EROSION THRESHOLD OF A WATER IMMERSED GRANULAR BED BY A NORMAL WATER JET

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EROSION BY JETS

U.S. Departement of Agriculture: Hanson et al.
- Use in Civil Engineering
- Jet erosion Test on soils

University of Alberta, Canada: Rajaratnam et al.
- Civil Engineering
- Many types of jets on grain beds

NASA: Metzger et al., Journal of Aerospace Engineering and Soft condensed matter, 2009
- Air jets on grain beds
- Lift-off/landing of rockets

Crater evolution as a function of time
EROSION BY VORTEX RINGS


Study of the critical conditions for particle resuspension and crater characteristics.
EXPERIMENTAL SETUP

- Jet = sheet of 4 mm thickness
- \(0,5 \leq l \leq 35\) cm
- Bi-dimensional setup: jet width \(\approx\) tank width

Measurement of the mean jet velocity \(V_j\) at erosion threshold, as a function of the distance \(l\)
EROSION THRESHOLD

- Increase of $V_j$ with $l$ at threshold
- Non-uniform evolution

Graph showing $V_{jc}$ vs. $l$ with $d=250\mu m$.
EROSION THRESHOLD

- Increase of $V_j$ with $l$ at threshold
- Non-uniform evolution
- Flow visualisation with dye

d=250μm
JET VISUALISATION AT THRESHOLD

Rectilinear laminar jet

\[ l = 3.4 \text{ cm} \]
\[ V_j = 0.056 \text{ m.s}^{-1} \]

Oscillating jet

\[ l = 5.6 \text{ cm} \]
\[ V_j = 0.070 \text{ m.s}^{-1} \]
JET VISUALISATION AT THRESHOLD

Mixed jet

\[ l = 13.5 \text{ cm} \]
\[ V_j = 0.134 \text{ m.s}^{-1} \]

Turbulent jet

\[ l = 25 \text{ cm} \]
\[ V_j = 0.261 \text{ m.s}^{-1} \]
Jet visualisation at threshold

Rectilinear laminar jet

Oscillating jet

Turbulent jet

Mixed jet

$$\text{Re}_j = \frac{V_j b}{\nu}$$

$$d = 250\mu m$$
Locked regime: the jet sees the confinement.

PMMH, ESPCI, Schlumberger in Paris:
Maurel et al., *Physical Review E*, 1996
JET VISUALISATION AT THRESHOLD

Maurel et al.,
*Physical Review E*, 1996

Free jet

\[ \text{Re}_j \]

\[ l/b \]

\[ d=250\mu m \]
JET VISUALISATION AT THRESHOLD

Rectilinear laminar jet

Maurel et al.,
Physical Review E, 1996

d=250µm
JET VISUALISATION AT THRESHOLD

Maurel et al.,
Physical Review E, 1996

Oscillating jet
JET VISUALISATION AT THRESHOLD

Maurel et al.,
*Physical Review E*, 1996

Mixed jet

$d=250\mu m$
JET VISUALISATION AT THRESHOLD

Maurel et al.,
*Physical Review E*, 1996

Turbulent jet

- $d=250\mu m$
EROSION PARAMETERS

3 parameters:
• $l/b$ for jet confinement
• $Re_j$ for jet hydrodynamics
• $Sh$ for sediment erosion

<table>
<thead>
<tr>
<th>$v$</th>
<th>$d = 250 , \mu m$</th>
<th>$d = 1 , mm$</th>
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<td>$1.10^{-6} , m^2 s^{-1}$</td>
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<td>$4.10^{-6} , m^2 s^{-1}$</td>
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Viscous Shields
$$Sh_v = \frac{\mu V_j}{\Delta \rho g d^2}$$

Inertial Shields
$$Sh_i = \frac{\rho V_j^2}{\Delta \rho g d}$$
INERTIAL REGIME

Threshold measurements at $l/b \approx 5$

Constant $Sh_i$ in the inertial regime $Re_p > 1$
CONCLUSIONS AND PERSPECTIVES

- Detailed study of erosion threshold

- Collaboration with **LHSV** lab (D. Nguyen, F. Levy, J-S. Finck et D. Pham-Van-Bang) on a [numerical model](#).

- Crater formation above threshold.
INERTIAL REGIME

\[
\text{Sh}_i = \frac{\rho V^2_j}{\Delta \rho g d}
\]

\[
\text{Re}_s = \frac{V_{sed} d}{v}
\]

\[
V_{sed} = \sqrt{\frac{3 \Delta \rho g d}{2 C_D \rho}}
\]

\[
C_D = \frac{24}{Re_p} \left(1 + 0.15 Re_p\right)^{0.687}
\]

\[
Re_p = \frac{V_j d}{v}
\]

Threshold measures at \(l/b \approx 5\)

Constant \(\text{Sh}_i\) in the inertial regime \(\text{Re}_p > 1\)
INFLUENCE OF CELL WIDTH

\[ d = 250\mu m \]