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Rock Erosion of Unlined Spillway - Hydro-Quebec's Cases and Research Projects

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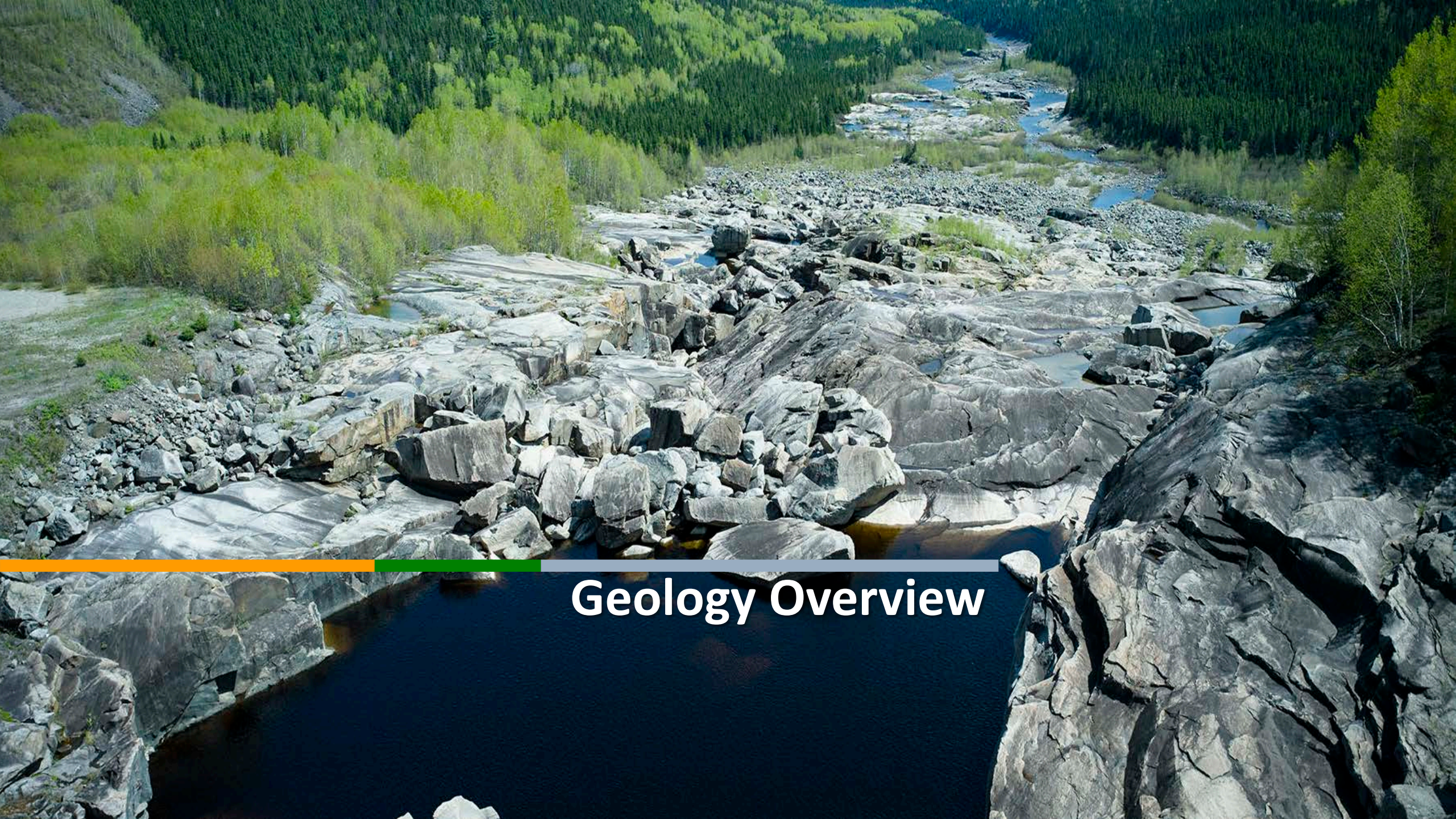
November 25th 2020

Overview

- Regional Geology
- Scour events in Hydro-Quebec Spillways
- Rock Scour Mechanisms and Estimation Methods
- Research Projects
  - Susceptibility of Unlined Spillways to Erosion
  - Large Scale Experimental Simulations of Scour Mechanisms of Unlined Spillways



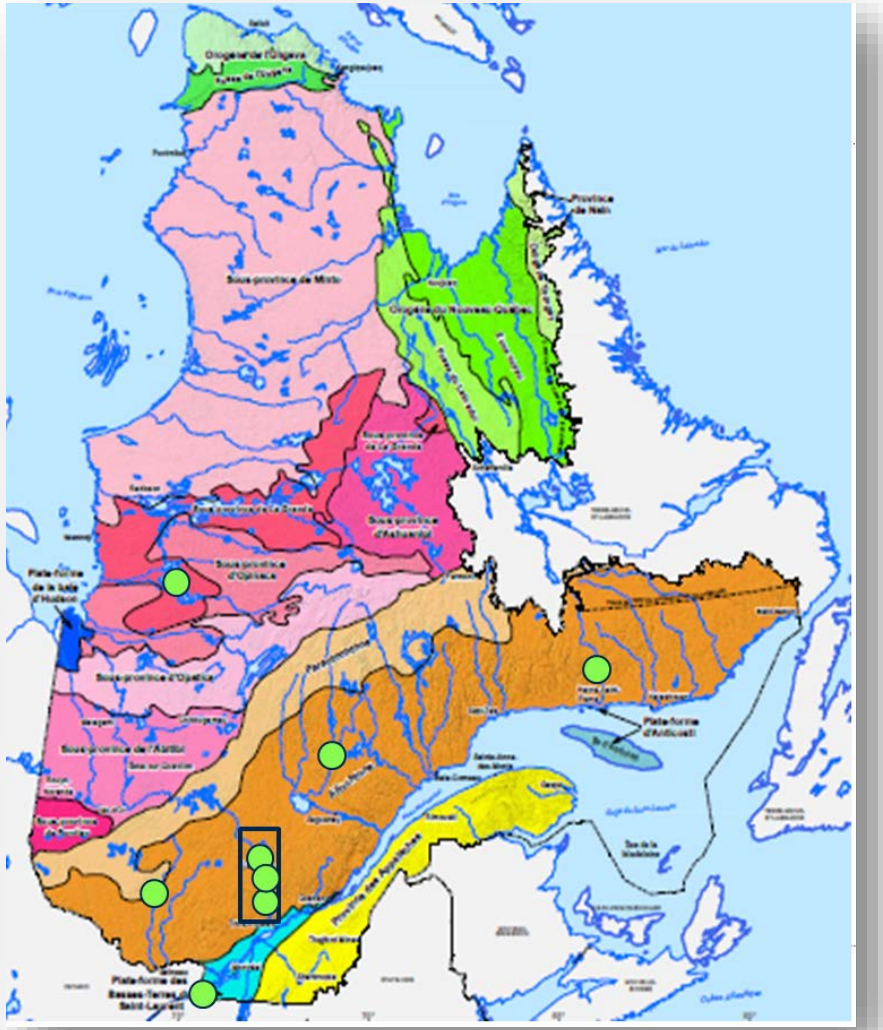
Geology Overview

Geological Provinces of Québec

Crystalline Rocks
(Granite, gneiss)

Sedimentary Rocks
(Limestone, Shale)

Metamorphic Rocks
(Low Grade : Schist)



