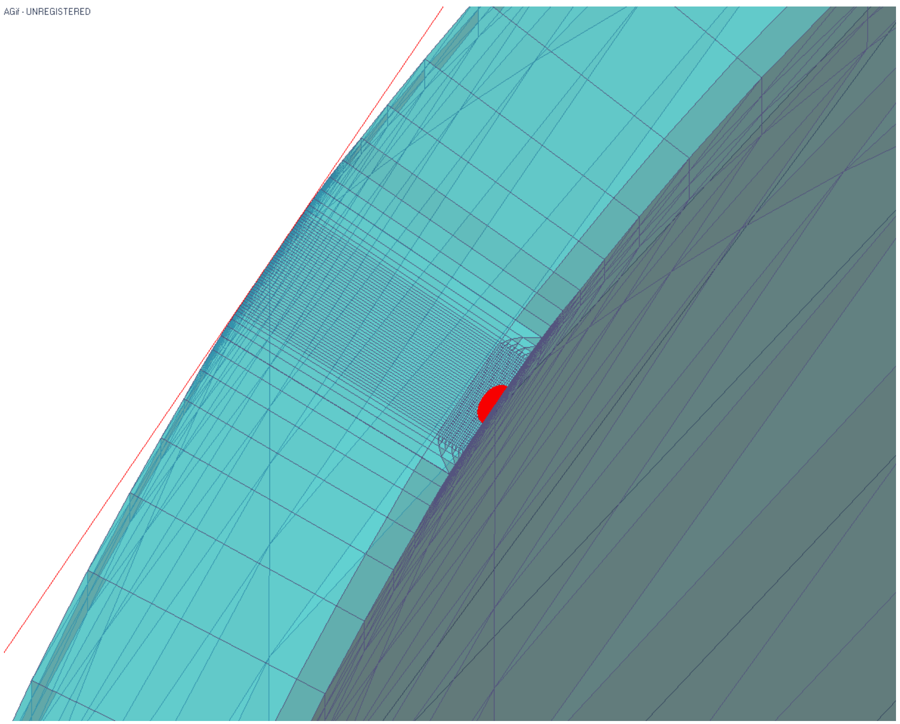
Mesh adaptation for mechanical studies in industrial process

Workshop *a posteriori* error estimates and mesh adaptivity for evolutionary and nonlinear problems

July 7, 2010

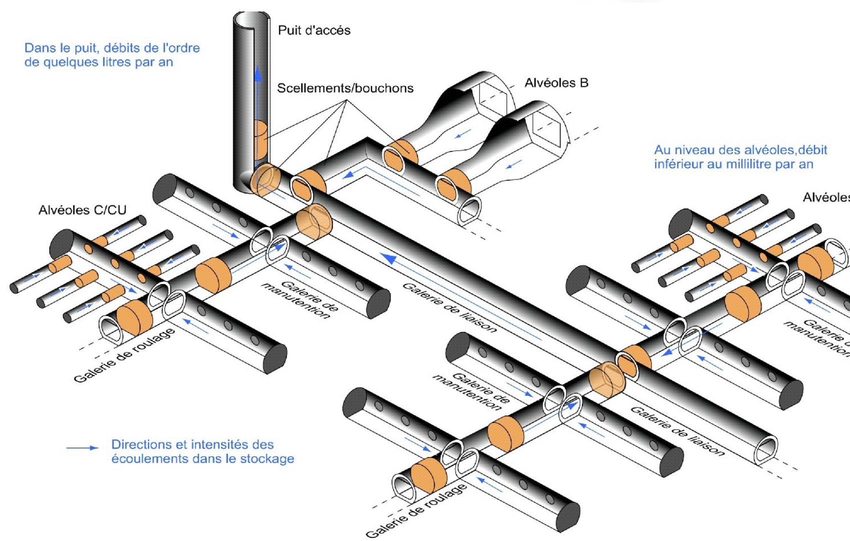
S. Meunier

Introduction



- Crack propagation

- Radioactive waste storage



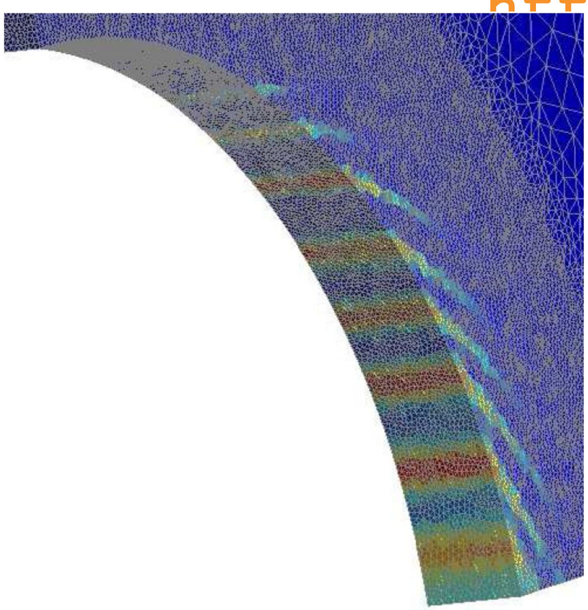
ANDRA

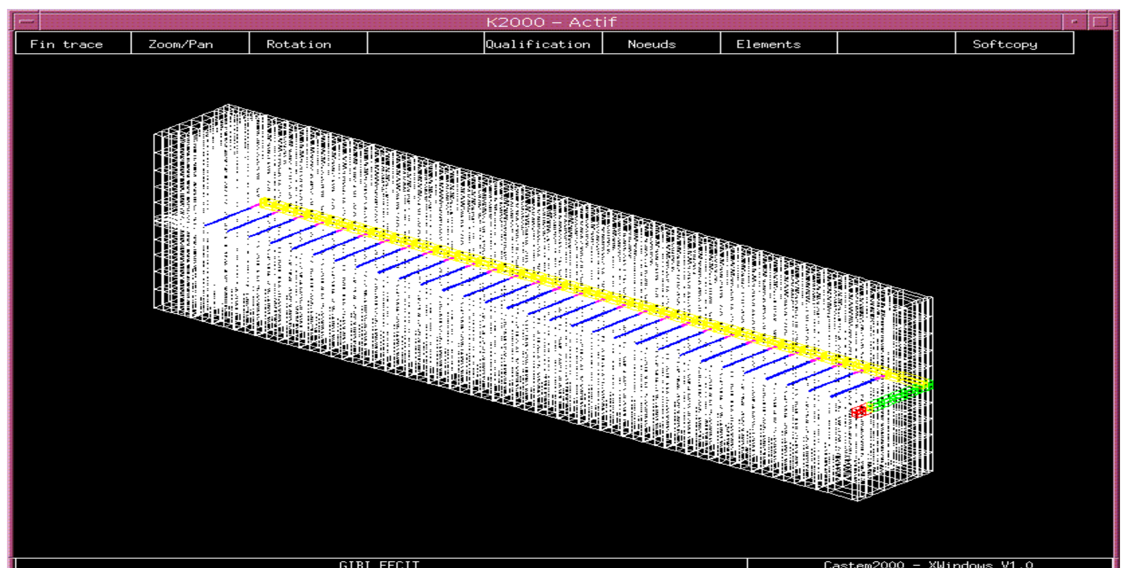
EDF

Introduction

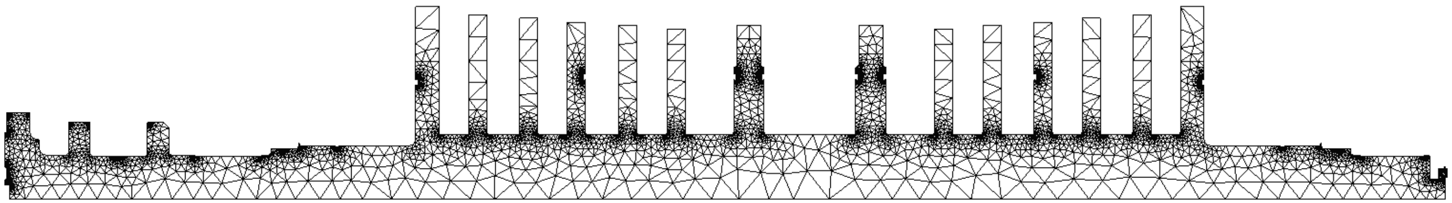
- Numerical simulation in *Code_Aster*
  - Finite Element industrial software of computational mechanics with Quality Assurance requirements
  - Multiphysics functionalities : seismic analysis, porous media, acoustics, thermics, fatigue, metallurgy, damage …
  - Various modelisations : XFEM, FEM, interface elements, structural elements, … more than 360 FE types !
  - Free download

