



Strength of embankments on peat

Cor Zwanenburg

Relevance



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


Three field trials




Bergambacht (2001)



Uitdam (2011-2013)




Ijkdijk (2008)




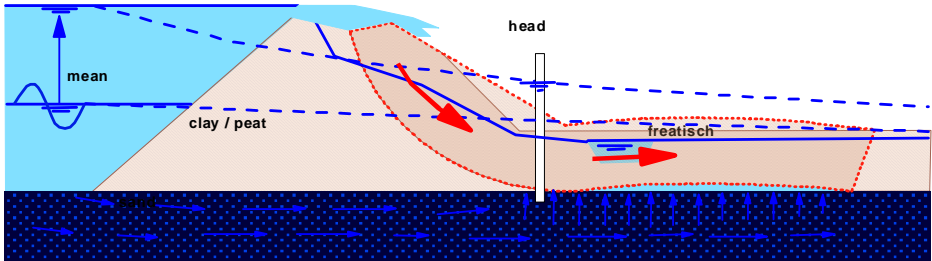
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Deltares

Bergambacht case (2001)



design level

mean

clay / peat

head

freatisch

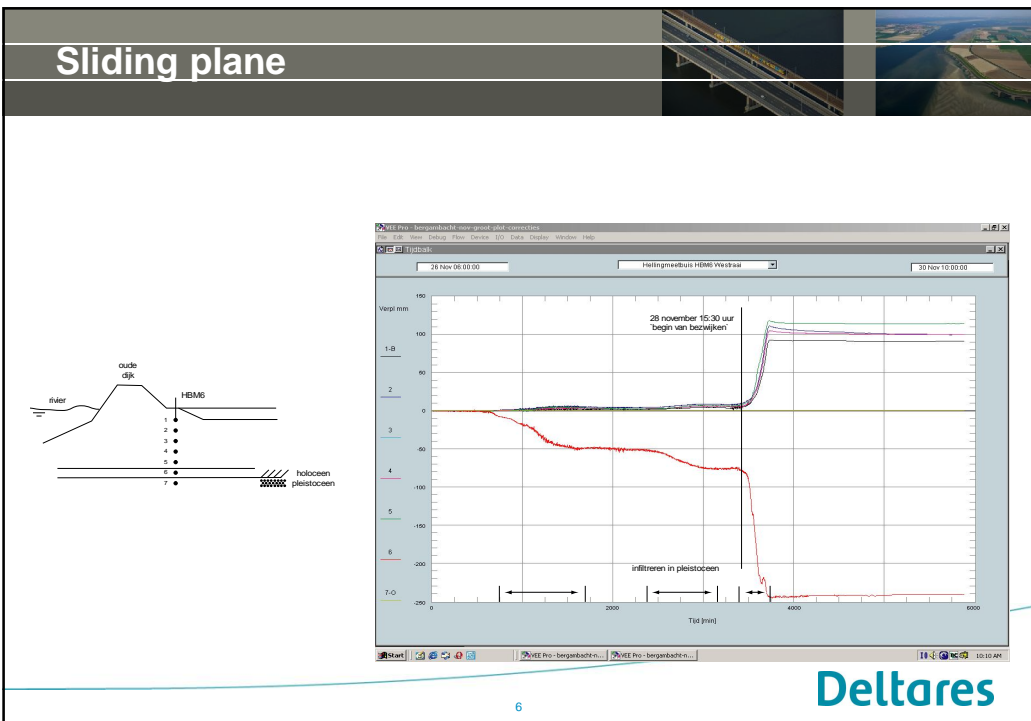
S

Failure plane



Deltares

Sliding plane

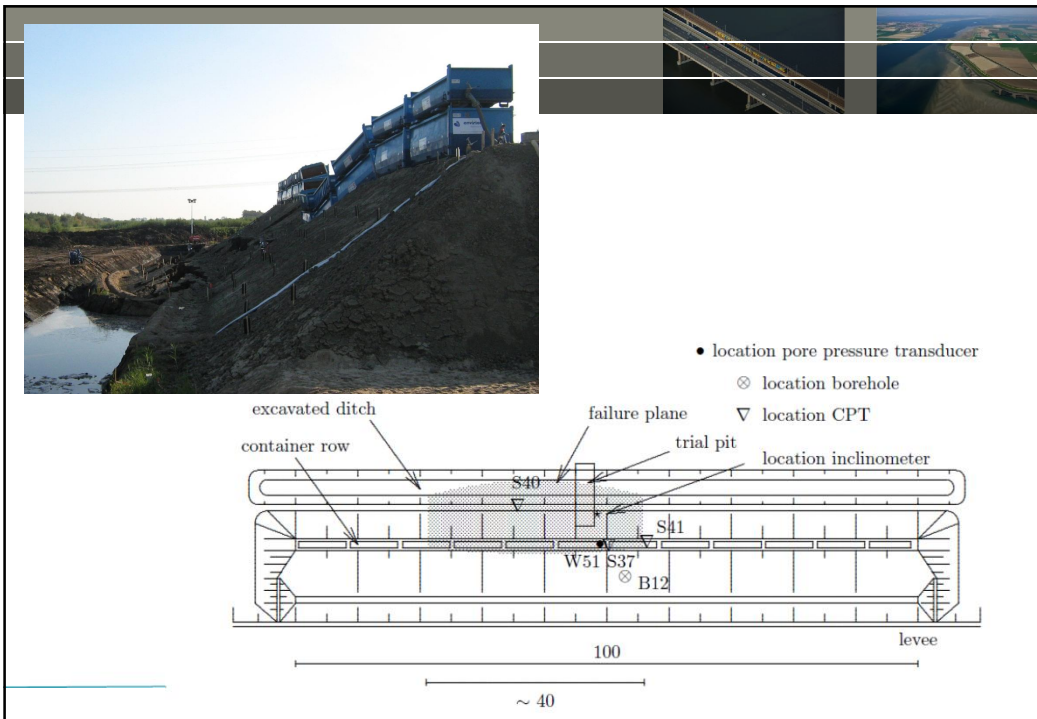
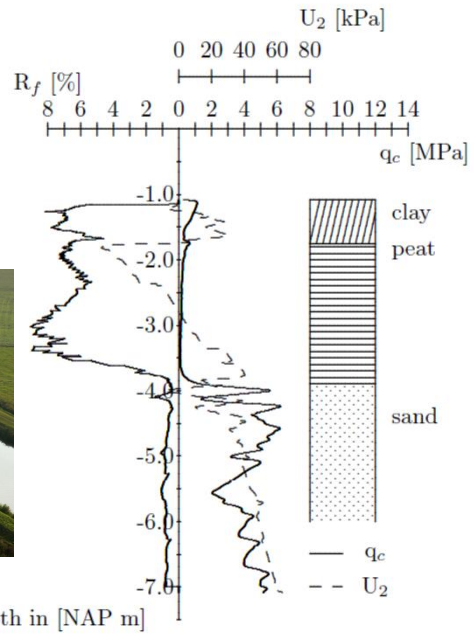


Deltares

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IJkdijk

Test for early warning systems





Design parameters for peat, according to present day guidelines

	c' [kPa]		ϕ' [°]	
	mean	design	mean	design
Dike	9,8	2,4	21,7	18,2
Berm	5,7	2,1	18,3	14,1
Non-pre loaded	1,6	0,5	15,7	10,1

Deltares

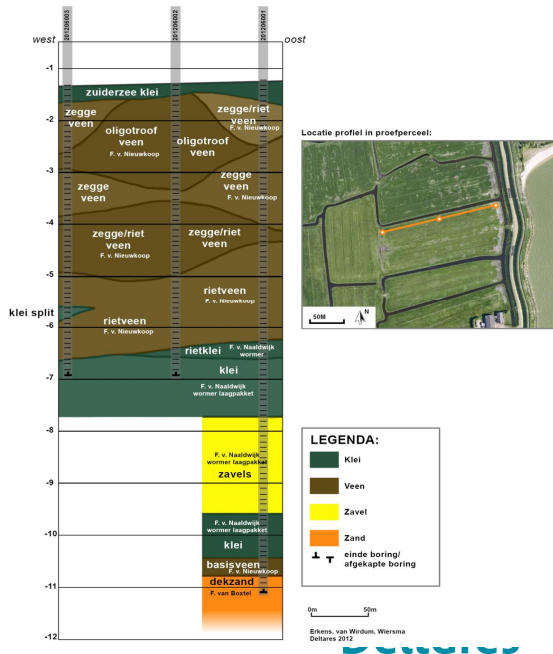
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characterisation

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.

