UMONS
Université de Mons

FPMs MINES

Study of rock drillability in oil reservoir conditions

Tests in atmospheric conditions, evolution with confinement, numerical simulation

Mathieu CORNET June 2012

Under the direction of Pr. Dr. Ir. J-P Tshibangu K

POLYTECH MONS

Problem

Economic issues in oil drilling

↓

Maximizing drilling rates

↓

Optimizing drilling tools

↓

Knowledge of rock cutting mechanism

↓

Modeling the cutting process under confinement

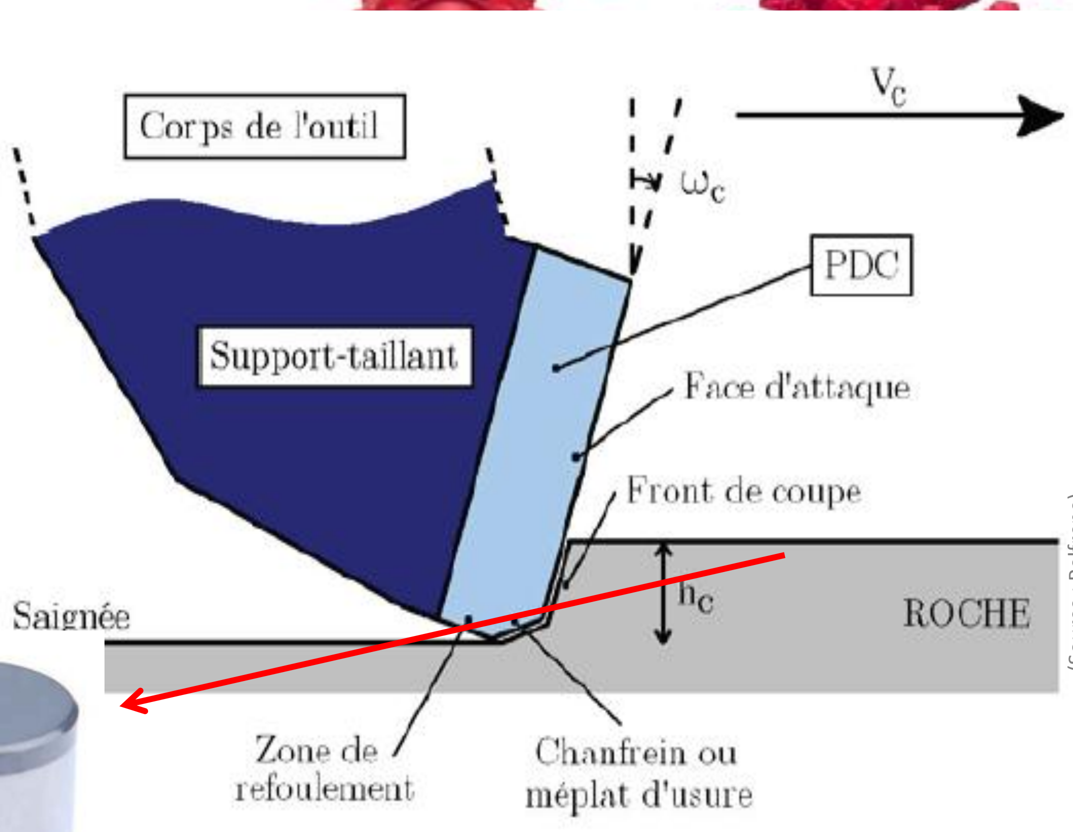
Objectives

- Understanding of rock cutting
    - → Mechanism of chip formation
    - → Evolution of cutting force
- Theoretical study of phenomenological models
- Laboratory tests in atmospheric conditions *(single cutter test device currently out of service)*
- Development of a numerical model with $FLAC^{2D}$
    - in atmospheric conditions
    - extension to underground conditions

→ Comparison of models

Cutting : an overview

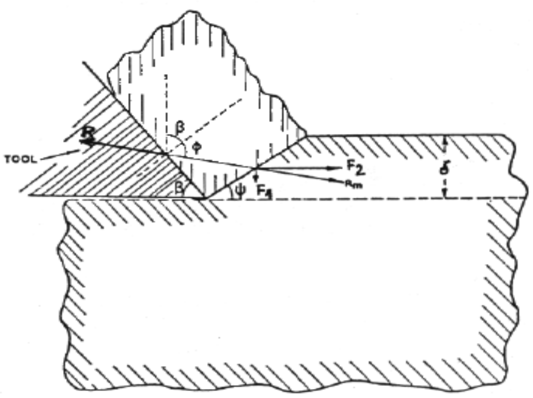
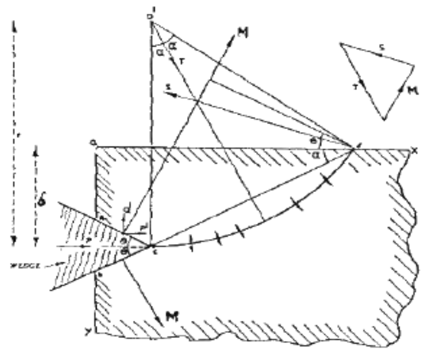
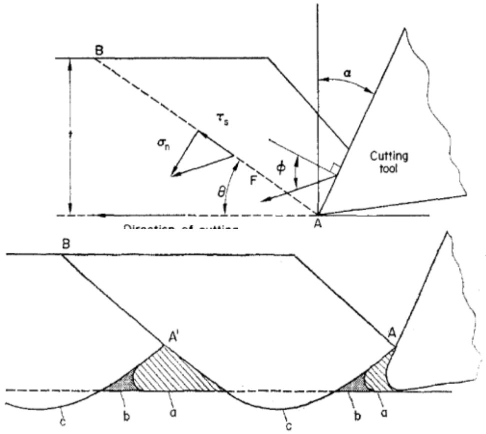
- Drill bit
- PDC cutter
- Cutting angle: 15°
- Depth of cut: 0.1 to 1 mm
- Cutting width: 10 mm
- ~~Ch~~
  ~~ar~~



(Source : Pelfrene)

