Validation of Sellmeijer's model for backward piping under dikes on multiple sand layers

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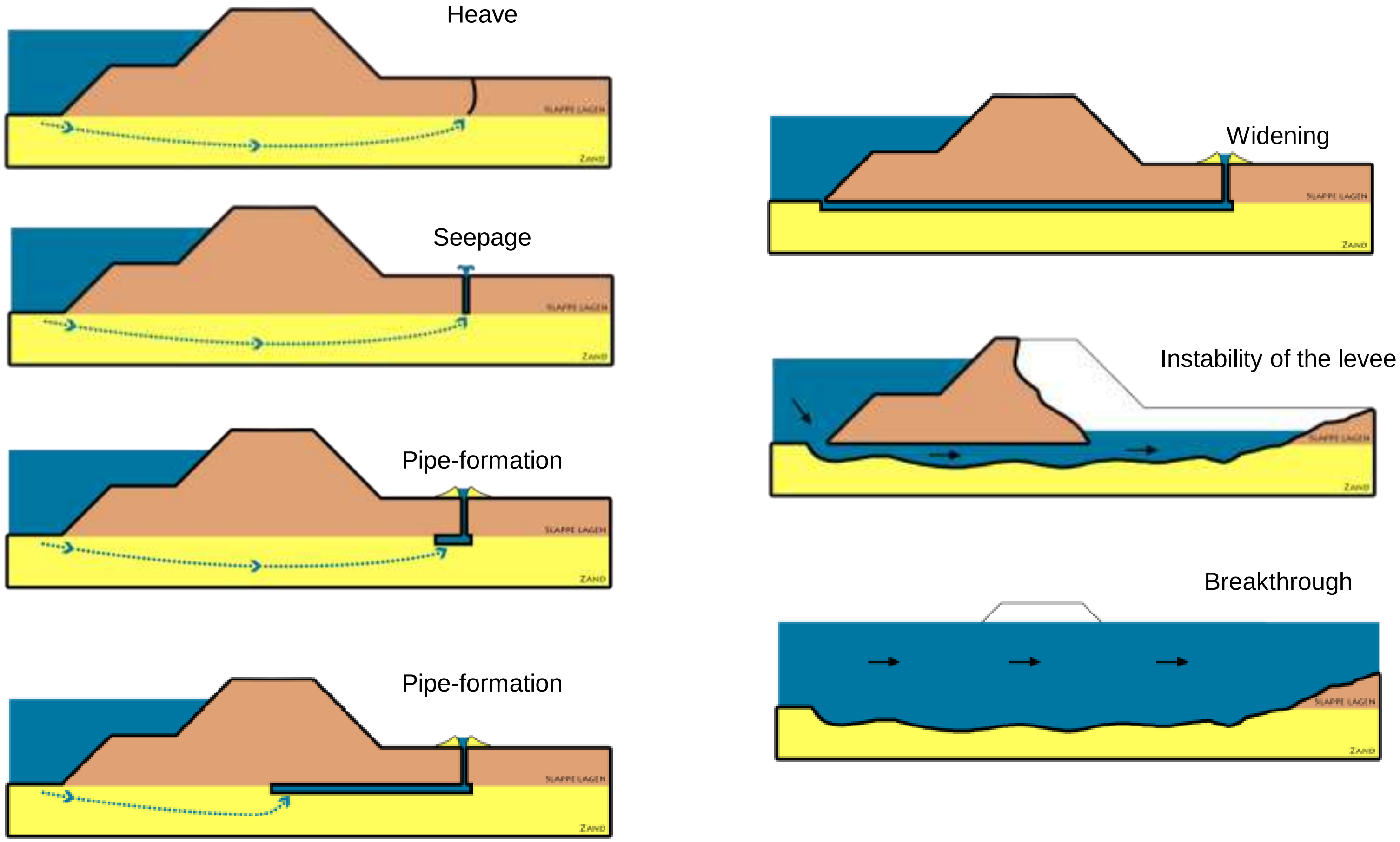
Introduction – backward erosion



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Introduction - Backward erosion

Sand boils are observed regularly in the Netherlands

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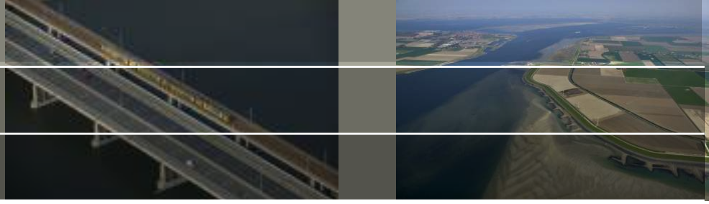
Backward erosion in China

