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Incorporating subsurface heterogeneity in hydrological models for assessing dike stability

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Introduction

In addition to external dike failure mechanisms related to increased loads, internal triggering conditions (e.g. slumping) are related to reduced resistance and within- and sub-dike pore pressure changes. Pore pressures are strongly related to both dike and subsurface heterogeneity, as the groundwater flow paths and velocities are induced by the spatial variability in permeability. There are three ways in which groundwater flow increases dike failure probability:

(1) Direct seepage into the dike core decreases cohesion.

(2) Groundwater intrusion in the river channel or on the floodplain may increase pore pressures at the dike base and cause seepage into the dike core.

(3) Groundwater flow underneath the dike core is strongly related to indirect failure mechanisms as piping.

The probability of higher pore pressures under climate change is thus a combination of high water levels and the local dike and subsurface heterogeneity. To compare all these effects, a combined hydrological-stability model is created, which over time will be expanded into a helpful tool for indicating most relevant dike failure mechanisms on a sub-dikestretch scale.

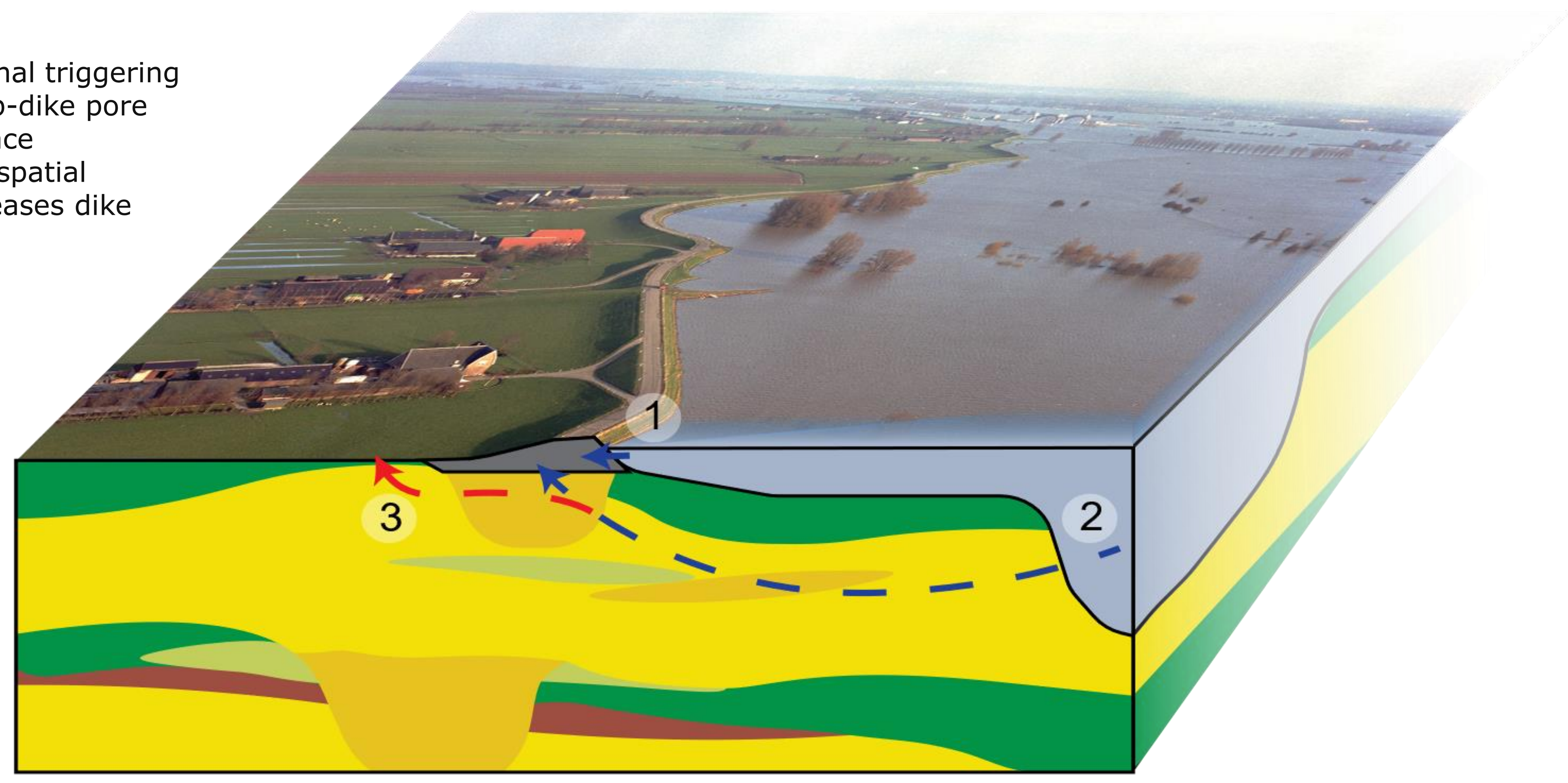
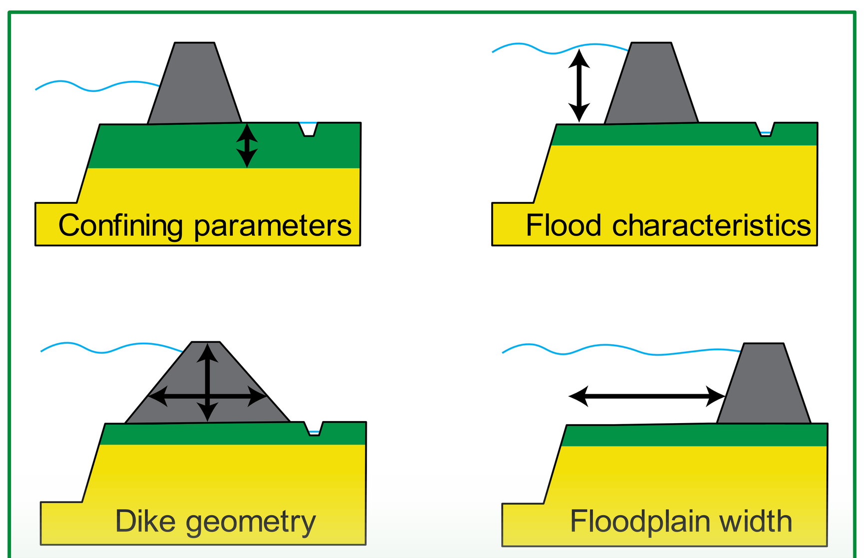
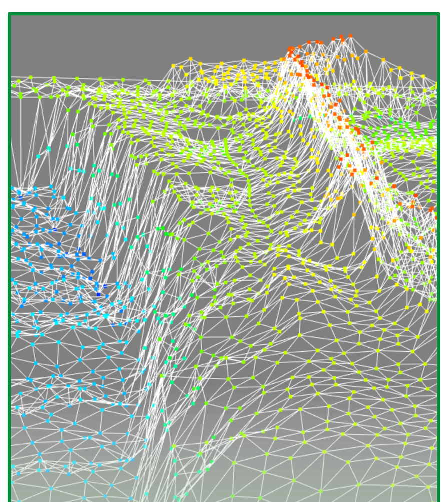


