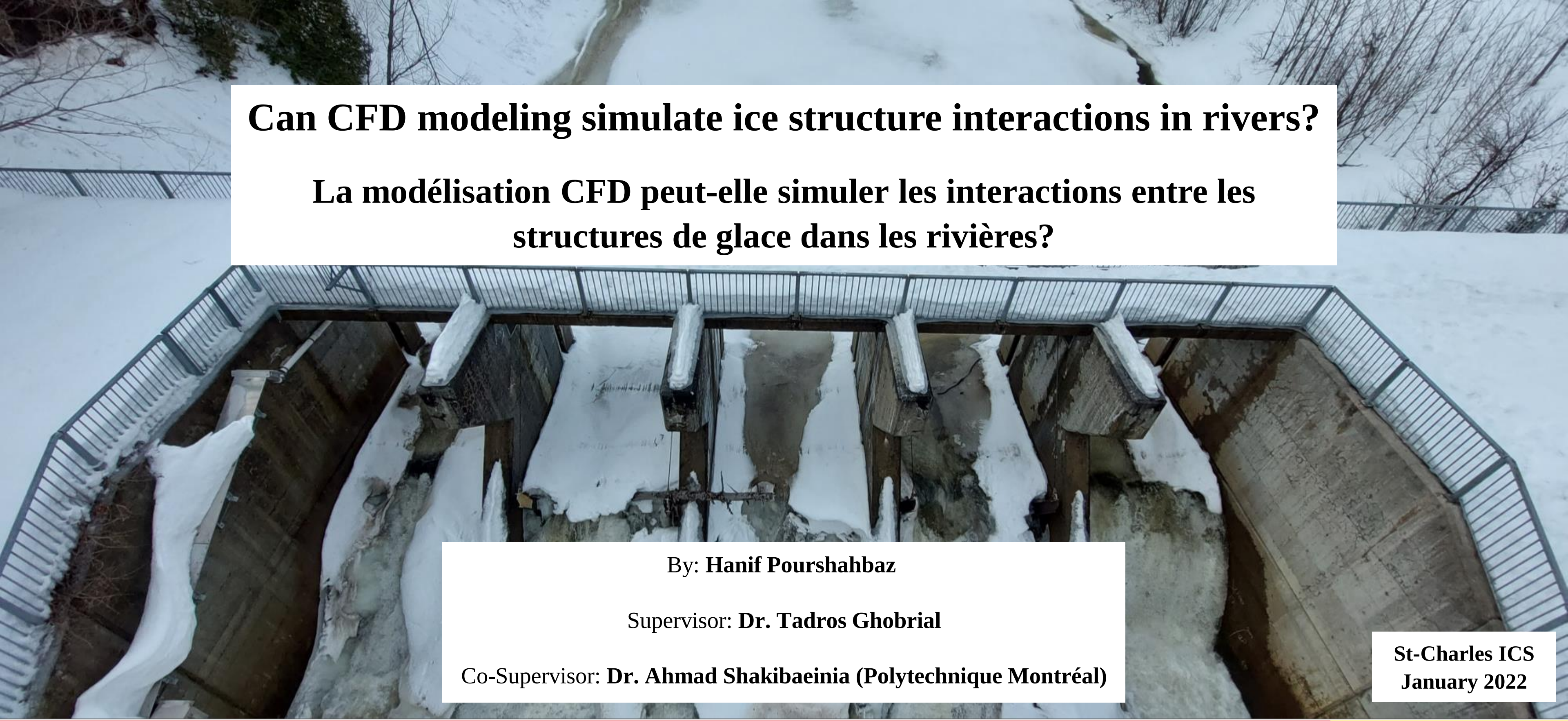

Can CFD modeling simulate ice structure interactions in rivers?

La modélisation CFD peut-elle simuler les interactions entre les structures de glace dans les rivières?

By: **Hanif Pourshahbaz**

Supervisor: **Dr. Tadros Ghobrial**

Co-Supervisor: **Dr. Ahmad Shakibaeinia (Polytechnique Montréal)**

St-Charles ICS
January 2022

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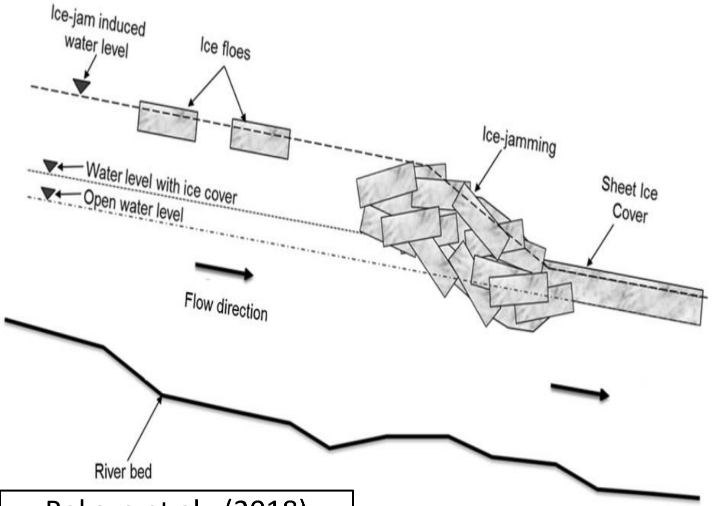
INTRODUCTION - MOTIVATION



Rokaya et al., (2018)

Pourshahbaz et al., (2023)