Statistics of Piping in Yangtze River Main Dike during the '98 Flood:
52.4% of the instability threats were related to piping [Ding and Sun, 2002]

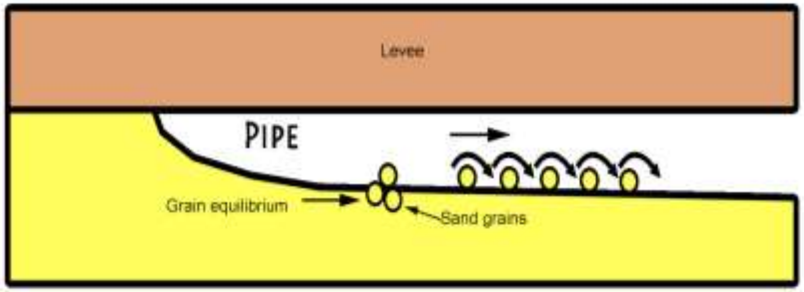
Kinds of risks	**Piping**	Riverbank collapse	Leakage	Crack	Drop	Sloughing	Wave erosion	Culvert gate	Others	Total
Total risks	**2025**	330	2763	2795	106	615	316	220	235	9405
Percentage	**21.5%**	3.5%	29.4%	29.7%	1.1%	6.5%	3.4%	2.3%	2.5%	100%
Total severe risks	**366**	56	40	130	6	56	9	20	15	698
Percentage	**52.4%**	8.0%	5.7%	18.6%	0.9%	8.0%	1.3%	2.9%	2.1%	100%

Prediction models

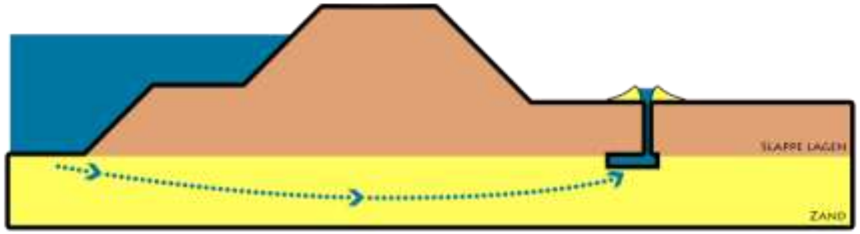


Sellmeijer model:

- Based on:
  - Groundwater flow
  - Flow through the pipe
  - Equilibrium of forces on grains
- Model implemented in 2D groundwater flow software
- Calculation rule for standard dike geometry



Sellmeijer's rule



$$\frac{H_c}{L} = \frac{1}{c} = F_R F_S F_G$$

$$F_R = \eta \frac{\gamma'_p}{\gamma_w} \tan\vartheta \left(\frac{RD}{RD_m}\right)^{0.35} \left(\frac{U}{U_m}\right)^{0.13} \left(\frac{KAS}{KAS_m}\right)^{-0.02}$$

$$F_S = \frac{d_{70}}{\sqrt[3]{\kappa L}} \left(\frac{d_{70m}}{d_{70}}\right)^{0.6}$$

$$F_G = 0.91 \left(\frac{D}{L}\right)^{\frac{0.28}{\left(\frac{D}{L}\right)^{2.8} - 1} + 0.04}$$

[Sellmeijer et al., 2011]

