Recent developments towards water-tight structures

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ABSTRACT: Where the presence of leaks in water-tight structures cause risks, they are not acceptable. Four ways to decrease the potential risks are described: Risk analysis, monitoring, leak detection and extensive recovery techniques. Both last mentioned are subject of studies, carried out by GeoDelft**.**

1 INTRODUCTION

While excavations and constructions are executed deeper and more extended, leakage of the construction gives growing risks and is, therefore less acceptable. Recently, in the Netherlands a number of problems with leaking constructions was encountered which could only be solved against high costs. We will give a few typical examples:

In Zwolle, the capital of the Province Overijssel in the Netherlands, a bypass-road is crossing a railway in a subsurface geomembrane as water retaining structure. This application of geomembrane was one of the first in the Netherlands (1984). Since that time the functioning deteriorated gradually. The cause nor the location of the leak could be discovered, while the leakage became unacceptably large, even hampering the traffic. As a last rescue the municipality advertised for help in local and national newspapers on no-cure-no-pay base, but – as far as we know – nobody had an appropriate answer available. Until now Zwolle has spent more than 500,000 dollar without any result.

A different problem was encountered in the tramway tunnel in The Hague, where leakage of a grout-arch already has led to additional costs of about 70 million dollar. A third example is the Prinsenhof underground parking lot in Delft with a leaking sheet pile wall, where the additional costs are about 1 million dollar. The large variation in type of problems and in the nature of underground constructions makes it implausible that a single, simple solution exists for all leaks in water retaining structures. The conclusion of this analysis is that a coherent investigation program is necessary to mitigate leakage problems of water retaining walls. In this paper we will give an overview of a recent analysis to fill in some gaps in such a coherent investigation program to become better equipped against the negative effects of leakage in the future.

2 FOUR WAYS TO DECREASE RISKS

To obtain a better view on the scope of the problem, we have made a brief evaluation of those leakage problems we met in recent history. In the first place it appeared that in virtually all cases no substantial risk analysis had been performed before. In the case of the tramway tunnel in The Hague, it became clear in an early phase that a leak was present, but the amount of water was not insuperable. However, the location was not exactly known and nobody was aware of the risk that piping could take place. When this finally happened, a substantial amount of soil was transferred and large settlements took place, damaging the pavement in one of the most crowdy streets of The Hague.

When the risks are evaluated before, and where risks are judged to be unacceptable, preventive measures can be taken, as a second way to decrease risks. We found that in some cases preventive measures are insufficient or the results of the measures are neglected and even sometimes they are even not recorded. In the case Prinsenhof in Delft, lock-alarms had been applied during the pressing of the steel sheet piles. Some of the lock alarms had not been triggered, but afterwards it was only known that that there had been problems, but no exact locations had been recorded.

A third way we mention is the localisation of the leak. Generally there is agreement that a leak is present, because of the larger than expected pumping rate, but there is no agreement about the way how it should be detected. In many cases it is not clear who is responsible: the principal claims a leak in the structure , the contractor claims a geologic inhomogeneity. Although time consuming and, in many cases, difficult to apply , the geohydrological method is the traditional method to try to pinpoint the leak. When the presence of a leak has been confirmed principal and contractor are in a hurry to solve the particular problem at short terms, money and interest for structured experiments are lacking

The fourth and last aspect is the recovery of the leak. Since the location of the leak is often not well known as was mentioned above, in practice very rigid measures are taken. One wants to be 100 % sure that the problem is solved and from that moment on, money seems to be no limit any more. This could have a financial reason (delay-time is much money for a contractor), or a political reason (we cannot allow ourselves a second disaster).

In this article most attention is paid to the last two items: leak detection and recovery methods.

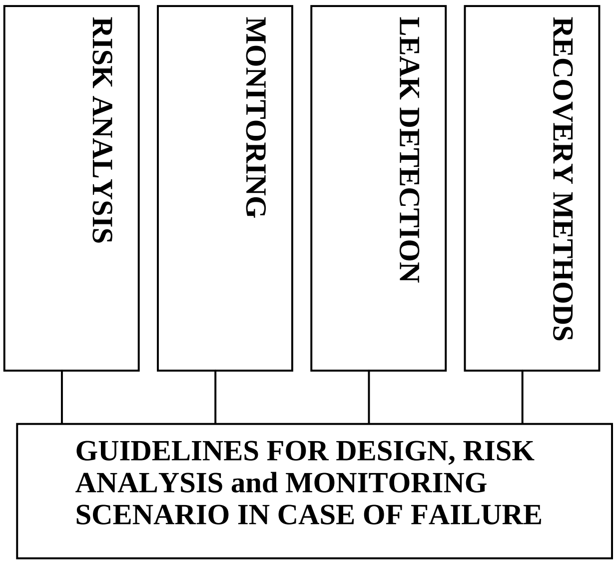

Fig. 1 Four ways to decrease risks of failure

3 RISK ANALYSIS

The risk of a leak is described as the product of the chance times the costs of the damage if the leakage really occurs.

