ON THE NUMERICAL MODELLING OF THE JET EROSION TEST

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Outline

INTRODUCTION

❶The Jet Erosion Test

❷CFD Numerical Modelling

❸Results

CONCLUSION

CONTEXT

- Most ruptures of embankment hydraulic structures are induced by erosion (Foster, 2000)
- To quantify the soil resistance to erosion several test apparatus have been developed : Jet Erosion Test (Hanson and al., 2002) among others

  ⇨ measurements of erosion characteristic parameters

  ⇨ time remaining before failure of the hydraulic structure

  ⇨ necessary to verify the reliability of the interpretation model.

OBJECTIVES

- To develop a numerical model able to predict the erosion due to turbulent flows :

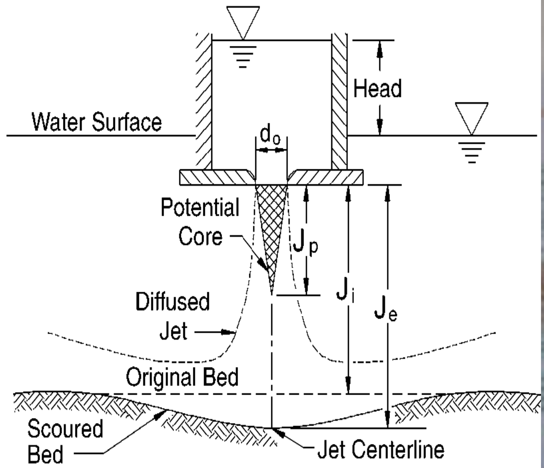
  ⇨ For a better understanding of the erosion processes

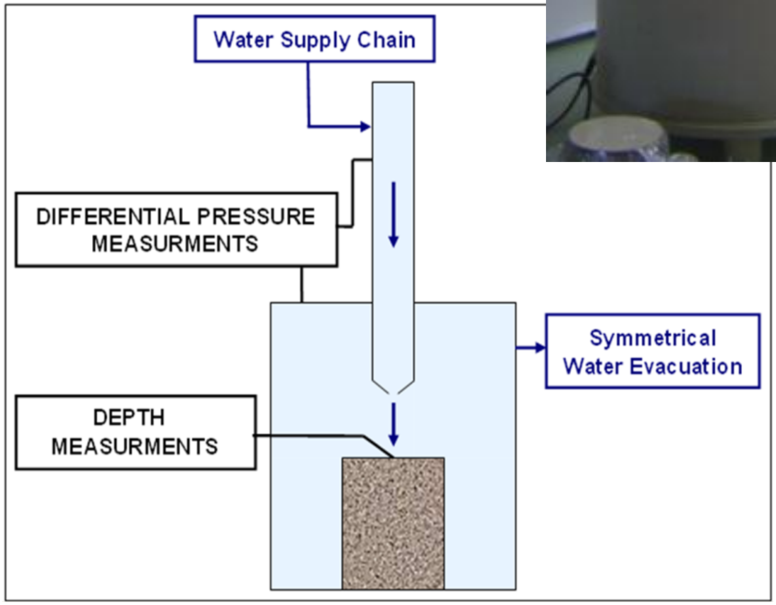
  ⇨ Eventually to justify or/and to improve the Jet Erosion Test interpretation model.

Hanson et al. (2002)

- Testing apparatus which provides the erodibility parameters of the soil : kinetic erosion coefficient (k_d) and critical shear stress (τ_c).
- Operational in laboratory or in situ.
- Interpretation model based on
  - Hydraulic theoretical and semi-empirical relations,
  - Determination of a friction coefficient,
  - Empirical relation between the interface velocity (c_Γ) and the flow shearstress (τ) at the water/soil interface :

$$c_\Gamma = \begin{cases} k_d(\tau - \tau_c) \text{ if } \tau > \tau_c \\ 0 \text{ else} \end{cases}$$





Fine cohesive soils, fluid/soil interface of no thickness

NAVIER-STOKES TURBULENT MODELLING WITH INTERFACE MOVEMENT AND REMESHING

Hypothesis:

