



### Piping: mechanisme en gangbare oplossingen

Vera van Beek

3 mei 2016

### Dike breaches in the Netherlands



Wiel van Bassa (source: google maps)

3 mei 2016



### Dike breaches

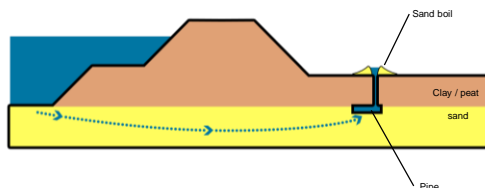


Illustratie Erik-Jan Bosch, Naturalis (<http://www.geologievannederland.nl/landschap/landschapsvormen/doorbraakgaten>)

3 mei 2016



### The failure mechanism 'backward erosion piping'



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### The failure mechanism 'backward erosion piping'



Photo: Beeldbank Rijkswaterstaat

3 mei 2016



### The failure mechanism 'backward erosion piping'

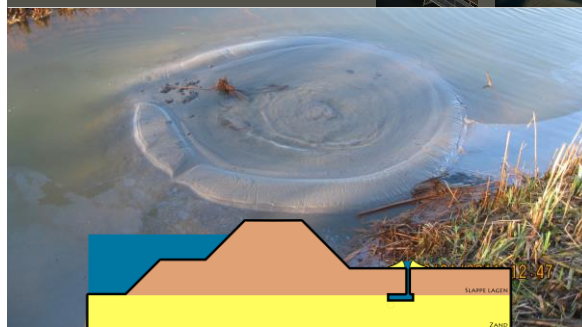


Photo: Beeldbank Rijkswaterstaat

3 mei 2016



The failure mechanism 'backward erosion piping'

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The failure mechanism 'backward erosion piping'

Pipe

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The failure mechanism 'backward erosion piping'

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Backward erosion piping internationally

US NL US China

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Safety assessment: the Sellmeijer model

DIKE  
PIPE  
GRAIN EQUILIBRIUM  
SAND GRAINS  
GROUNDWATER FLOW

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Safety assessment: the Sellmeijer model

1. Darcy flow  
2. Viscous flow through the pipe  $\rightarrow H_{eq}$   
3. Equilibrium of grains

head drop  $H$

$H_{eq}$

Pipe length [m]

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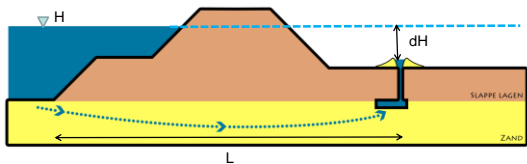
### Safety assessment: the Sellmeijer model

1. Darcy flow
2. Viscous flow through the pipe  $\rightarrow \frac{H_c}{L} = F_k F_s F_G$
3. Equilibrium of grains

$$F_k = \frac{g_s^2}{g_w} \tan \varphi$$

$$F_s = \frac{d_{90}}{\sqrt{k} L}$$

$$F_G = 0.91 \left( \frac{D}{L} \right)^{\frac{0.28}{2} - 0.004}$$



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### Adjustment of the Sellmeijer model (2011)



Adjustment Sellmeijer rule:

$$\frac{H_c}{L} = \frac{1}{c} = F_k F_s F_G$$

$$F_k = \eta \frac{g_s^2}{\gamma_w} \tan \varphi$$

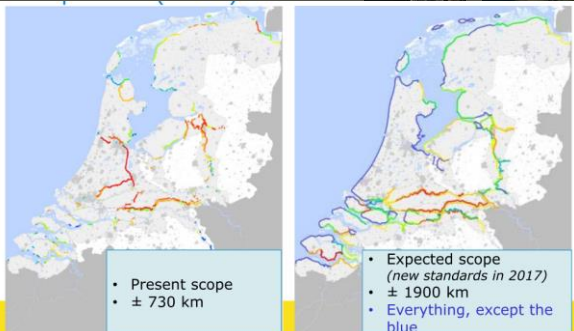
$$F_s = \frac{d_{90}}{\sqrt{k} L}$$

$$F_G = 0.91 \left( \frac{D}{L} \right)^{\frac{0.28}{2} - 0.004}$$

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### Scope (bron HWBP)



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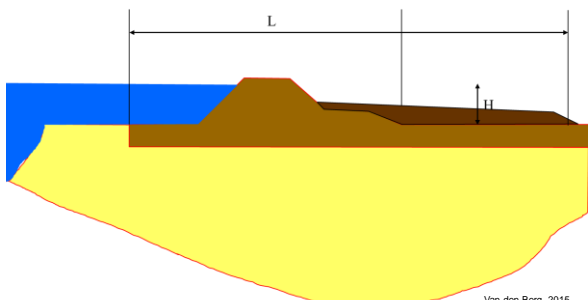
### Piping maatregelen

