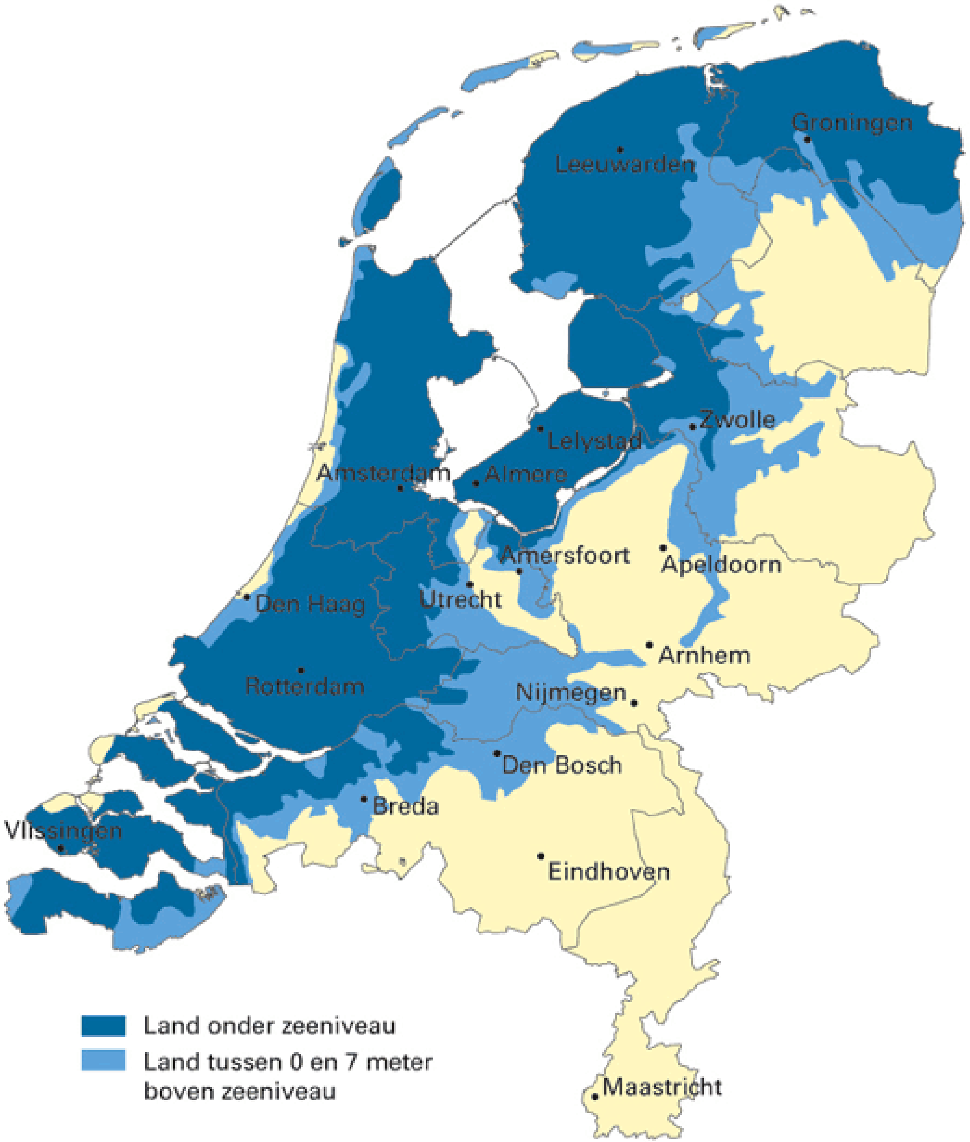
Deltares
Enabling Delta Life

Full scale stability tests

Dr. C. Zwanenburg

30 september 2016

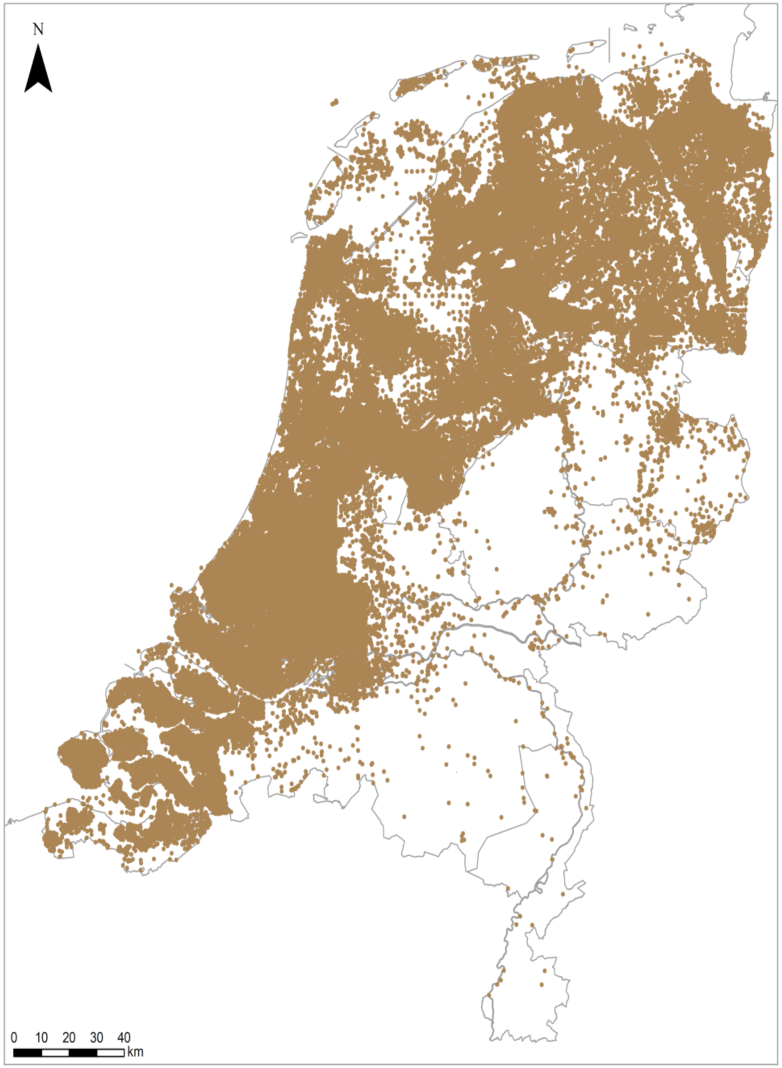
Area to be protected

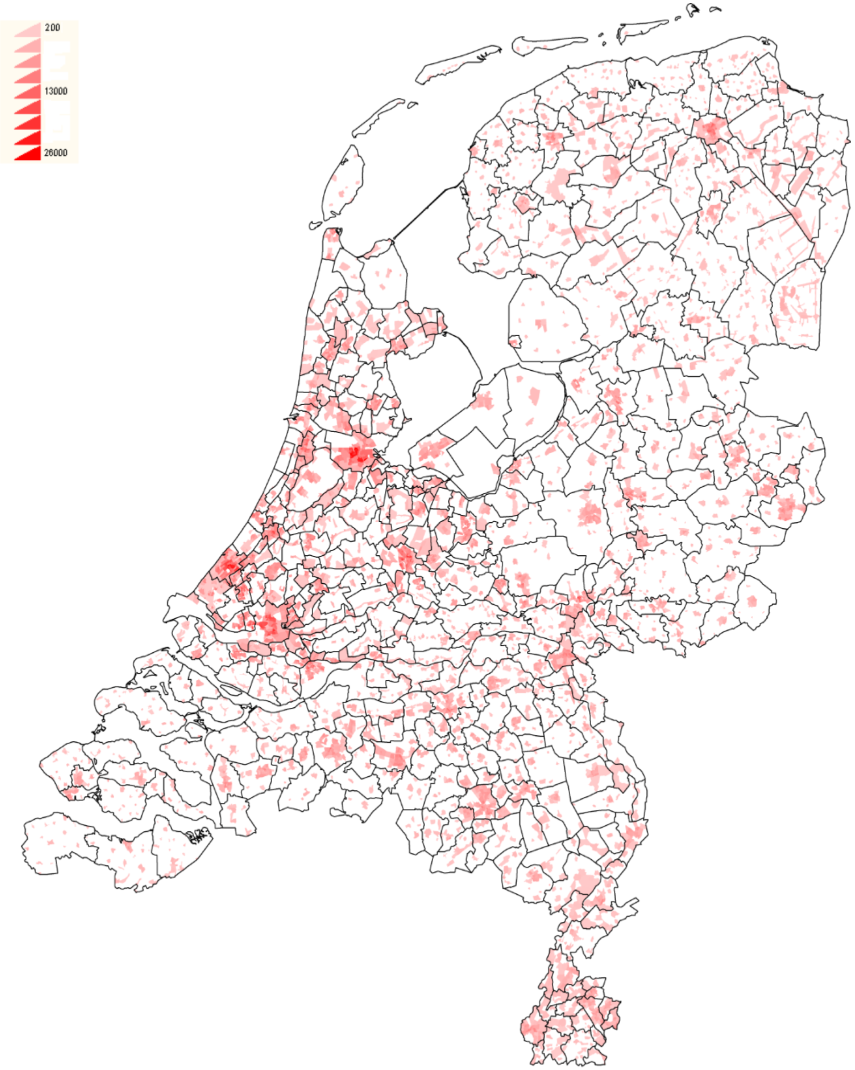


The Netherlands without dams and dikes

Kaart:
Hans van der Maarel
Red Geographics

Distribution of peat (Nieuwkoop formation) and population density





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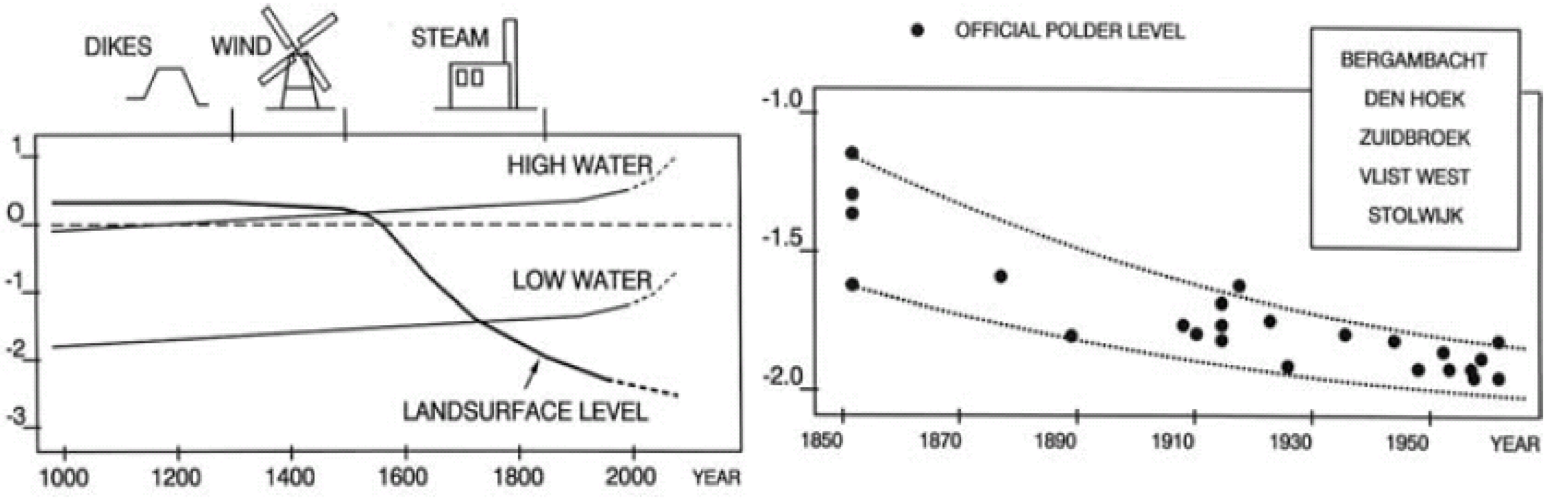
Subsidence in peat areas



POLDER LAND SUBSIDENCE IN HOLLAND

POLDER WATER LEVEL IN HOLLAND

(vertical scales give elevation in m relative to Dutch datum N.A.P.)

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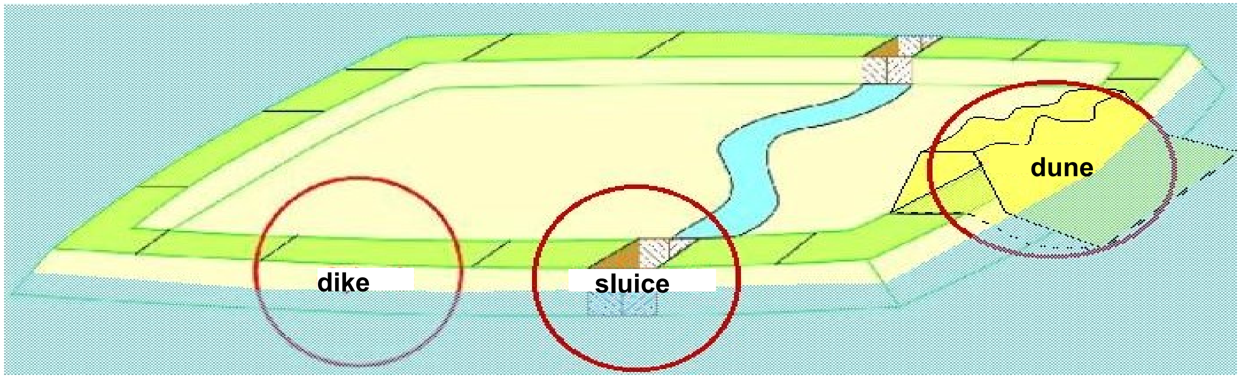
Safety assessment cycle

- different inundation risks for different regions
- safety assessment for all known failure mechanisms
- Macro-stability, failure planes through dike and sub soil is an important failure mechanism

Assessment method: division in reaches

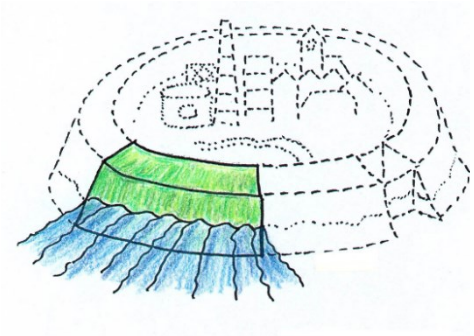
Every dike ring consists of reaches: dikes, dunes, civil structures

Each reach can fail by various <u>failure mechanisms</u>.