http://www.code-aster.org





Introduction



Studies characteristics

- 3D complex geometry
- Complex behaviour laws
- Multi-scale discretisation
  - Large and small space steps
  - Large and small time steps
- Multiphysics
  - Fully coupled Thermo-Hydro-Mechanical (THM) problems

Introduction

- Need to be confident with the results
  - Reliability : independence on the discretisation
  - Accuracy : comparison with experiments, when possible !
  - Safety : guaranty that physical thresholds are not overtaken
    - Ex : Maximal stresses, maximal fluid pressure, …
  - *A priori* or *a posteriori* error estimation

- Need of diminution of cost of the study process
  - Initial mesh realisation
  - Computational cost

➡ **Need of mesh adaptation and *a posteriori* error estimation**

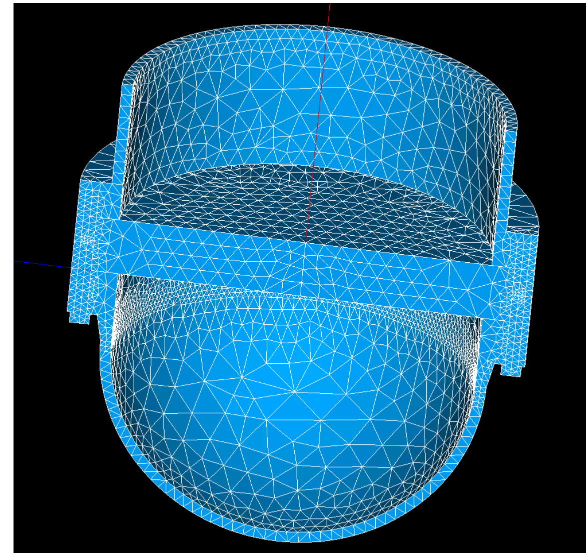
Outline

1. Mesh adaptation functionalities of *Code_Aster*
   1. *A posteriori* error estimators overview
   2. Adaptive mesh software : HOMARD

1. Studies with adaptive meshes
   1. Crack propagation industrial benchmark
   2. HM excavation study

1. Perspectives
   1. Our use experience of mesh adaptation and *a posteriori* error estimation
   2. Future work

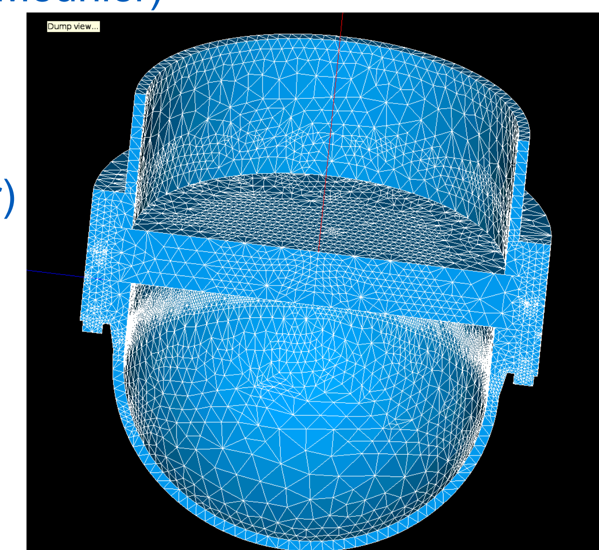
A posteriori error estimators overview



- Gradient recovery based estimators
  - Mechanics (available since 1993 ; Zienkiewicz-Zhu)

- Residual estimators
  - Mechanics (1994 ; Babuška, Rheinbolt, Verfürth)
    - X-FEM (2008 ; Hild, Lleras)
  - Thermics (2001 ; Bernardi, Metivet)
  - Hydro-Mechanics (+ time error estimators) (2007 ; Ern, Meunier)

- Goal-oriented quantities estimators
  - Mechanics (2006 ; Ainsworth, Oden, Becker, Rannacher)
    - Goal-oriented quantities : Mean-value over a subdomain of
      - a displacement component
      - a stress tensor component
      - Von-Misès equivalent stress
      - Stress intensity factor K



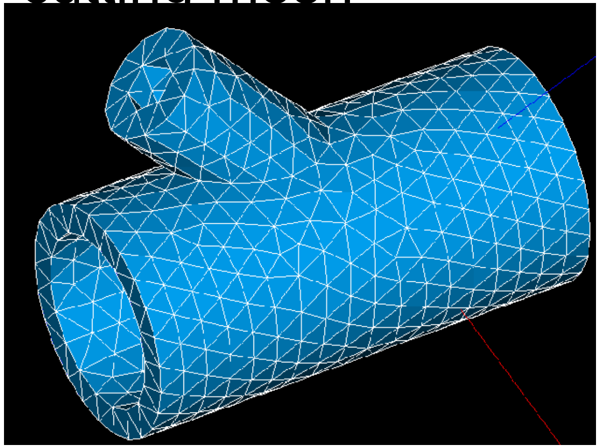
Courtesy of J. Delmas

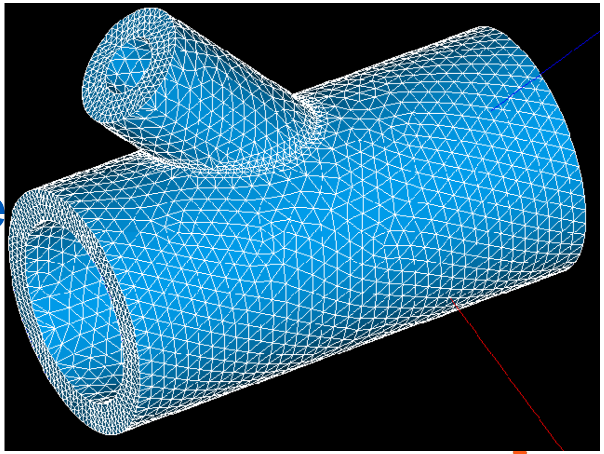
Adaptive mesh software : HOMARD

http://www.code-aster.org/outils/homard

- 2D and 3D refinement/derefinement tool by cutting mesh elements
  - Preservation of mesh conformity
  - Bounded variation of mesh quality
  - Tetrahedra, hexahedra, …
  - 1D-2D border tracking
- Refinement with respect to
  - Valued field and a threshold
  - Zone : rectangle, disk, parallelepiped, cylinder, sphere
- Use
  - Coupled with EDF software :