Introduction - Motivation

An ice jam is a localized accumulation of ice in a river

Extensive blockage of the channel flow

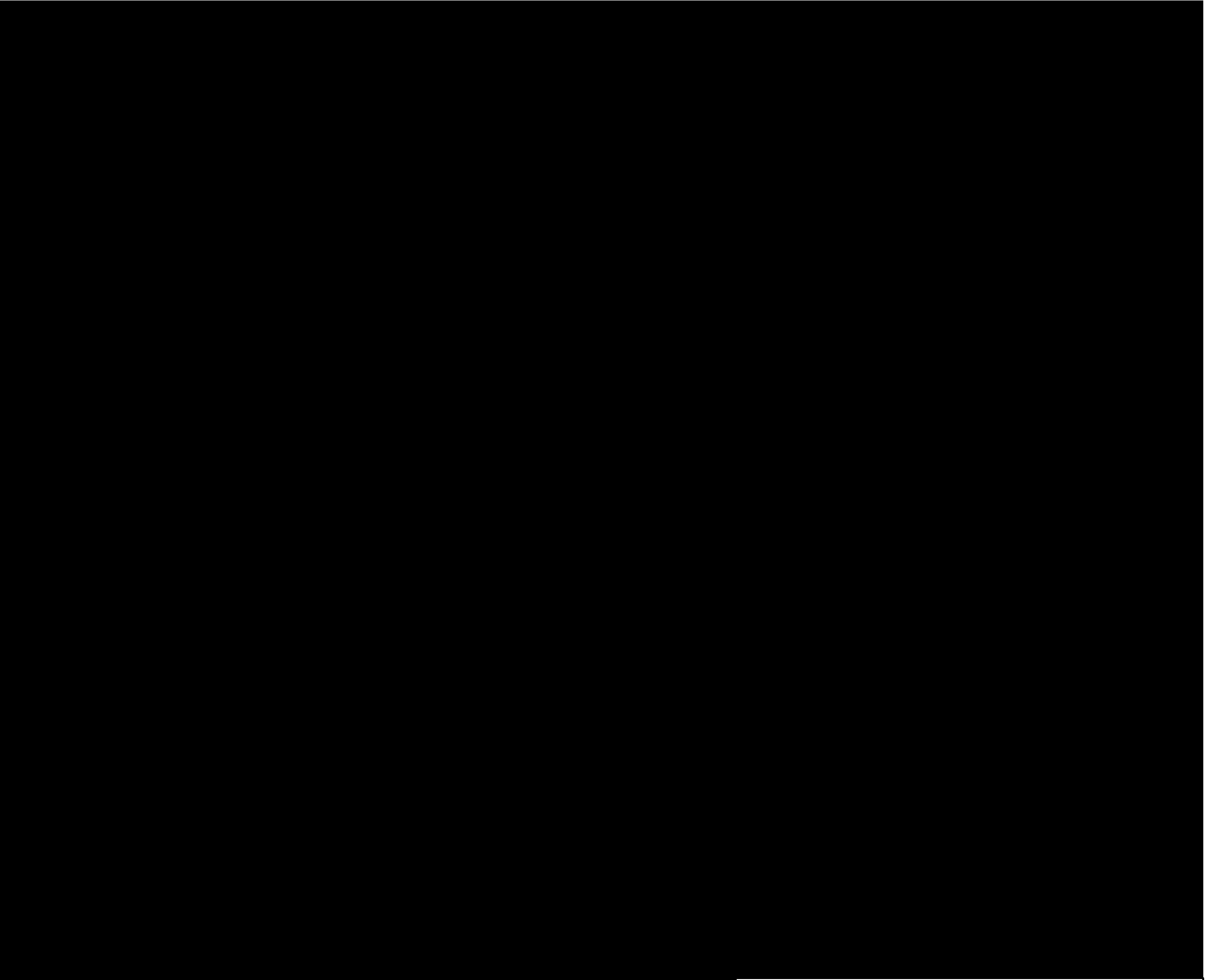
According to their mechanics of formation:

(1) Surface ice jams

(2) Frazil ice jams

Ice thickness, river alignment, slope, and velocity

Water levels rise quickly within minutes due to Ice Jam Floods (IJFs) compared to open water (Beltaos & Prowse, 2001; Mahabir et al., 2006)



Source: Jolicoeur, 2018 (YouTube)

Introduction – Motivation (Cont.)

Ice jam can potentially occur in all rivers that form an ice cover during the winter (Daly and Hopkins, 2001)

Examples:

- Athabasca River, Alberta, Canada in April 2020
- Quebec, Canada

  Chaudière River in April 2019

  Sainte-Anne and Montmorency River in December 2020

Introduction – Motivation (Cont.)

- Mitigation measures to reduce the risk of IJFs could be classified into structural and non-structural measures (Belore et al., 1990; Hicks, 2016)
- Structural measures or Ice Control Structures (ICS) → Construction and design of permanent or temporary engineering structures

Type of ICSs

- Piers or boulders
- Dams and weirs
- Weir with piers
- Ice booms
- Other ICS

Credit River ICS
Source: Tuthill, 1995

Israel River ICS
Source: Vuyovich and White 2006

Sartigan dam
Source: Pourshahbaz January 2023

Sainte-Anne River ice boom
Source: Pourshahbaz October 2021

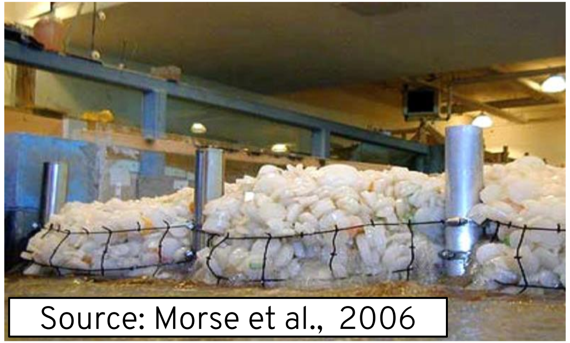
Sainte-Anne River ICS
Source: Pourshahbaz December 2022

Introduction - Motivation (Cont.)

Assessing ICSs' performance

- Historical studies and Long-term field observations
- Laboratory experiments
- Numerical modeling

Source: Lever and Gooch 2005



Source: Morse et al., 2006

Source: Billy et al., 2023

- Historical studies and Long-term field observations

Problems → (1 & 2) Instrumental and accessibility limitations (3) risk in every field monitoring (4) effect of one isolated parameter on the problem

- Laboratory experiments

Problems → Difficulty satisfying the scale effect

Introduction - Motivation (Cont.)

- 1D models → e.g., HECRAS; e.g., Lever & Daly (2003) Cazenovia Creek ICS
- 2D models → e.g., CRISSP2D; e.g., Nolin et al. (2017) Matane River ICS
- 3D methods → e.g., Meshless and Mesh based methods

✓ Highly dynamic interaction of ice and ICS

✓ Vertical velocity fields near ICS

Third dimension

Meshless (Mesh free) methods

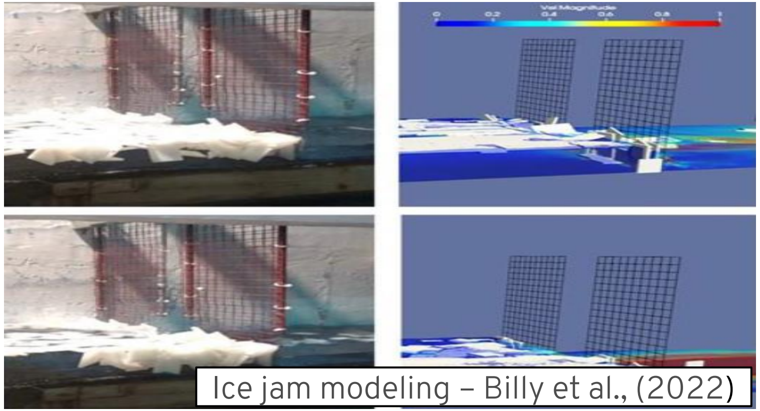
VS

Mesh based methods

Examples: DEM-SPH or DEM-MPS

✓ Free – More flexible and accessible

- Not user friendly

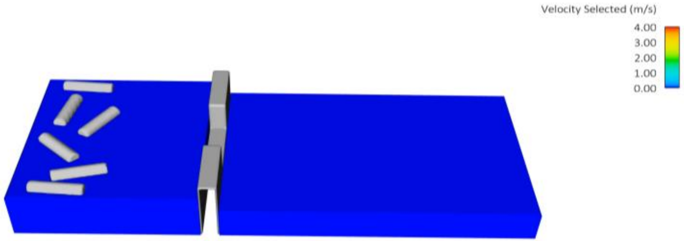


Ice jam modeling – Billy et al., (2022)

