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Enabling Delta Life

Interface stability of granular filter structures under currents

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Granular filters

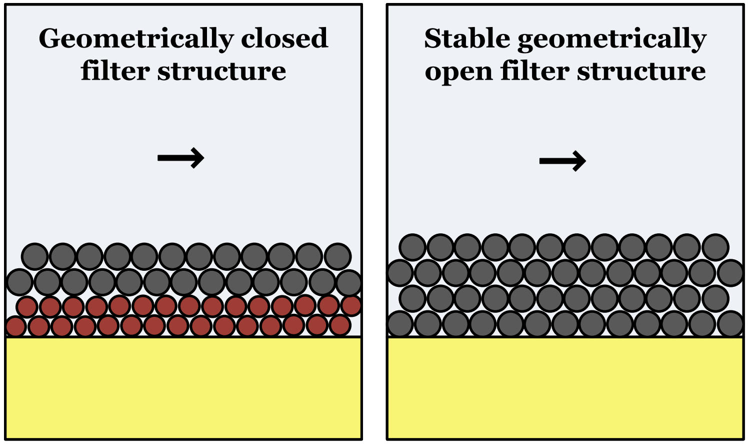
- Geometrically closed (sand-tight) filters

  $d_{f15} / d_{b85} < 4$
  (Terzaghi/Peck 1948)

- Stable Geometrically-open (sand-tight) filters

  1989 Wörman $$\frac{D_F}{d_{f15}} = 0.16 \frac{n_f}{1-n_f} \frac{d_{f85}}{d_{b85}} \frac{\Delta_f}{\Delta_b}$$

  1989 Klein-Breteler
  1994 Bakker-Konter



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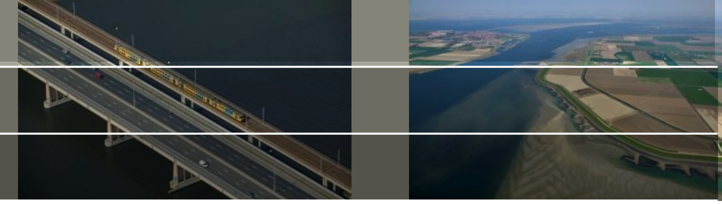
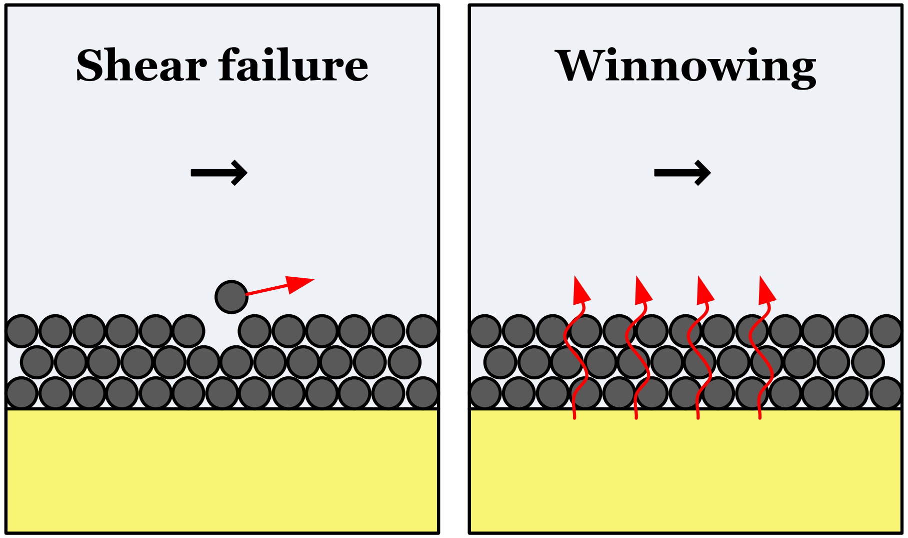
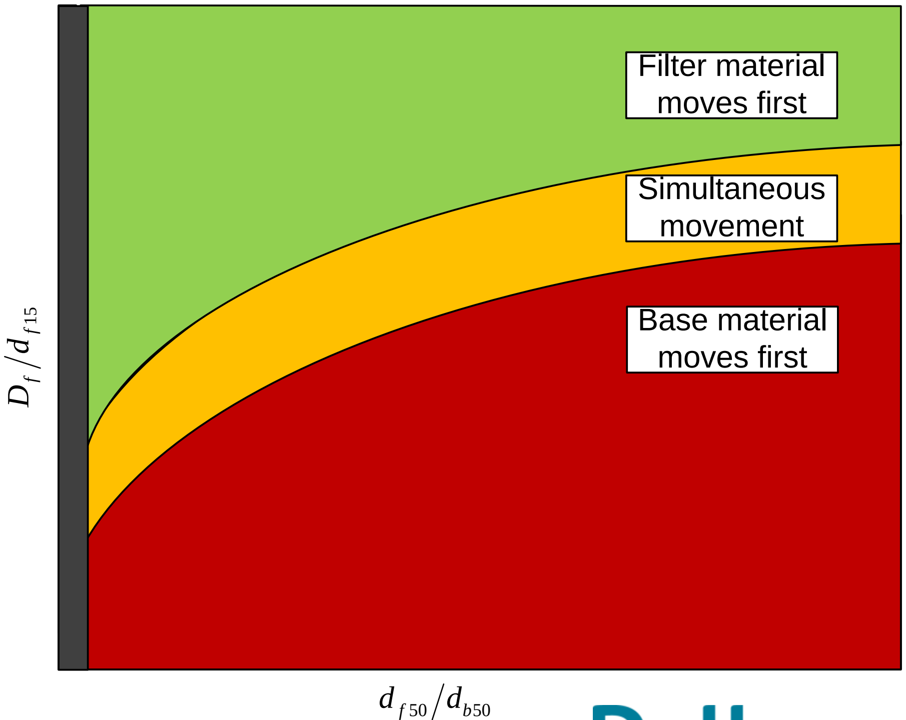
mechanisms



