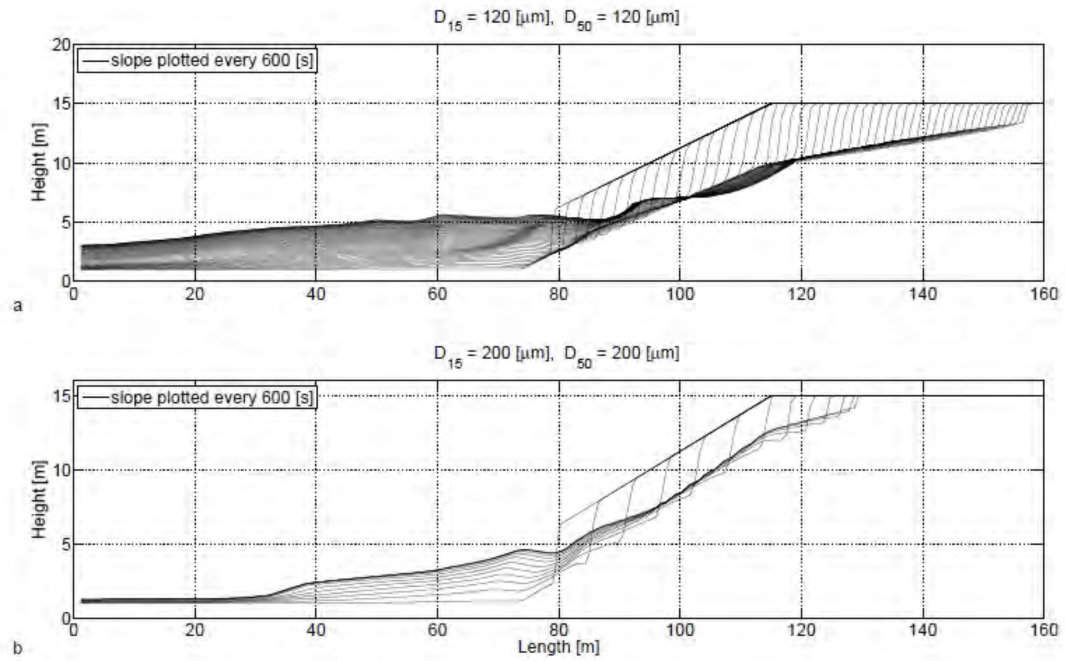
Slope Failure by Unstable Breaching

A sensitivity analysis



Prof. Dr. ir. C. van Rhee

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Sectie Offshore & Dredging Engineering

Delft University of Technology

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- Relevance of this topic for dredging
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- Conclusion

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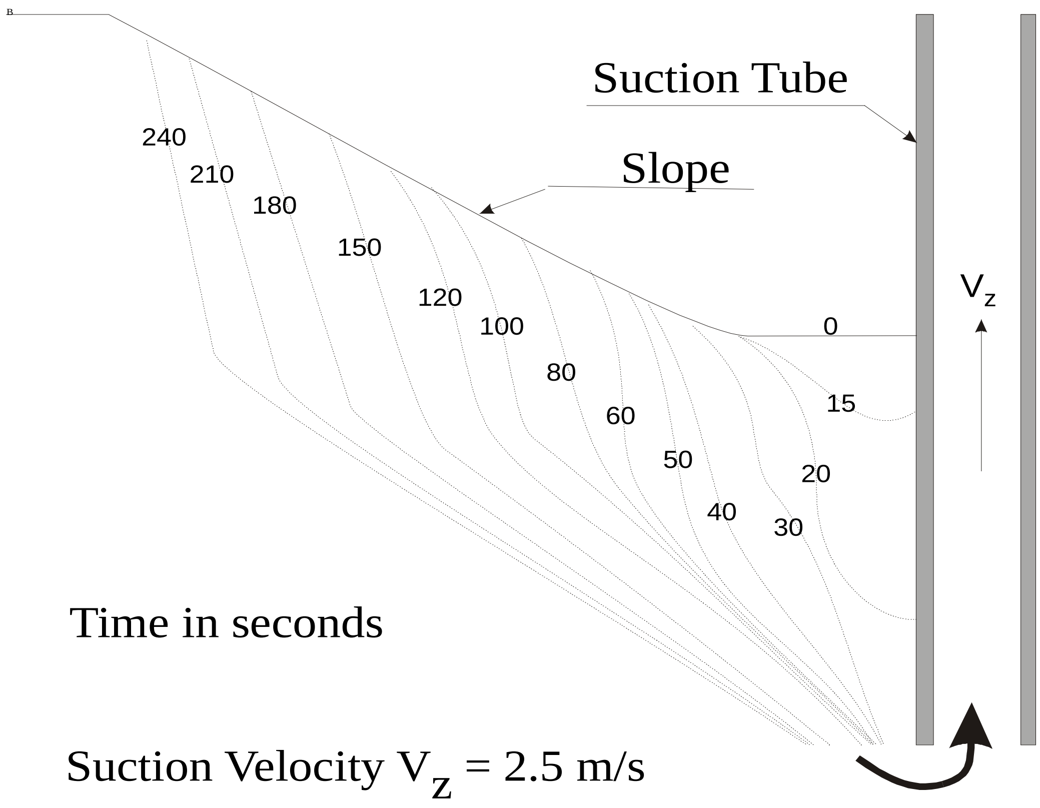
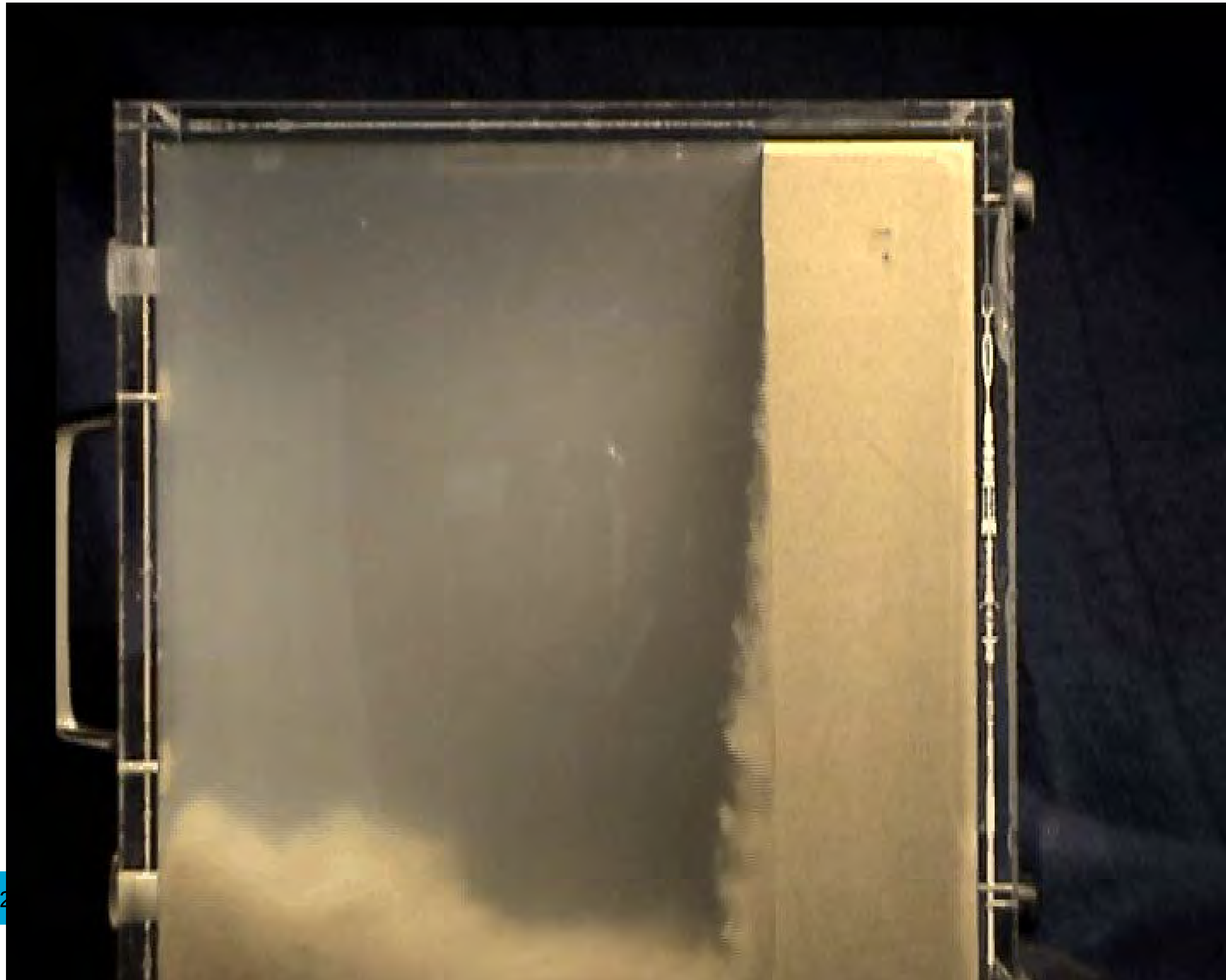
Slope failure mechanisms