Regulated safety assessment

- Repetitive assessment (each 5 years), in order to find and improve weak reaches/sections.
  - All relevant failure modes are considered
  - Current standards are based on assessment of single reaches/segments and single failure modes
  - New standards (under development) will be based on the annual system failure probability



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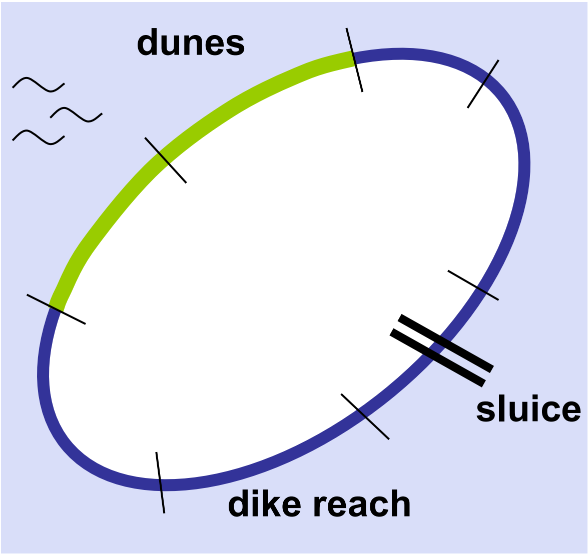
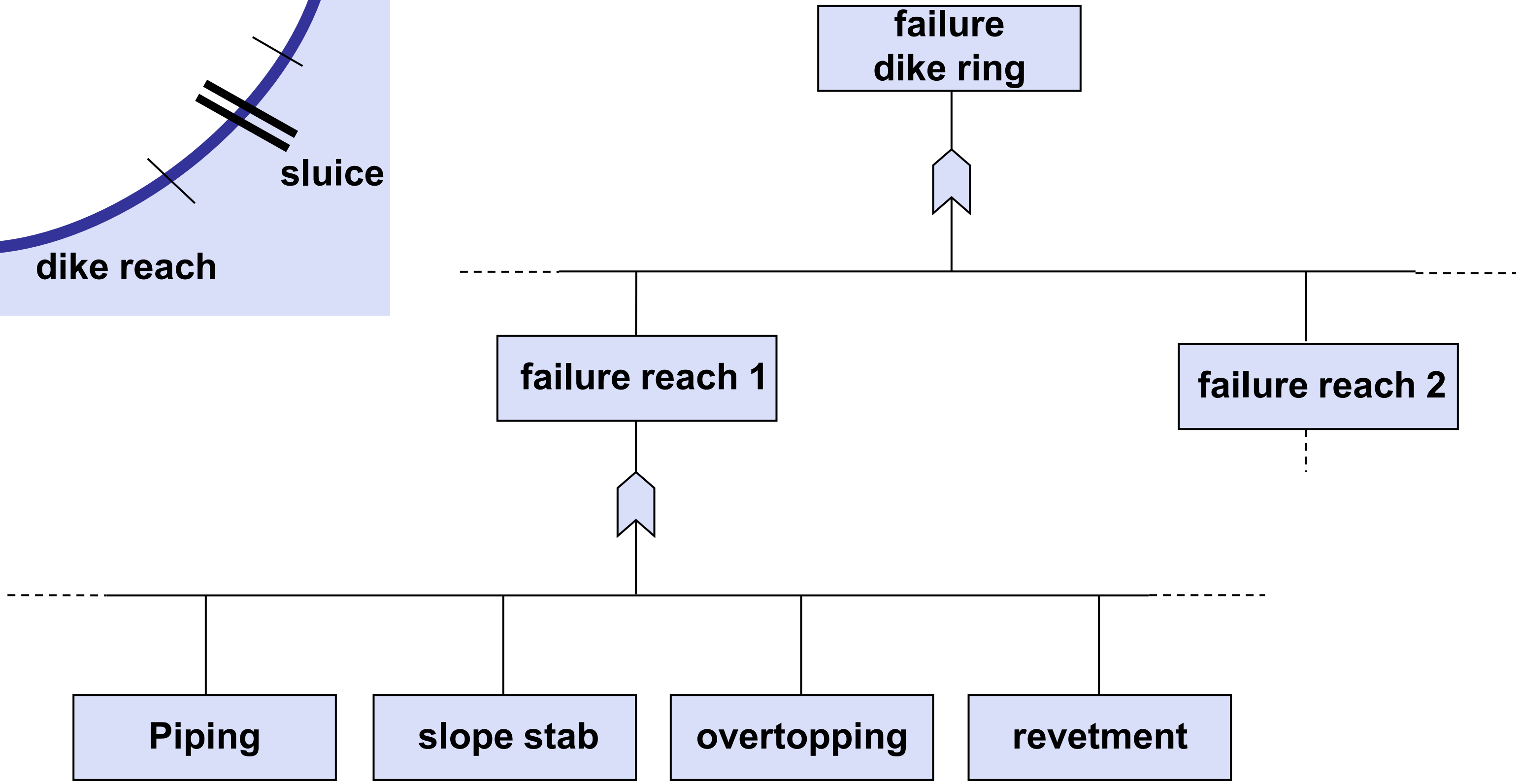
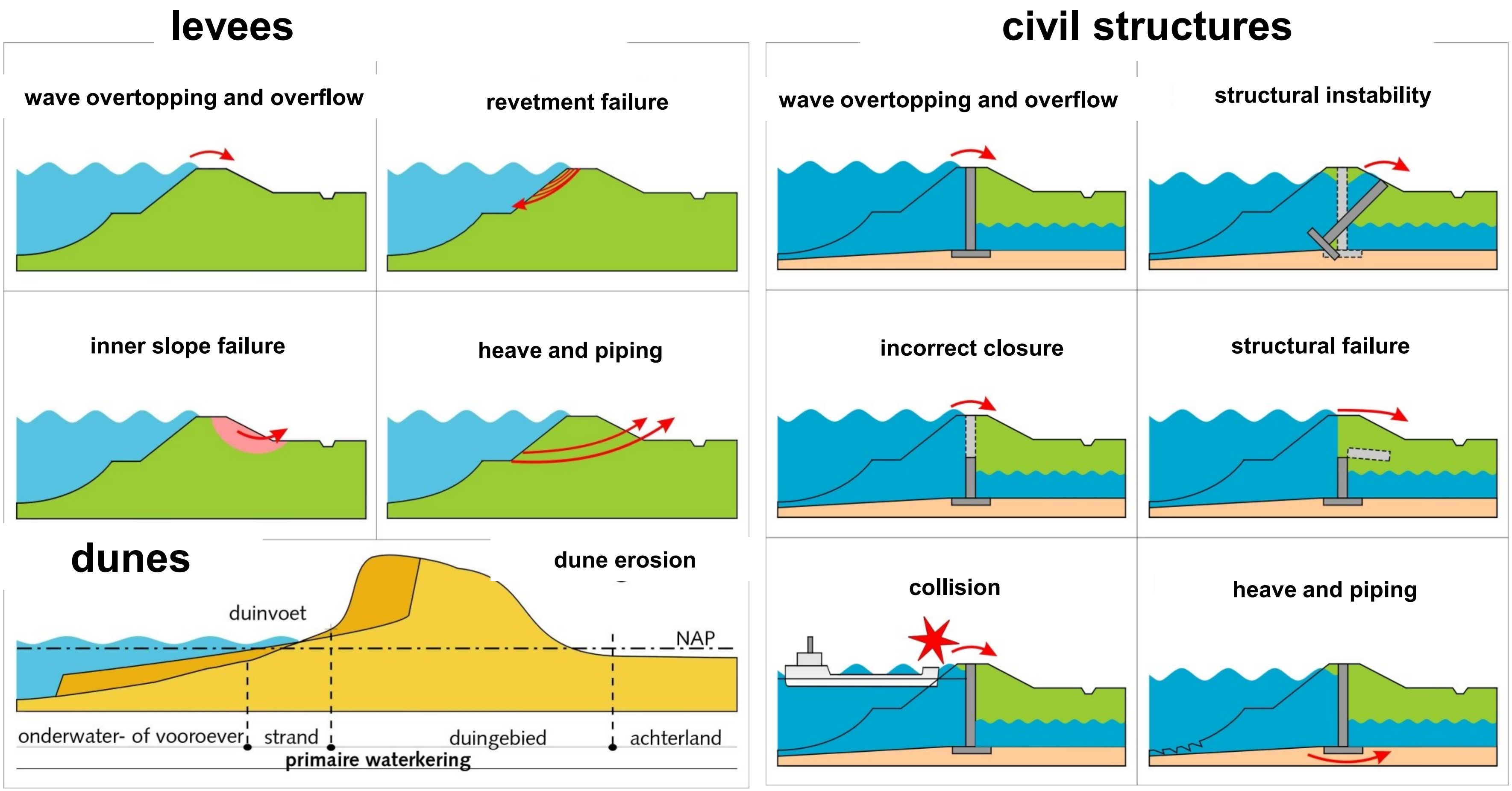
Reliability of Flood Defense Systems





Assessment method: Failure mechanisms



Models describe these mechanisms in terms of geotechnical, geometrical, material, hydrological and geographical data.

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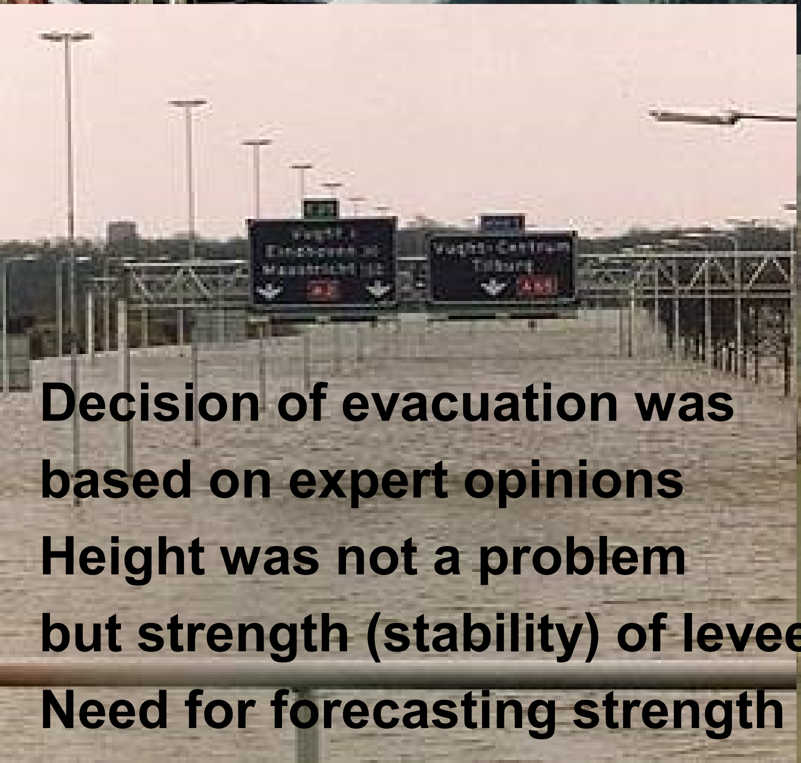
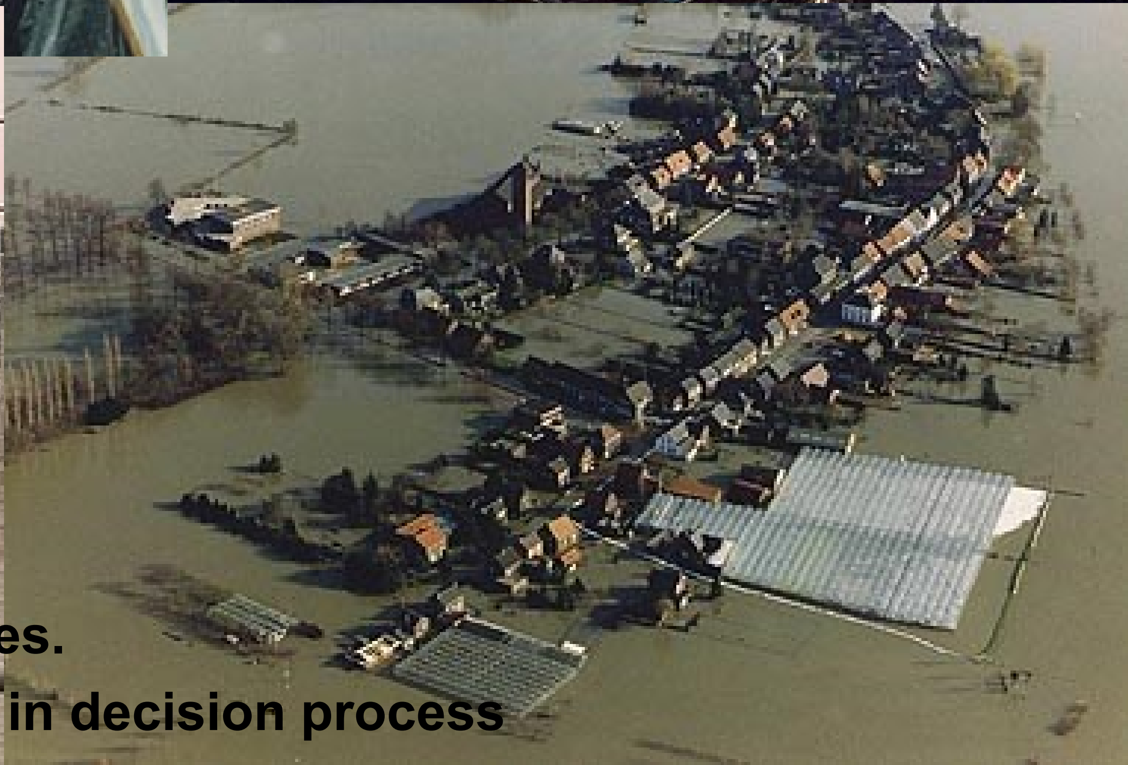
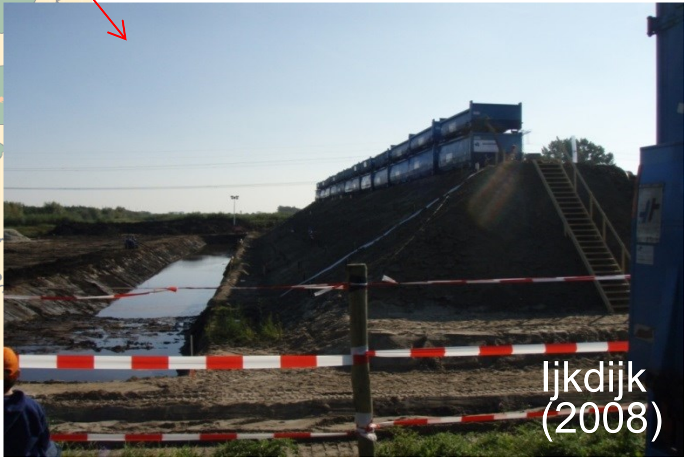
Evacuation 210000 people in 1995





Decision of evacuation was based on expert opinions
Height was not a problem but strength (stability) of levees.
Need for forecasting strength in decision process

5 Field tests since 2000



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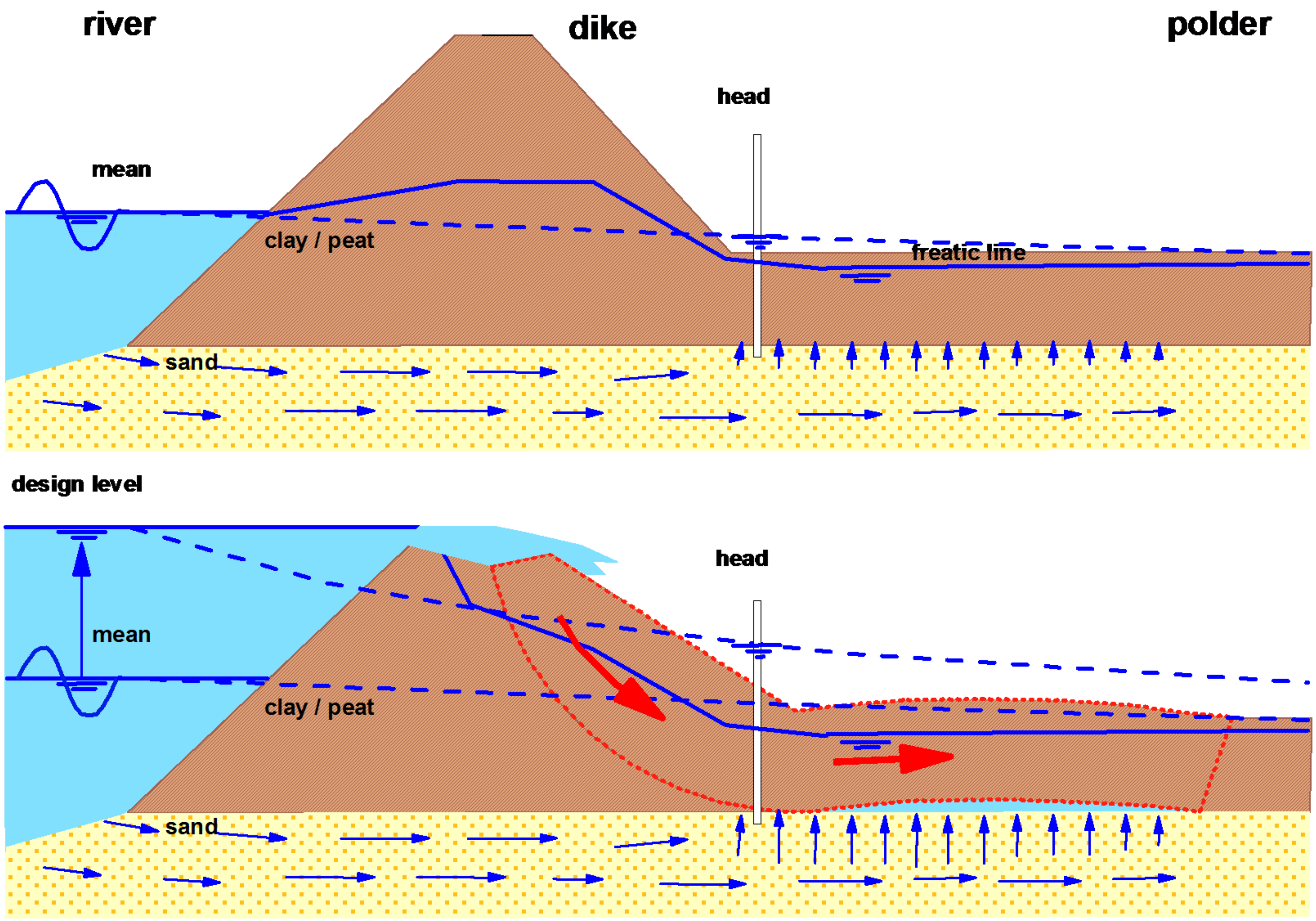
Bergambacht test; Stability during uplift



