EMBANKMENT DAMS AND DIKES OVERTOPPING EROSION

State of the Art – Part 2
Hydro-Québec Research

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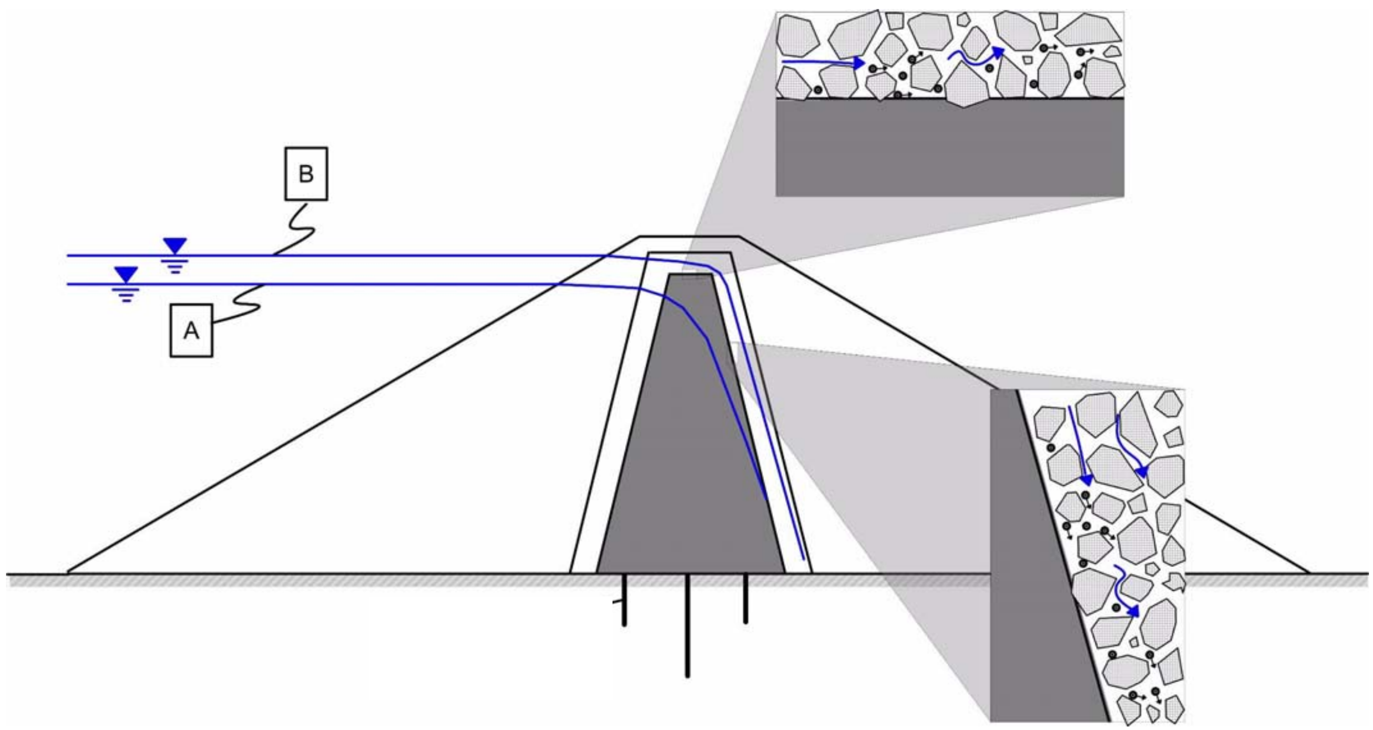
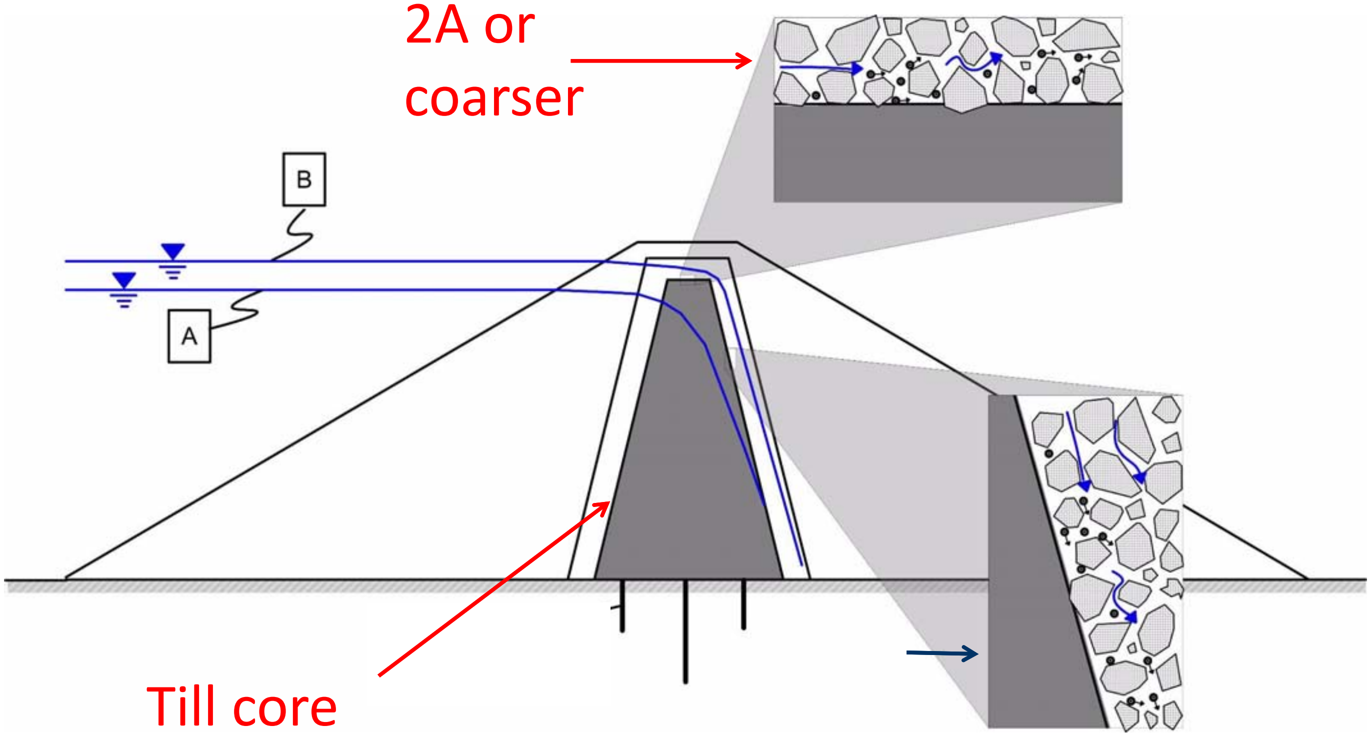
Introduction