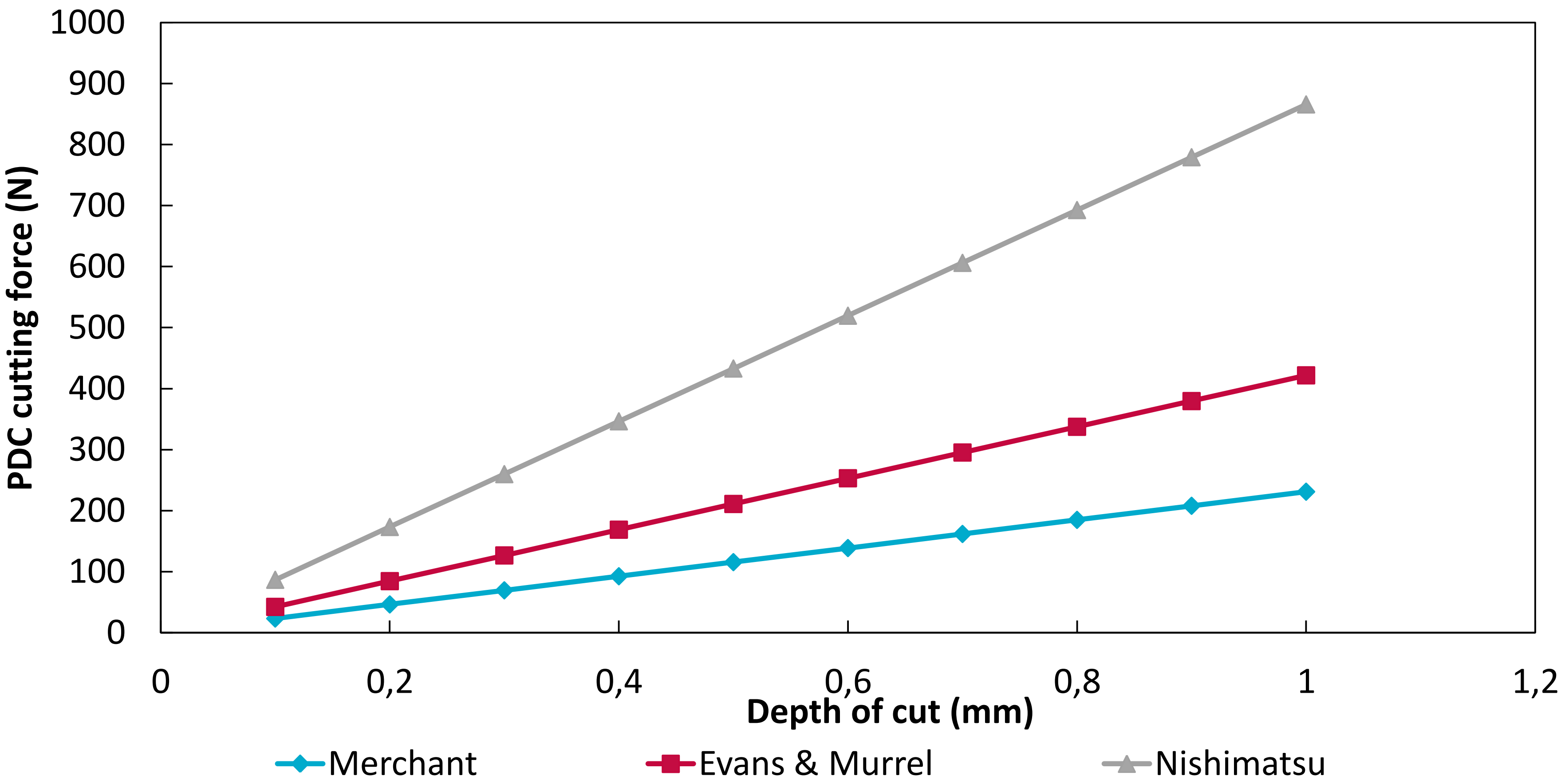
(Source : Schlumberger)

Phenomenological models

Merchant (1944)	Evans & Murrel (1965)	Nishimatsu (1972)
Plasticity law Shear	Crack propagation under tensile stress	Macrocracks propagation Shear
		
$F_c = R_{cis}\, A_c\, tan\frac{\beta-\varphi}{2}$	$F_c = 2R_t\, A_c\, \frac{\sin(\theta+\phi)}{1-\sin(\theta+\phi)}$	$F_c = \frac{2}{n+1} R_{cis}\, A_c\, \frac{\cos\varphi}{1-\sin(\varphi-\theta+\alpha)}$
→Plastic materials	→ Brittle materials (Coal)	→ Brittle materials

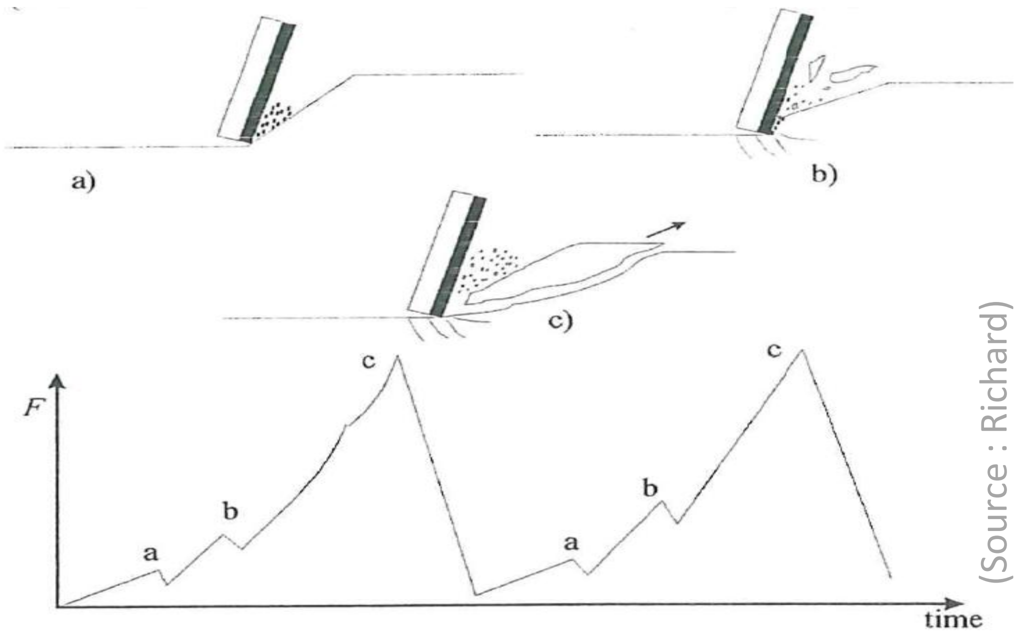
Comparison of cutting models (1)

- Phenomenological models
  - Only positive cutting angle (mining)



Cutting cycle

a) Crushing and formation of micro-chips
b) Increase of chip size
c) Formation of a macro-chip



(Source : Richard)