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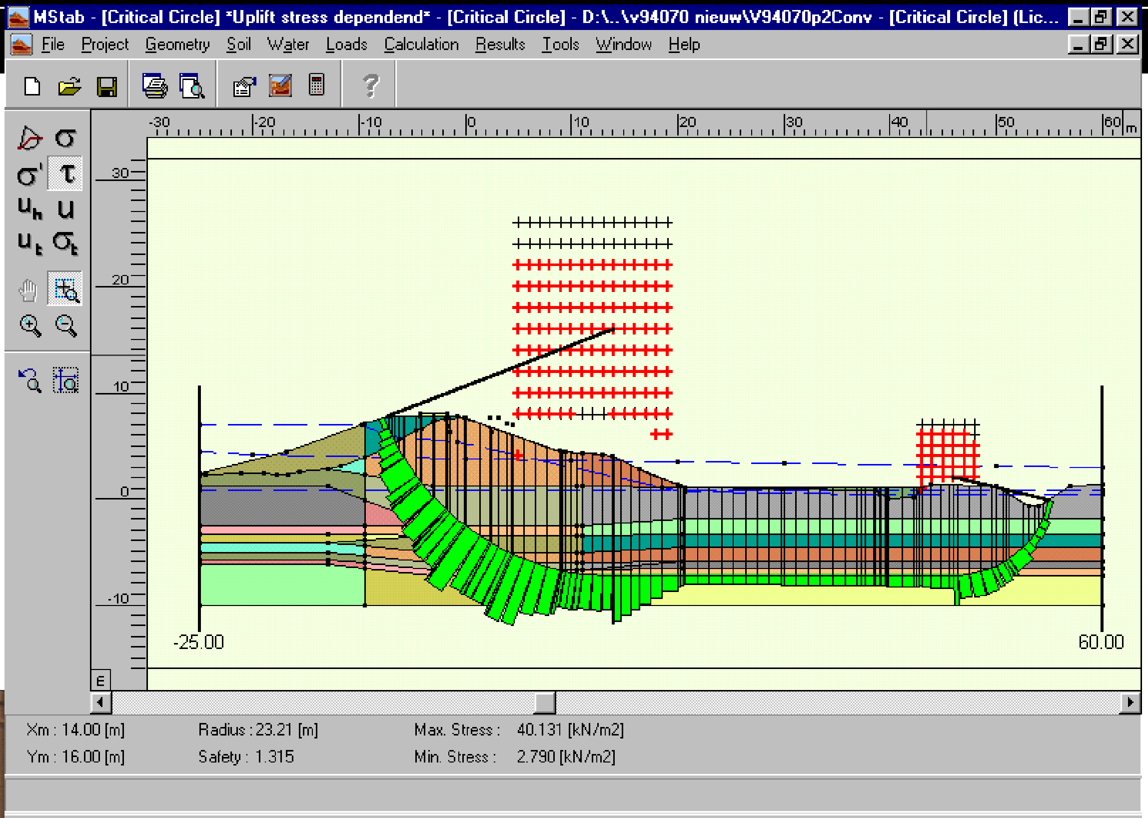
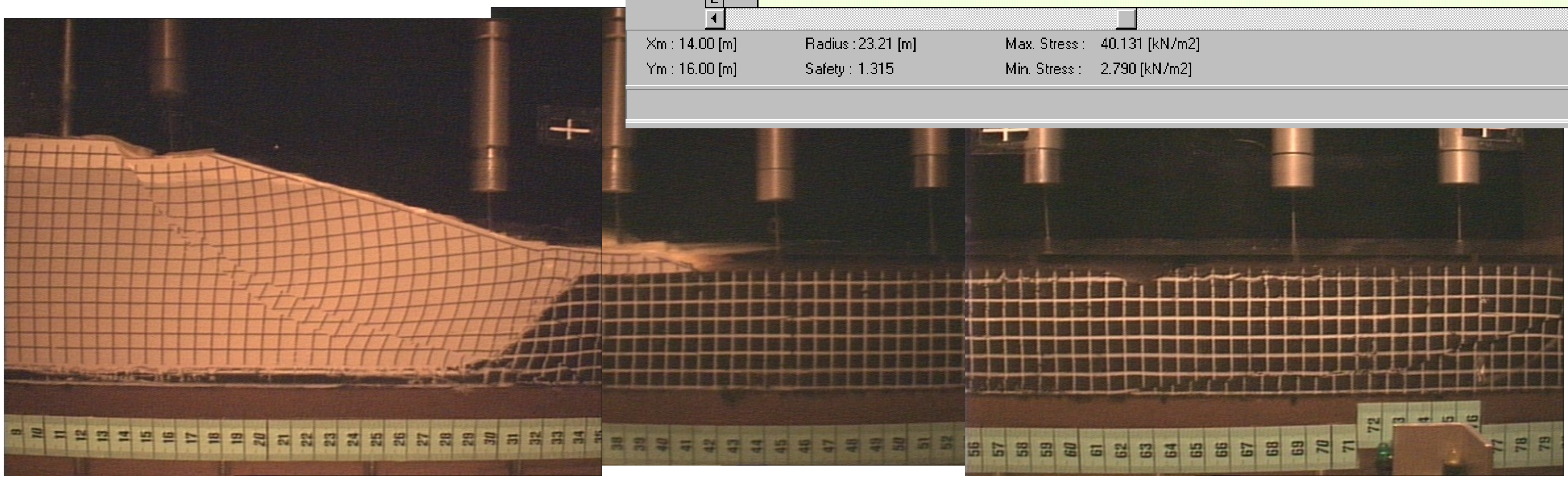
Validation model





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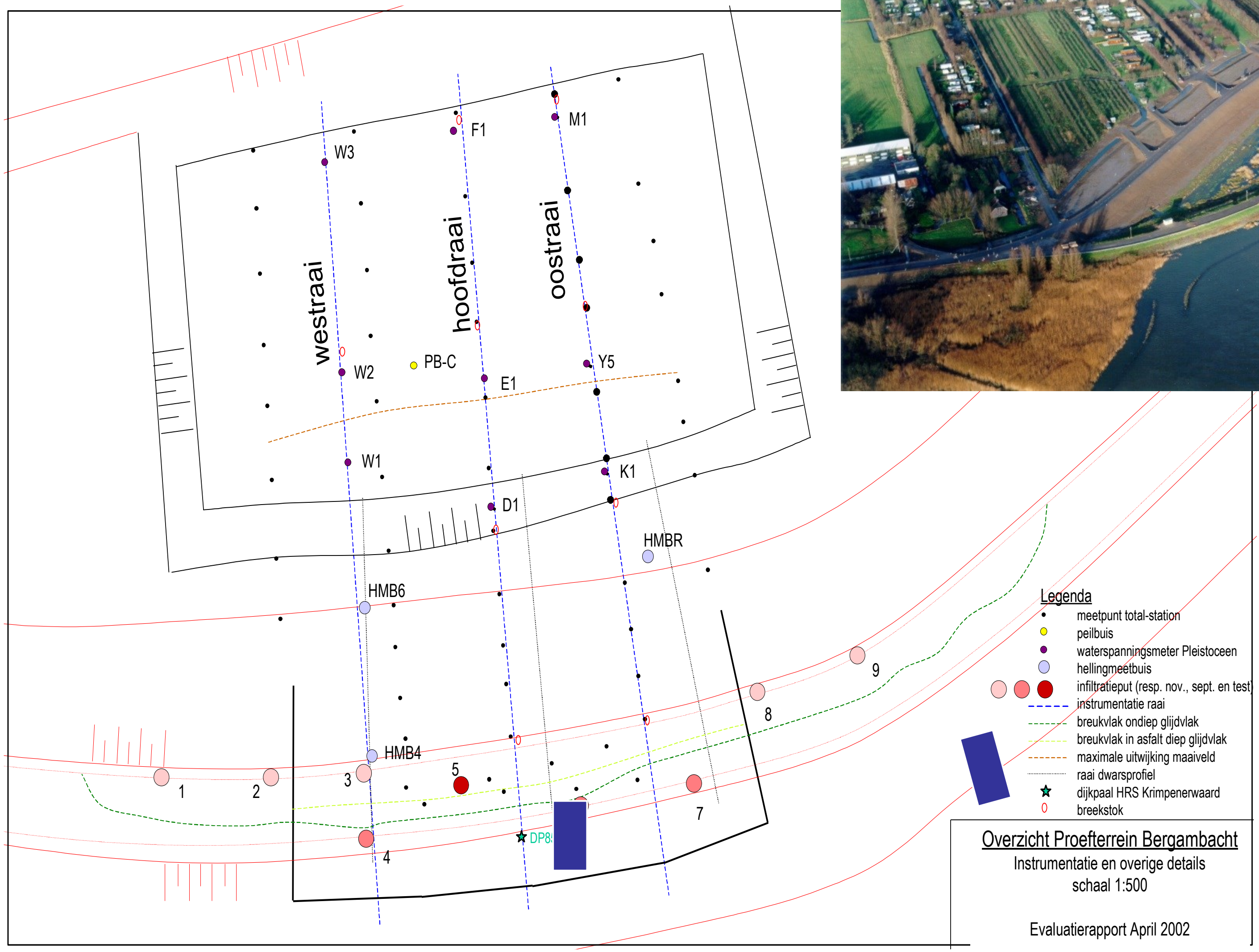
Test set-up



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Failure

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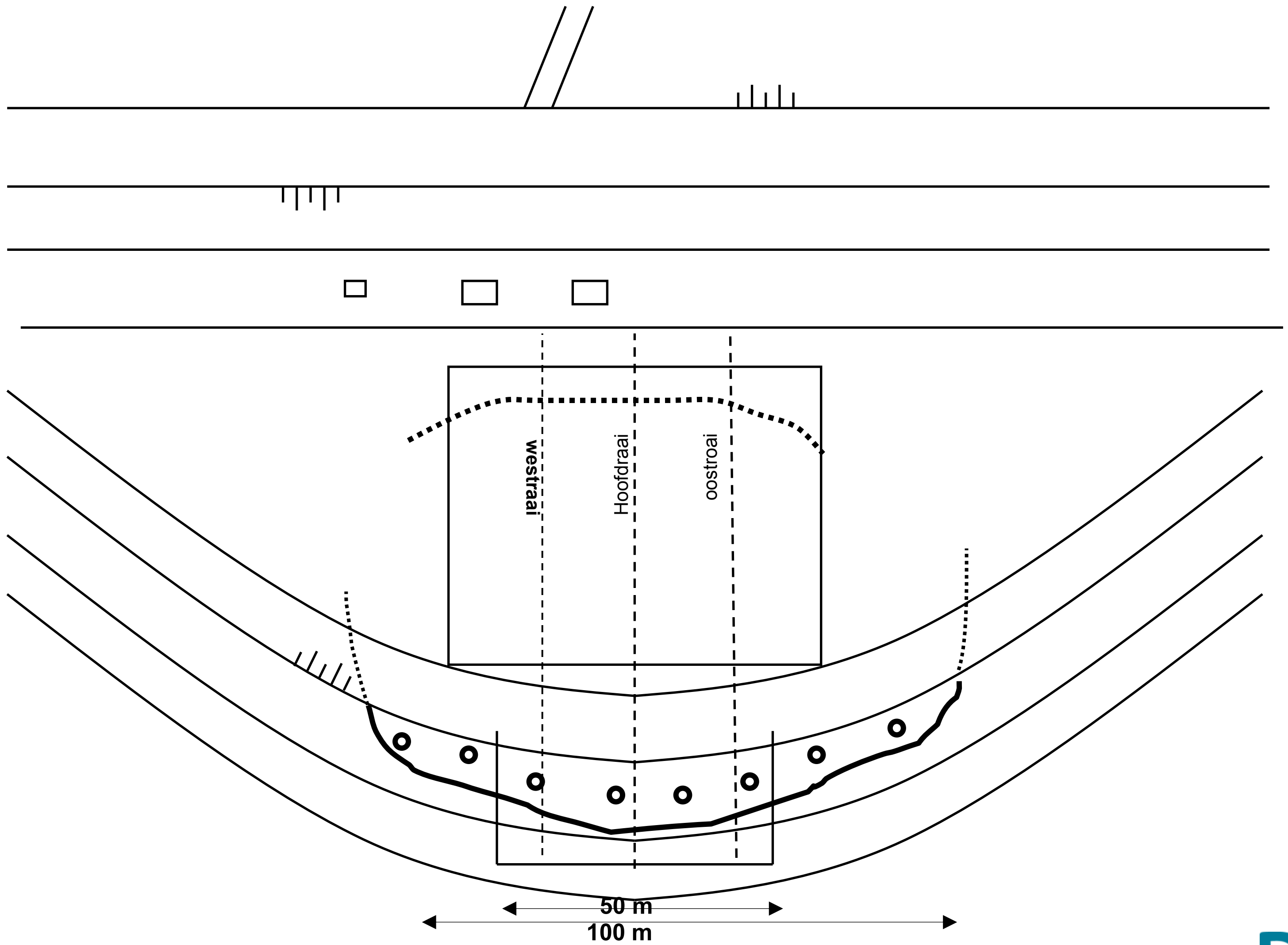
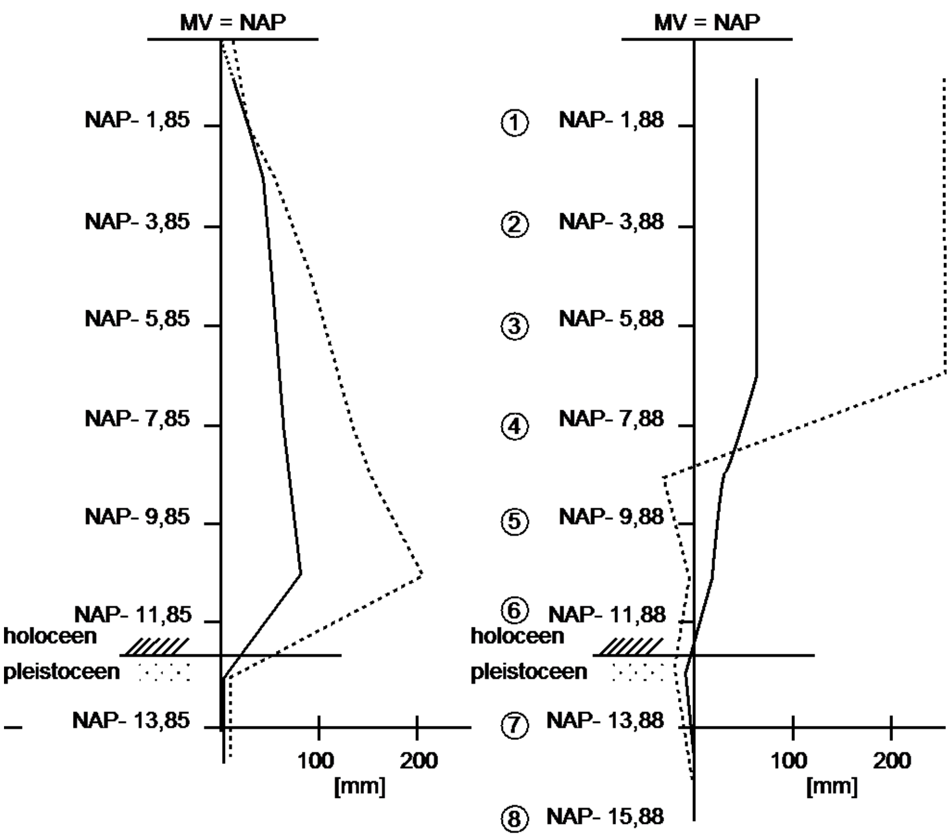
Failure

