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Peat Dike Failure in the Netherlands

Abstract

In August 2003, after a very dry and warm summer, one of the dikes along a canal in The Netherlands failed at night. Because of this dike breach, the water in the canal started to run into a housing quarter of the village Wilnis, which is about 30 km Southeast of Amsterdam. A local contractor immediately started to close off the canal. By the time this was finished, 600 houses were already half a meter under water. The 2000 residents were evacuated in the early morning. Almost all residents could return to their homes the same evening after the water was pumped out of this area.

Like many other small dikes in The Netherlands, the complete dike consists of peat. Since peat has a relatively low specific weight, a peat dike has a higher risk of being pushed aside by water pressure than sand or clay dikes. This horizontal sliding is a rare type of failure mechanism. Though, when the stability of this dike is checked with a simple one page computation, it becomes clear that the failure of the dike after a dry period was a realistic threat.

For many years it was known that this part of dike was at risk. This was reported to the minister of Public Works in 1993, but the two involved provincial authorities, the provincial government and the water board, did not take steps until after the dike failure.

1. Introduction

In The Netherlands there is more than 17.000 km of dikes. The Dutch are all familiar with the huge flood disaster of February 1953, at the islands of the province Zeeland (Sea land), in the Southwest of The Netherlands, in which 1836 Dutch people died. The sea dikes failed during a combination of high tide and a heavy storm. Also the problems of the river dikes during the high water situations in March 1988, December 1993, and January-February 1995 are not yet forgotten. So, the Dutch people expect a higher risk of dike failure during storm, high tide or after a long rain period sometimes combined with melting water from the glaciers in the Alps.

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Fig. 1. Canal (left) and dike(right)

Therefore the Dutch were very much surprised at August 26th 2003, after the warmest and driest summer in fifty years, that a dike along a canal failed.

Figure 1. shows the empty canal on the left and the dike on the right. Figure 2. shows the dike after failure. About 50 meter of dike was shifted towards the north (left of the picture), leaving two breaches through which the water from the canal streamed into a lower quarter of the village Wilnis, 30 km Southeast of Amsterdam.

Fig. 2. Shifted part of a canal dike

2. Primary and secondary dikes in The Netherlands

The Netherlands is a country crossed by rivers and surrounded in the North and West by sea. More than 50% of the country is below the high water level of the rivers or sea. To prevent these areas from flooding, dikes are build along the rivers and seas, with a total length of about 3200 km. These dikes are called the primary dikes.

A large part of these areas are even below average sea level. Most of these areas are in the province Holland, which is in the West of the country. For example the area "Haarlemmer meer" (Harlem's Lake) was until 1852 the largest inner lake and is pumped dry in order to create new land, up to 4.5 meters below sea level. In this former lake, at 2 m below sea level, the Amsterdam National Airport Schiphol is situated. Nowadays about 100.000 people live in this former lake.

The precipitation of the lower areas of the country drains into the many ditches crossing these flat lands. From the ditches the water is pumped up into canals with water levels sometimes several meters higher than the land. From these canals the water is pumped up into the rivers, or in some rare occasions into the sea. The water in the canals is stopped from flooding the land by canal dikes, which are called the secondary dikes. There is about 14000 km secondary dike in The Netherlands.

The main differences between the primary and the secondary dikes are:

- Primary dikes only seldom have a maximum load (water level to the head of the dike), secondary dikes have a constant maximum load.
- The water level of the primary dikes are driven by nature (sea dikes: tide, storm and wind direction; river dikes: precipitation and melting glaciers of the Alps), the water level of the secondary dikes are controlled by man.
- The water level of the primary dikes are in most cases much higher than of the secondary dikes. This results in a higher damage at failure of primary dikes.
- The primary dike are controlled by the state government, the secondary by both a democratically elected provincial water board and a democratically elected provincial government.
- Per year € 10.000 per km primary dike is spend on maintenance and € 2000 per km secondary dike.

3. Situation Wilnis

The village Wilnis is part of the community "Ronde Venen" (Round Peats). It is about 30 km Southeast of Amsterdam. There is a ring canal which goes from the lake near Vinkeveen, through Wilnis, towards the city Mijdrecht (Figure 3). The old part of Wilnis is South of the ring canal. The new housing quarter, named "Veenzijde" (Peat-side) is the square of land North of the ring canal.