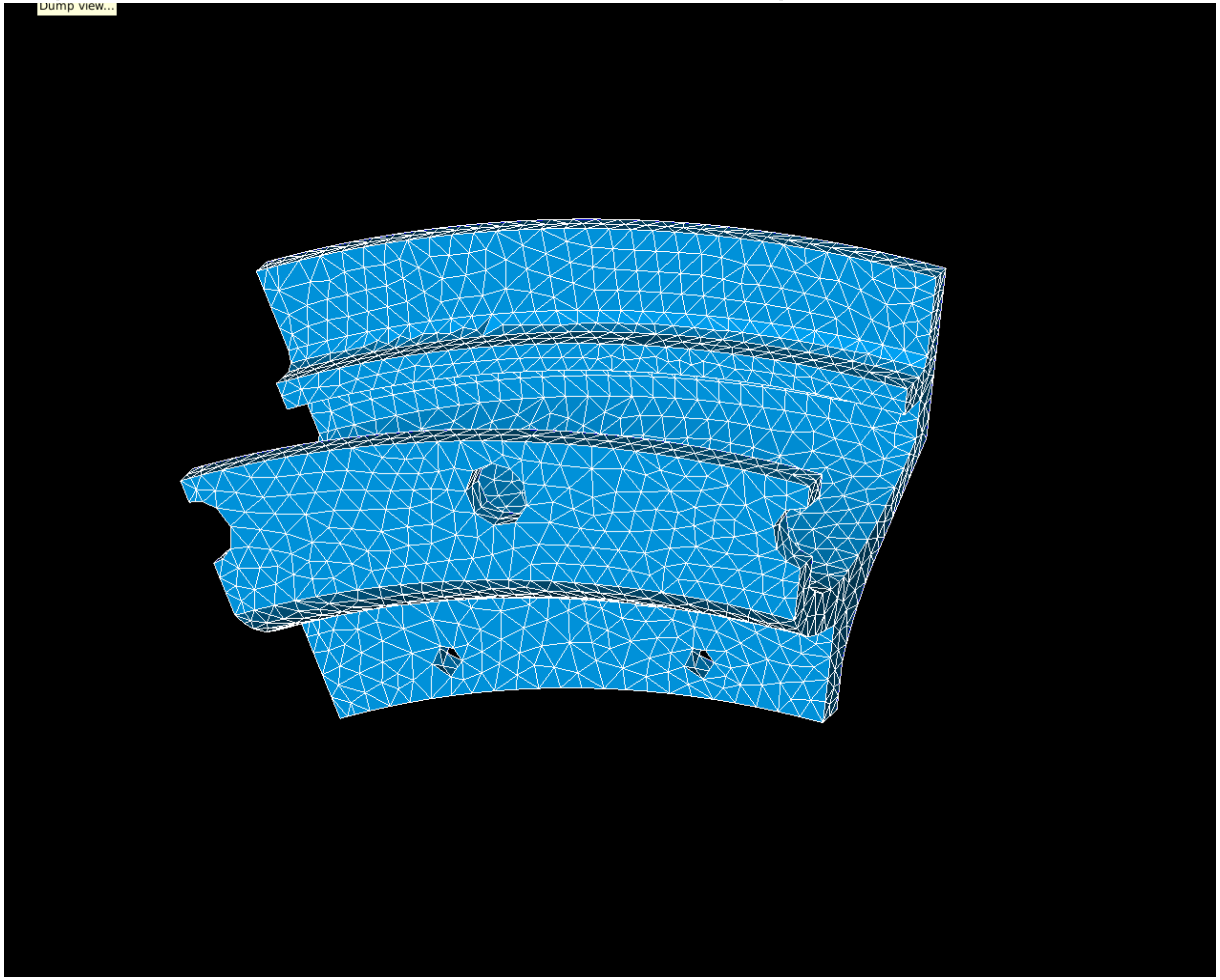
    Code_Aster, Telemac, Code_Saturne
  - Available in Salomé platform





Studies with adaptive meshes

- 3D crack propagation industrial benchmark (ECCM 2010, S. Geniaut)