Figure 1; Indication of groundwater flow paths during high water levels related to dike stability. Blue flow paths can cause direct dike instability due to pore pressure increase, the red path poses an indirect threat as it is linked to piping and heave.

Research layout and aims

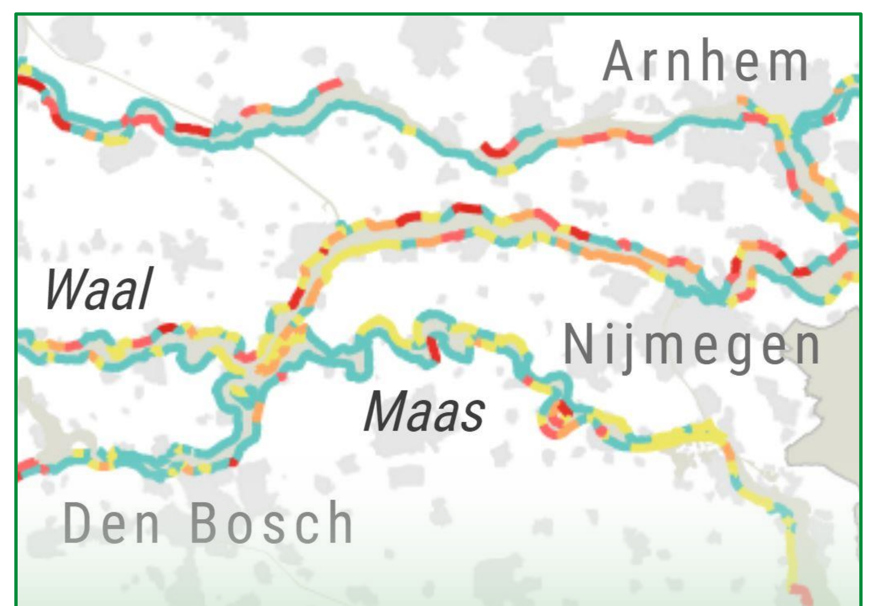


2D sensitivity
- Simple heterogeneity, variable geometry
- Relating stability Factor of Safety to modelled pore pressures
- Aim: Find degree of susceptibility of dike stability to parameters



2D-3D comparison
- Analyzing the effect of 3D subsurface variability on pore pressures
- Aim: Defining importance of 3D effects

Hydromechanic feedbacks
- Piping and liquefaction are nonlinear processes
- Aim: Define starting conditions and importance of feedback loops



Combine susceptibilities into tool
- Include high water scenario probabilities
- Aim: Indicate high-risk dike stretches and determine most relevant failure mechanisms as tool for more specific dike reinforcements

Current research

The current 2D sensitivity model is capable of calculating within-dike and sub-dike pore pressure changes under transient conditions and given (sub)surface characteristics, see above:

- Subsurface geometry (confining layer thickness, conductivity)
- Flood characteristics (height, duration, flood wave shape)
- Dike geometry (width, slope, height)
- Supporting parameters (floodplain width, drainage)

Similarly, an approximation of the dike probability to slumping and lateral displacement is be made using a deterministic threshold of the critical pore pressure from the static equilibrium analysis.