Example: DEM-FVM

✓ User friendly

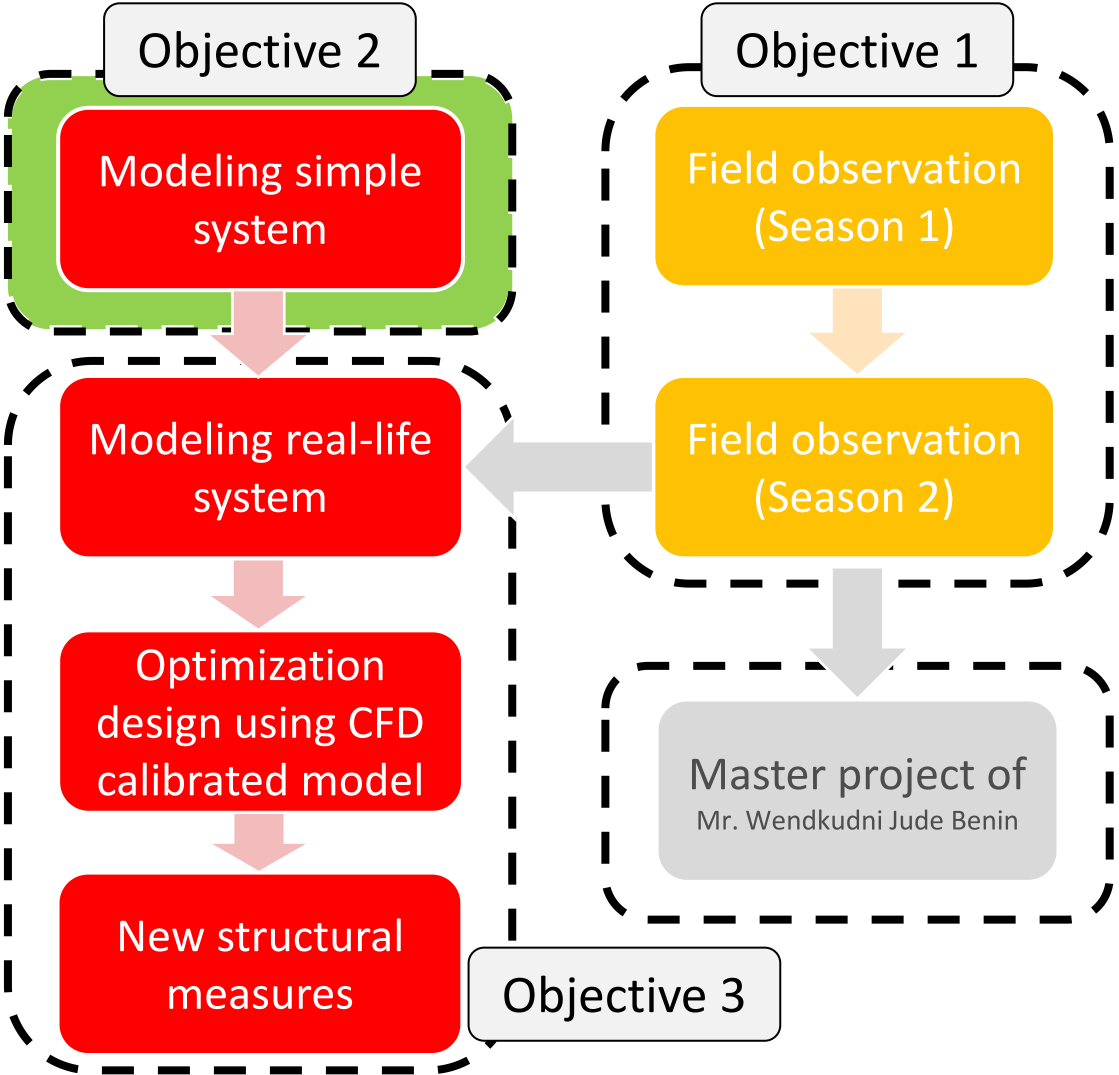
- Commercial software - Some limitations



Floating wood logs across weir by Lau (2021)

✓ Kennedy (1958) → Jam would respond as a "floating granular mass"

OBJECTIVES



Objectives - Overview

1) Quantifying river ice processes at existing ICSs and evaluating the effectiveness of existing structures

- ✓ Choosing and instrumenting the sites and analyzing the data

2) Assessing the capability and performance of numerical methods for simulating the ice-structure interaction

- ✓ Simple cases using laboratory experiments and comparing numerical methods results

3) Optimizing the design of existing ICSs and identifying and evaluating new structural measures

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Objectives – Specific

✓ Evaluating DEM-FVM method (FLOW-3D HYRDO model) for three-dimensional simulation of ice interaction with structures through

Laboratory experiments

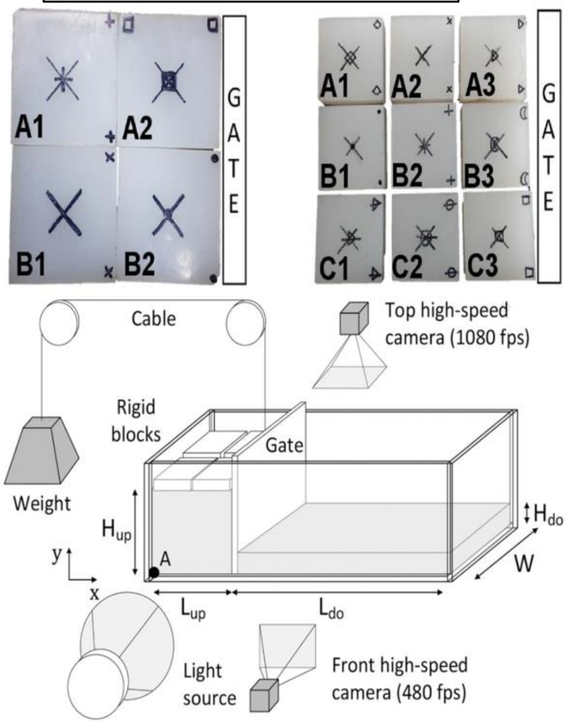
and

Other numerical methods

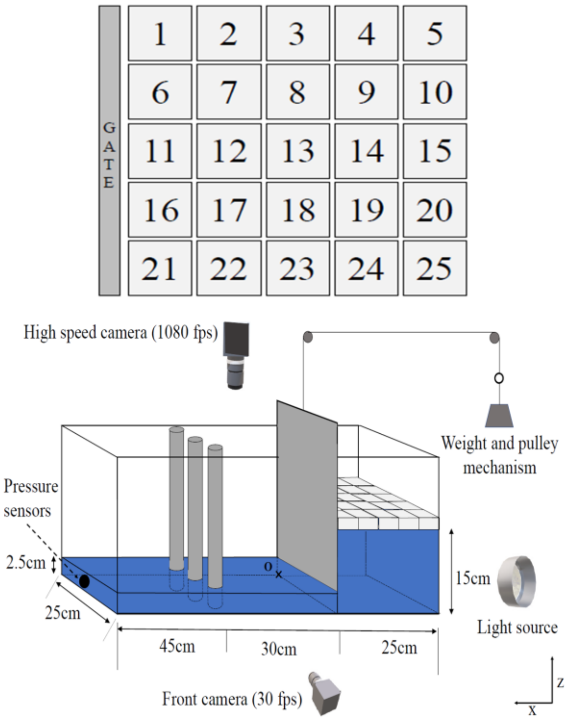
METHODOLOGY

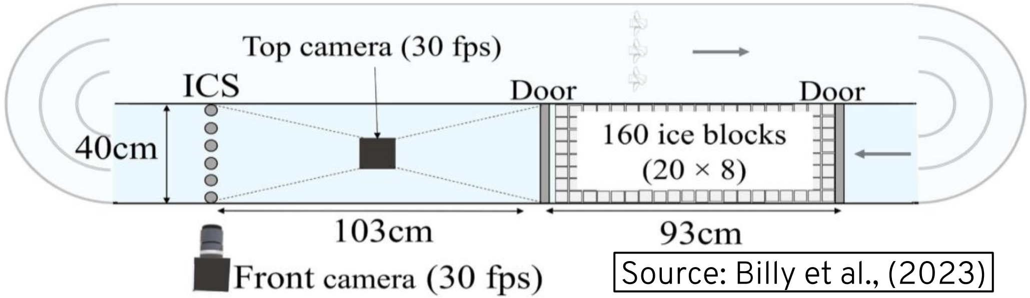
Methodology – Laboratory experiments

Source: Amaro et al., (2021)



