Interface stability of granular filter structures under currents

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Granular filters

• Geometrically closed (sand-tight) filters

\[ \frac{d_{f15}}{d_{b85}} < 4 \]

(Terzaghi/Peck 1948)

• Stable Geometrically-open (sand-tight) filters

\[ \frac{D_F}{d_{f15}} = 0.16 \frac{n_f}{1-n_f} \frac{d_{f85}}{d_{b85}} \frac{\Delta_f}{\Delta_b} \]

1989 Wörman
1989 Klein-Breteler
1994 Bakker-Konter
Shear failure

Winnowing

Shields (1936)

Principle idea behind the new formula
Hoffmans (2012)

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

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

\[
\eta = \frac{k_f(z)}{k_b} \approx \exp \left( \frac{z}{L_d} \right) \quad \text{(Klar, 2005)}
\]
# Laboratory experiments

<table>
<thead>
<tr>
<th>Test</th>
<th>(d_{50}) base [(\mu m)]</th>
<th>(d_{50}) filter [mm]</th>
<th>(d_{50} / d_{50}) [-]</th>
<th>(D_F / d_{15}) [-]</th>
<th>Thickness (D_F) [mm]</th>
<th>remark</th>
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<td>High turbulence due to sill</td>
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<td>High turbulence due to piers</td>
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<td>4.13</td>
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</table>

High turbulence due to sill

High turbulence due to piers
Geometrically closed filters

\[ \alpha_d = 1.2 \text{ (value proposed by Hoffmans)} \]

\[ \alpha_d = 0.86 \text{ (upper limit)} \]

\[ \alpha_d = 0.7 \text{ (90% lower)} \]

\[ \alpha_d = 0.28 \text{ (lower limit)} \]
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;
     • $\alpha_d = 0.82$ (safe upper limit)
     • $\alpha_d = 0.69$ (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 ($\alpha_d = 1.5$)
recommendations

Extra tests:

- Damping in the filter
- Influence of Turbulence on the $\alpha_d$ value

Large stones – no extra turbulence

Large stones – with extra turbulence
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 \[ \Delta_f = \Delta_b, \quad \Psi_{c,f} = \Psi_{c,b} \quad \text{and} \quad d_{f50} / d_{f15} = 1.2 \]

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