- Verlengen horizontale kwelweg
- Verlengen van de verticale kwelweg
- Verkleinen van het verval
- Voorkomen van uitspoelen van zand:
- Innovatieve maatregelen

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### Horizontale verlenging



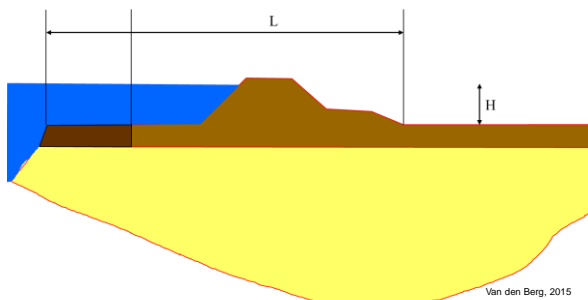
Van den Berg, 2015

Binnendijkse pipingberm

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### Horizontale verlenging

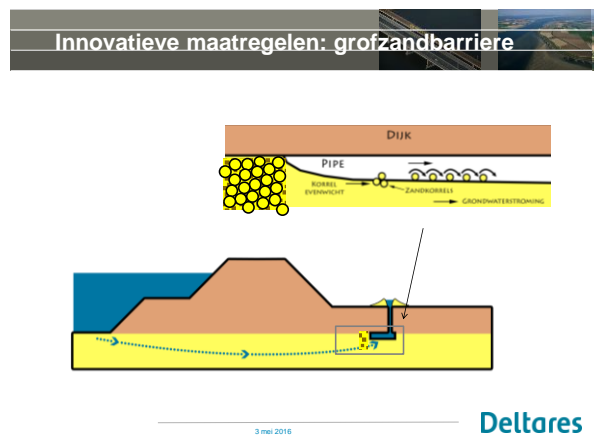
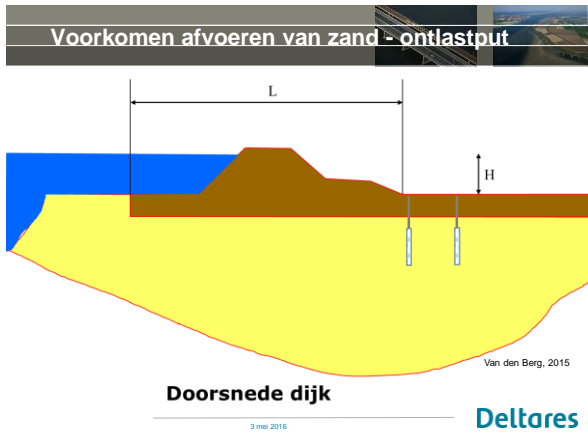
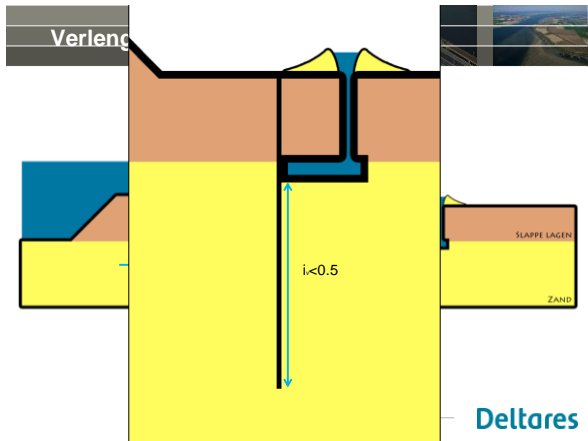


Van den Berg, 2015

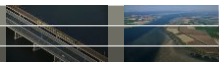
Klei ingraving voorland

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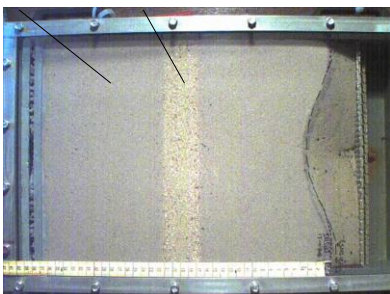


### Kleine-schaalproeven 2007



'fijn zand'

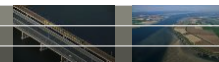
'Grof zand'



29 september 2015\_25

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### Meer oplossingen?



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