Unlined Spillways Impacted by Erosion

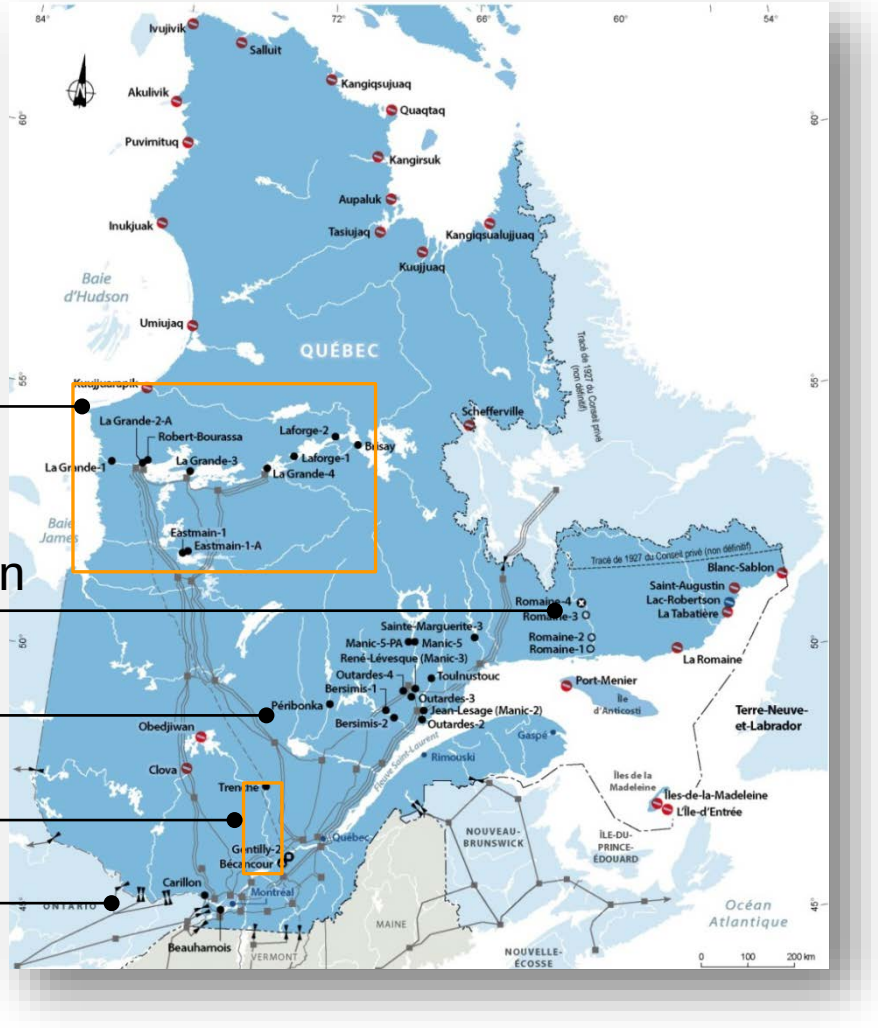
James Bay Region

Lower North Shore Region

Saguenay Region

St-Maurice River

Ottawa River



Typical Joints in Crystalline Rocks

Unlined Spillways Erosion: History Cases

St-Maurice River [1] (2004)

- Rock erosion downstream of spillway channel
- Accumulation of sediments, gravel and blocks downstream of the powerhouse's tailrace
- Highlights
  - Underwater blasting
  - High Explosive loads
  - Significant subdrillings

St-Maurice River [2] (2008)

- During design, the rock downstream of the spillway was considered vulnerable (pegmatite)
- Highlights
  - Concrete protection at the foot of the sidewalls
  - 2008 Hydraulic Testing – Signs of erosion observed at the downstream end of the protection
  - 2010 Inspection indicates no further erosion

St-Maurice River [3] (2010)

- Autumn flood 2010 evacuated through one gate (VE4)
- Outflow of 470 m^3/s for 86 hours
- Significant damages at the spillway's apron
- Highlights
  - Construction in the 1940's
  - Low concrete thickness
  - Many concrete construction joints

Some issues…

Baskatong Reservoir (2007)

- Addition of a powerhouse starting in 2004
- Flood in 2007 evacuated by the bottom outlet during construction
- Boulders accumulation downstream
- Highlights
  - Outflow 400 m^3/s during 4 months
  - Velocities above 20 m/s
  - Described as exceptional

James-Bay Region (2008)

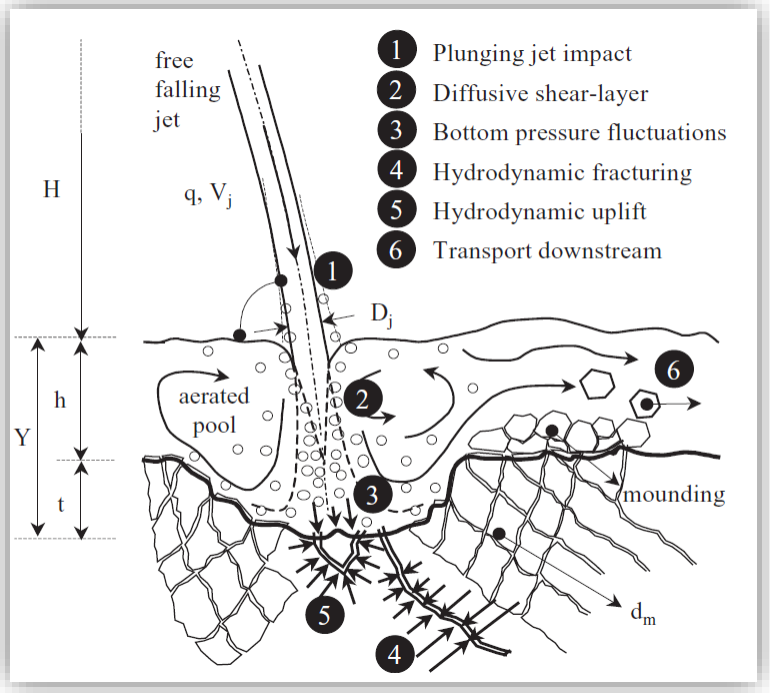
- About 2 m thick of rock eroded following the opening of the gates
- Corresponds to the thickness of rock affected by blasting
- Highlights
  - Shear zone
  - Significant subdrillings

Erodibility Potential Evaluation

Hydro-Québec's Typical Spillways Configuration

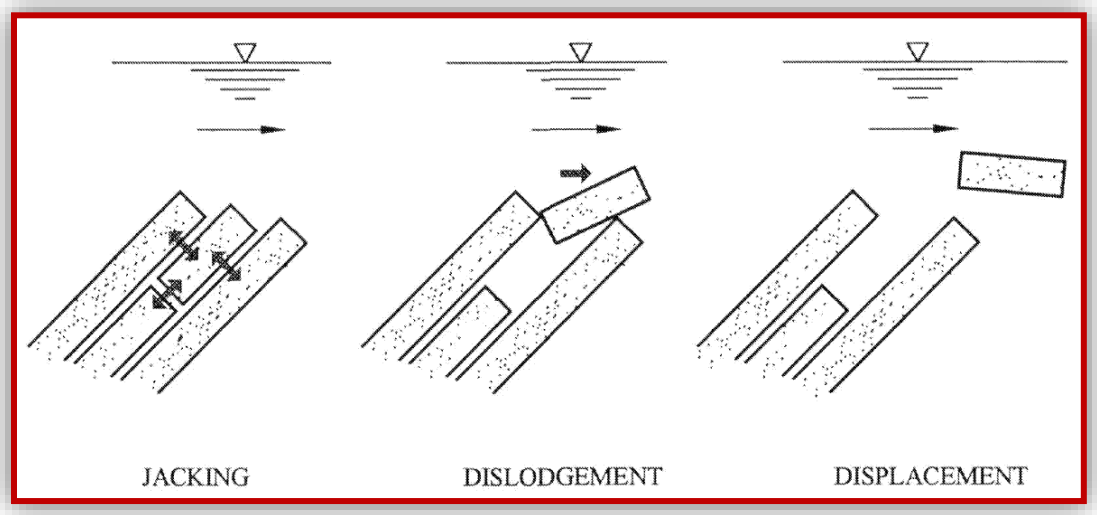
Rock Scour Mechanisms

Plunging Jet



Bollaert, E., Schleiss, A., (2003) J. Hyd. Res.: 41 (5)

Parallel Flow



Annandale, G. (1995) J. Hyd. Res.: 33 (4)

Annandale's Method for Erodibility Potential

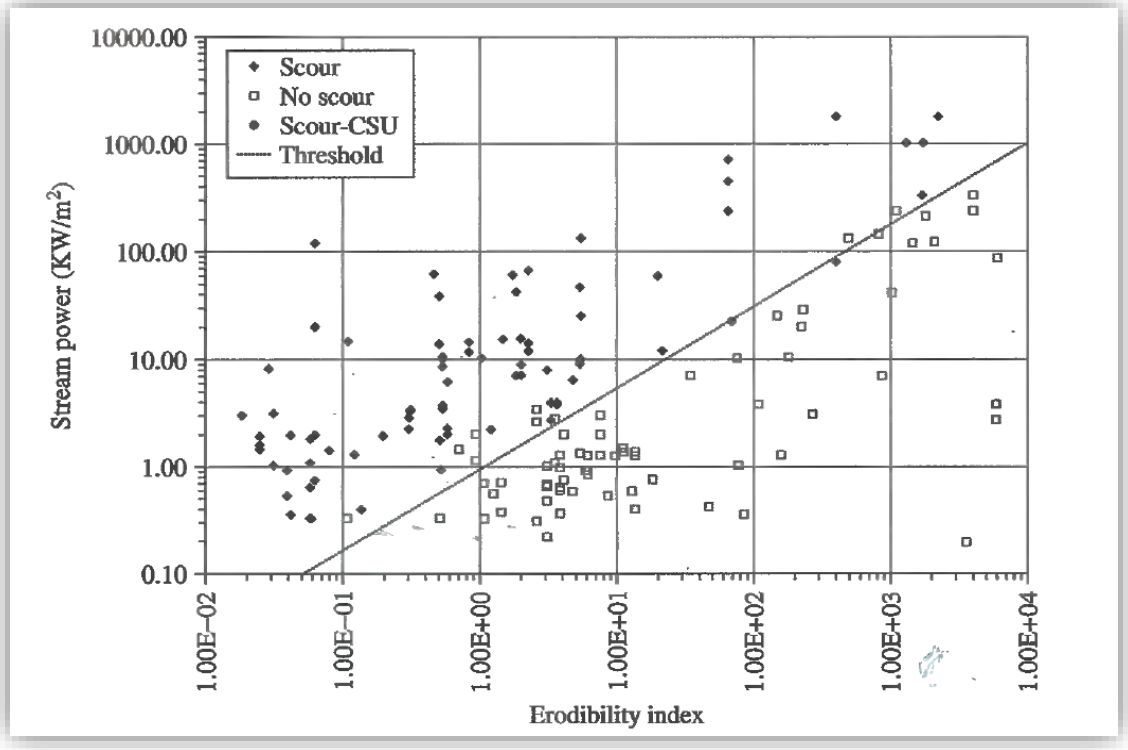
$$K = Ms \times K_b \times K_d \times J_s$$