➢ Increase of the cutting force with the chip size

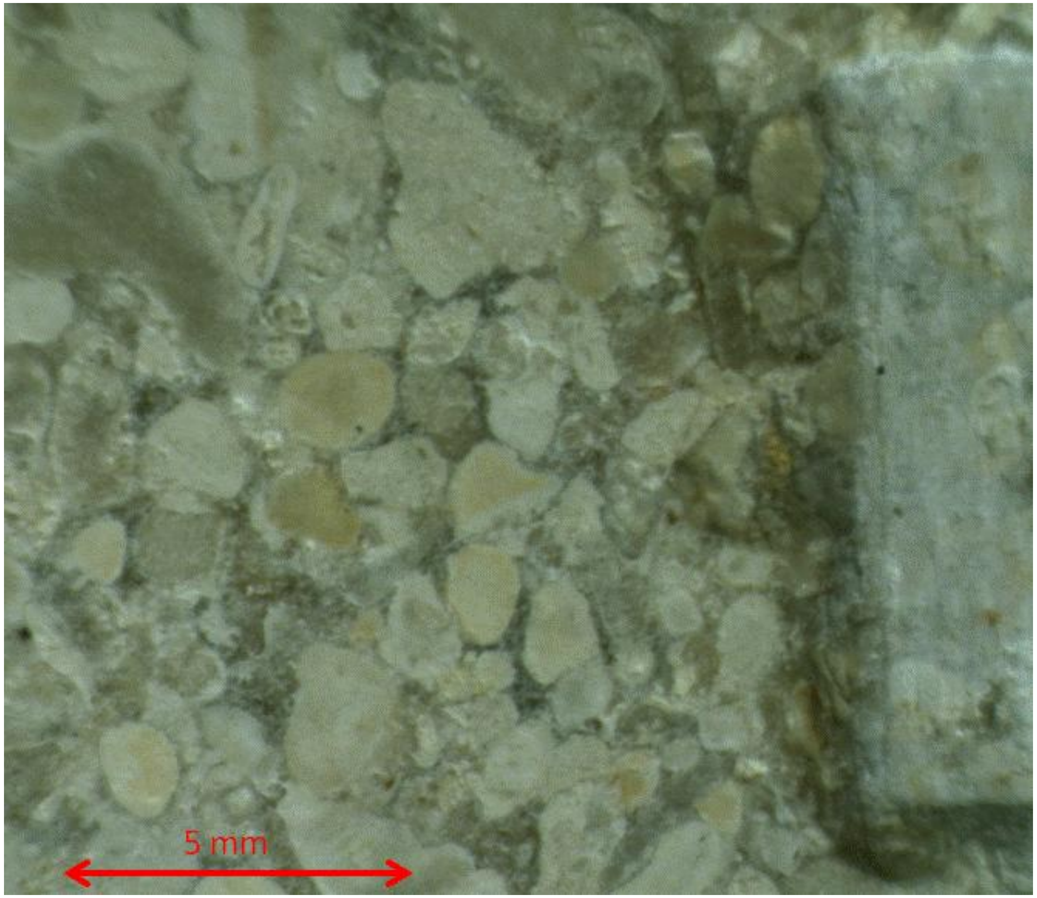
Valid for brittle materials

↔Plastic materials: chips and cutting force = continuous

Rock selection and characterization

- Moca limestone

- Density : 2.4
- Young's modulus : 17 900 MPa
- Poisson's ratio : 0.33
- Compressive strength : 44 MPa
- Tensile strength: 4.5 MPa
- Internal frcition angle: 40°
- Cohesion : 15 MPa