Source: Billy et al., (2023)





Source: Billy et al., (2023)

1) Dam break with 4 and 9 blocks (Amaro et al., 2021)
2) Dam break with 25 blocks and interaction with ICS (Billy et al., 2023)
3) Channel case with 160 blocks with ICS (Billy et al., 2023)

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Methodology (Cont.) – Numerical methods

	DEM-MPS Fully Meshless method	DEM-SPH Fully Meshless method	DEM-FVM Mesh-based method
Dam break with 4 blocks	Amaro et al., (2021)		Pourshahbaz et al., (2023)
Dam break with 9 blocks	Amaro et al., (2021)	Billy et al., (2022)	Pourshahbaz et al., (2023)
Dam break with 25 blocks and ICS		Billy et al., (2023)	Pourshahbaz et al., (2023)
Channel with 160 blocks and ICS		Billy et al., (2023)	Future study

RESULTS

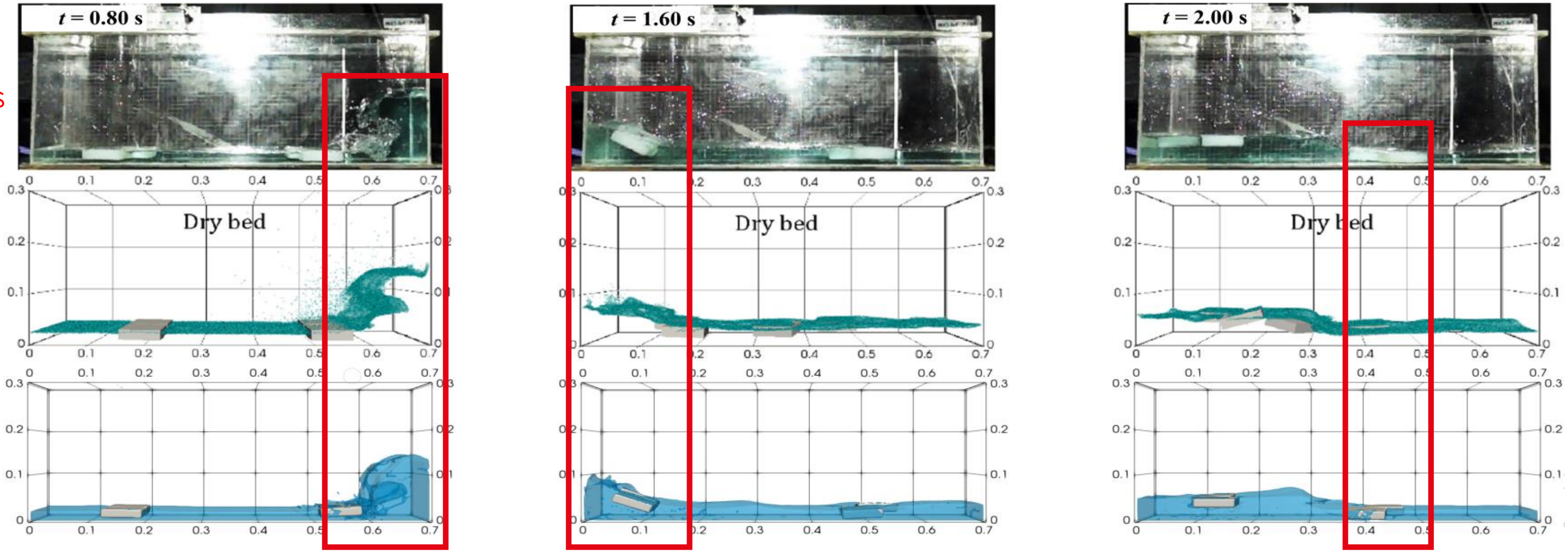
Results – Dam break with 4 blocks

- Acceptable wave profiles and block positions
- t=0.8s, a backward wave was generated
- t=1.6s, the wave reversed
- After t=1.2s, DEM-FVM mehtod exhibits better block positions