M_s : Compressive Strength of Intact Rock

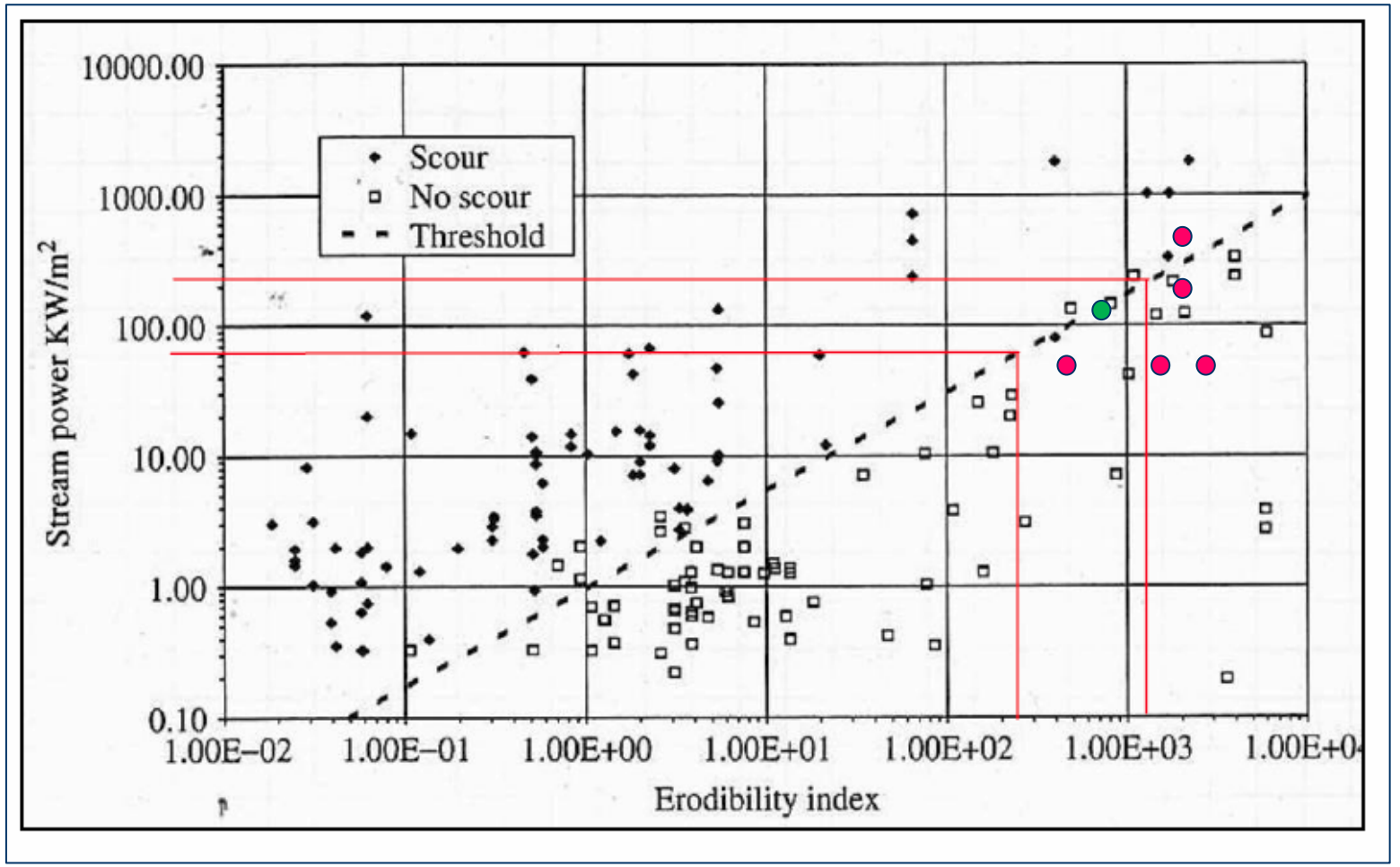
K_b : Rock Block Size

K_d : Discontinuities Shear Strength

J_s : Relative Block Structure



Erosion Potential – History Cases



Some Observations

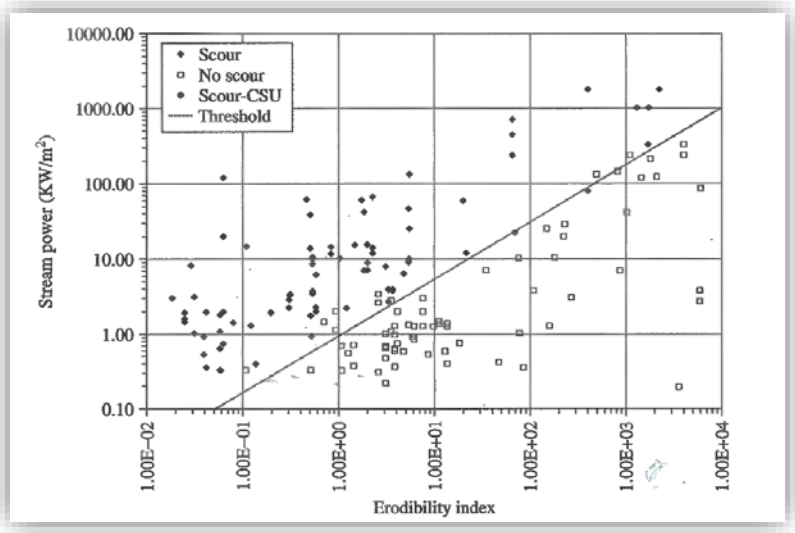
- Hydro-Québec's erosion cases often involve excavation issues or the use of spillways in particular conditions
- Calculation of erosion capacity in design, or following a damage event, is solely based on the Annandale's concept
  - Better understand and know the basis of the method
  - The possible extent of erosion is difficult to predict
  - Guidelines to calculate stream power would be beneficial

Research Projects

Hydro-Québec's Research Projects – Phase 1

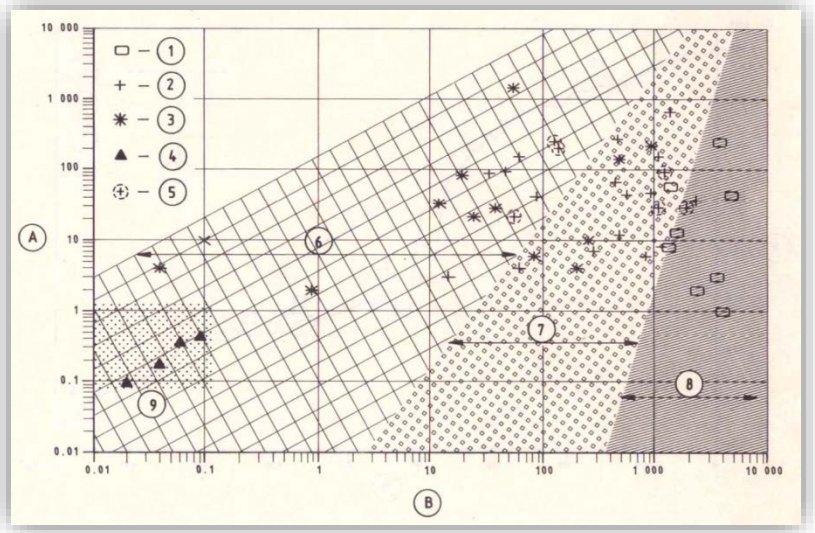
- Susceptibility of Unlined Spillways to Erosion
  - Funding
    - 2016 – 2017 NSERC- ENGAGE PROGRAM
      - intended to foster the development of **new research partnerships** by supporting short-term research and development projects aimed at addressing a company-specific problem.
    - 2017 – 2019 MITACS ACCELERATION PROGRAM
      - link between industry and universities, driving to develop projects which solve business challenges, and develop the nation's innovation capacity.
  - Results
    - Lamine Boumaiza obtained his Ph.D Degree in July 2020
    - Thesis: Rock mass parameters governing the hydraulic erodibility of rock in unlined spillways (https://constellation.uqac.ca/5755/1/Boumaiza_uqac_0862D_10682.pdf)