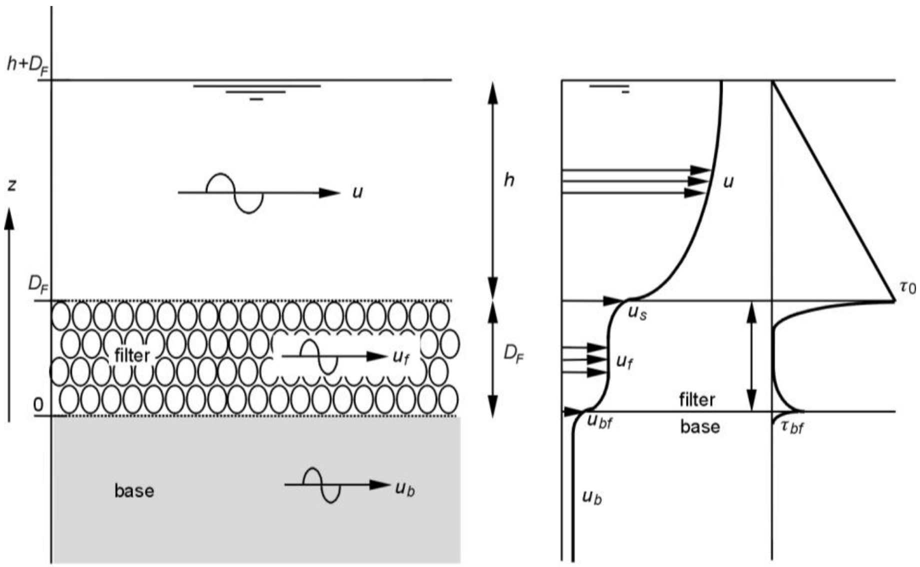


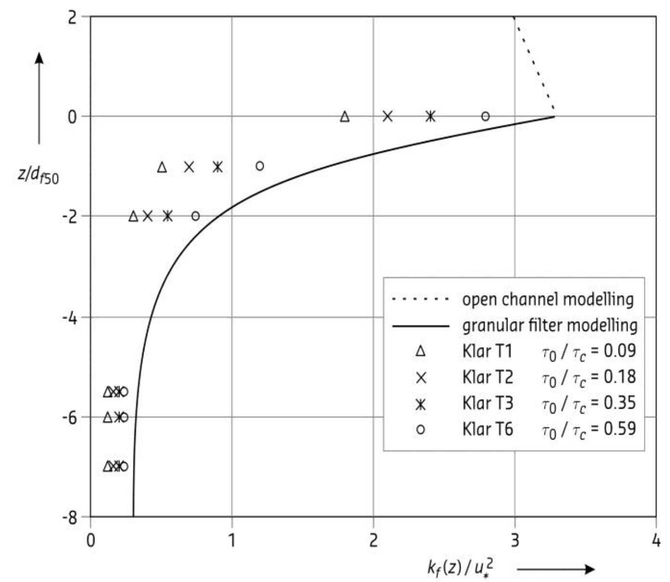
Shields (1936)