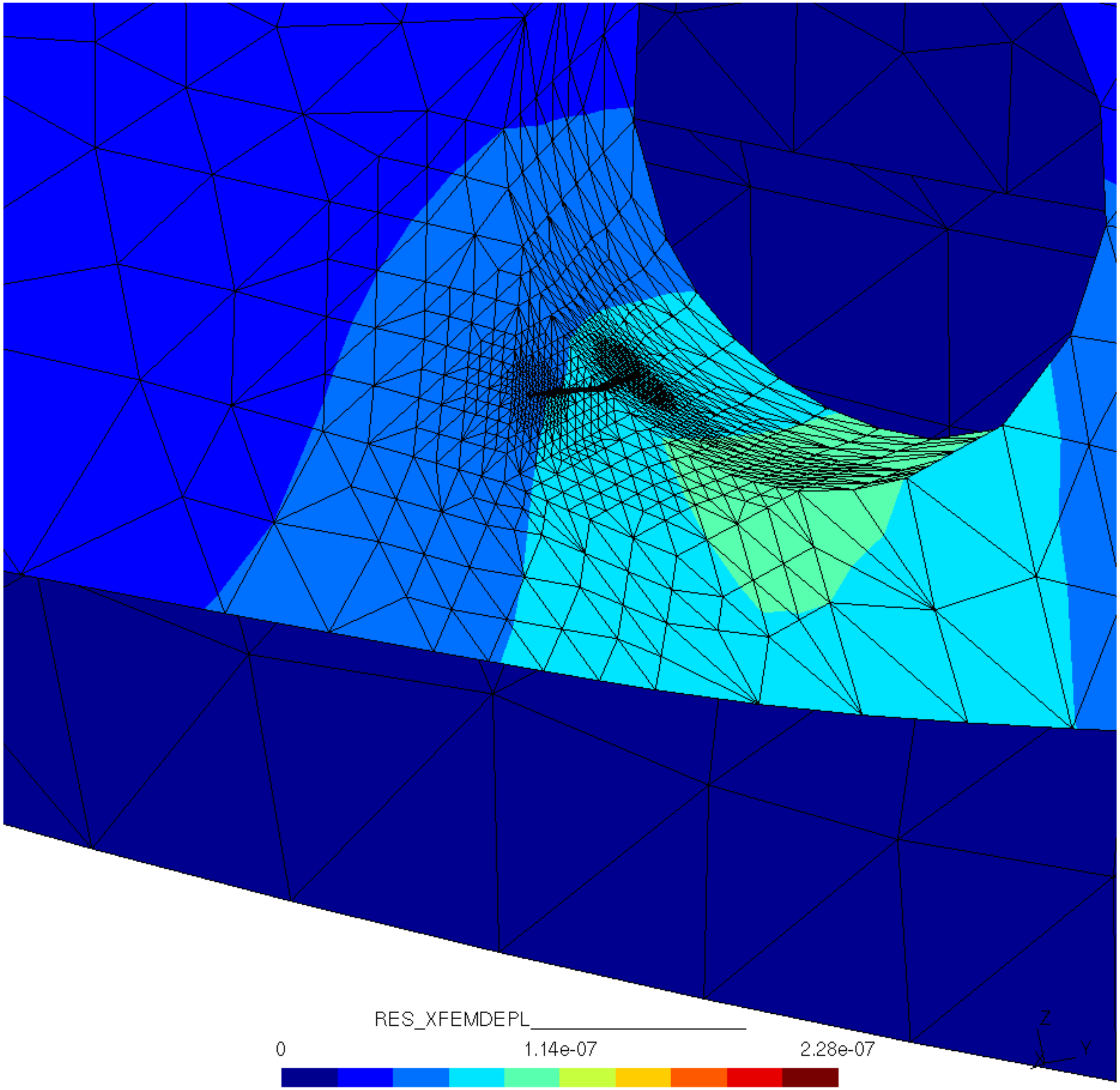


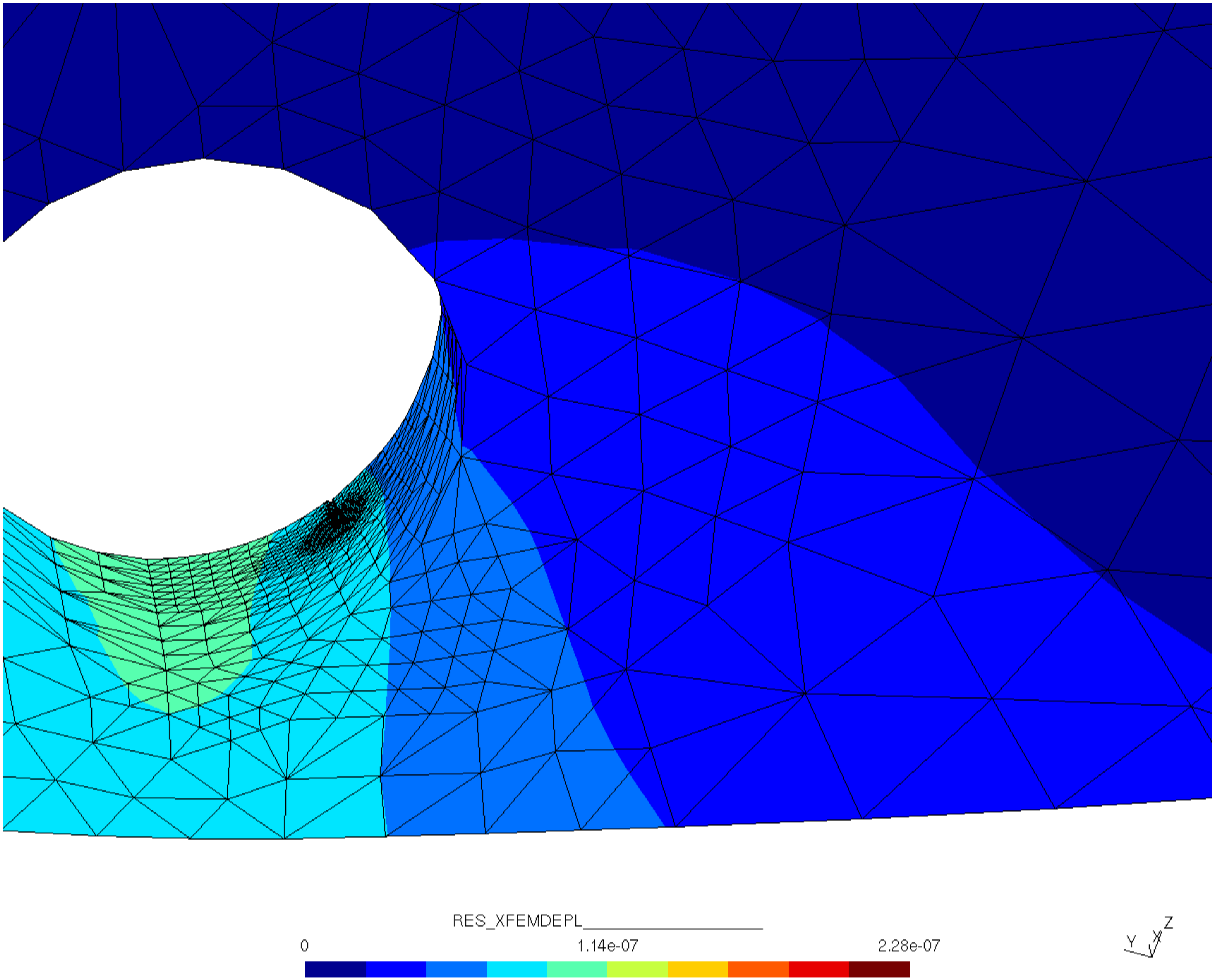
3D crack propagation industrial benchmark

- Quarter-circle shaped crack in main hole
  - Pressure on the central hole
  - Axial fixation of 2 other holes
  - Fixation of both cut faces

- Mesh fineness near front advance
  - Necessary for classical FEM
  - Necessary for XFEM

- Refinement near crack front advance
  - *A priori* mesh refinement
  - Automatically done using distance to crack front
  - Stopping criterion : maximal mesh cell size $h_{\max}$


RES_XFEMDEPL
0
1.14e-07
2.28e-07
Z
Y
X

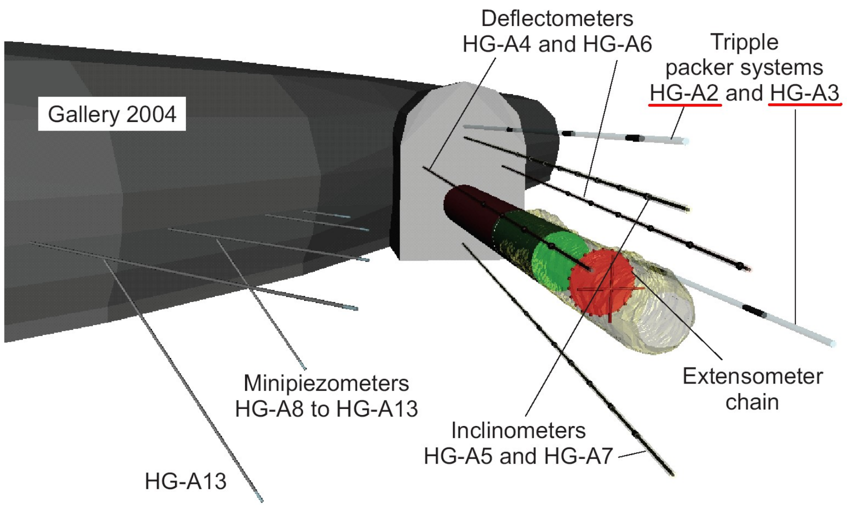

RES_XFEMDEPL
0
1.14e-07
2.28e-07
Z
Y
X

HM excavation study

- Framework : FORGE benchmark

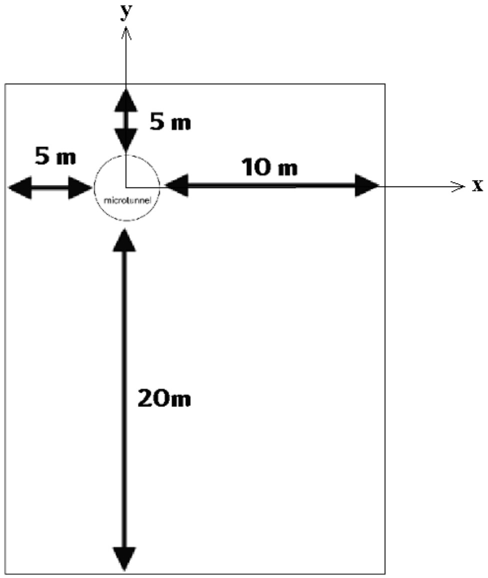
- Goals of the HM excavation study
  - Understand physical phenomena due to excavation
  - Comparison of numerical simulation with experimental data
  - Evaluate mesh adaptation and error estimation

- Work of F. Chansard (MSc student)

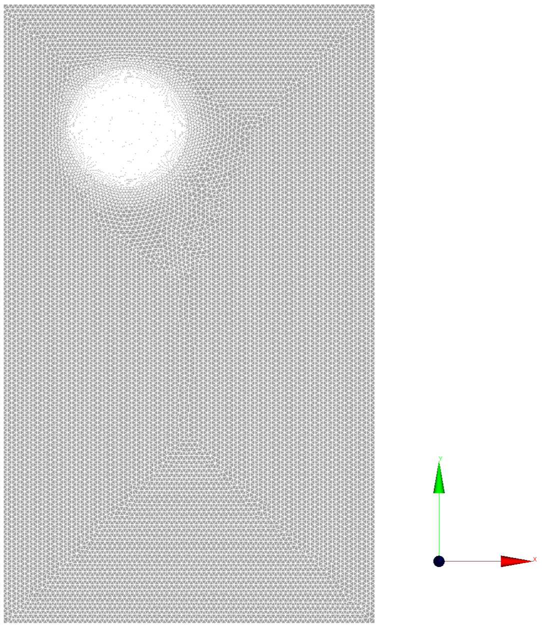


2D modelisation

- Geometry



- Fine reference mesh



<u>30 712 quadratic triangles</u>

- Modelling hypothesis
  - Excavation (2 hours)
  - HM saturated model
  - 2 behaviour laws
    - Elasticity
    - Drücker-Prager viscoplasticity (VDP)