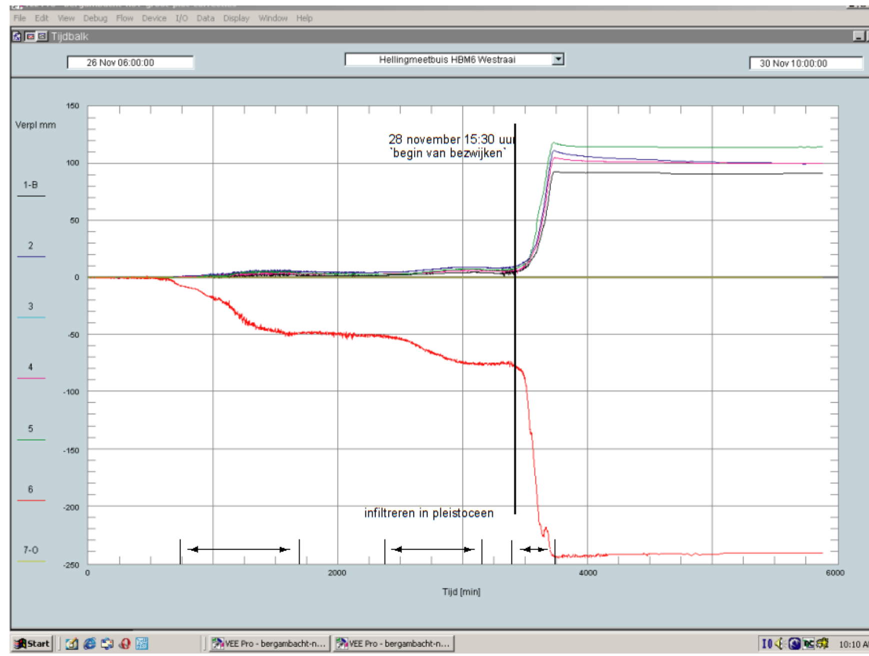
Top view failure



Some measurements and analysis

Displacement profiles





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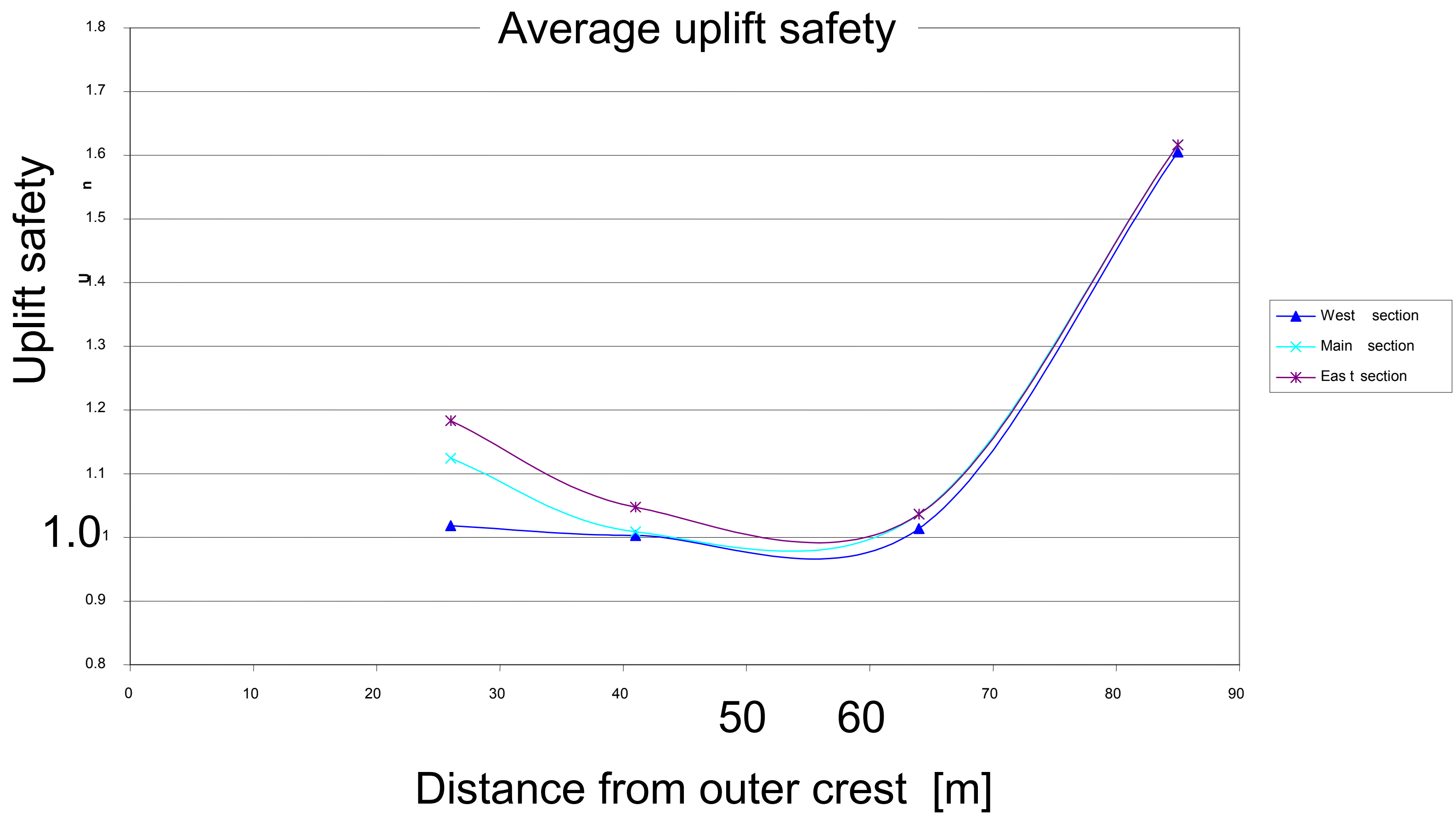
Uplift safety



Conclusions from Bergambacht test:

- Uplift is dominant in engineering practise and has large impacts.
- Is uplift a serious or fictive problem?

Uplift is an important failure mechanism, shown by centrifuge tests and field test

- If it is a serious problem, how to design a strong dike

The analytical model is developed and validated by centrifuge and field test, so made available for dike design; Lift Van method

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Second Field test, the IJkdijk stability test

Background

After events in Stein and Wilnis push from sensor technology.
However:

- Which sensors are useful?
- At what location?
- Length of period between warning and dike failure?

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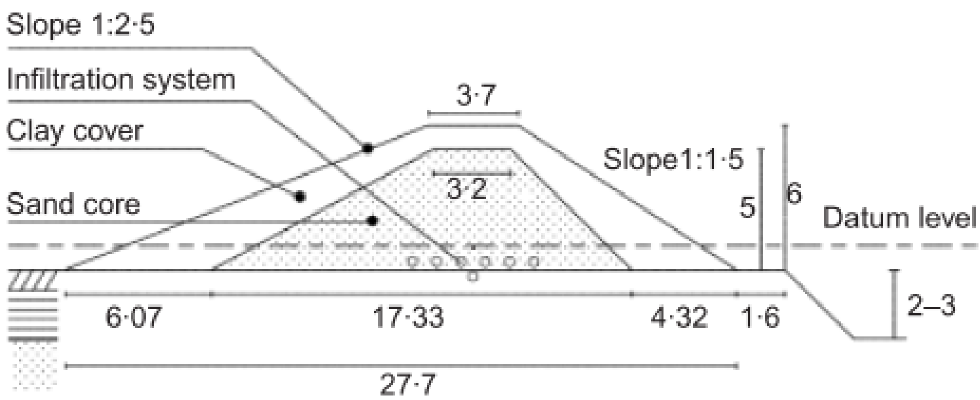
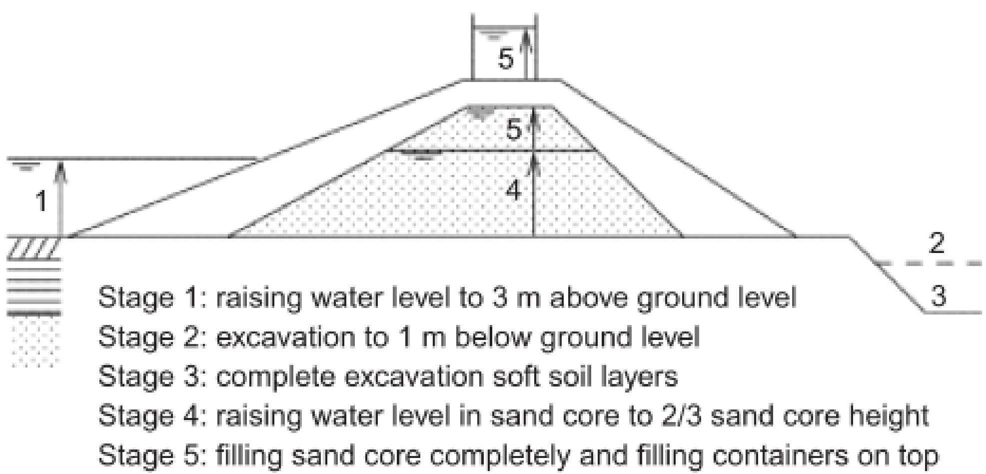
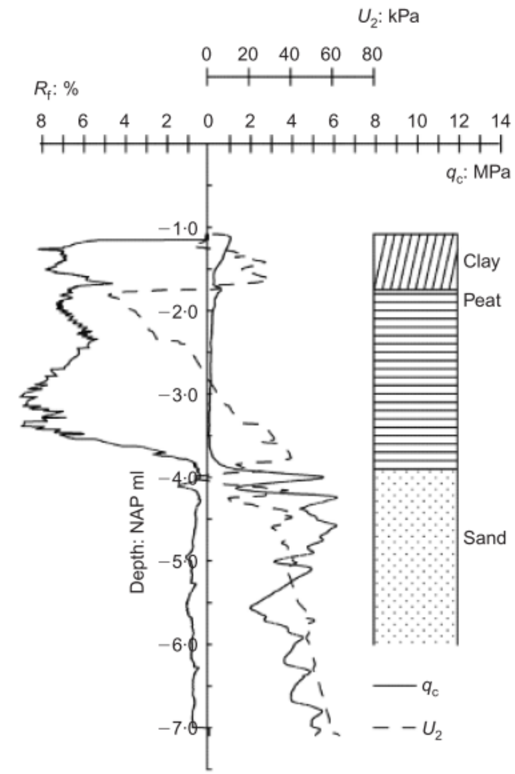
Test set up



Cross section, measures in [m]



Test procedure



Typical soil profile

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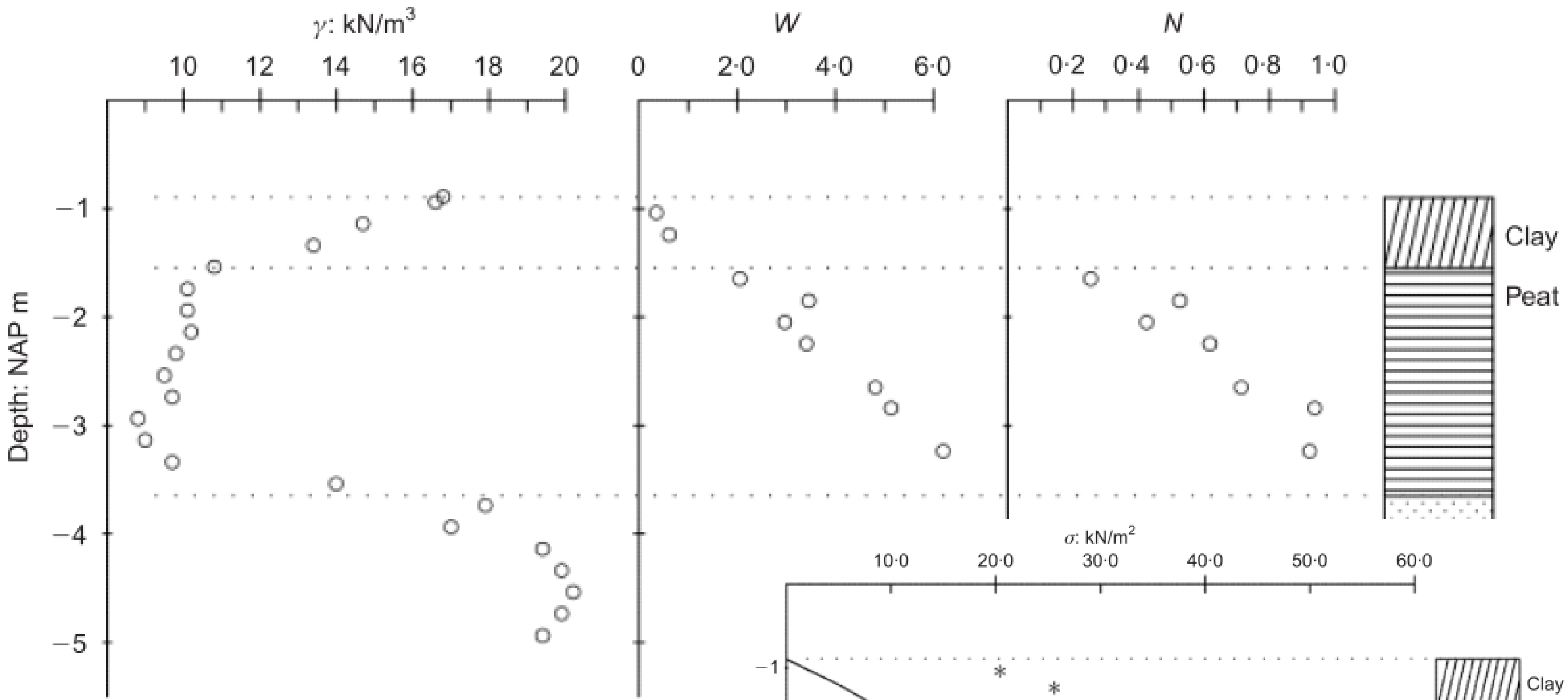
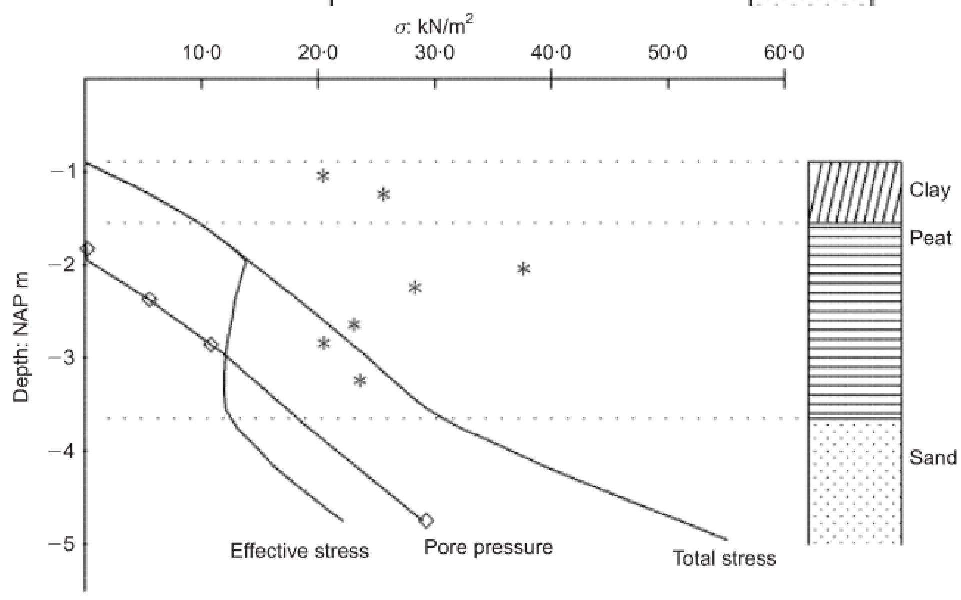
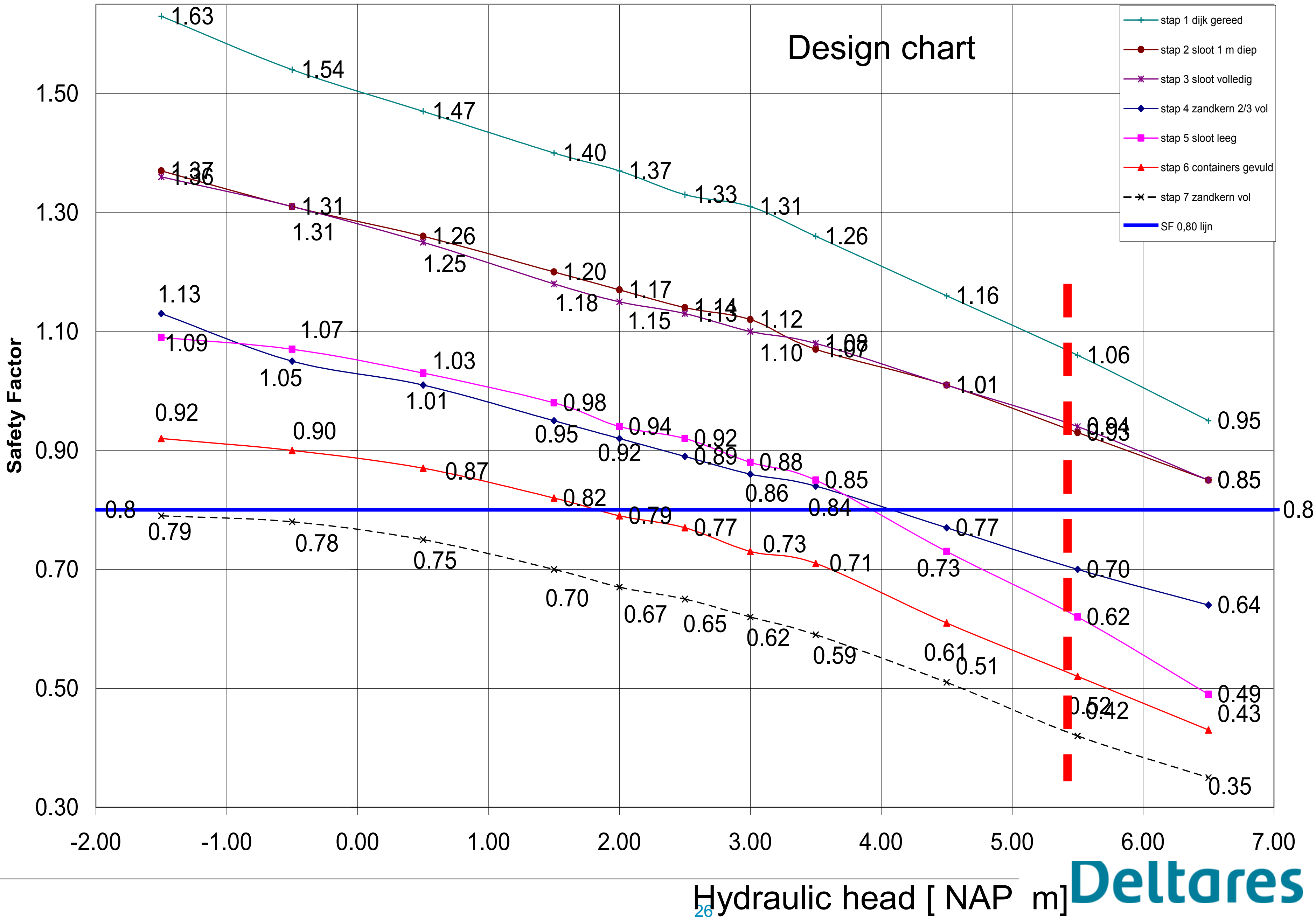
Sub soil conditions





