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Laboratoire de Mécanique et d'Acoustique

**KNDS**

# Tube/projectile interaction modeling using finite element method

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T. COLLAS, F. LEBON, I. ROSU and C. NINGRE.

7th International Conference on Computational Contact Mechanics, July 5-7, 2023, Torino - Italy



## Introduction

### I. Analytical model

- a) Rigid cone
- b) Elastic cone

### II. Finite element models

- a) Quasi-statics
- b) Dynamics

## Conclusion

- Manage the loading/unloading cycle of the artillery projectile:

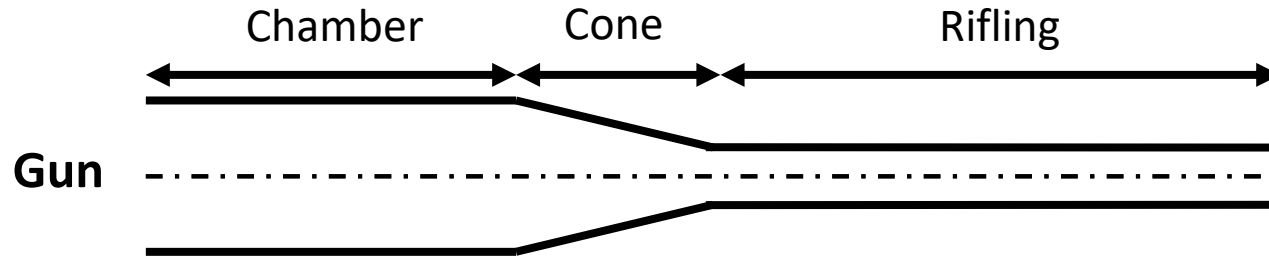


Fig. 1. Gun barrel.



Fig. 2. Projectile.

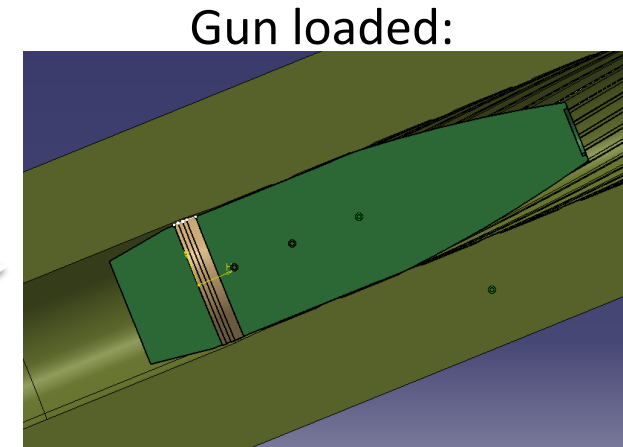
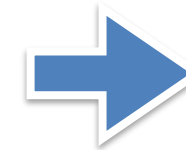


Fig. 3. Loaded projectile.

➔ Conical shrink fit assembly

- Objective: Focus on shrink fit assembly

- Non-linearities to take into account:

Elastic-plastic material

Complex geometries

Contact + Friction

Finite strain ( $\approx 30\%$  locally)

# I.a) Analytical model – Rigid cone

- Cone to cone interaction with no strain:

Principles of statics:

- $E_p = PS \left( \frac{\mu_p}{\tan(\alpha/2)} + 1 \right)$
- $E_{ex} = -PS \left( \frac{\mu_{ex}}{\tan(\alpha/2)} - 1 \right)$

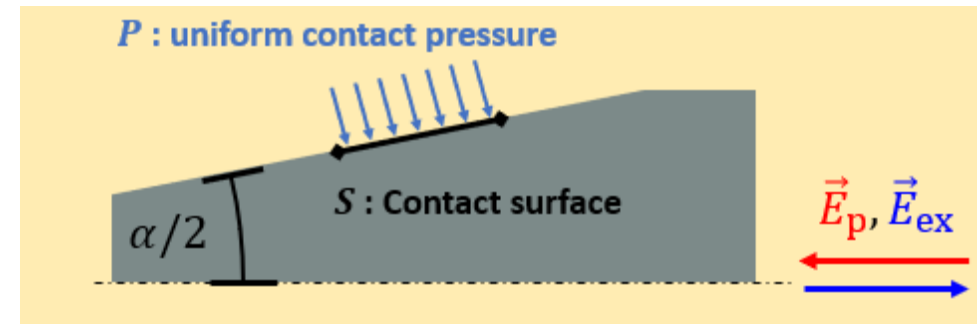


Fig. 4. Rigid cone model.

- “Reaction” factor:

$$r_{\text{rigid}} = \frac{-E_{ex}}{E_p} = \frac{\mu_{ex} - \tan(\alpha/2)}{\mu_p + \tan(\alpha/2)}$$

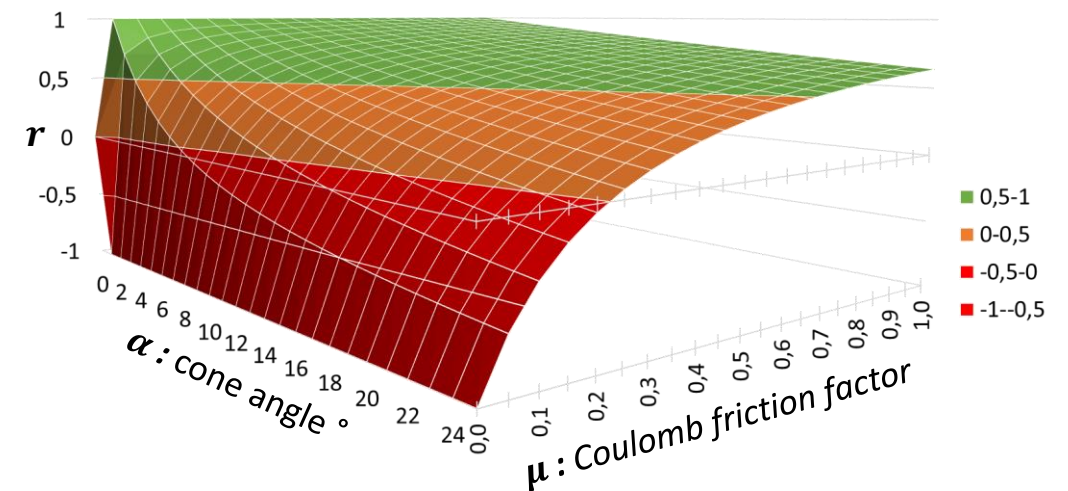


Fig. 5. r response.

- Extraction force is lower than penetration force.

# I.b) Analytical model – Elastic cone

➤ Adding an elastic behaviour:

- Obtaining a 3 steps model:

1. **p**enetration: push into cone ;
2. **s**pringback: partial relief of stress ;
3. **e**xtraction: pull until contact loss.

- 1.  $\rightarrow \frac{F_{x,p}}{F_{y,p}} = \frac{1 - \mu_p \tan(\alpha/2)}{\mu_p + \tan(\alpha/2)}$  et 3.  $\rightarrow \frac{F_{x,ex}}{F_{y,ex}} = \frac{1 + \mu_{ex} \tan(\alpha/2)}{-\mu_{ex} + \tan(\alpha/2)}$

- Leads to:  $r_{elastic} = \frac{-E_{ex}}{E_p} = r_{rigid} \frac{1 - \mu_p \tan(\alpha/2)}{1 + \mu_{ex} \tan(\alpha/2)}$

➤ « Inversion » factor :

$$f_{inv} = \frac{1 - \mu_p \tan(\alpha/2)}{1 + \mu_{ex} \tan(\alpha/2)}$$

➤ New factor describing the evolution of loading direction.