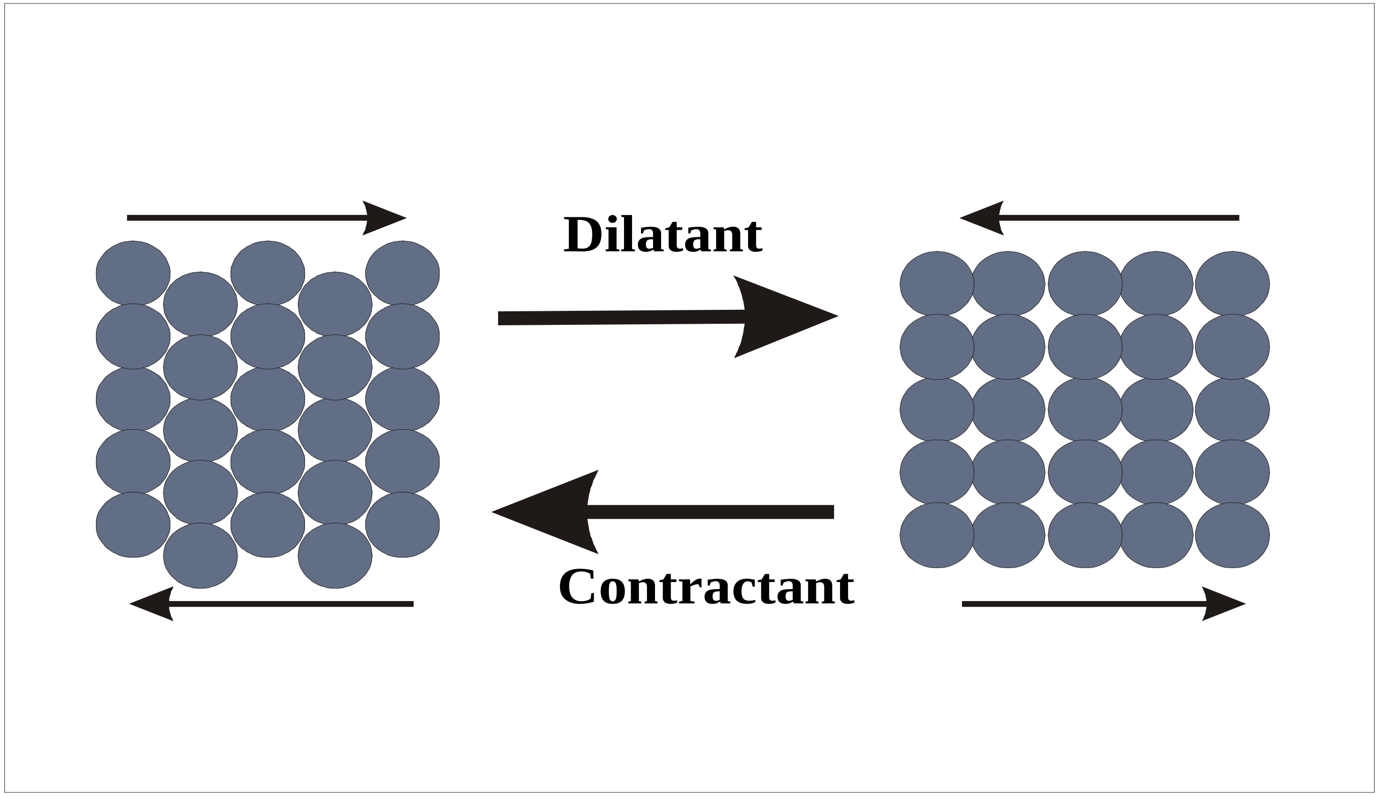
- (Rotational) Sliding
- Static liquefaction
- Piping
- Etc. etc
- Unstable (under water) breaching
  - Not well known in geotechnics
  - Often confused with static liquefaction
  - Can occur during construction (dredging)
  - Often leads to discussion / claims