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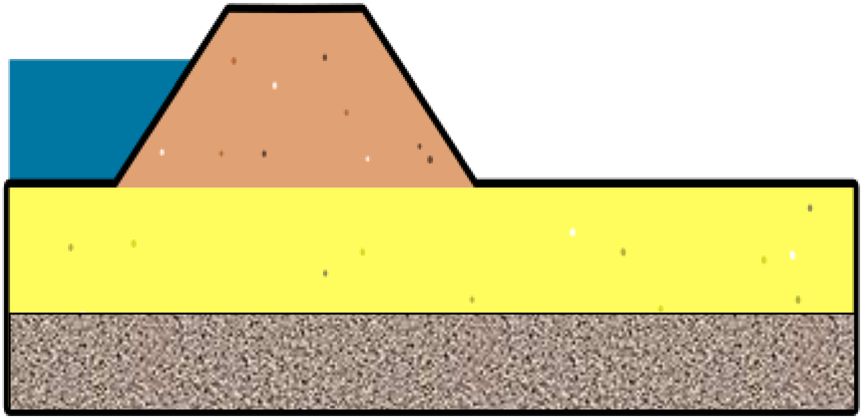
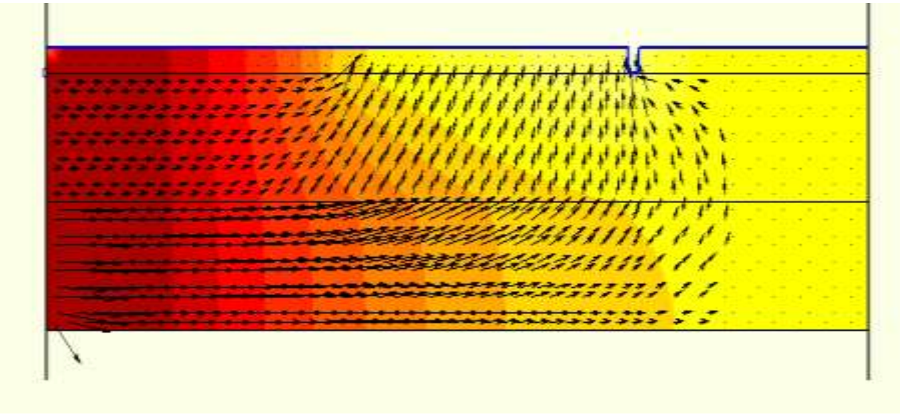
Objectives

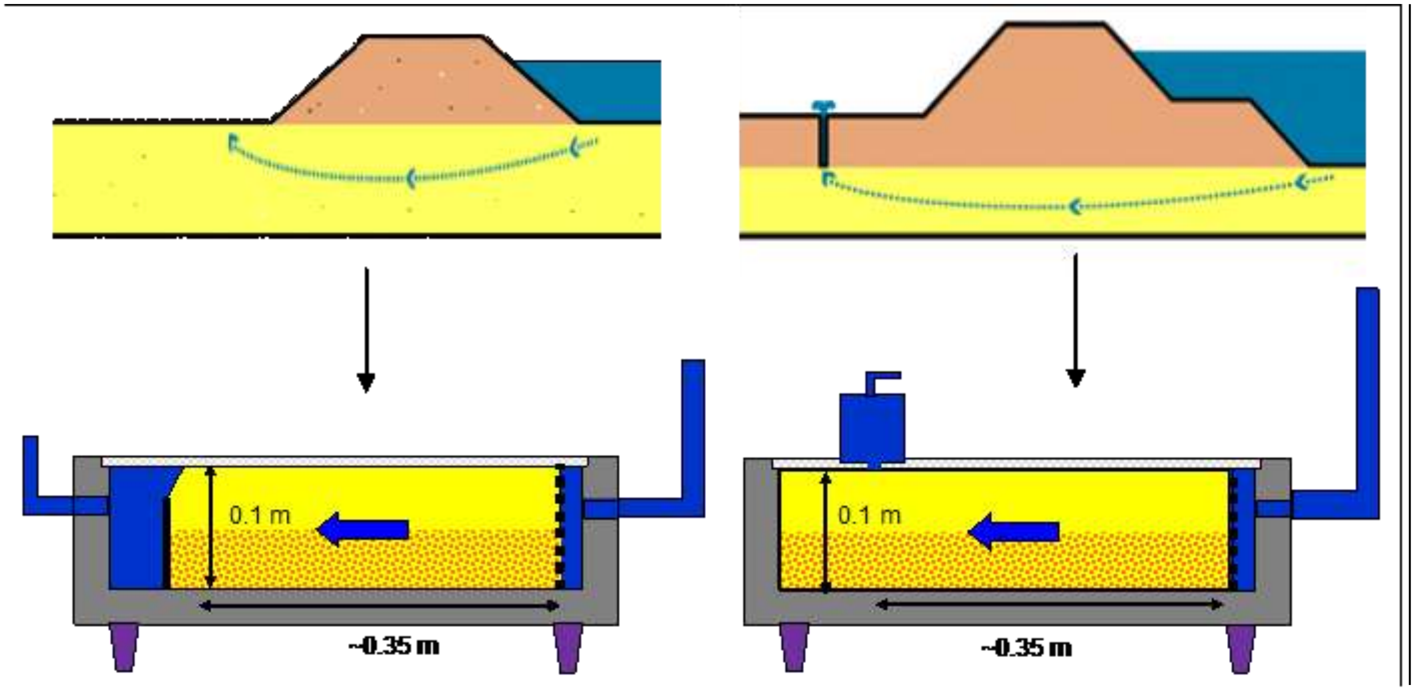
- Validation of Sellmeijer’s model for multi-layer configurations using experiments
- Adaptation of the calculation rule for for multi-layer configurations