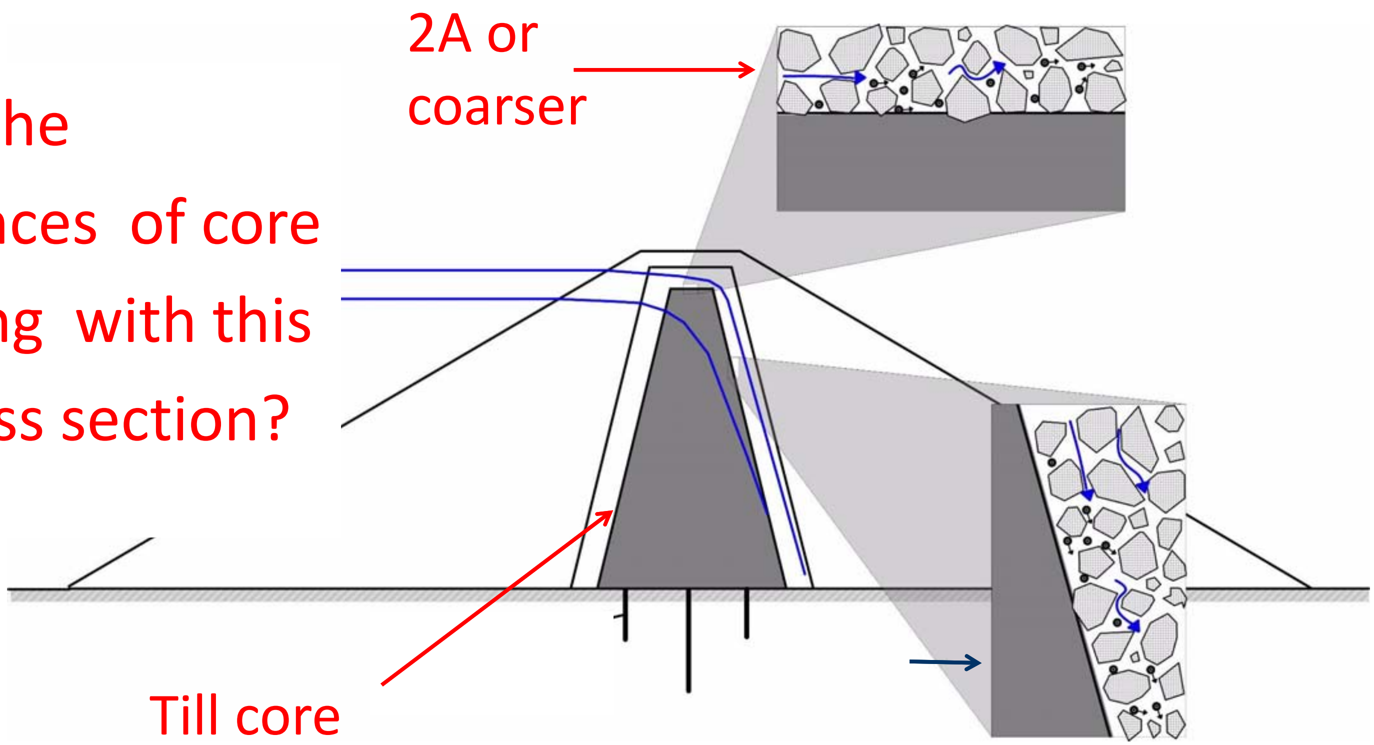


Introduction



Introduction

What are the consequences of core overtopping with this typical cross section?