- Eroded particles are transported immediately by the flow out of the eroded area => diluted flow hypothesis and vice-versa (particle concentration < 0.1%)
- Erosion velocity << flow velocity => stationary flow ($1 < V_{flow} < 10$ m/s, $10^{-8} < k_d < 10^{-3}$ m².s/kg)

GOVERNING EQUATIONS:

Conservation Equations

$$\begin{cases} \nabla \cdot \mathbf{u} = 0 \\ \rho_w \left[\dfrac{\partial \mathbf{u}}{\partial t} + (\nabla \mathbf{u}) \cdot \mathbf{u} \right] = \nabla \cdot \mathbf{T} \end{cases}$$

- $\mathbf{u}$ averaged velocity
- ρ_w water density
- $\mathbf{T}$ Reynolds stress tensor
- p static pressure
- μ_w molecular viscosity of water
- $\mathbf{u}'$ velocity fluctuations
- $\mathbf{D}(\mathbf{u})$ symmetrical part of velocity gradient

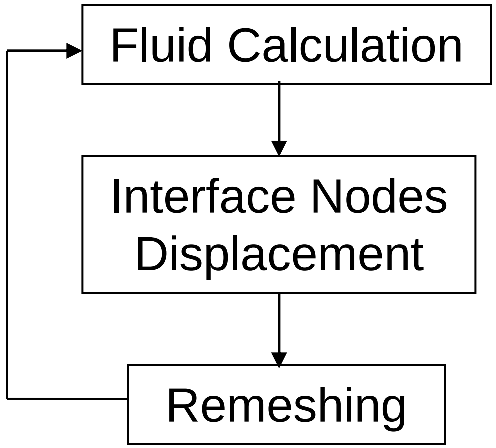
Flow Constitutive Law

$$\mathbf{T} = \underbrace{-p\mathbf{I}}_{\text{static pressure}} + \underbrace{2\mu_w \mathbf{D}(\mathbf{u})}_{\text{viscous stresses}} \underbrace{-\rho_w \overline{\mathbf{u}' \otimes \mathbf{u}'}}_{\text{turbulent stresses}}$$

Conditions on the Moving Frontier

$$\mathbf{u} = 0, \; c_\Gamma = \begin{cases} k_d(\tau - \tau_c) \text{ if } \tau > \tau_c \\ 0 \text{ else} \end{cases}$$

EULERIAN / LAGRANGIAN NUMERICAL MODEL:



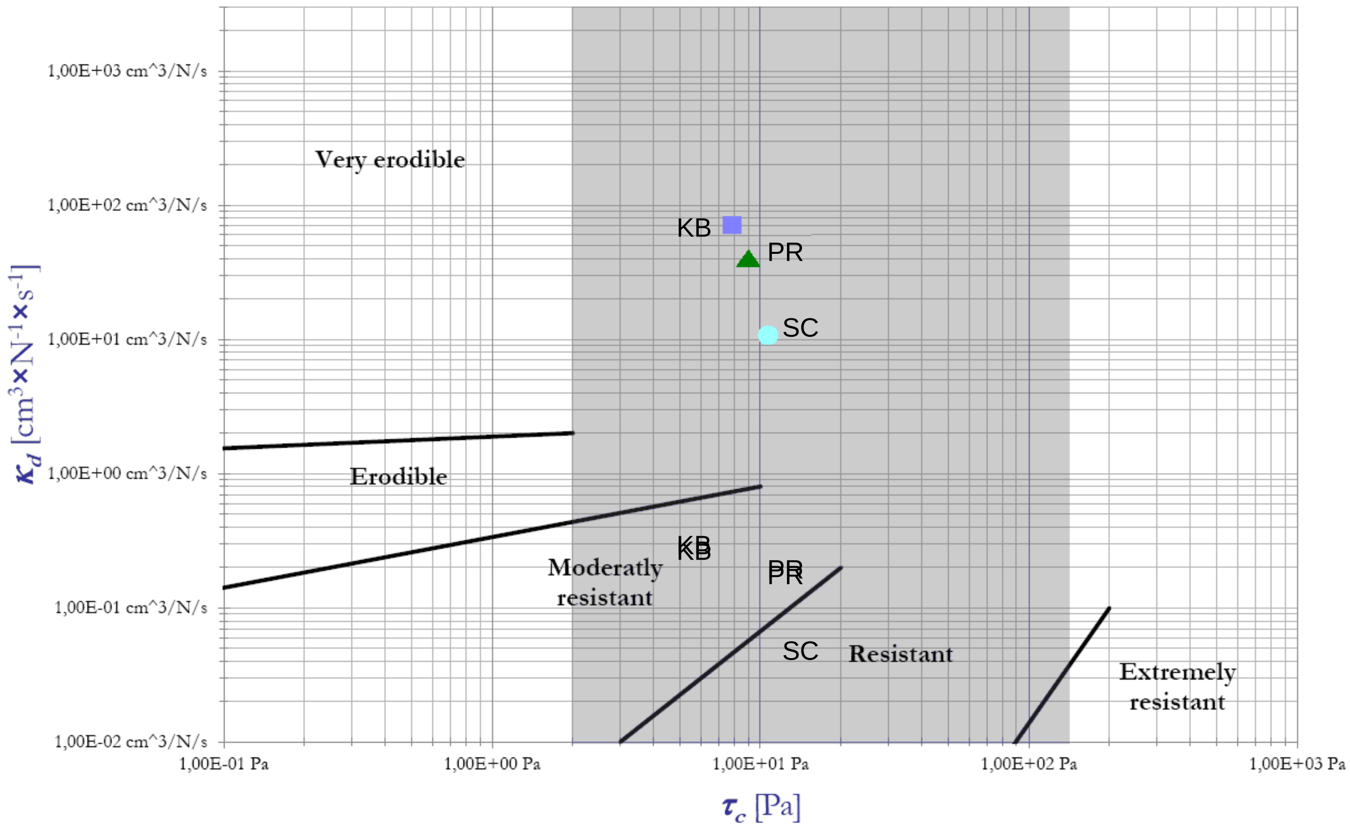
Lagrangian approach: mesh follows continiously the interface evolution
→ determine the movement of the "monitored interface"

Main advantage:
→ allows to model a flow through obstacles of complex shape, with a fine description of the phenoma which occur near the walls.
=> describes finely the stress at the fluid/soil interface

A full calculation of the erosion process for a typical JET test :

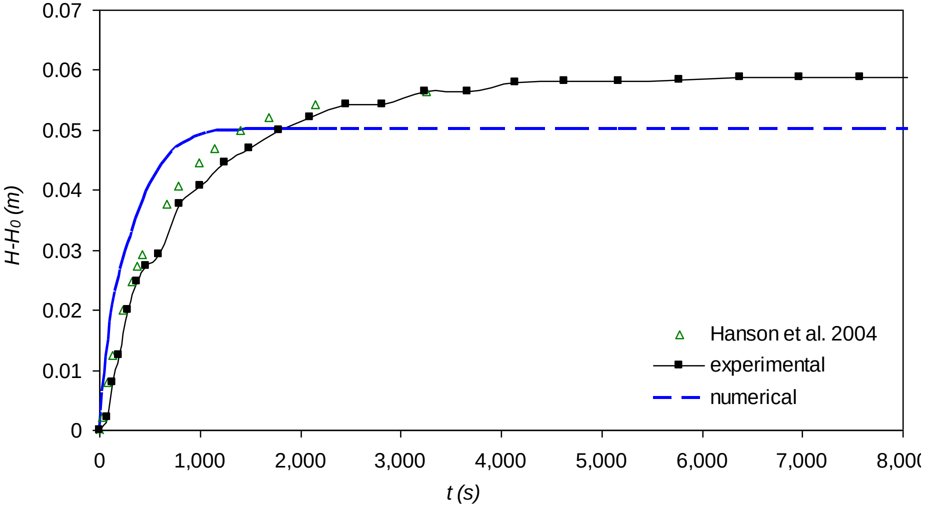
≈ 1 month calculation on the 8 cpu of a bi-processor node (Intel Xéon EMT64 3.2 GHz)