Start construction August 2008


Design chart
Safety Factor
Hydraulic head [NAP m]
0.30
0.50
0.70
0.90
1.10
1.30
1.50
-2.00
-1.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
0.8
stap 1 dijk gereed
stap 2 sloot 1 m diep
stap 3 sloot volledig
stap 4 zandkern 2/3 vol
stap 5 sloot leeg
stap 6 containers gevuld
stap 7 zandkern vol
SF 0,80 lijn

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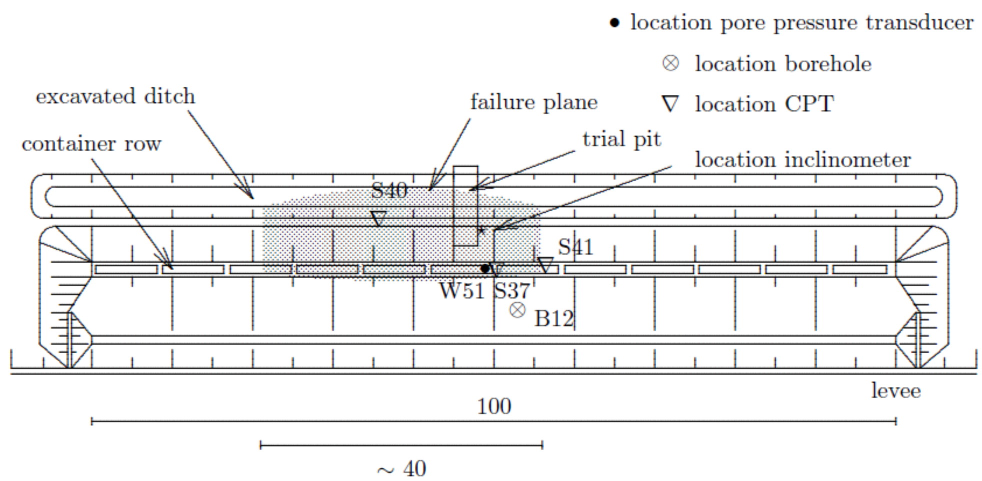
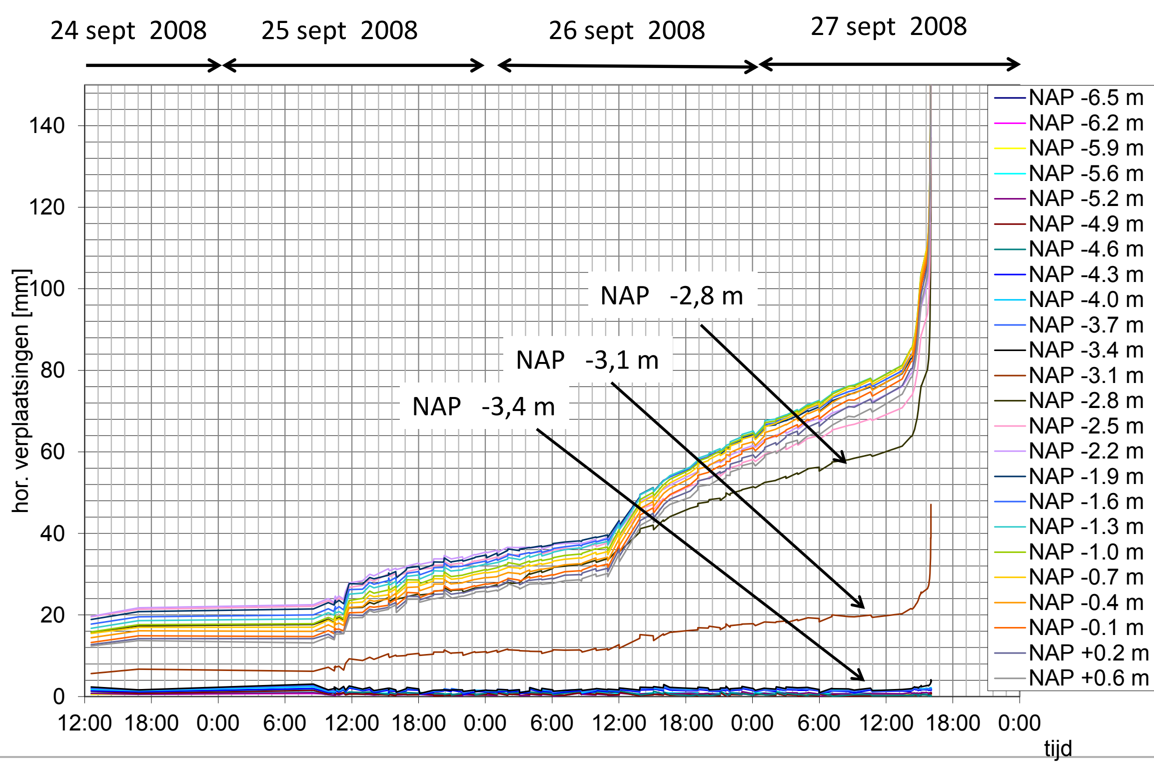
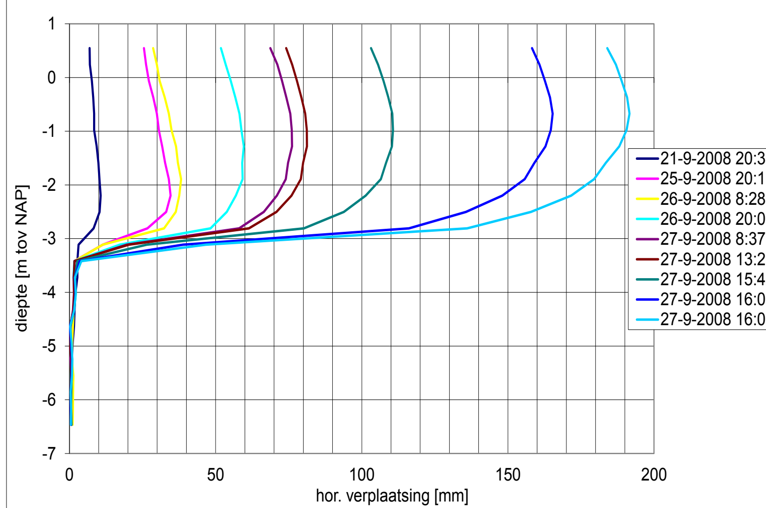
measurements







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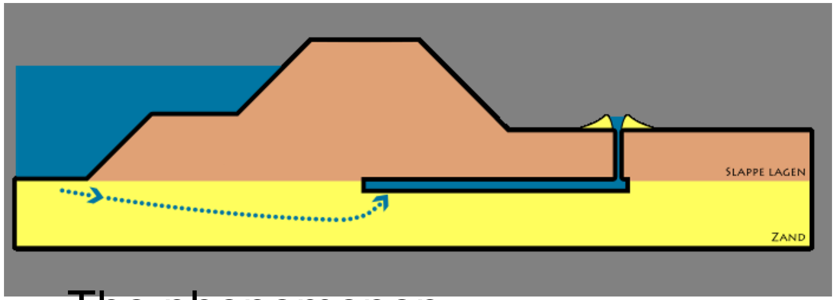
Second Field test, the IJkdijk piping test

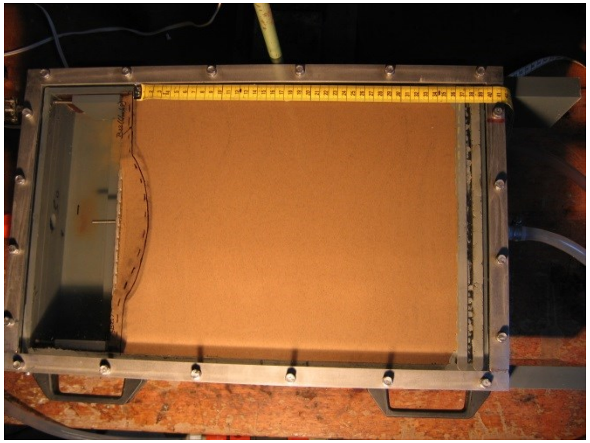
Piping / backward erosion

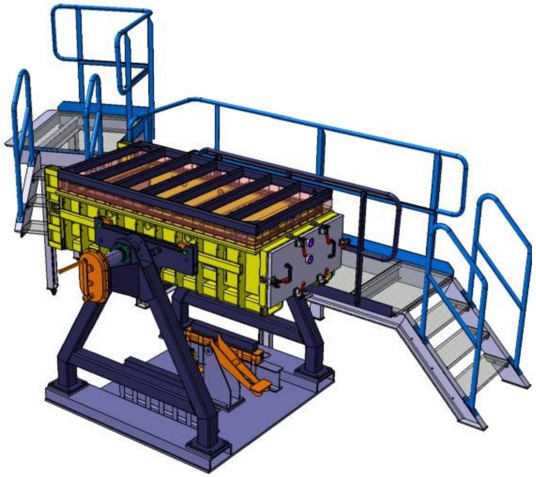


The phenomenon

Initiation often observed,
failure due to piping rarely observed

- Small-scale experiments
- Medium-scale experiments
- Multi-variate analysis
- Centrifuge experiments
- Full-scale experiments





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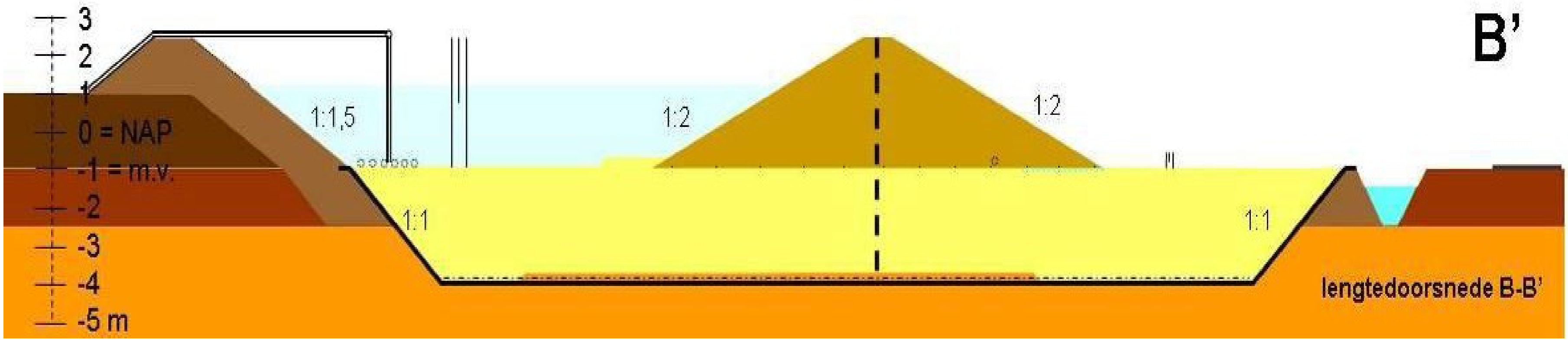
Full-scale experiments



2 basins for 2 sand types, 4 tests

Test nr.	Sand type	Monitoring equipment	Objective
1	Fine sand	Low disturbance techniques	Validation of model and process / Testing monitoring techniques
2	Coarse sand	No additional monitoring	Validation model and process
3	Fine sand	No additional monitoring	Validation model and process
4	Coarse sand	High disturbance techniques	Testing monitoring techniques

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Building the IJkdijk

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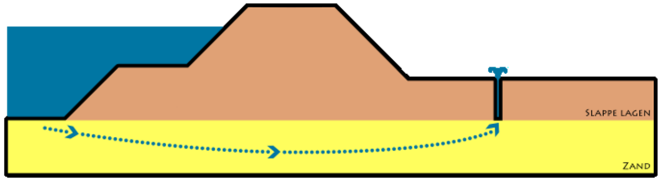
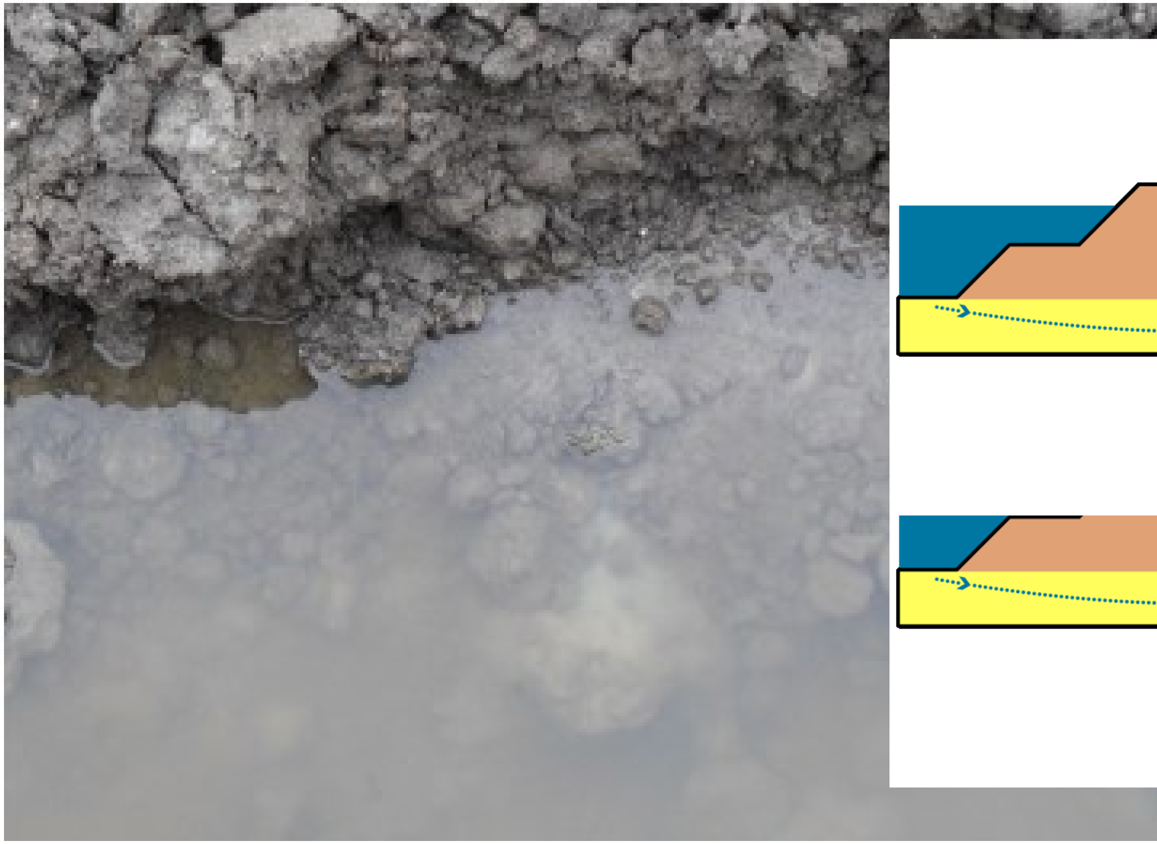
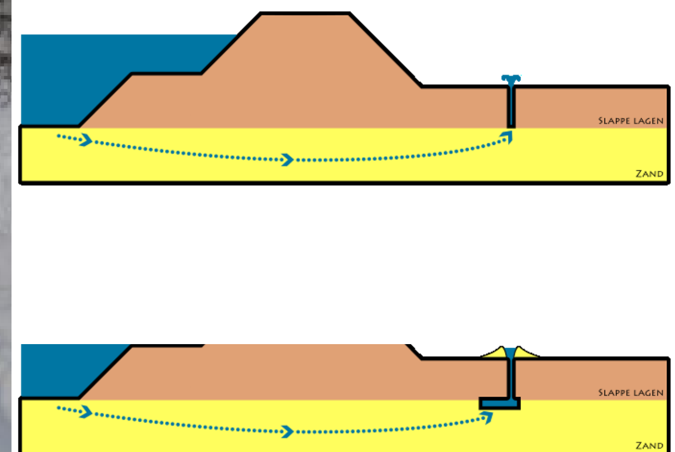
Observations: Backwards erosion - seepage