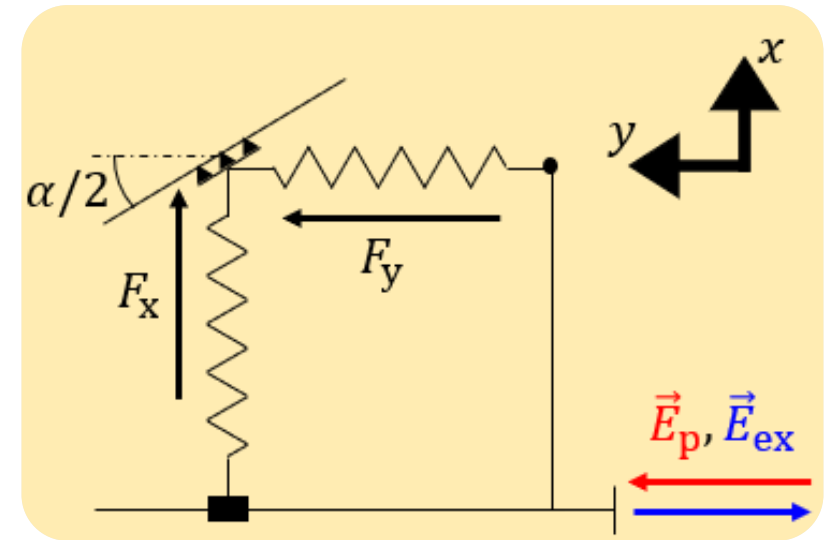


Fig. 6. Elastic cone model.

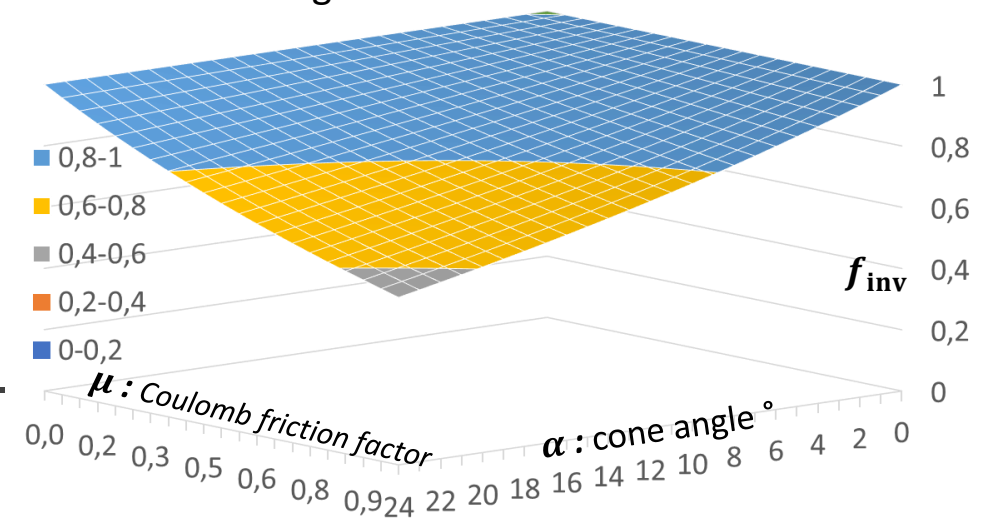


Fig. 7.  $f_{inv}$  response surface.

## II.a) Finite element models – Quasi-statics

➤ Axisymmetric numerical model:

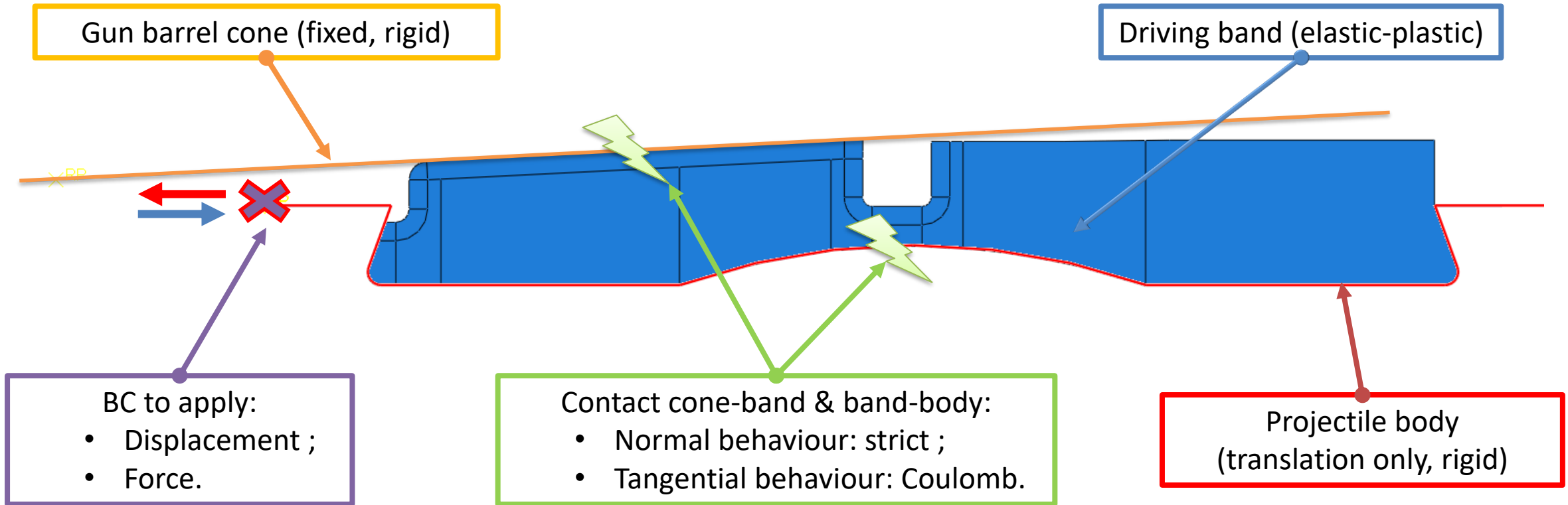


Fig. 8. Quasi-static model formulation.

■ Simulation in three steps :

1) Penetration

2) Springback

3) Extraction

- von Mises stress during the three steps:

Step: Penetrat Frame: 0  
 Total Time: 0.000000

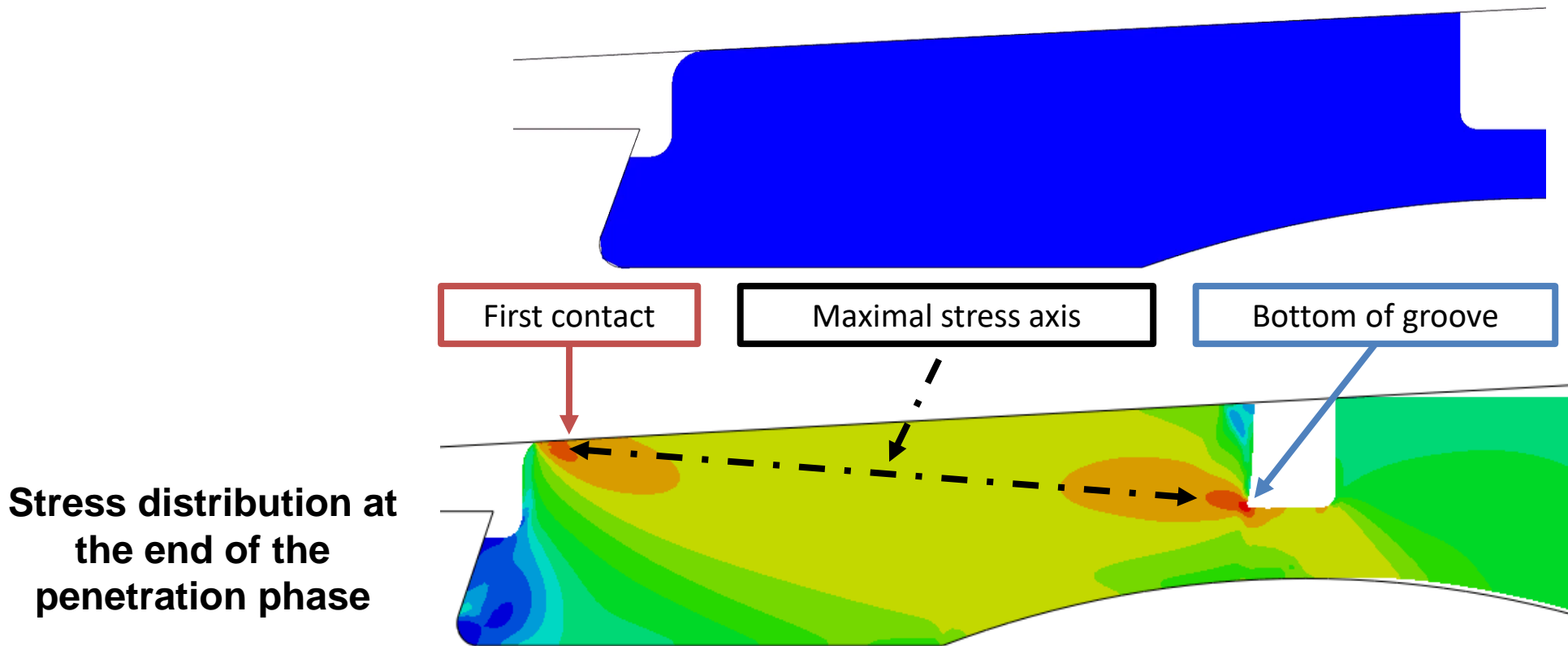


Fig. 11. von Mises stress color map.

- Typical stress repartition due to geometry. I obtain:  $r_{\text{simulated}} = \frac{-E_{\text{ex}}}{E_{\text{p}}}$



➤ Mesh optimisation on extraction force:

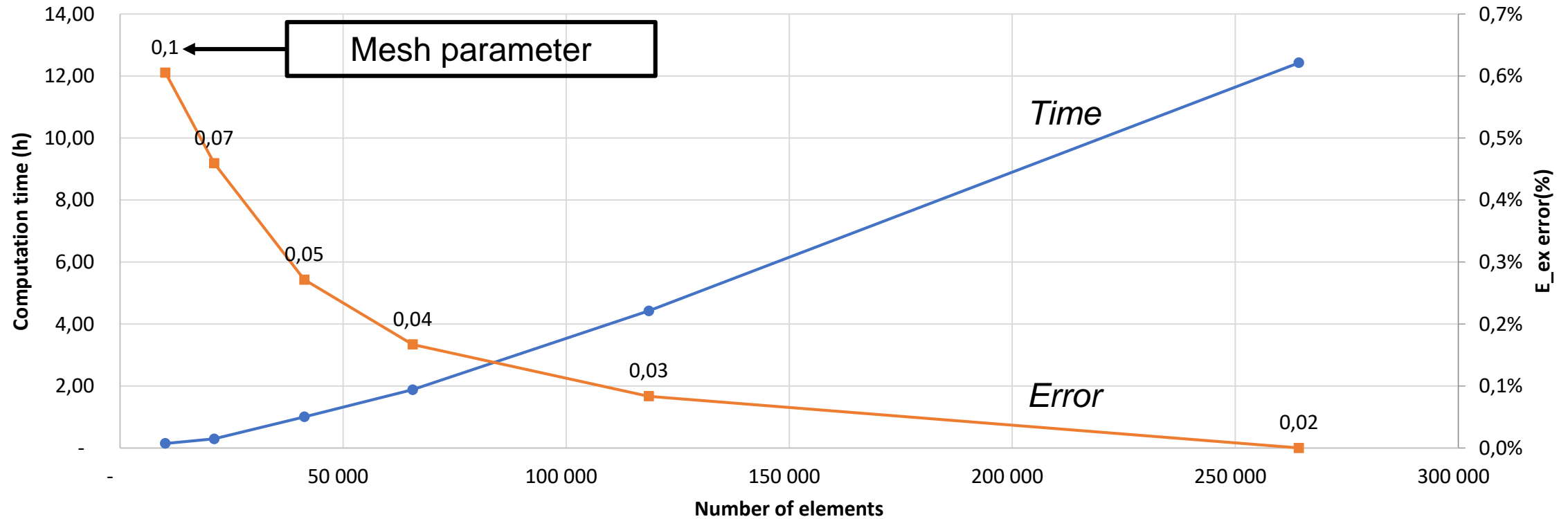


Fig. 12. Performances of an homogeneously meshed band.

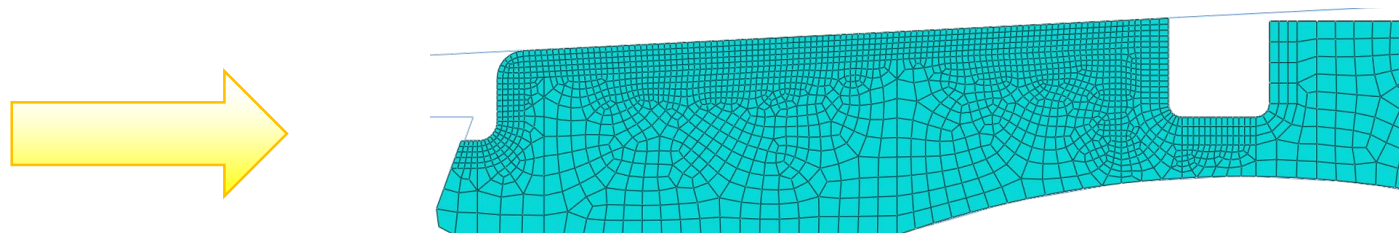


Fig. 13. Axisymmetric adapted mesh (2868 elements).

➤ Pressure – Overclosure ( $P - o$ ) relationships for normal contact:

- Strict : “hard contact”

- $\forall P, o \leq 0$  ;

- Linear :

- $P = K_0 * o$  ;

- Exponential :

- $P = \frac{P_0}{\exp(1)-1} \left( \frac{o}{C_0} + 1 \right) \left( \exp\left(\frac{o}{C_0} + 1\right) - 1 \right)$ .