Breaching process

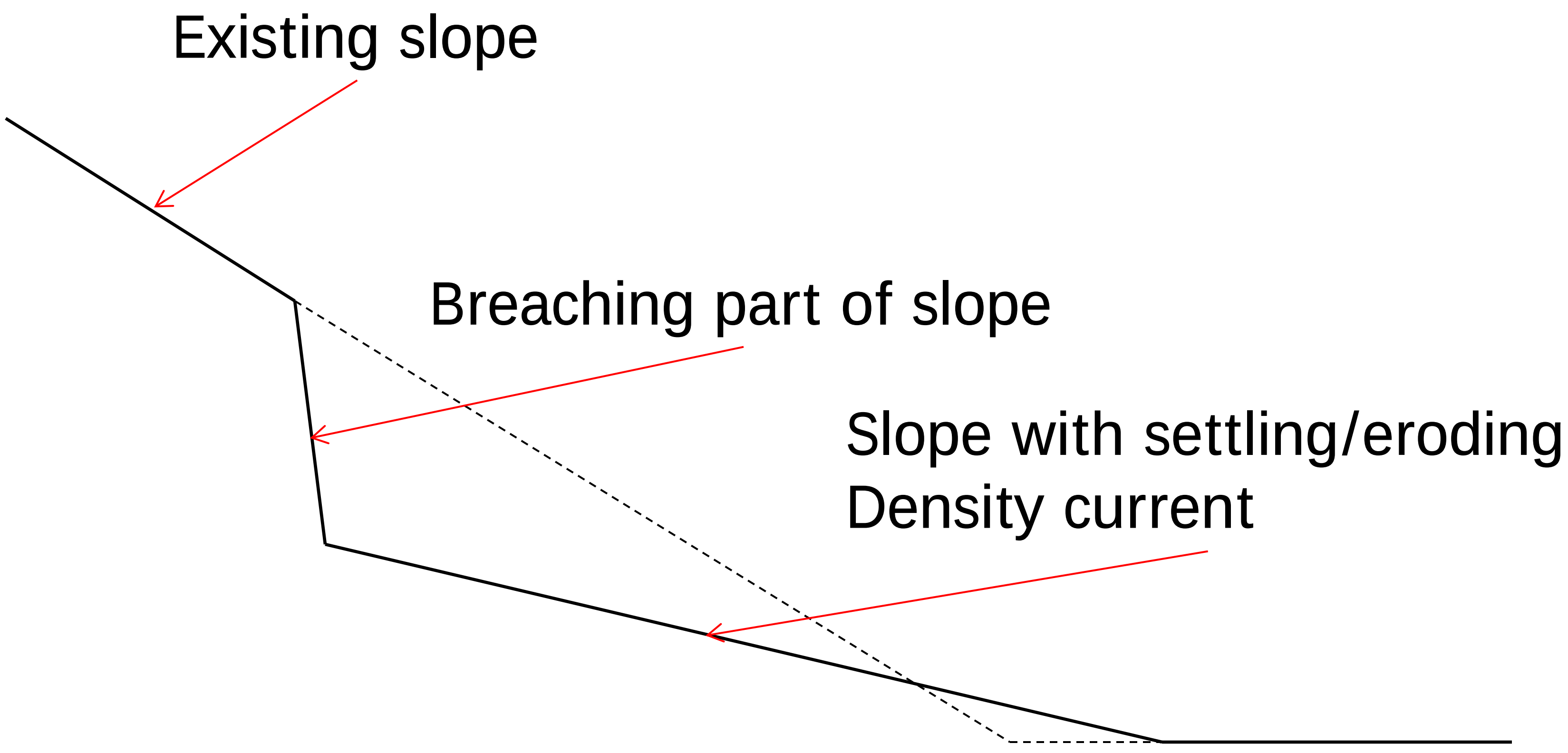




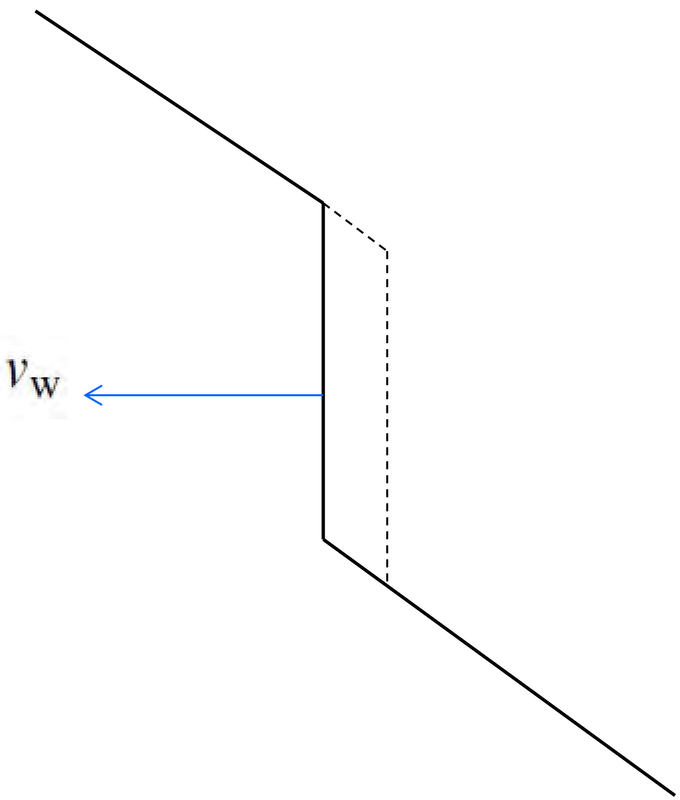
Dilatancy⇔ Contractancy



Different parts of slope



Breaching part



$$v_\mathrm{w} = (1 - n_0)\frac{\rho_\mathrm{s} - \rho_\mathrm{w}}{\rho_\mathrm{w}}\frac{k_1}{\Delta n} \cdot \cot\phi$$

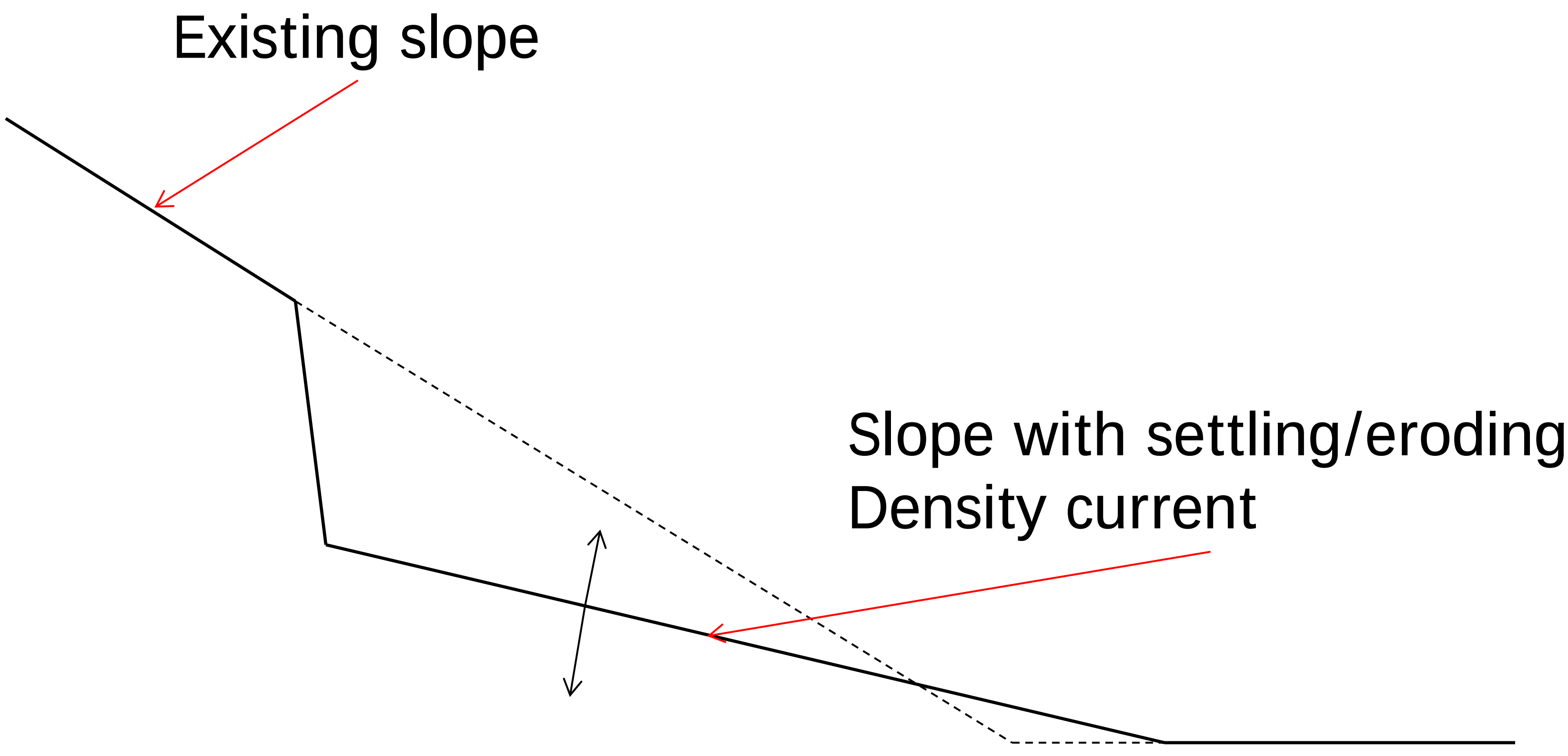
Van Rhee, 2015:

$$v_w \approx 30 k_0$$

k_0 = In-situ permeability

$$k_0 = \frac{g}{160\nu} D_{15}^2 \frac{n_0^3}{(1 - n_0)^2}$$

Lower part of the slope



Slope angles during settling of sand

2 EXPERIMENTAL SET-UP

The experimental set-up consisted of a horizontal flume (see fig. 1), with dimensions 32 x 2,5 x 0,5 m, created by placing steel frames in the concrete basin of the Dredging Flume at DELFT HYDRAULICS.

