Developments in Scour and Erosion

1. More than 10 years ICSE conferences
2. Influence of Turbulence on Soil Erosion
3. Road to 2020

Henk Verheij & Gijs Hoffmans (Deltares)
August 29, 2012
More than 10 years ICSE conferences

(2000) Melbourne
2002 College Station
2004 Singapore
2006 Amsterdam
2008 Tokyo
2010 San Francisco
2012 Paris

RESULT:
an overwhelming number of papers and:
- new formulas
- new monitoring methods
- results of field tests and lab experiments

In addition, synthesised knowledge in manuals, for example:

- Melville & Coleman
- Hoffmans & Verheij
- Whitehouse
- Sumer & Fredsoe
- Annandale
- HEC

Newton (1687)
Schoklitsch (1932)
Veronese (1937)
Jaeger (1939)
Eggenberger (1944)
Hartung (1957)
Franke (1960)
And so on
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Two situations

- Simple structure
- Simple conditions
- Formula

- Complex structure
- Complex conditions
- Physical modelling

Do we make sufficient progress?

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Examples of recent developments

Rock erosion: power of the bubble (Eric Bollaert)

Erodibility of materials: EFA method (Jean-Louis Briaud)
More than 10 years ICSE conferences

Examples of recent developments:

- Normal current plus wave conditions
- High scour depth
- Stiff clay
- Mud
- Sandy mud
- Muddy sand
- Sand
- Gravel
- Pebbles
- Cobbles

Conceptual model of the relative scour depth for different sediments in the marine environment.

Initiation / scour of bed materials:
(Sumer & Fredsoe, Whitehouse, Briaud, Shields)

Range of scour protection materials:
- Decreasing mobility or erodibility
- Increasing time for scouring

Liquefaction risk

Examples of recent developments:
Initiation / scour of bed materials:
(Sumer & Fredsoe, Whitehouse, Briaud, Shields)

Critical velocity, $V_c$ (m/s):

- $V_c = 0.03 (D_{50})^{-1}$
- $V_c = 0.1 (D_{50})^{-2.2}$
- $V_c = 0.35 (D_{50})^{0.45}$

Mean grain size, $D_{50}$ (mm):

Joint spacing for jointed rock

1767 Brahms: Weight = Velocity

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So, major steps have been taken.

Now a new milestone:

Influence of turbulence on soil erosion
New developments

Influence of Turbulence on Soil Erosion

- *Stone stability*
- Granular filters
- Erodibility grass
- *Jet scour*
- Sill, bridge and abutment scour
Stone stability

Modern load parameters

RMS value of fluct. vel.     Flow velocity

Turbulence

\[ u_{RMS} \]

\[ U_0 \]

\[ \bar{u} \]

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Strength and load parameters:
- Strength is $f$(relative density, stone diameter, grading)
- Load is $f$(velocity, RMS-value of velocity and frequency)
Stone stability

Definition of turbulence energy

\[ k(z) = \frac{1}{2} \left( u_{\text{RMS}}^2(z) + v_{\text{RMS}}^2(z) + w_{\text{RMS}}^2(z) \right) \]

Depth-averaged value

\[ k_0 = \frac{1}{h} \int_0^h k(z) \, dz \]

Depth-averaged relative turbulence intensity

\[ r_0 = \frac{\sqrt{k_0}}{U_0} = 1.2 \frac{u_*}{U_0} = 1.2 \frac{\sqrt{g}}{C} \]

