Stability of underwater slopes realized by means of a suction dredger

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ABSTRACT

In Flanders (Belgium) large amounts of sands, to be used in the construction and glass industry, are excavated by means of suction dredgers. It showed that for deep excavations the dredging process cannot be modelled by conventional methods. In order to comprehend the process of breaching a laboratory test set up was elaborated and a full scale breaching test was performed.

RÉSUMÉ

En Flandres (Belgique) l’extraction de larges quantités de sables, destinées à la construction et la fabrication du verre, est réalisée au moyen de dragueurs à suction. Il est mis en évidence que pour des excavations profondes le processus de dragage ne se laisse pas modeler par des méthodes conventionnelles. Afin de mieux comprendre la formation de brèches un banc d’essai a été élaboré, et un essai en vraie grandeur a été réalisé.

Keywords : Excavation slopes, sand, breaching, full scale test, laboratory test, monitoring.

1 INTRODUCTION

The Flemish authorities want to stipulate stability requirements, in exploitation licences for sand quarries in Flanders (Belgium).

Based on conventional slope stability studies (Bishop Method) following slopes could be imposed for dry excavation below groundwater level:

- 1/1.5 to 1/2 for quarries that will remain dry
- 1/2 to 1/3 for quarries that will be flooded

These slopes are rather safe and until now almost no problems occurred with dry excavations.

For wet excavation below groundwater level a slope of 1/3 can be allowed. Based on past experience and literature research, gentler slopes were proposed in 2002:

- 1/4.5 up to 20m depth
- 1/6 from 20m till 30m depth
- 1/8 from 30m and deeper.

Due to environmental considerations and the actual fact that open space is rather sparse in Flanders, opening of new quarries is dissuaded by policy makers.

Therefore existing quarries are actually deepened to depths of up to 45m, using suction dredging techniques,. However during the last years several rather big slides occurred. So it has been decided to review the stability regulations for dredged sand quarries and a working group has been installed.

2 SUCTION DREDGING PROCT

he suction dredging process cannot be modelled by conventional slope stability methods.

Suction dredging initiates slope instability by erosive sand-water mixtures flows running down the slope. This slope failure initiation, called breaching, retrogrades up slope with a velocity dependent on the permeability of the sand.

Figure 1 illustrates the breaching process.

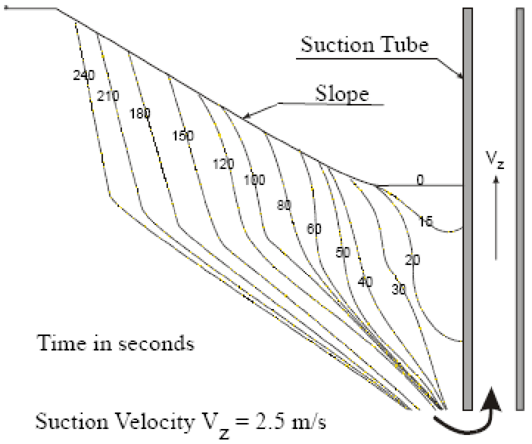

Figure 1 Breaching process

When a suction tube is lowered to a certain depth in a sand layer a cylindrical hole with nearly vertical slopes is created around the tube. These active banks retrograde radially from the suction mouth. If breaches are higher than 1 to 2m density flows occur along the breaching surface. By the effect of erosion only a gentler slope is needed for the same horizontal movement. This is the reason why the slopes at breaching are commonly curved, with steeper upper part and gentler slopes near the toe.

In practice breach heights of 5m or more will result in large scale instabilities.

As a result of the bigger volumes of soil involved a turbulent density current is generated along the slope. At the base of the breach a very gentle slope occurs, and even sedimentation may take place at the toe of the breach, as shown in figure 2.

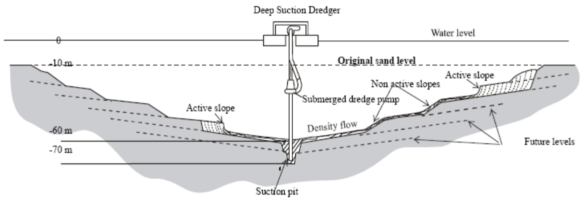

Figure 2: breaching in a sand quarry

Based on the active bank theory, developed by TU Delft (Netherlands) the pit production, i.e. the amount of sand that comes available at the base of the pit, can be predicted.