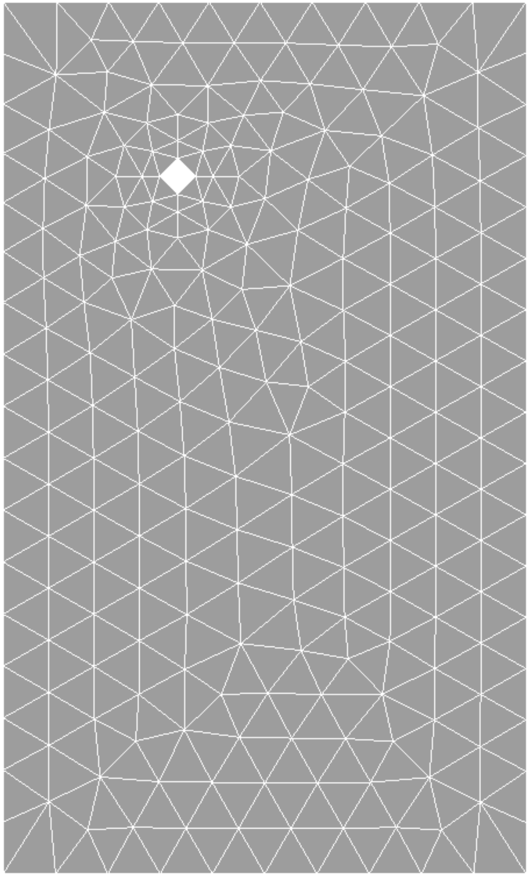
HM mesh adaptation

- Use of HM residual error estimators

- Theoretical validity
  - HM saturated model with elastic behaviour
  - Dirichlet and Neumann BCs

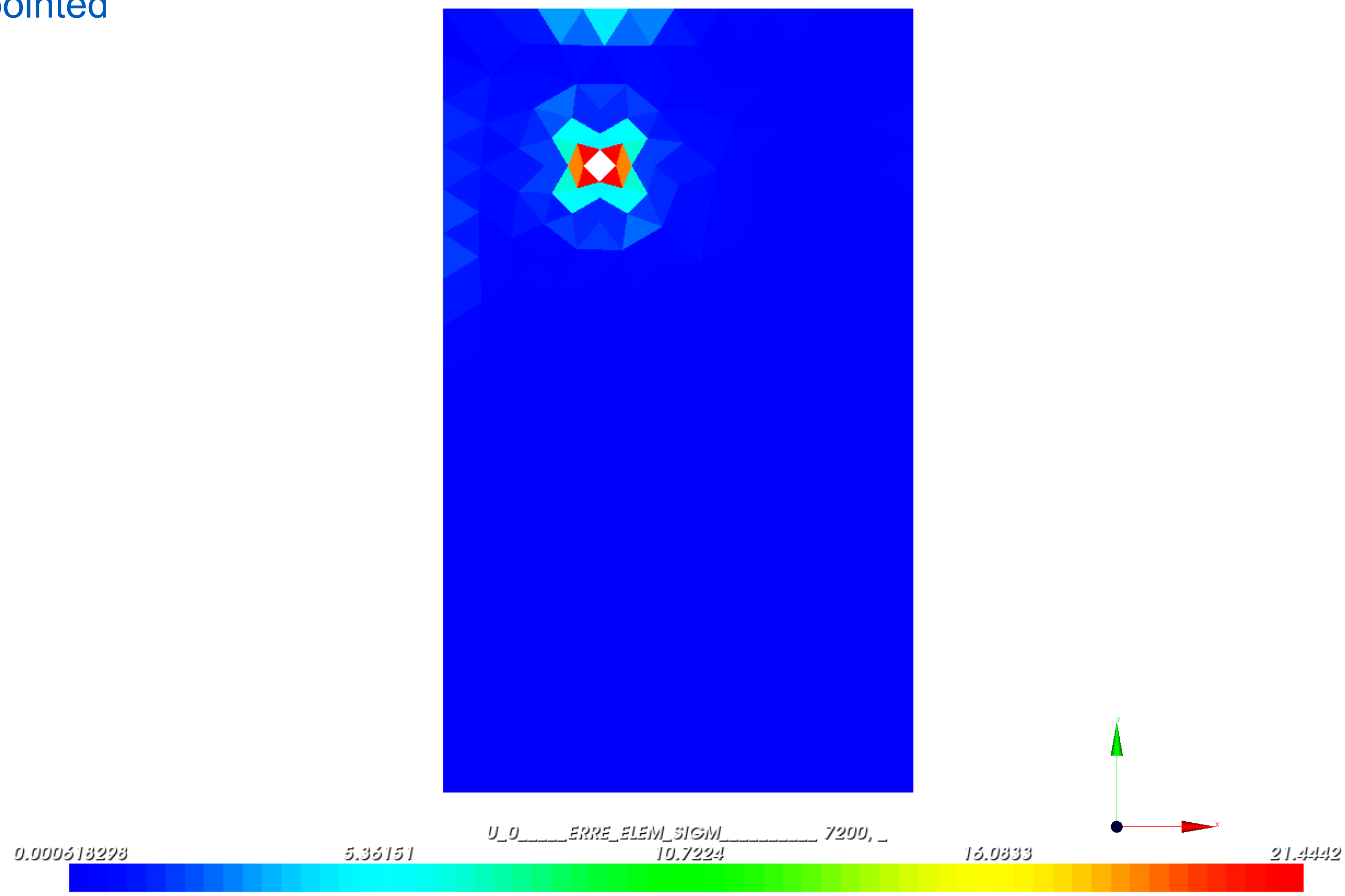
- Computation with
  - Coarse initial mesh
  - Nodal reactions at cavity

- Adaptive procedure
  - Same mesh during one simulation
  - Error estimation at the end of simulation
  - Adaptation of current mesh
  - Simulation on adapted mesh etc…