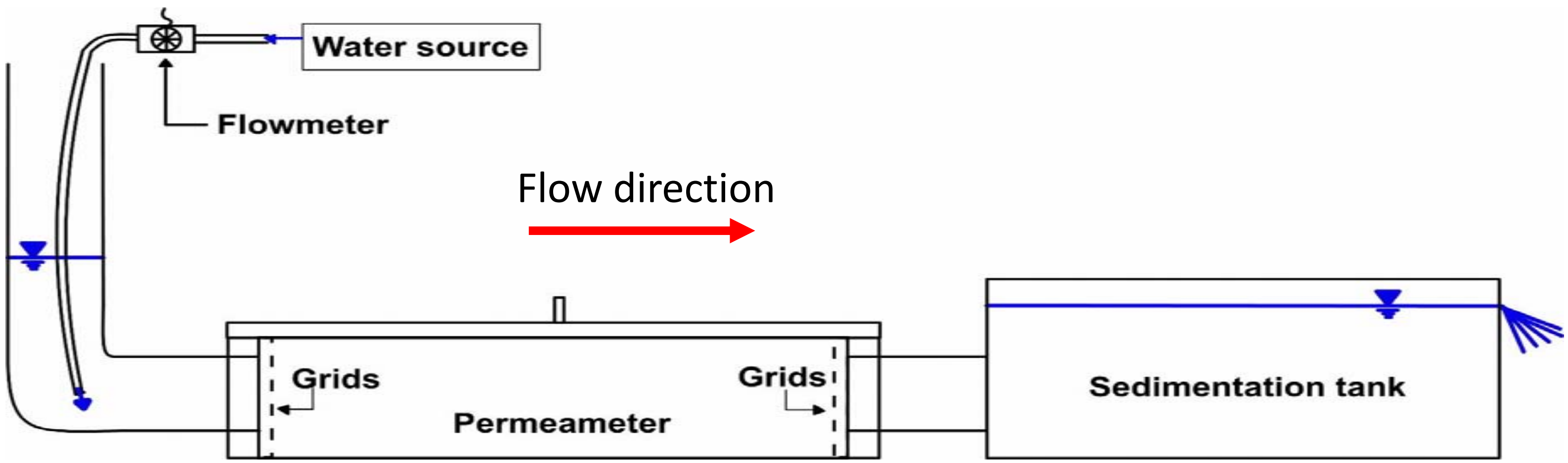


Research Needs

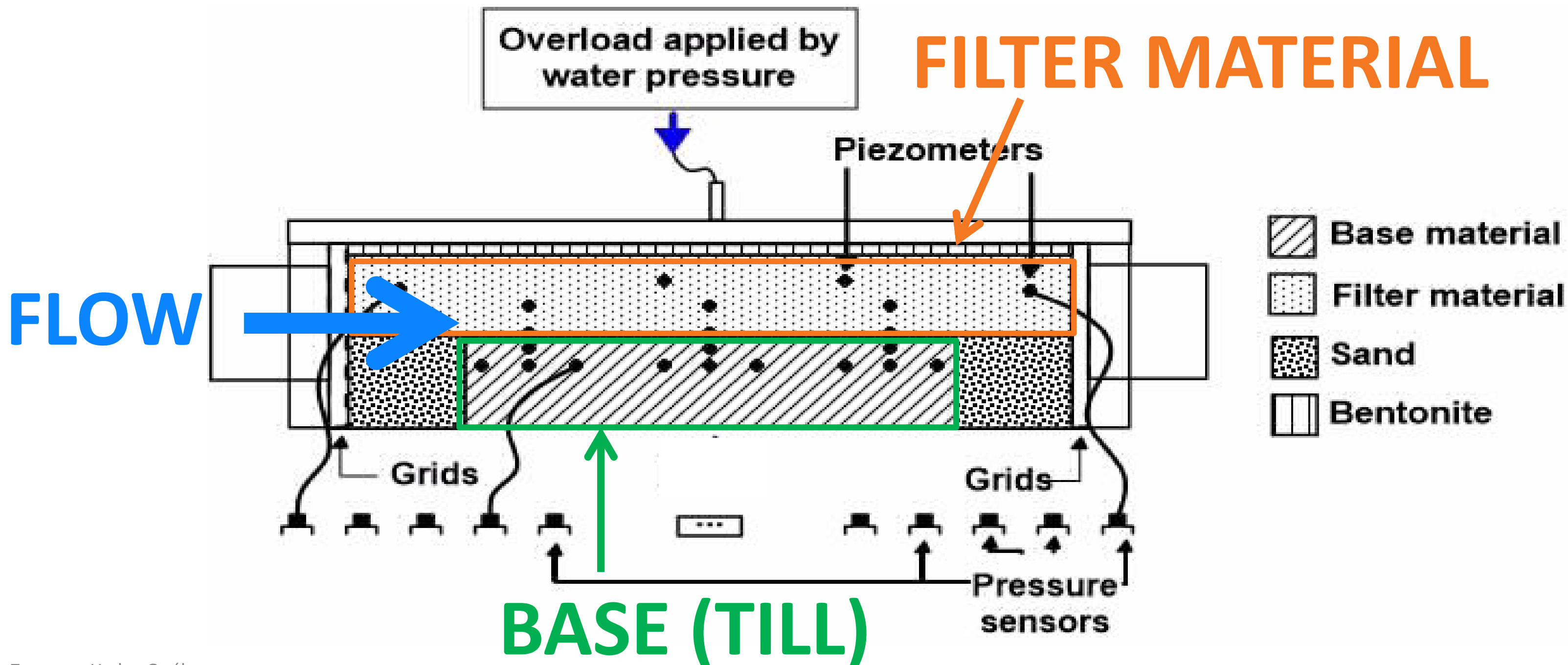
- Few research on contact erosion with well graded materials (till) base soil (mostly uniform base soils)
- Few lab experimental research representing our typical cross section
- How does the erosion progress for a real dam crest where hydraulic gradients, stresses, porosity, grain size distributions, etc. vary in time and space?
- Little information on the progression of erosion and few modelling tools

Project 1 – Characterize Influence of well graded base soil on the initiation and progression of contact erosion

Experimental Setup (Laval University)

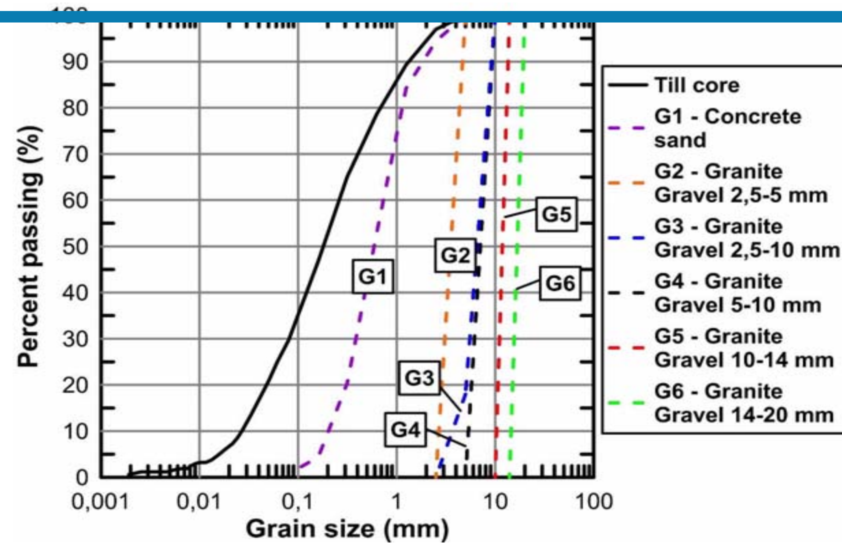


Project 1 –Influence of well graded base soil –
Experimental Setup



Project 1 –Influence of well graded base soil –
Experimental Program

1. Verification of the applicability of the modern design filter criteria if flow parallel to an interface (contact erosion)
2. Only G1 respect Sherard (1989) ratio DF15/DB85 lower than 2.1
3. Initiation and progression of contact erosion (tests G4 to G6)

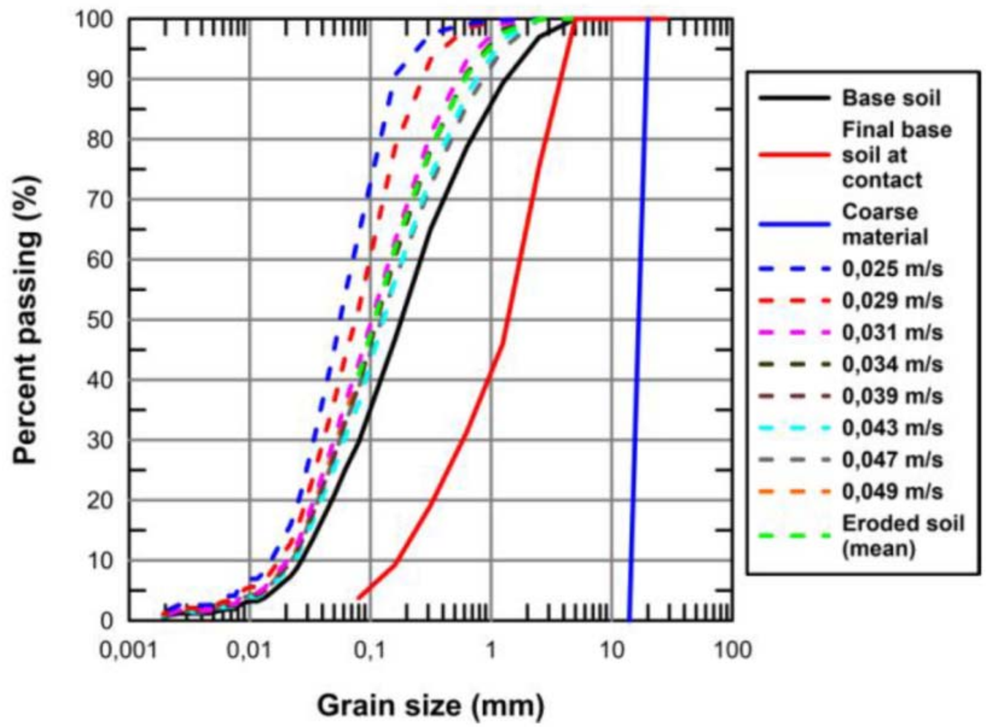


$6 \leq D_{15F} / d_{85B} \leq 17$
$C_{u\ Till} = 9,2$
$1 \leq C_{u\ filter} \leq 2$