NUMERICAL MODELLING OF 3 JET EROSION TESTS :

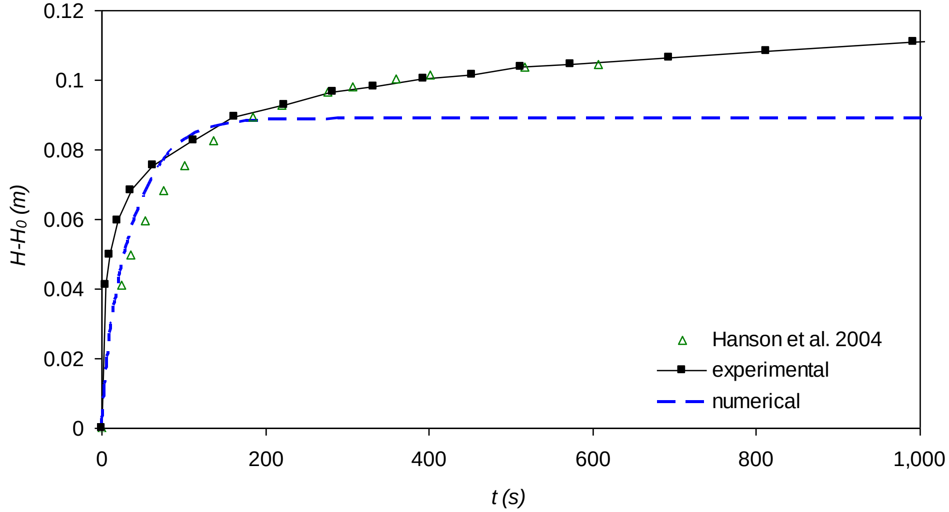


	SC	KB	PR
Pressure gradient (Pa)	30 000	14 100	15 200
Initial distance jet outlet / soil surface (cm)	14.6	7.8	4.1
Critical shearstress (Pa)	11	8.5	9.1
Erosion coefficient (m².s/kg)	1.0×10^{-5}	7.2×10^{-5}	4.5×10^{-5}