Principle idea behind the new formula



New formula





Hoffmans (2012)

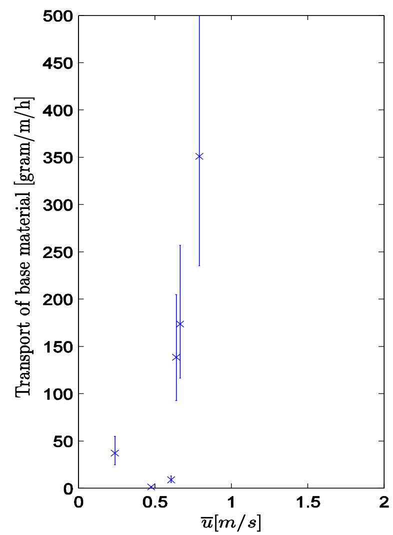
$$\frac{D_F}{d_{f15}} = \alpha_d \ln\left(\frac{d_{f50}}{d_{b50}} \frac{\Delta_f}{\Delta_b} \frac{\Psi_{c,f}}{\Psi_{c,b}} \frac{1-\gamma V_f}{1-\gamma V_b}\right)$$

$$\frac{D_f}{d_{f15}} = \alpha_d \ln\left(\frac{d_{f50}}{d_{b50}}\right)$$

$$\eta = \frac{k_f(z)}{k_b} \approx \exp\left(\frac{z}{L_d}\right)$$ (Klar, 2005)

Laboratory experiments

Test	d_{b50} base [µm]	d_{f50} filter [mm]	d_{f50} / d_{b50} [-]	D_F / d_{f15} [-]	Thickness D_F [mm]	remark
T-01	309	7.1	23.0	3.29	20	
T-02	309	21.3	68.9	1.44	27	
T-03	309	21.3	68.9	3.29	61.5	
T-04	633	21.3	33.6	1.44	27	
T-05	309	15.1	49.0	0.57	8	
T-06a	309	15.1	49.0	3.01	40	
T-06b	309	15.1	49.0	3.01	40	High turbulence due to sill
T-06c	309	15.1	49.0	3.01	40	High turbulence due to piers
T-07	309	15.1	49.0	4.13	57	



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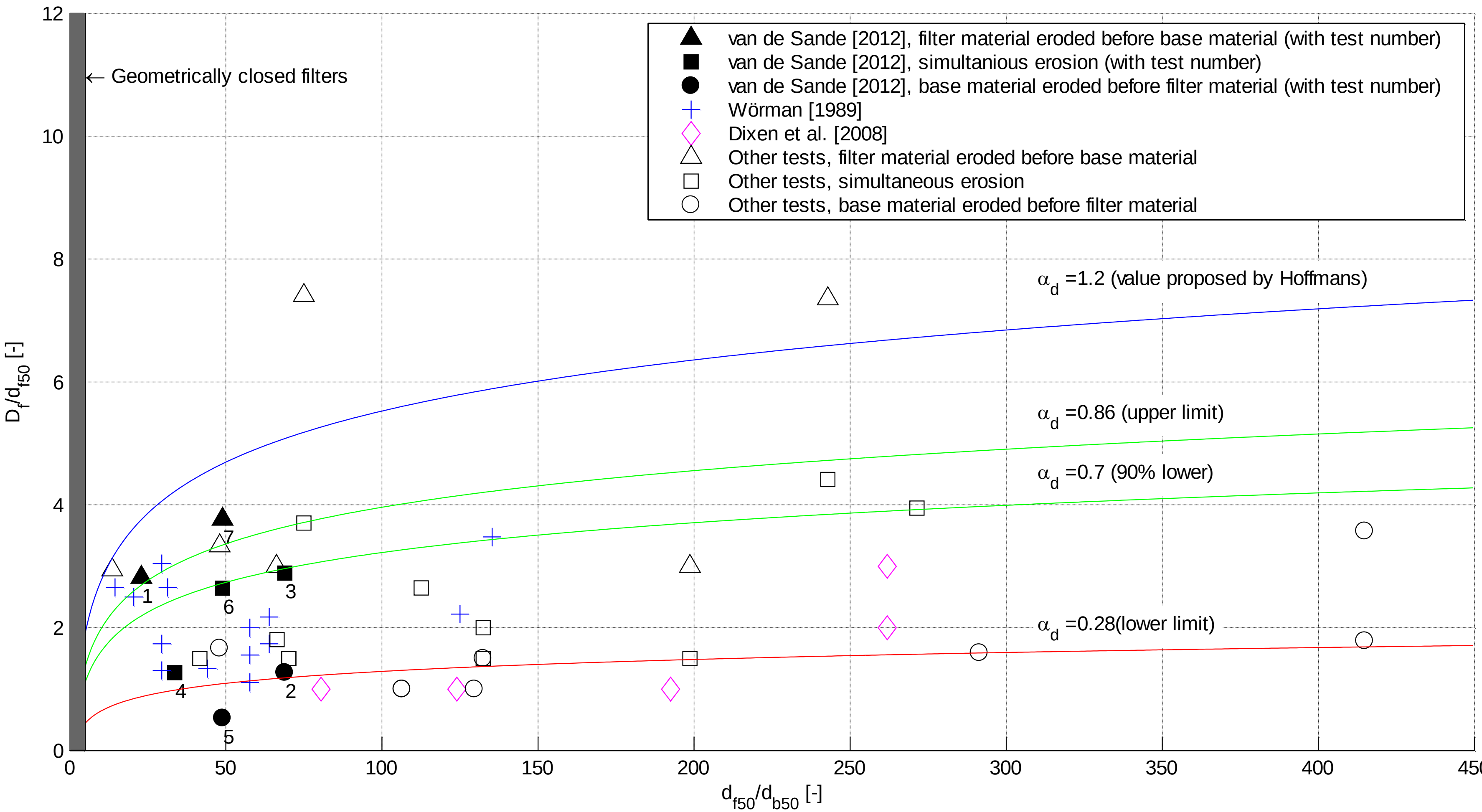
results