Experimental work

- 2 Configurations – slope and hole configuration
- 3 ratios of fine layer thickness and coarse layer thickness



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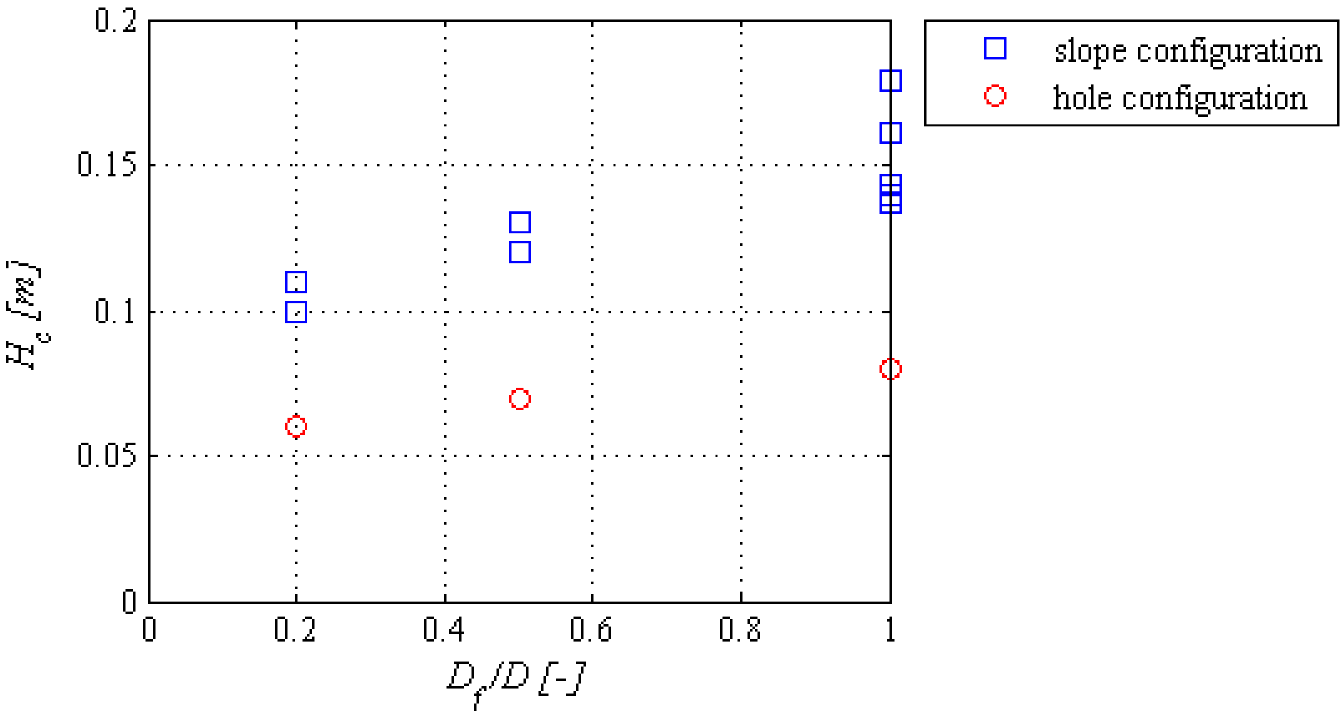
Experimental work

Increase of critical head for increasing ratio of fine layer thickness and total layer thickness