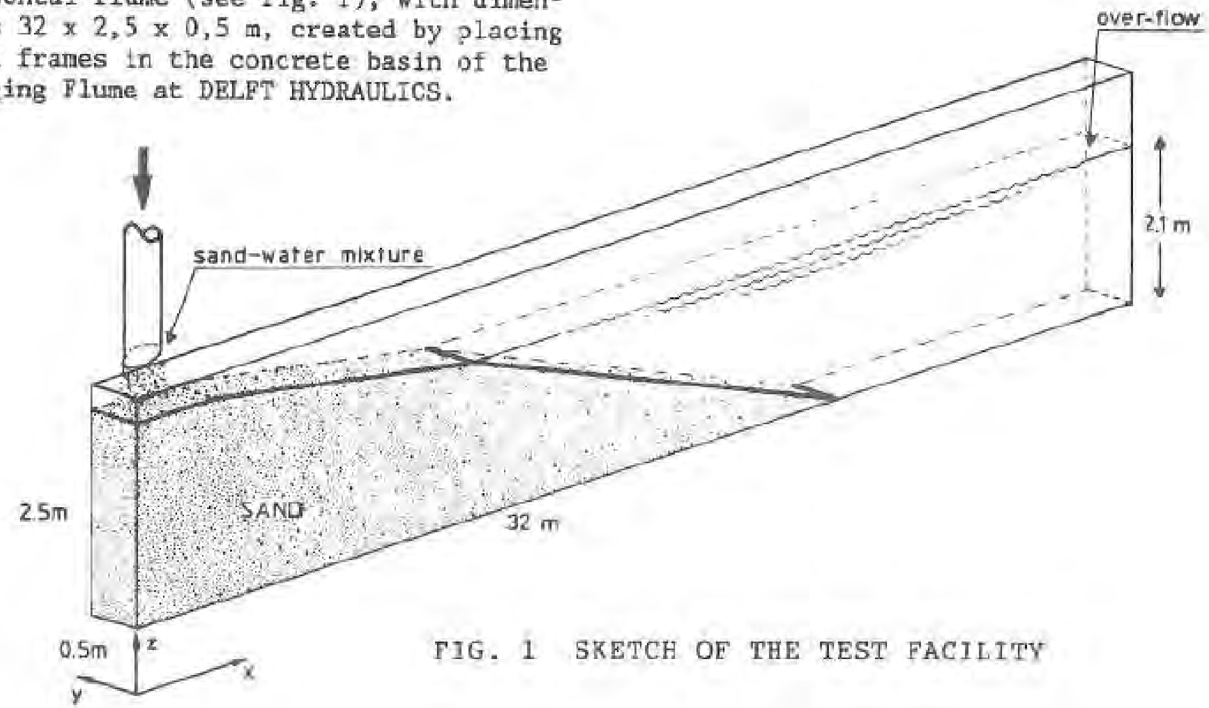


FIG. 1 SKETCH OF THE TEST FACILITY

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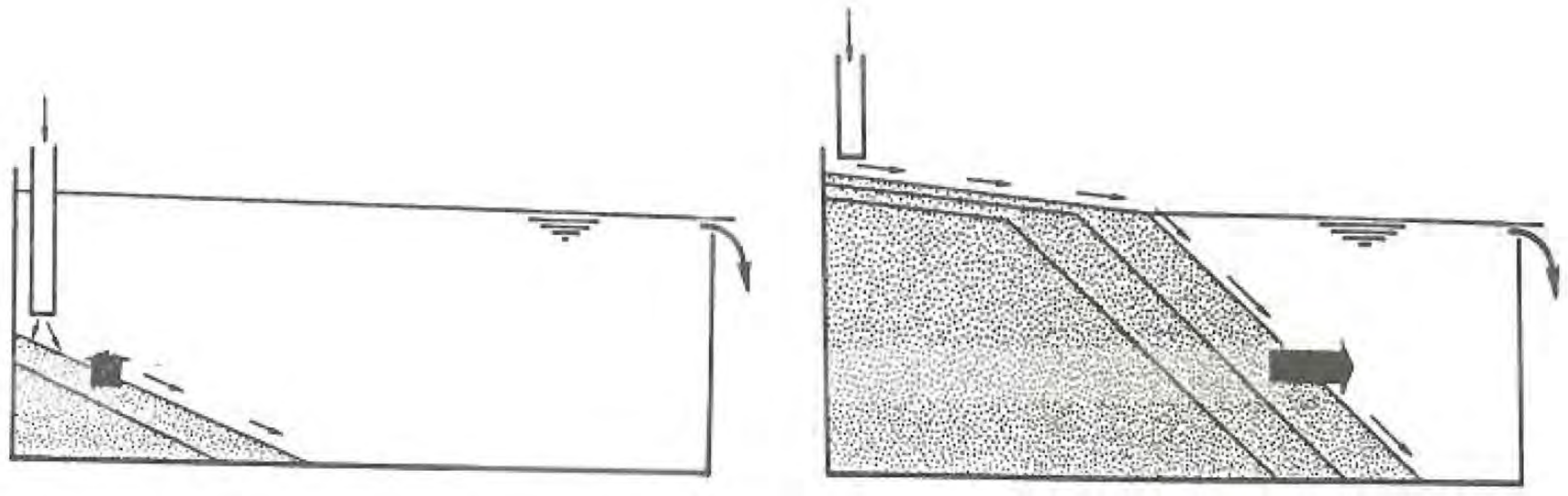
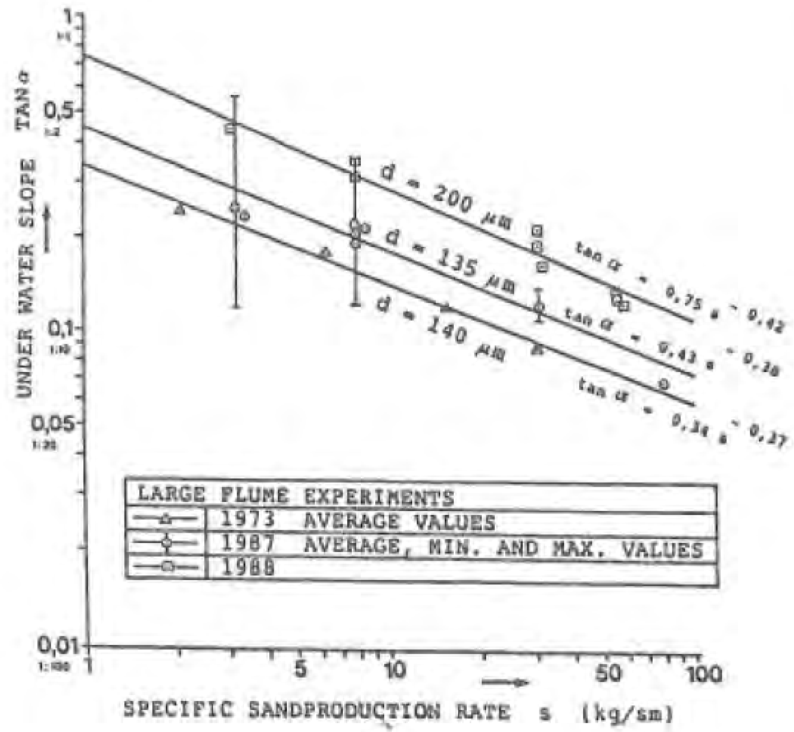
Slope angles during settling of sand

- Experiments (Mastbergen & Winterwerp 1988)



Slope angles under water



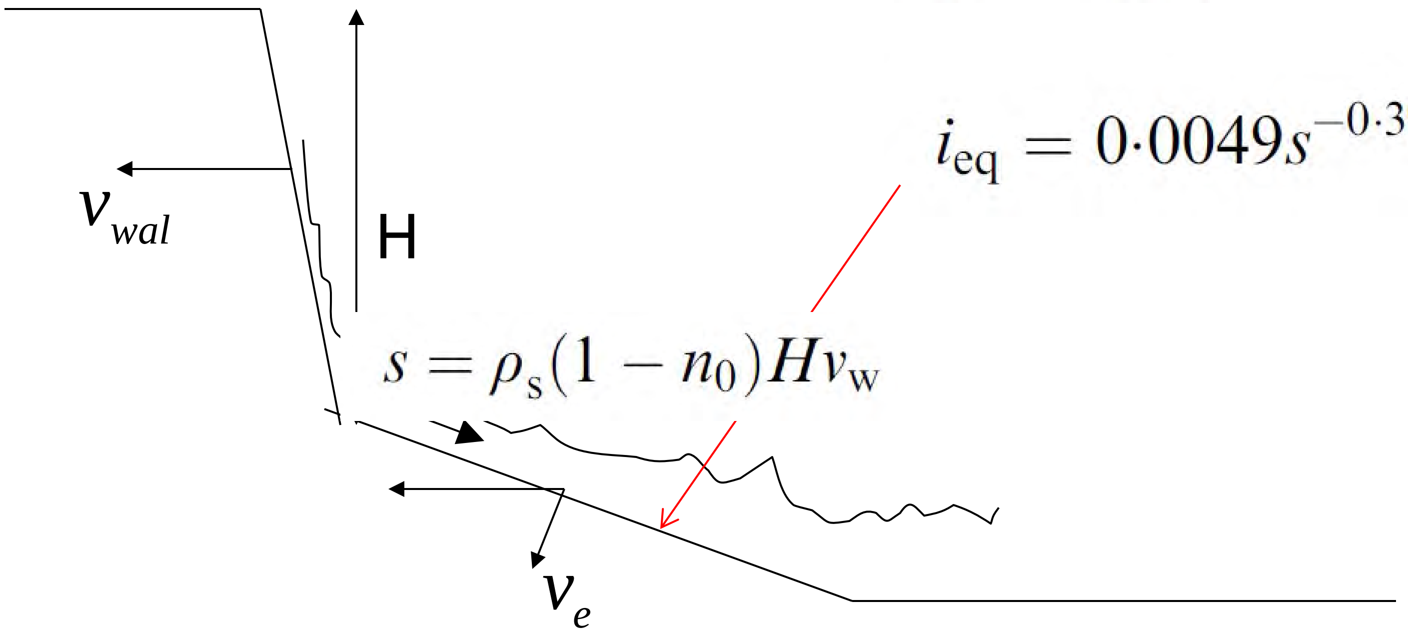
$$i_{slope} = 0.0049 s^{-0.39} d_{50}^{0.92}$$

D50 in micron !