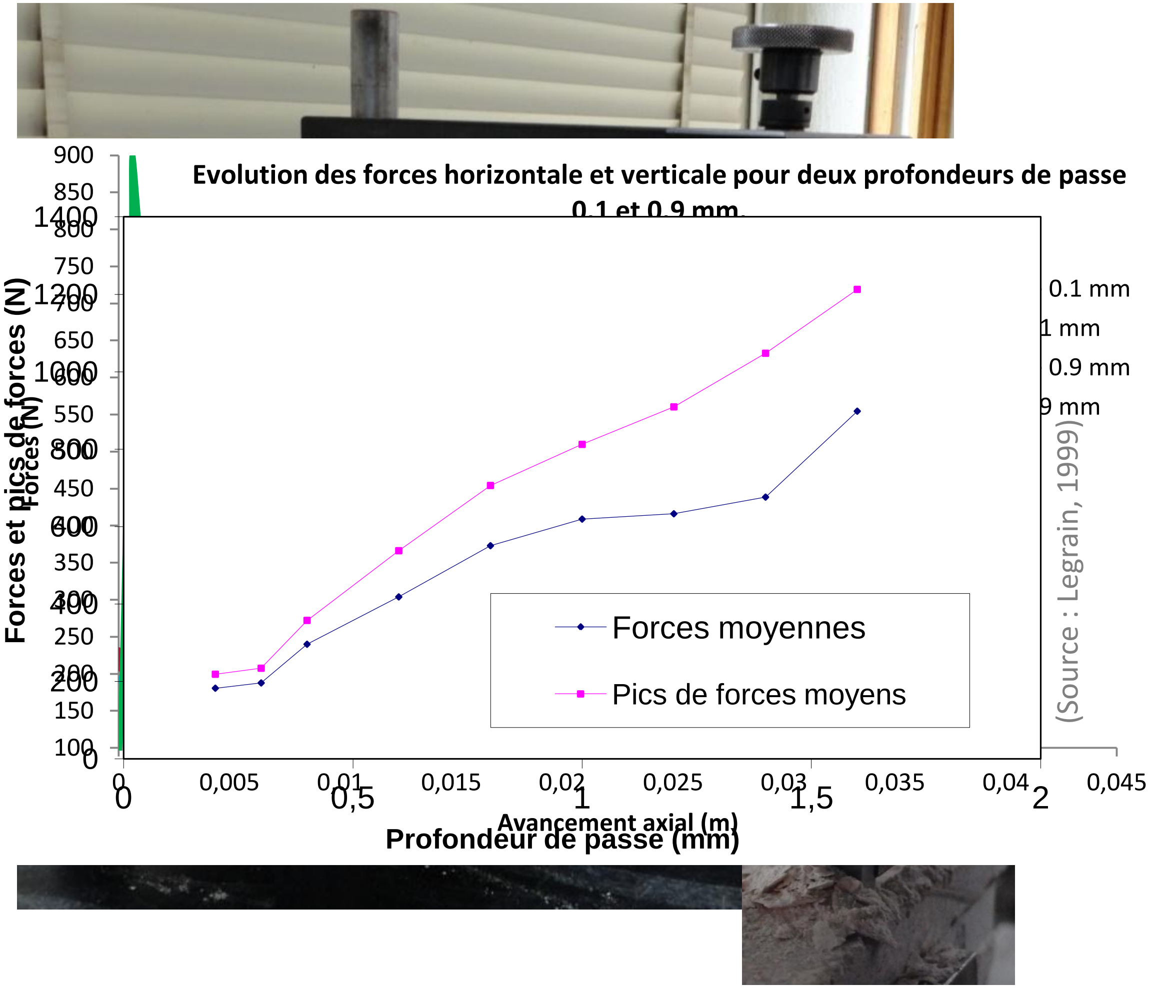
- ➢ Slightly abrasive
- ➢ Well known

Laboratory tests

- RSD tests

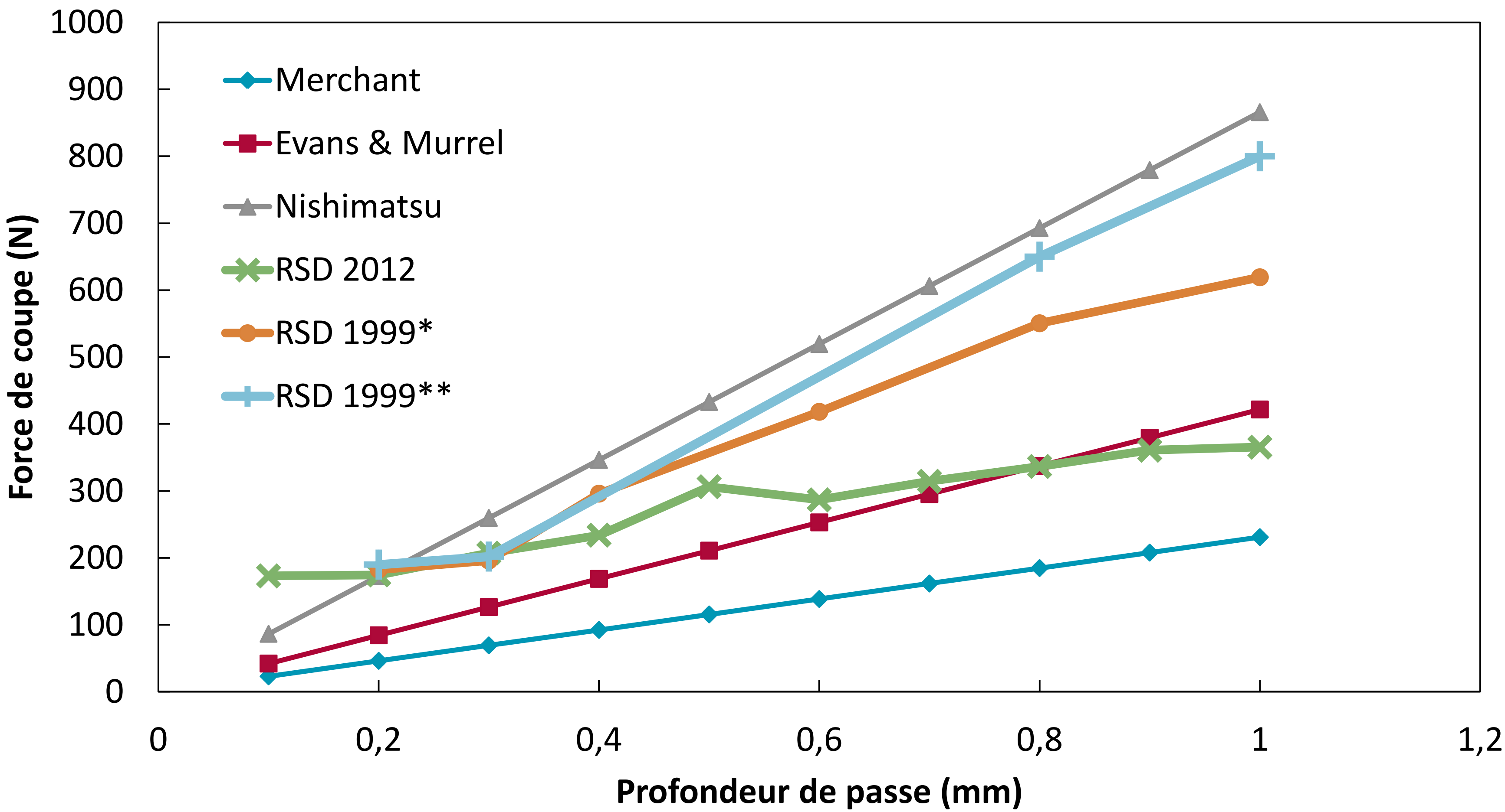
  « Rock Strength Device »

- Cutting results
  - 0.1 mm : friction dominated
  - 0.9 mm : brittle
- Cutting forces
  - Mean forces
  - Mean of force peaks : representative of formation of large sizes chips



Comparison of cutting models (2)

- Experimental model : horizontal force
  - 2012 : mean values
  - 1999 (Legrain H.) : mean values *; mean peak values **



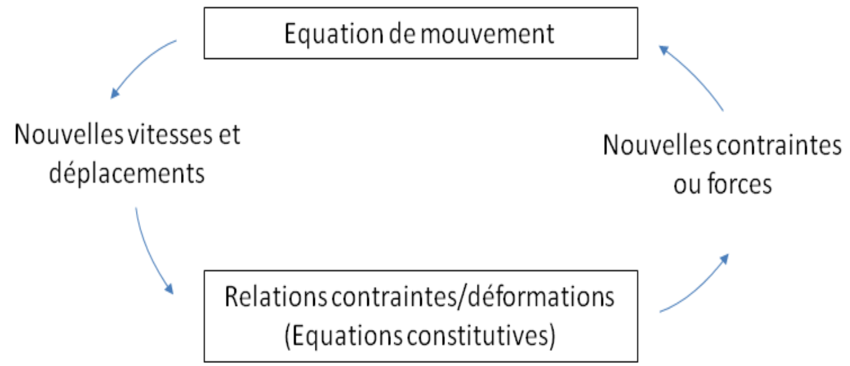
Numerical simulation

- FLAC^{2D} (Fast Lagrangian Analysis of Continua) :

  Finite differences method

  + Ideal for non linear problems

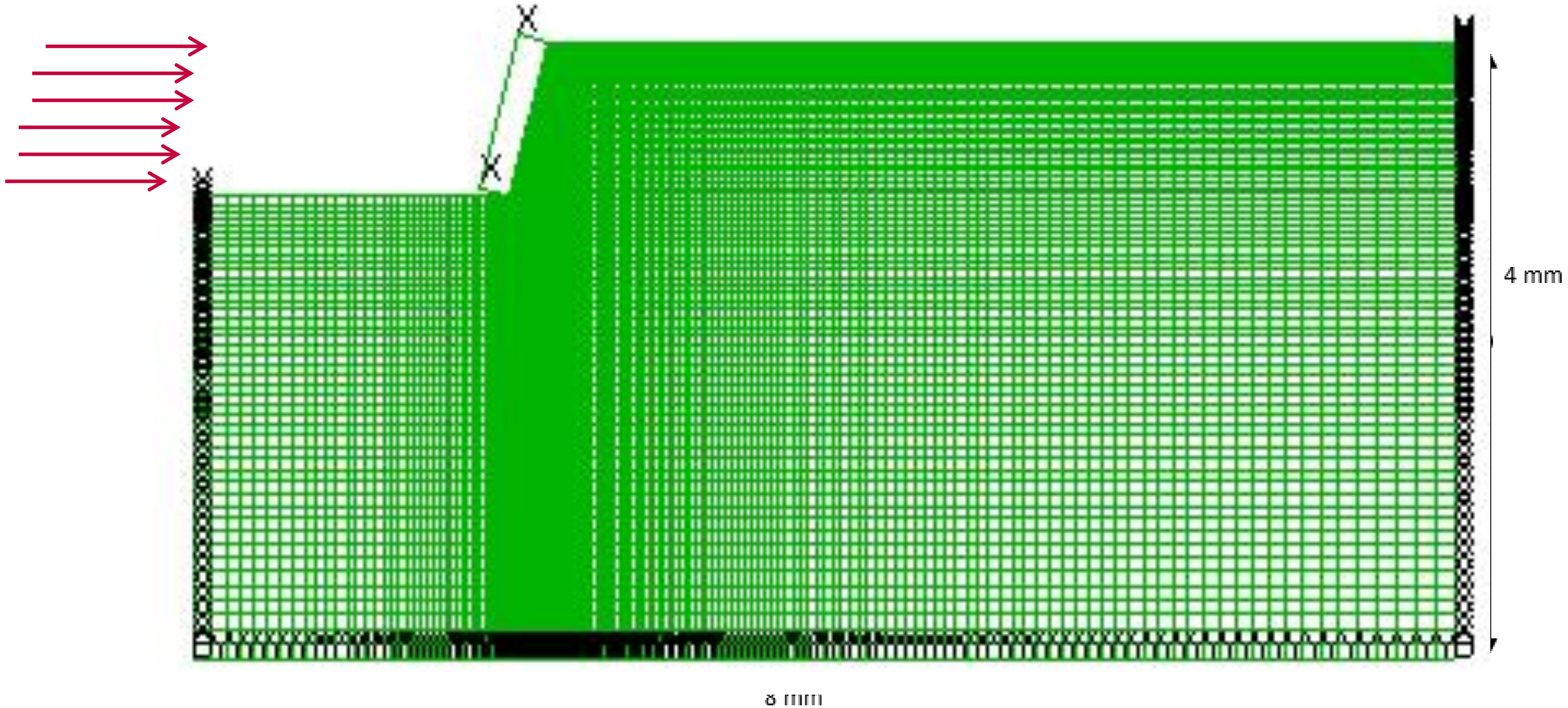
  + Spatial coordinates updated at each calculation step (large strain mode)