Laboratory experiments

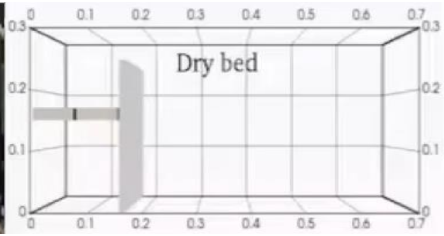
DEM-MPS

DEM-FVM

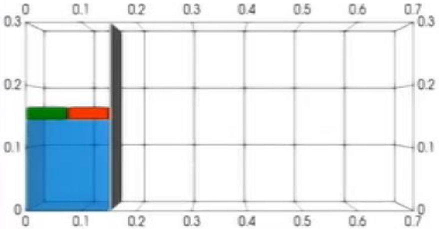


Results (Cont.) – Dam break with 4 blocks

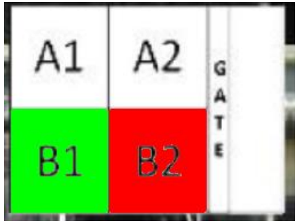
Laboratory experiment

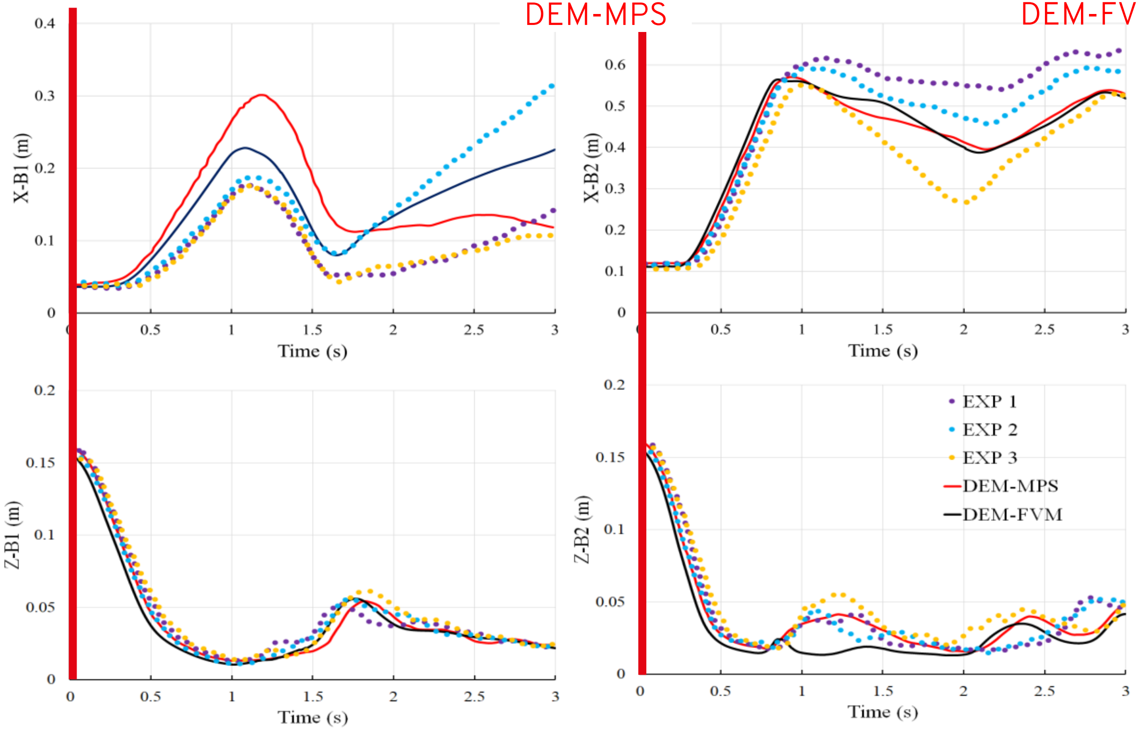


DEM-MPS



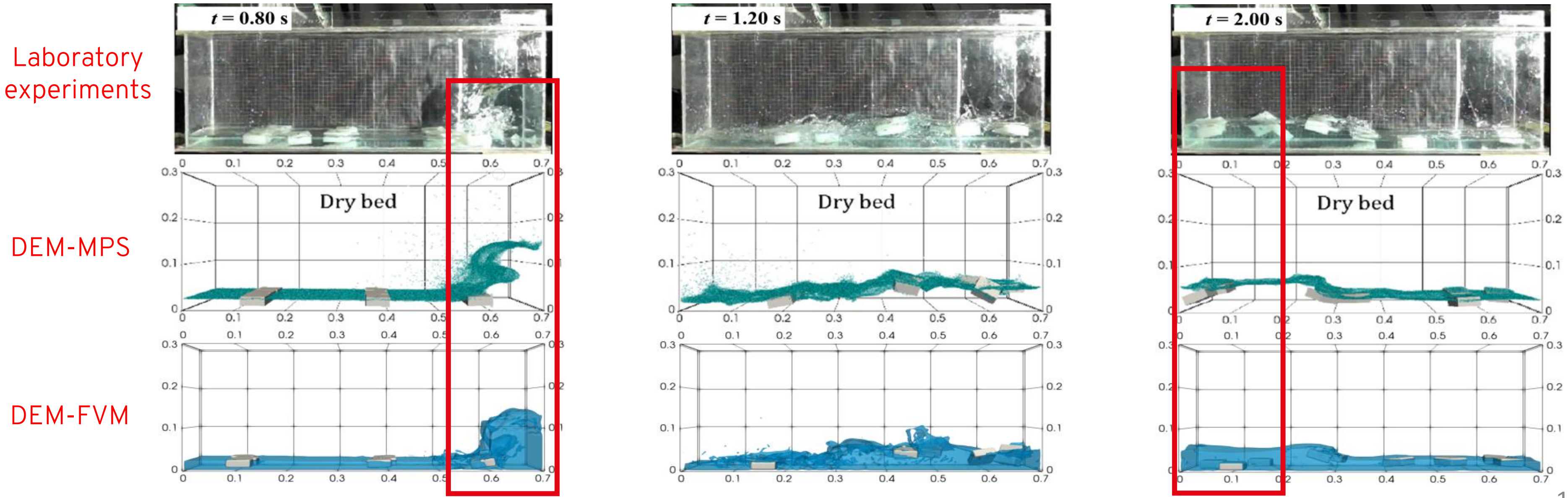
DEM-FVM





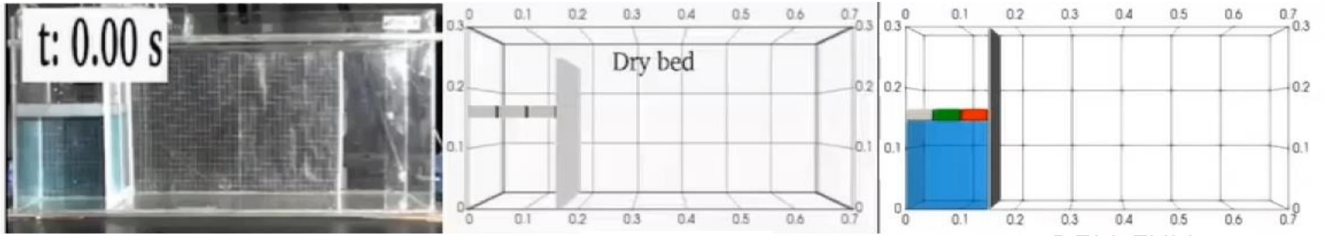
Results – Dam break with 9 blocks

- Both numerical models exhibit good agreement
- t=0.8s, a backward wave was generated
- t=1.2s, wave collapses
- After t=1.6s, last series of blocks stuck in DEM-FVM method



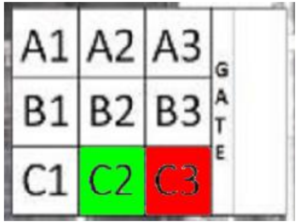
Results (Cont.) – Dam break with 9 blocks