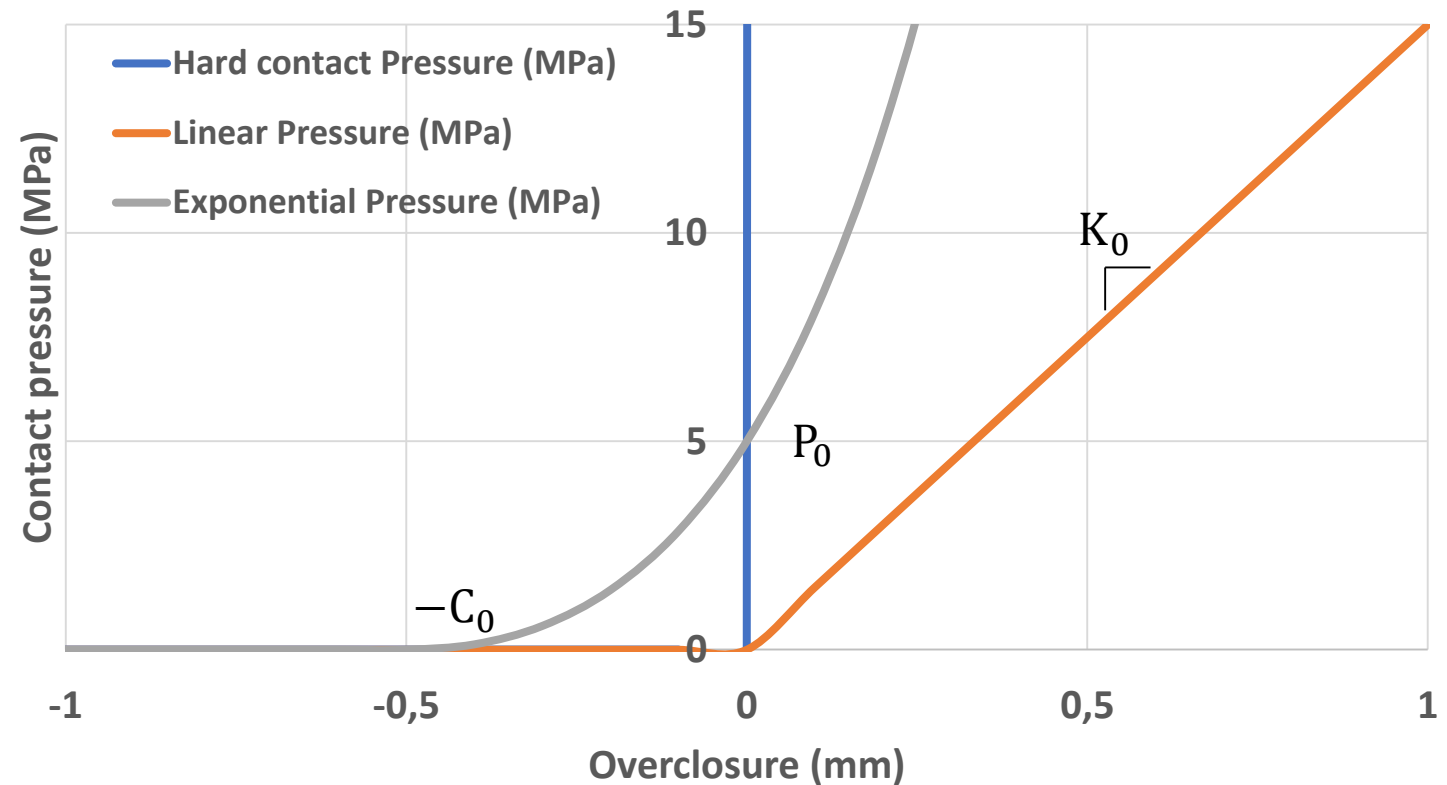


Fig. 14. Normal contact laws.

## II.a) Finite element models – Quasi-statics

➤ Comparison of soft and hard contact laws:

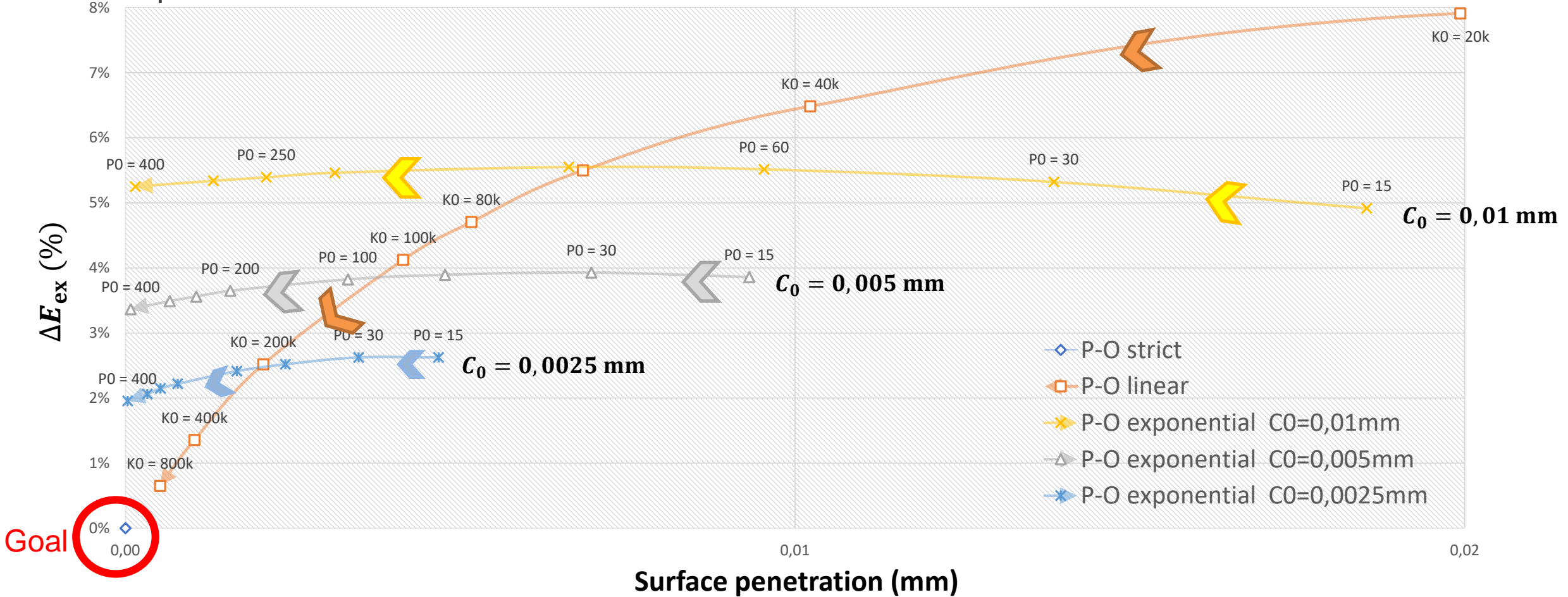


Fig. 15. Comparison of normal contact strategies accuracies.

➤ Bias can be reduced by “hardening” the law.

➤ Plotting the external forces:

Fig. 16. Nodal force evolution.

At the end of each step, we plot the pressure distribution.

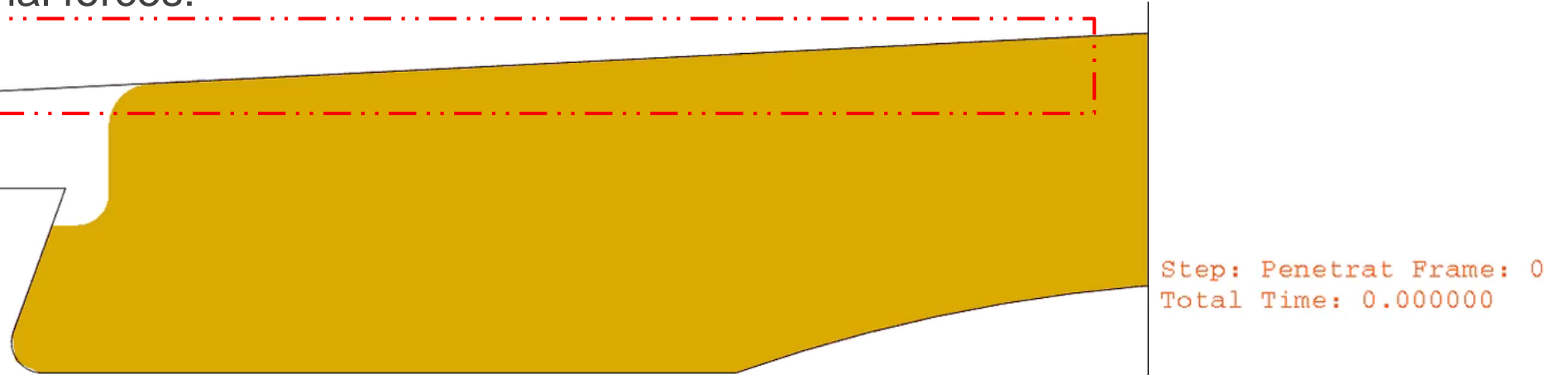
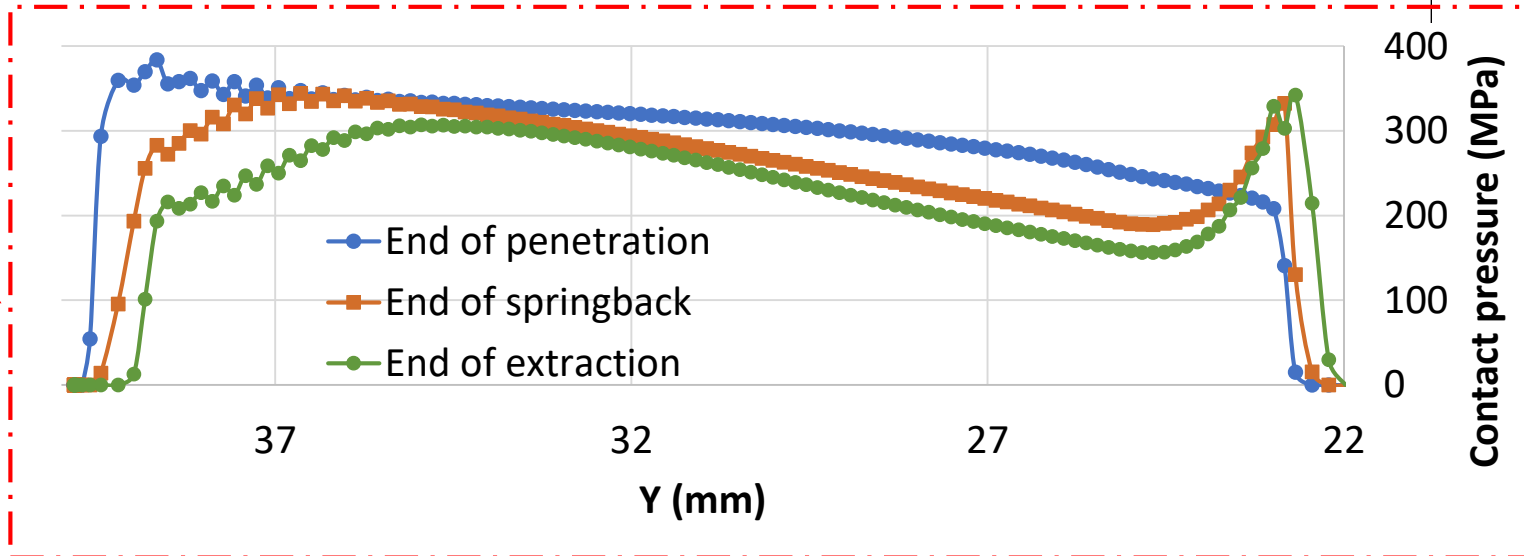