Profiel proefperceel Uitdam
Mei 2012

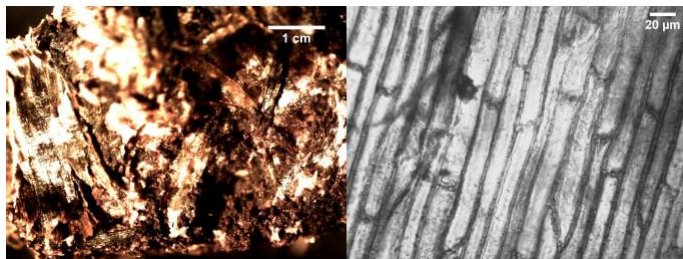


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Peat in detail



Galigaan,
(*cladium mariscus*)



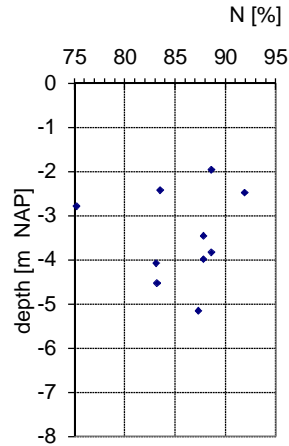
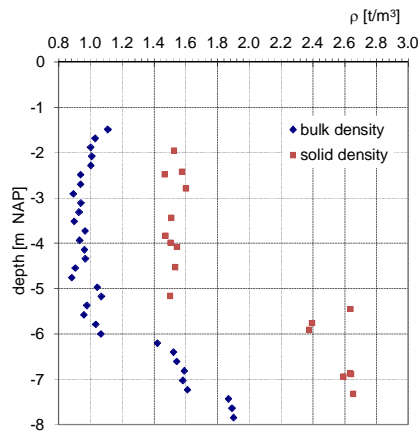
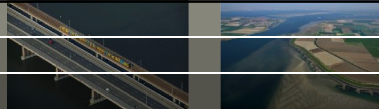
Veenbloembies,
(*Scheuchzeria palustris*)

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Characterisation of peat layer

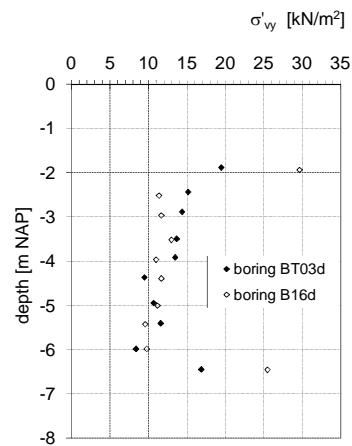
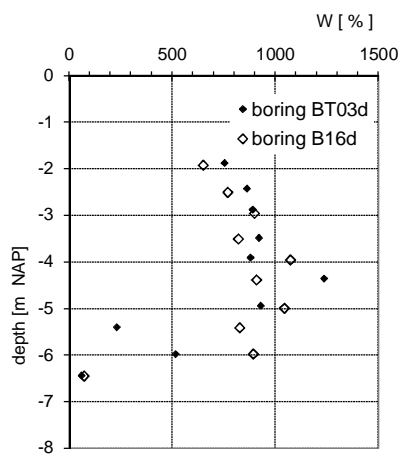
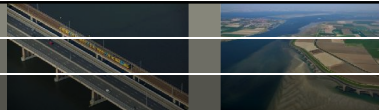


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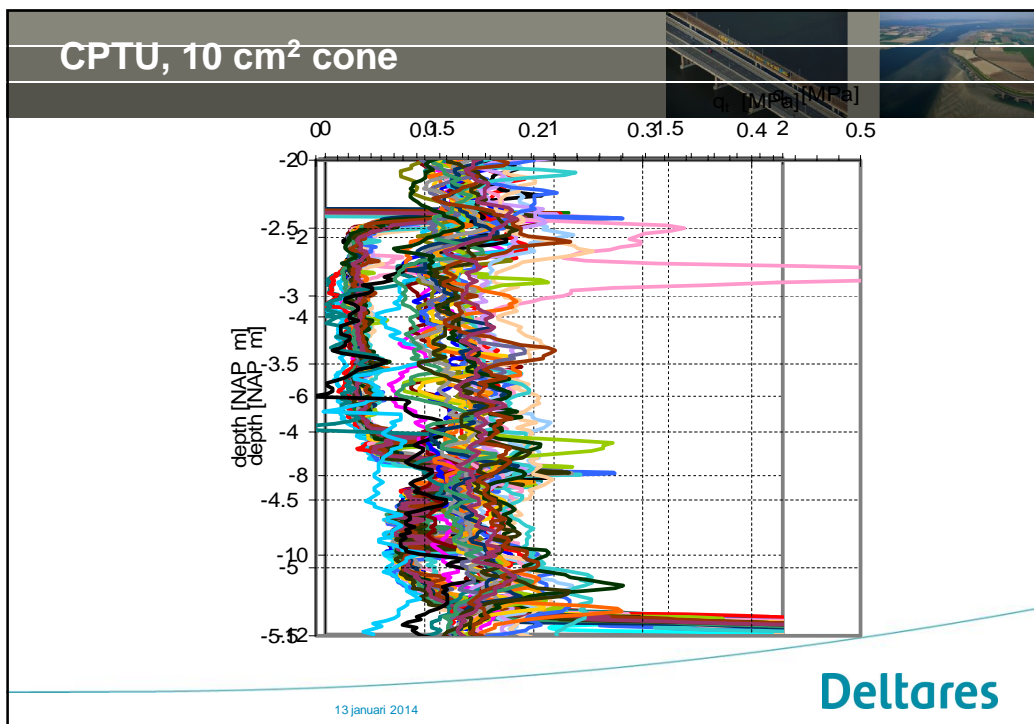
Characterisation of peat layer



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Deltares



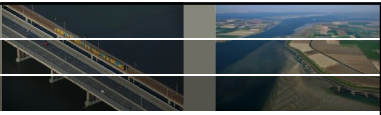
Comparison

	μ_{qt}, μ_{ball} [MPa]	V_{qt}, V_{qball} [-]
10 cm ² cone	0.14	0.21
15 cm ² cone	0.12	0.17
Ball penetrometer (1)	0.11	0.17
Ball penetrometer (2)	0.13	0.11

NEN-EN-ISO 22476-1: accuracy required for class 2 CPT(U) is 100 kPa (0.1 MPa)

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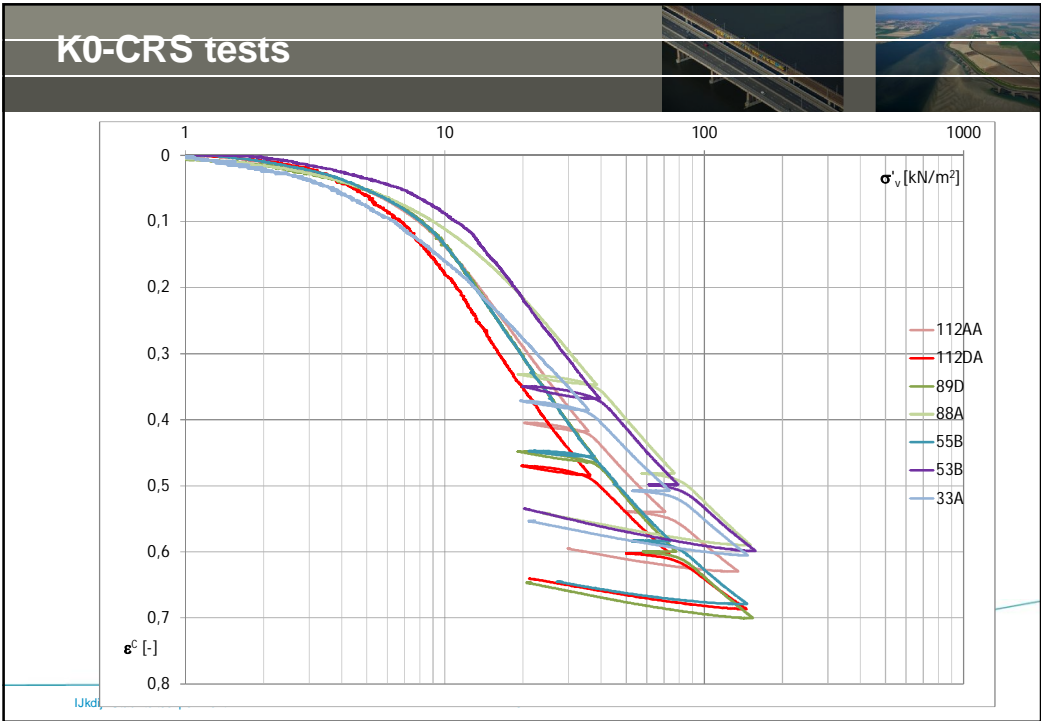
Deltares