12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
450
D_f/d_{f50} [-]
d_{f50}/d_{b50} [-]
← Geometrically closed filters
van de Sande [2012], filter material eroded before base material (with test number)
van de Sande [2012], simultanious erosion (with test number)
van de Sande [2012], base material eroded before filter material (with test number)
Wörman [1989]
Dixen et al. [2008]
Other tests, filter material eroded before base material
Other tests, simultaneous erosion
Other tests, base material eroded before filter material
α_d =1.2 (value proposed by Hoffmans)
α_d =0.86 (upper limit)
α_d =0.7 (90% lower)
α_d =0.28(lower limit)
1
2
3
4
5
6
7

conclusions

1. The relative layer thickness fits better with d_{f50} than with d_{f15}

2. Simplified design equation: $$\frac{D_f}{d_{f15}} = \alpha_d \ln\left(\frac{d_{f50}}{d_{b50}}\right)$$

   - Deterministic approach;
     - **α_d** = 0.82 (safe upper limit)
     - **α_d** = 0.69 (90% confidence bound)

   - Probabilistic approach;
     - **$\mu(\alpha_d)$**= 0.47
     - **$\sigma(\alpha_d)$**= 0.04

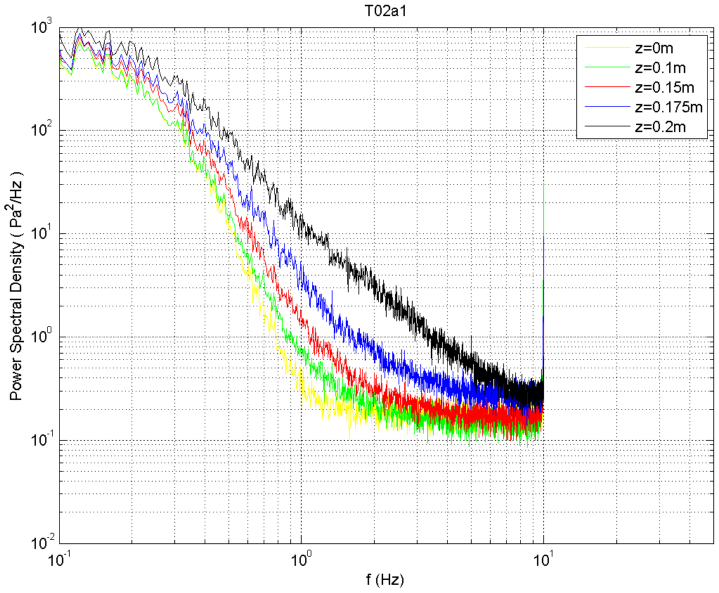
3. The alpha value proposed by Hoffmans [2012] is too high (α_d = 1.5)