## Stone stability

### Indicative values of the depth-averaged relative turbulence intensity

<table>
<thead>
<tr>
<th>$r_0$</th>
<th>Turbulence intensity</th>
<th>Type of flow</th>
<th>Remarks</th>
<th>Hydraulic conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>no turbulence</td>
<td>laminar flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&gt; 0$</td>
<td></td>
<td>turbulent flow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&lt; 0.08$</td>
<td>minor turbulence</td>
<td>uniform flow</td>
<td></td>
<td>smooth</td>
</tr>
<tr>
<td>0.08–0.15</td>
<td>normal turbulence</td>
<td>uniform flow</td>
<td>channel/river flow</td>
<td>rough</td>
</tr>
<tr>
<td>0.15–0.20</td>
<td>high turbulence</td>
<td>uniform flow</td>
<td>channel/river flow</td>
<td></td>
</tr>
<tr>
<td>0.20–0.30</td>
<td>very high turbulence</td>
<td>uniform flow</td>
<td>steep channel with limited flow depth</td>
<td></td>
</tr>
<tr>
<td>0.30–0.60</td>
<td>extreme high turbulence</td>
<td>uniform flow</td>
<td>very steep channel with limited flow depth</td>
<td></td>
</tr>
<tr>
<td>0.15–0.20</td>
<td>high turbulence</td>
<td>non-uniform flow</td>
<td>downstream of hydraulic structures (sills, bridge piers, abutments)</td>
<td></td>
</tr>
<tr>
<td>0.20–0.30</td>
<td>very high turbulence</td>
<td>non-uniform flow</td>
<td>below hydraulic jumps, sharp outer bends, mixing layers (propeller)</td>
<td></td>
</tr>
</tbody>
</table>
Stone stability

Uniform flow

\[ \Psi_c = \frac{U_0^2}{\Delta d C^2} \]

with

\[ r_0 = 1.2 \sqrt{\frac{g}{C}} \]

\[ \Psi_c = \frac{\text{Load}}{\text{Strength}} = 0.7 \left( \frac{r_0 U_0}{\Delta g d} \right)^2 \]

Load - Strength diagram/depth-averaged approach

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Stone stability

Non-uniform flow conditions

\[ \Delta d = 0.7 \frac{(r_0 U_0)^2}{g \Psi_c} \]

experiments of Uwland (1982) are used for validation

\[ r_0(x) = \sqrt{0.0225 \left(1 - \frac{D}{h}\right)^{-2} \left(\frac{x - 6D}{6.67h} + 1\right)^{-1.08} + \left(1.2 \frac{u_*(x)}{U_0}\right)^2} \]

Jet scour

Scour parameters

Load
- Bed shear stress
- Turbulence

Strength
- Critical bed shear stress
- Grading or heterogeneity
Jet scour

Newton’s second law

$$\sum F = \frac{d(mu)}{dt}$$
Jet scour

In the equilibrium phase of the scour process the sum of forces on the fluid element equals zero

\[ z_{m,e} + h_t = \frac{\text{load}}{\text{strength}} = \frac{\sqrt{q U_1 \sin \theta / g}}{(c_{2v})^{-1}} \]

with \[ c_{2v} = \sqrt{\frac{\alpha \alpha_{b}^2}{\Psi c \Delta D_{90}^{2/3}} - (1 + \varepsilon \tan \Phi)} \]

For \[ d_{90} < 0.0125 \text{ m} \]
\[ c_{2v} = 20/(D_{90})^{1/3} \text{ similar to Schoklitsch (1932)} \]

For \[ d_{90} > 0.0125 \text{ m} \]
\[ c_{2v} \text{ is 2.9 similar to Veronese (1937)} \]

Closure problem to jet scour (2009) and Reply by Author (2011)
Journal of Hydraulic Research, 47(1) 100–109
Journal of Hydraulic Research, 49(2) 276–282
Jet scour

2D-H \[ z_{m,e} = c_{2H} \left( q \left( U_1 - U_2 \right) / g \right)^{\frac{1}{2}} \] with \[ c_{2H} = 20(D_{90*})^{-\frac{1}{2}} \]

3D-H \[ z_{m,e} = c_{3H} \left( Q \left( U_1 - U_2 \right) / g \right)^{\frac{1}{3}} \] with \[ c_{3H} = 7(D_{90*})^{-\frac{1}{3}} \]


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Road to 2020

Continuation:
more specific semi-empirical formulas,
field tests, et cetera

Or

Common steps to improve the scour and erosion issue
road to 2020

Goal:
• theoretically based formulas / approach for scour and erosion prediction
• numerical modelling → software available

Roadmap
2014 ICSE conference: state-of-the-art report
2015 – 2020 Joint Effort
2020 ISCE conference: presentation results

Coordination: TC 213

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Let us keep in mind:

Nature is simple, however we make complicated formulas because we do not understand it.

- **1767 Brahms:** Weight = Velocity^6
- **Einstein:** E = mc^2
- **2012 milestone:** roughness = f (turbulence)
Thank you for your attention

More information

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