Calculation of pit production is however dependent on multiple parameters. Based on empirical knowledge, confirmed by calculation, for fine sands the following typical breach slopes are adopted in the Netherlands:

- 1/2 up to 5m depth
- 1/3 from 5m till 10m depth
- 1/4 from 10m till 20m depth
- 1/4 from 10m till 20m depth
- 1/8 from 20m till 30m depth
- 1/15 from 30m till 40m depth
- 1/25 from 40m till 50m depth

The working group involved with the review of stability regulations for dredged sand quarries chose for empirical verification of design rules instead of calculations based on parameters that are not known accurately..

3 EMPIRICAL APPROACH

In order to better comprehend the process of breaching first a laboratory test set-up was elaborated. The next step was to perform a full scale breaching test at a typical sand extraction site.

The main idea was to establish (or not) empirical confirmation of prescribed slopes as a function of suction depth, as proposed in Dutch regulations {ref 1}

3.1 *Laboraty test set up.*

The aim of the test set-up was to

- visualize the breaching process (through video monitoring)
- monitor pore pressure changes during breaching.

The test container (L 2000 x B 1200 x H 1000mm) was equipped with a sliding wall, that could be pulled out to initiate breaching.

The front of the test container was made out of plexiglas for visual observations through video monitoring.

Figure 3 shows test set up, at moment of pulling out sliding wall

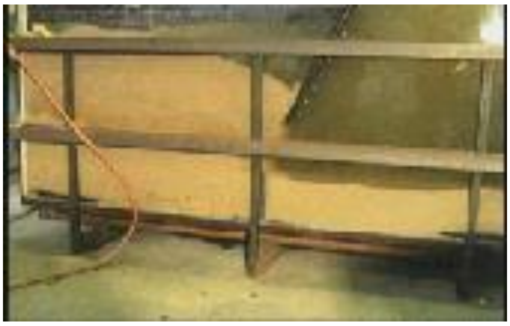

Figure 3 laboratory test set up

The sand was compacted close to in situ conditions, and 4 porewater pressure transducers were installed.

Particle size distribution data for sands used in the tests are given in table 1.

Cumulative fraction sand passing each sieve	white %	grey %	dark %
2.5000	0.0	0.0	0.0
2.0000	0.0	0.0	0.0
1.8000	0.0	0.0	0.0
1.2500	0.0	0.0	0.0
0.9000	0.1	0.1	0.0
0.6300	0.3	0.1	0.1
0.4500	0.8	0.3	0.3
0.31600	23.8	21.1	17.5
0.2240	81.6	85.7	77.6
0.1600	93.9	97.3	96.5
0.1120	97.7	99.2	98.8
0.0800	99.2	99.6	99.3
0.0630	99.6	99.7	99.4

Table 1: Particle size distribution

After a few test runs to optimize test and measuring setup, results of 4 tests show:

A decrease in porewater pressure during instability initiation; it is only after dissipation of these negative porewater pressures (having a beneficial effect on slope stability) that the sand mass adjusts itself to gentler slopes

The equilibrium state is only reached after a sand flow downwards the existing slope has occurred. Typical slopes that were observed are 32º in the upper part, 23º in the middle and 18º near the toe. These observations confirm the Dutch studies on dynamic slope development.

3.2 *Full scale breaching test*

3.2.1 GENERAL

The full scale breaching test was performed at a typical sand extraction site in Flanders, as shown on aerial view – figure 4

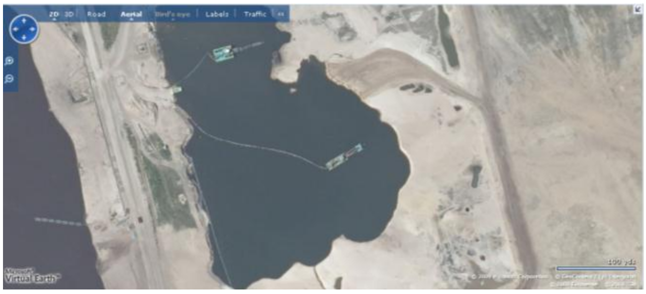

Figure 4: Arial view of test site

Figure 5 shows a typical CPT-diagram with geological profile

A: disturbed upper layer
B: Quaternary deposits – reworked Tertiary
C: Mol formation – Maatheide Member quartz sands.
D: Mol formation – De Maat Member lignite layer, consisting mainly of lumps of wood (sometimes complete trunks)
E: Mol formation – Donk Member quartz sand

Typical particle size distribution curves of extracted sands (after washing) are given on figure 6.