Scour Evaluation Methods for Parallel Flow



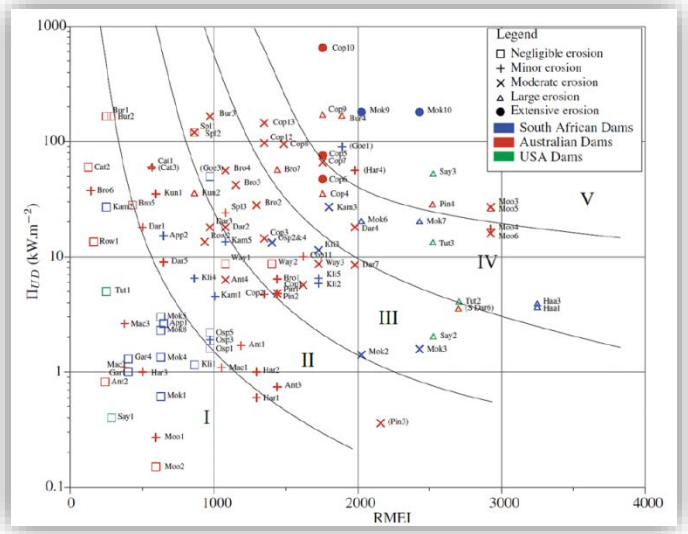
Annandale

- Kirsten Erodibility Index
- Threshold line



Van Schalkwyk

- Kirsten Erodibility Index
- 3 Erosion domains



Douglas (based on Pells work)

- Rock Mass Erodibility Index
- 5 Erosion domains

Boumaiza Findings

Relevant Rock Mass Parameters

- Rock block volume
- Rock block's shape and orientation relative to flow direction
- Nature of the eroding surface
- Joints opening
- Joints shear strength

For example

- *Unconfined compressive strength found not be relevant over 50 MPa for Crystalline rock mass moderately jointed*

Importance (weight) of Parameters

- Joints shear strength,
- Nature of the potentially eroding surface
- Rock block volume,
- Joints opening
- Rock block's shape and orientation relative to the direction of flow

Erodibility Index

- **Roberston (1970); Jenning (1973)**
  - Guide to soil profiling
  - Geological factors in slope theory

M_s

- **Barton's Q-Index (1974)**
  - Rock mass classification and reinforcement selection

K_b and **K_d**

- **Kirsten Ripability Index (1982)**
  - Excavatability (Riping)

J_s

$$K = Ms \times \left(\frac{RQD}{J_n}\right) \times \left(\frac{J_r}{J_a}\right) \times J_s$$

M_s : Compressive Strength of Intact Rock

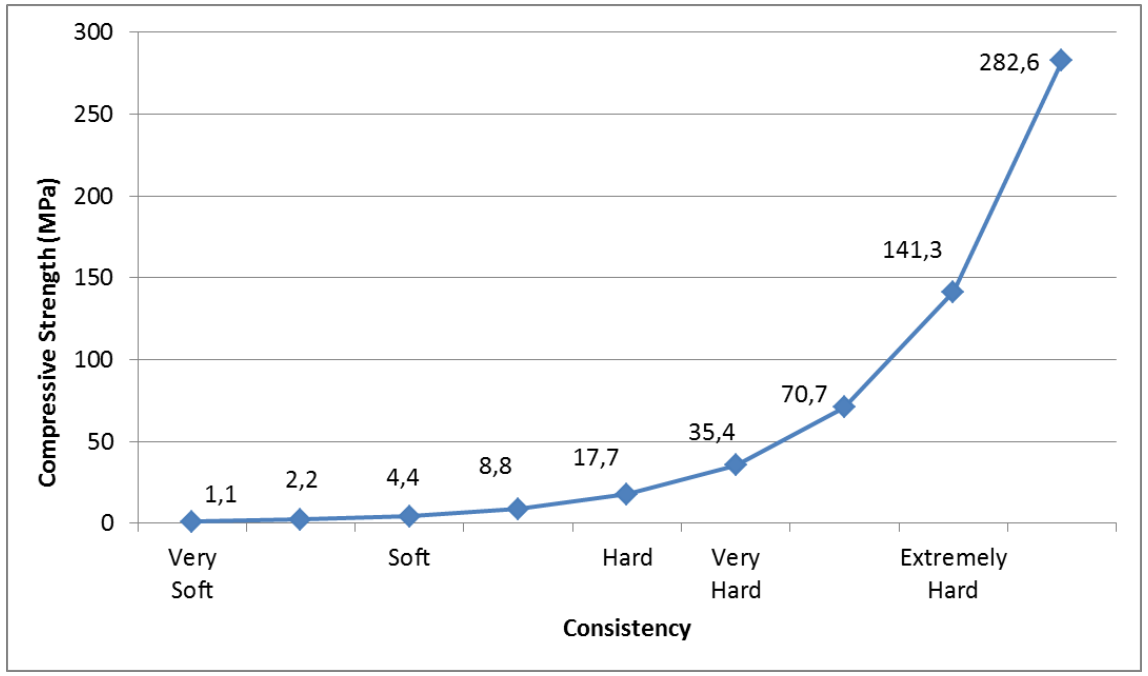
K_b : RQD/J_n : Rock Block Size

K_d : J_r/J_a : Discontinuities Shear Strength

J_s : Relative Block Structure

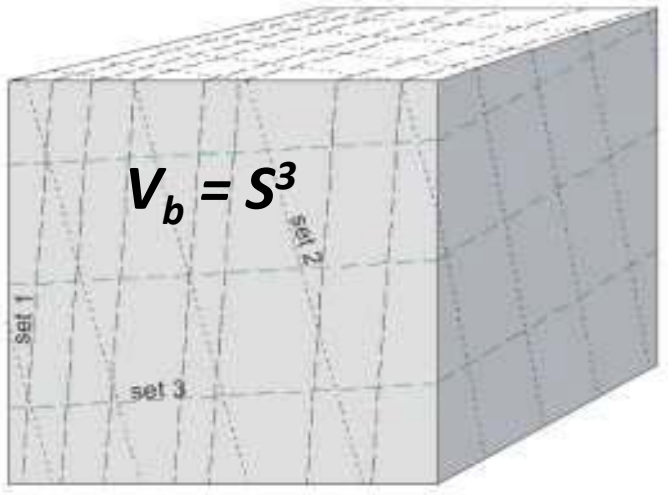
Example of Parameter Importance and Description

Compressive strength



Block Size

$$K_b = \frac{RQD}{J_n}$$



Publications Available

Journal of Rock Mechanics and Geotechnical Engineering 11 (2019) 72–87

Contents lists available at ScienceDirect

Journal of Rock Mechanics and Geotechnical Engineering

journal homepage: www.rockgeotech.org

Full Length Article

Determining relative block structure rating for rock erodibility evaluation in the case of non-orthogonal joint sets

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ABSTRACT

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Check for updates

Assessment of rock mass erosion in unlined spillways using developed vulnerability and fragility functions

Ali Saeidi [a], Esmaeil Eslami [a,b], Marco Quirion [c] and Mahdiyeh Seifaddini [a]

[a]Department of Applied Sciences, Université du Québec à Chicoutimi, Chicoutimi, Canada; [b]Department of Physics, Iran University of Science and Technology, Tehran, Iran; [c]Expertise e

ABSTRACT
Hydraulic power can lead to the ero

Sustainable and Safe Dams Around the World – Tournier, Bennett & Bibeau (Eds)
© 2019 Canadian Dam Association, ISBN 978-0-367-33422-2

Avoiding rock erosion in the discharge channel of the Péribonka spillway

C. Correa & M. Quirion
Hydro-Québec, Montréal, Québec, Canada

ABSTRACT: The Péribonka hydroelectric scheme is located North of Lac St-Jean in the Province of Québec, Canada. It includes an underground generating stati
dam, two dikes and one spillway with a capacity of 4900
excavated in strong anorthosite, however a zo
investigations. Durin

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Full Length Article

A method to determine relevant geomechanical parameters for evaluating the hydraulic erodibility of rock

Lamine Boumaiza [a,*], Ali Saeidi [a], Marco Quirion [b]

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ABSTRACT

Among the methods used for evaluating the potential hydraulic erodibility of rock, the most common methods are those based on the correlation between the force of flowing water and the capacity of a rock to resist erosion, such as Annandale's and Pells' methods. The capacity of a rock to resist erosion is evaluated based on erodibility indices that are determined from specific geomechanical parameters of a rock mass. These indices include unconfined compressive strength (UCS) of rock, rock block
shear strength, a block's shape and orientation relative to the dire
nature of the surface to be potentially eroded. How
mechanical parameters for evaluating the hyd
spillways of dams has shown that
Using more than 100 case
rameters for evalu