$$v_w \approx 30 k_0$$

$$i_{eq} = 0{\cdot}0049 s^{-0{\cdot}39} D_{50}^{0{\cdot}92}$$

$$s = \rho_s (1 - n_0) H v_w$$



Erosion due to density current

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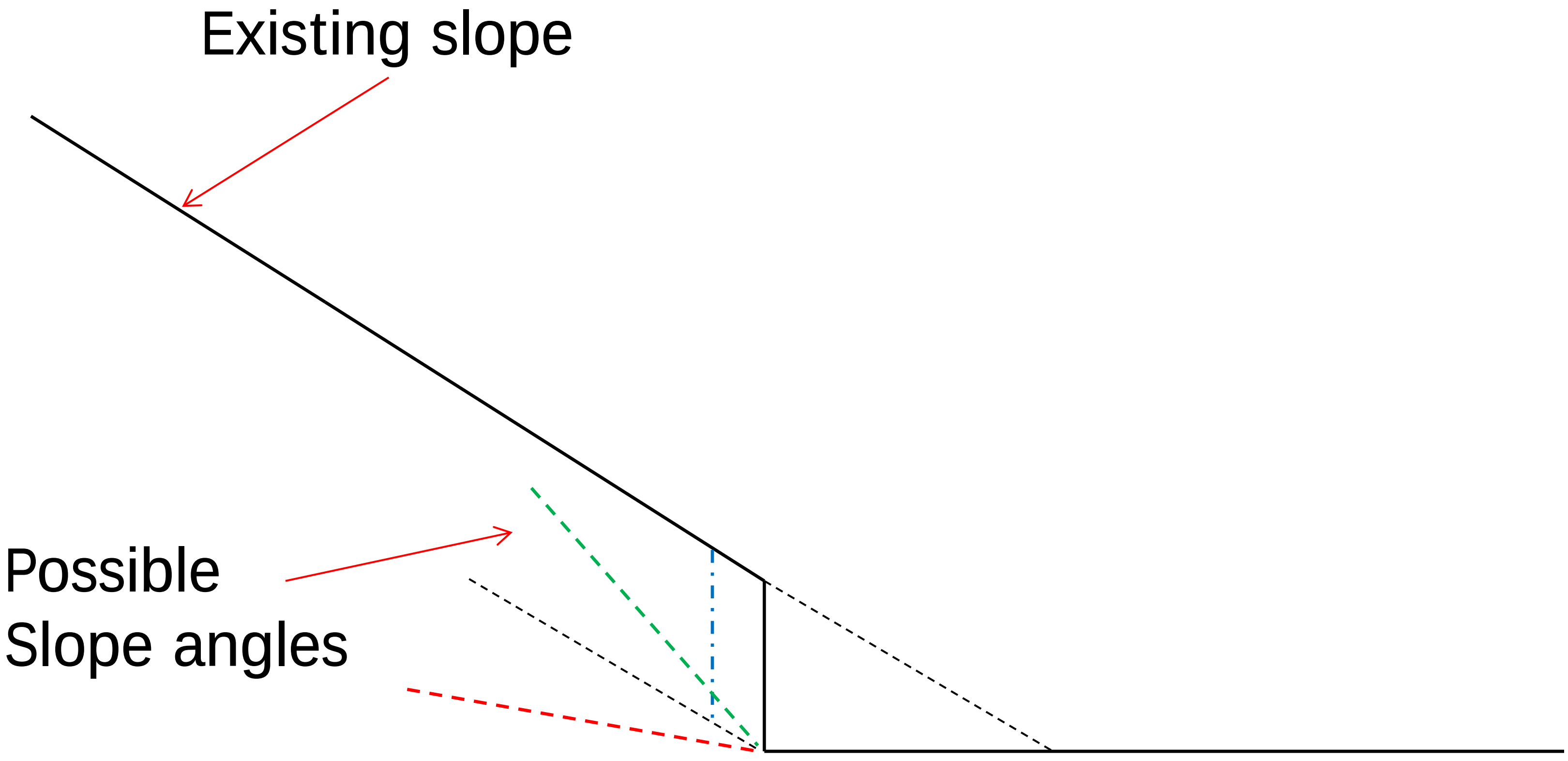
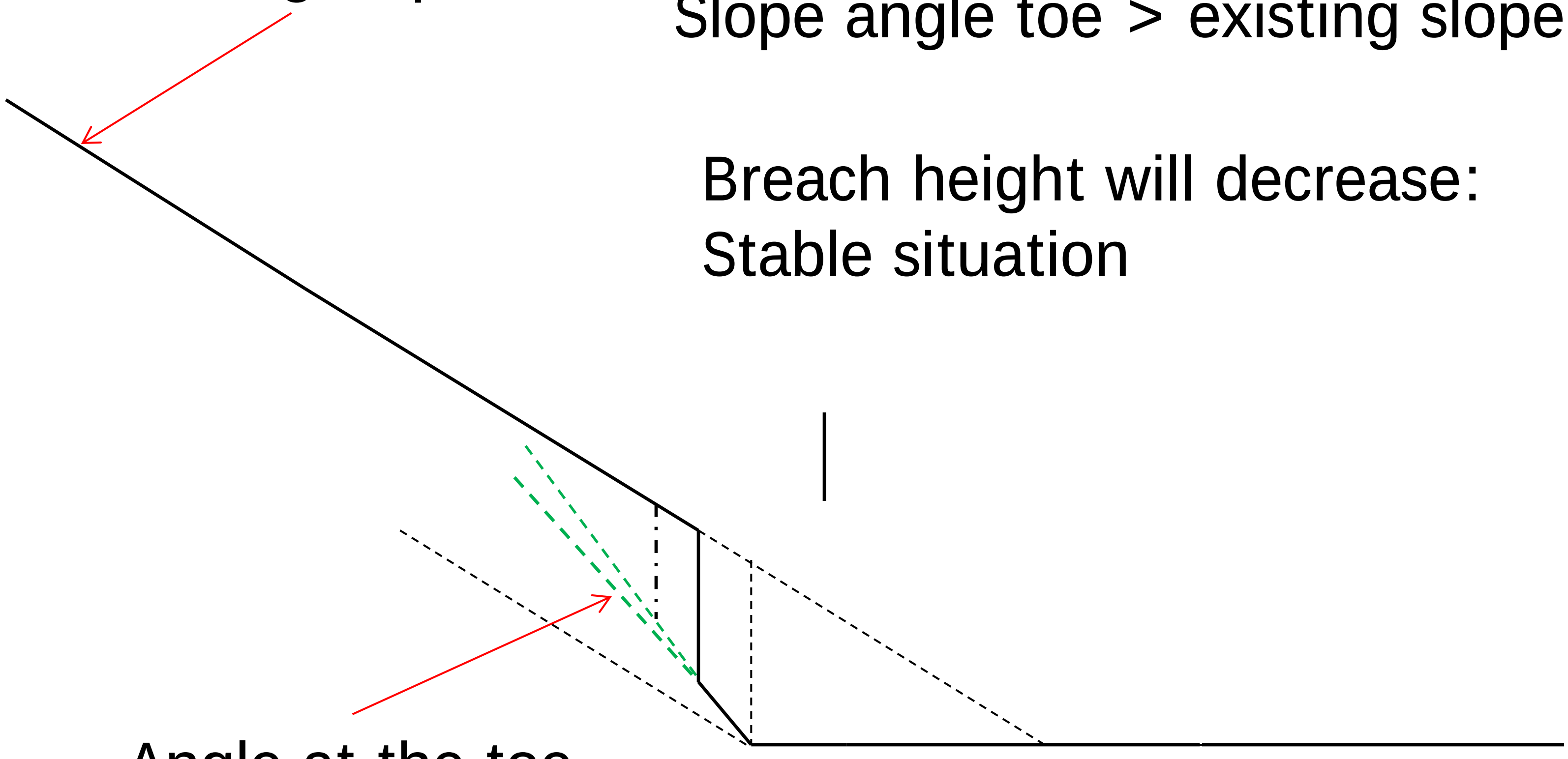
Stable or unstable