recommendations

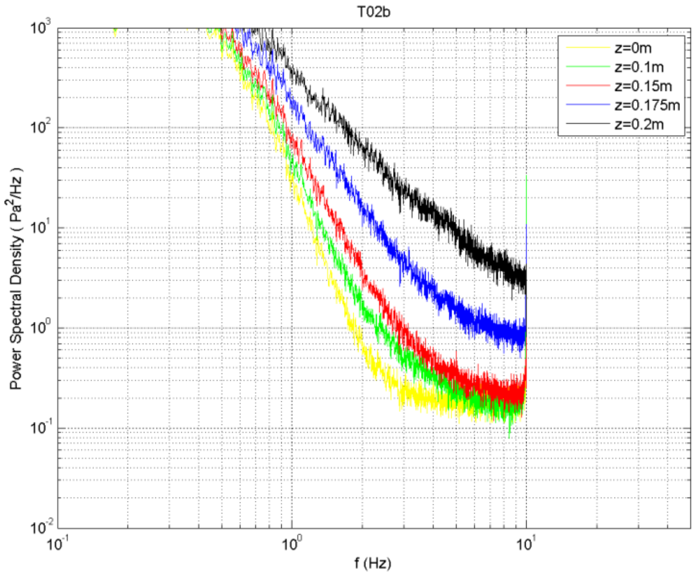
Extra tests:

- Damping in the filter
- Infuence of Turbulence on the α_d value

Large stones – no extra turbulence



Large stones – with extra turbulence



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Thank you for your attention

More information

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Granular filters

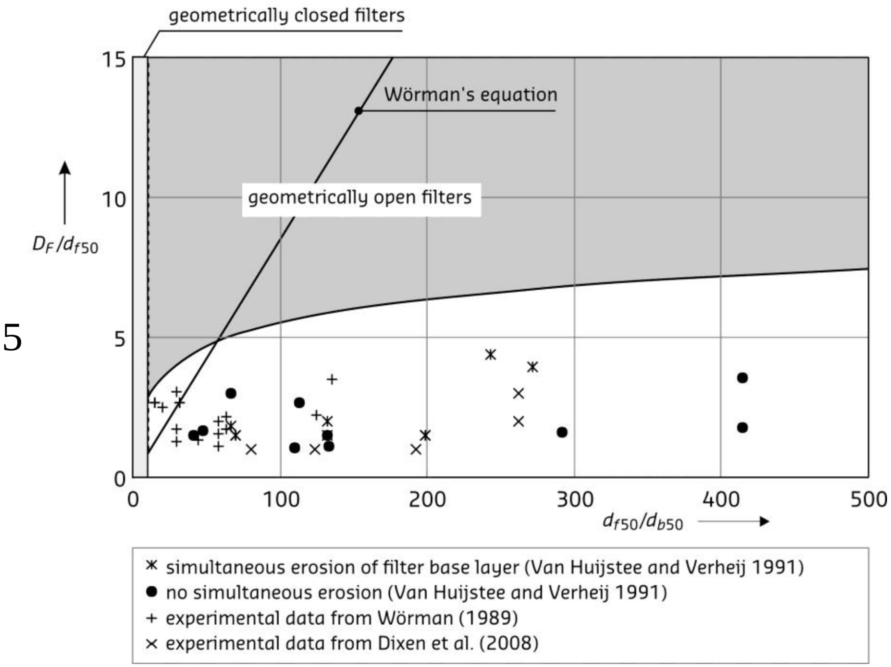
Relevant equations for designing geometrical open filters

1) Relative strength $$\eta_c = \frac{\tau_{c,bf}}{\tau_c} = \frac{\rho g d_{b50}}{\rho g d_{f50}} \frac{\Delta_b}{\Delta_f} \frac{\Psi_{c,b}}{\Psi_{c,f}}$$

2) Relative load $$\eta = \frac{k_f(z)}{k_b} \approx \exp\left(\frac{z}{L_d}\right)$$

3) Damping length $$L_d = \alpha_d d_{f15} \quad \text{with} \quad \alpha_d = 1.5$$

4) Critical phase $$\eta_c = \eta \quad \text{and} \quad z = -D_F$$



If $\Delta_f = \Delta_b, \Psi_{c,f} = \Psi_{c,b}$ and $d_{f50}/d_{f15} = 1.2$

and combining Eq's 1, 2, 3 and 4 then $$\frac{D_F}{d_{f50}} = 1.2 \ln\left(\frac{d_{f50}}{d_{b50}}\right)$$