Falling aprons at circular piers under currents

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Introduction

- Scour is a critical threat to infrastructure (bridge piers, monopiles)

- Well-designed scour protection can provide protection against all failure mechanisms (e.g. Chiew, 1999, 2004)
  > shear failure
  > winnowing failure
  > edge failure
  > bed-form induced failure
  > bed degradation failure

- No guidelines to account for bed lowering at pile
Research objectives

- Investigate behaviour of falling aprons at circular piers under currents

- Develop a guideline to quantify the stone volume required to account for a given bed level degradation
Set-up of physical model experiments

- Physical model tests in Atlantic Basin at Deltares
- Two transparent model piers with various scour protection layouts in sandy test section ($d_{50} = 0.16\text{mm}$)
- Bed degradation represented by eroding sill
- Monitoring by internal & external camera’s
- Stereo photography for 3D bathymetry
The test program consists of 7 tests with 2 models each, using the L03 reference layout.

<table>
<thead>
<tr>
<th>Test</th>
<th>Layout name</th>
<th>Extent $b_{f,0}$ [-]</th>
<th>Thickness $D_{f,0}$ [mm]</th>
<th>Sill height $h_{bd}$ [mm]</th>
<th>Water depth $h_w$ [m]</th>
<th>D.a. current velocity $u_c$ [m/s]</th>
<th>Duration T [hr]</th>
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Test results

- Filling the basin

- Reference case: extent of 4D with sill height of 0.5D
Test results

- Effects of sill height, extent and layer thickness

- Reference
- Reduced extent
- Larger sill height
- Lower thickness
Development in time

- Largest development within first 3h.
- Hereafter, gradual erosion at upstream and downstream side

after 3h  after 6h  after 12h
Analysis

- Consistent behaviour in tests:
  - layer thickness gradually decreases towards outside
  - similar slope angles (1:2 outer slope; 1:2.5 inner slope)
  - no scour occurred where an extent of 3D was maintained

- Behaviour can be schematized with volume balance
• Design formula for falling apron

\[
r_{f,0} = \frac{\pi}{6} \left( L_2 - r_{f,A} \right) - \frac{\pi}{3} \tan \gamma \left( L_2 - d_{t,50} \right)^3 - \left( L_2 - d_{t,50} - \frac{h_{bd}}{\tan \gamma} \right)^3 \pi D_{f,0}
\]

Or simplified: \( r_{f,0} - r_{f,A} = 1.4 \times h_{bd} \)

• Validation
Conclusions

- Falling apron process at pier
  > starts upon being undermined
  > initial stone redistribution by rolling, later sliding and sinking
  > protective mound formed (with external slopes of 1:2)

- Scour prevented for tests in which extent of 3D was maintained

- Bed degradation can be accounted for by designing a falling apron

- Design rule derived to estimate stone volume needed for falling apron at pile

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