SC



PR



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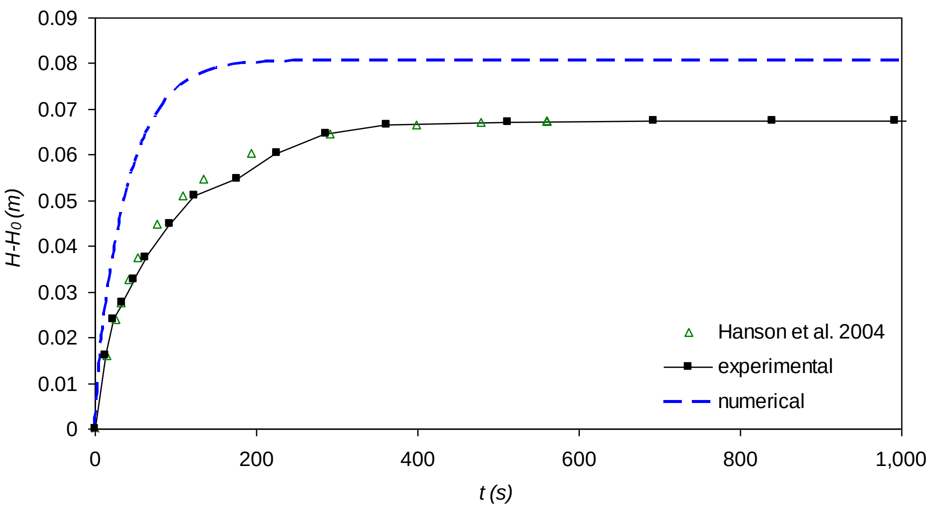
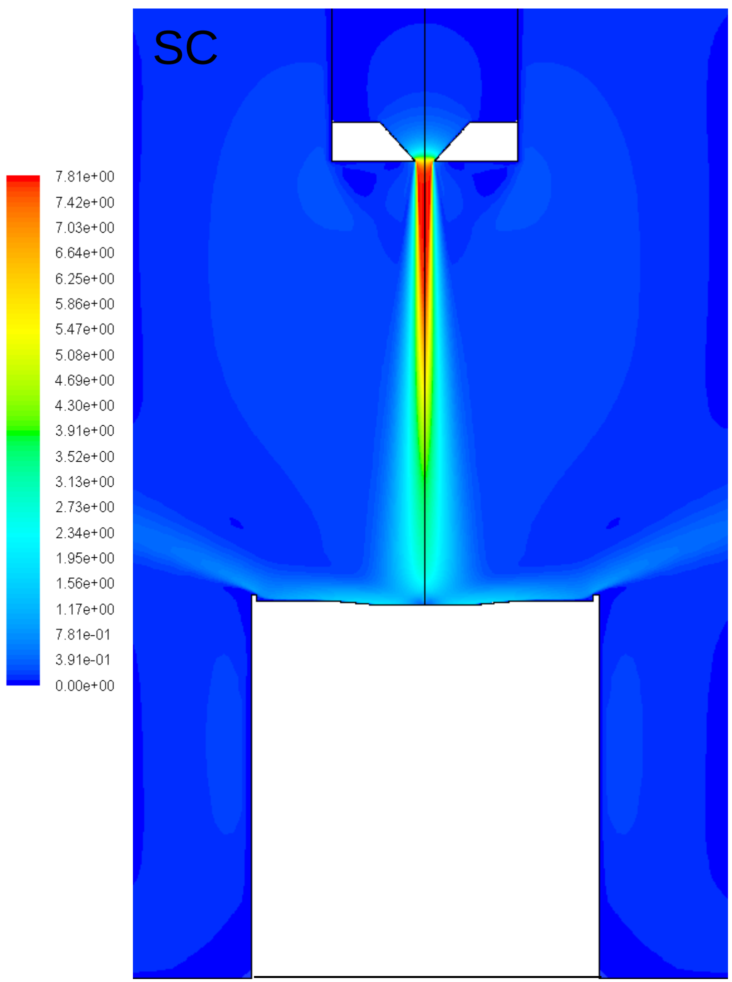
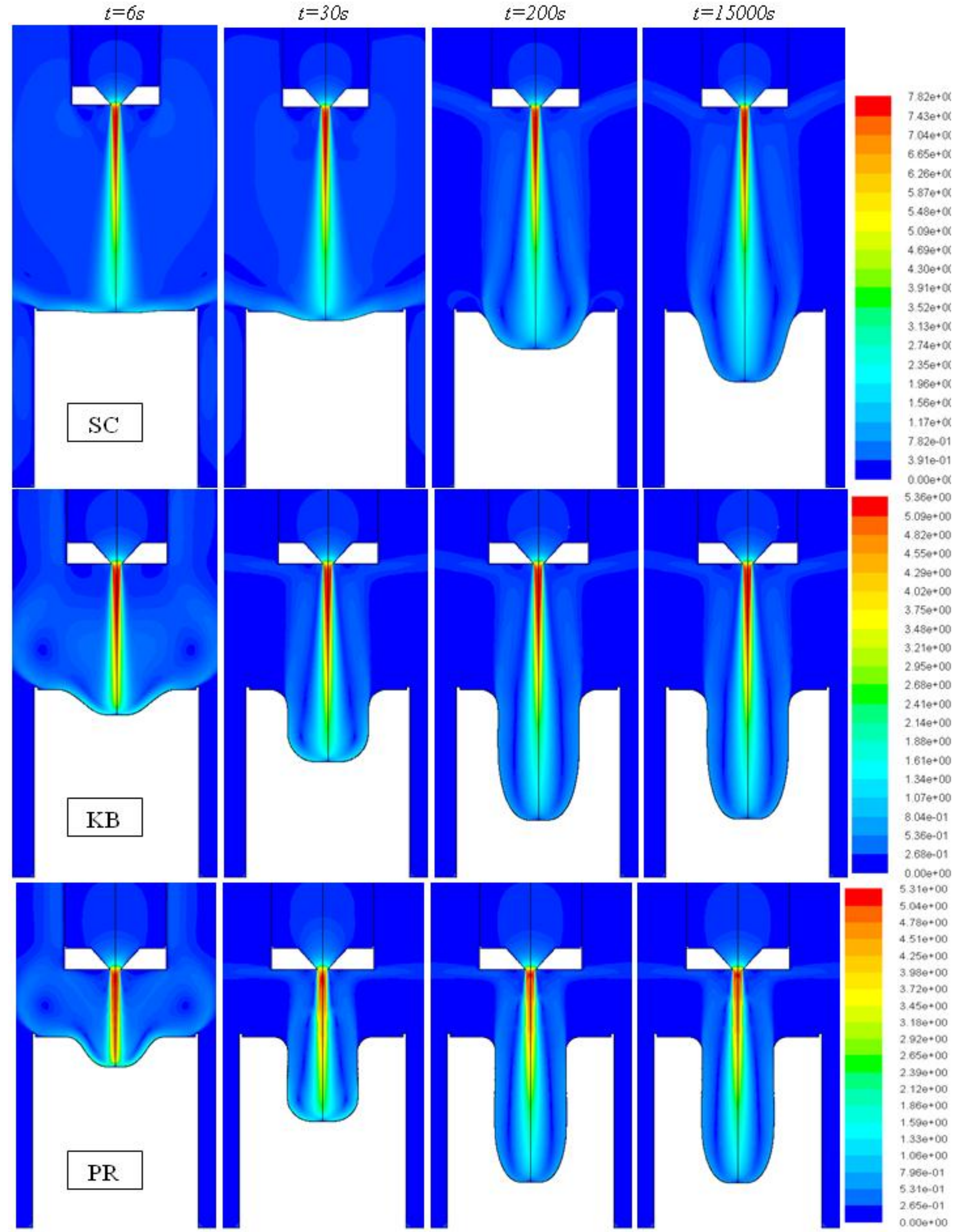