Hydro-Québec's Research Projects – Phase 2

Large Scale Experimental Simulations of Scour Mechanisms of Unlined Spillways

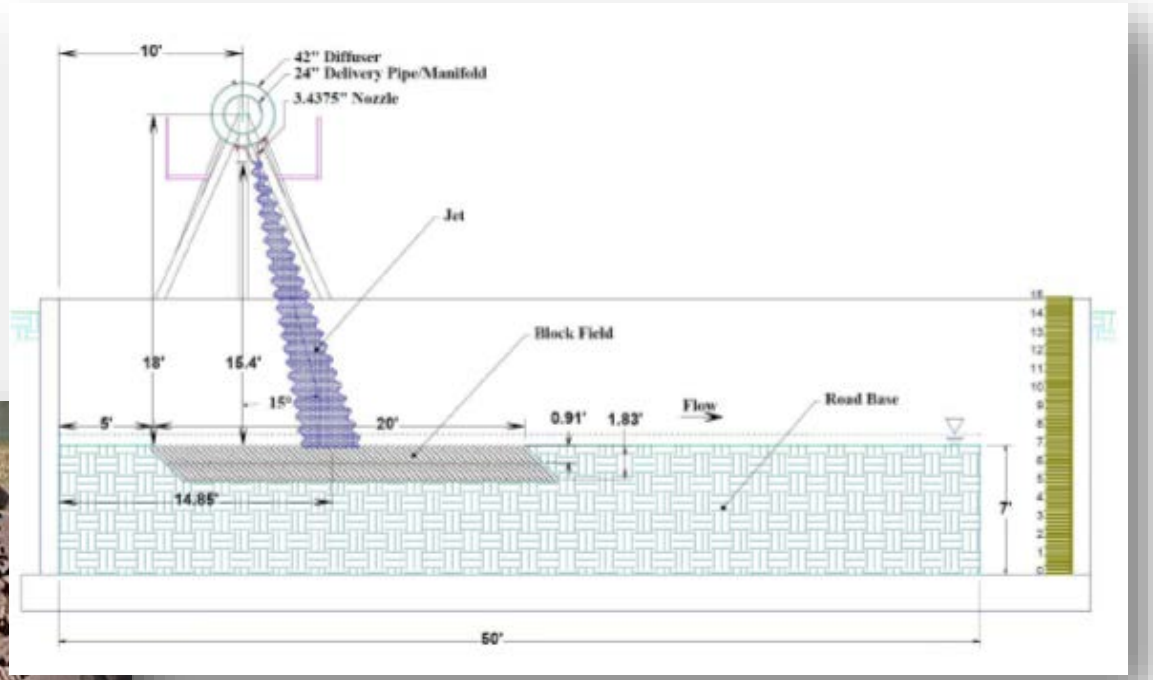
2020 – 2025 NSERC- Collaborative R&D PROGRAM
- CRD Grants support well-defined projects undertaken by university researchers and their partners

2020-2023 MITACS ACCELERATE PROGRAM
- Grants for postgraduate students

Experimental Study of the Influence of Geomechanical Parameters in Rock Mass Erosion

- Master's Research Project
- Student : Aboubacar Sidiki Koulibaly
- General Objectives
  - Design and build a laboratory medium scale model
  - Selection and validation of instrumentation of rock blocks
  - Experimental program design and implementation

Near Prototype Testing – Colorado State University

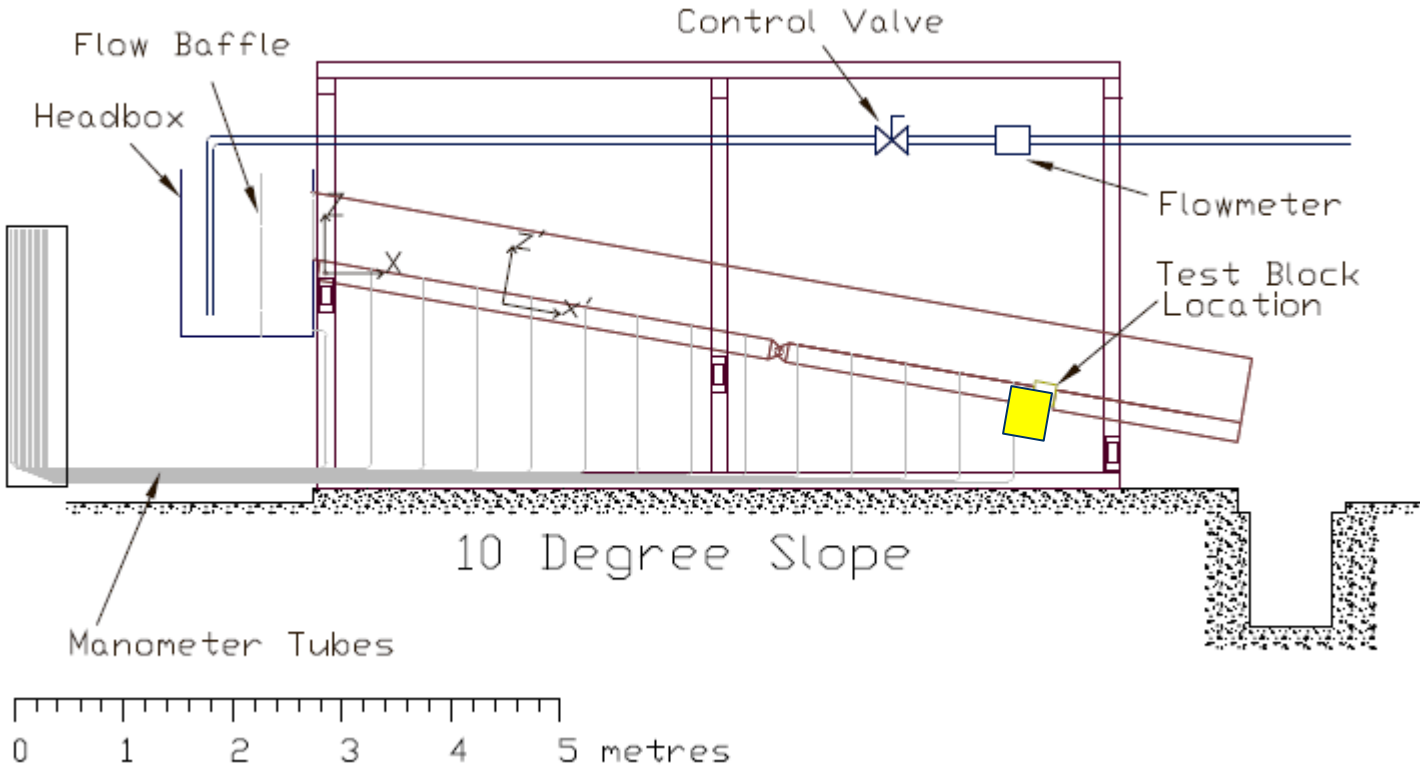


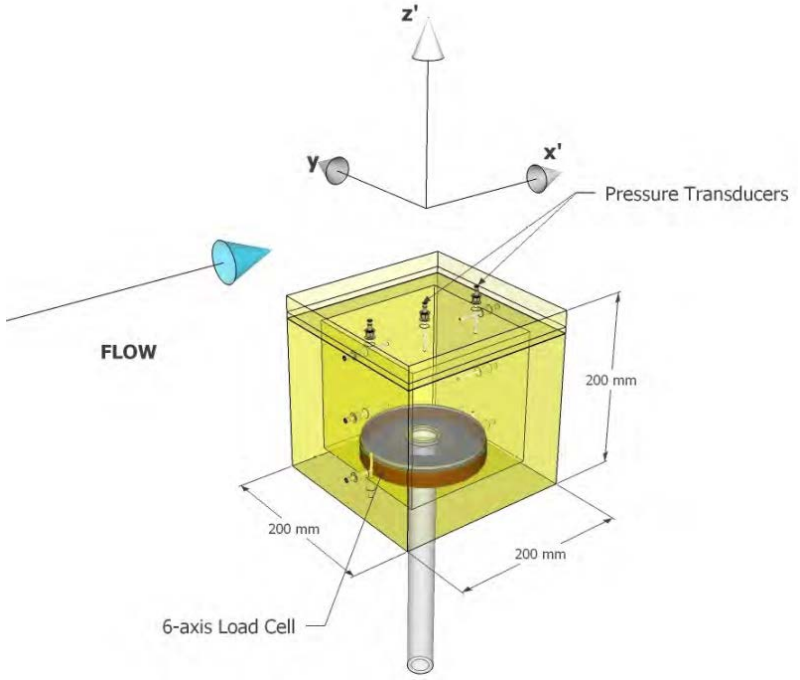
(Annandale et al., 1998)