	G1	G2	G3	G4	G5	G6
D_{F15} (mm)	0.27	2.8	4.5	5.6	10.5	14.8
D_{F50} (mm)	0.59	3.6	6.6	7.1	11.8	16.7
D_{F15}/d_{B85} (-)	0.3	3.2	5.1	6.4	11.9	16.8
C_u (-)	3.3	1.4	1.9	1.4	1.2	1.2

Project 1 –Influence of well graded base soil – Typical results

- When Filter velocity ↗ = eroded material coarser
- After test, base soil coarser at the contact of filter.
- But under the modified contact layer, the base soil did not show any change
- Each time v ↗ = transport rate initially ↗ steeply then ↘ with time



Project 1 –Influence of well graded base soil –
Paving and Clogging Occur

Initial contact

Project 1 –Influence of well graded base soil – Paving and Clogging Occur

Initial contact

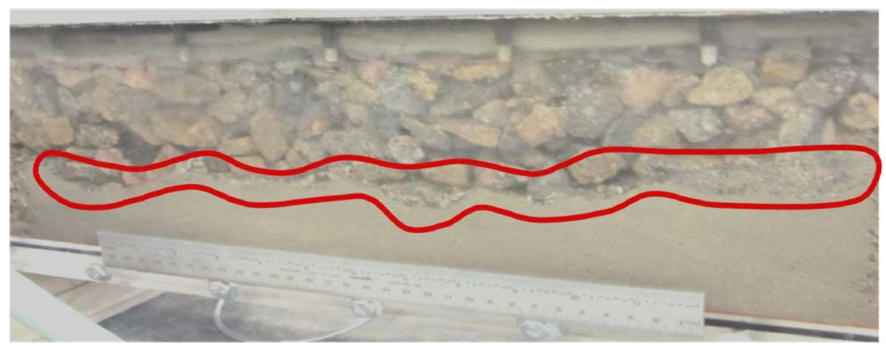
Final contact

11 Hydro-Québec

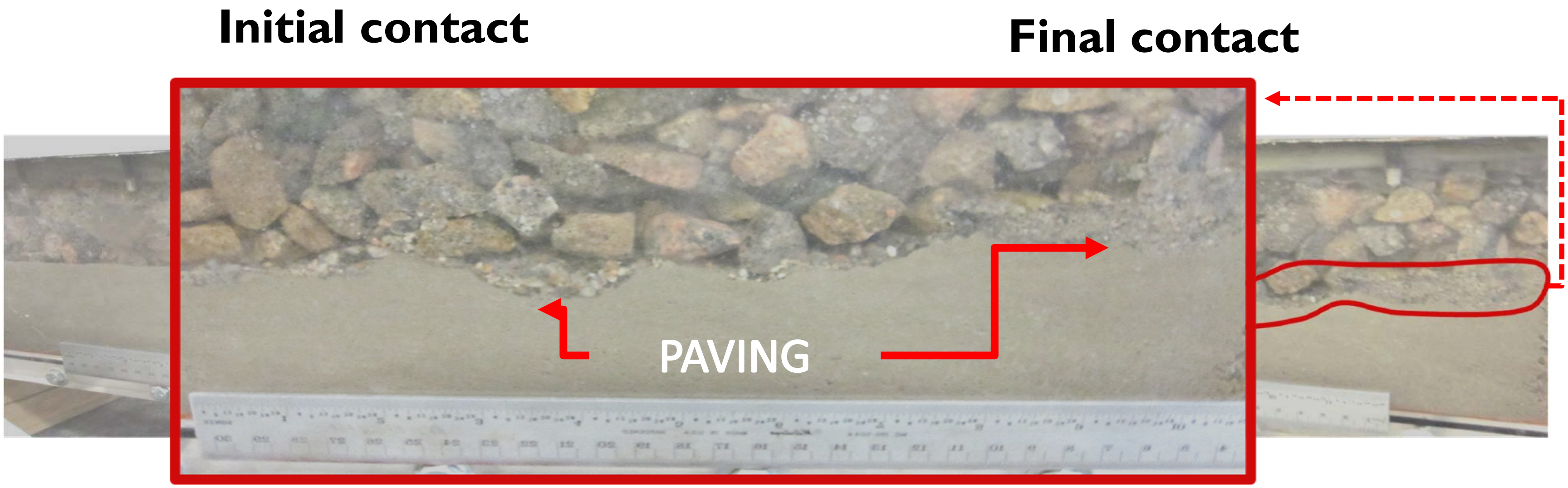
Project 1 –Influence of well graded base soil –
Paving and Clogging Occur

Initial contact

Final contact

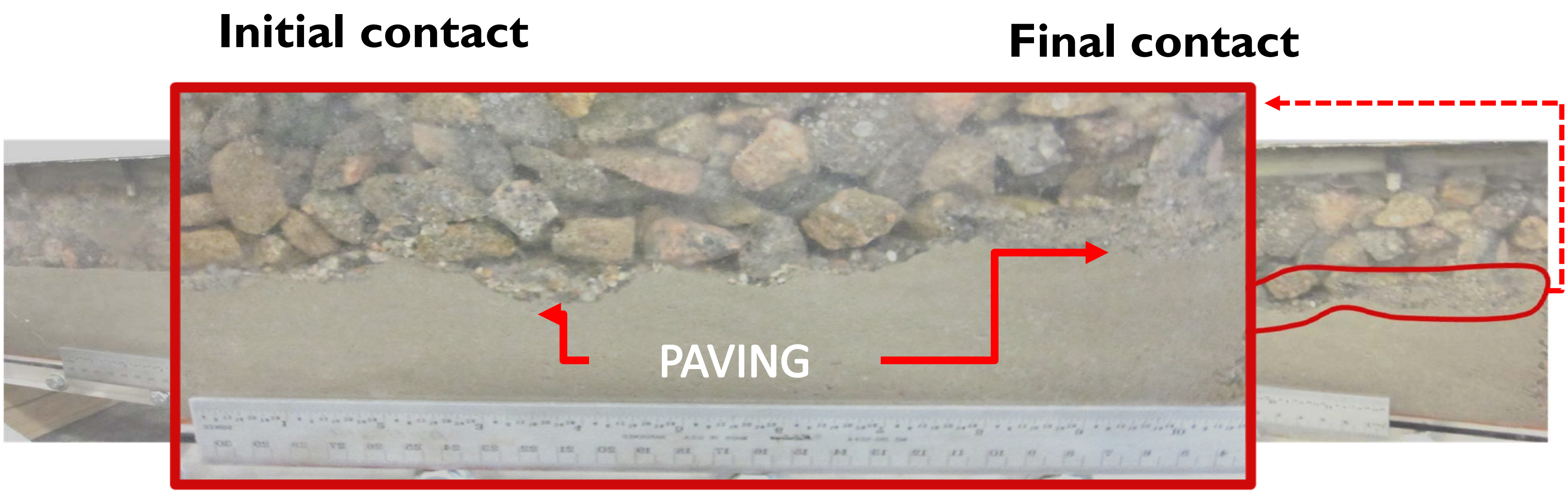


Project 1 –Influence of well graded base soil –
Paving and Clogging Occur



Project 1 –Influence of well graded base soil –
Paving and Clogging Occur

- Creation of a transition zone of the particle sizes at the interface
- A shielding effect develops at the interface