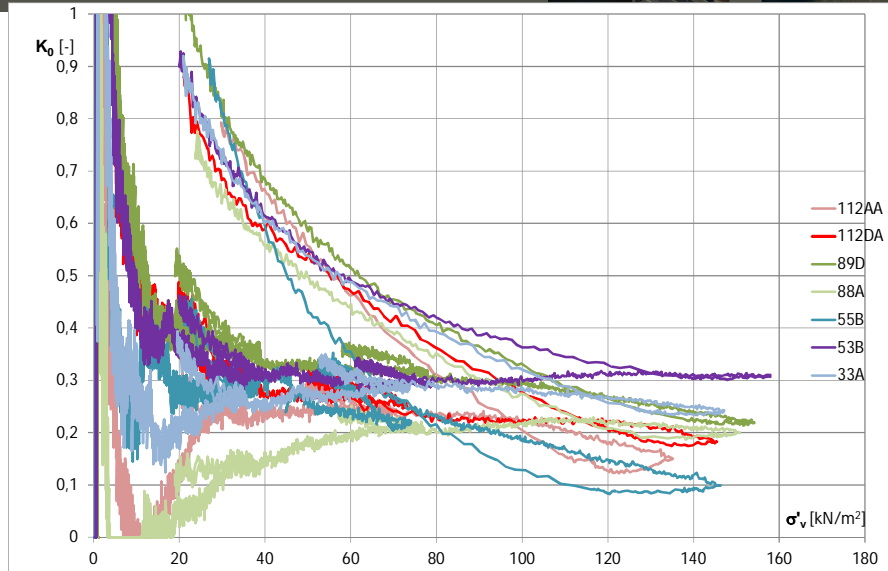
Some laboratory test results

Deltares

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K0-CRS tests

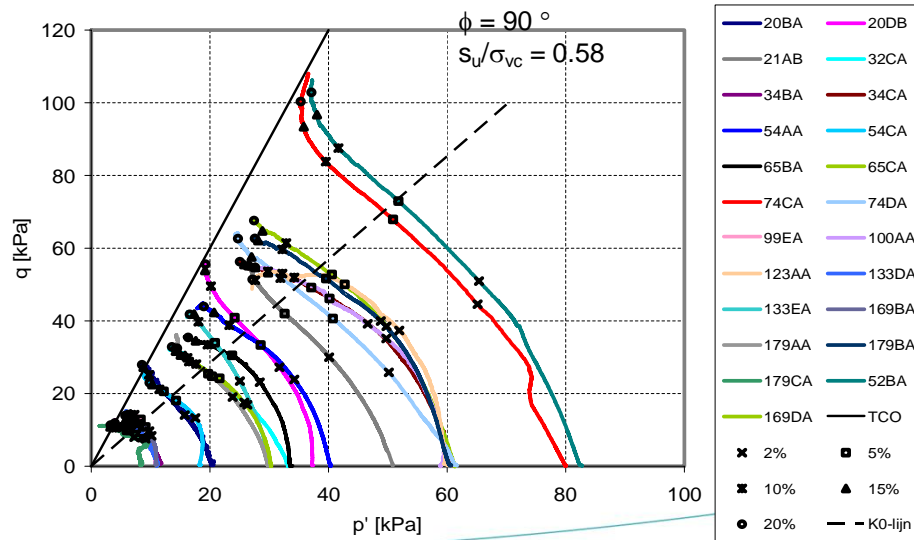


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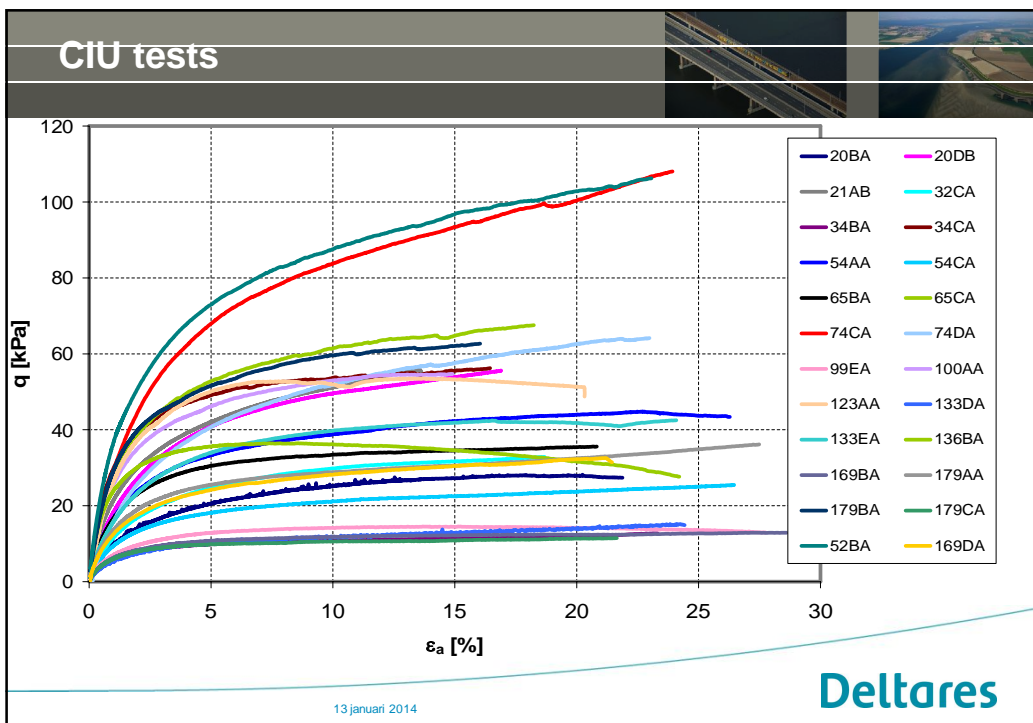
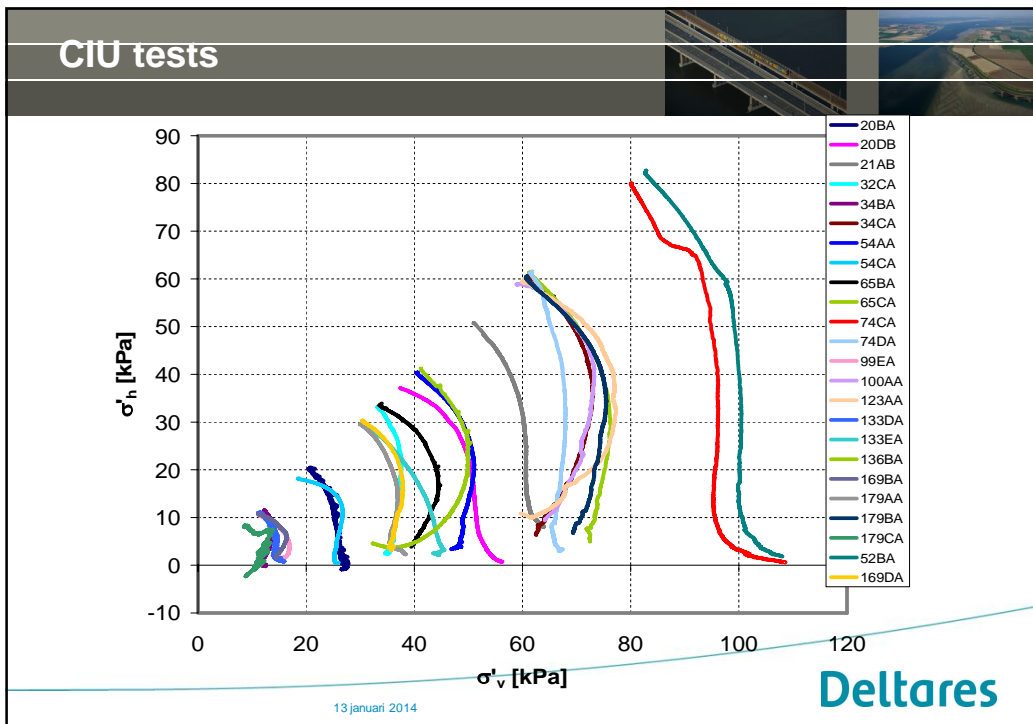
Deltares