- Model behavior of the rock : elastoplastic with Mohr-Coulomb criterion

	ρ (kg/m³)	E (MPa)	ν	R_c (MPa)	R_t (MPa)	ϕ(°)	C (MPa)
Moca	2 400	16 000	0.33	57	4.5	40	15
PDC Cutter	15 800	650 000	0.25				

The mesh



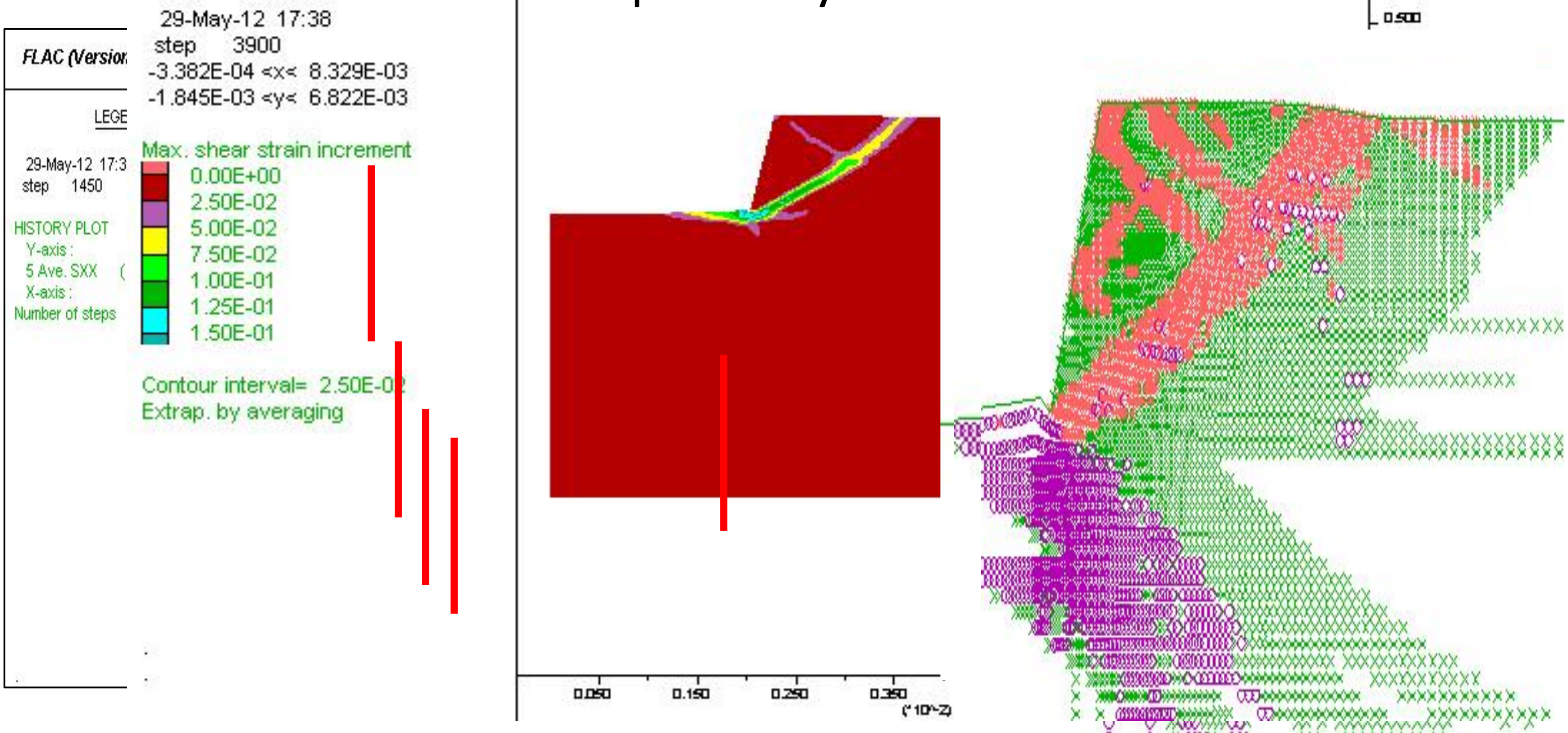
- X for fixing the lateral edge
- Y for fixing the bottom edge
- 160 columns and 80 rows, with a concentration at the cutting interface
- Horizontal velocity at the cutting interface : 10^{-8} m/s $V = \frac{D}{N}$

→ Impossible to achieve balance

Chip formation

Hypothesis : failure occurs when the reaction force is maximum at the interface

- Evolution of the state of plasticity

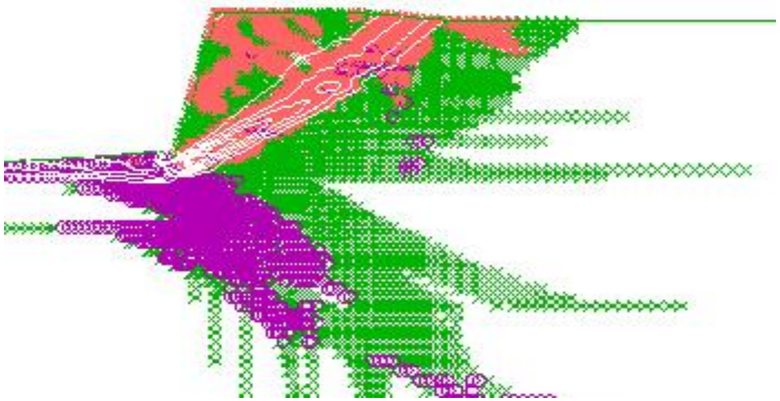


Modeling with a cutter

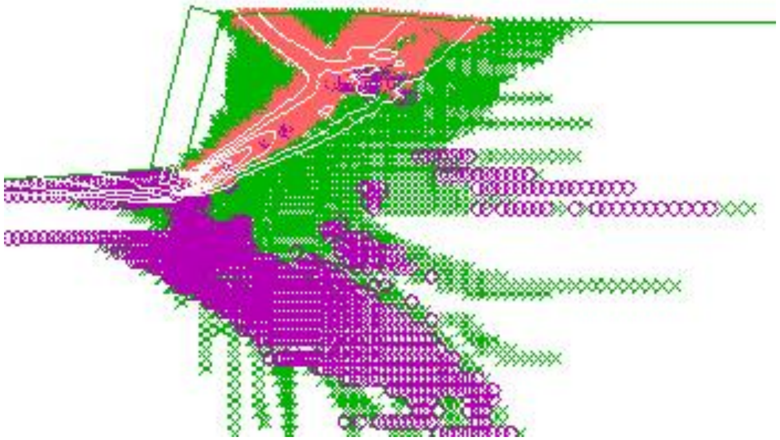
- Interest :
  - Rigidity of the cutter
  - Friction at the interface