If this product is large (great chance and large costs), we consider the risk as unacceptable. In such cases we need to take measures to avoid the risk. However, a reliable estimate of the risk can be given only on the basis of a quantitative risk assessment.

The possibilities to decrease the risk are dependent on its nature: to decrease uncertainties about the geologic and geohydrologic characteristics a more extended soil survey can be carried out. Where uncertainties are inherent to the structure, like damage of a geomembrane in the welded joints, a more stringent quality control should be undertaken to avoid leaks at those areas where they can lead to unacceptable risks.In this case we could think about more intensive monitoring (process control), or the incorporation of a permanent leak detection system.

4 PREVENTION AND MONITORING

As is stated before, where disfunctioning of the structure is unacceptable, much attention has to be paid to prevention and monitoring. In the case of geomembranes, preventive techniques may consist of strict control of all welds and – if possible – to avoid welding at risky places. Built-in detection techniques can be applied and a scenario should be made what to do if failures are detected.

Additional monitoring with piezometers and/or measuring extraction rates is helpful to detect leaks in an early stage. However, we should be aware of the fact that geomembranes are always leak to some extent; numbers of 14 punctures per 10,000 m2 are mentioned [van Meerten et al, 1993]. In many cases, however they do no harm as far as they don't exceed certain dimensions and as far no follow-up mechanisms occur. .

As mentioned before, prevention nor monitoring will help as far as no actions are taken if failures are detected. In a scenario, all actions and responsibilities should be described.This scenario should take into consideration the complete life cycle of the structure. In the Netherlands examples are known, where a geomembrane was damaged by the foundation of new placed traffic lights. After 15 years apparently nobody remembered the presence of the geomembrane and it had not been incorporated

adequately on any map.

5 LEAK DETECTION

Despite all efforts, accidents will happen. If so, we need to be capable to minimize the negative effects of the leakage. In most cases this means that we try to bring the wall or liner into a state which is comparable to the initial design. Other possibilities however, should be taken into account:

- reduction of the negative effects to an acceptable minimum (e.g. injection of groundwater) to mitigate groundwater effects outside the construction area.
- recovery of the structure until a minimum acceptable quality is reached. This possibility is discussed in the next chapter.

Presuming that the leak should be recovered in such a way that the initial design quality of the structure is achieved, we should be able to find the location of the leak as exactly as possible. Until now two methods are commonly used in the Netherlands: a geohydrological method and a geoelectrical method (for geomembranes only).

The geohydrological method is based on the observation of the effects on the groundwater table, when groundwater is extracted inside the construction area. In case of no or only slight leakage, the groundwater table inside the construction areawill become almost horizontal. If leaks are present, the groundwater table nearby the leak will be less infected by the extraction and will be higher in consequence. To achieve an accurate localisation of the leak, many observation wells, or in case of soft soils as common in the the Netherlands, many piezometers have generally to be placed and observed. In general, the (horizontal) location of the leak can be detected rather exact, for example an interruption in a confining clay layer below the bottom of the construction pit. Until now, there is little experience in accurate locating the vertical situation of the leak. Disadvantage of this method is that it is a rather time consuming activity, because installation of pumps and piezometers is required, a stationary situation has to be approached and the effects on the groundwater table may be rather small.

The geo-electrical method is based on the isolating qualities of a geomembrane. Where the geo-electrical method measures the electrical resistivity of the bottom (and all structures in it), a geomembrane forms a strongly resistant object in the bottom. Where leaks are present, the electrical resistivity is less. The geo-electrical method measures the resistance across the geomembrane between electrodes inside and outside the structure [Nijdeken, 1994]. Interpretation of the geo-electrical observation, leads to a global localisation of the leak. This method is very quick, but is easily infected by the presence of current conductors like steel sheet piles and pipelines

The purpose of our survey was to identify technique(s) to be developed to fill a toolbox of standard techniques for leak detection. The emphasis in this paper will be on the process how we came to our conclusions more than on the techniques themselves .