Stable breaching

Slope angle toe > existing slope

Breach height will decrease:
Stable situation



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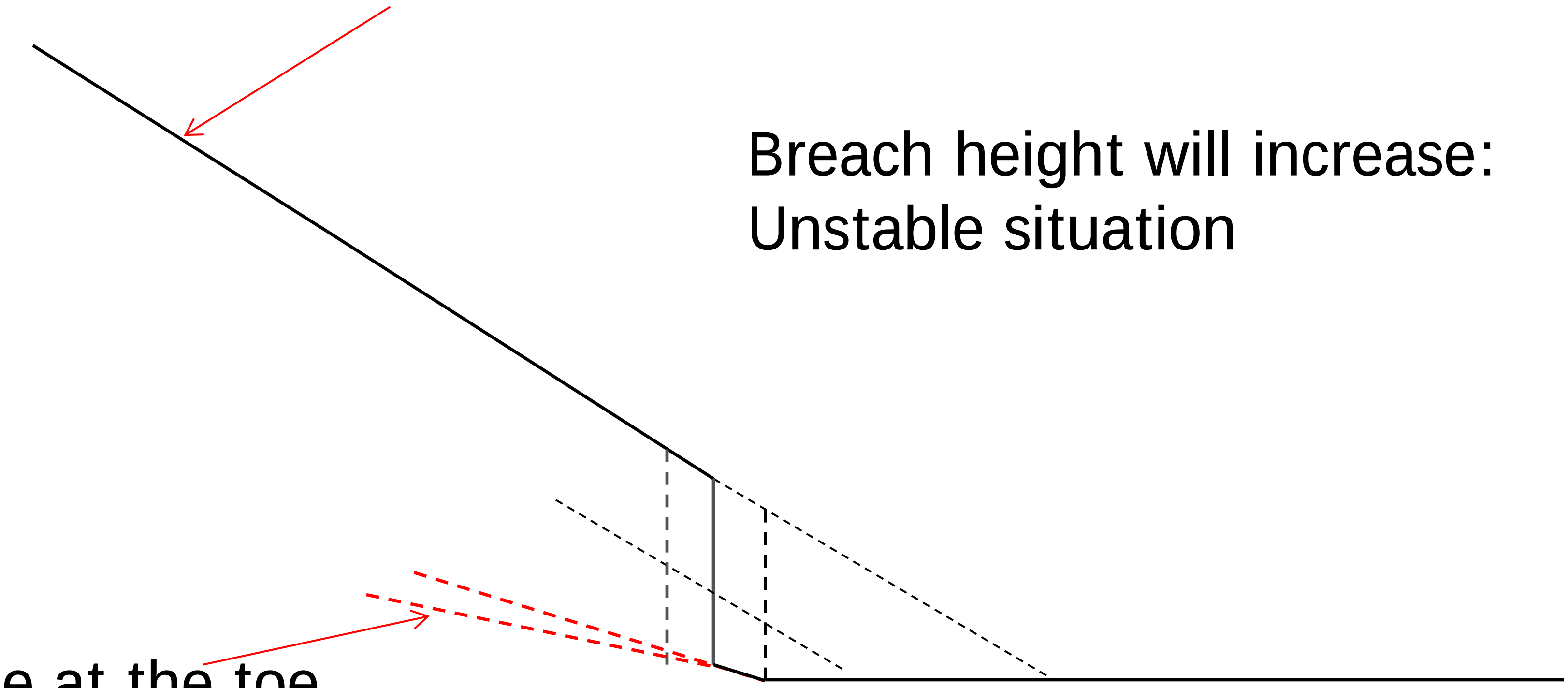
Unstable breaching



Slope angle toe < existing slope

Breach height will increase:
Unstable situation

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Stability criterium

$$i_{\mathrm{eq}} = 0{\cdot}0049 s^{-0{\cdot}39} D_{50}^{0{\cdot}92}$$

$$i_{crit} = 0.0049(30\rho_s(1-n_0)Hk_0)^{-0.39} D_{50}^{0.92}$$

$$H_{crit} = 1.22 \cdot 10^{-6} \frac{i_{slope}^{-2.56} D_{50}^{2.36}}{30\rho_s(1-n_0)k_0}$$

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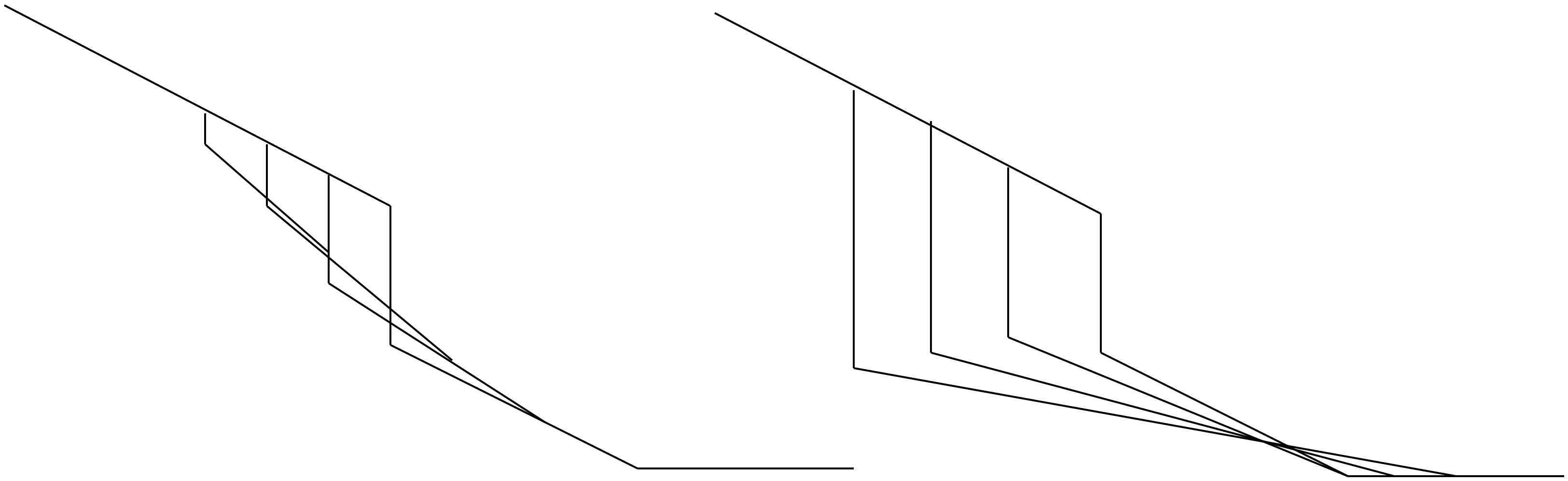
Stable - Unstable breaching



Disturbance diminishes
Stable situation

Disturbance grows
Unstable situation

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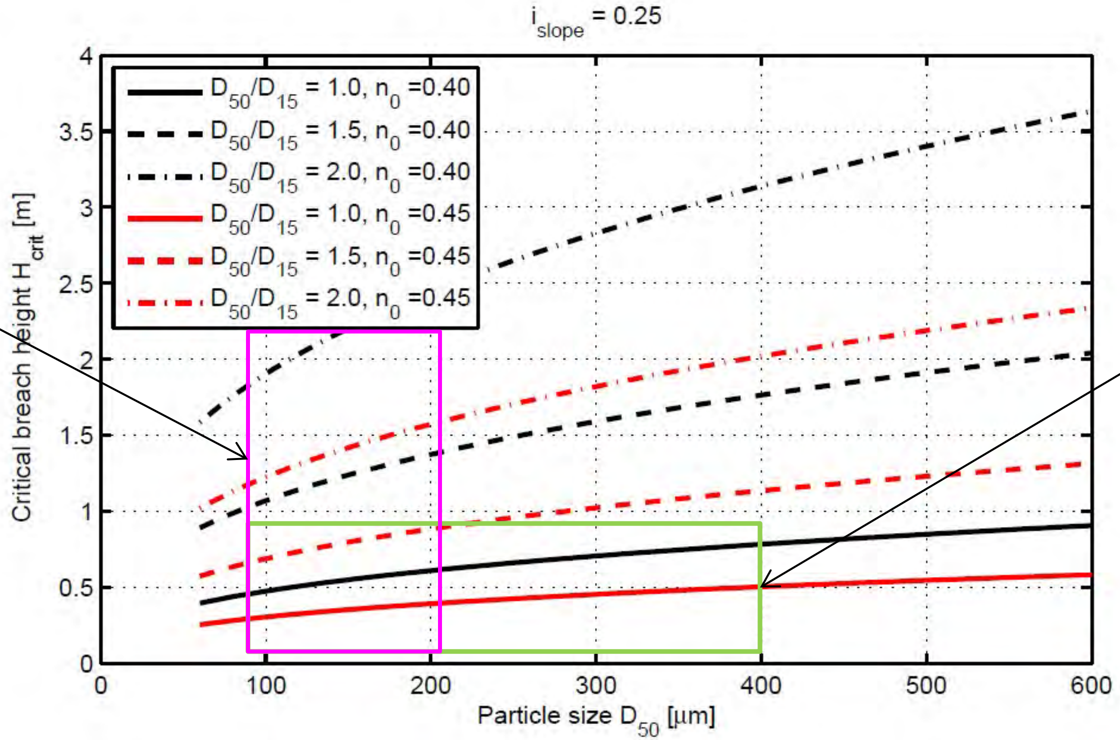
Stability graph

Range
Slope exp.