EPFL - Experimental Set-up for Plunging Jet

Federspiel, 2011

Pells Experimental Study – University of New South Wales

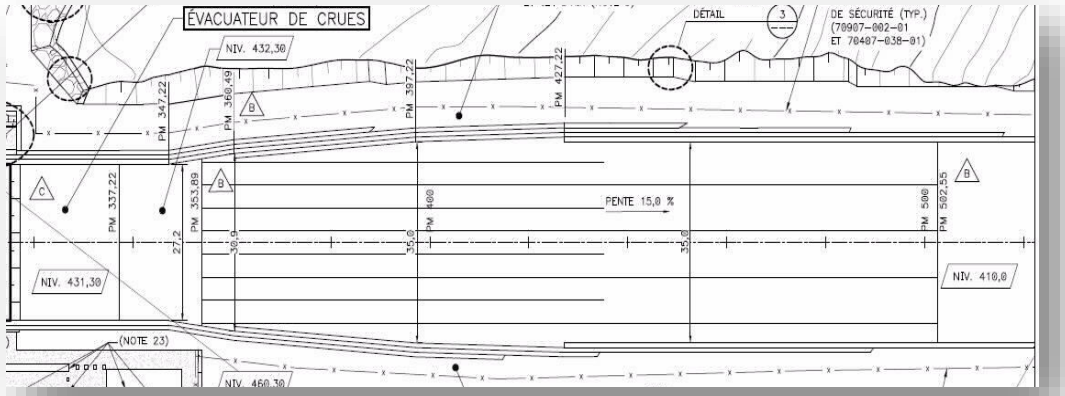




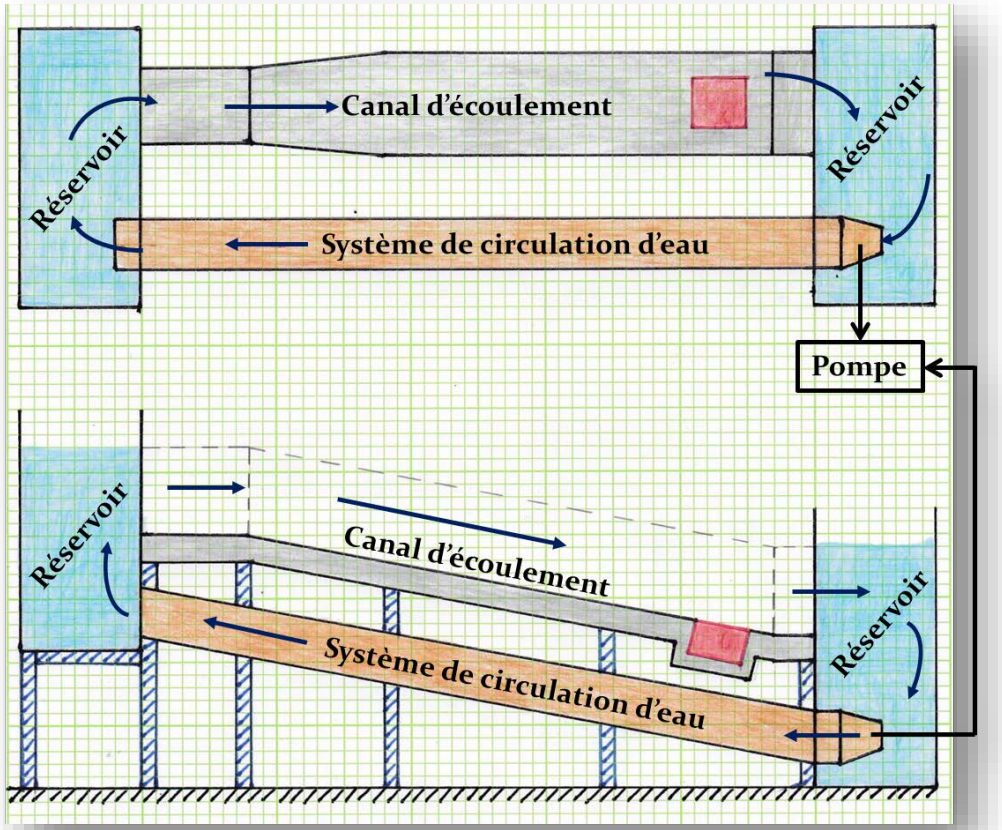
(Pells, 2016)

UQAC Laboratory Scale Model

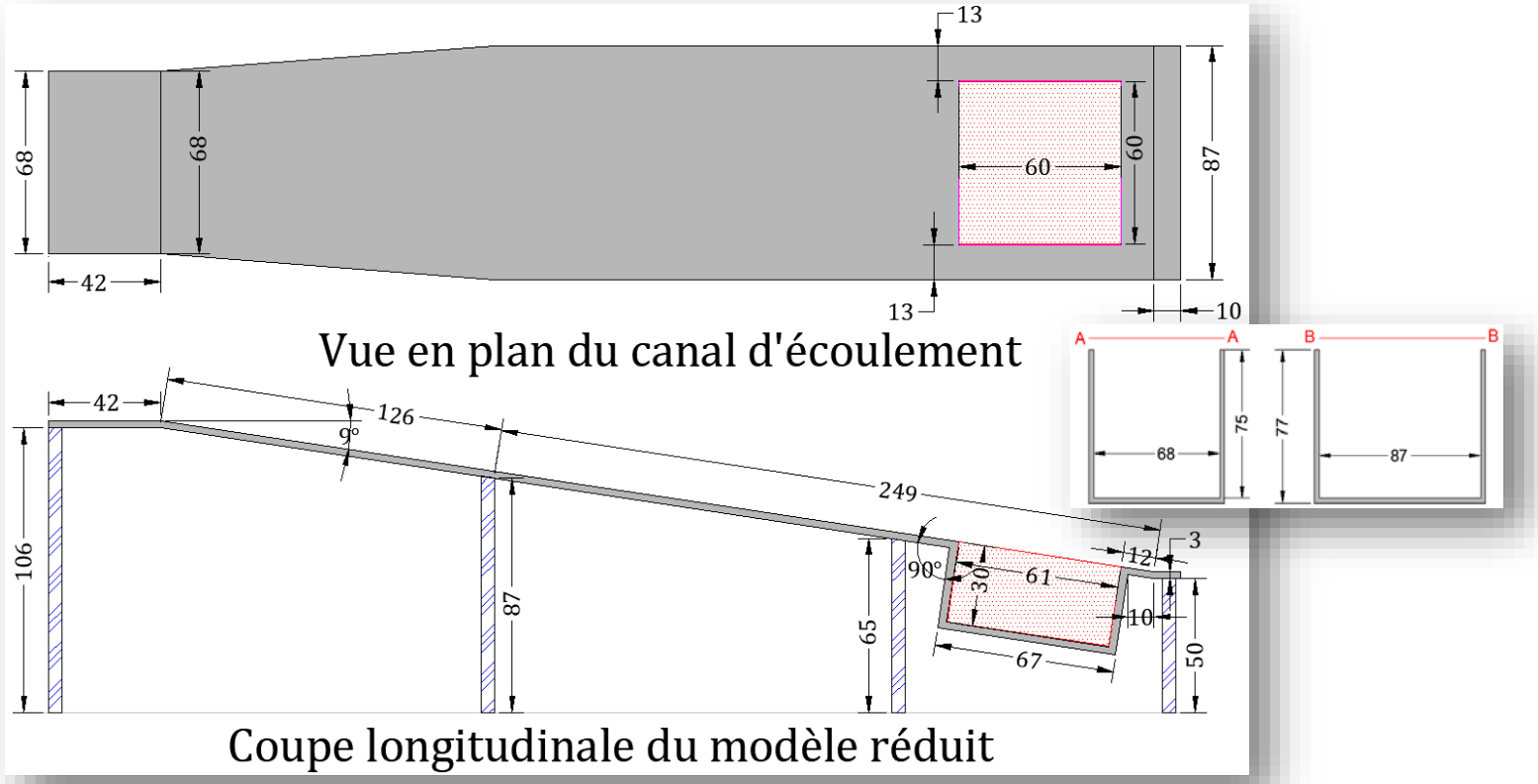
Romaine Spillway

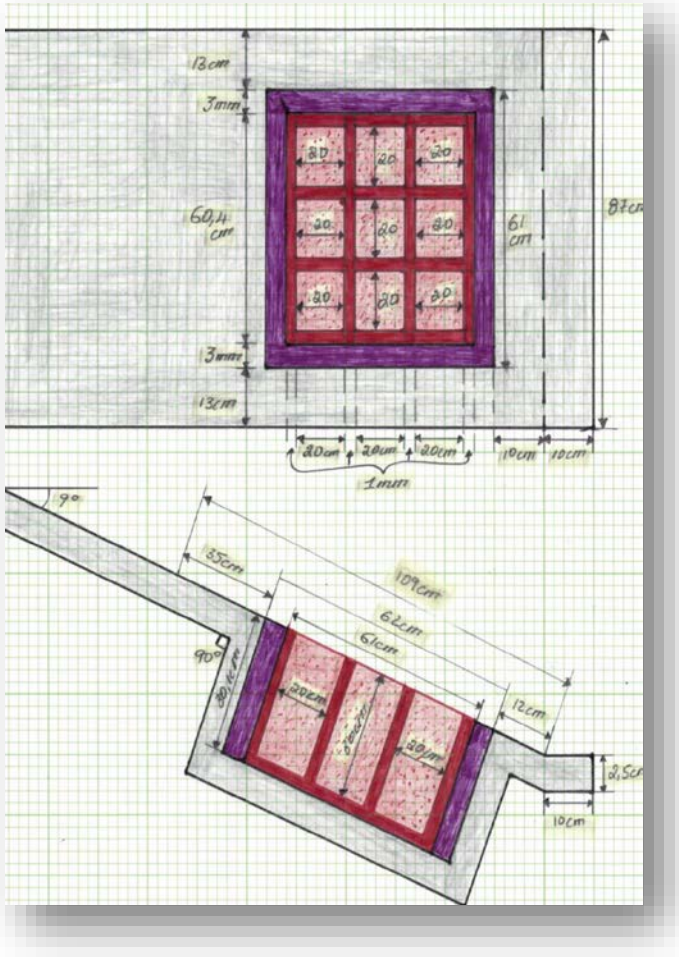


Scale Model Preliminary Design



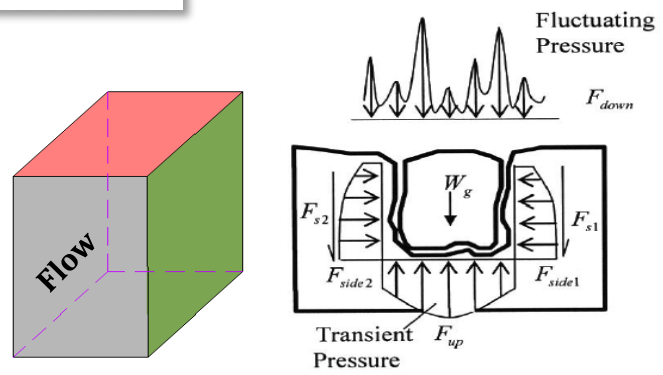
UQAC Laboratory Scale Model– Design in Progress