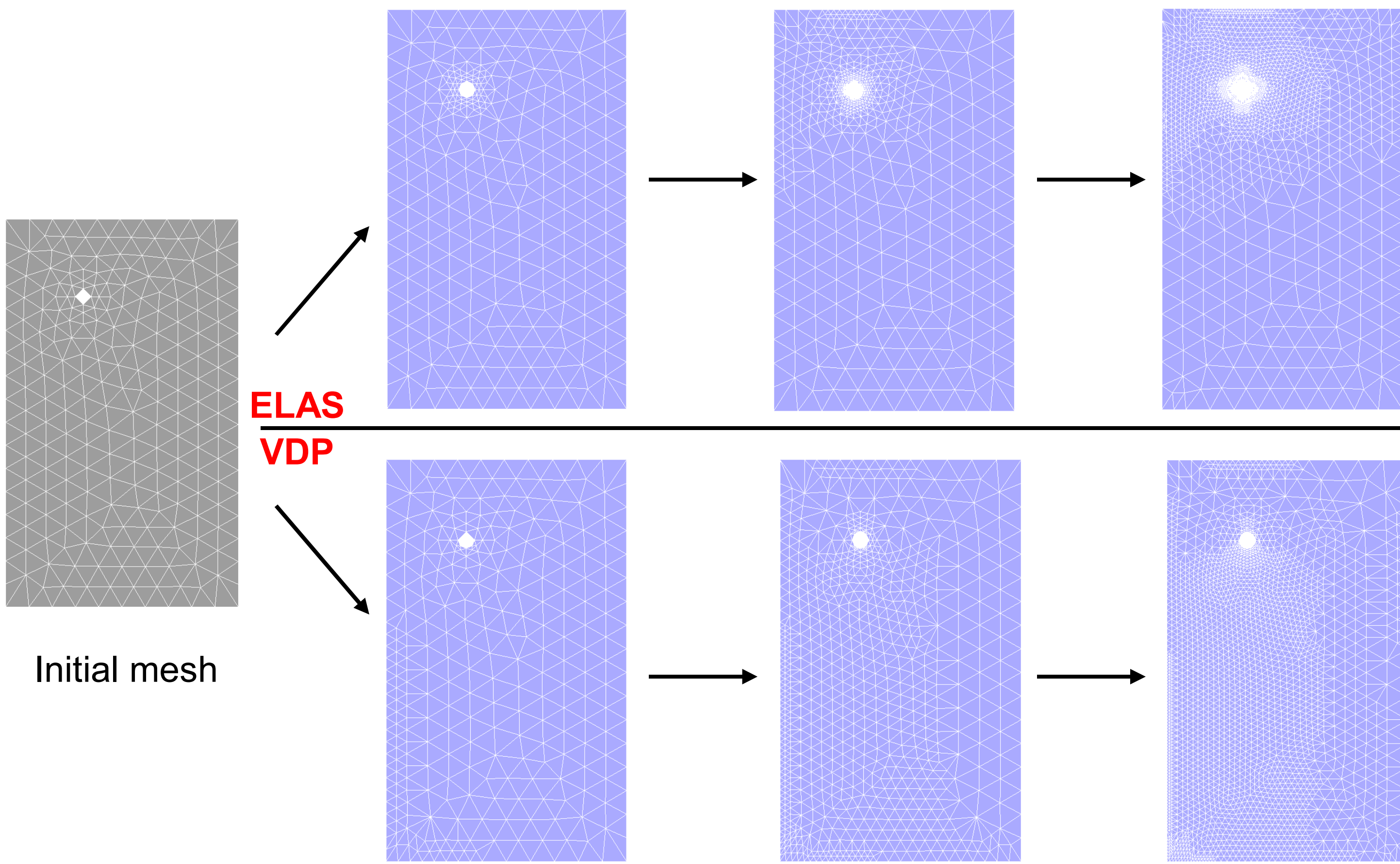
HM mesh adaptation

- Result for elasticity
  - Cavity is pointed



HM mesh adaptation

- Mesh adaptation with HOMARD
  - Border tracking
  - 5% cells with worst estimators



Initial mesh

1 adaptation

5 adaptations

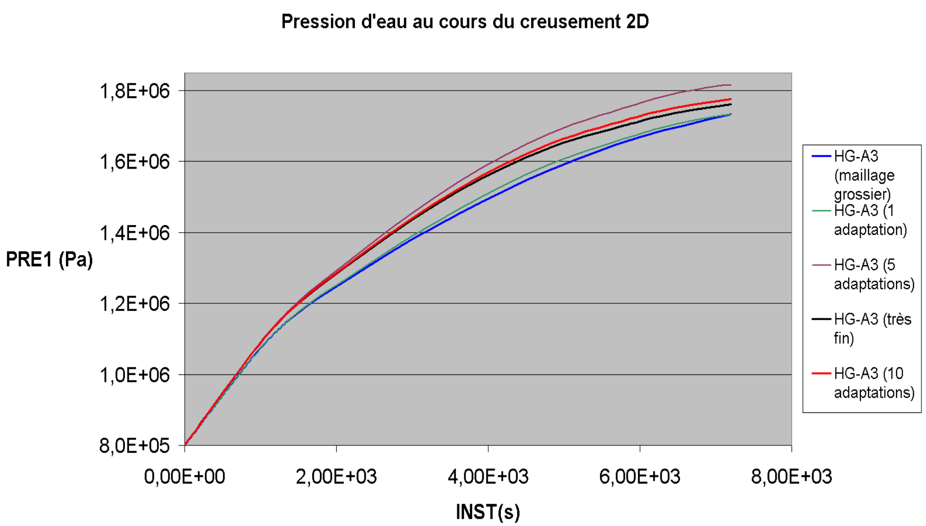
10 adaptations

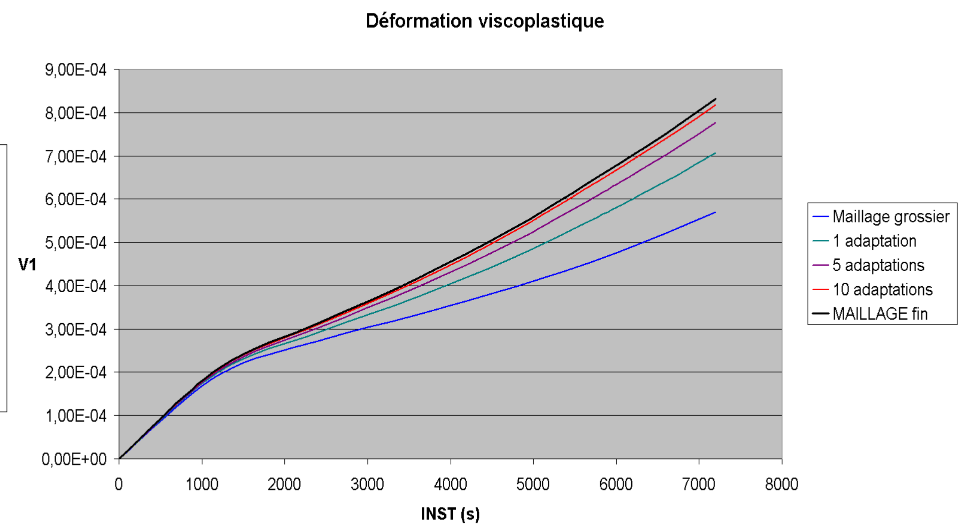
- Refined cavity

- Refined cavity
- Refined border, corner and center

HM mesh adaptation

- Comparison of liquid pressure and viscoplasticity strain





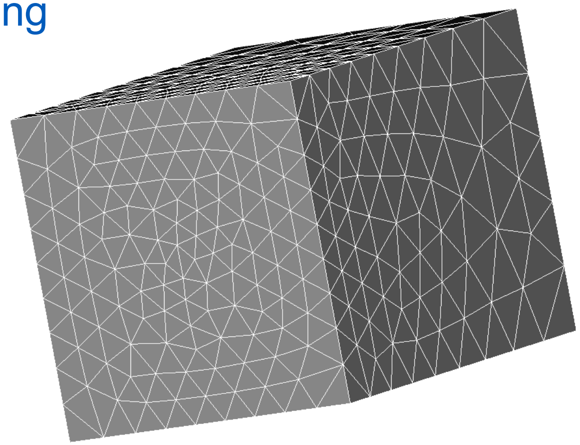
- Maximal difference < 5%
- Maximal difference > 45%

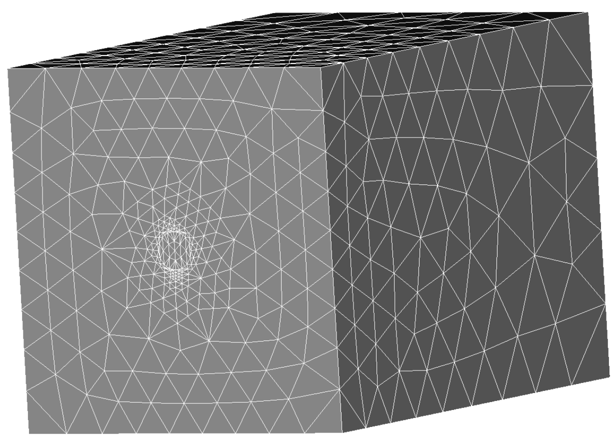
- Convergence after 10 adaptations

HM mesh adaptation

- Mesh adaptation in 3D
  - Leaded by displacement along *x*-axis
  - « From scratch » iterative process
  - With border tracking
  - Elasticity law

- Work in progress
  - High computational cost with VDP !