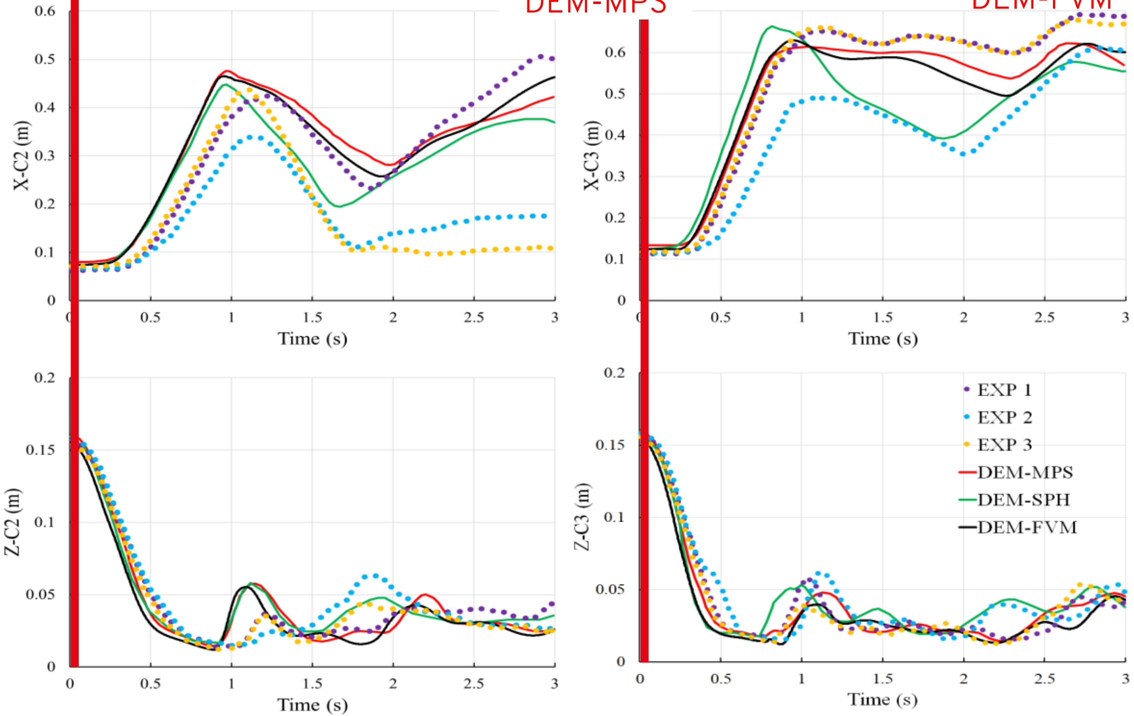
Laboratory experiment



DEM-MPS

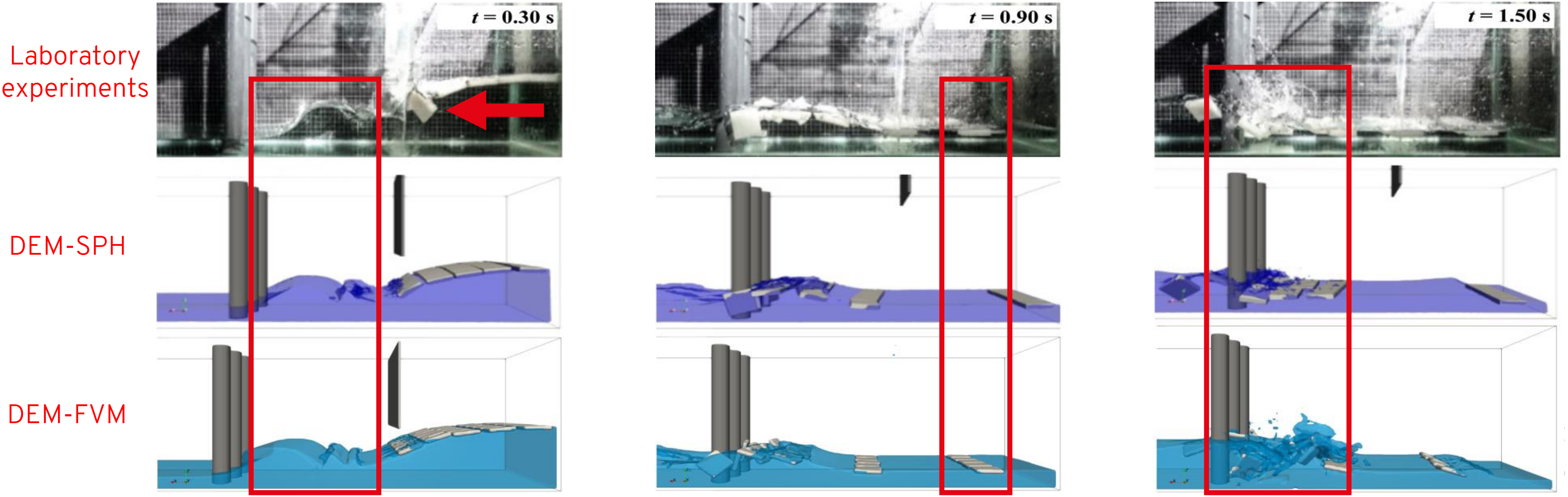
DEM-FVM



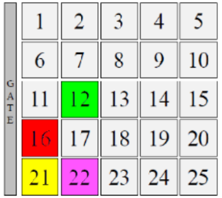


Results (Cont.) – Dam break with 25 blocks

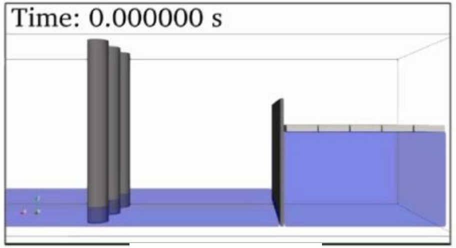
- Numerical wave propagation appears slightly faster in both models
- Flipping of blocks caused by friction with the gate not simulated (t=0.3s)
- The motion of the last row of blocks is accurately simulated by DEM-FVM method
- t=1.5s, shows reflected wave after hitting the downstream tank face



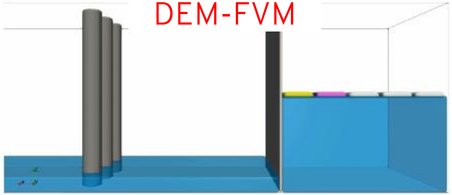
Results (Cont.) – Dam break with 25 blocks