Exp. Range
breaching

Result of unstable breaching

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CFD 2DVModel

- Based on Reynolds Averaged Navier Stokes Equation
- 2D Horizontal and Vertical
- Hydrodynamic
- K-eps turbulence model
- Moving bed and water surface
- Suspended sediment transport using drift flux (mixture) approach
- Influence Particle Size Distribution by using multiple fractions

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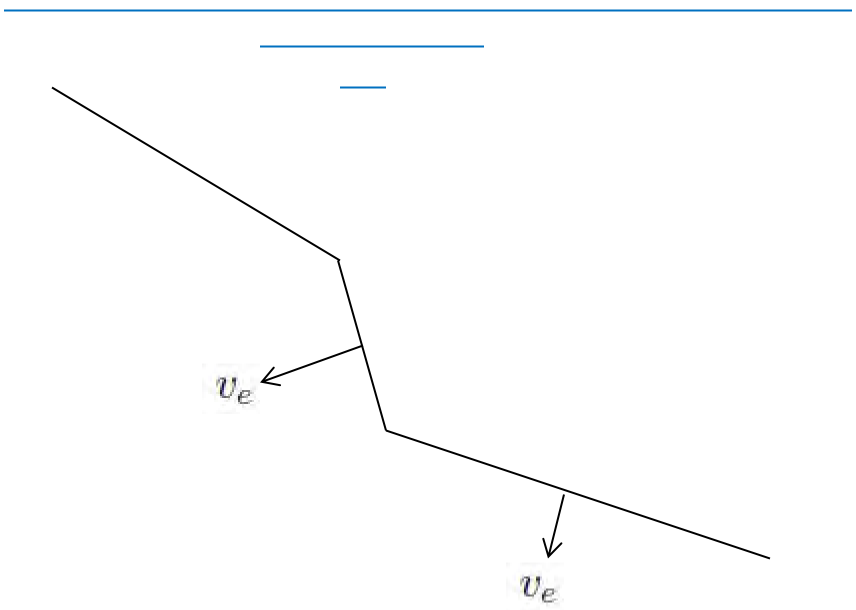
Bed boundary condition



$$v_e = \frac{E - S}{\rho_s (1 - n_0 - \overline{c_b})}$$

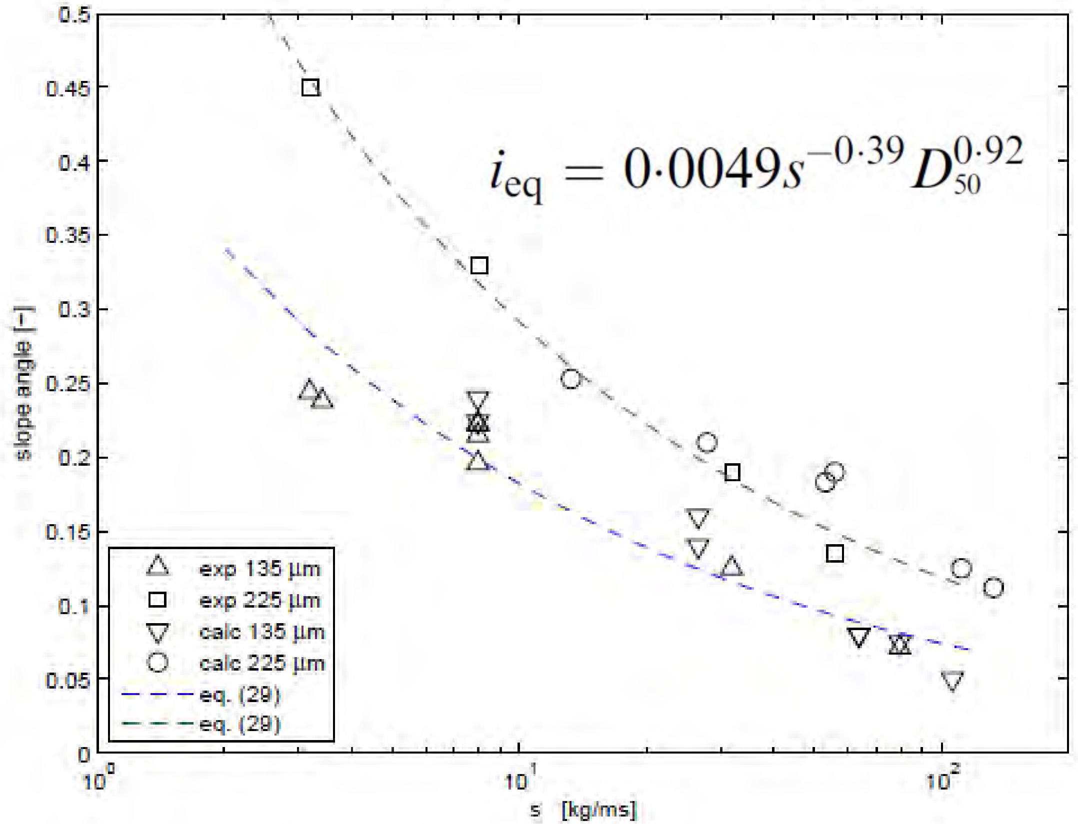
$$S = \rho_s \sum_{j=0}^{N} c_{b,j} w_{s,j}$$

$$\Phi_p = \frac{E}{\rho_s \sqrt{\Delta g D_{50}}} = f(\theta, \theta_{cr}, D_{50}, \ldots)$$

$$\Phi_p = A \frac{\theta}{\theta_{cr}^1} \frac{1 - n_0 - \overline{c_b}}{1 - n_0}$$

$$\theta_{cr}^1 = \theta_{cr} \left(\frac{\sin\phi - \beta}{\sin\phi} + v_e \frac{\Delta n}{k_l (1 - n_0) \Delta} \right)$$

