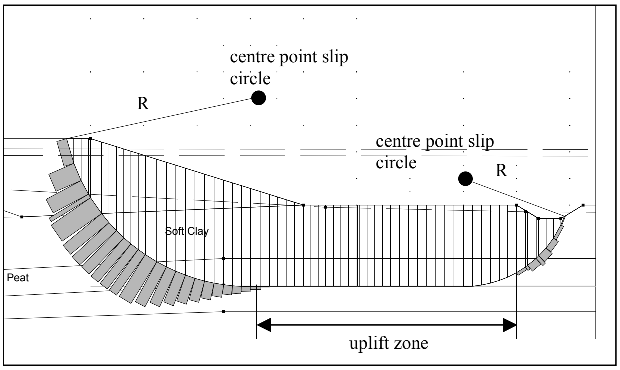

Figure 3. Calculated effective vertical stresses of the Uplift Van model

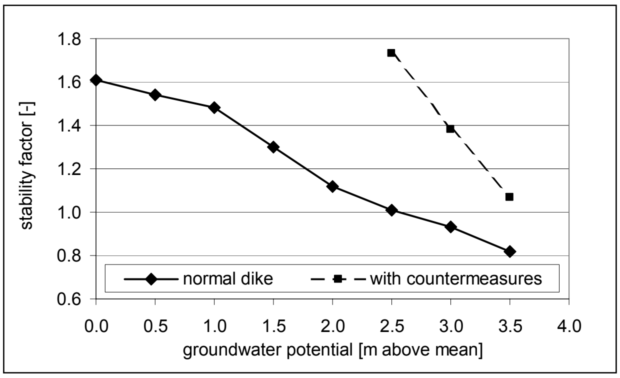

Figure 4. Calculation results for case study

4 SUMMARY AND CONCLUSIONS

This contribution discussed the possible use of an observational method for dike management. Due to different causes, dikes in The Netherlands are exposed to an increase in and variation of loads. Though many dikes have sufficient safety, the safety of a significant number of dikes is classified as doubtful.

From a safety perspective, these dikes would have to be strengthened. This is, however, undesirable due to the economical, environmental and societal impacts of large-scale dike strengthening.

The proposed observational method uses monitoring of relevant parameters to assess the safety of dikes under actual circumstances, by comparing measurement results with predefined boundary values. As soon as the boundary values are exceeded, dike managers are expected to undertake measures. In this way, dike strengthening is limited to those situations for which it is truly necessary. By automation of the monitoring process an additional increase in safety is achieved, since the system provides dike managers with a continuous warning system.

To wind up this contribution it is remarked that the proposed observational method is only meant to serve as basis for the further development of dike management systems. At present valuable research on monitoring, including remote sensing, is being performed by several scientific organisations in The Netherlands. In addition every dike requires a proper analysis of its specific situation and relevant failure mechanisms. The proposed method is however considered generally applicable.

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