=> Good agreement between numerical, experimental and (Hanson et al., 2004) interpretation model

VELOCITY FIELDS





CONCUSION

- Our numerical model is able to predict the erosion of a soil by a turbulent flow

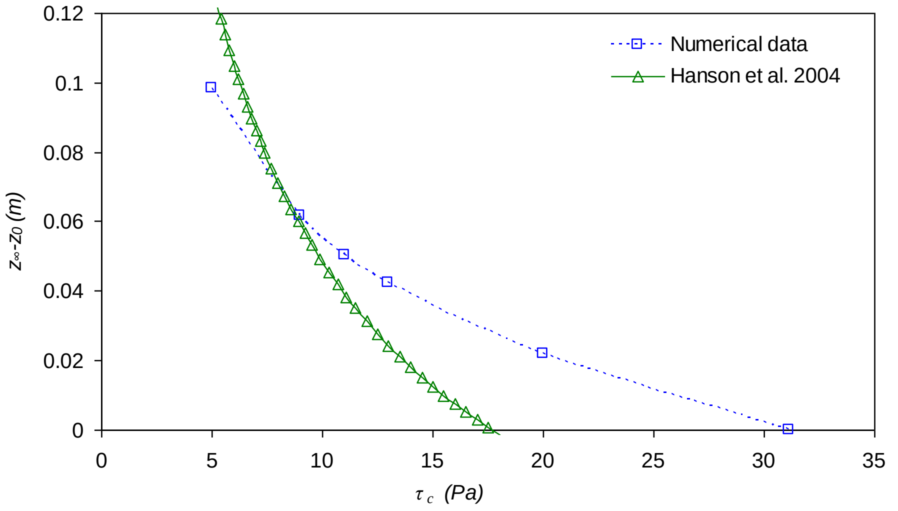
  => Good agreement between numerical, experimental and (Hanson et al., 2004) interpretation model