Numerical simulation under water slope angles



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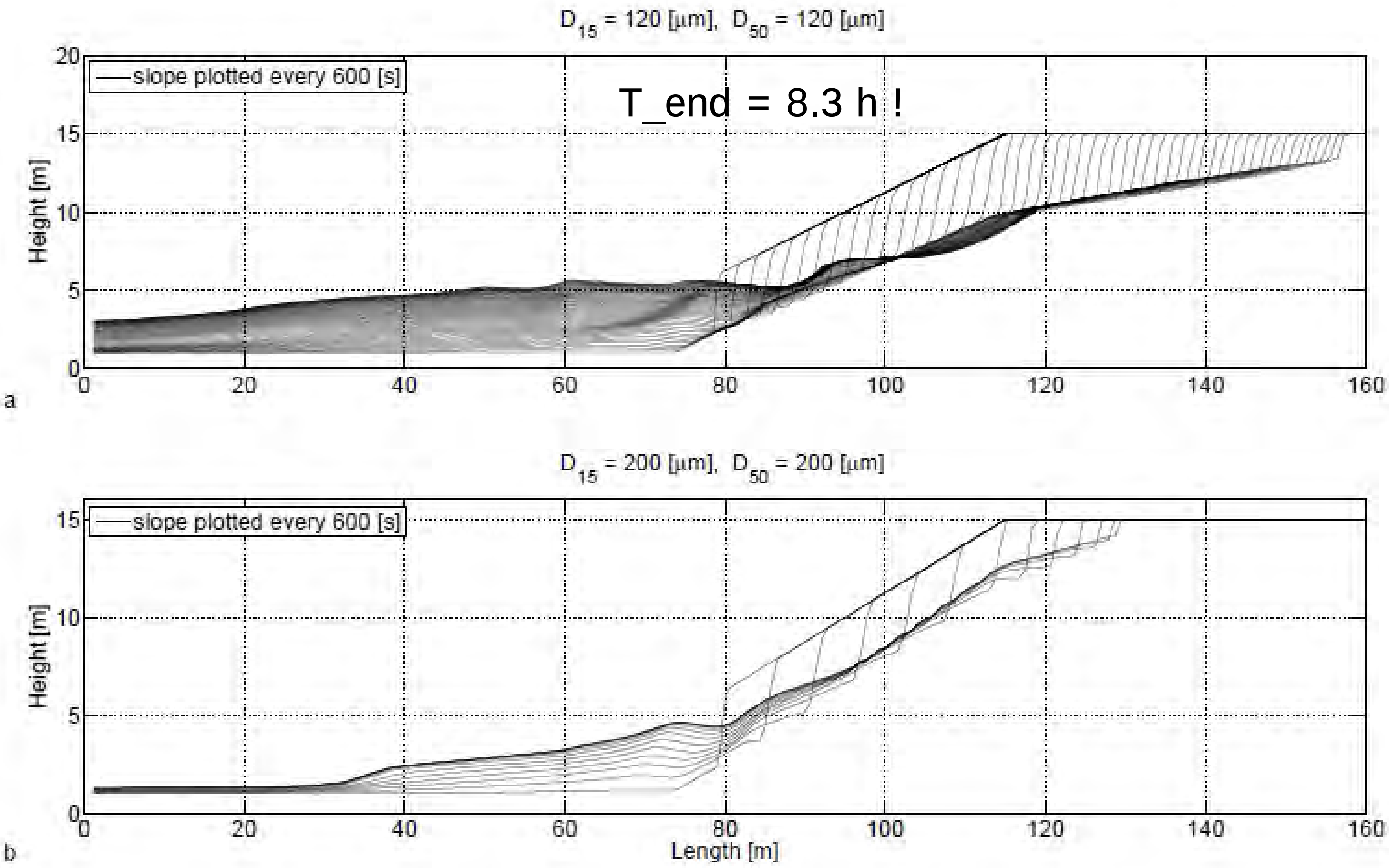
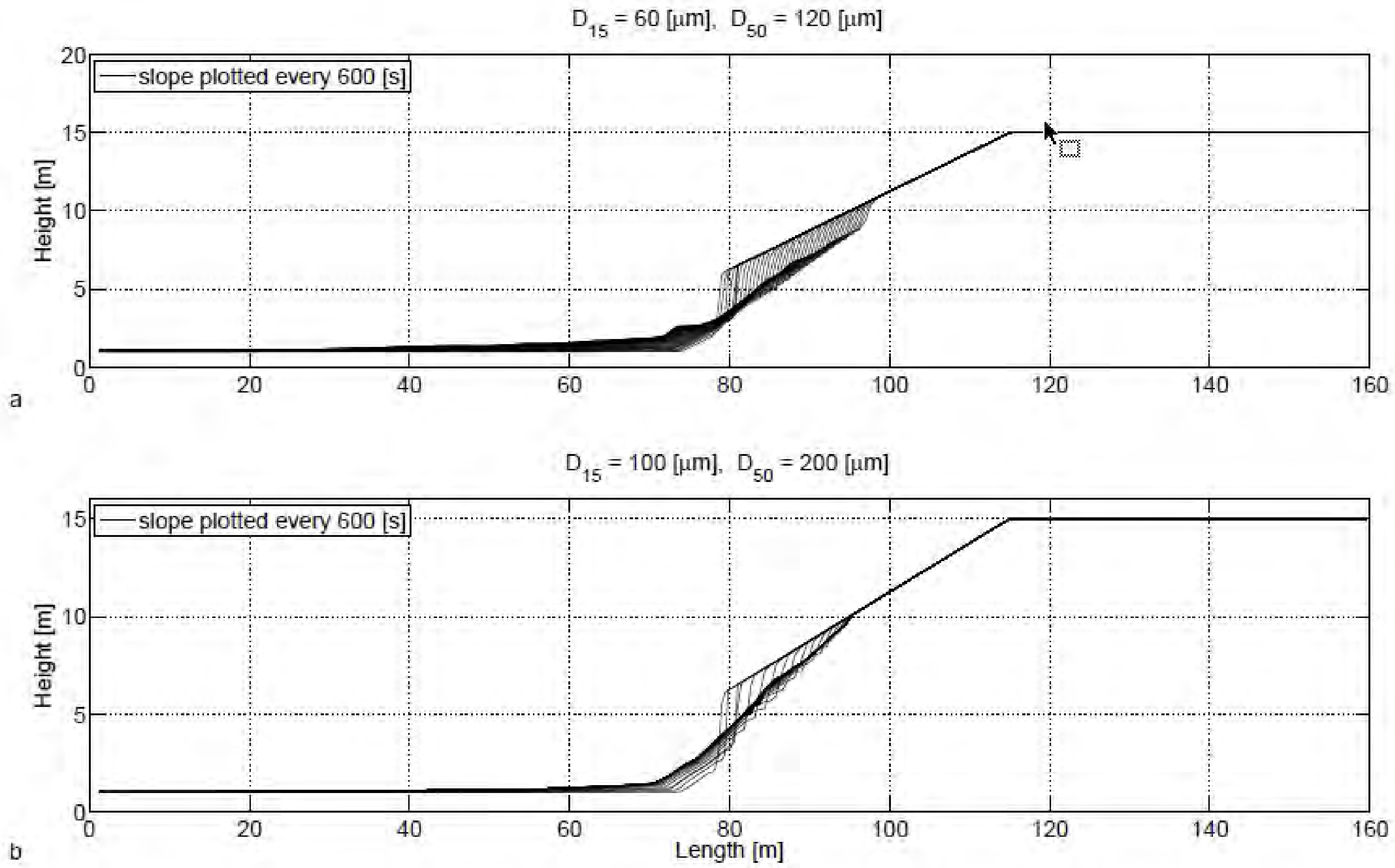
Results 2DVModel uniform sand



Results 2DVModel graded sand



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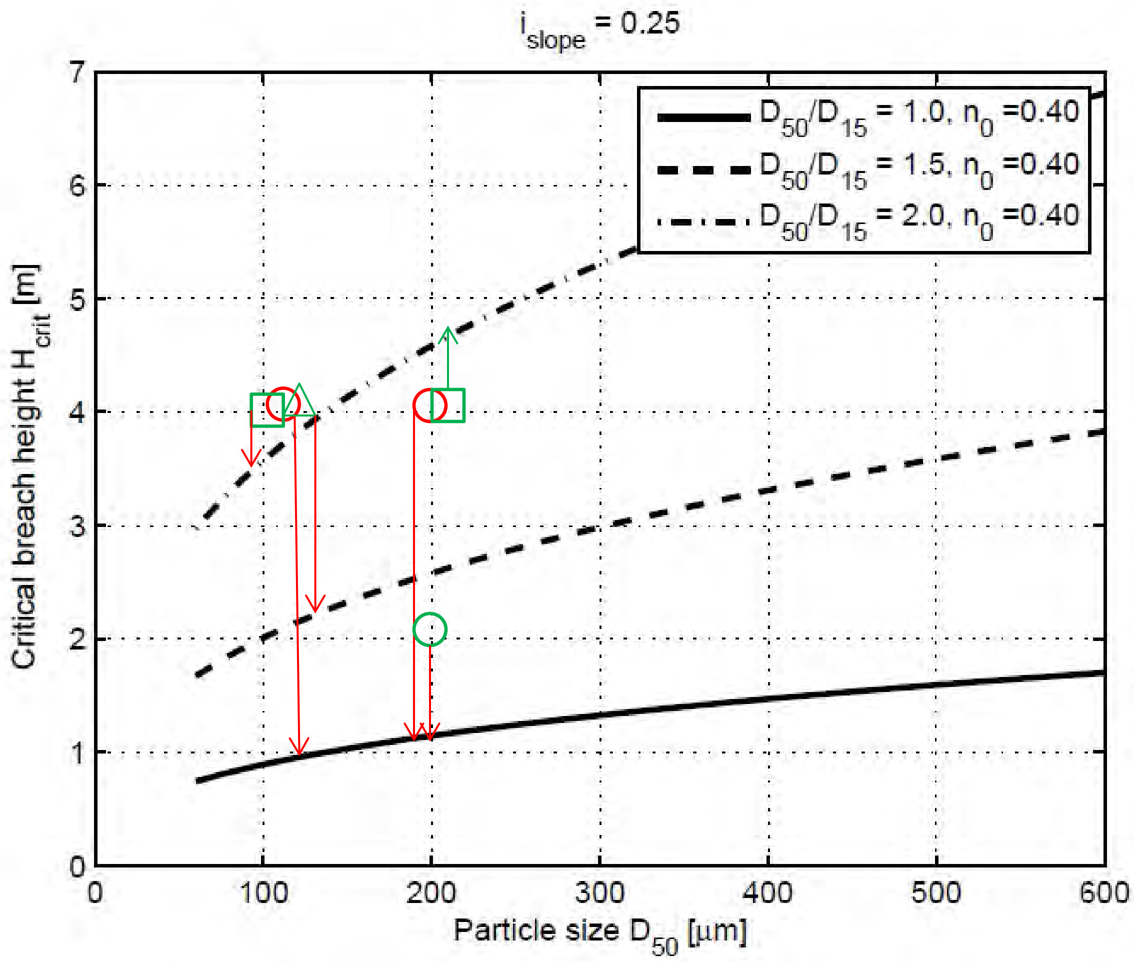
Comparison 2DVModel with empirical relation



Empirical Stability chart

Active slope:

$\beta = 60^o$

Conclusions

- 2DVModel can predict stable or unstable breaching
  - But restricted to 2D
  - 3D simulations needed -> Dave Weij
  - Soil mechanical behaviour at steep section should be improved -> Dave Weij
- Empirical relation is more conservative compared with 2DVModel

- Experimental validation still needed