- Mechanical properties of the cutter
- Friction coefficients at the interface

→ Slight increase of the cutting force and the volume of the chip



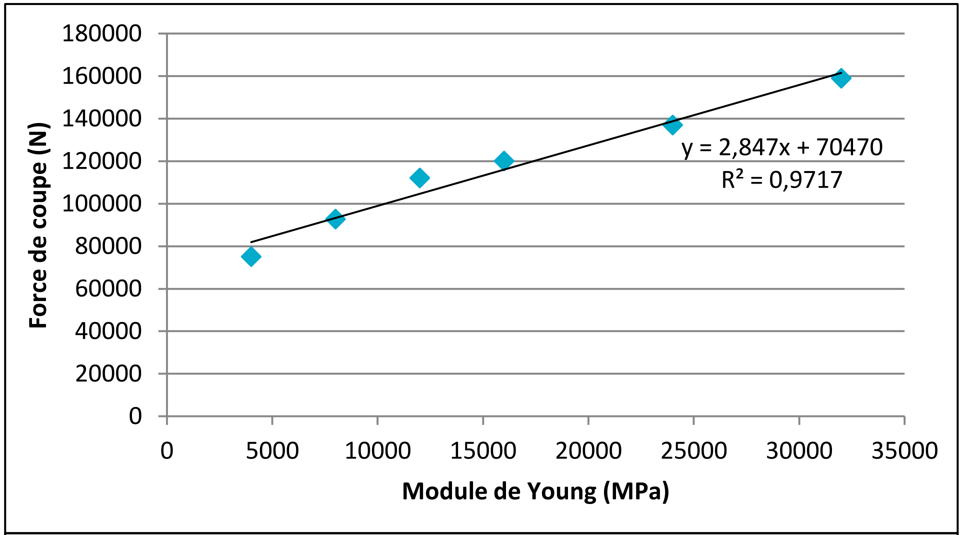
Without cutter : Fc = 1200 N



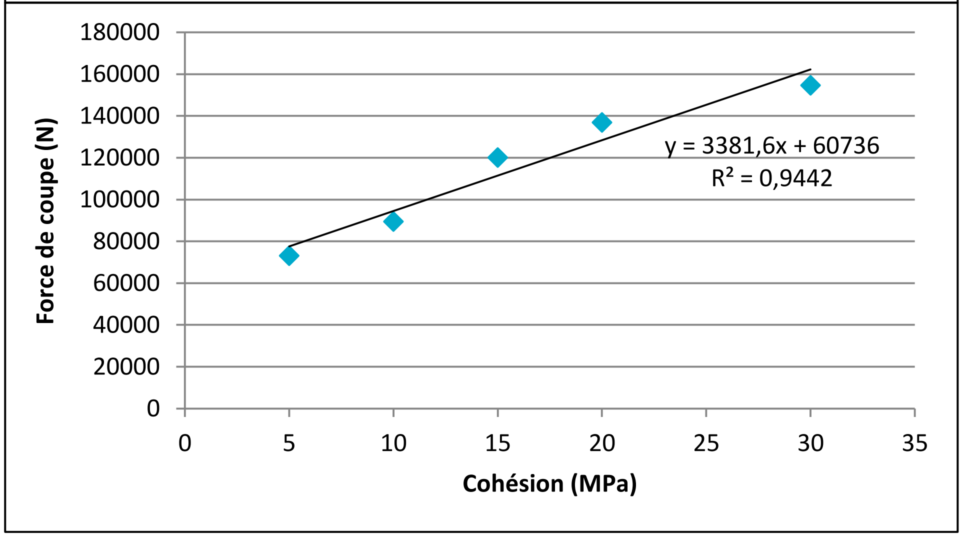
With cutter : Fc = 1300 N

Parametrical study

- Young's modulus

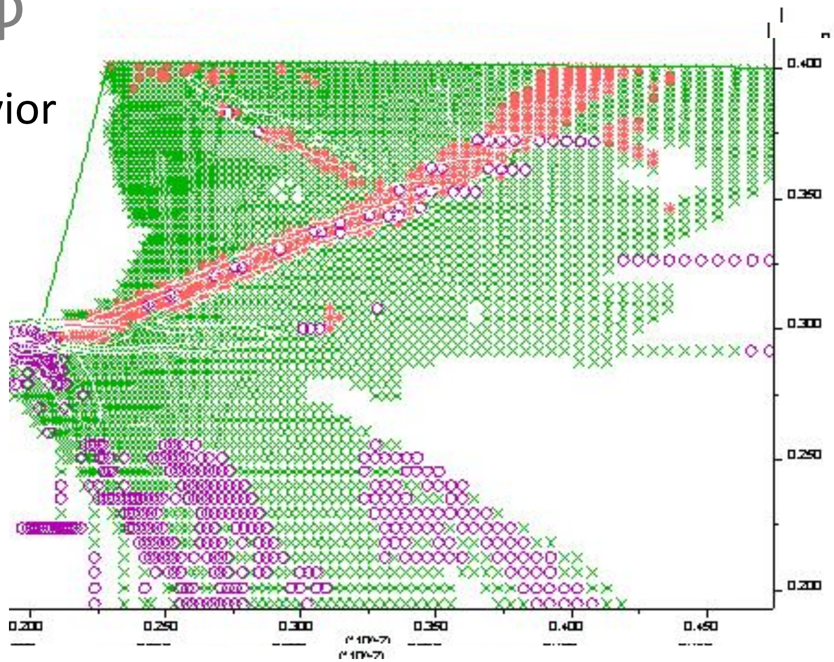


- Cohesion



Parametrical study

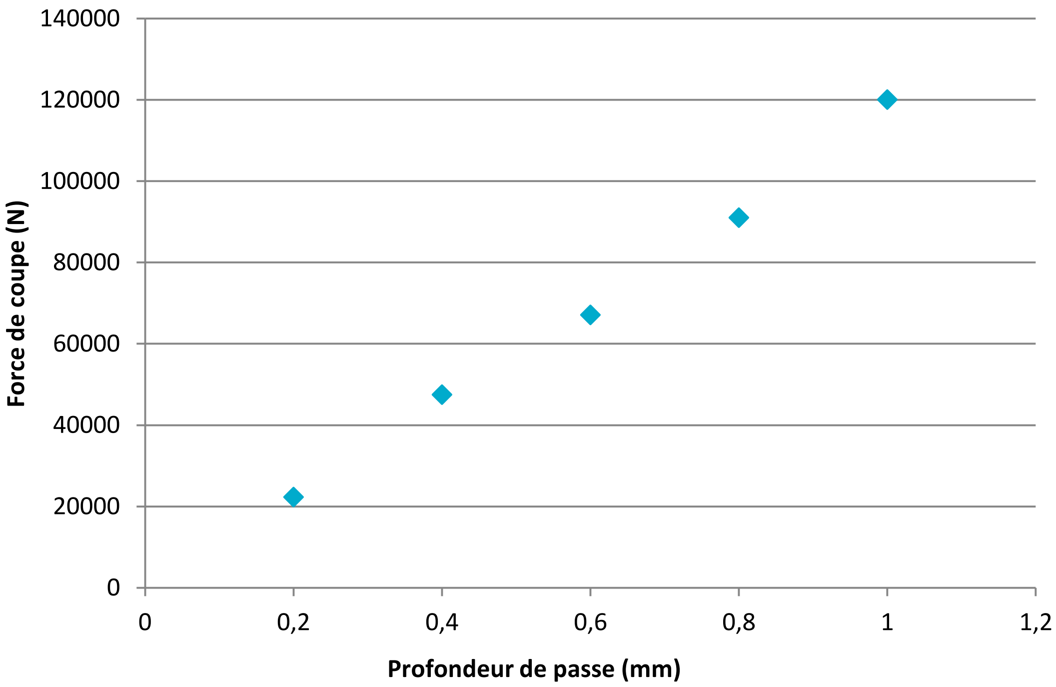
- Rock internal friction angle ϕ
  - ➢ Evolution towards a more brittle behavior
  - ➢ Increase of the cutting force