Fig. 3. Wilnis connected with the lake

Most of the soil in these areas are peat layers. In some areas the peat has been excavated for heating houses. This peat extracting took place from the middle ages up to one century ago when coal was found in the Southeast of the country, but mostly in the 17th and 18th century.

Fig. 4. Wilnis along the ring canal

In figure 4, a dot marks the location of the dike failure. The new housing area Veenzijde is North of this dot and is one of these excavated peat areas. The secondary ring dike between Veenzijde and the canal is not like most of the Dutch dikes man-made, but is a left-over from the peat-excavation. The area south of the ring canal is not excavated and is therefore as high as the failing ring dike on the other side. The ring dike is the only barrier between 10 square km of water of the "Vinkeveense plassen" (Finch-Peat's Lakes).

The complete dike consists of rather homogeneous forest-peat. Below this forest-peat there is a layer of swamp-peat, full of reed, leaves and roots. Below this layer there is a thin fat-clay layer, which lays on a very thick sand layer. Because of the soft subsoil, the houses in the South are founded on wooden piles, the new houses in the North on prefab concrete piles.

4. Dike Breach Wilnis

Fig. 5. Shifted part north-dike

In the night of Monday on Tuesday August 26th, at 1:30 h, more than 50 m of the secondary dike along the ring canal near Wilnis was translated sideways over 15 m. Because of this, the water in the canal started to run, along both ends of the shifted dike part, into the new housing quarter Veenzijde.

Fig. 6. Circular slip surface failure of the south-quay

Fortunately, a local contractor immediately started to close off both ends of the ring canal in the East and the West and a side canal in the South. By the time the ring canal was closed off with clay, which was immediately brought by other contractors, the 600 houses in Veenzijde were already half a meter under water. The 2000 residents were evacuated in the early morning. Almost all residents could return to their homes the same evening after the water was pumped out of this area. Because of the failure of the north-dike, the water level in the canal dropped instantly. Because of this the supporting horizontal water pressure on the south-quay disappeared, creating this quay to fail by a circular slip surface, see figure 6.

5. Failure mechanism

The failure mechanism of the dike is a horizontal pushing aside of the dike. The forces reacting on the dike and sizes are more or less as shown in figure 7. The stability of this dike can be checked easily with a simple one page computation.

The specific weight of wet peat is rather low. Because of the large amount of water (up to 80% or 90%!) and organic mater (lighter than water!) the specific weight is not more than γ_{wet} = 10 kN/m^3. When peat dries out in a dry summer, the specific weight can drop easily to γ_{dry} = 6 kN/m^3, or even lower.

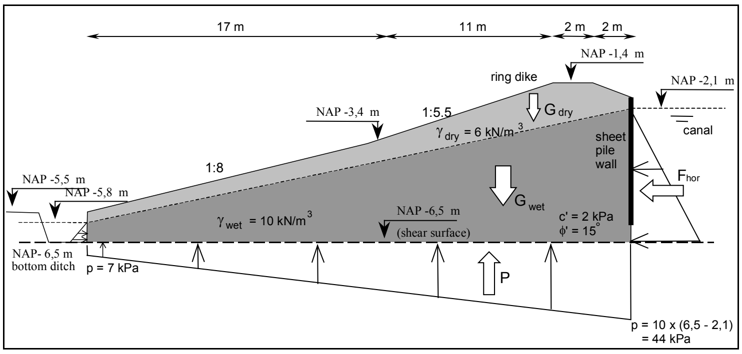

Fig. 7. Cross section and failure mechanism

In figure 7, the total cross section of the dike above the horizontal slip surface is $I_{tot} = 99{,}85\ \text{m}^2$. The cross section of the peat below the diagonal freatic line is $I_{wet} = 81{,}6\ \text{m}^2$, so the part of peat which is able to dry out is: $I_{dry} = I_{tot} - I_{wet} = 99.85 - 81{,}6 = 18{,}25\ \text{m}^2$. The vertical uplifting water pressure P is identical to the weight of the wet part of the dike G_{wet}, since in this case the specific weight of peat is the same as the specific weight of water.