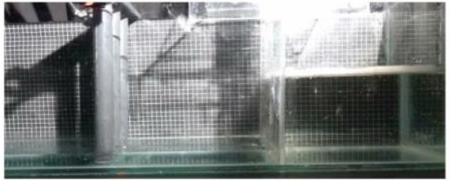


DEM-SPH

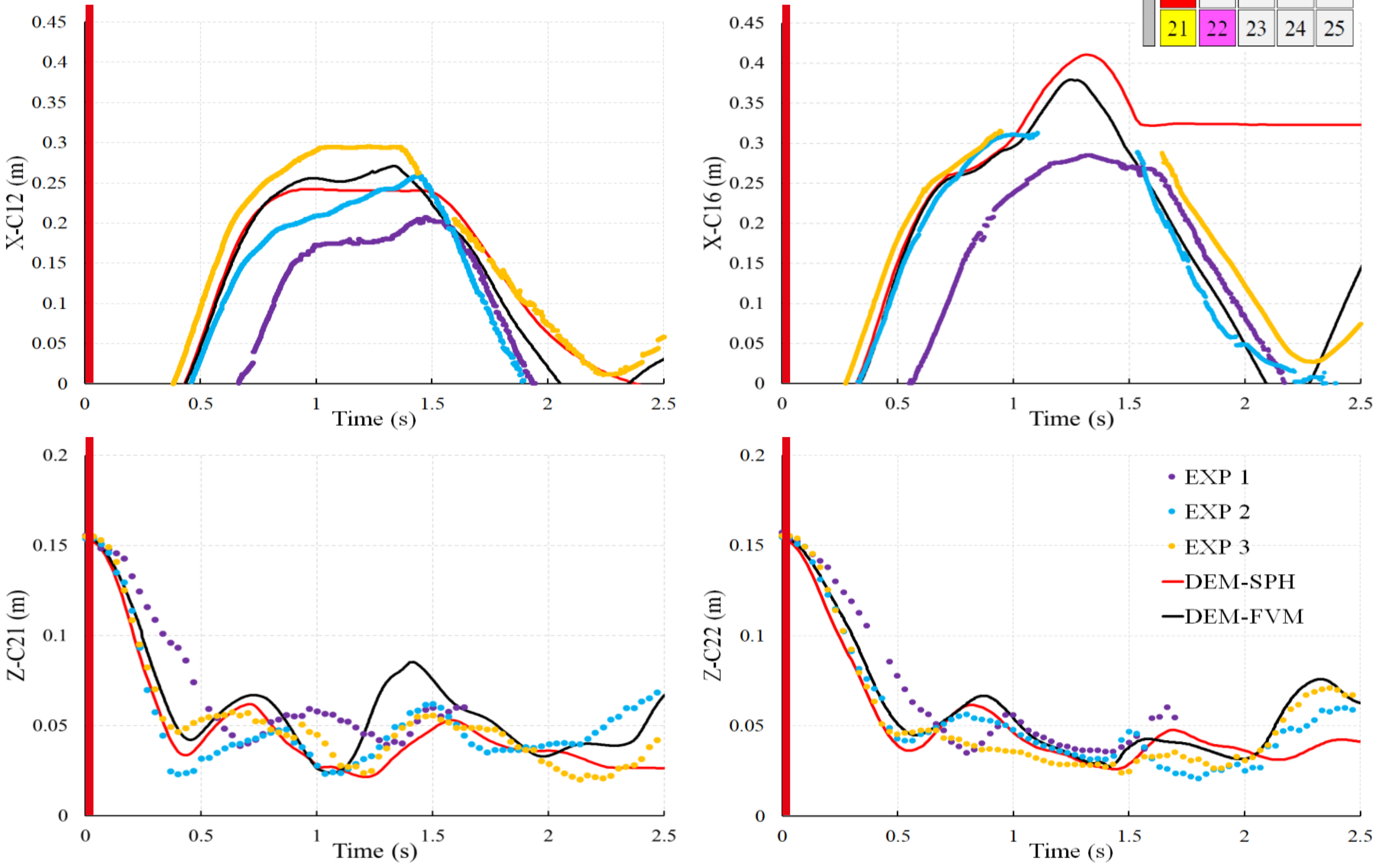


DEM-FVM





Laboratory experiment



Results (Cont.) – Computational time

Numerical method	DEM-FVM mesh-based		DEM-MPS meshless	DEM-SPH meshless
Software/Developer name	FLOW-3D HYDRO		MPARS	DualSPHysics
Case study	4 and 9 blocks	25 blocks	4 and 9 blocks	25 blocks
CPU	Intel(R) Core(TM) i7-10700 @ 2.90GHz		Intel(R) Xeon (R) E5 v2 @ 2.80 GHz	Intel(R) Core(TM) i7 @ 3.60GHz
CPU cores	8		20	8
GPU	---*		---**	NVIDIA GeForce GT 730
CUDA cores	---*		---**	384
Number of cells or particles	1,450,000	1,780,000	1,500,000	1,797,790
Physical time (s)	3.0		3.0	3.0
Total runtime (h)	28	57.2	30 - 60	23.5

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Results (Cont.) - Conclusion

- The DEM-FVM method demonstrated high accuracy and its capability to effectively handle dynamic interactions among water, ice, and structures
- DEM-FVM method exhibits accuracy and computational performance that are comparable to those of affirmation mesh-free fully Lagrangian methods
- While DEM-FVM method offers a user-friendly interface, its application is limited unlike open-source methods.

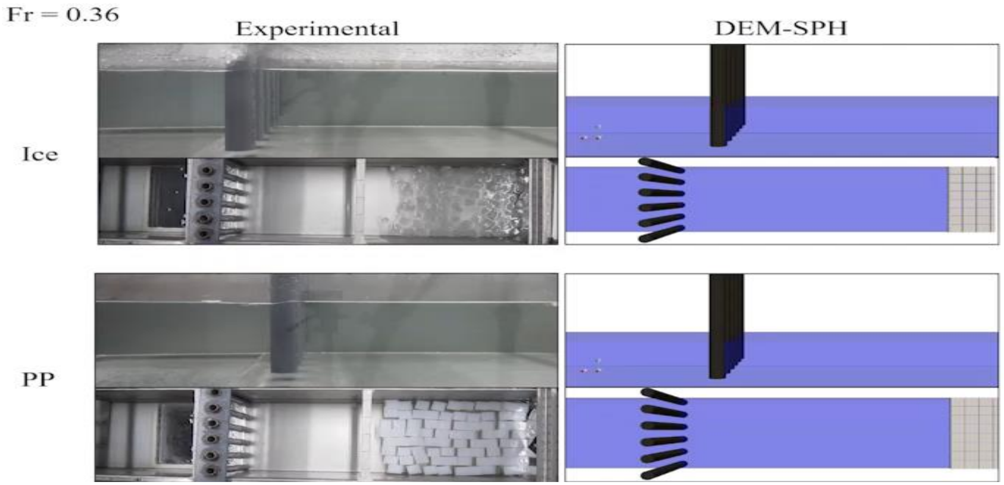
ACCOMPLISHMENTS AND FUTURE WORKS

Accomplishments

- Preliminary results from numerical modeling are published in CRIPE 2023 conference with the title of “Evaluating a CFD model for three-dimensional simulation of ice structure interaction”

Future works

- Quantified the evaluation and make a comparison between DEM-FVM method and meshfree methods
- Cases with higher number of blocks as FLOW-3D HYDRO limit is 500 objects
- Try different influential factors that can have effects on the results, like different turbulence models
- Model real life systems



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ACKNOWLEDGEMENTS

Acknowledgements

- The Quebec Ministry Public Safety

- FLOW-3D® software made available through the FLOW-3D Academic Program.