Observations: Backwards erosion – sand traces





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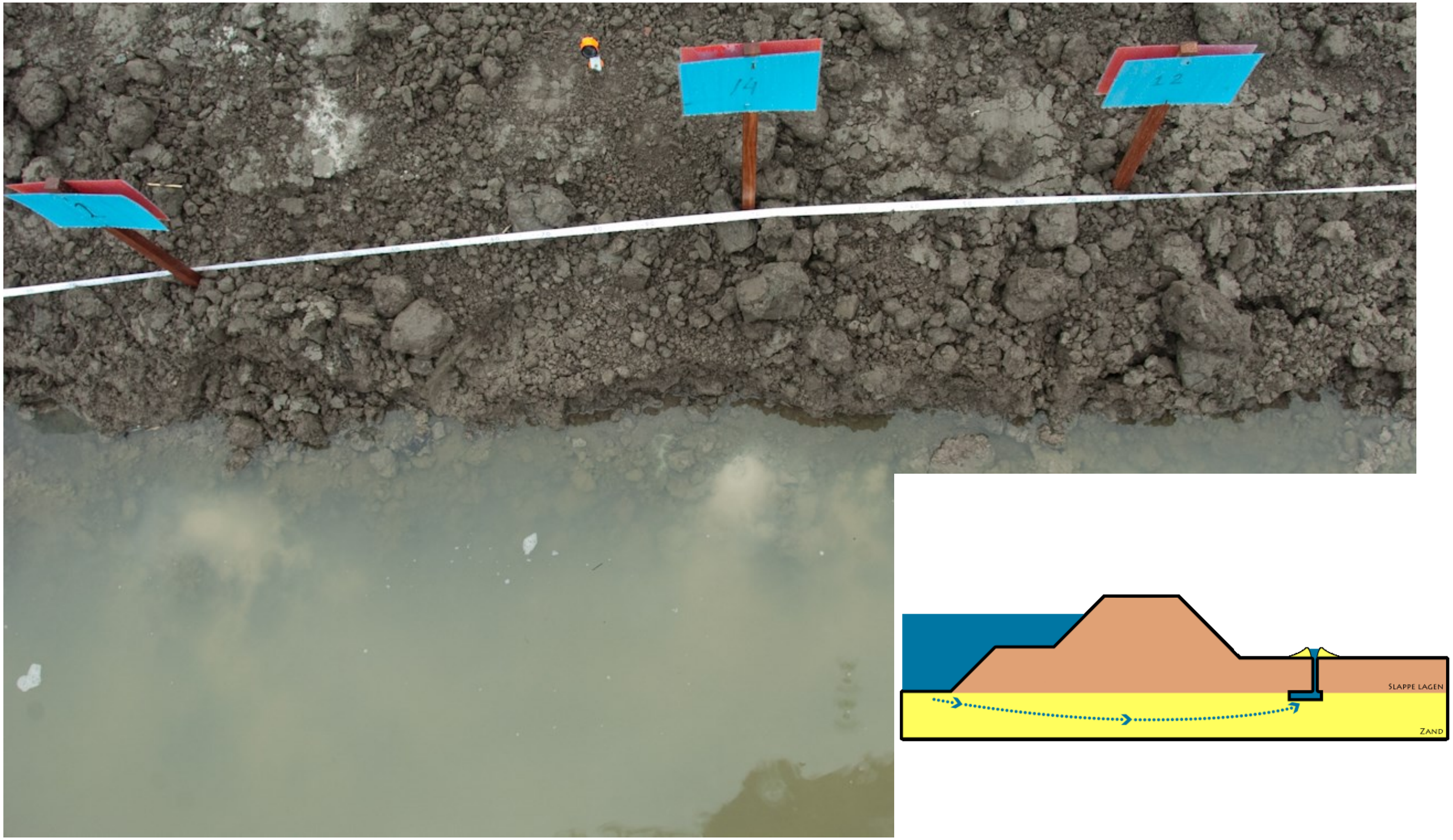
Observations: Backwards erosion – seepage wells



No visible sand transport, but boiling of sand. A change is noticed in the pore pressures

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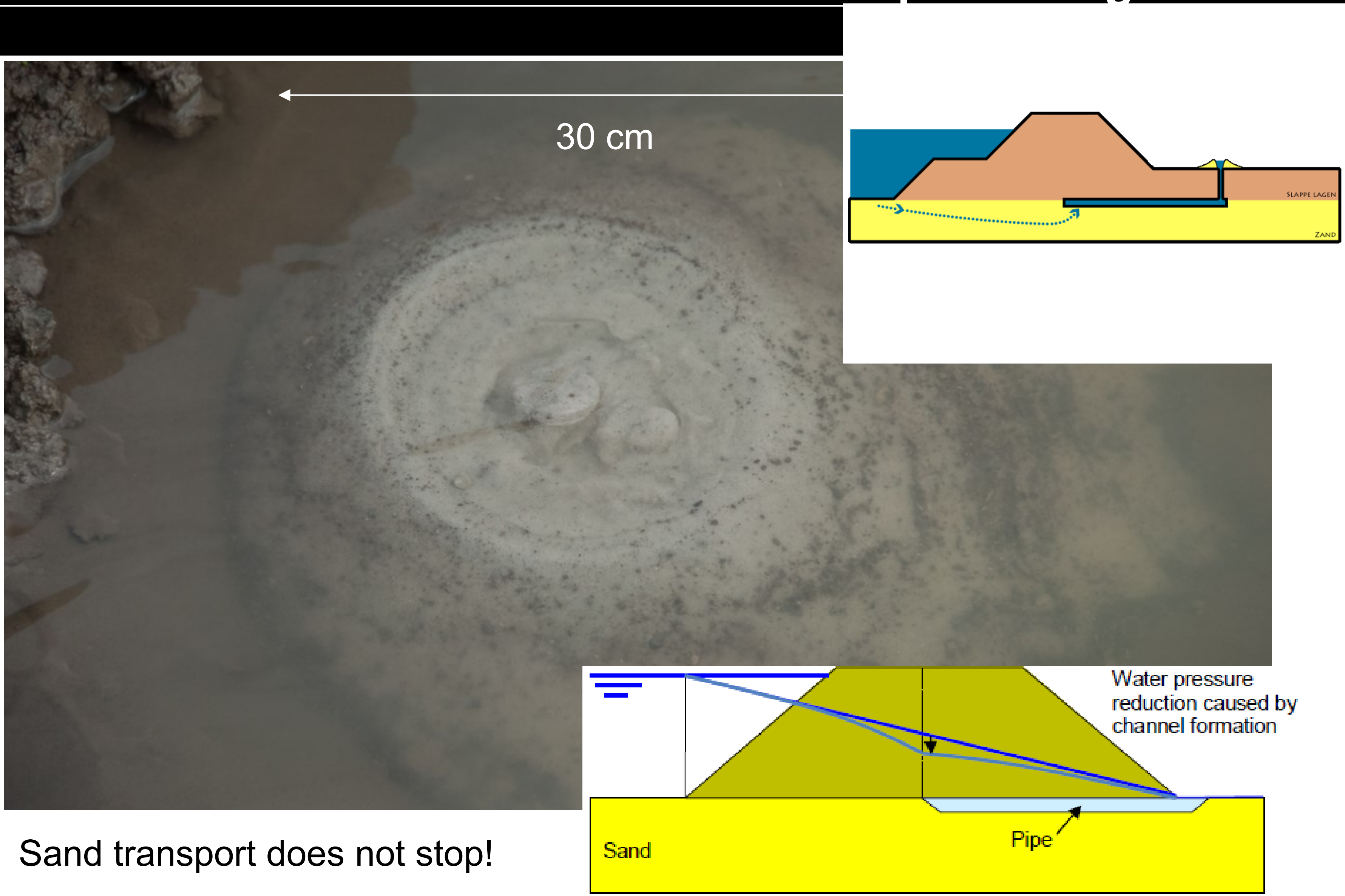
Observations: Backwards erosion – sand producing wells



Sand transport does not stop!

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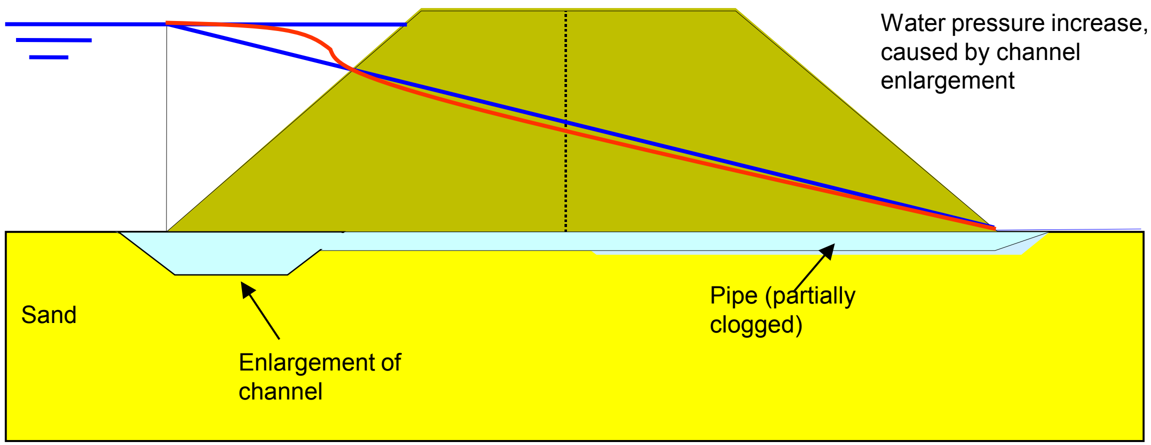
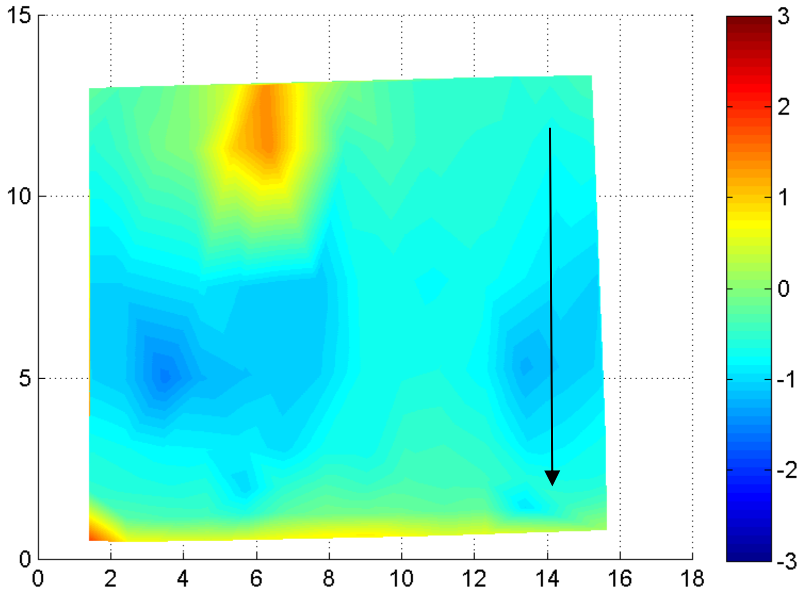
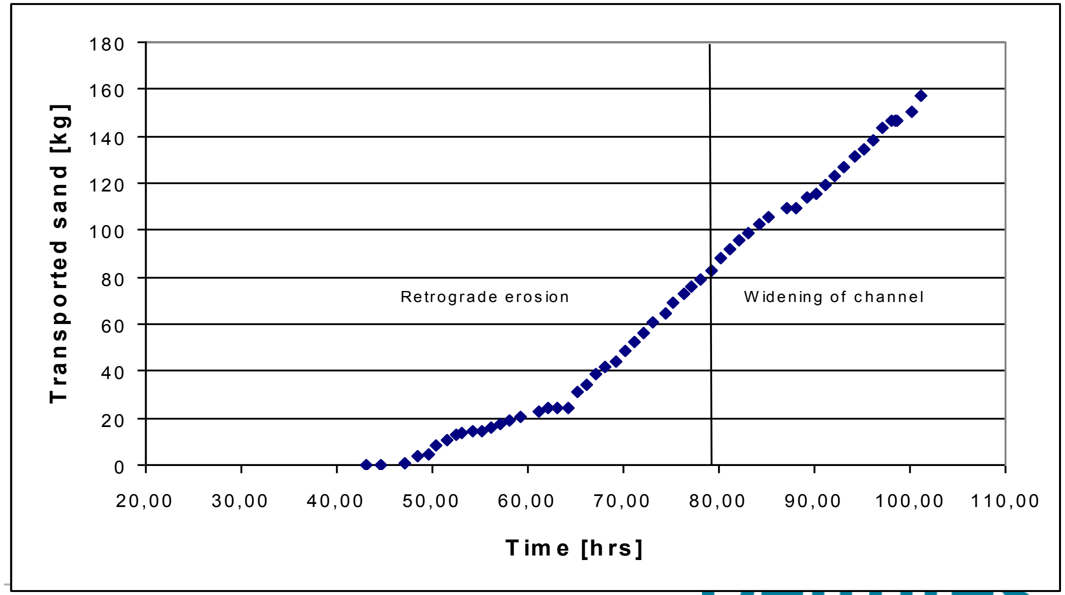
Observations: Widening of the pipe



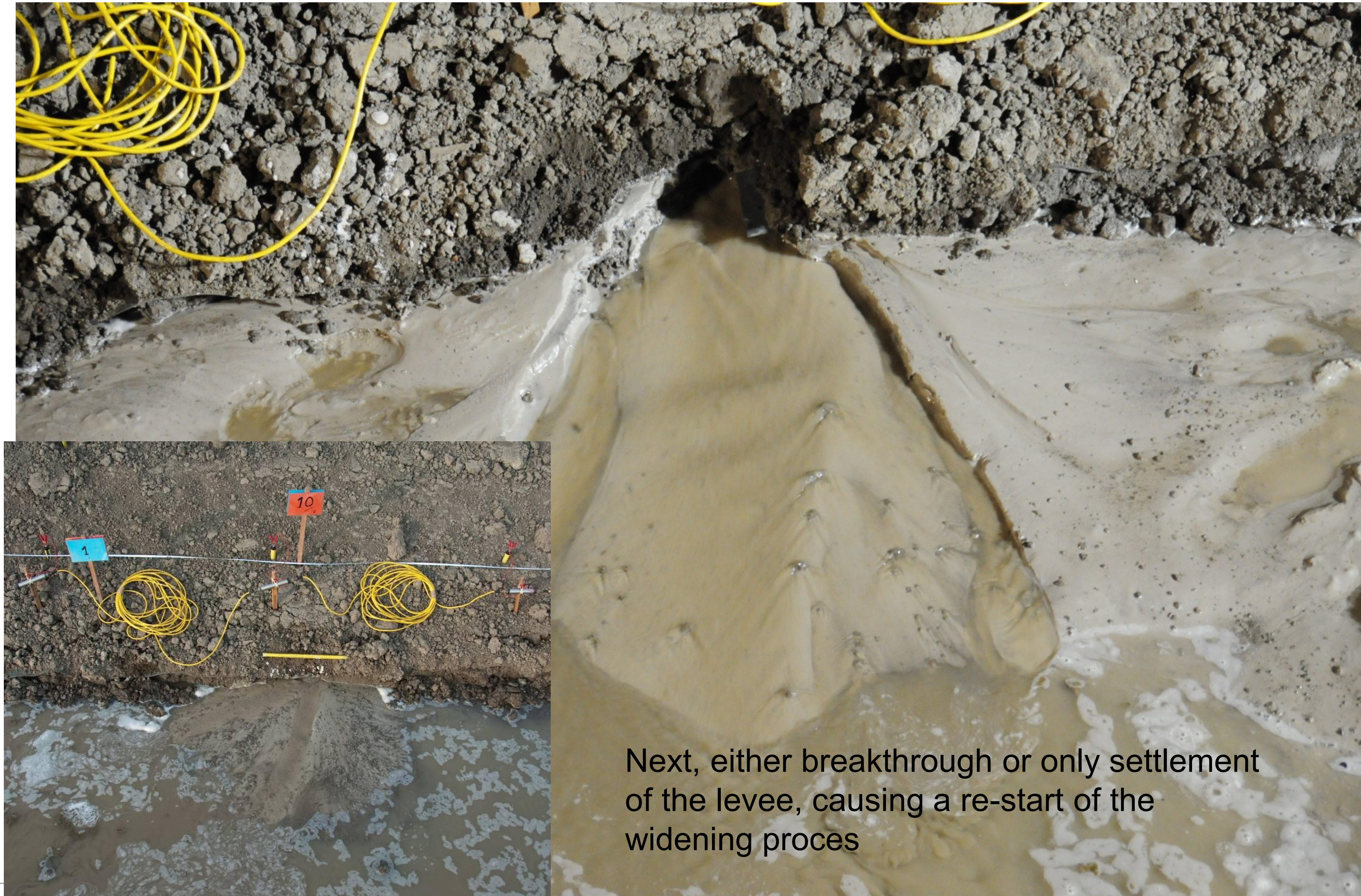
Very slow process. Start of process cannot be seen visually.