  => First numerical validation of Hanson model based on complex turbulent modelling

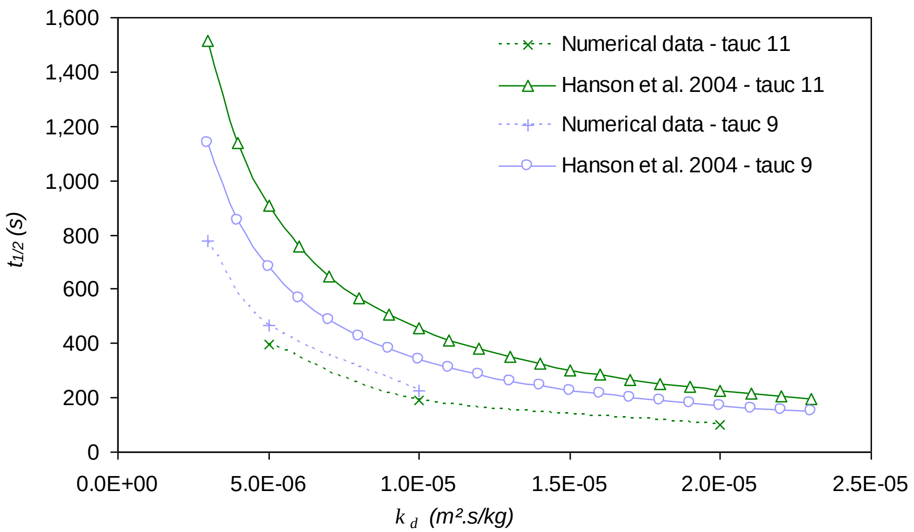
- Better understanding of the flow behaviour in the scour