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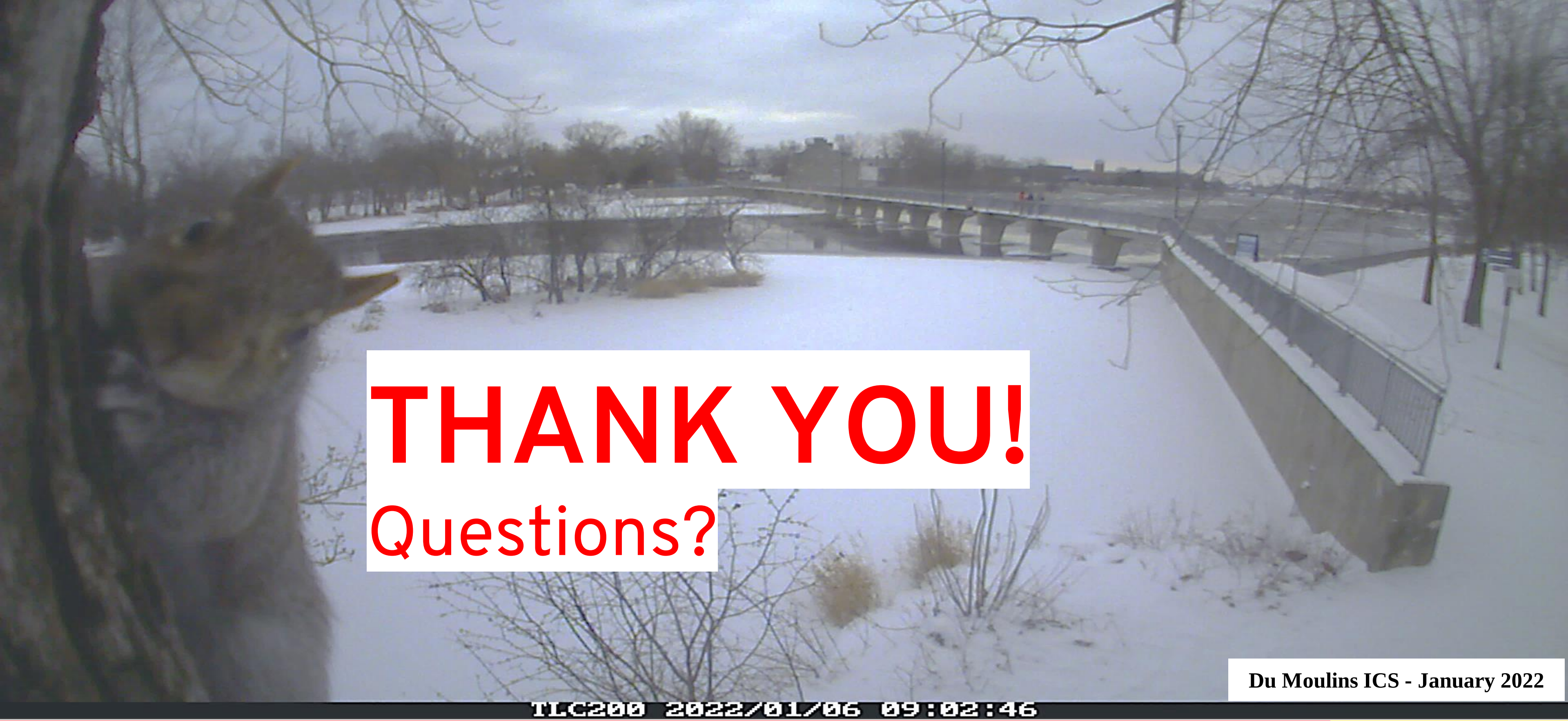

THANK YOU!

Questions?

Du Moulins ICS - January 2022

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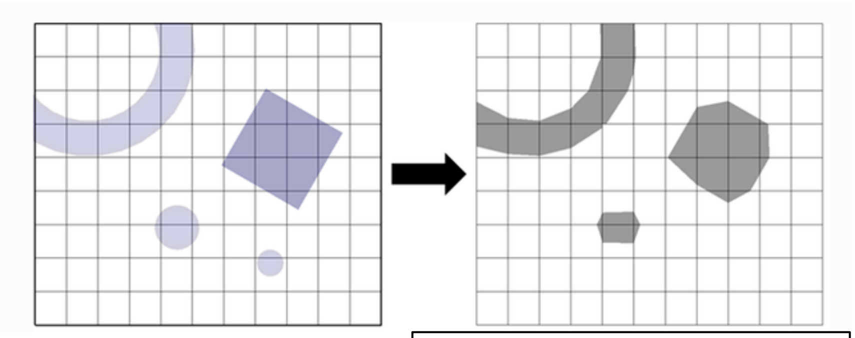
APPENDIX

Appendix (1)

Used methods and calibrated values



Source: FLOW-3D manual

✓ Physical Parameters

Coefficient of Restitution = 0.68

Coefficient of friction = 0.412

Limited to define the material (Young's modulus)

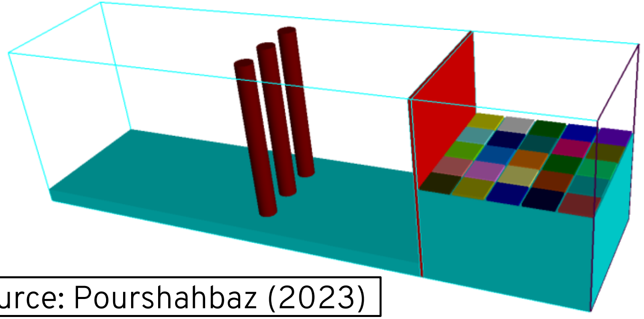
✓ Numerical Parameters

Volume-of-fluid advection = Split Lagrangian method

Order of momentum equation approximation = second order

FAVOR tolerance = 0.0001

Pressure solver type = GMRES algorithm



Source: Pourshahbaz (2023)

✓ Grid size (cell size)

1,450,000 cells – 2.8 mm (4 & 9 blocks cases) and 1,780,000 cells – 3.5 mm (25 blocks cases)

Appendix (2)- Field observations (Winter 2022 – 2023)

- Instruments:

Water level sensors; Water temperature sensors; Acceleration Pendant (Anchor ice); Trail cameras

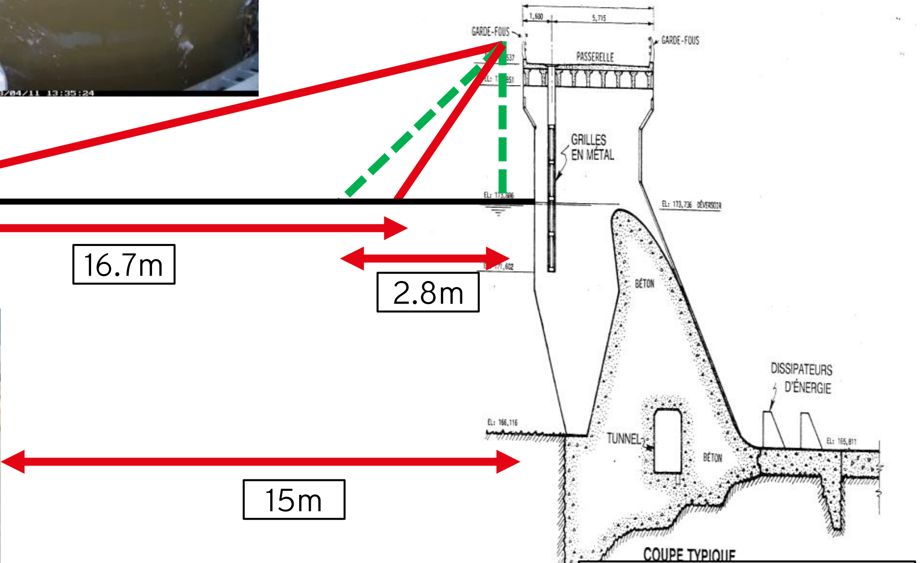
ADCP with Echogram

Velocity field around the ICS + Geometry of floating ice Ghobrial et al. (2013)

45 Degree – April. 2023

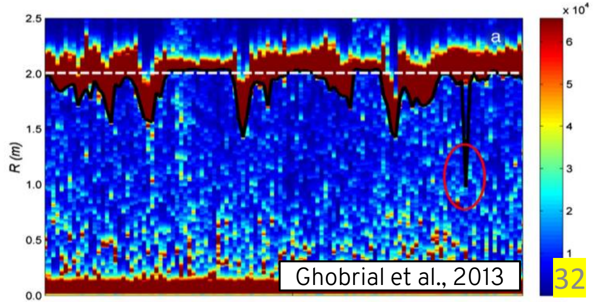
90 Degree – April. 2023

Pierre – Nov. 2022



Laganiere & Larouche

Pourshahbaz – Nov. 2022



Ghobrial et al., 2013