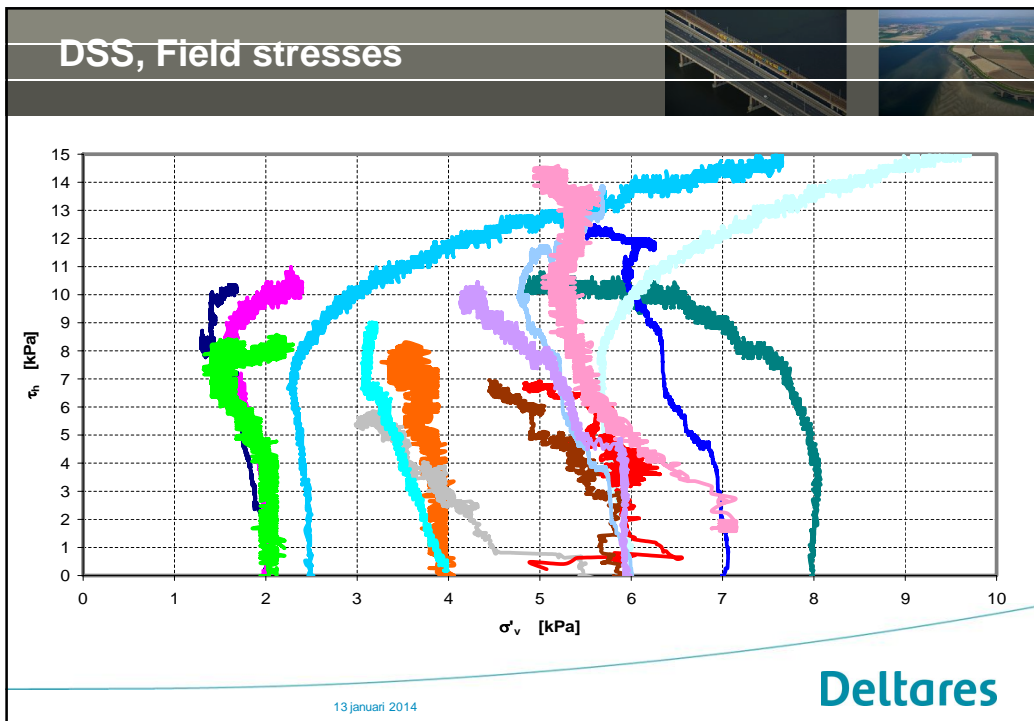
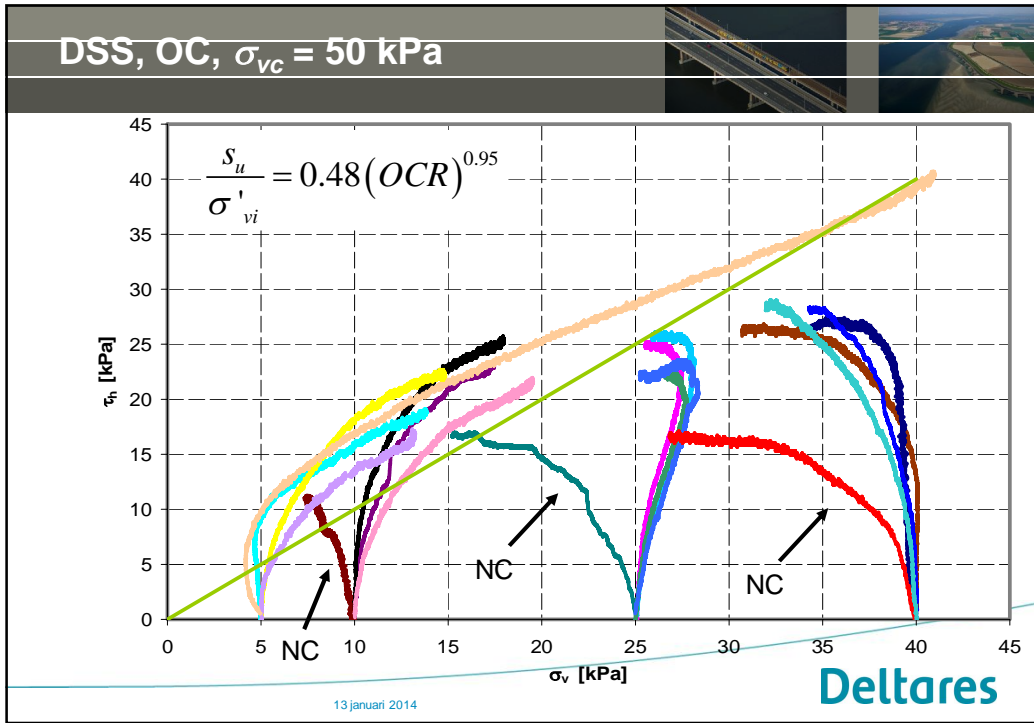
CIUC tests

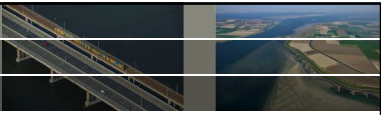


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Deltares



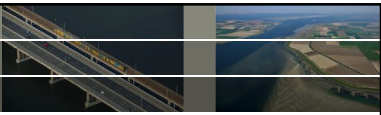




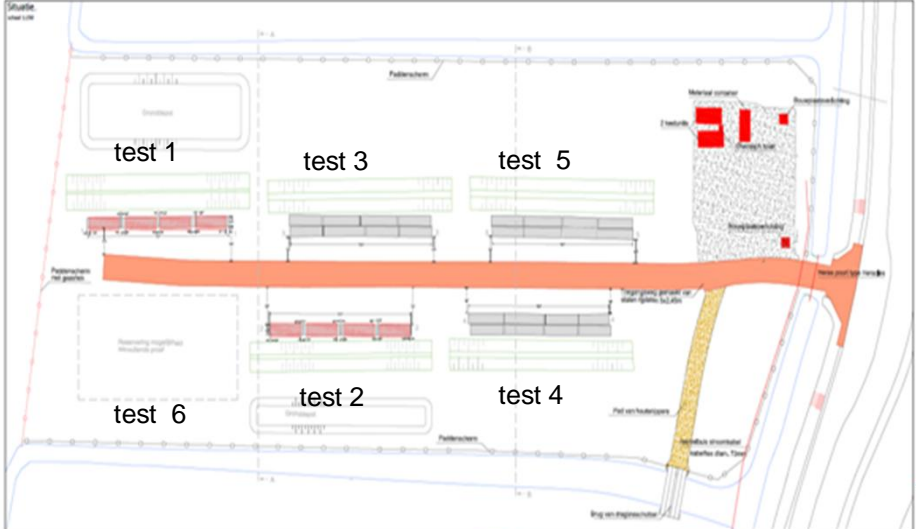
Field tests

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Deltares



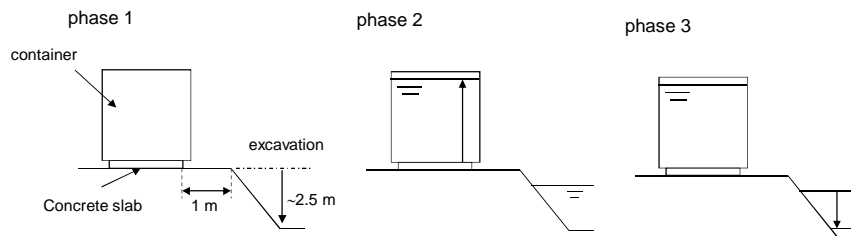
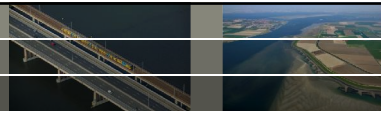
Test location



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Deltares

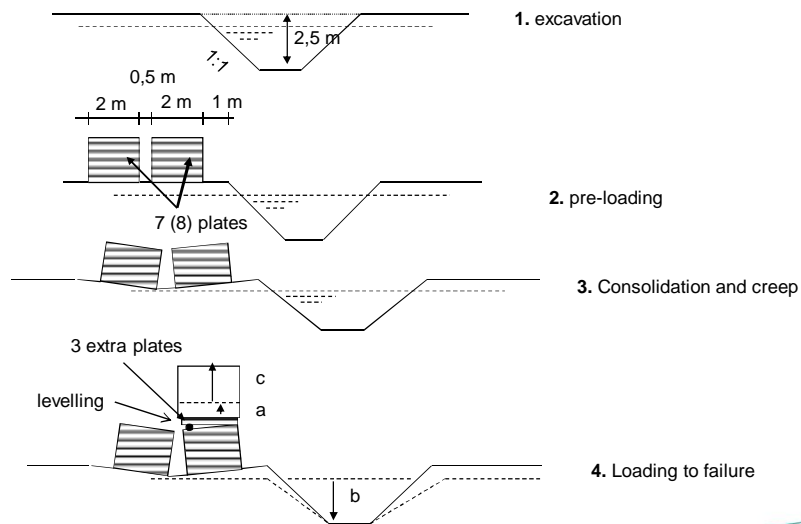
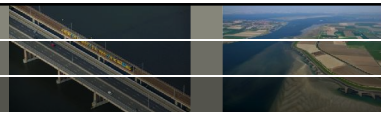
single stage loading test



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Deltares

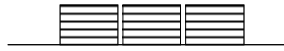
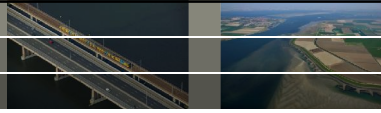
test 4 and 5



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Deltares

test 6



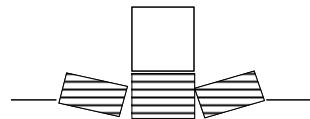
1. pre-loading; **10 concrete slabs**, $q = 33 \text{ kN/m}^2$, construction period 56 days