The driving horizontal force of the water pressure is:

$$F_{hor} = \tfrac{1}{2} \times 10 \times \left[(6{,}5 - 2{,}1)^2 - 0.7^2 \right] = 94{,}35\ \text{kN/m}\ .$$

In the Dutch Standard for soil mechanics (code: NEN 6740, table 1) lower representative soil parameters are given in case no soil investigation has been carried out. For unloaded or nonpre-stressed peat a specific weight of γ_{wet} = 10 kN/m^3 is given and a angle of internal friction of $\phi' = 15°$ and a cohesion of c' = 2 kPa. (Since the reed and leave parts lay flat (horizontally) in the peat, the shear resistance is minimal in horizontal direction.)

Suppose the dike is completely wet, which means also the part above the freatic line (γ = 10 kN/m^3). In this case the maximum resistance force of the dike against horizontal shear failure is:

$$\begin{aligned} F_{max} &= c' A + \tan(\phi') I_{dry} \gamma_{wet} \\ &= 2 \times 32 + 0.268 \times 18.25 \times 10 \\ &= 112.90 \text{ kN/m} \end{aligned}$$

This results in a stability factor during wet times of:

$$f = 112{,}9 / 94{,}35 = 1.20$$

However when the peat of the upper part has dried out during a long hot summer, an average specific weight of the top layer of 6 kN/m^3 or lower is possible, so:

$$\begin{aligned} F_{max} &= c' A + \tan(\phi') I_{dry} \gamma_{dry} \\ &= 2 \times 32 + 0.268 \times 18.25 \times 6 \\ &= 93{,}35 \text{ kN/m} \end{aligned}$$

This results in a stability factor after a dry and hot period of:

$$f = 93.35 / 94{,}35 = 0.99$$

which explains the failure of the dike of Wilnis.

Interesting is that in this case about 2/3 of the maximum shear resistance is obtained from cohesion ($c' A = 2 \times 32 = 64$ kN/m) and not from friction. This makes the dike in fact less sensible to mass reduction caused by drying out. So, the drying out was more like the last straw that broke the camels back, because the safety of the dike was already rather low.

Another interesting question is why the dryness did not decrease the pore pressure and as a result increase the effective stresses and strength near the slip surface? There may be several reasons for this:

1) The slip surface is too deep to be influenced by the dryness.
2) The horizontal permeability of the forest-peat is much higher than the vertical.
3) The permeability of the swamp-peat (near slip surface) is higher then the forest-peat.
4) A combination of these three.

This question is still part of research.

6. Warning for unsafe dikes

In January 1960 a canal dike failed in the village Oostzaan near Amsterdam, leaving many houses of the village flooded. Because of this the governmental Technical Advisory board for Water barriers (TAW) was erected in 1965 with the task to determine which primary and secondary dikes were unsafe. They reported to the minister of public works firstly about the primary dikes and in 1993 finally about the secondary dikes, saying:

"1730 km secondary dikes of the most important 200 polders have been surveyed. 323 km of dike was unsafe. 167 km of dike has been improved already, 156 km of dike is still unsafe (date: January 1st, 1993)".

The dike of Wilnis was among these unsafe dikes. Although the minister and the governmental TAW have no power over this provincial situation, the minister has asked in 1993 to improve the unsafe dikes.

7. Geotechnical expertise

As mentioned many river and sea dikes have caused mayor problem in the long history of the battle of The Netherlands against its water. Every time a new lesson had to be learned or old knowledge had to be relearned.

A good example is the failure of a canal dike in January 2004 near Stein, a town in the Southeast of the country. A large part of the inner slope slided down, leaving only a very small part of dike between thousands of houses and the water of the canal. The water level was lowered 2 m immediately (see fig. 8). Still over time more and more water was streaming out of the gap. After several days working the amount of leaking water was not decreasing but increasing. The ministry of public works decided to install a sheet pile wall in the dike. By regulations all water pipes in the area were shut off before the installation. Immediately no more water was leaking out of the remaining dike part. A leaking water pipe was found right under the gap. This is not the first time the cause of a dike failure. Why then did nobody think of a leaking water pipe?