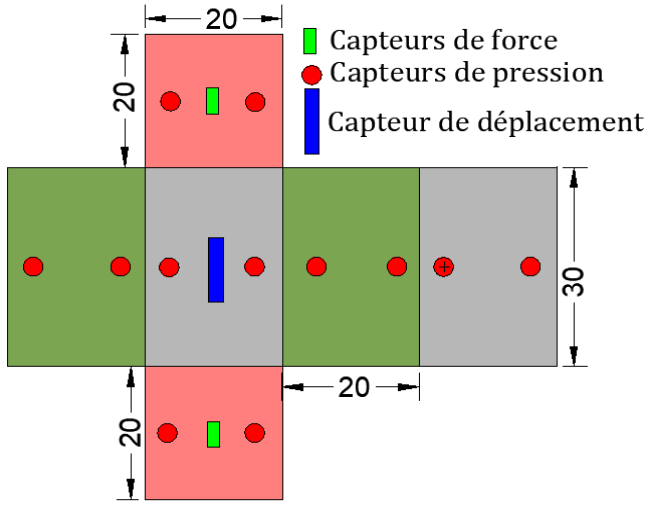




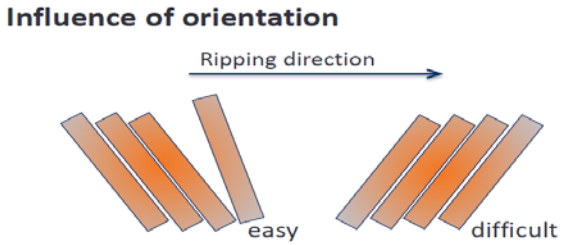
Parameters to be Studied

Pressure

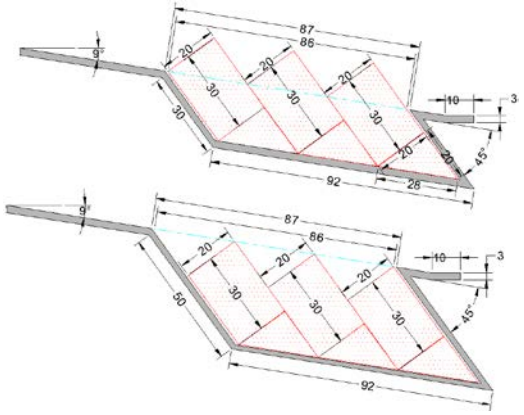




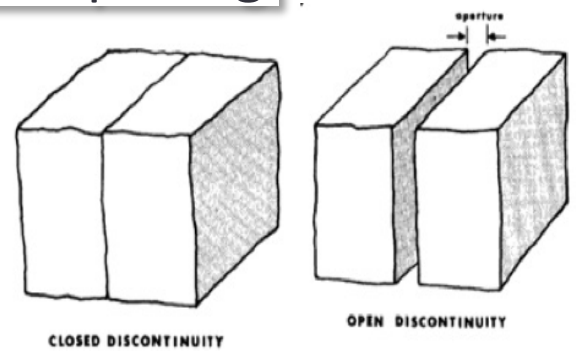
Orientation

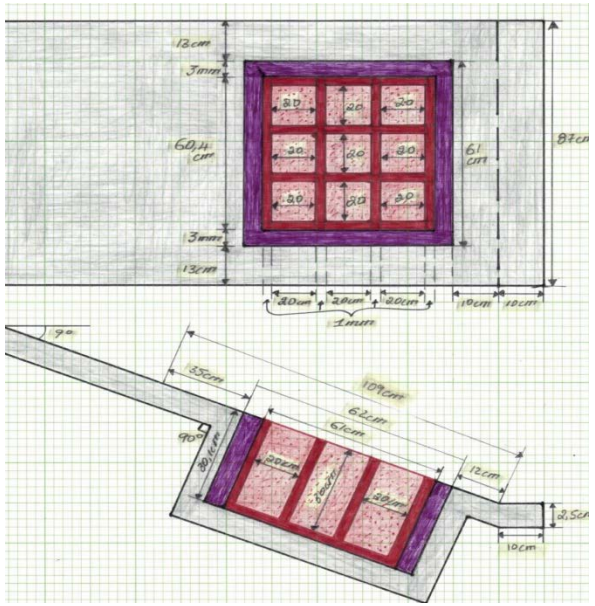


-45°



Joint Opening





Experimental Study of the Influence of Geomechanical Parameters in Rock Mass Erosion

- Doctoral Research Project
- Student : Yavar Jalili Kashtiban
- General objectives

  • In terms of hydraulics, what is the main parameter that should be considered as an hazard parameter for the potential of erosion?

    • Velocity of flowing?

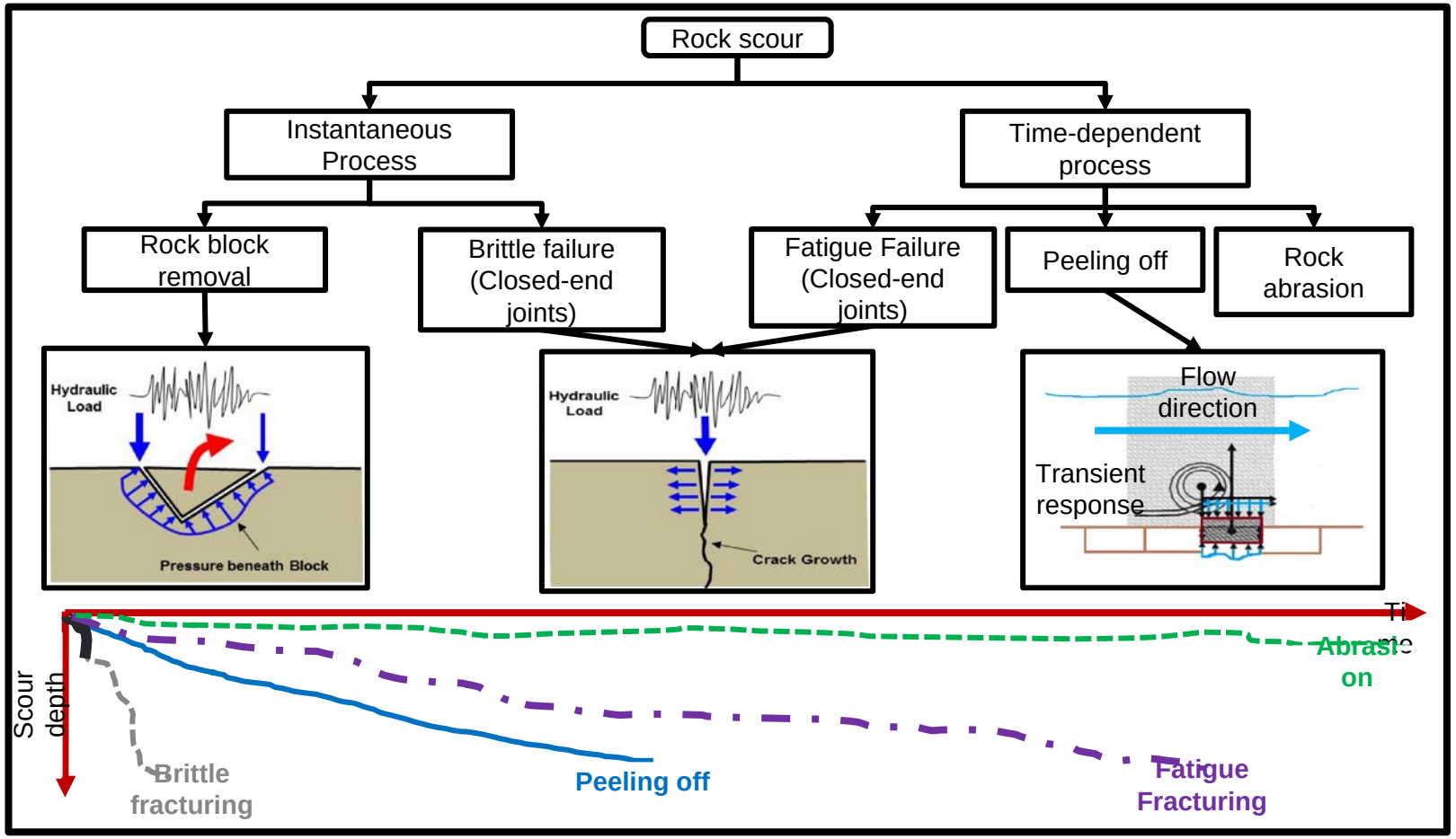
    • Pressure of water?

    • Hydraulic Energy?