Only after a continuous, widened pipe has developed, the sand transport increases.



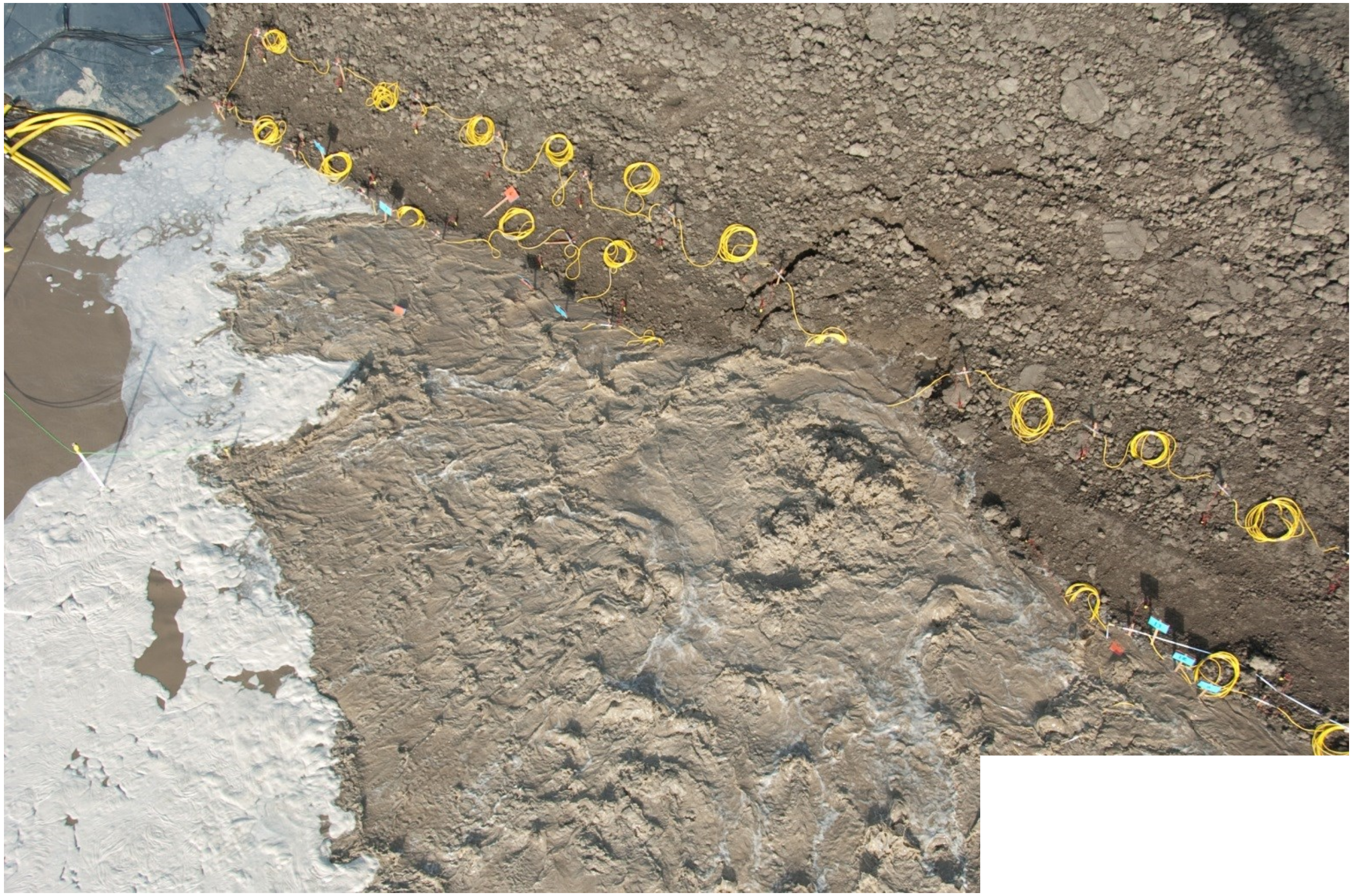


Observations: Failure

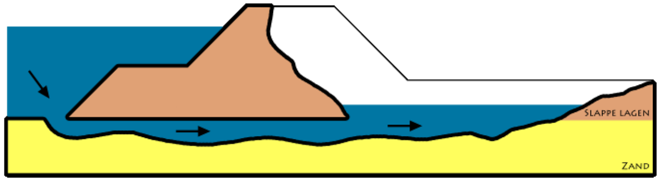


Next, either breakthrough or only settlement of the levee, causing a re-start of the widening proces

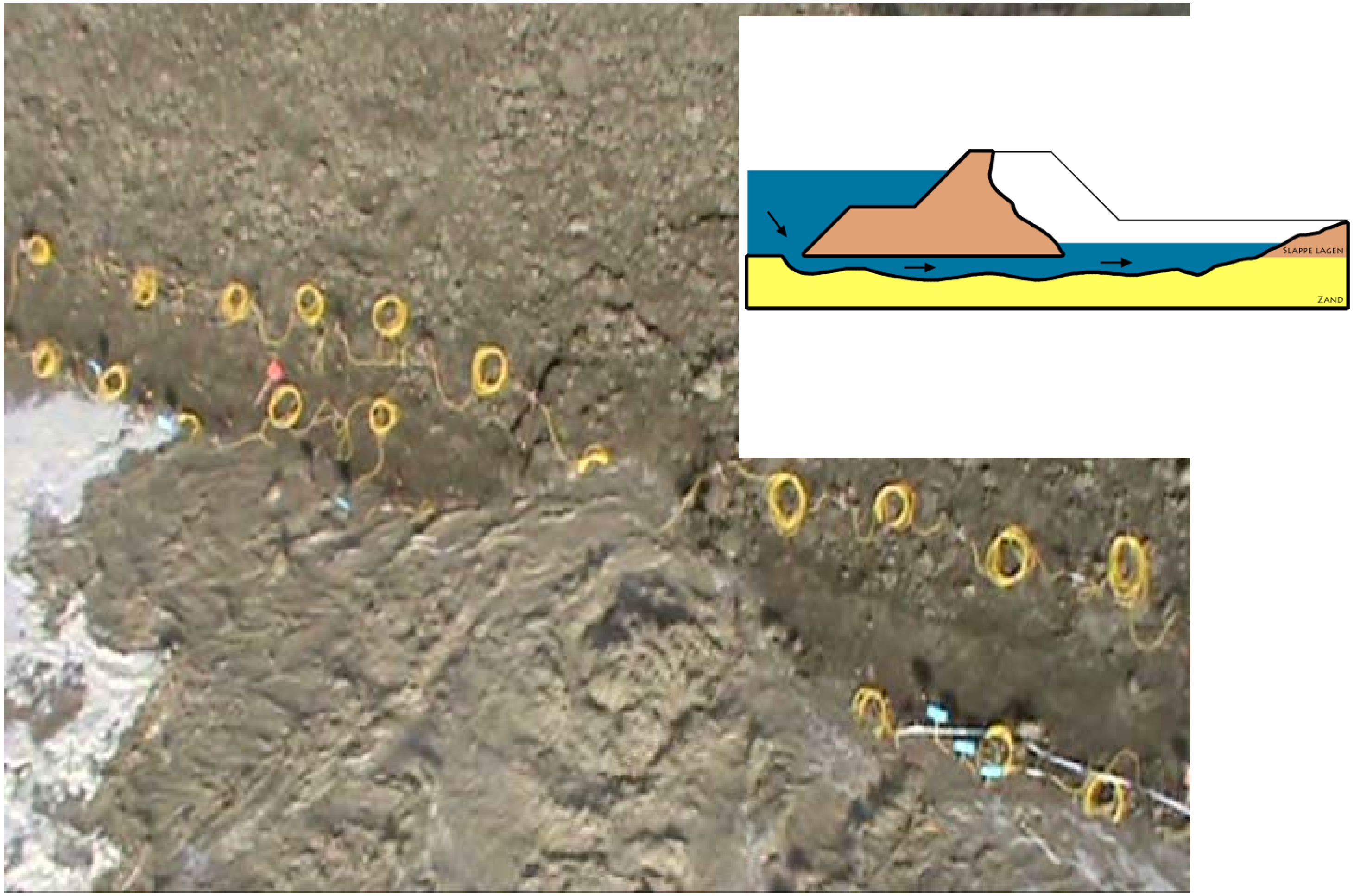
Observations: failure of levee



Test 2



Observations: failure



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Observations: failure of levee

Test 1

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Third Field test, the Uitdam experiments

Background

High safety levels for dikes in The Netherlands requires a regular check on stability regarding the latest insight on extreme water levels etc.

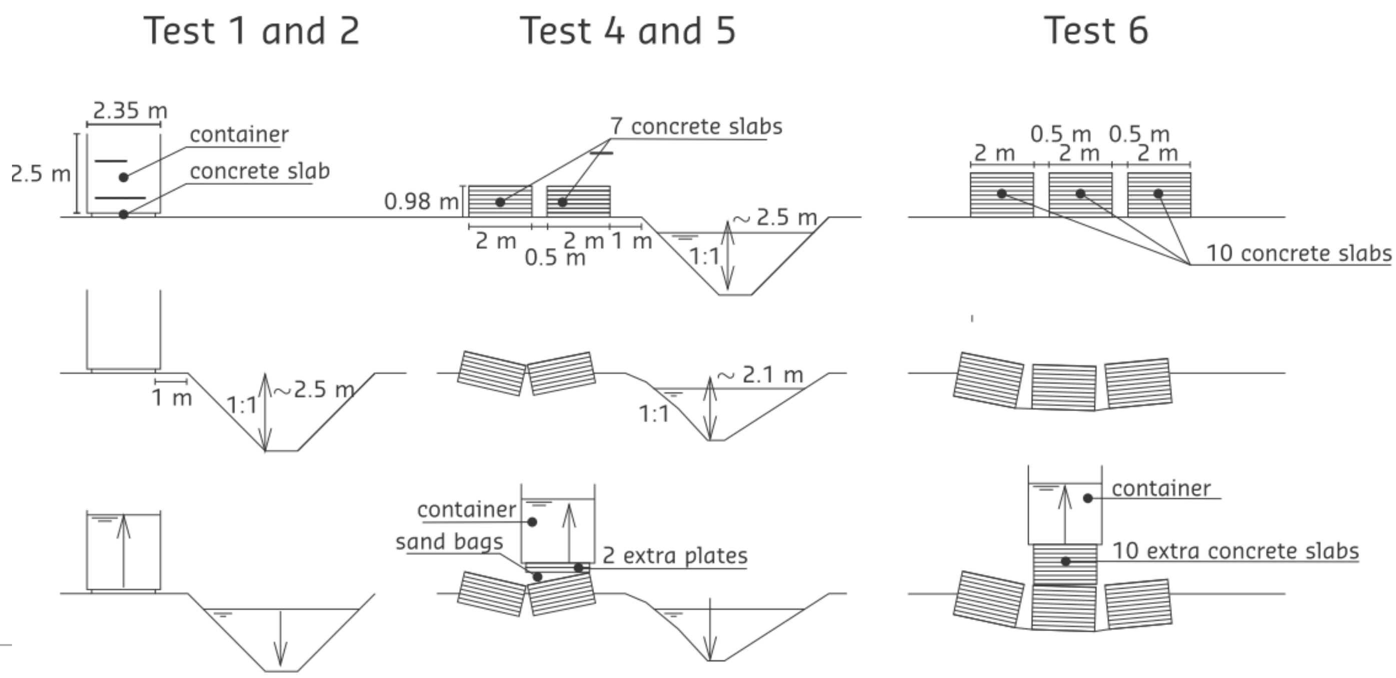
A 30 km long dike near Amsterdam does not fulfill the required safety level. However, the origin of the dike is more than 800 years old and closing the direct connection to the sea (1932) reduced max water levels considerably

The calculated stability does not match engineering judgment.

Uncertainty in the peaty subsoil contributes strongly to the low, calculated, stability factors

5 field trials

- Due to safety reasons tests on the real dike were not allowed
- Instead tests at the toe of the dike
- Aim is finding operational shear strength of peat and finding relation with field probe tests and lab tests
- Test is based on remotely, stepwise filled containers in combination to concrete slabs for foundation and pre-loading



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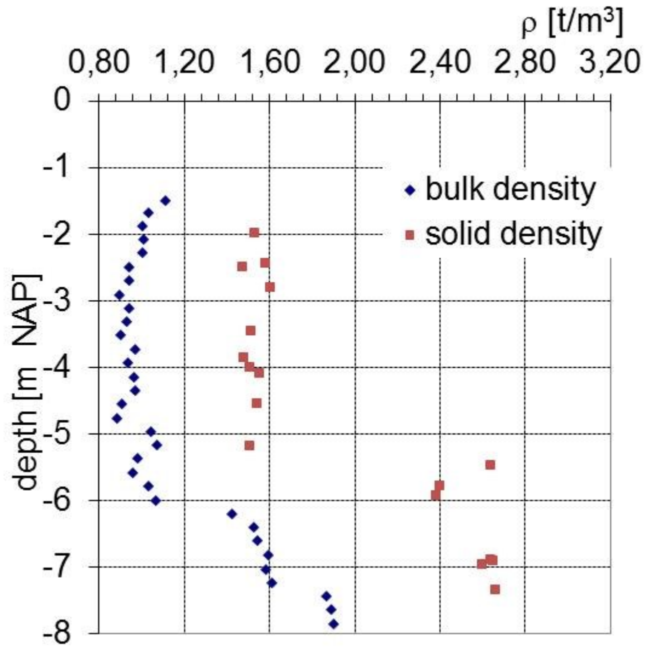
Characterisation test site

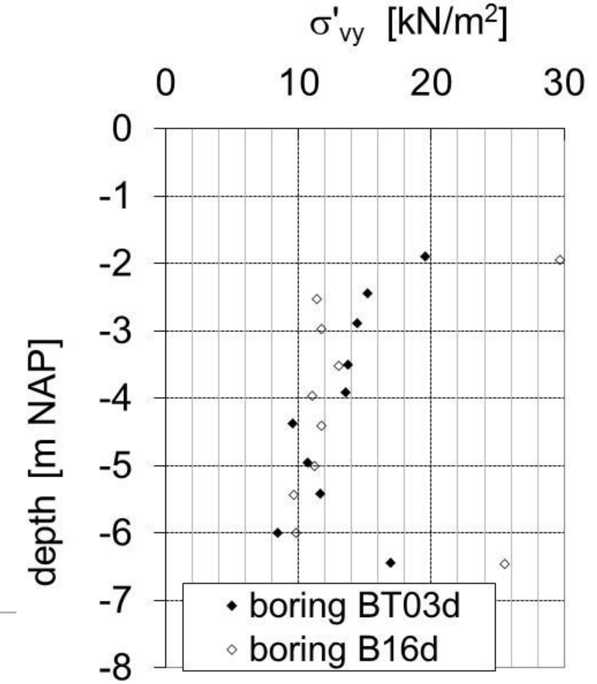
Biological background peat:
mainly sedge – reed

Von Post classification: H2 - H3, meaning that the peat is undecomposed (H2) or very slightly decomposed (H3). Plant remains are identifiable and no amorphous material is present.