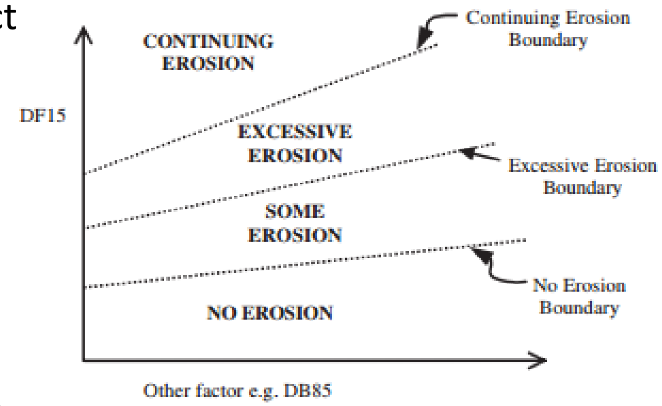


Project 1 –Influence of well graded base soil – Conclusion

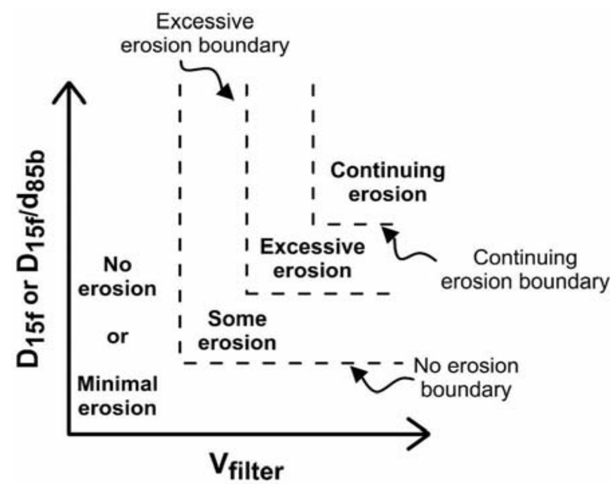
- Condition for no contact erosion :

  $D_{15F} / d_{85B} \leq 5$

- Two mechanisms
  - Paving
  - Clogging
- Not only geometrical conditions influences contact erosion for well-graded material but also velocities
- Proposed conceptual approach for well-graded soils



Filter erosion boundaries
(Foster et Fell, 2001)



Erosion boundaries as a function of the filter material and of the filter flow velocitiy

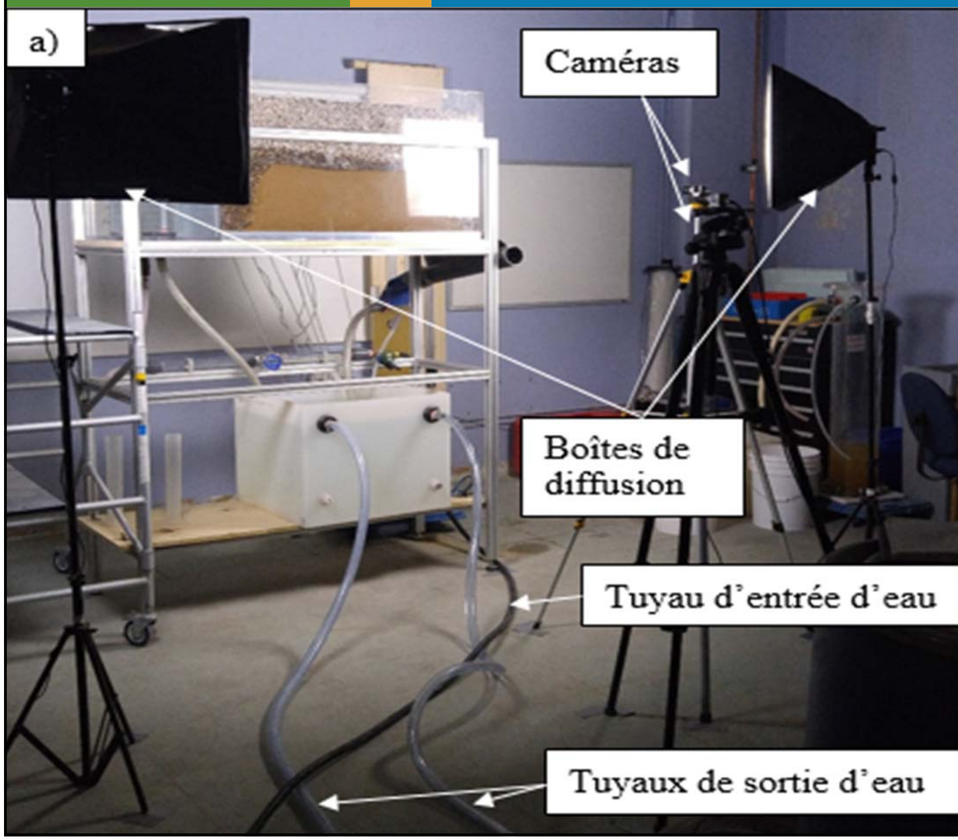
Project 2 - Core Overtopping Laboratory Tests
Introduction

Design of a reduced scale model to determine the potential failure mechanisms during core overtopping (ÉTS)

- Where does the erosion start?
- How does it evolve in time for different material combinations?
- This project also generates experimental data for the numerical method project.

First results presented by Dumberry et al. (2017)