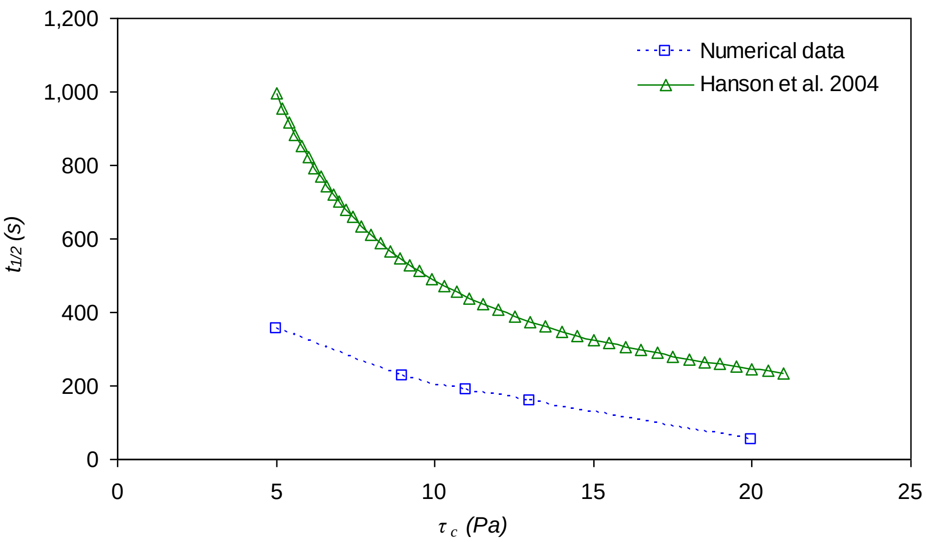
To be continued…

THANKS FOR YOUR ATTENTION



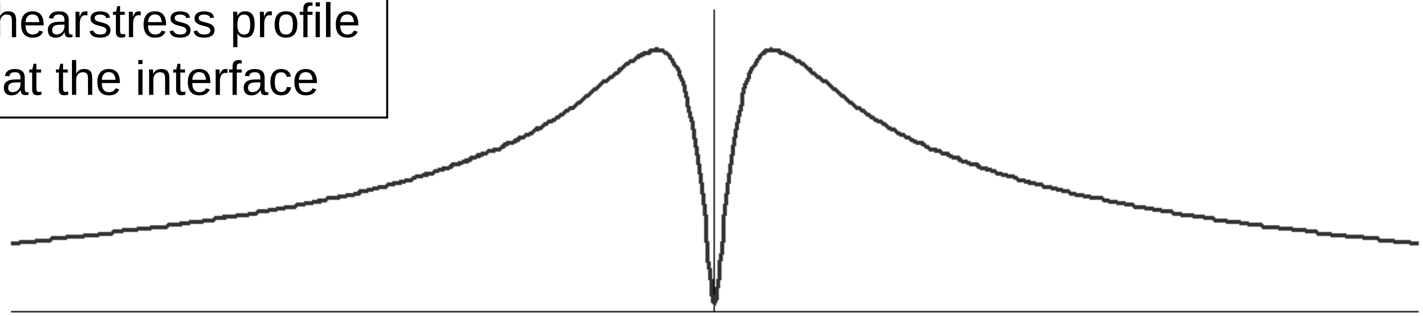
STUDY OF THE CRITICAL SHEARSTRESS AND EROSION COEFFICIENT



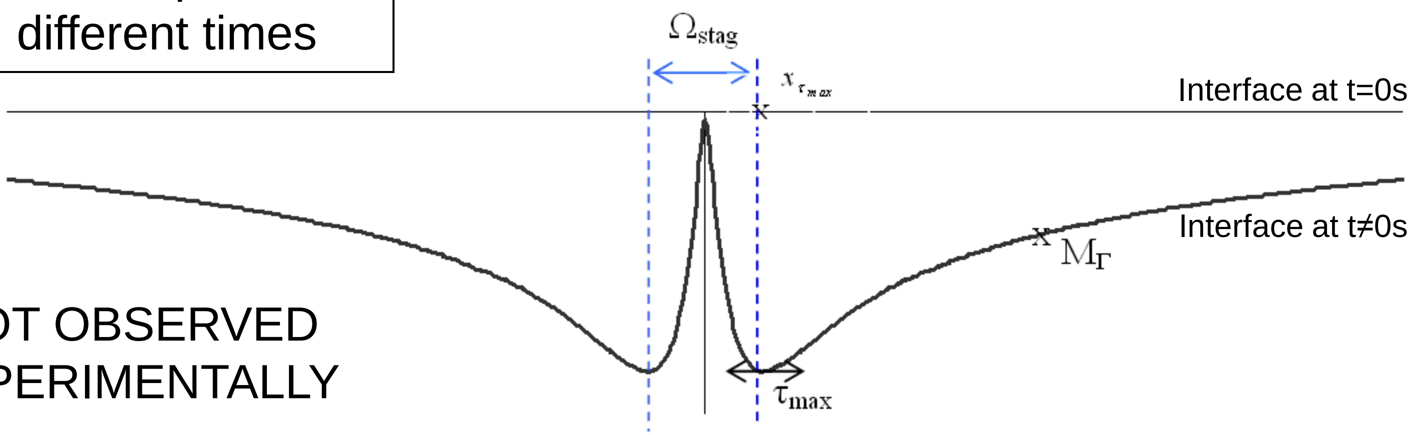


$$c_\Gamma = \begin{cases} k_d(\tau_{\max} - \tau_c) \text{ if } \tau_{\max} > \tau_c \text{ in } \Omega_{\text{stag}} \\ k_d(\tau - \tau_c) \text{ if } \tau > \tau_c \text{ and out of } \Omega_{\text{stag}} \\ 0 \text{ else} \end{cases}$$

Shearstress profile at the interface



Interface profile at different times



NOT OBSERVED EXPERIMENTALLY