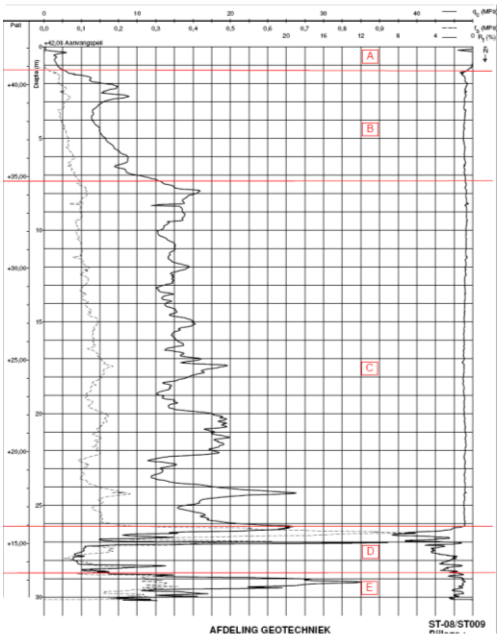

Figure 5 CPT diagram with geological profile

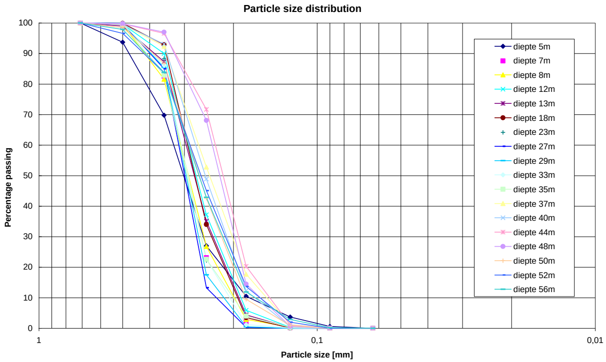

Figure 6: Particle size distribution

Aim of the test was to induce breaching in de sand layers between 0 en 25m beneath water level.

Before the start of the test a large area was dredged till a depth of about 25m in order to obtain an almost unlimited horizontal flow of the sand during breaching. Then the suction tube of the dredger was lowered at the toe of the existing slope to a depth of 30m and the suction tube has been moved towards the slope, with a combined lateral movement over a distance of about 25m.

During the breaching test 4 breaches were initiated. The position of the suction mouth at initiation of the breaches is given in fig. 7

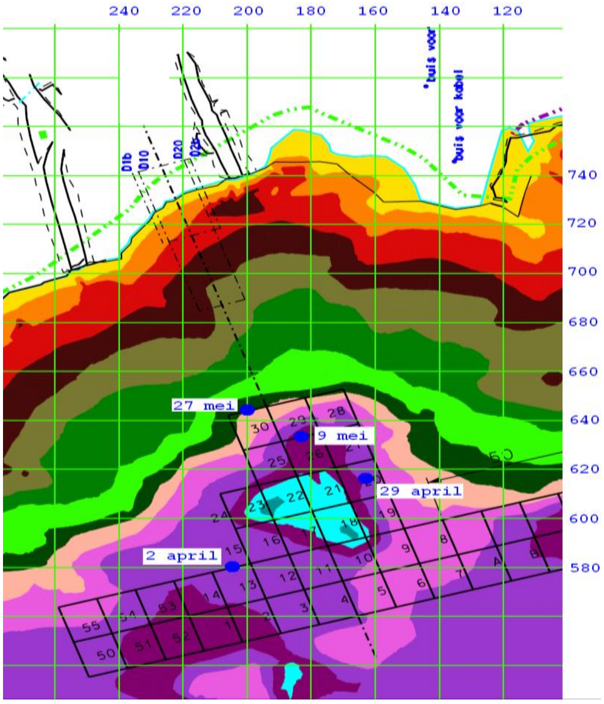

Figure 7 Position of suction mouth at breaching

After each breaching the sediments of the slides were removed in order to avoid obstruction for further breaching.

3.2.2 MONITORING

Piezometers and water pressure cells were placed at a safe distance beyond the expected reach of breaching instability, i.e. resp. at 50m and 80m from the crest of the existing slope. (figure 8)

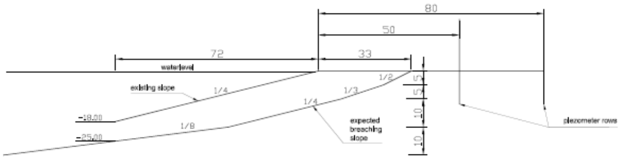

Figure 8: expected breaching versus emplacement piezometers

The emplacement of the piezometers in also shown on the aerial view figure 9.