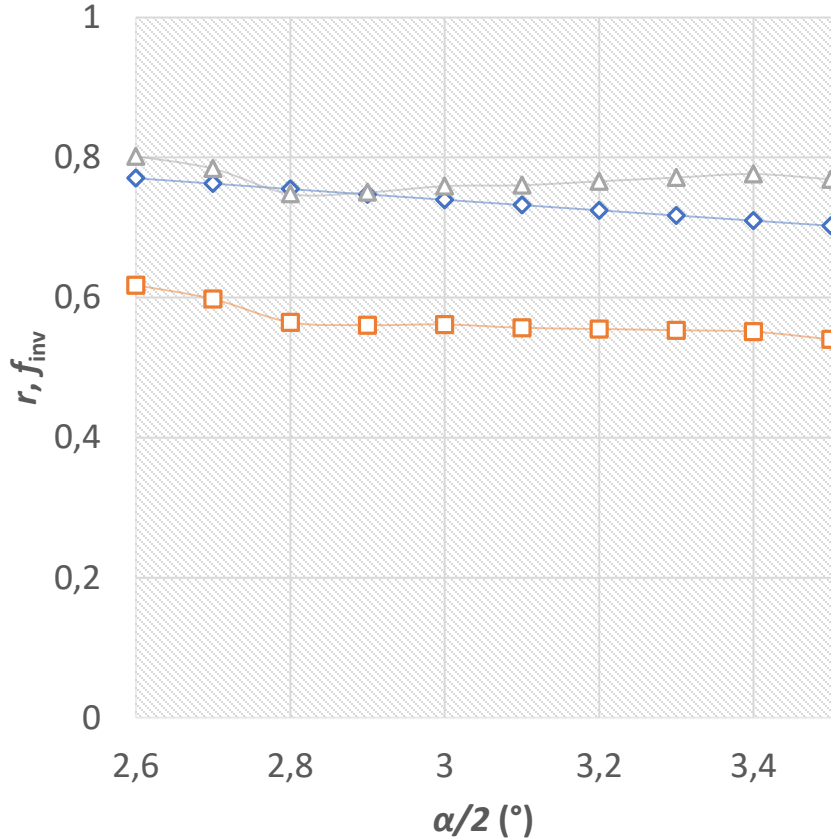
Fig. 17. Pressure evolution at the interface.



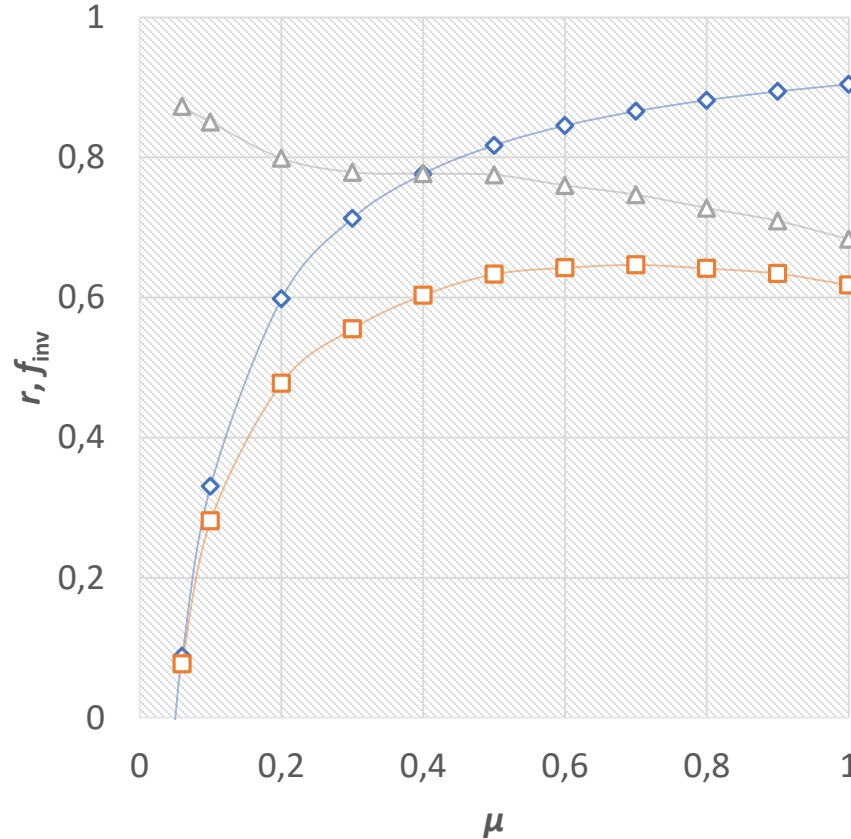
➤ Heterogeneous contact pressure evolving with loading.

## II.a) Finite element models – Quasi-statics

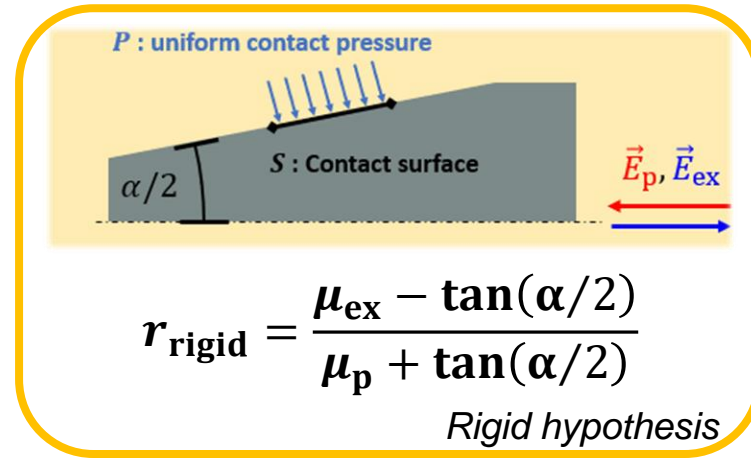
➤ Input parameters sensitivity:



—◇—  $r_{rigid}$  —□—  $r_{simulated}$  —△—  $f_{inv}$



—◇—  $r_{rigid}$  —□—  $r_{simulated}$  —△—  $f_{inv}$



$$r_{simulated} = \frac{-E_{ex}}{E_p}$$

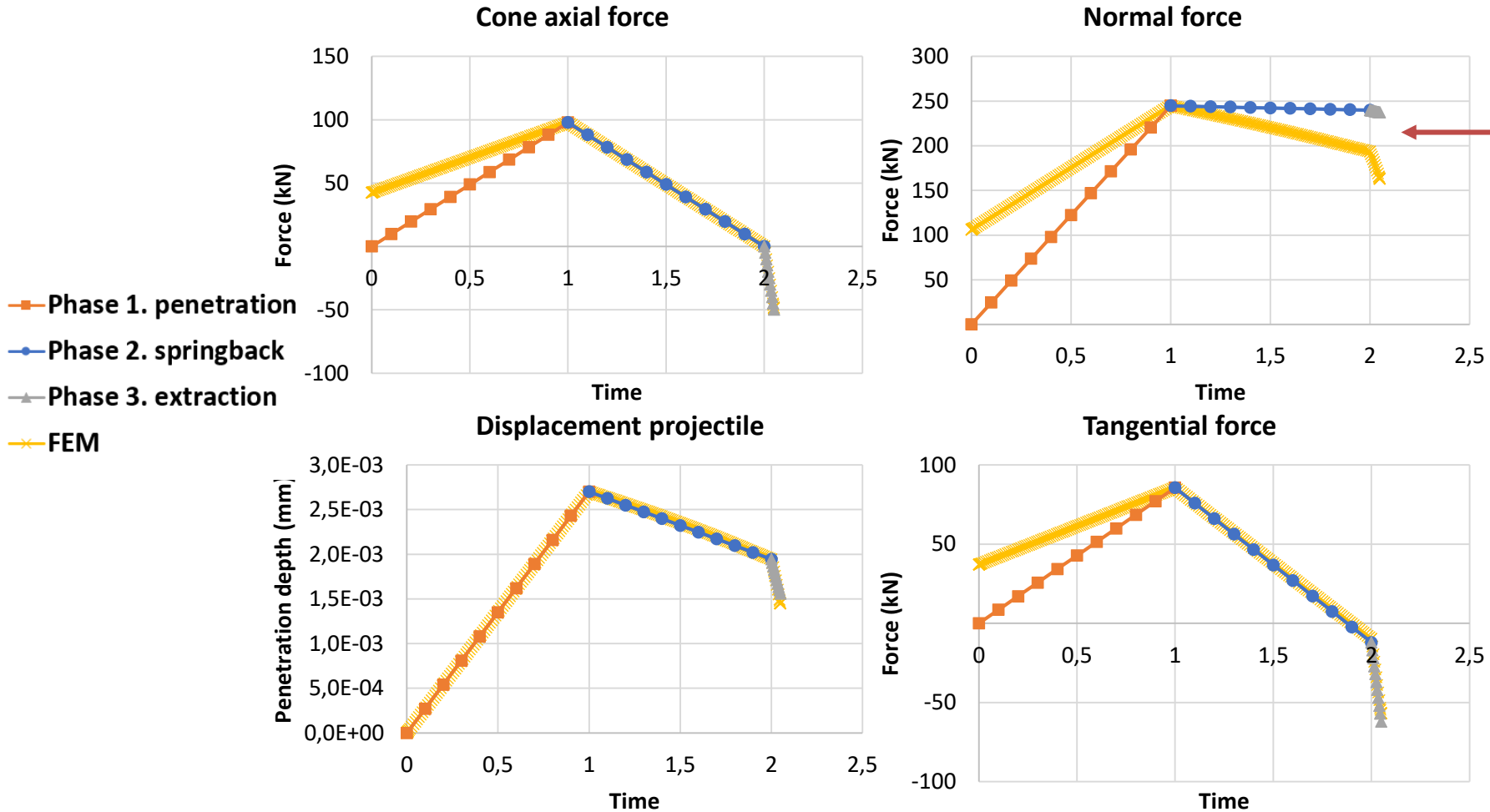
$$f_{inv} = \frac{r_{simulated}}{r_{rigid}}$$

Fig. 18. Influence of cone angle  $\alpha$  and friction coefficient  $\mu$  on  $r$  and  $f_{inv}$ .

➤ For typical cone angles,  $\mu$  is more impactful than  $\alpha$ .

## II.a) Finite element models – Quasi-statics

- Comparison between FEM and analytical model. Temporals of the elastic model:



Discrepancies in the evolution of normal force.

Analytical/FEM error	
Position	Force
0,05%-0,6%	20%-40%

Fig. 19. Comparison between FEM and elastic model for interface variables.

- Elastic model qualitatively describes the phenomena.

## II.b) Finite element models – Dynamics

➤ Axisymmetric numerical model:

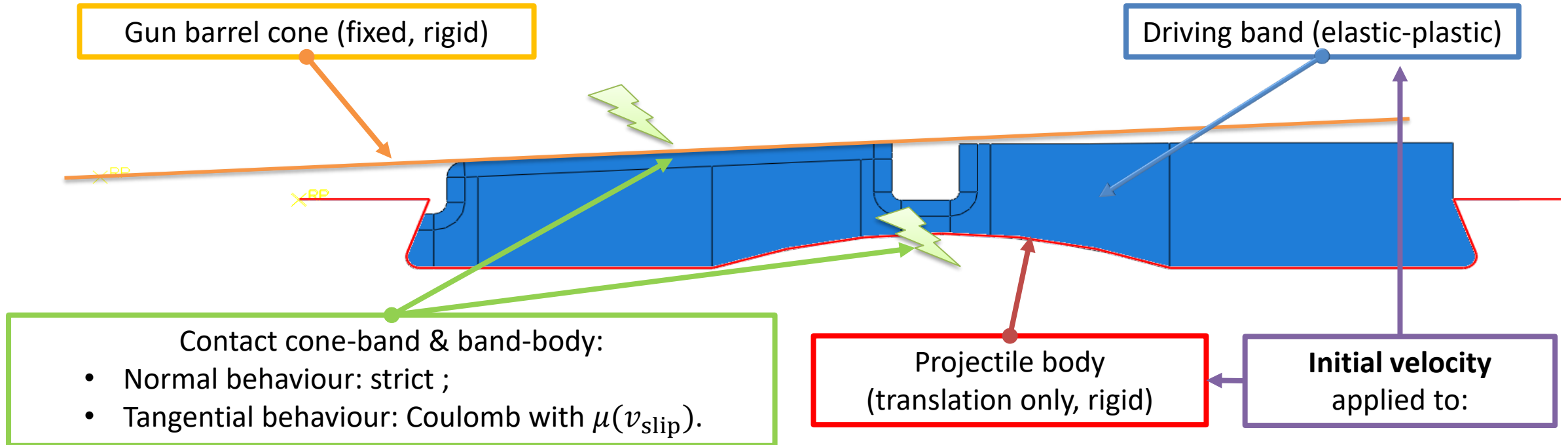


Fig. 20. Dynamic model formulation.