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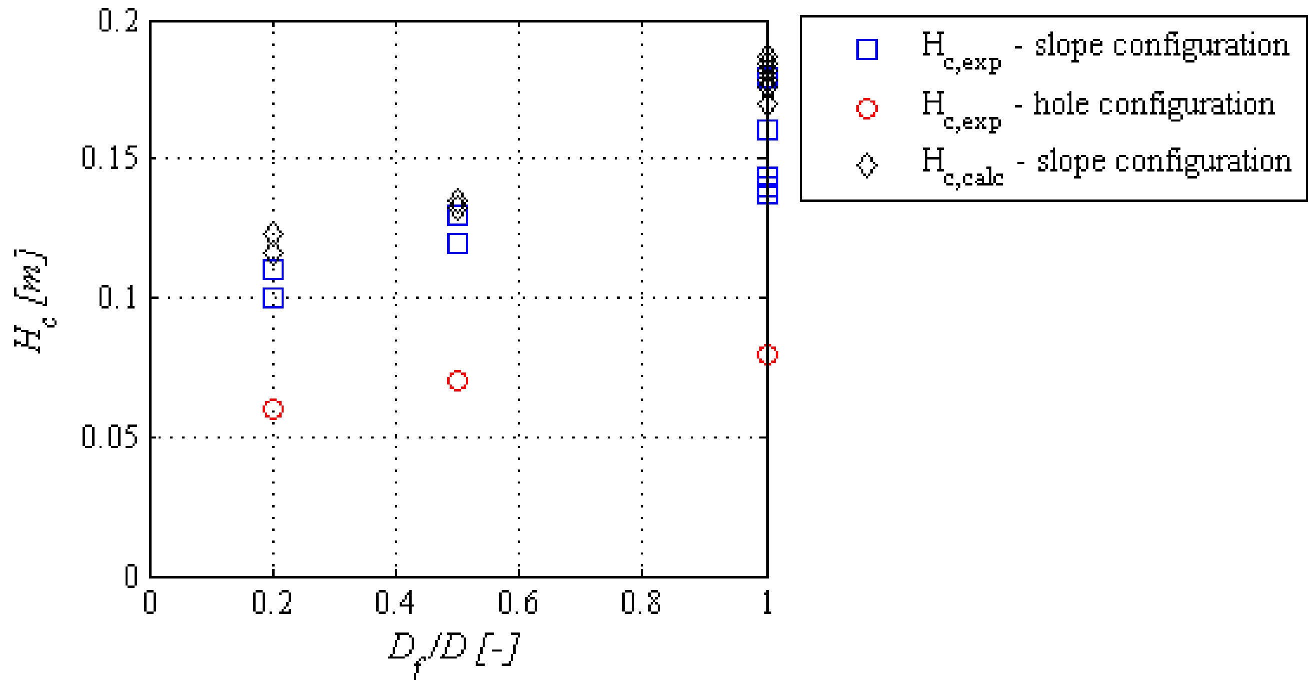
Numerical work

- Slope experiments have been simulated in 2D numerical model MSEEP
- Calculated critical heads are in fair agreement with measured critical heads



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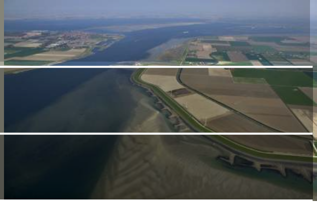
Adaptation of calculation rule

- According to the theory behind the Sellmeijer model, the onset of grain movement is largely determined by the flow towards the pipe.
- Due to the presence of a more permeable layer the flow towards the pipe is increased, resulting in a decrease of critical head.

$$k_{h,avg} = \sum_{i=1}^{n} \frac{k_{h,i} D_i}{D}$$

- The decrease in critical head as result of the presence of a permeable layer under the pipinglayer can therefore be calculated using:

$$F = \frac{H_{c,ml}}{H_{c,hom}} = \frac{\sqrt[3]{k_f}}{\sqrt[3]{k_{h,avg}}} = \sqrt[3]{\frac{k_f}{k_{h,avg}}}$$