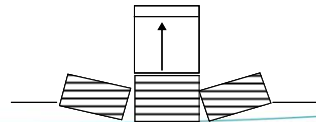
2. Consolidation and creep, 160 days



3. Start application failure load, **10 extra concrete slabs**.



4. Application failure load, placement **containers**.

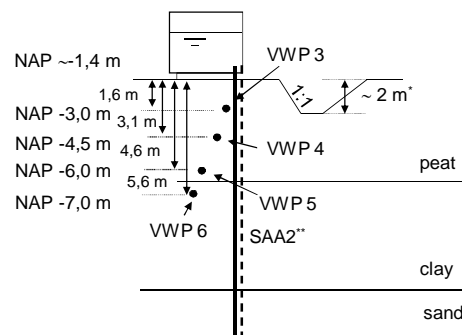
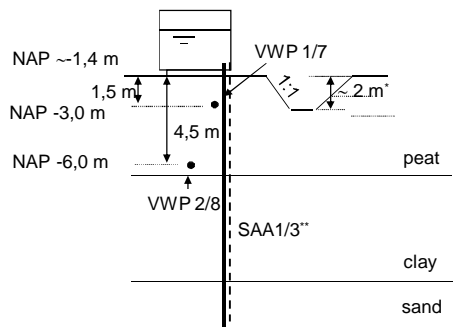
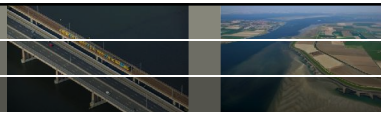


5. Application failure load, **stepwise filling** the containers.

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cross section



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Deltares

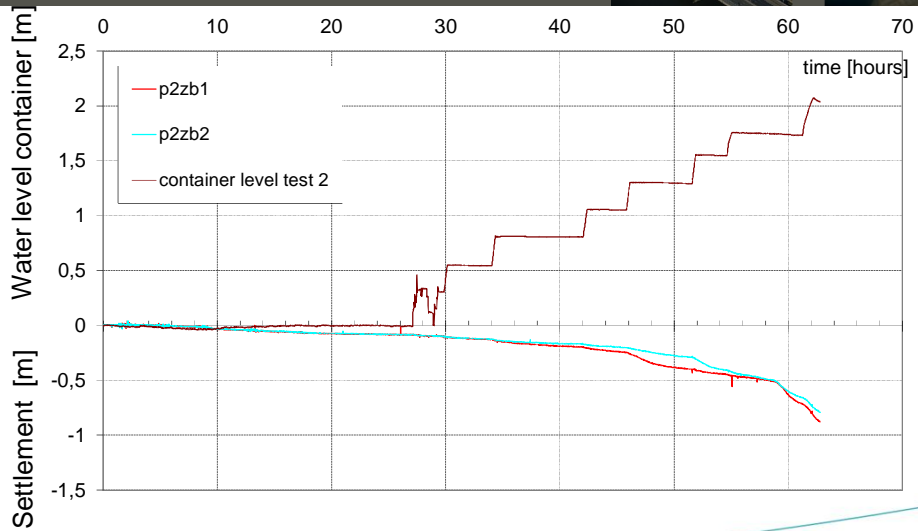
Impression test 2



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Deltares

Failure test 2

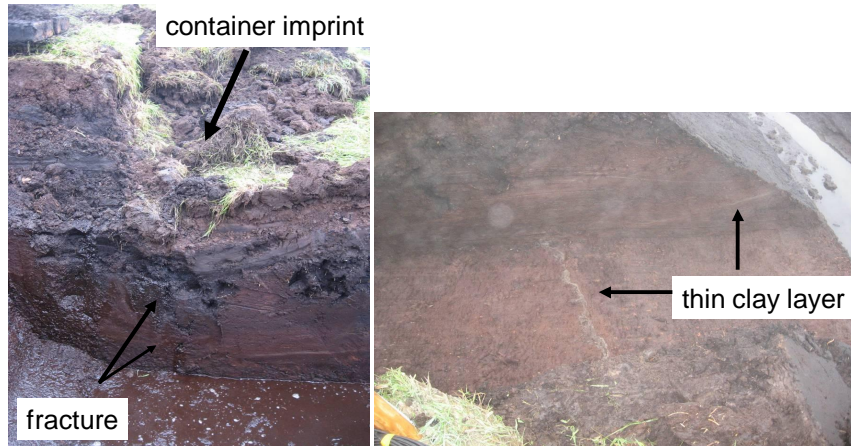
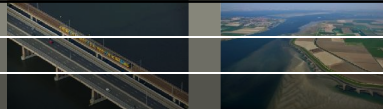


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Deltares

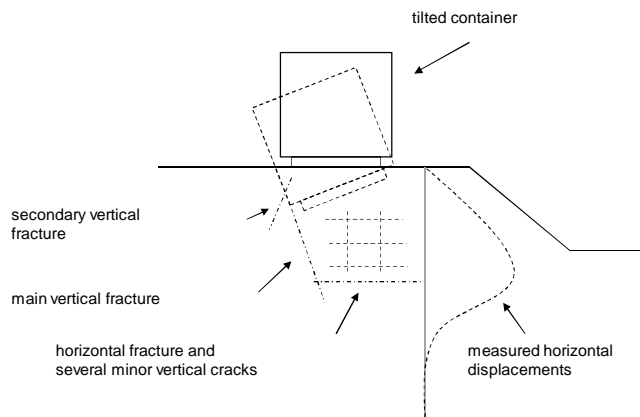
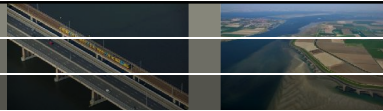
Failure mechanism



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Deltares

Failure mechanism



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Deltares

Test 4 and 5



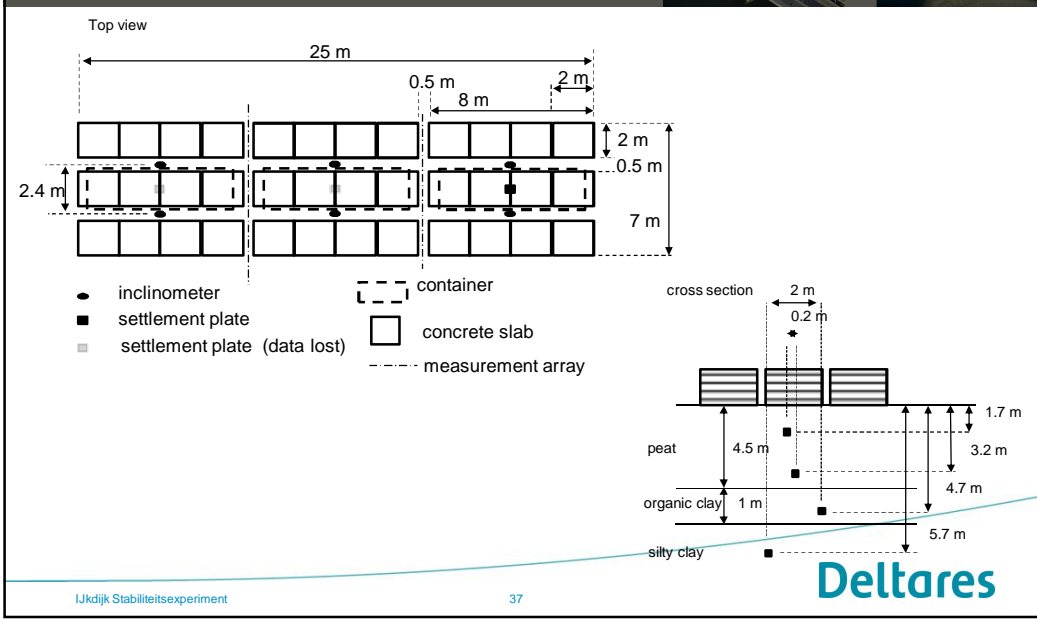
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Deltares