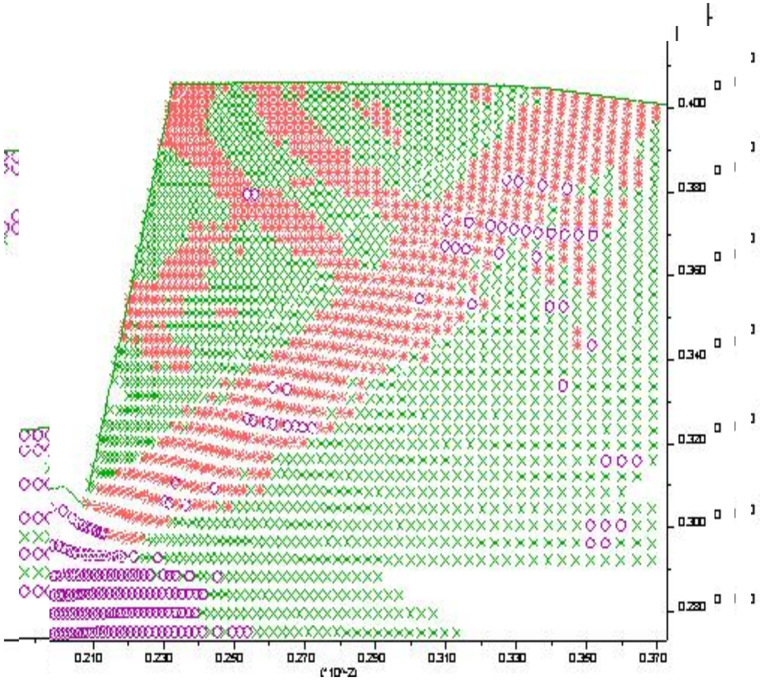


ϕ= 30°

- Tensile strength
  - ➢ No change

Changing the depth of cut





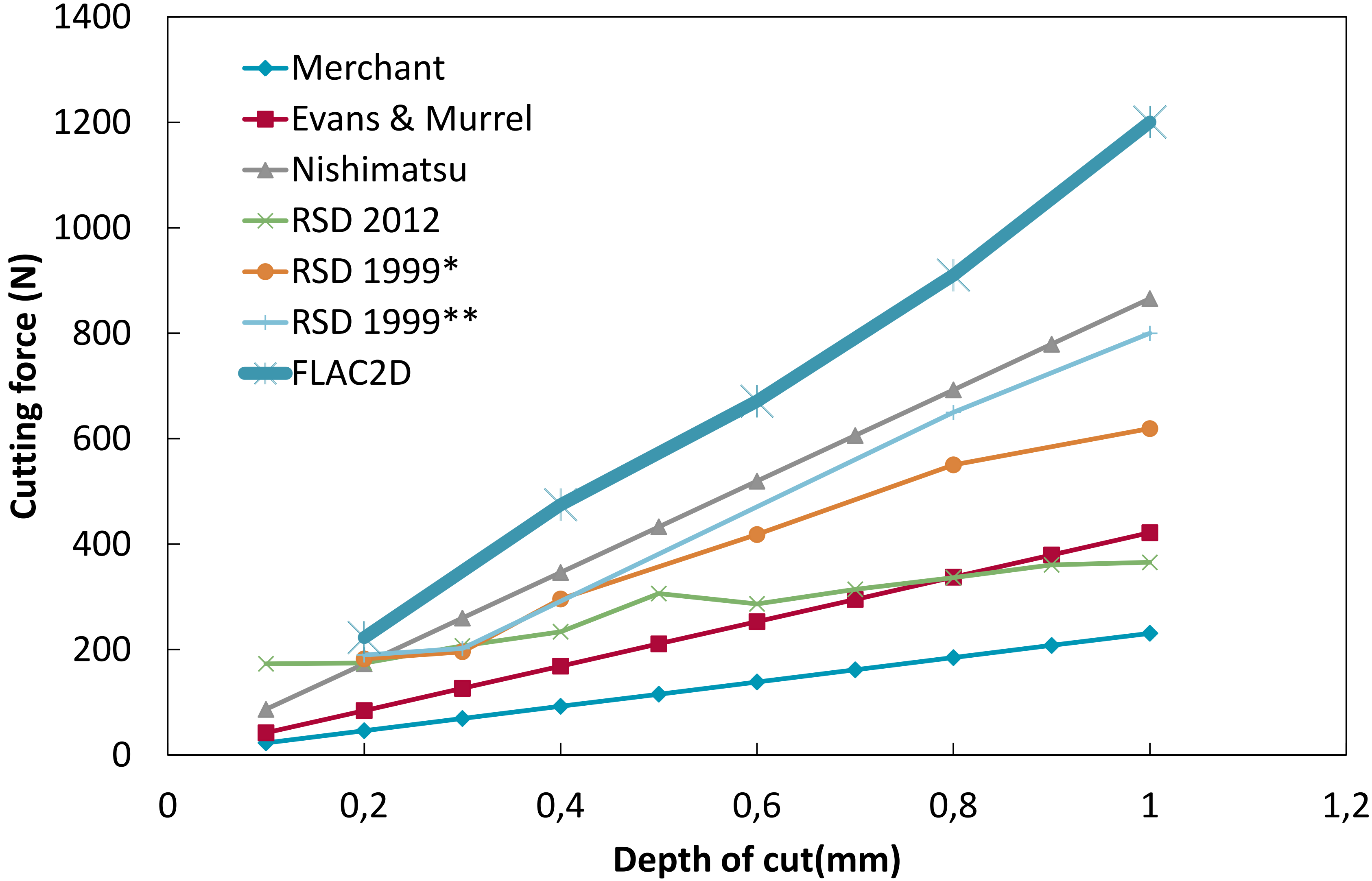
01[illegible]mm

Increase of size of chip with the depth of cut

- ➢ Friction behavior dominant at low depth of cut

Comparaison of cutting models (3)