Water content 750 – 1200 %

Loss on ignition 85 %





Construction

Execution test 1 & 2

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Test 4 & 5

Test 6

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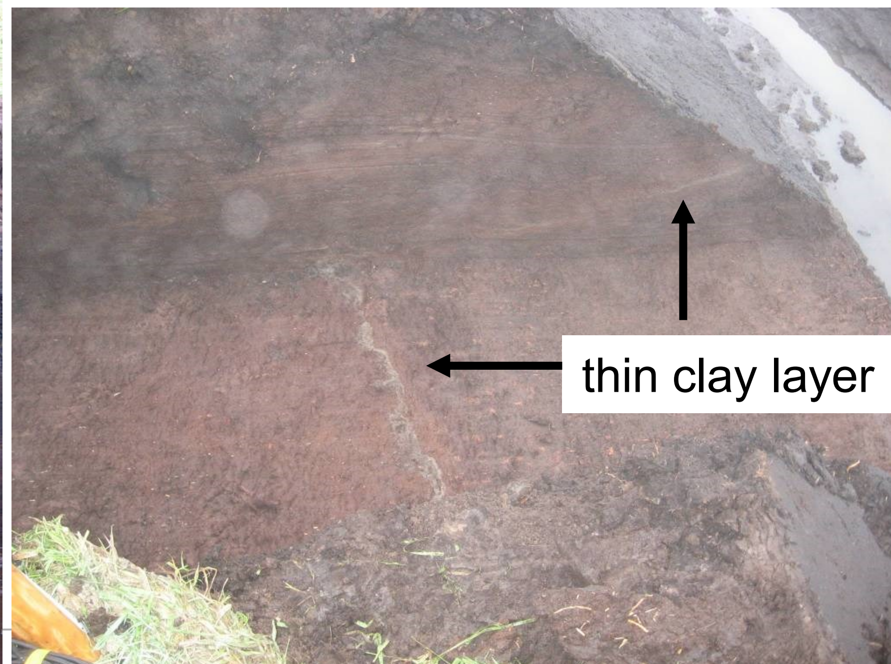
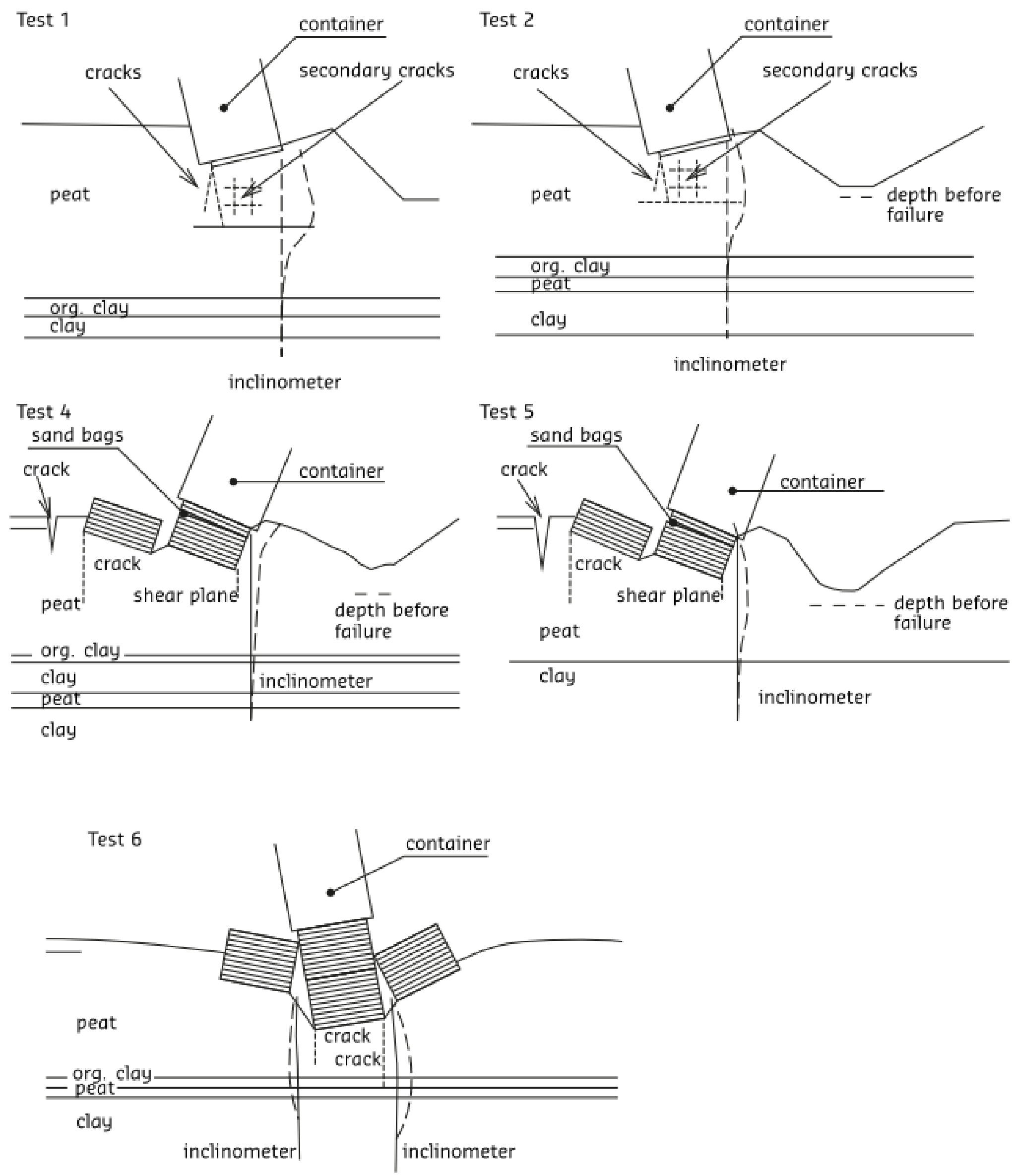
Finding Failure mechanism

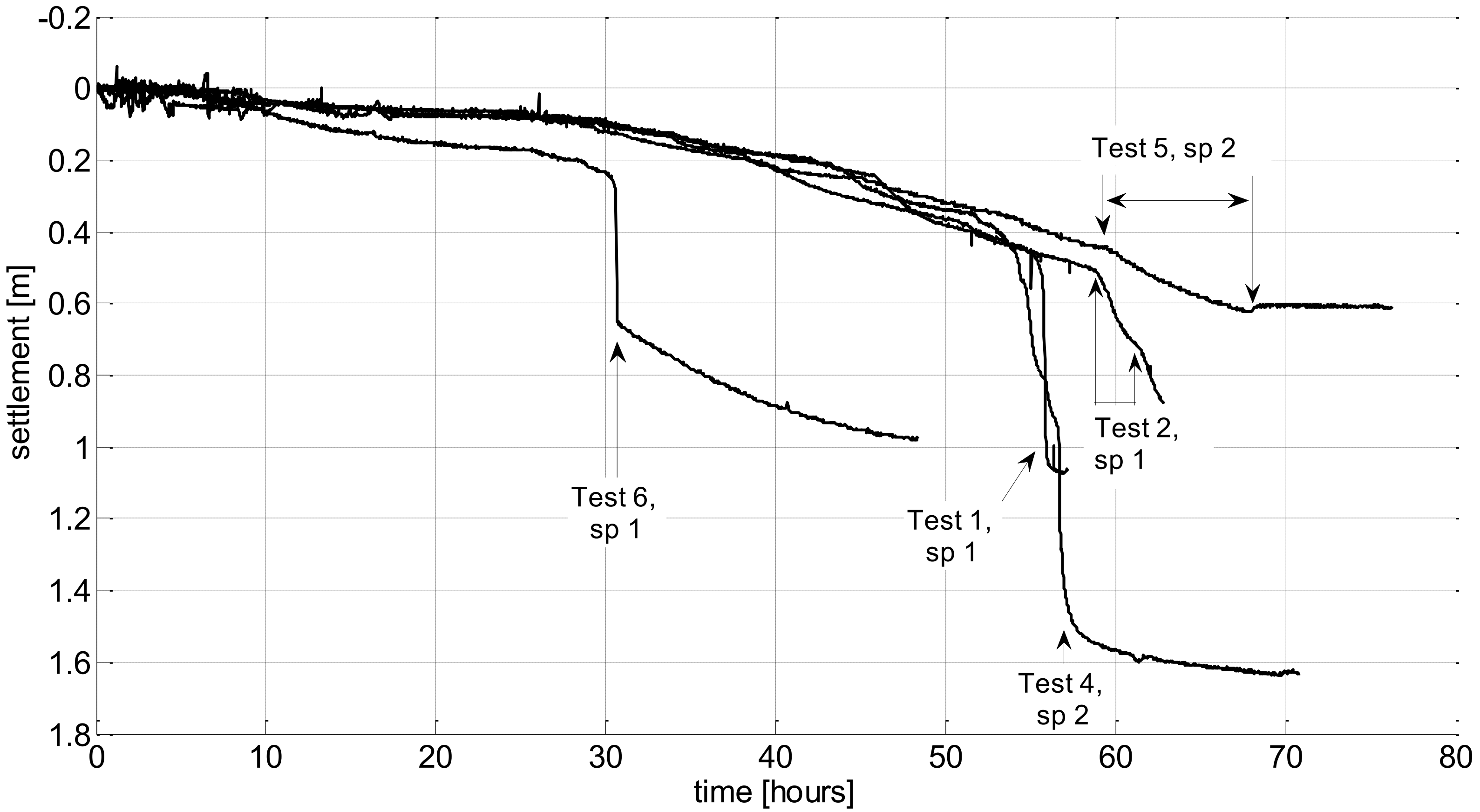


Observed Failure mechanism

- Failure is reached in each test
- The failure mechanism is established by excavating trial pits and displacement measurements
- Brittle behaviour is observed in test 6, ductile in tests 1 and 2



Failure rate



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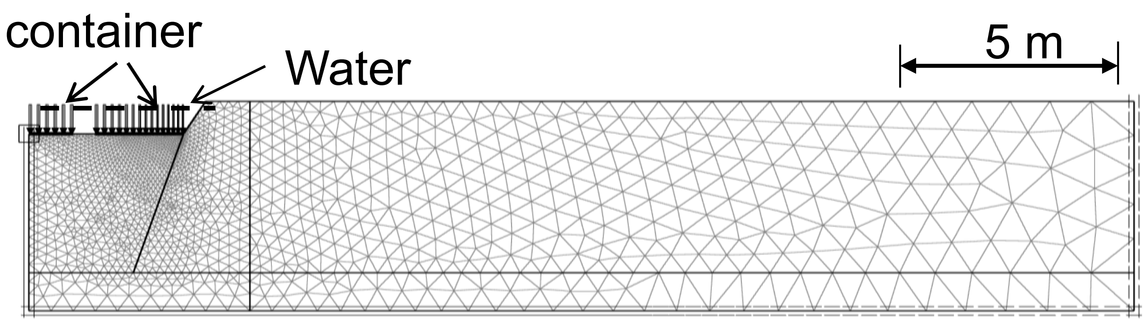
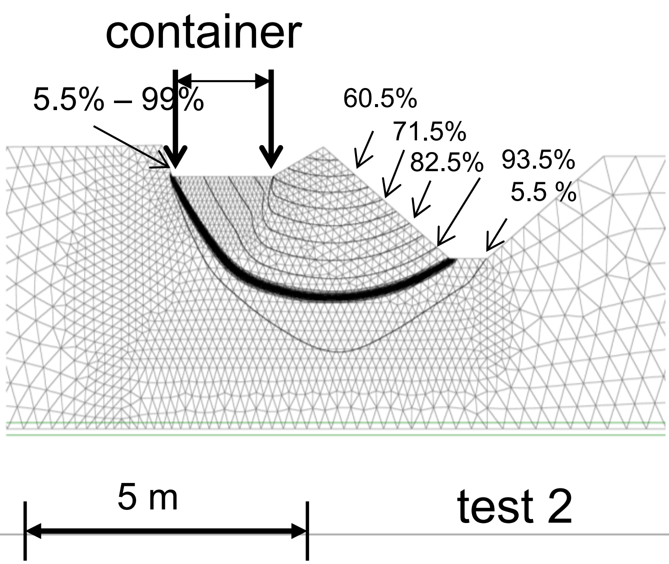
Analysis (% max displacement)

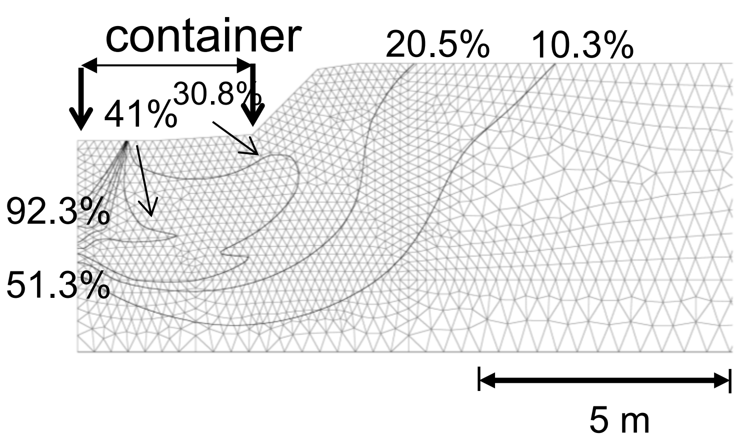
test	s_u [kPa]
1	7,4
2	7,3
4	(13,2)
5	8,5
6	8,9
6	12,6 / 5,5



test 6



test 2



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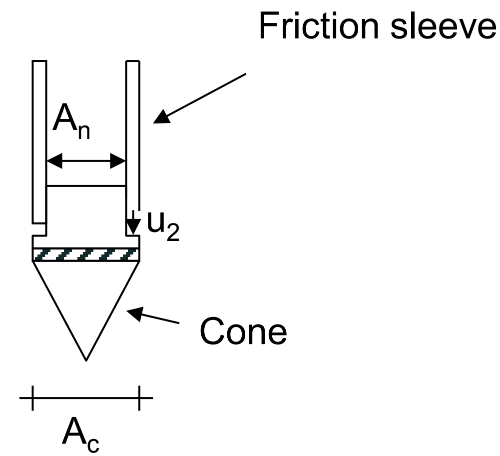
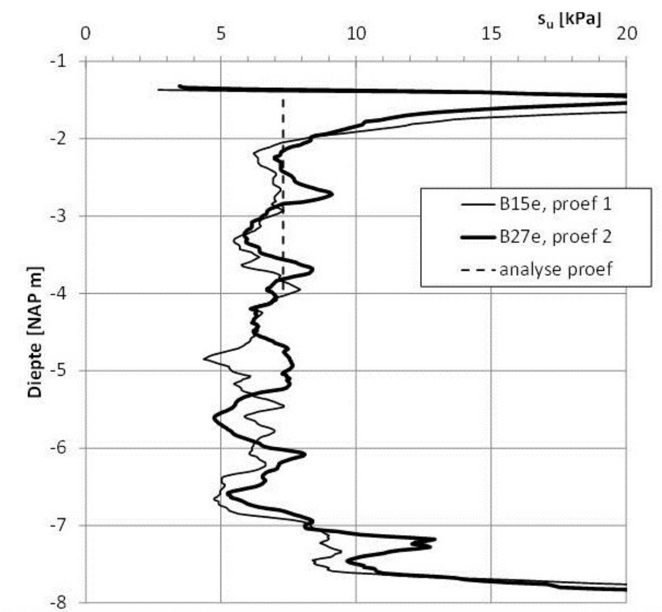
Comparison field test and CPTu data

	N_{kt}	N_b
average	14.0	17.9
Coefficient of variation	0.2	0.06

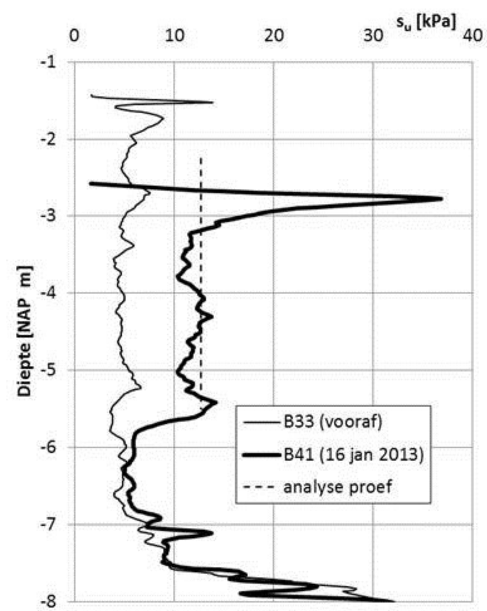
$$N_{kt} = \frac{q_c + (1-a)u_2 - \sigma_{v0}}{s_u}; \quad N_b = \frac{q_b}{s_u}$$

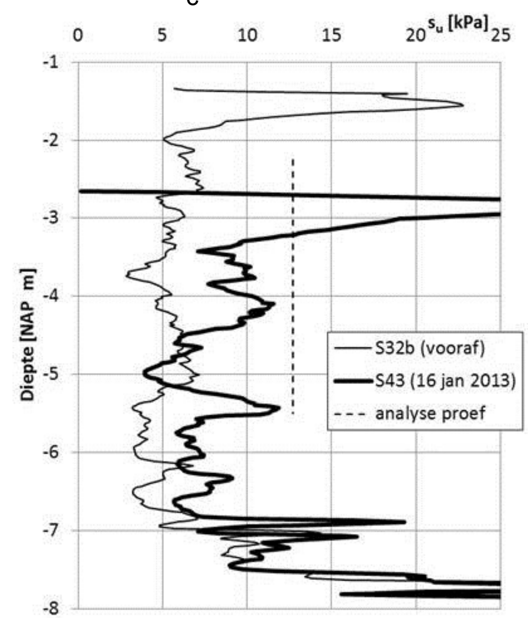


Test 1 & 2



Test 6





Overall Summary

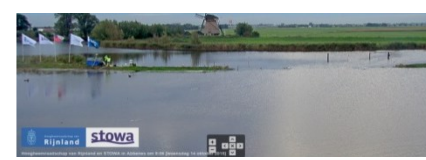
3 field trials related to dike stability are discussed

Each test has its own research goals

Together the tests and analysis provide experience

Lessons learned from the tests:

- The uplift mechanism is realistic and design software is developed and validated, input for further development for partial safety factors
- Modern sensor technology for dike stability assessment / forecasting is tested and monitoring procedures developed
- Piping rules are checked and improved
- Relation between available shear strength in the field and lab. / penetrometer tests validated with special focus on low stresses / peat
- The validity of design procedures is tested for small regional dikes



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