Adaptation of the calculation rule

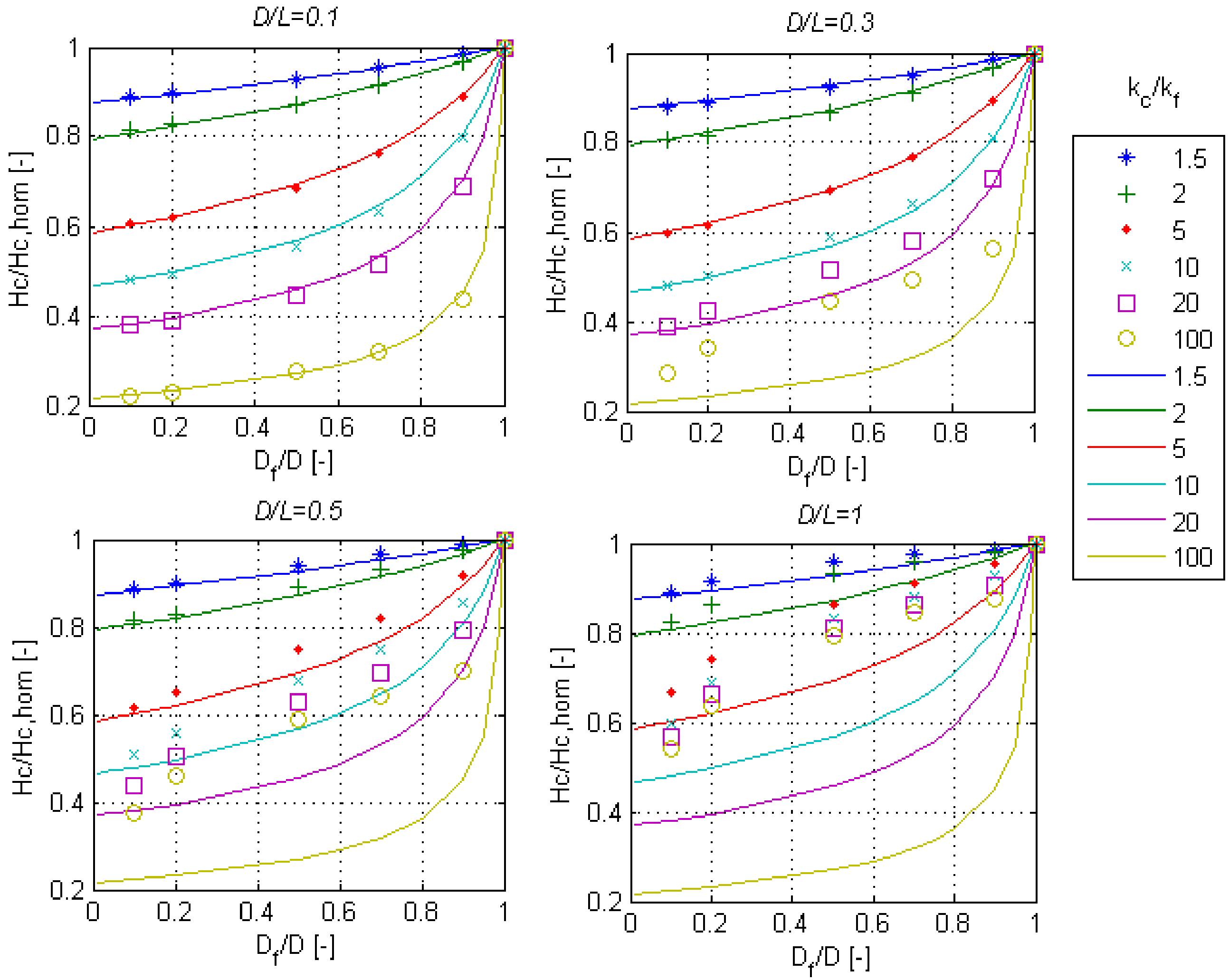
$$F = \frac{H_{c,ml}}{H_{c,hom}} = \sqrt[3]{\frac{k_f}{k_{h,avg}}}$$

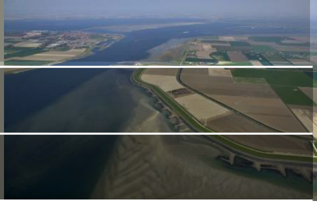
$$k_{h,avg} = \sum_{i=1}^{n} \frac{k_{h,i} D_i}{D}$$

for two layers

$$F = \sqrt[3]{\frac{k_f}{k_{h,avg}}} = \left(\frac{D_f}{D} + \frac{k_c}{k_f} \left(1 - \frac{D_f}{D} \right) \right)^{-\frac{1}{3}}$$

Comparison numerical model and adapted rule





Conclusions

- Small-scale experiments with an open outflow area show that the experimentally obtained critical heads agree well with the calculated critical heads in MSEEP.
- The critical head, obtained in small-scale experiments with a circular exit point in the cover could not be predicted by the 2D numerical program. More research is recommended for safe dike assessment in case of such 3D flow to a local hole.
- Sellmeijer’s rule has been extended for multi-layer aquifers. Calculations with MSEEP show, that for elongated aquifers (D/L<0.3) with low permeability contrasts (kc/kf<10), the adapted Sellmeijer’s rule can be applied to calculate the critical head properly for 2D-situations.

Ongoing research – New full-scale experiments

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