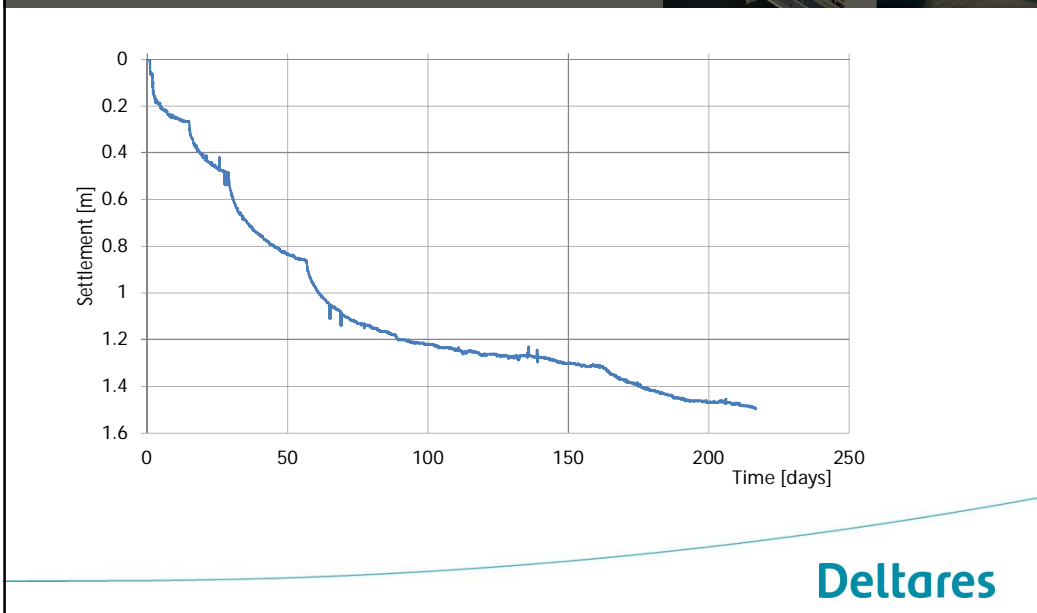
Impression of test 6



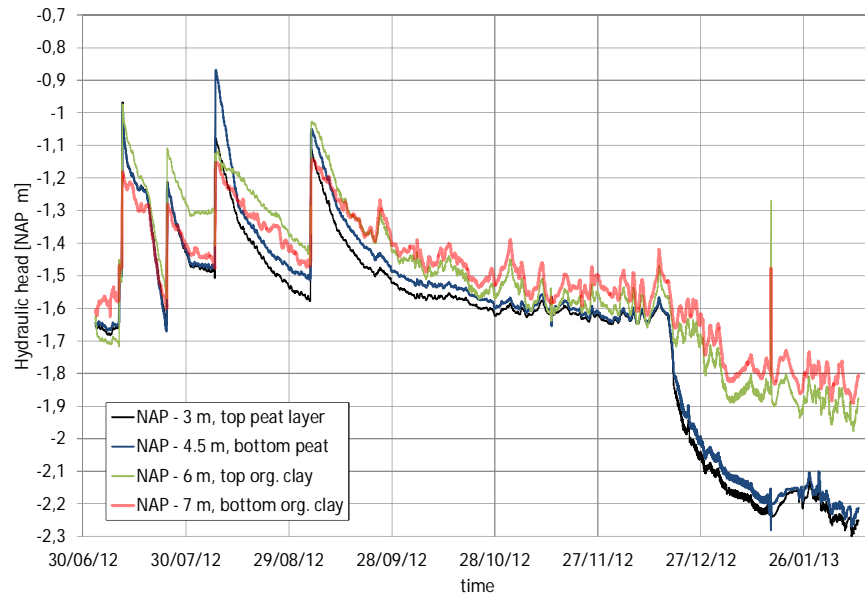
Test 6



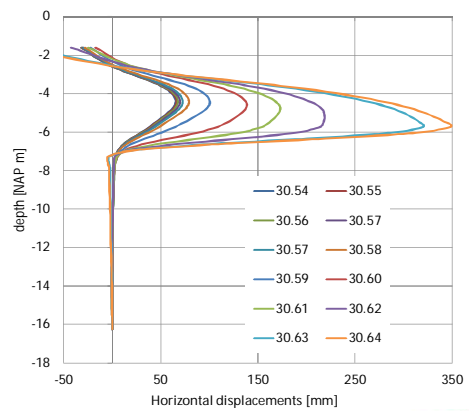
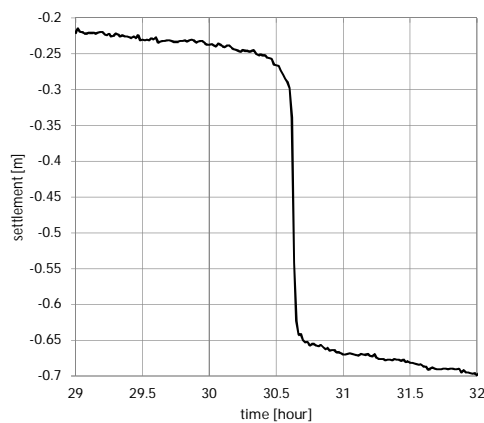
Settlement during pre-loading

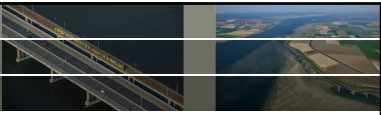


Hydraulic head during pre-loading



Displacements at failure



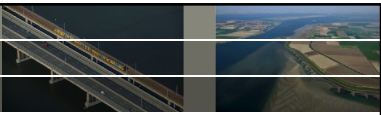


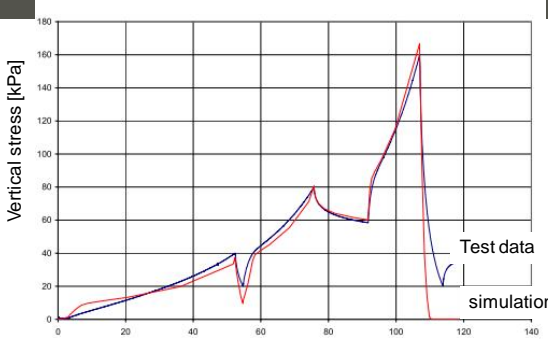
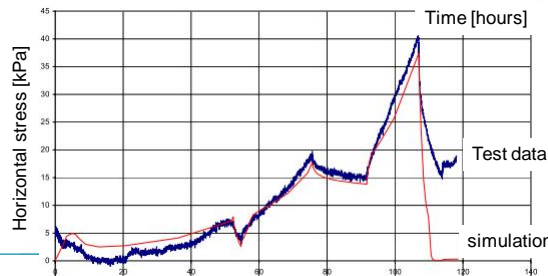
(numerical) analysis:
 displacements
 failure

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Deltares

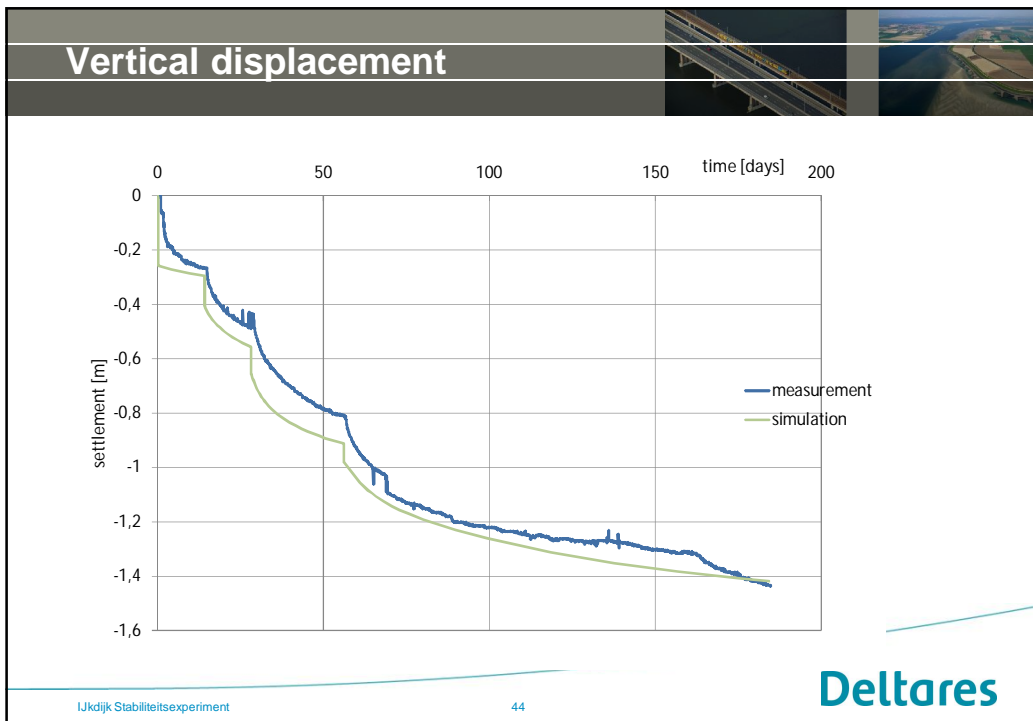
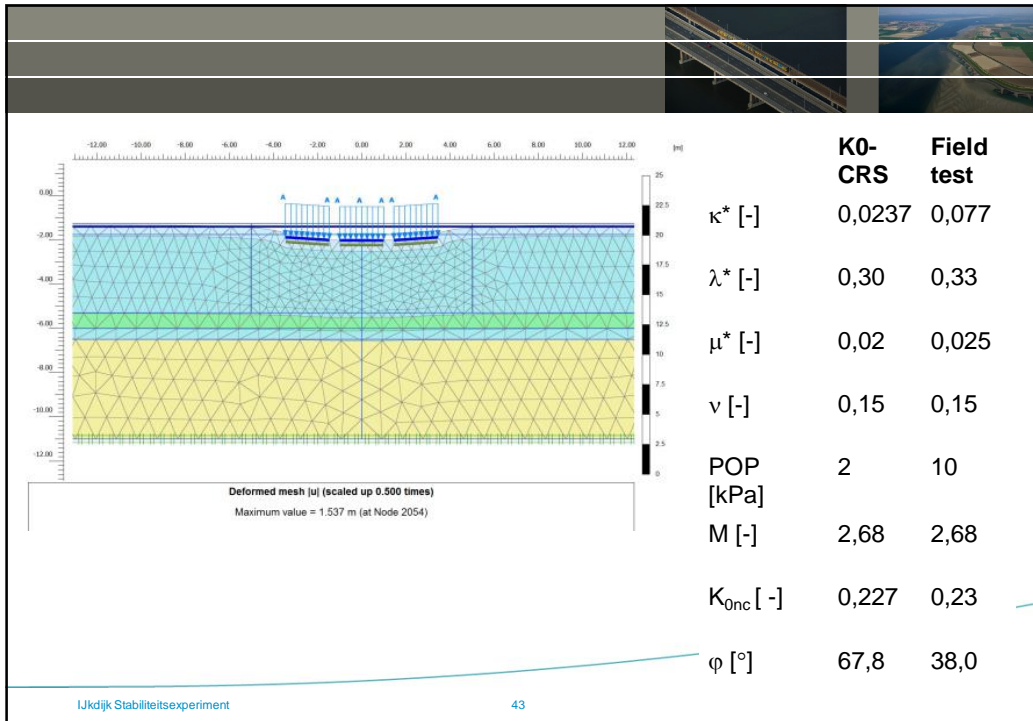
Simulation test 88A SSC-model