Preliminary results

An example of variability in dike and subsurface geometry (Figure 2) already indicates the importance of heterogeneity in dike stability assessment. Most important to notice is:

- Dike stability decreases if sub-dike pore pressure increases
- Dike base width and confining layer conductivity are important parameters
- Dike stability for slumping does in some cases temporarily increase during higher water levels

Future investigations will focus on finding further relations between subsurface heterogeneity, pore pressure evolution and dike stability, before applying these insights to real-world scenarios.

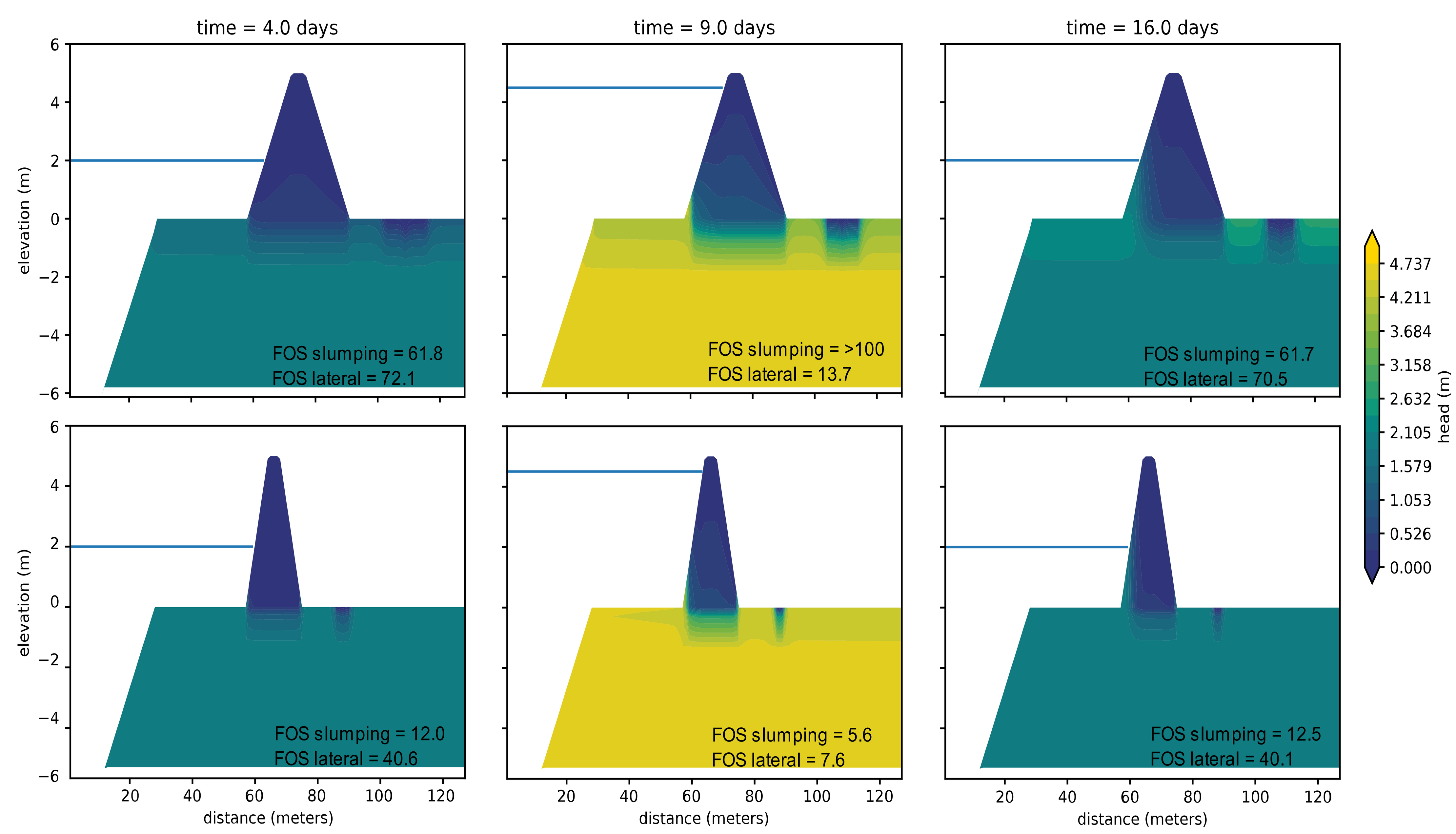


Figure 2; First results; Differences in dike stability as a result changes in (sub)surface geometries and a 20 day flood wave with a maximum elevation of 5 m. The input variables are shown below. Dike stability generally decreases with higher water levels, but this is not always the case (Case 1).

	Dike height (m)	Dike slope (°)	Dike width (m)	Confining layer thickness (m)	Confining layer conduct. (m d^{-1})
Case 1	5	20	32.5	0.8	10^{-5}
Case 2	5	35	17.3	0.3	10^{-3}