- Simulation in two steps :
  - 1) & 2) Penetration & springback
- Using same mesh than quasi-statics.

c) Extraction

➤ Dynamic implicit results for  $v_{ini} = 1 \text{ m.s}^{-1}$  :

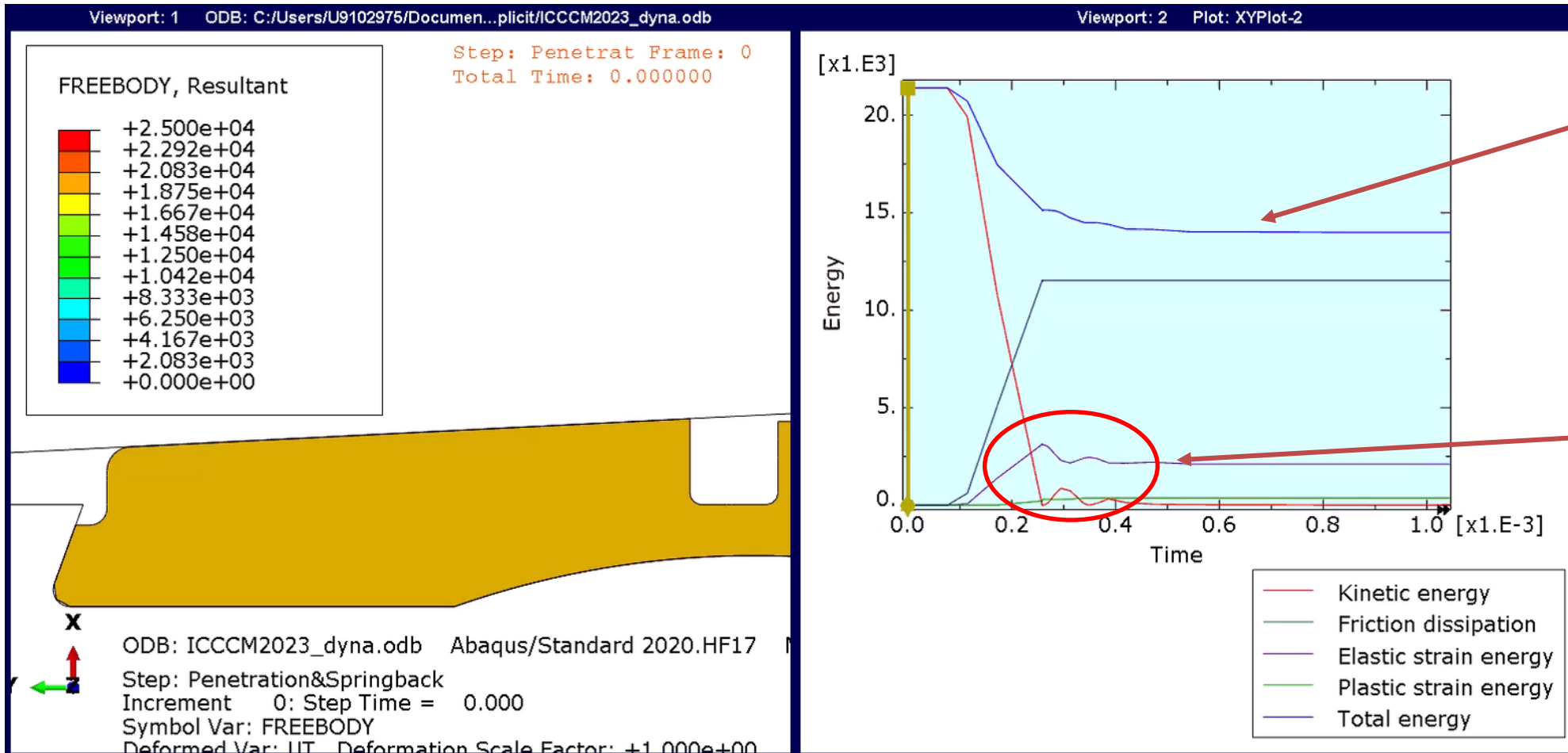


Fig. 21. Nodal forces evolution.

Fig. 22. Energies evolution.

➤ The elastic wave is quite costly in terms of computation time.



- Extraction force comparison for static and dynamic implicit simulations:

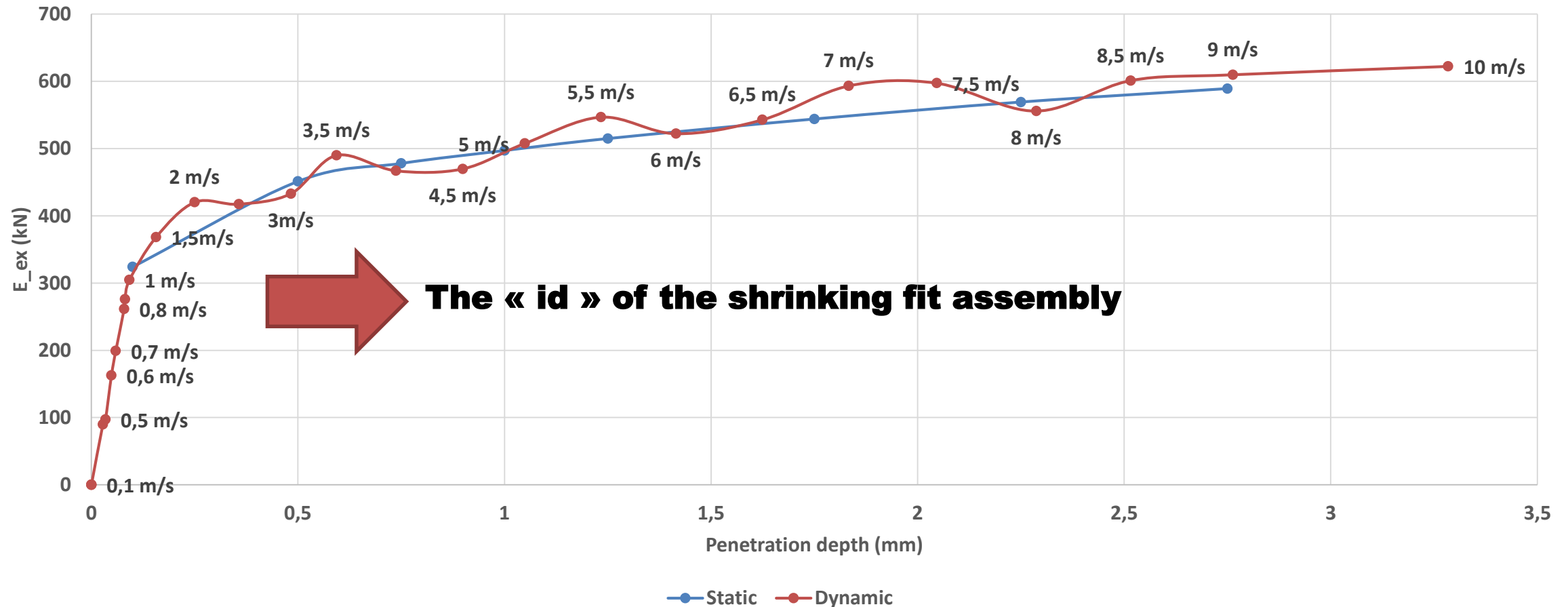


Fig. 23.  $E_{ex}$  (penetration depth) for quasi-statics and dynamics implicit models.

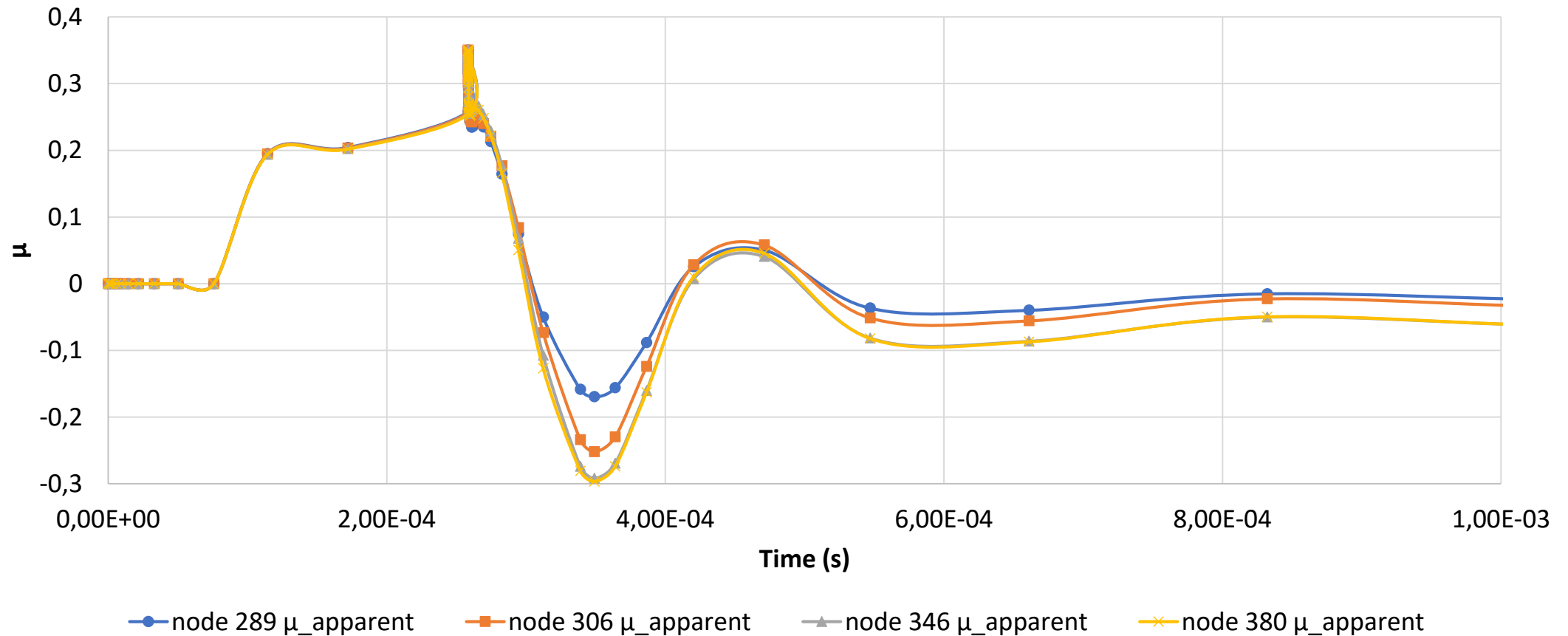
- Good tendency adequation but oscillations have to be managed.