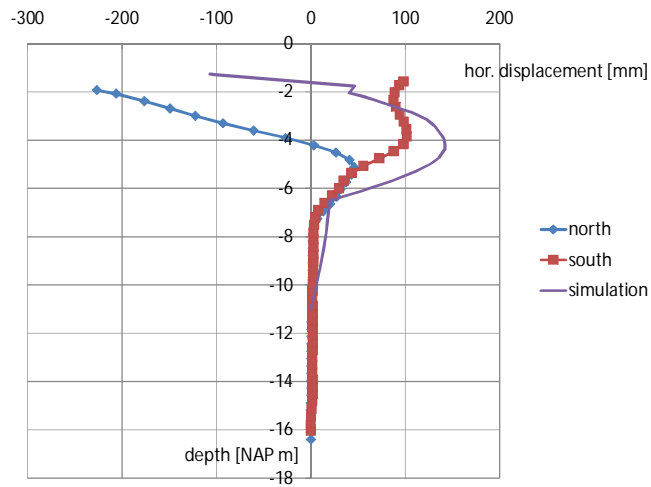
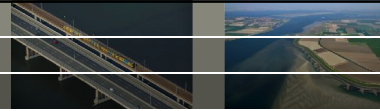



κ^* [-]	0,0237
λ^* [-]	0,30
μ^* [-]	0,02
ν [-]	0,15
POP [kPa]	2
M [-]	2,68
K_{0nc} [-]	0,227
ϕ [°]	67,8

Deltares



Horizontal displacement

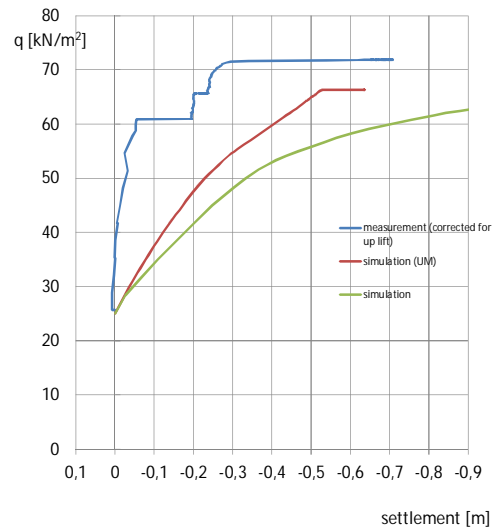
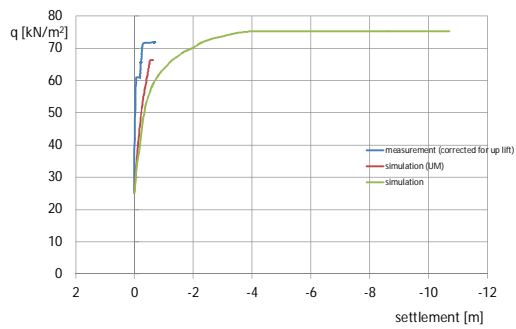
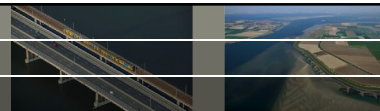


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Deltares

Simulation of failure

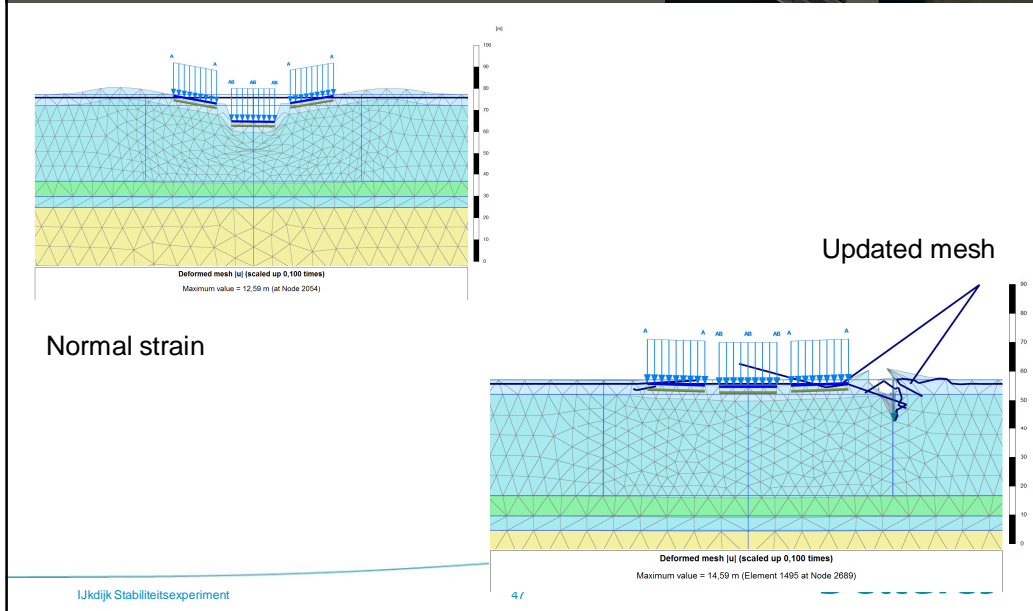


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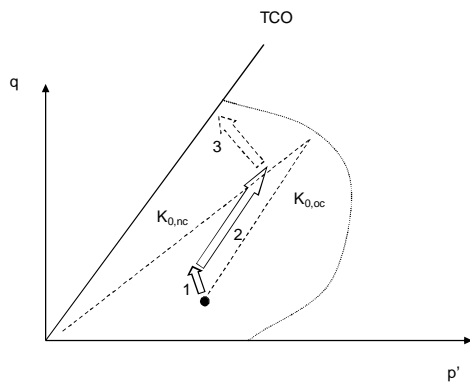
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Deltares

Failure mechanism



Final element modelling test 1 and 2



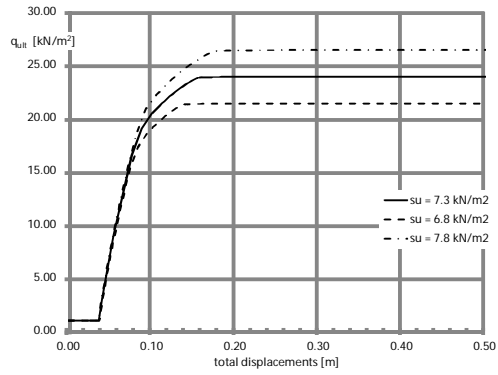
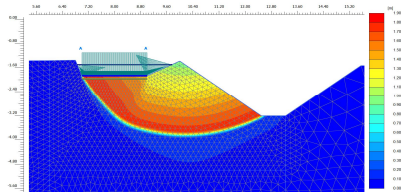
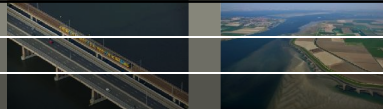
problems with very low stresses
problems with tension cut off
problems with modelling over consolidated behaviour, incl. fracturing

hard to reproduce field measurements by FEM

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Deltares

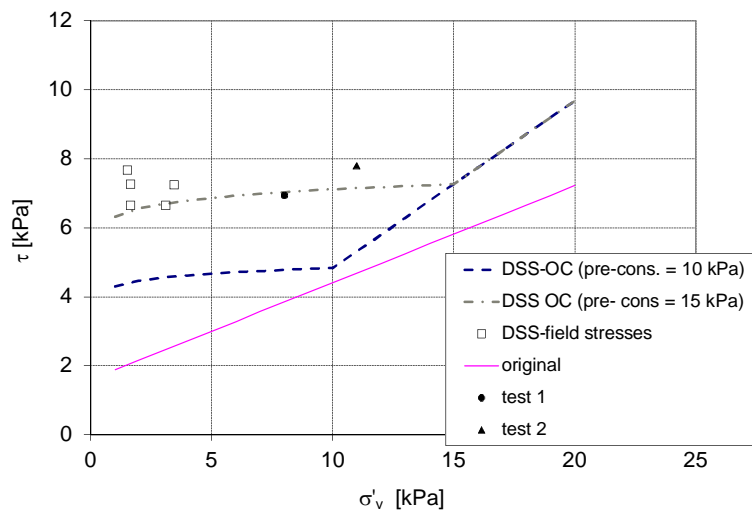
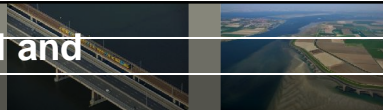
MC simulation of test 2



Failure load
 Test: 23,77 kN/m²
 Simulation: 24,13 kN/m²

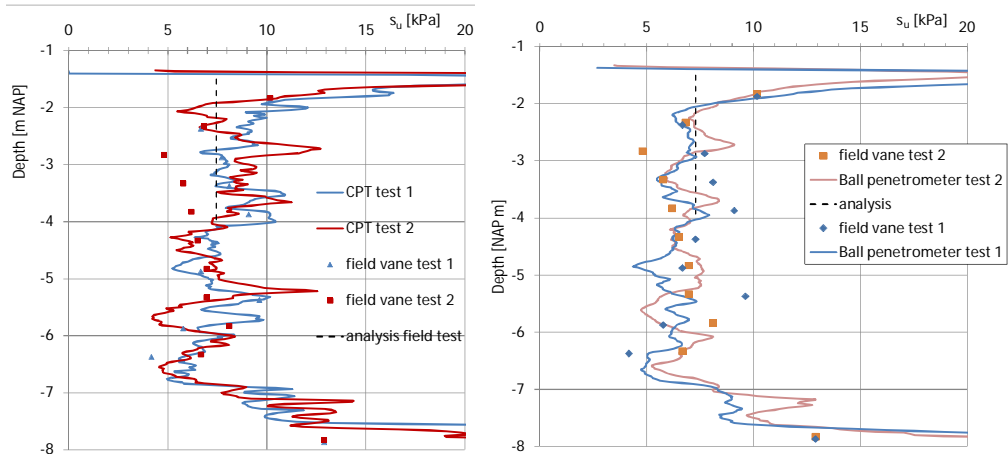
Deltares

Comparison of test results to field and laboratory tests



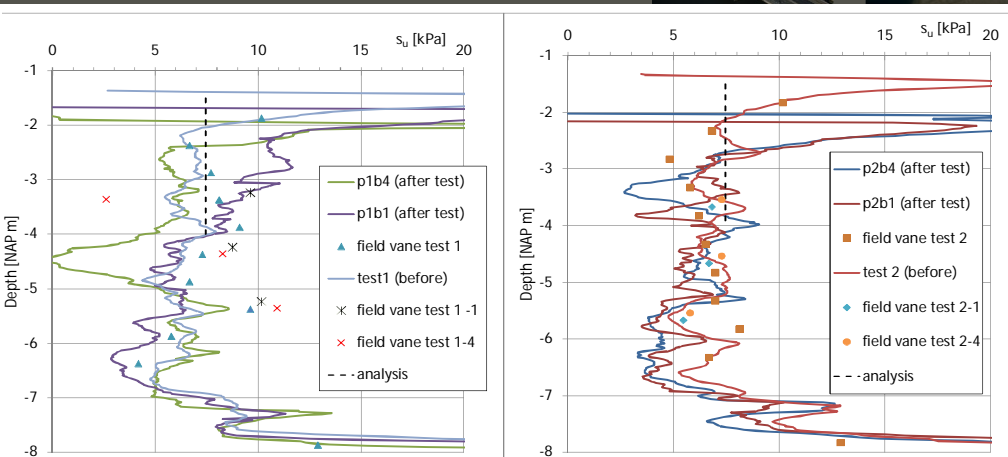
Deltares

Comparison between field probe test results and analysis



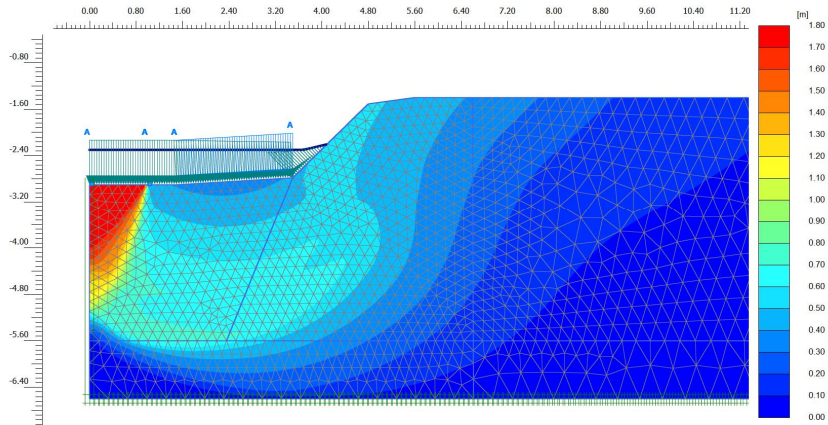
Deltares

Before and after test



Deltares

MC simulation

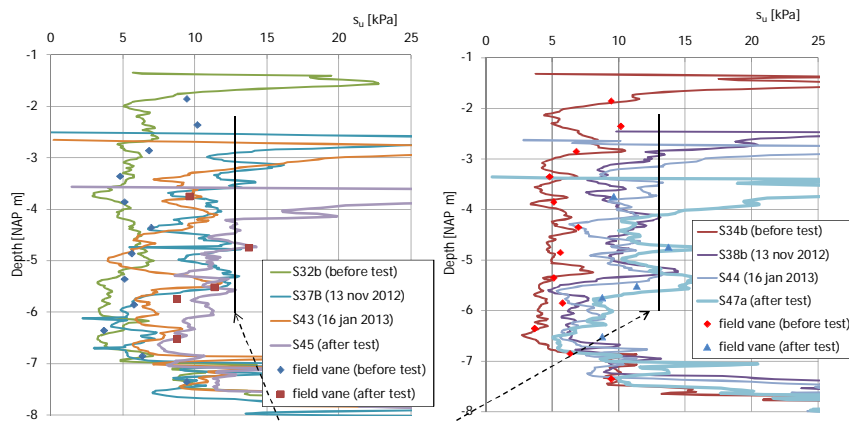


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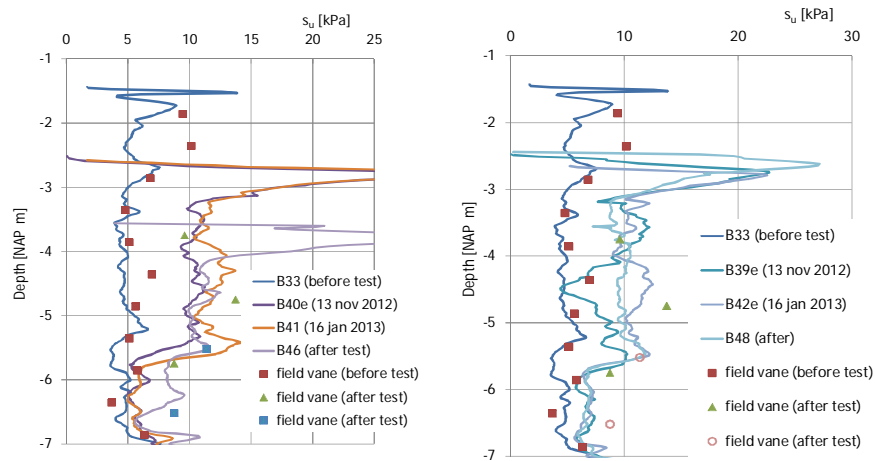
Test 6, CPTu results



Simulation MC-model $s_u = 13,2 \text{ kN/m}^2$

Deltares

Test 6 ball penetrometer tests



Deltares

Conclusions

- Typical peat characteristics, like low density, low stiffness makes numerical analysis difficult
- This holds especially for non pre loaded peat when initial conditions lead to relatively large OCR
- Horizontal and vertical deformations can be simulated well, with parameters calibrated from laboratory tests
- Failure is not well captured

Deltares