Fig. 8. Inner slope dike failure near Stein

After the dike failure of Wilnis the water board stated that this was the first time a dike failed with a horizontal sliding mechanism caused by draught. According to the water board the state-of-art geotechnical knowledge was insufficient to predict this failure.

However, in books of the Technical Advisory board for Water barriers the horizontal failure mechanism is mentioned [TAW 1993b, 1998] and also the long term representative strength of peat which can be used in calculations [TAW 1993b]. So, the geotechnical knowledge was sufficient in these days to prevent dike failures like Wilnis.

Still, there is some truth in the statement of the water board because among a lot of dike experts of the TAW the idea grew that the horizontal failure mechanism only existed in theory, but not in reality. Apparently they did not think about the horizontal failure of a peat dike in Wilnis in 1874 !!, nor about the peat dike failure of Oostzaan (near Amsterdam) in January 1960 after a very dry year or about the peat dike failure in Bleiswijk (near Rotterdam) in August 1990 after two very warm and dry summers (Vonk, 1994). This is the reason why in the Safety Manual [TAW, 1999] this failure mechanism was excluded. The water board decided in 1999 to follow the standards of this latest safety manual [DWR 1999].

8. Safety and priority

After the mayor flood disaster in 1953 in Zeeland most of the attention went to the sea dikes. After the dike failure in 1960 in Oostzaan more attention was paid to calculation methods for all primary dikes. Since primary dikes mainly consist of sand and clay, which effective specific weight is far more than of peat, little attention was paid to horizontal shear failure. In 1988 there was a huge high water threat in the rivers, so not much attention went to the secondary dikes. The report of the TAW about the bad state of the secondary dikes came out in August 1993. I brought only little attention to the secondary dikes, because it was immediately followed by another threat of high water in the rivers in December 1993 and another one in 1995, which led again most attention to the primary dikes.

Nevertheless the water board for Wilnis, named after three important small rivers in this area "Amstel, Gooi and Vecht" (AGV), made in those years an inventory of all its main dikes surrounding all polder districts [DWR, 1999]. It proposed a large upgrading of these dikes between the year 2000 and 2004. Many of these dikes were in bad shape and because of a lack of money, no other dikes could be handled. The dike of Wilnis was not on the list because it is not a dike surrounding a polder district, it only crosses a district. These secondary dikes were planned to be upgraded later because of financial reasons.

9. Responsibilities

Flooding can lead to huge financial damage in The Netherlands. In order to prevent insurance companies from getting bankrupted after a huge flood, the Dutch government has accepted a law which forbids insurance companies from insuring any damage caused by flooding or dike failure. Another law has been accepted which gives the state the option to pay (a part) of the occurred damage, but this does not mean that the victims have any rights to claim for money after a flood disaster. In most cases, however, the government pays a part of the damage. In the case of Wilnis, half a year after the dike failure, the people of Wilnis haven't got any money and they are told that each person has to pay at least the first € 1000,- of the personal damage himself. The only way for the victims to get all the damage paid is to prove that some party has been negligible in doing its duties. Therefore knowing who is responsible, and for what part, can be important for the victims. The damage is estimated on M€ 10,- for the people in Wilnis and M€ 6,- for the municipality.

In The Netherlands the primary dikes are the responsibility of the state government by the ministry of public works, who is in most cases also the owner of the dike. The responsibility of the secondary dikes and some river dikes is more complex. First of all the owner (private person, company, city or province) is not responsible for dike failure. The water boards should maintain the dikes such that they remain in good shape. Upgrading of the dikes to a higher safety level is, according to the water board, more than maintenance so the water board will only do this if provincial rules prove this is necessary and if there is enough money available. The provincial governments are responsible for making rules to which these dikes should satisfy, but they haven't made any rules for the dikes yet. Besides, they don't want to pay for all of the costs. This has led to a stalemate situation. Since the provincial governments and water boards are both directly elected, this situation can not easily be solved by state regulations. The state government is not allowed to intervene in this provincial matter.

The water board and the provincial government are officially the only two authorities who can be held responsible for the dike failure of Wilnis. The questions whether these two authorities are responsible and which of these two, are not easy to answer. At least one point is clear. The dike failure is not a geotechnical engineering problem but a governmental (water) management problem.

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