Figure 9 emplacement of piezometers

The piezometers have a filter element of 2m, placed of depths of resp. 3m and 15m and are equipped with divers (ceramic

pressure sensors in stainless steel housing with a memory capacity of 24000 measurements)
Frequency of measurement was 5s.

A diver was also placed at the suction tube mouth. In addition 2 vibrating wire porewater pressure cells were placed in boreholes at depths of resp 12m and 13m.

To visualize the way the instability front proceeded during breaching 2 cameras were installed:

- One high on a pole, situated on the shore of the pond
- One at the mouth of the suction tube

As the crest of the extracted sands was situated below water level 2 dams of about 5m width were realized to make visualization of instabilities possible.

3.2.3 RESULTS OF MONITORING

Water pressures measured in piezometers and porewater pressure cells show a decrease of about 10 cm to maximum 40cm after initiation of the instability, followed by an increase and stabilization to the pressure corresponding to the water level in the pond (figure 10)

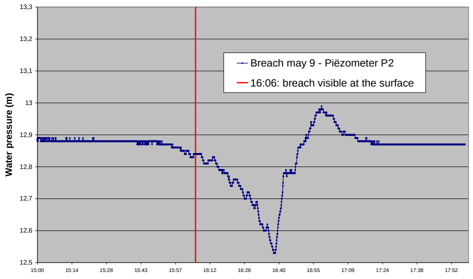

Figure 10 pore water pressure

Water pressures measured at the suction mouth are a measure for the depth of the tube below water level. Figure 11 shows that the tube was lifted (probably due to pit production exceeding suction capacity) at 20h05, where instabilities at surface level were visually observed at 21h20. This shows clearly time dependency of breaching.

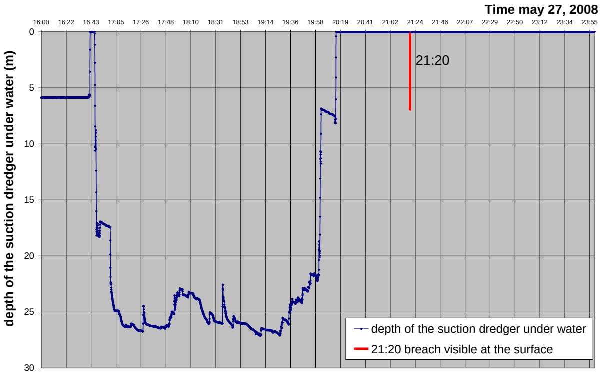

Figure 11: pressures measured at suction mouth

The video recordings confirm these findings, and show a steadily progressing instability front during breaching. With regular time intervals soil layers with a thickness of some decimeter come apart and then gently slide away.

Figure 12 shows a picture of fissuring observed at surface level.

Figure 12: fissuring at surface level

Depth profiling before and after breaching show there in a good match between theoretical (= slopes adopted in the Netherlands) and observed slope line (figure 13)

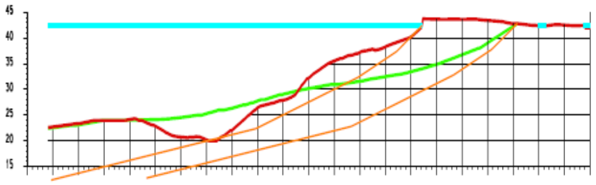

Figure 13: depth profiling before (red) and after (green) breaching + theoretical breach lines (orange).

4 CONCLUSIONS

Observations made during breaching tests show that for sand extraction pits in fine sands the theoretical breaching curve proposed by Delft Hydraulics has been confirmed. This means that for sand extraction by means of suction dredgers following slopeline has to be adapted.

- slope 1/2 from 0 till 5m
- slope 1/3 from 5m till 10m
- slope 1/4 from 10m till 20m
- slope 1/8 from 20m till 30m

Steeper slopes can only be realized if cutter dredgers are used. Observation showed clearly that once a breach is initiated it extends rather slowly, first under water, then resulting in gradual sliding of the slope. Once the instability is triggered it cannot be stopped.

The breaching test also showed that water pressure measurements in the sand mass and at the suction mouth do not enable the prediction of breaching.

5 REFERENCE

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