In the first place we made an inventarisation of groundwater retaining structures and described the way how they are carried out, which materials are used and which kind of failures may be expected. Example calculations were made to indicate the additional quantity of groundwater to be extracted, depending from the dimensions and the situation of the leak, as well as from the potential difference in- and outside the structure.

From this survey we derived criteria for the development of applicable leak detection techniques:

Technical

Techniques which are known and have proved themselves (not necessarily for this application) give a better score than techniques which are not already accepted

Techniques, applicable for various structures score better than techniques, applicable only for one kind of structure

Techniques, applicable to horizontal as well as to vertical structures score better.

Sensitivity for disturbing elements (e.g. the mentioned conductors) gives a negative score

A positive score is given to those techniques which have a high degree of resolution and accuracy

Financial

The costs consist of the costs for the application itself and the time necessary for observation and interpretation. The higher the expected costs for the application of the technique the lower the score. The higher the expected costs of development the lower the score. Risks for failure of the development give a negative score

The next step was an inventory of possible qualities of a leak in a structure (in other words: in what respect there is a e difference between the structure and the leak)

- difference in flow
- thermic qualities
- acoustic qualities
- geometric qualities
- chemical differences
- mechanic qualities.

This inventory was used as a help to make a complete as possible list of observation techniques

All techniques, applied to detect the mentioned differences are judged against the criteria. This has led to the following conclusions:

It was derived that geophysical detection methods have the highest potency. To avoid disturbance of the observations, it is advised to find combinations with tracer techniques. It is expected that the combination with tracer techniques (chemical, acoustic, electrical etc.) can lead to strong improvements, for example to avoid disturbances. Difference measurements (i.e. measuring in the same circumstances except that groundwater is pumped or not) strongly enhances the sensitivity but is not always possible, for example a construction pit with has already been dug out.

In a second phase we have planned a field-experiment to compare the results of a number of techniques, with and without tracer additives.

6 EXTENSIVE RECOVERY TECHNIQUES

The following considerations have led to the conclusion that the development of so-called extensive recovery techniques may lead to cheaper and quicker recovery of the leaking structure.

- we can use existing chemical and physical qualities of soil and groundwater for recovery methods
- in most cases it is allowed that the permeability of the recovered leak is (even orders of magnitude) higher than the permeability of the structure, but it should be orders of magnitude lower than the permeability of the surrounding soil
- while groundwater flows through the leak, matters dissolved in groundwater will be transported through the leak by consequence.

If we are able to find dissolvents or combinations of them, which form a precipitation nearby the leak, they might form a less permeable zone and, by consequence, a recovery of the leak structure. While the dissolvents find their own way towards the leak, an extensive recovery method might make leak detection less urgent in future.

Until now, a number of possible methods were identified :

- application of oxygen in iron-rich groundwater
- application of micro-cement with retardation additives
- application of one chemical with retardation additive
- application of two chemicals which, meeting each other form a precipitation
- microbiological activities, to be urged in an artificial way.

A first experiment has been performed with micro-cement in a laboratory set up. Micro-cement was injected at a distance of the leak so that the estimated transport time was comparable to the retardation time of the cement. However teh soil-cement interaction proved too strong so that the cement was spread only a few centimetre from the injection points. Other laboratory tests are in preparation.

7 CONCLUSIONS

The application of groundwater retaining structures for temporary and for permanent structures is growing. While structures become ever more intricate , the risks of disfunctioning of the structure increase.

The design of each groundwater retaining structure should therefore be accompanied by a risk assessment study. In this study all possible failure mechanisms of the structure should be taken into account, given the proposed construction method and geological and geohydrological circumstances.

Where risks of failure are unacceptable, we need to minimize the chance of failures and take preventive measures and monitor the quality of the structure. It is important that results are recorded and lead to action. Responsibilities should be regulated. If we cannot guarantee acceptable risks, adaptation of the design should be considered.

Despite all precautions, we will have to accept that undesirable leakage of structures will occur time by time. If this happens, we should have quick and reliable detection methods available. It is nit realistic to expect that one methoed will be the panacee for all problems. Rather we have to think of a toolbox of methods. On short term, further development of geophysical detection methods seems to have best chances. To avoid disturbance of observations, these methods can be accompanied by tracer applications.

Recovery of leaks until the design permeability of the structure is reached is, in most cases, not necessary. Extensive recovery methods have to be developed where the permeability is decreased to an acceptabel level.

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