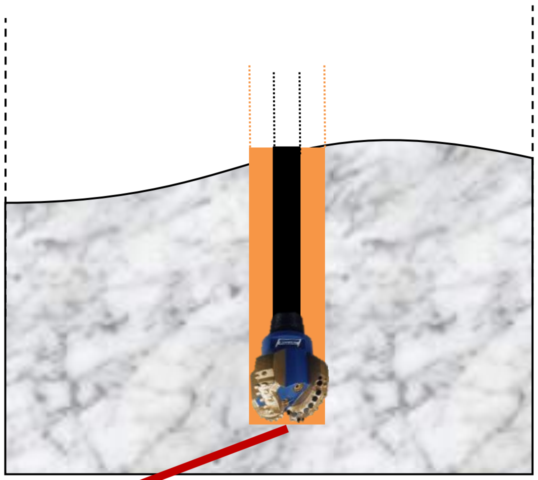
- Numerical model FLAC^{2D}

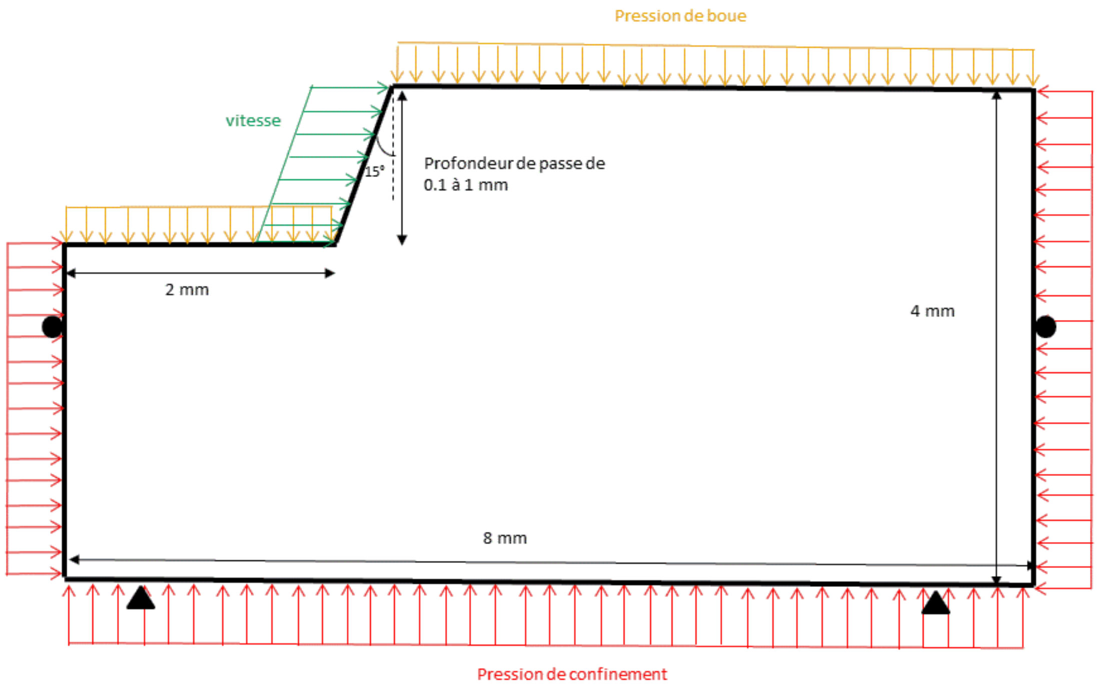


Modeling under confinement

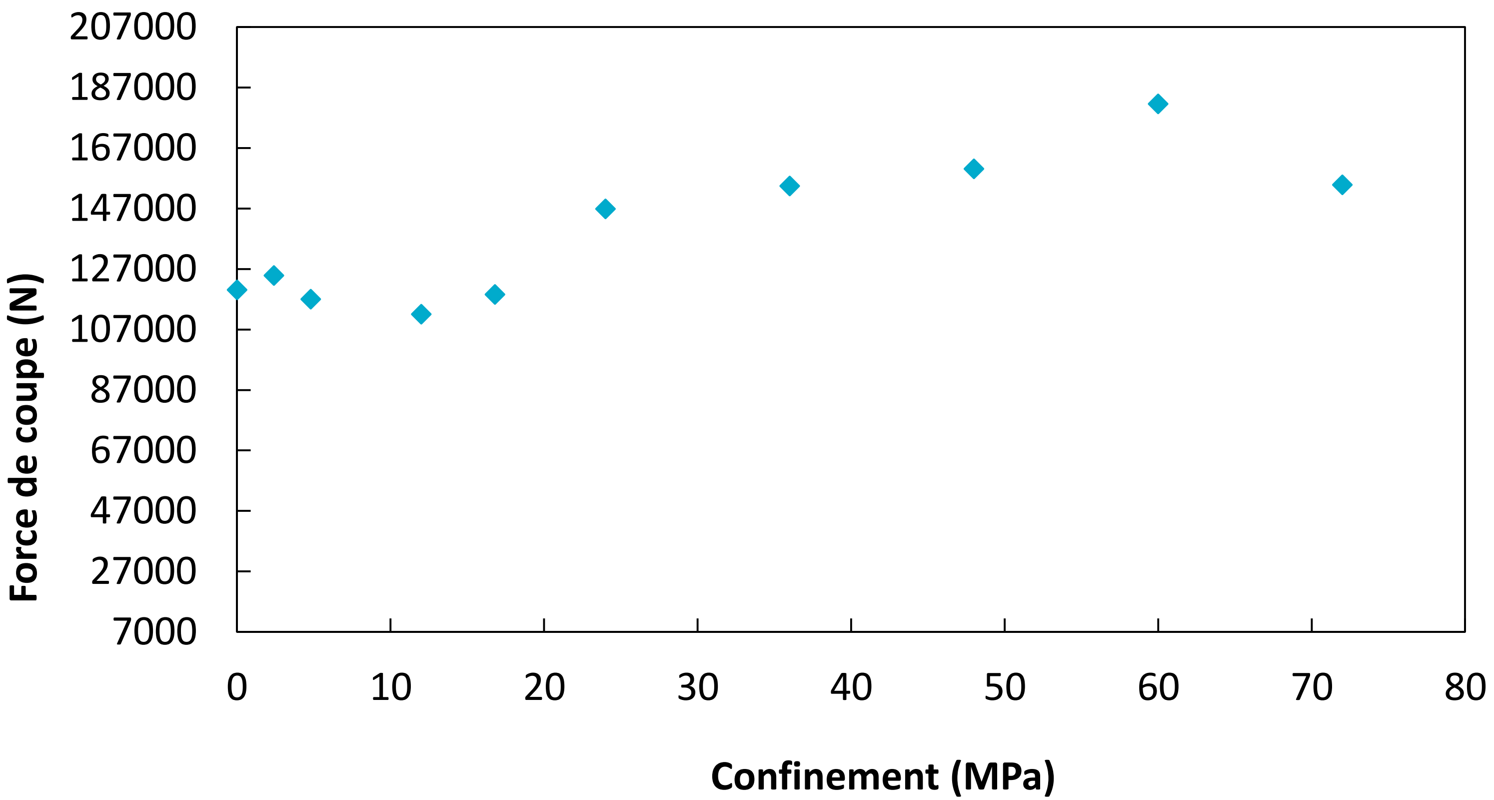
Confining pressure =
depth x rock density

Mud pressure =
depth x mud density





Modeling under confinement



The cutting force increases with confinement but the rate of increase decreases with the confinement.

Conclusions

Cutting is a complex process with a multitude of possible configurations (geometries, materials, operating conditions, etc.)

- Difficult to provide a general formulation
- Interest for numerical modeling

PDC cutter :

- The main cutting mechanism is SHEAR
- Evolution towards a dominant friction behavior with decreasing depth of cut
- Increase of cutting force with confinement until stabilization

Comparison of models :

- Nishimatsu, experimental and numerical are comparable FOR THIS ROCK

Perspectives

- Changing the behavior model of the rock
- Establishing relations : properties (rock + cutter), depth of cut, confinement
- Uploading factors : temperature, normal force, wear of the cutter, action of the mud, etc.
- 3D modeling: edge effects, cutter geometry
  - Comparison with cutting device equipped with a three-dimensional force sensor
- Discrete element method (PFC$^{2D\ ou\ 3D}$) : heterogeneity of the rock

Thank you for your attention