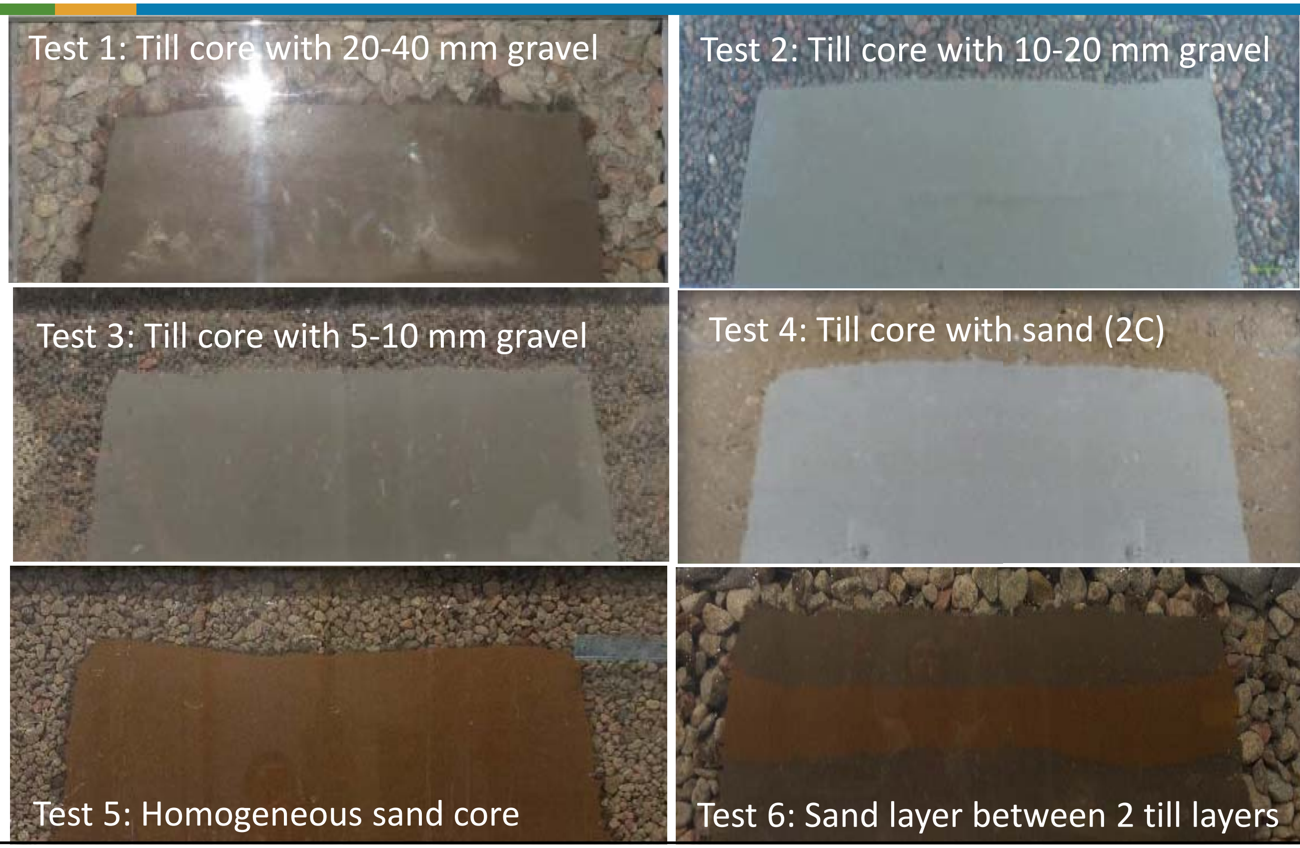
Project 2 - Core Overtopping Laboratory Tests
Experimental Setup



b) -Piezometers and sensors behing the setup
- Flow rate measurements
Sediment mass
- Cameras

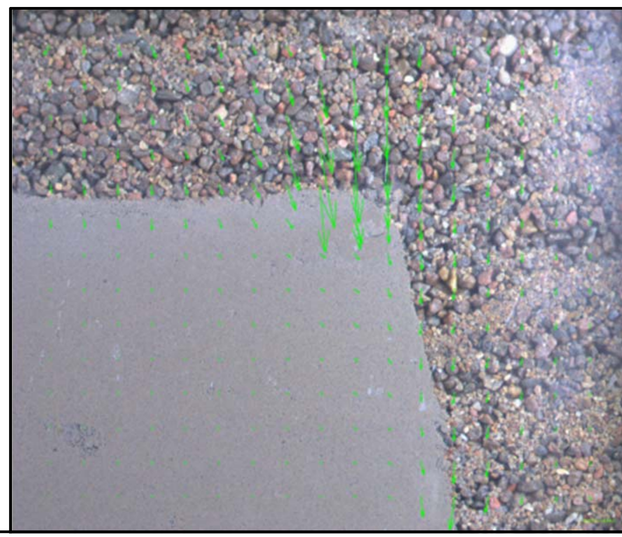
Project 2 - Core Overtopping Laboratory Tests

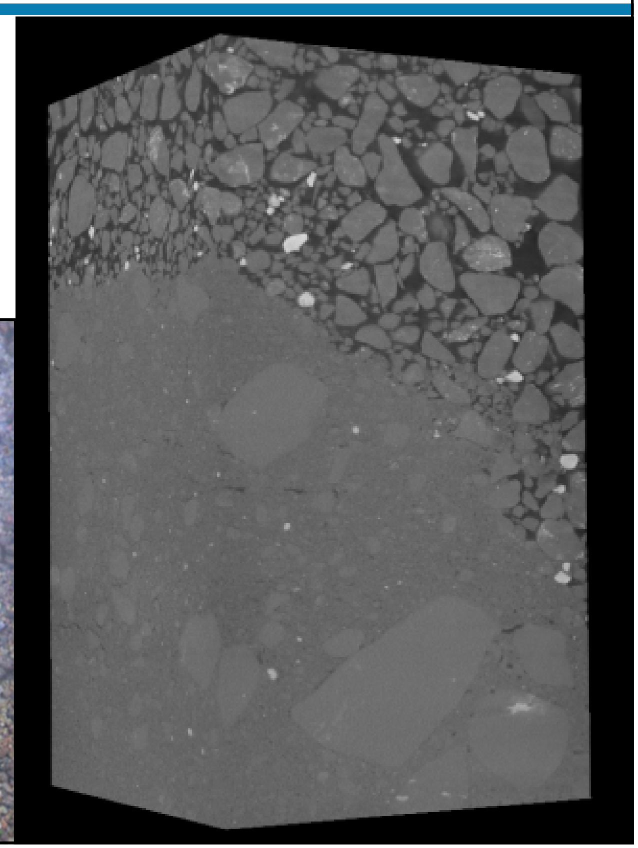
Material Tested



Experimental tests

- Imaging and image analysis techniques: CT-scan (microcomputed tomography μCT) and digital image correlation (DIC).
- Results for DIC mainly reflected settlements within the filter due to erosion.
- The magnitude of the displacement vector obtained with DIC is directly proportional to the volume of till eroded.



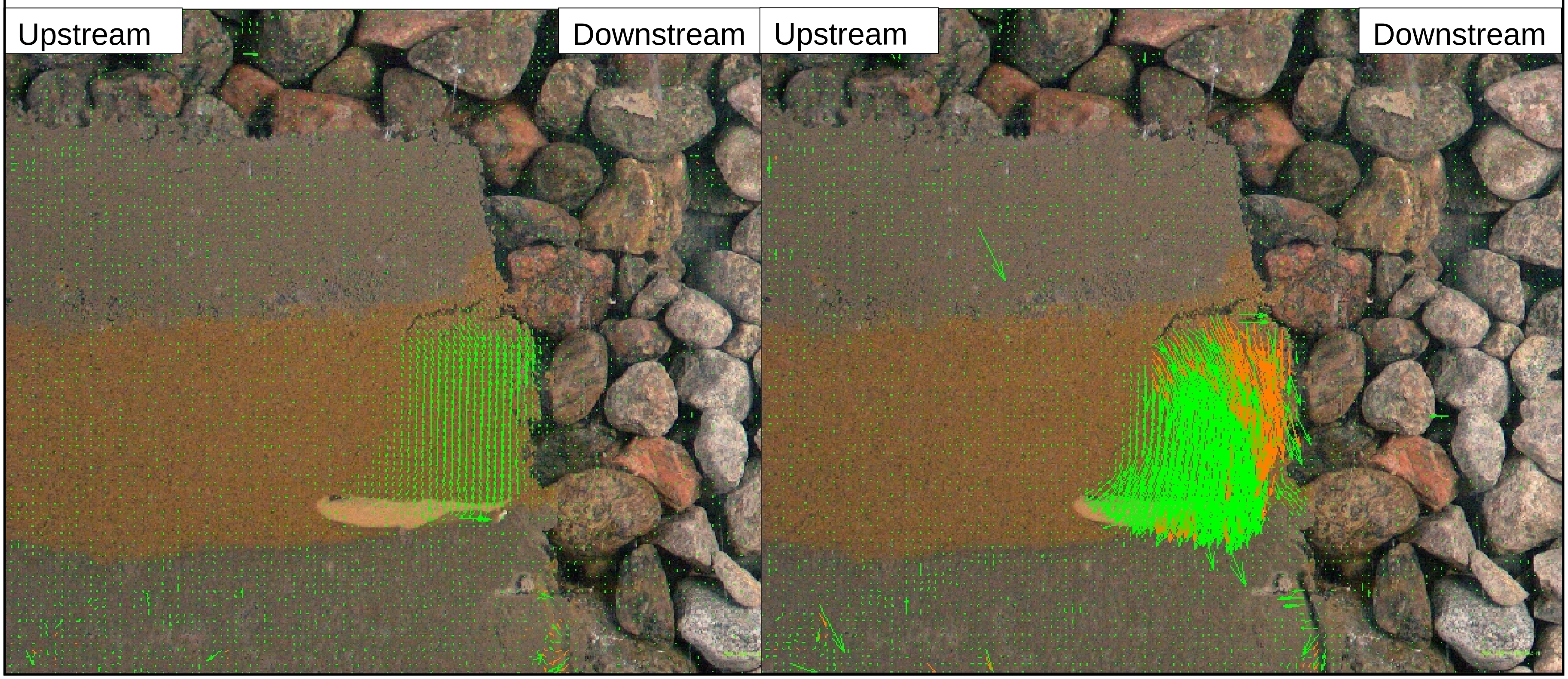


Project 2 - Core Overtopping Laboratory Tests - Results

- 3 images/sec
- Erosion Initiation by piping in sand
- Collapse of sand and till over piping
- Piping progression in sand layer
- Erosion in till below

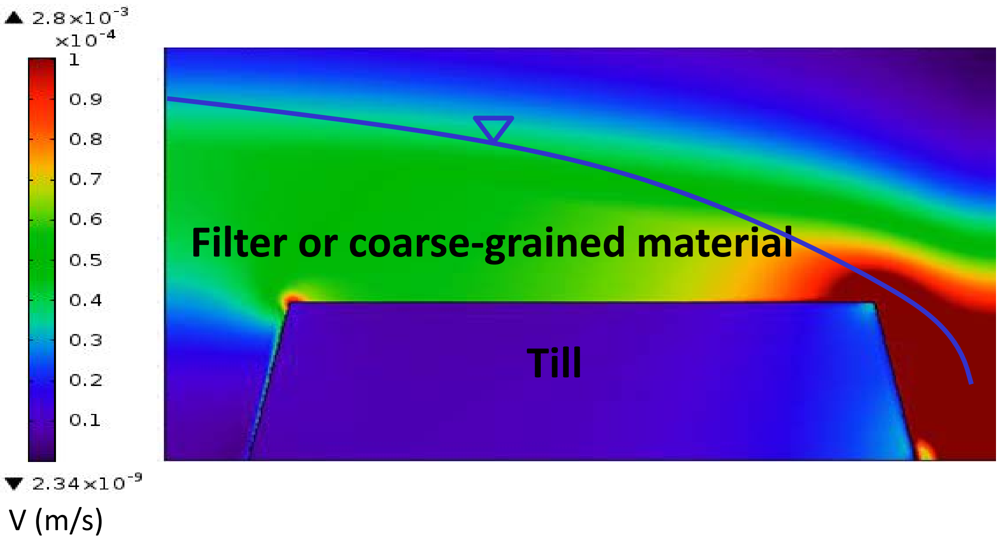
Project 2 - Core Overtopping Laboratory Tests

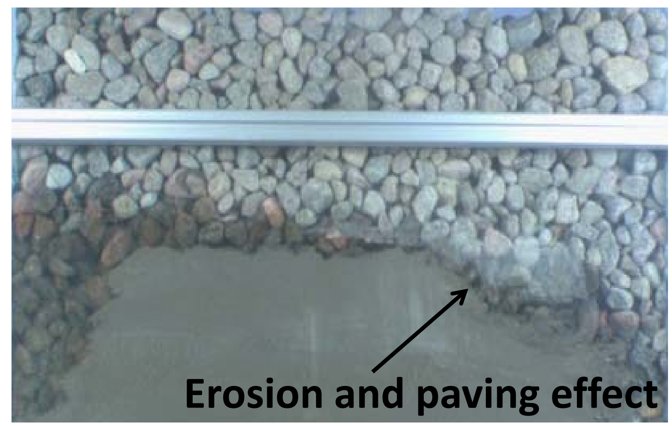
PIVLab Software (DIC) - Vectors



Project 2 - Core Overtopping Laboratory Tests

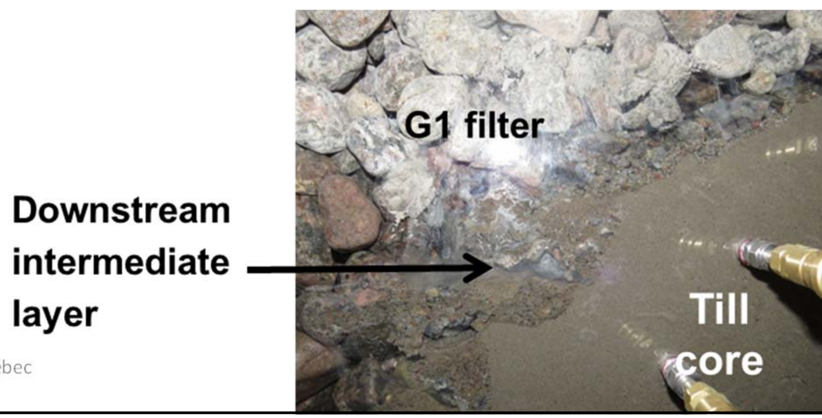
Modeling Velocities





Project 2 - Core Overtopping Laboratory Tests
Conclusion

- Only one of the six material combinations satisfied the Fell et al. (2015) filter criteria. No contact erosion occurred during this test.
- Material combinations that did not respect the filter criteria, piping occurred within the core along the downstream slope when the water level reached the top of the core.
- As a result of the self-healing process within the core material, the erosion rate decayed with time as the hydraulic gradient increased (paving and clogging).
- The flux of eroded sediments follows a decreasing power function over time

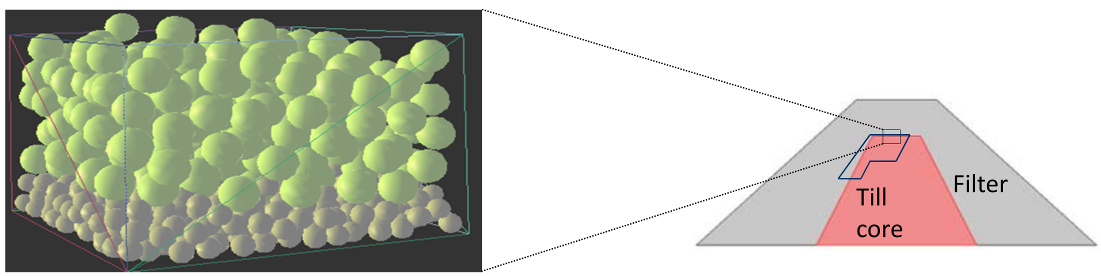


Project 3 – Numerical model Introduction

Internal erosion depends on :

- microstructure (local particle size distributions, particle arrangement and pore network geometry)
- macroscopic variables (hydraulic gradient, seepage velocity, and stresses)

A multi-scale modeling approach would allow to consider both scales.



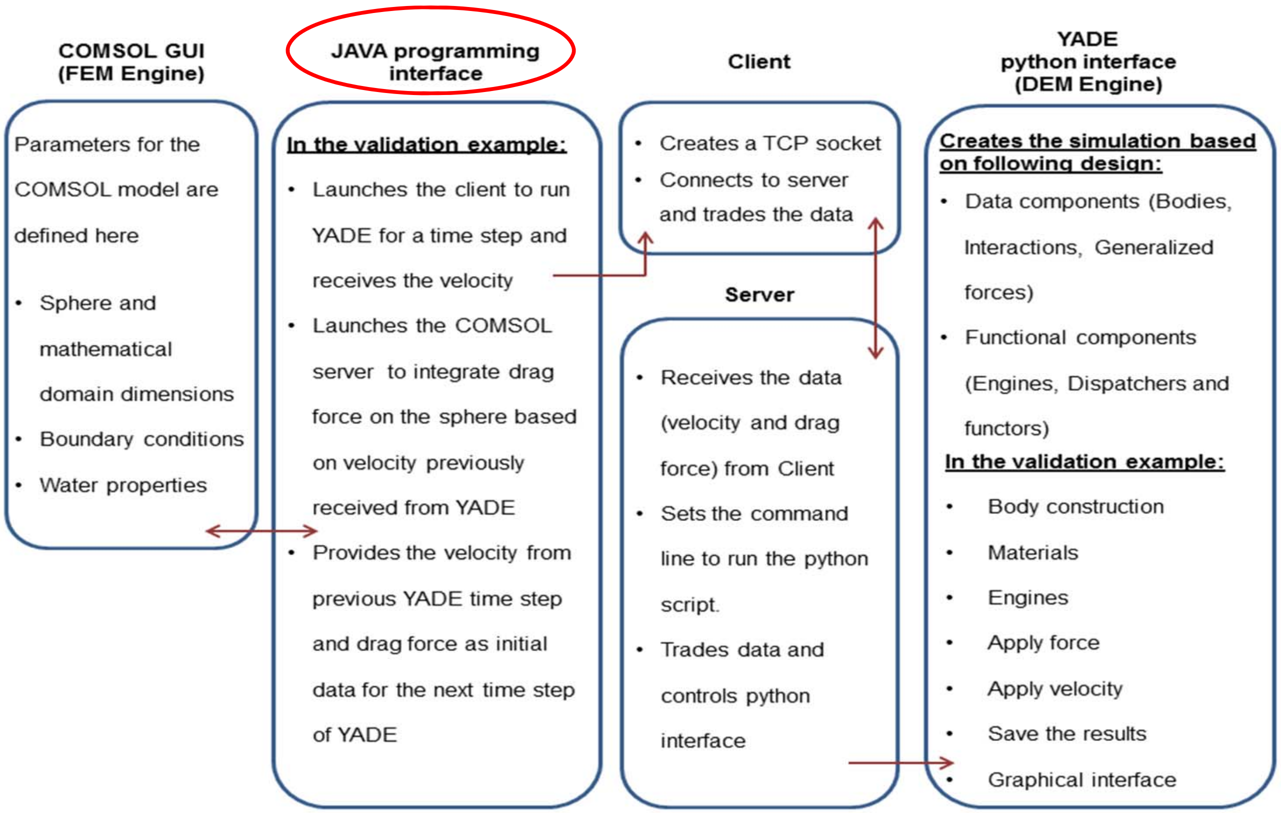
<u>YADE</u>

- Discrete elements
- Python scripts

<u>COMSOL</u>

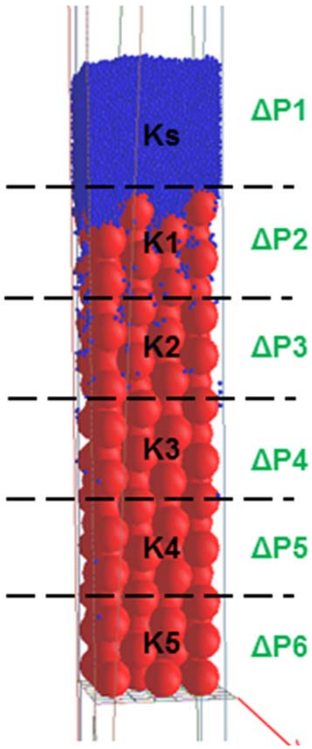
- Finite elements
- Multiphysics simulations and custom equations
- JAVA Programming interface

Project 3 – Numerical model
iCY framework



Project 3 – Numerical model

iCY framework



At this point iCY was verified on simple problems

iCY

YADE (microscale)

COMSOL (macroscale)

Seepage model to estimate microscale drag force

Particle flux calculations

Mass conservation equation for small particles

Conclusion of the 3 projects

- Even if the till didn’t respected filter criteria, often there was no erosion or the erosion was started and then stopped by 2 mechanism : Paving and Clogging
- Contact erosion with a well-graded base soil (till) is not only based on geometric parameters but also on water velocities
- Erosion was initiated when there was core overtopping (for project 2)
- Project showed that erosion was initiated by piping and not at the contact parallel to the flow
- Technologies like PIV and CT-scan showed interesting results and further development will be done
- Numerical models showed promising results for simple problems and development should be continued for eventually applying them to model the experimental approach

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