  • Study the relationship between rock mass geomechanical parameters, hydraulic parameters and spillways geometrical parameters

  • Large Scale Pilot Test Design

In-Depth Study of Scour Processes



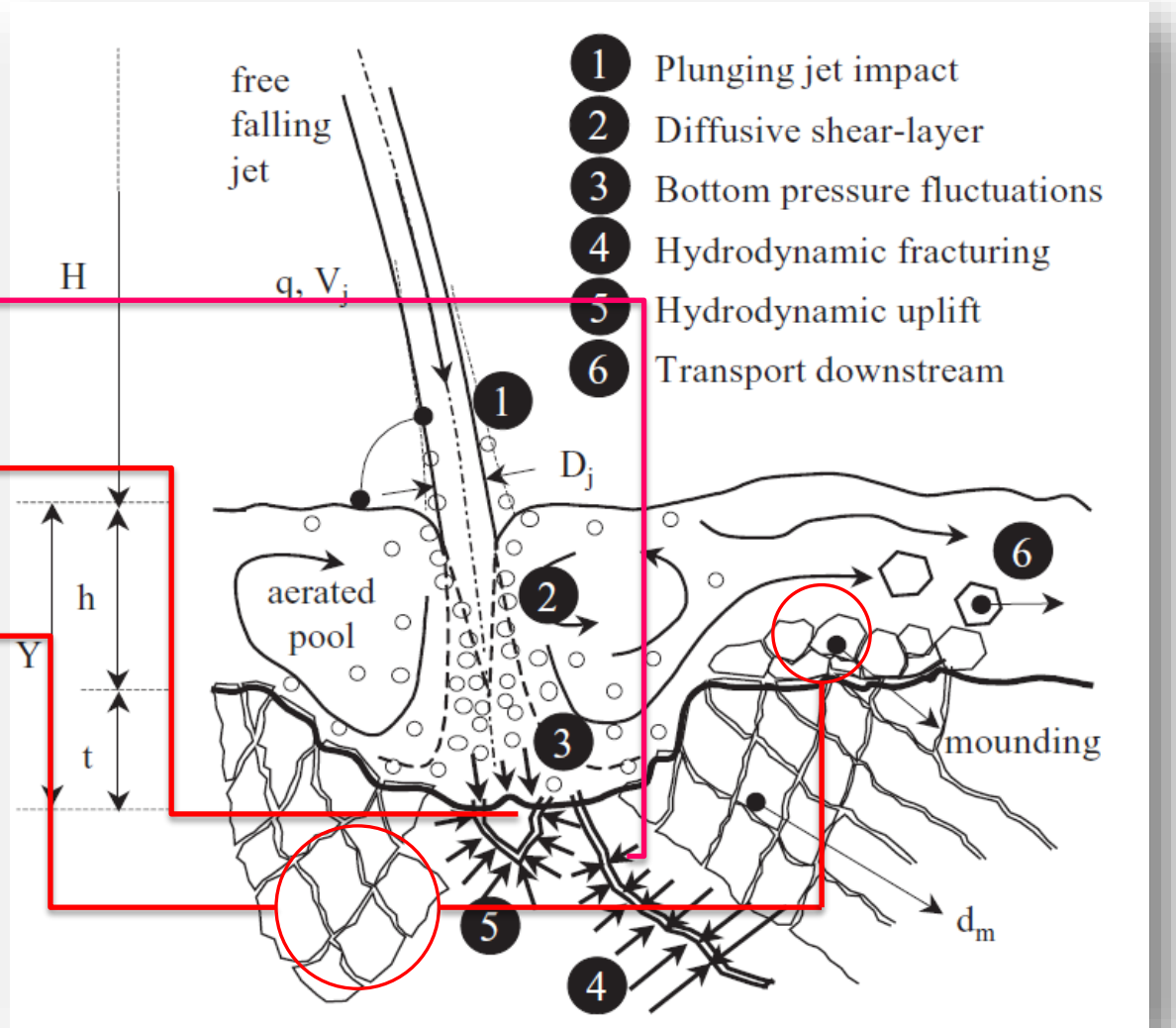
Physics Based Approach

Comprehensive Scour Model (CSM)

Comprehensive Fracture Mechanics ***(CFM)*** ***(Closed-end joints)***

Dynamic Impulsion ***(DI)*** ***(Open-end joints, Single block)***

Quasi-Steady Impulsion ***(QSI)***



Pilot Test Plant Example - UNSW Spillway Erosion Project

Pells, Douglas, Fell, Peirson, UNSW, 2017

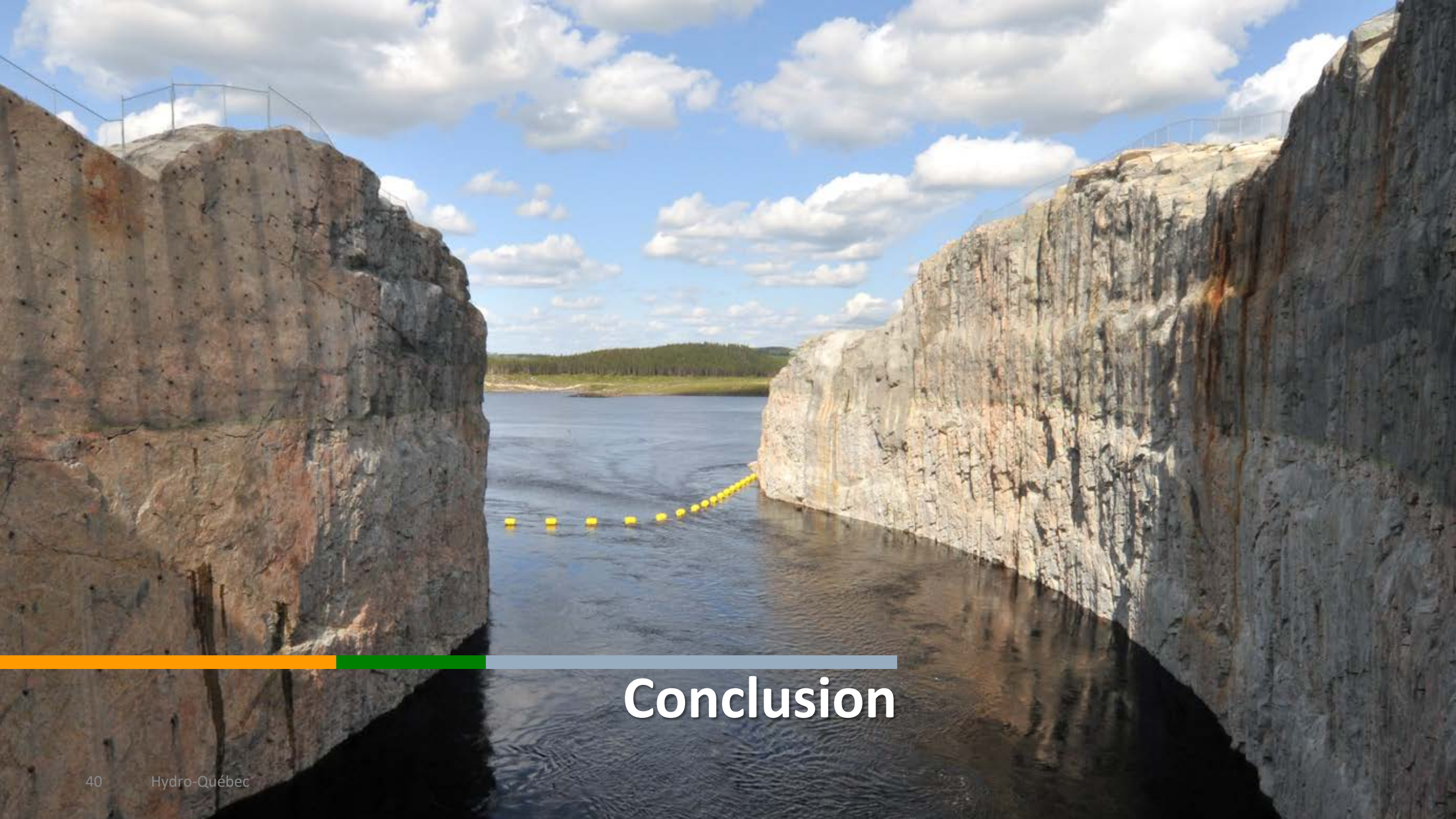
Projects in Preparation

- Postdoctoral Researcher
  - Abbas Kamali involved in research and supporting students
- Master's Research

  Marie-Hélène Wisse
  - Starting Autumn 2020
  - Project description in preparation
- Ph.D Research

  Mahsa Mahdavirad
  - Starting Autumn 2020
  - Project description in preparation

  Student be confirmed
  - Starting 2021



Conclusion

Conclusion

- Research Phase 1
  - Comprehensive study of existing empirical and semi-empirical scour evaluation methods
  - Theoretical determination of relevant geomechanical parameters that has the most influence on erodibility index
- Research Phase 2
  - Design and build medium and large scale physical models
  - Aiming to confirm experimentally the effect of geomechanical parameters on the potential of erosion
  - Study scour mechanisms with a physics based approach
  - Emphasis on better understanding the hydraulic parameters

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- Carl-Oscar Nilsson - Uniper