Experience and interrogations : mesh adaptation

- Mesh adaptation

  - Few users only : learnings and demonstrations

  - Lack of user-friendliness :
    - Command files quite tricky
    - More automatic and simple adaptive procedures

  - Which criterion choose ?
    - Geometrical
    - Physical
    - Error estimator

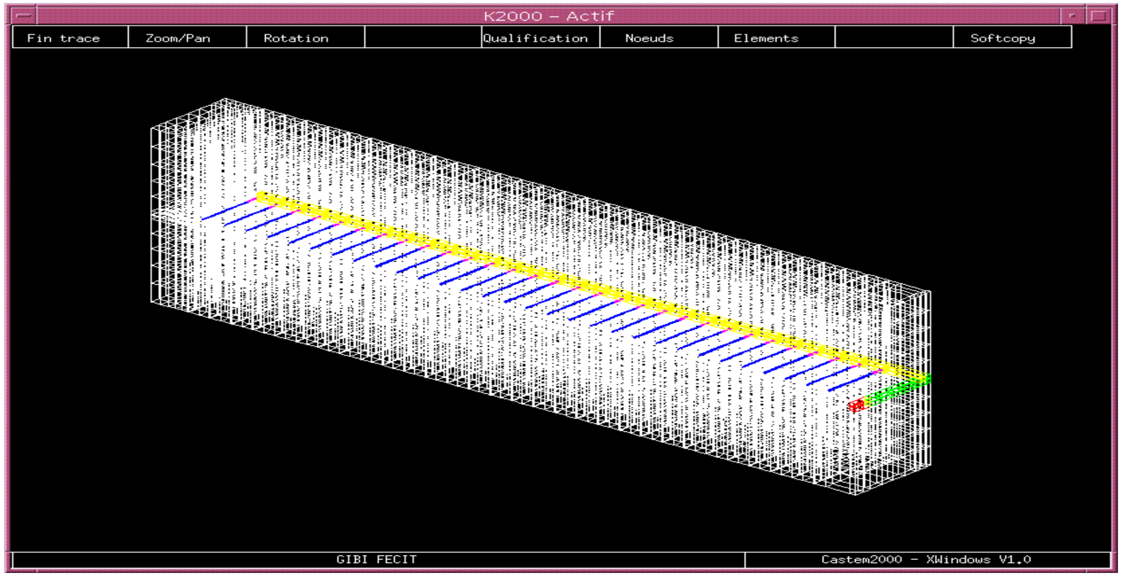
  - Constrained fields projection are difficult (Gauss points)

Experience and interrogations : error estimation

Error estimation

- Universal estimator
  - Framework genericity : which signification of estimators with
    - Connecting conditions
    - Multi-scale
    - Multiphysics
    - Contact
    - Non-elastic behaviour laws … ?
  - Still available in Code_Aster : jump of a quantitie between an element and its neighbors
- Many estimators : which are fitted for our problems ?
- Sensitivity to element types ? (triangle/quadrangle, tetrahedron/pentahedron/hexahedron, …)
  - Estimation of reliability constant for residual estimators ?

Future work

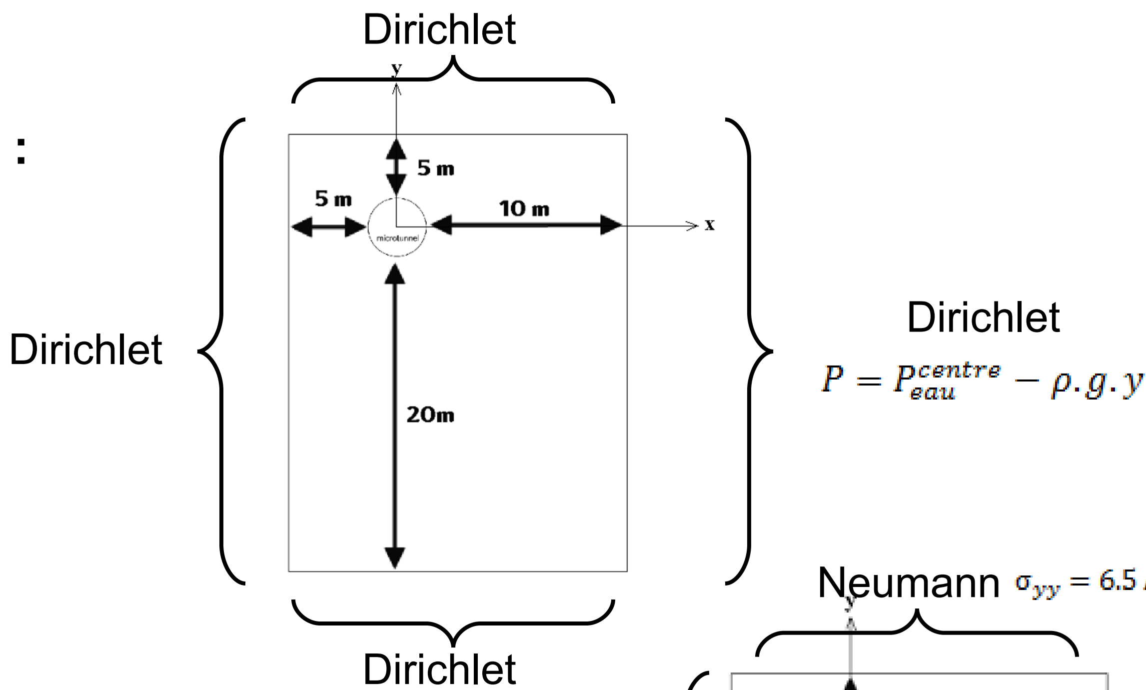


- Mesh (and time !) adaptation
  - Automatization of adaptive procedures
  - Adaptive procedures for time-dependent problems (HM)
  - Time adaptation w.r.t. space adaptation

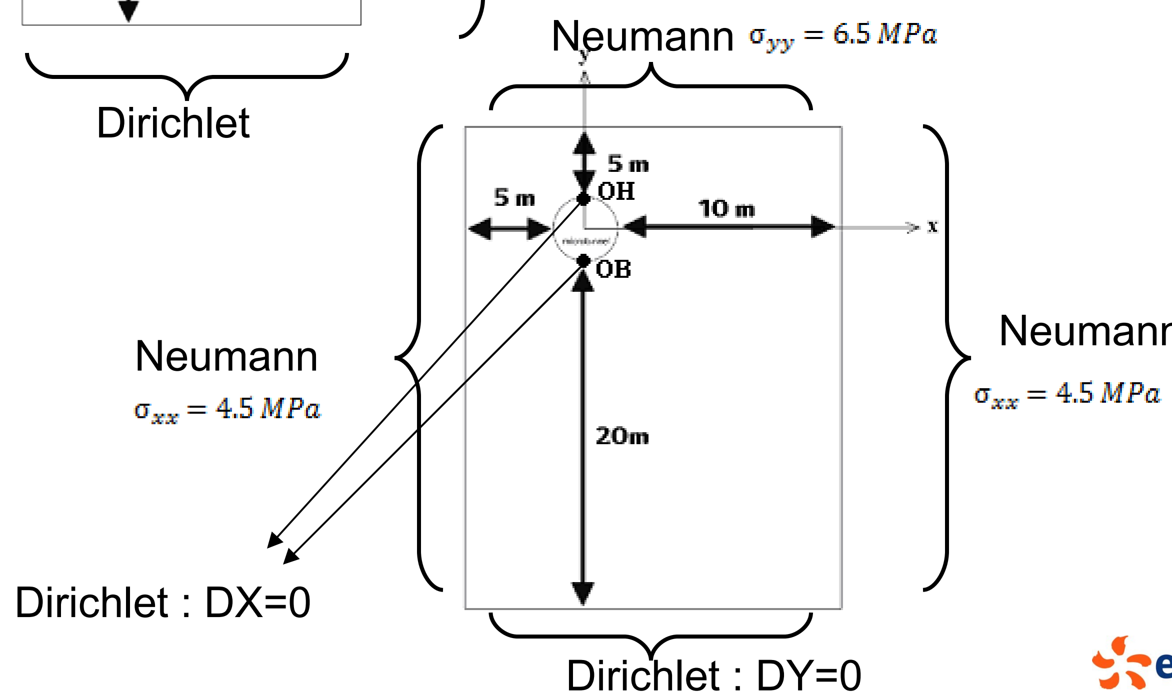
- Error estimation
  - Which kind of error estimators ?
  - Developement of this error estimator
  - Assessment of time error estimation

2D modelisation

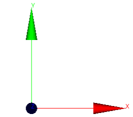
- BC :
  - **Hydraulics :**

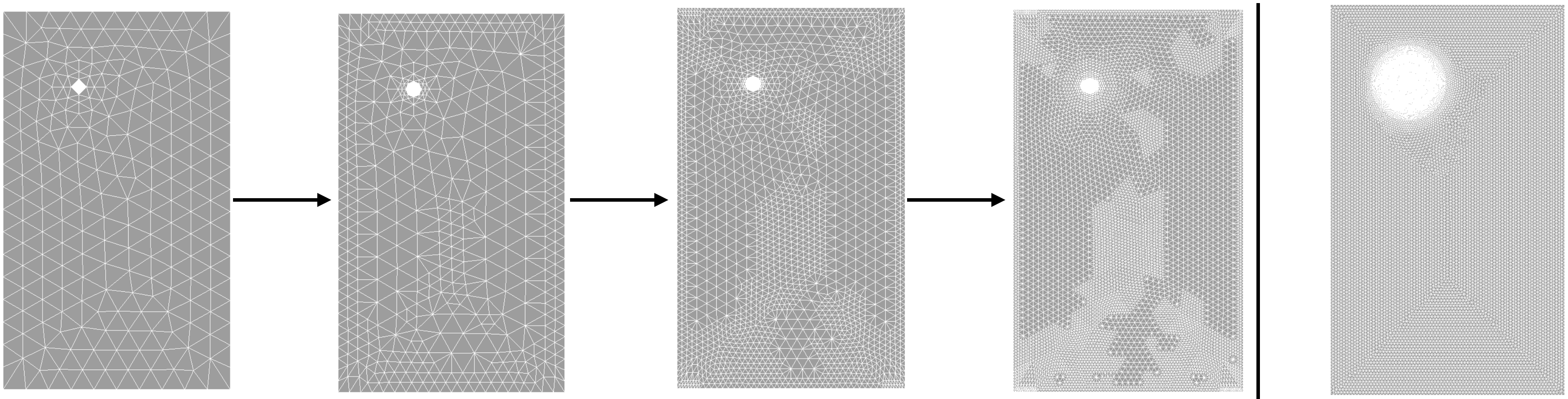


  - **Mechanics :**



Indicateurs d'erreur et adaptation de maillage



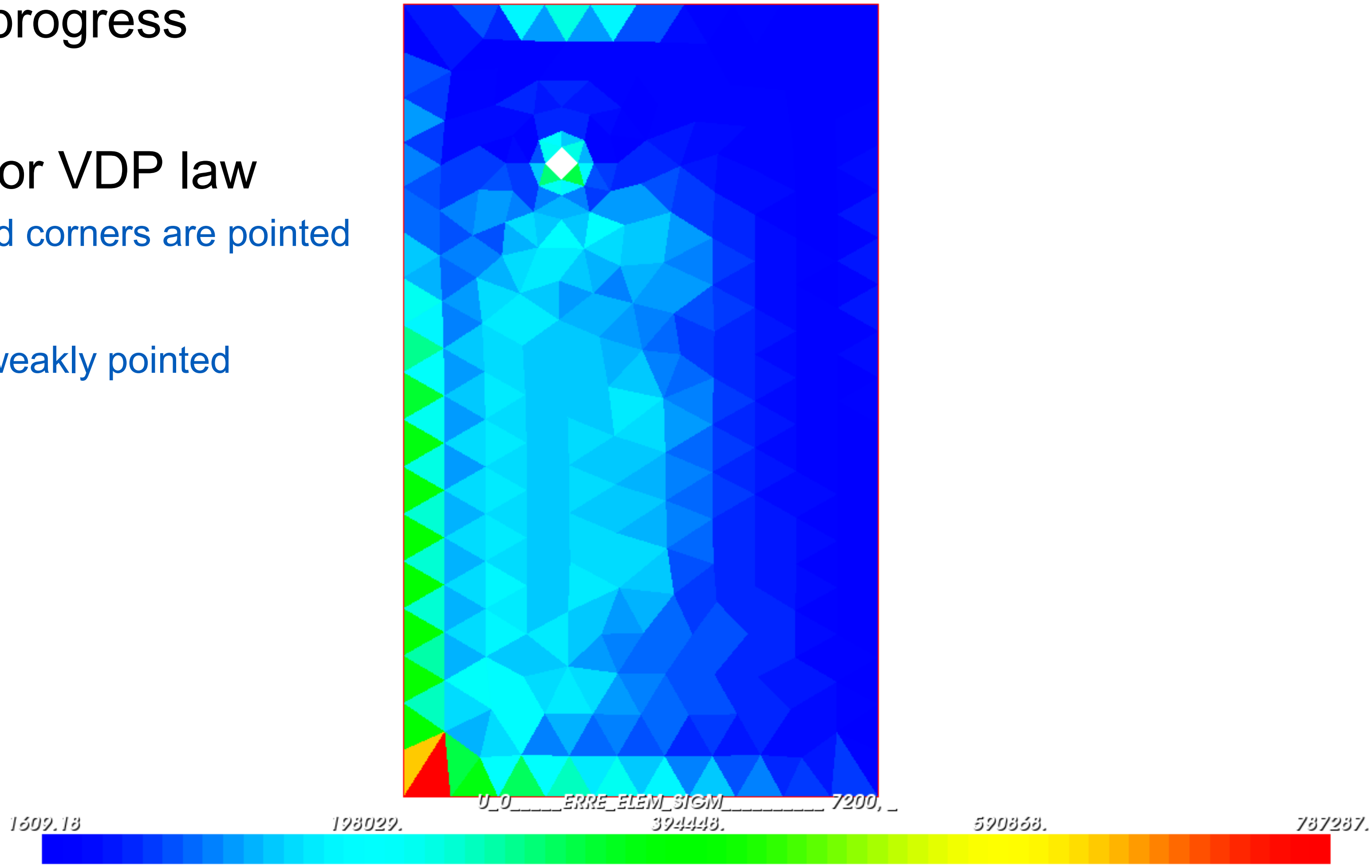


maillage initial	1 adaptation	5 adaptations	10 adaptations	Maillage des simulations
906 nœuds	1 932 nœuds	7 607 nœuds	26 619 nœuds	61 824 nœuds
424 éléments	908 éléments	3 683 éléments	13 069 éléments	30 712 éléments
2 215 ddls	4 694 ddls	17 856 ddls	82 308 ddls	140 052 ddls
7 s	29 s	2 min 14 s	9 min 43 s	11 min 21 s

Séquentiel

HM mesh adaptation

- Work in progress
- Results for VDP law
  - Border and corners are pointed
  - Cavity is weakly pointed



Error estimators / 10 adaptations with VDP

- 10 times adapted mesh