- FEM as a tool for research in difficult access area.
- No large discrepancy between analytical or FEM model identified ;
- Theoretical demonstration of  $-E_{ex} < E_p$  ;
- $\mu$  is the most important parameter in a conical shrink fit assembly ;
- Further developments:
  - Experimental campaign to validate the numerical results ;
  - Analytical model have to be enhanced.

**THANK YOU FOR LISTENING !**

**Now it is time for questions !**

- Looking at some nodes at the interface (dynamic implicit simulation):



➤ Main simulation parameters:

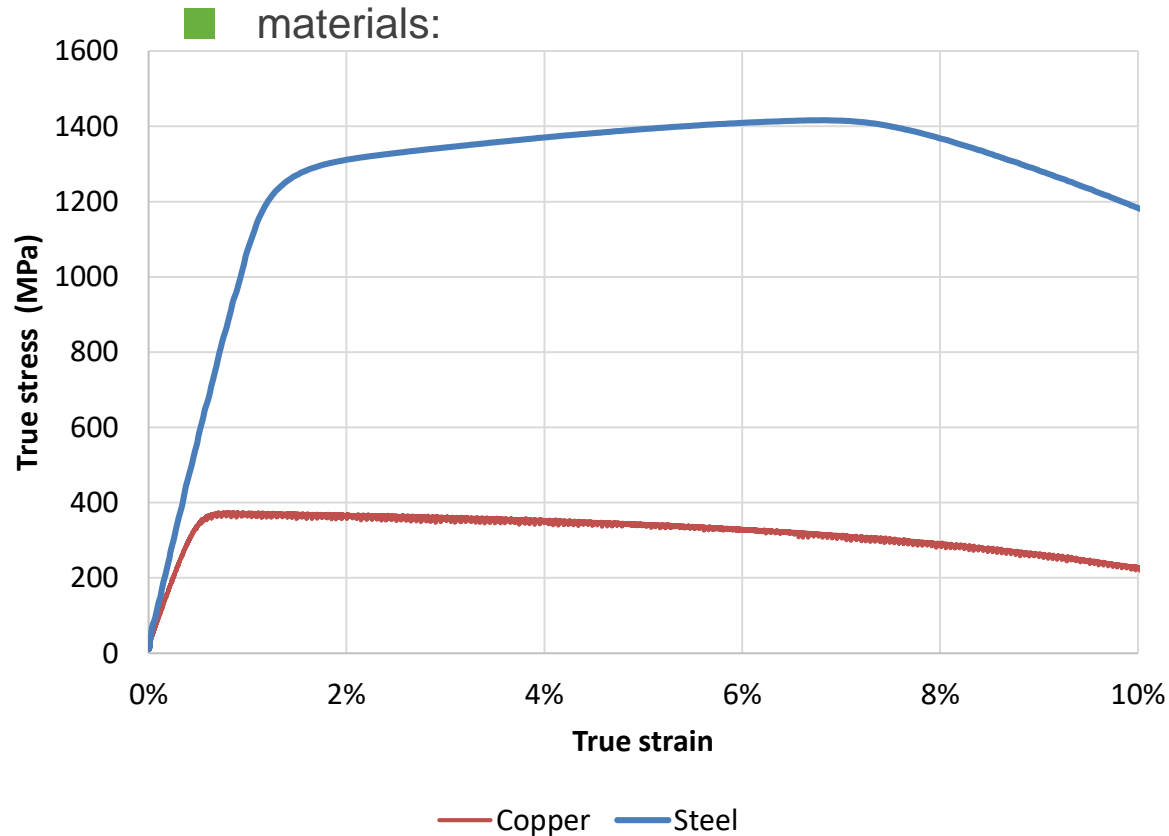


Fig. 9. Copper and steel stress-strain curves.

➔ The copper band will take most of the strain.

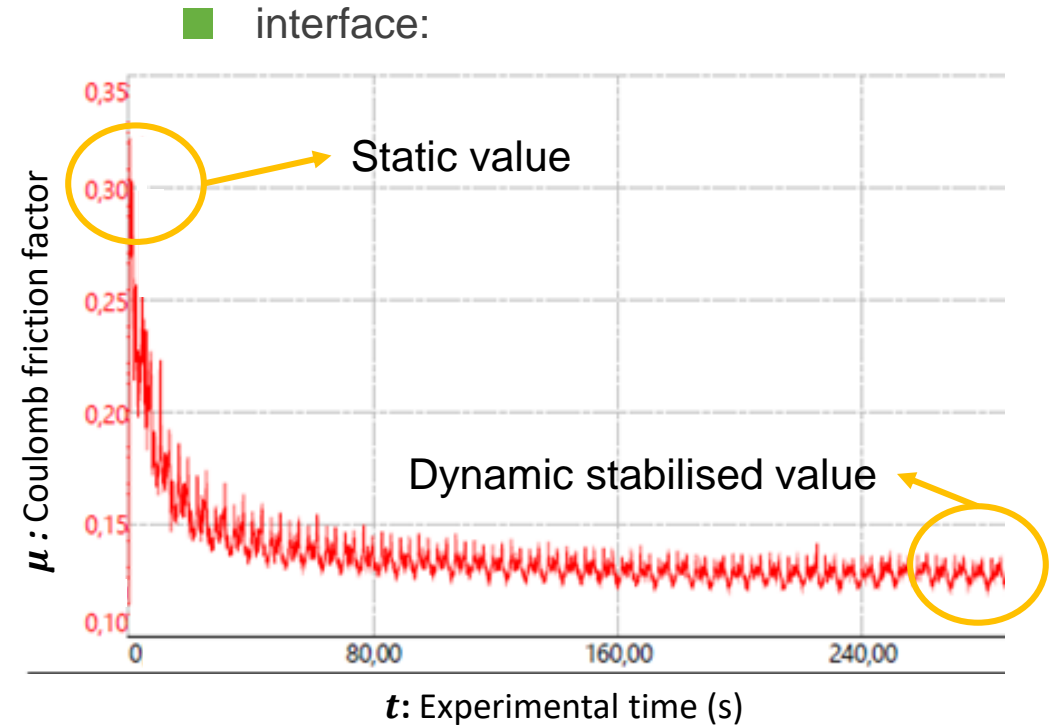


Fig. 10. Friction coefficient steel-copper on pin-disk tribometer.

➔  $\mu$  depends on materials and contact conditions.

➤ Characterisation campaign to obtain inputs for simulation.

- Energy loss is due to the implicit scheme instability for contact pairs: