Computational fracture mechanics with SAMCEF

New trends and illustration on an industrial test case

C. Henrard[1], M. Suptille[2], N Visseaux[2], M. Bruyneel[1]

[1]SAMTECH Liège, Belgium
[2]SAMTECH Paris, France

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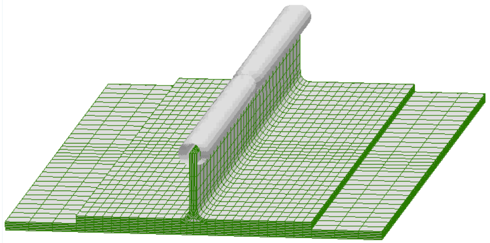
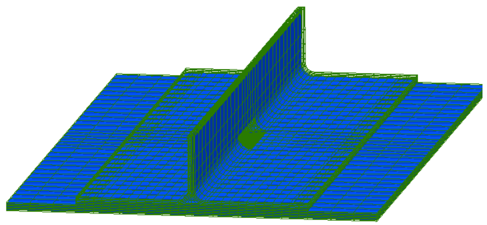
Few words about SAMTECH

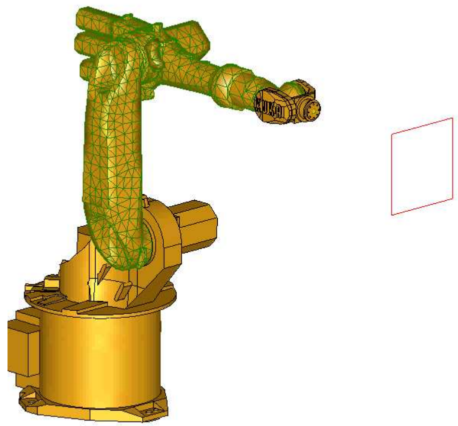
Composite and aeronautics applications

Delamination in a composite structures



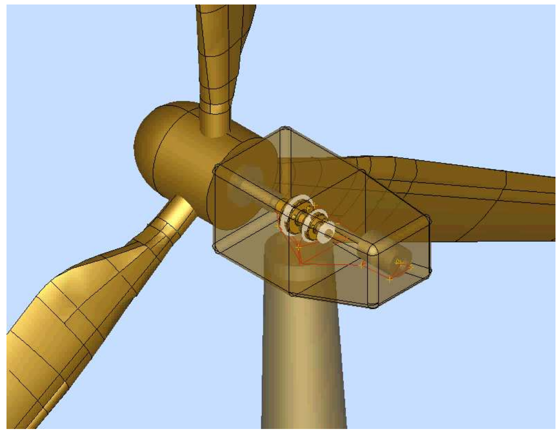


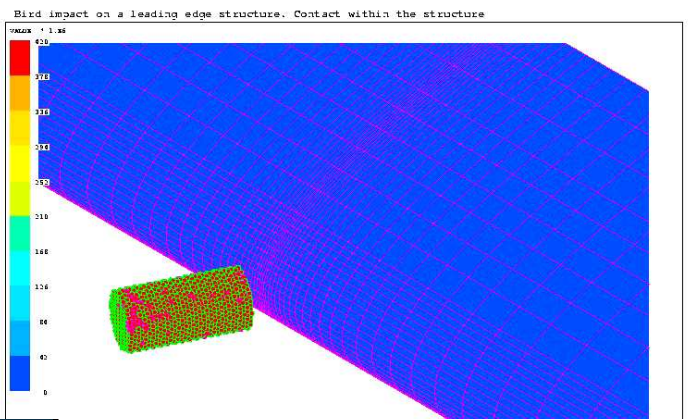
Flexible systems dynamics and mechatronics



SAMCEF Finite Element code

Wind turbine modelling





Bird impact
on a slat

Courtesy
of SONACA

Few words about SAMTECH

SAMTECH

AIRBUS · eurocopter an EADS Company · THALES · MTU Aero Engines · KAI KOREA AEROSPACE INDUSTRIES, LTD.

EADS · SPIRIT AEROSYSTEMS · Snecma Groupe SAFRAN · cnes CENTRE NATIONAL D'ÉTUDES SPATIALES · AleniaAeronautica · AleniaAermacchi · esa · Avio propulsione aerospaziale

MBDA MISSILE SYSTEMS · GIAT industries · RÉPUBLIQUE FRANÇAISE MINISTÈRE DE LA DÉFENSE · RHEINMETALL · Souey HOLDING INC.

GE · ABB · Enel L'ENERGIA CHE TI ASCOLTA. · AREVA · eDF · SIEMENS

SAINT-GOBAIN · Glaverbel · ArcelorMittal · PICANOL · COMAU

PSA PEUGEOT CITROËN · BMW · RENAULT · DAIMLER

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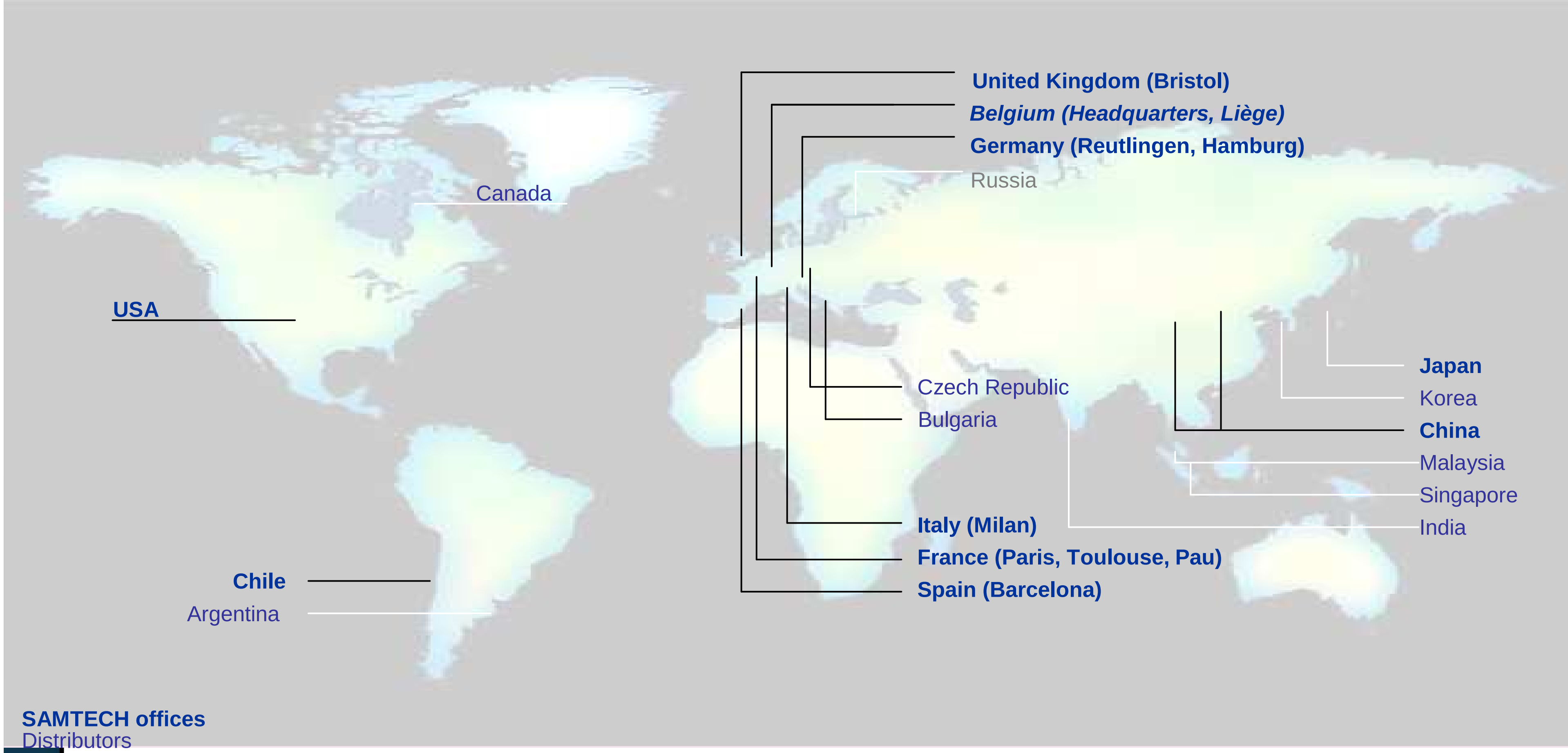
PORSCHE

Few words about SAMTECH

World wide representation



Outline

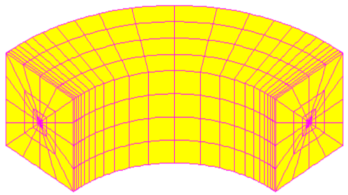
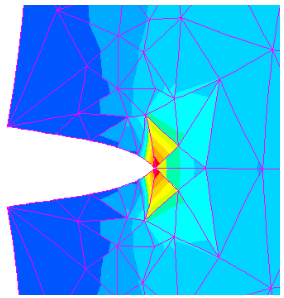
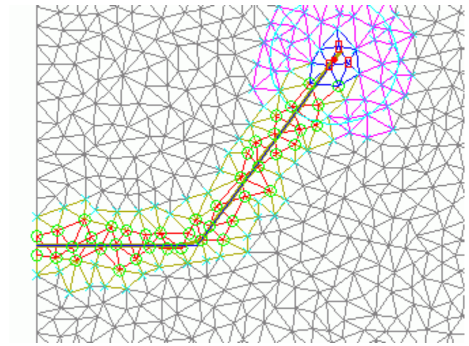
- Methods available in SAMCEF for fracture mechanics
- XFEM method in SAMCEF
- Applications of XFEM with SAMCEF
- Conclusions

…let me recall that SAMCEF has been used for more than 25 years by the largest aerospace companies in Europe

…SAMCEF is already selected for its XFEM solution by :

AIRBUS Snecma Groupe SAFRAN ASTRIUM AN EADS COMPANY

Methods available in SAMCEF

	FEM with crack box	FEM without crack box	XFEM
			
2D	☺	☺	☺
3D	☺	☺	☺

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Why XFEM method ?

Classic FE approach

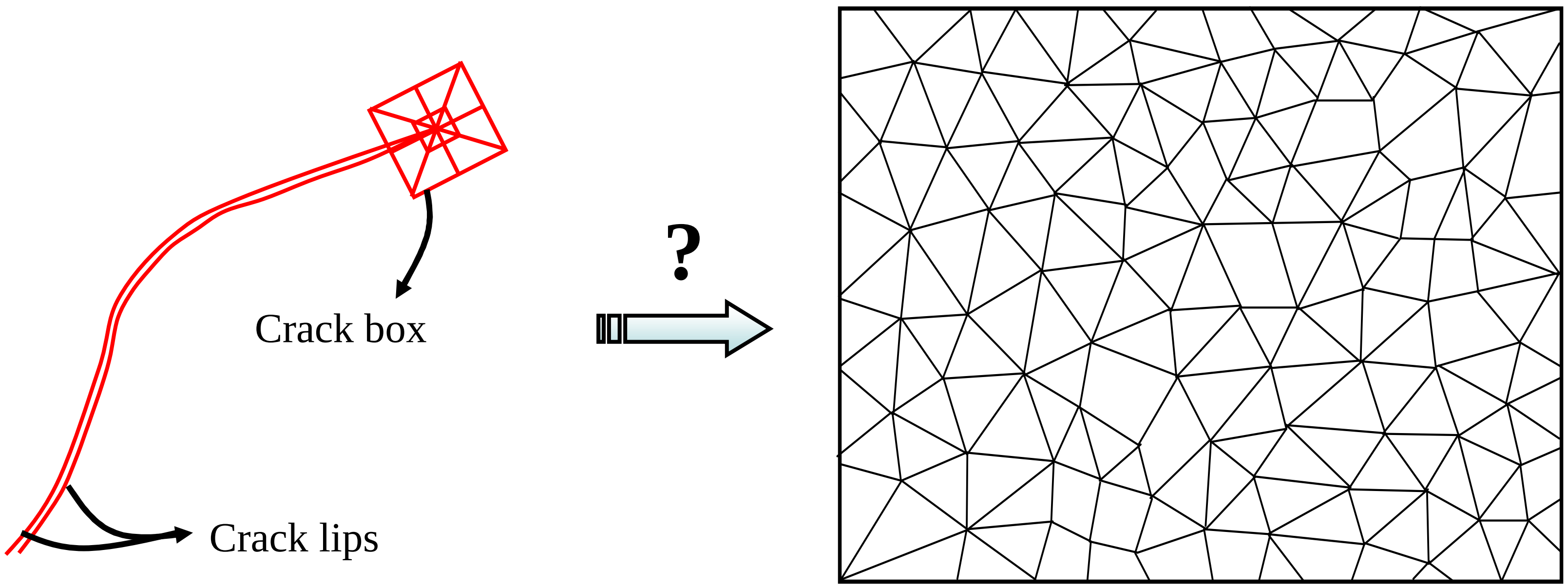
- Difficulty to include a crack in an existing mesh

  => define new geometric items (crack lips) + define a crack box around the crack tip

- Difficulty to study a crack propagation

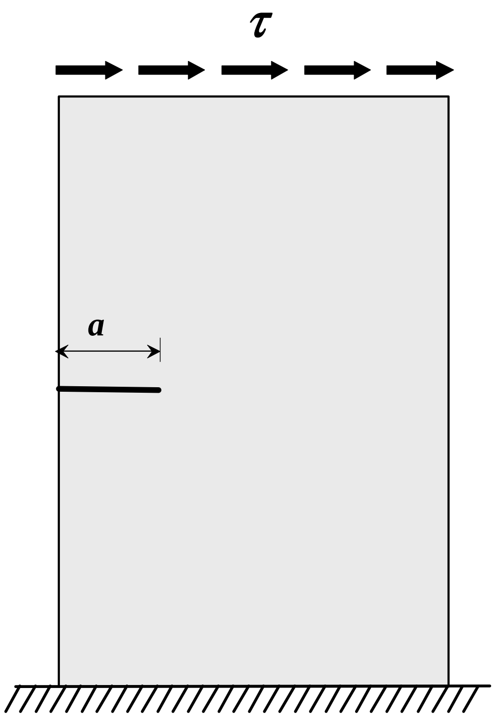
  => modification of the geometry

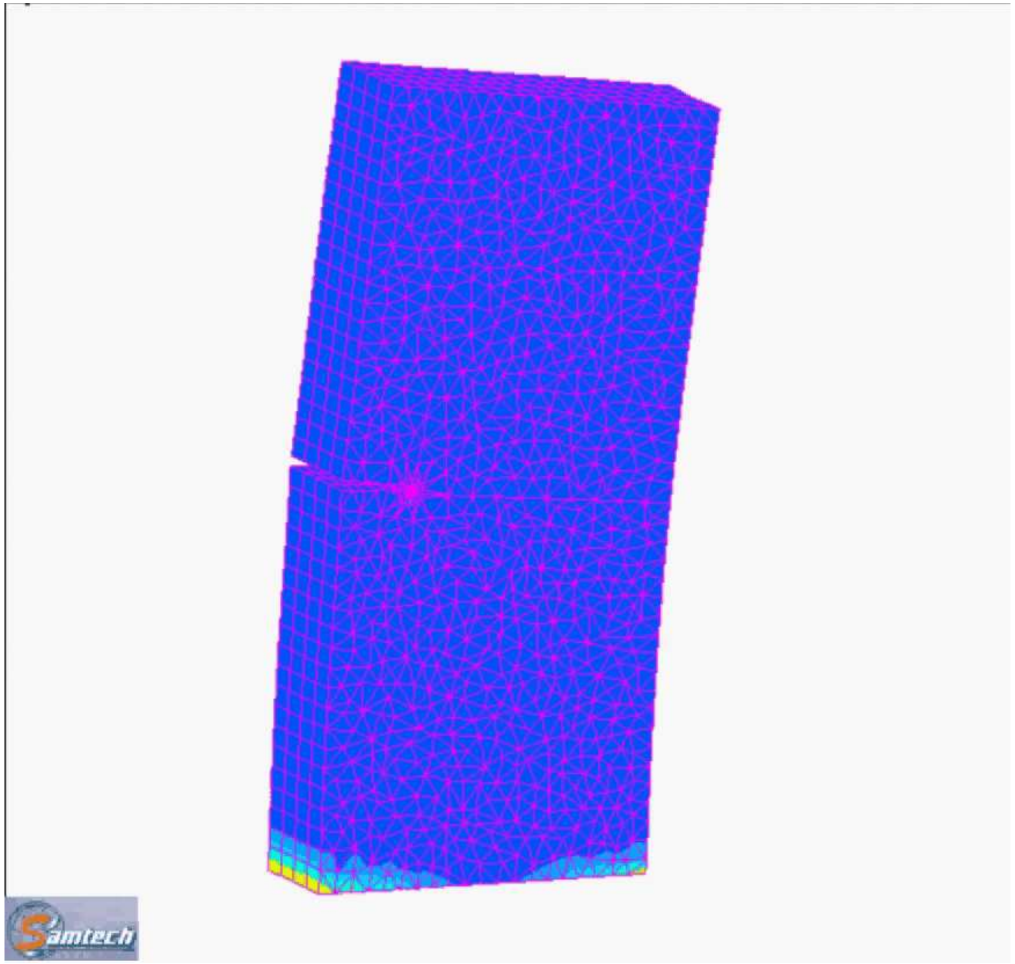
  => remeshing is required at each step



Classic FE method: illustration

Crack propagation with bifurcation (crack box)



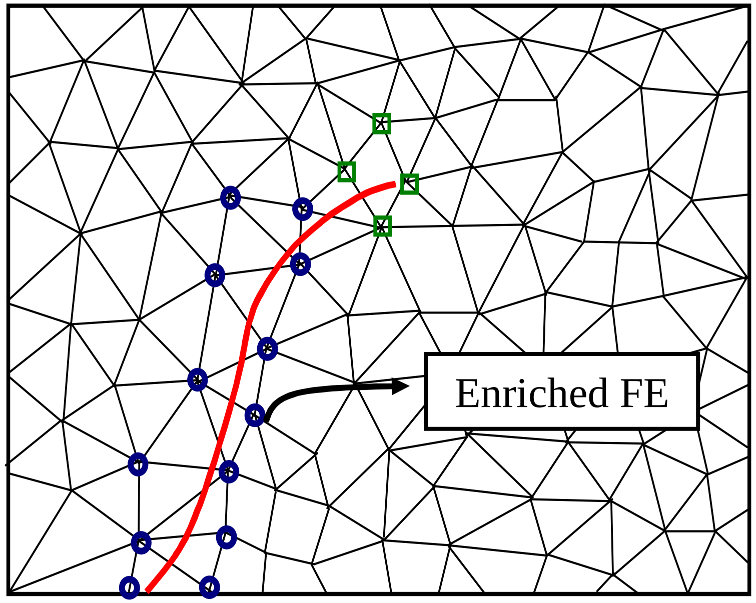


Modeling time

Advantages of XFEM method

XFEM approach: easier definition of a crack

- A crack can be easily defined in the structure
- The crack is defined on the mesh, and can cut the elements
- No more crack box (the stress singularity is included in the enrichment)
- A same mesh can be used to study different crack configurations



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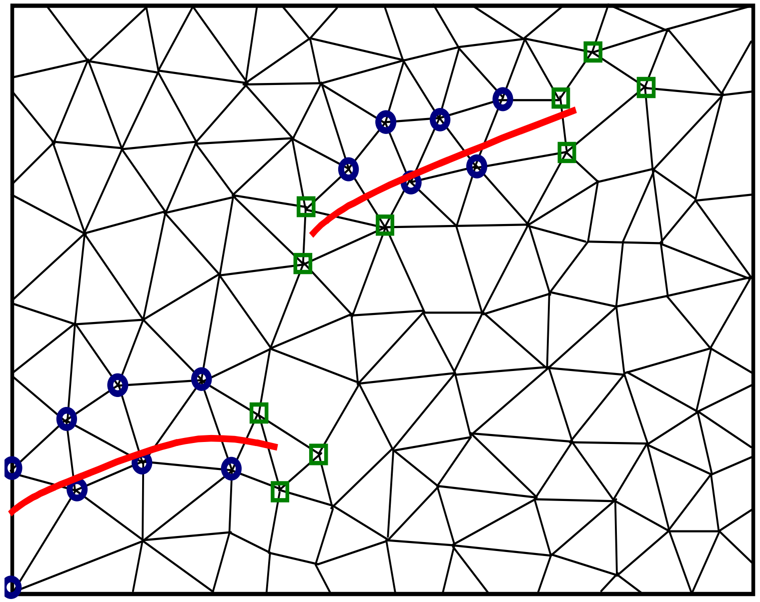
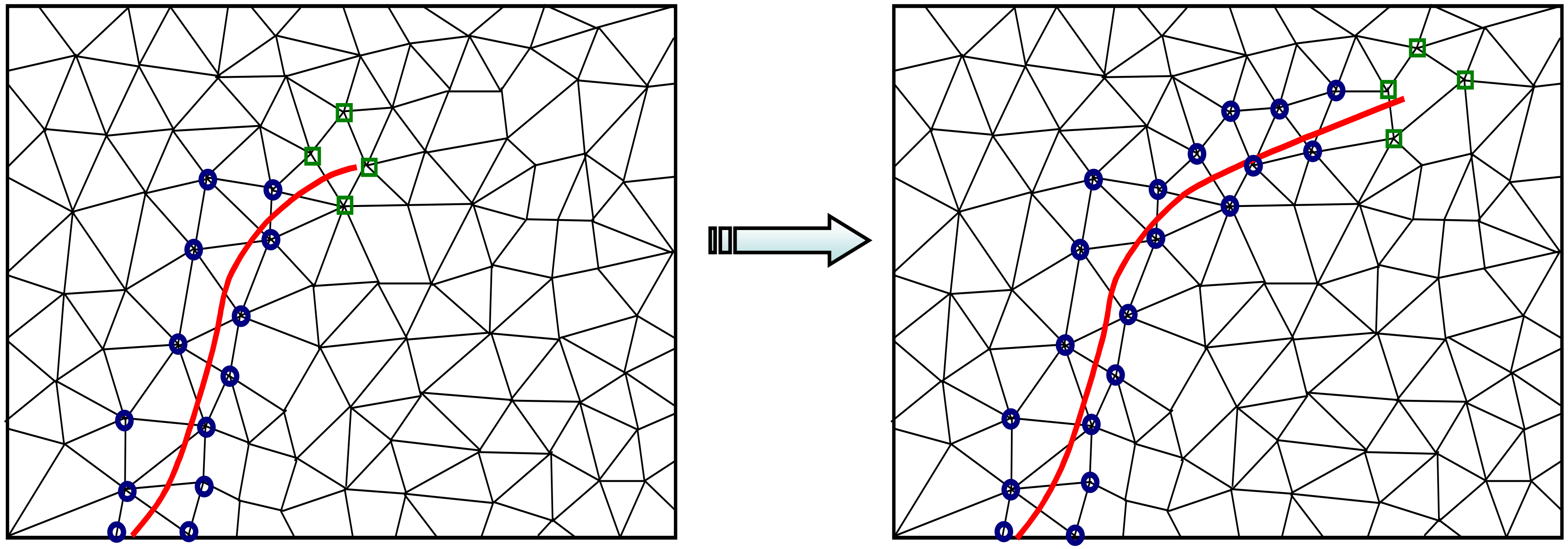


Advantages of XFEM method

XFEM approach: simplified crack propagation

- The crack is defined on the mesh, and can cut the elements
- No more crack box to move with the crack tip
- No more updating of the geometry (crack tips)

=> no remeshing (*to some extent*)



XFEM method features in SAMCEF

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XFEM in SAMCEF

- **Enrichment** **(true XFEM method of Belytschko and Moes)**
- **Specific integration scheme is adpoted**
- **Implicit crack representation with level-sets**
- **Stress Intensity Factors (SIF) computation**
- **Automatic fatigue crack propagation**
- **Research contacts and partnerships**

  - Prof. Nicolas Moës (Ecole Centrale de Nantes, France)

  - CENAERO (Belgium): our key partner

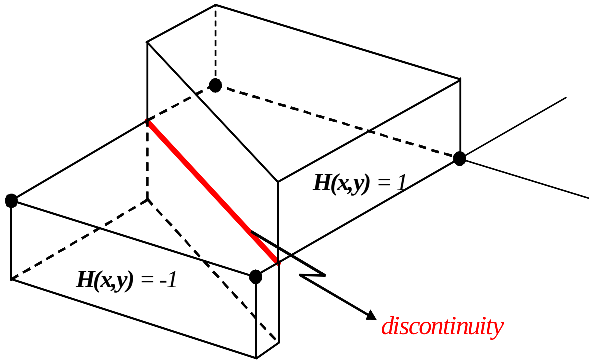
Cenaero

XFEM method: enrichment

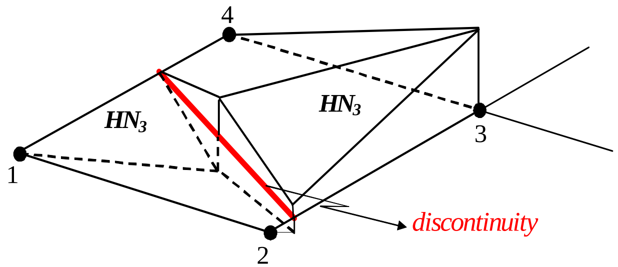
Displacement field

$$u(\mathbf{x}) = \underbrace{\sum_{i \in N} u_i N_i(\mathbf{x})}_{\text{Classical dof}} + \underbrace{\sum_{i \in L} b_i N_i(\mathbf{x}) H(\mathbf{x}) + \sum_{i \in K_1} N_i(\mathbf{x}) \left(\sum_{l=1}^{4} F_l(\mathbf{x}) c_i^l \right)}_{\text{Additional dof}}$$

Displacement discontinuity

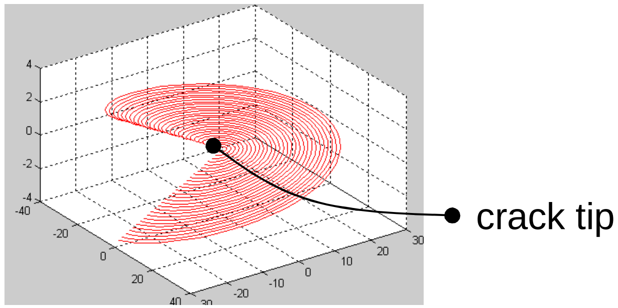


function
H (+1,-1)



Crack tip

- discontinuity of $u(x)$ $\quad F_1(\mathbf{x}) = \sqrt{r}\,\sin(\theta/2)$



- accuracy of the solution

$$F_1(\mathbf{x}) = \sqrt{r}\,\sin(\theta/2) \qquad F_3(\mathbf{x}) = \sqrt{r}\,\sin(\theta/2)\sin(\theta)$$

$$F_2(\mathbf{x}) = \sqrt{r}\,\cos(\theta/2) \qquad F_4(\mathbf{x}) = \sqrt{r}\,\cos(\theta/2)\sin(\theta)$$

XFEM method: integration

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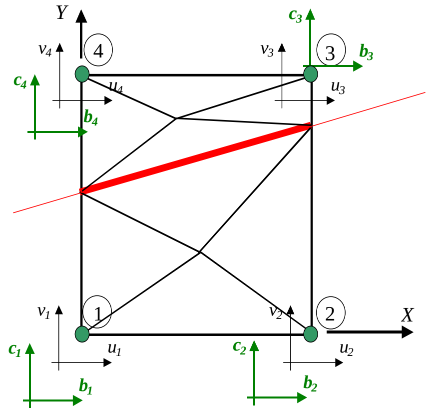
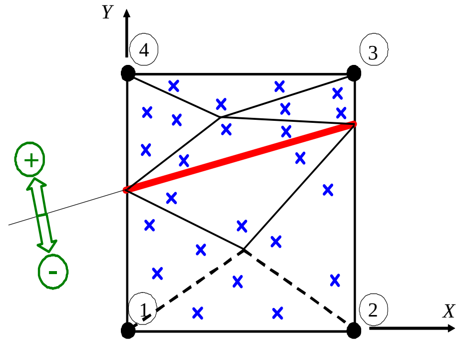
Integration (2D elements)

Element cut by the crack

⇩

Triangulation of the element for the integration





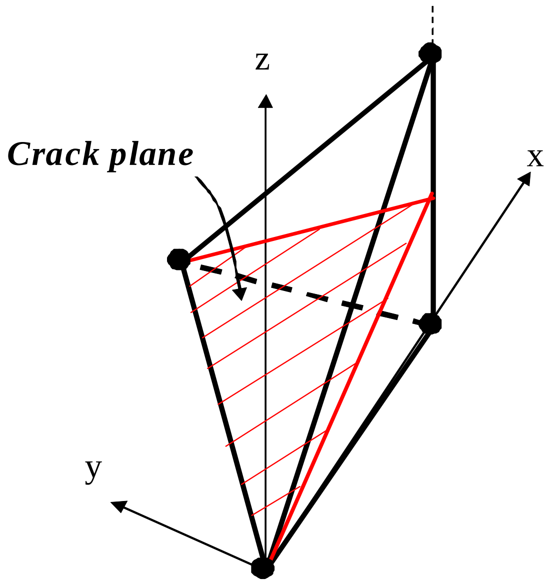
Discontinuous H function => integration on each side

Integration (3D elements)

Element cut by the crack

⇩

Division of the element for the integration



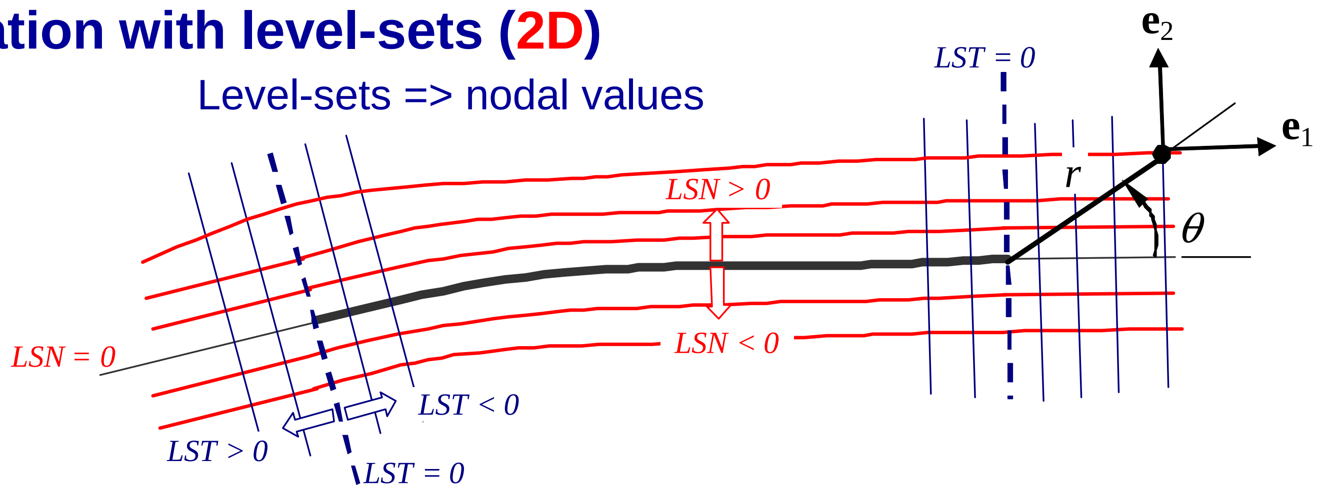
XFEM method: crack representation

Implicit representation with level-sets (2D)

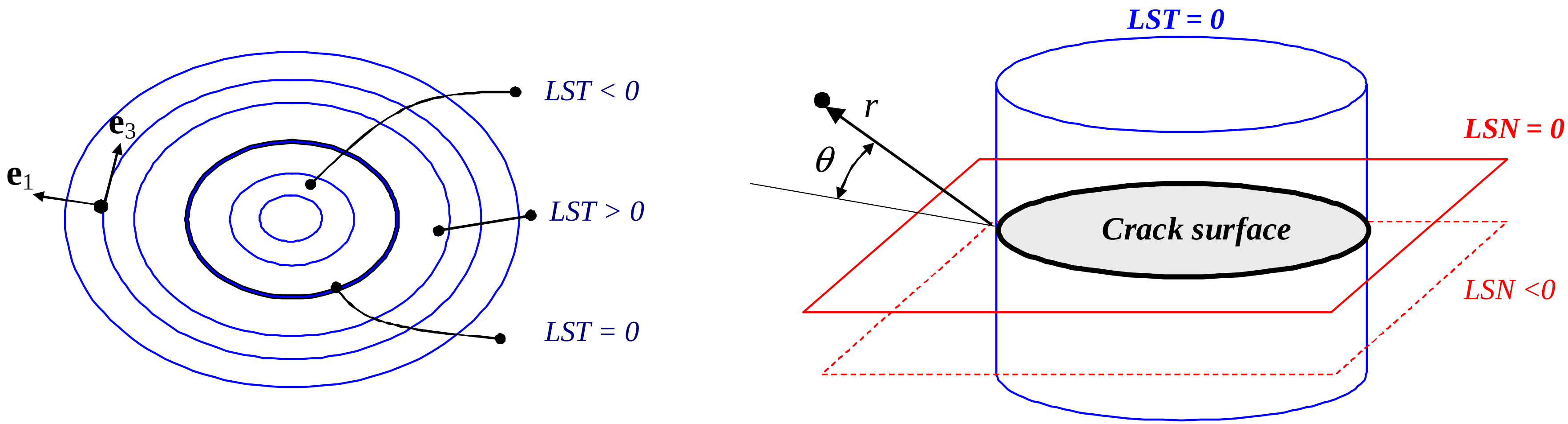
Level-sets => nodal values

$$r = \sqrt{LSN^2 + LST^2}$$

$$\theta = tg^{-1}\frac{LSN}{LST}$$



Implicit representation with level-sets (3D)



XFEM method: SIF computation

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Computation of the Stress Intensity Factors K_1 and K_2 (2D)

Interaction integral

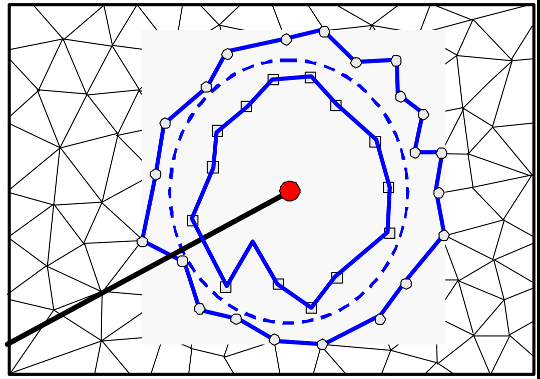
(variant of the J integral on an equivalent domain)

$$J = J^{(1)} + J^{(2)} + I^{(1,2)}$$

(1) Present state

(2) Auxiliary state

$$I^{(1,2)} = -\int_A \theta_{m,j}(\sigma_{kl}^{(1)}\varepsilon_{kl}^{(2)}\delta_{mj} - \sigma_{ij}^{1}u_{i,m}^{(2)} - \sigma_{ij}^{(2)}u_{i,m}^{(1)})dA$$



$$I^{(1,2)} = \frac{2(1-\nu^2)}{E}\left(K_I^{(1)}K_I^{(2)} + K_{II}^{(1)}K_{II}^{(2)}\right)$$

=> K_I for $K_I^{(2)}=1$ and $K_{II}^{(2)}=0$

=> K_{II} for $K_I^{(2)}=0$ and $K_{II}^{(2)}=1$

Computation of the Stress Intensity Factors K_1, K_2 and K_3 (3D)

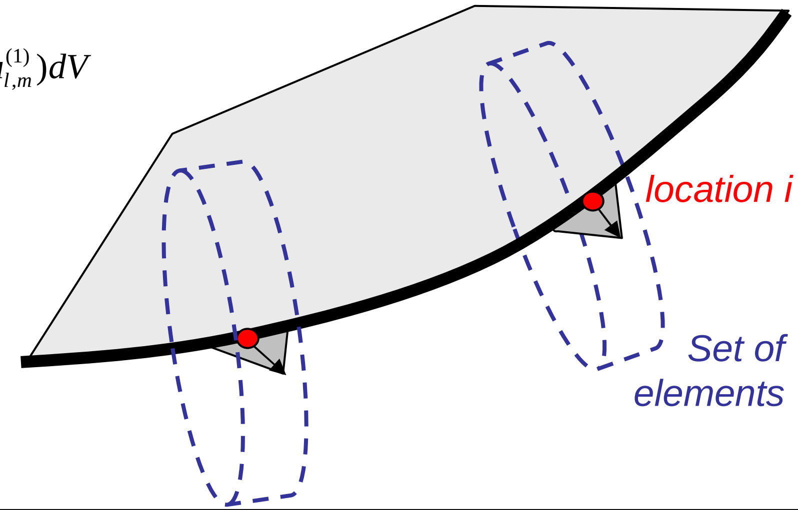
Interaction integral

(variant of the J integral on an equivalent domain)

$$I_i^{(1,2)} = -\int_A \theta_{m,j}(\sigma_{kl}^{(1)}\varepsilon_{kl}^{(2)}\delta_{mj} - \sigma_{lj}^{1}u_{l,m}^{(2)} - \sigma_{lj}^{(2)}u_{l,m}^{(1)})dV$$

$$I_i^{(1,2)} = G_i^{(1,2)}\int_{\Gamma_i}\theta ds$$

$$G^{(1,2)} = \frac{2(1-\nu^2)}{E}\left(K_I^{(1)}K_I^{(2)} + K_{II}^{(1)}K_{II}^{(2)}\right) + \frac{1}{\mu}K_{III}^{(1)}K_{III}^{(2)}$$



XFEM method: crack propagation

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For 2D problems (available since 2005 in SAMCEF)

- Not automatic
- Iterative process managed by the user
- Possibility to use BOSS quattro, with a parameterized BACON bank file
- Level-sets completely re-initialized at each iteration

For 3D problems

- Automatic
- Based on the update of the level-sets (Δa, θ^p)
- Criterion = maximum principal stress
- Fatigue based on the Paris/Nasgro law

Bifurcation angle

$$\theta^p = 2\arctan\left(\frac{K_I \pm \sqrt{K_I^2 + 8K_{II}^2}}{4K_{II}}\right)$$

Propagation / fatigue

$$\frac{da}{dN} = C\left(\Delta K_I^{eff}\right)^m \qquad \Delta a = \Delta a^{\max}\left(\frac{\Delta K_I^{eff}}{\Delta K_{\mathrm{Im}ax}^{eff}}\right)^m$$

$$\Delta K_I^{eff} = fct\left(\Delta K_I, \Delta K_{II}, \Delta K_{III}, \theta^p, material\right)$$

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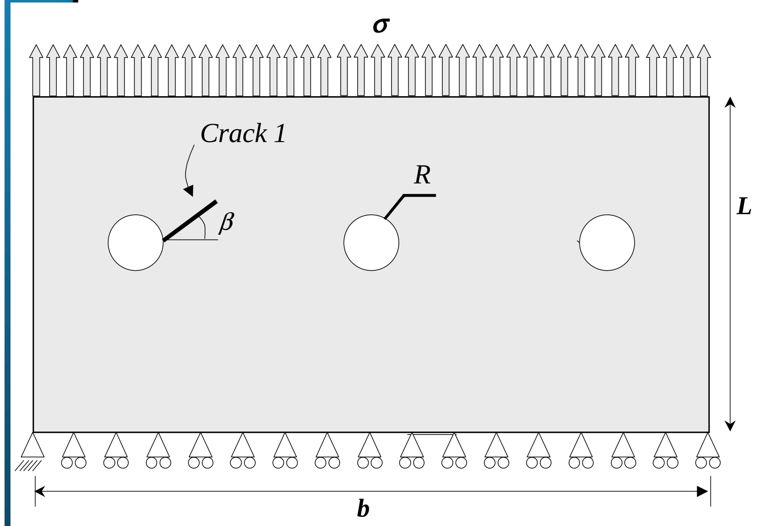
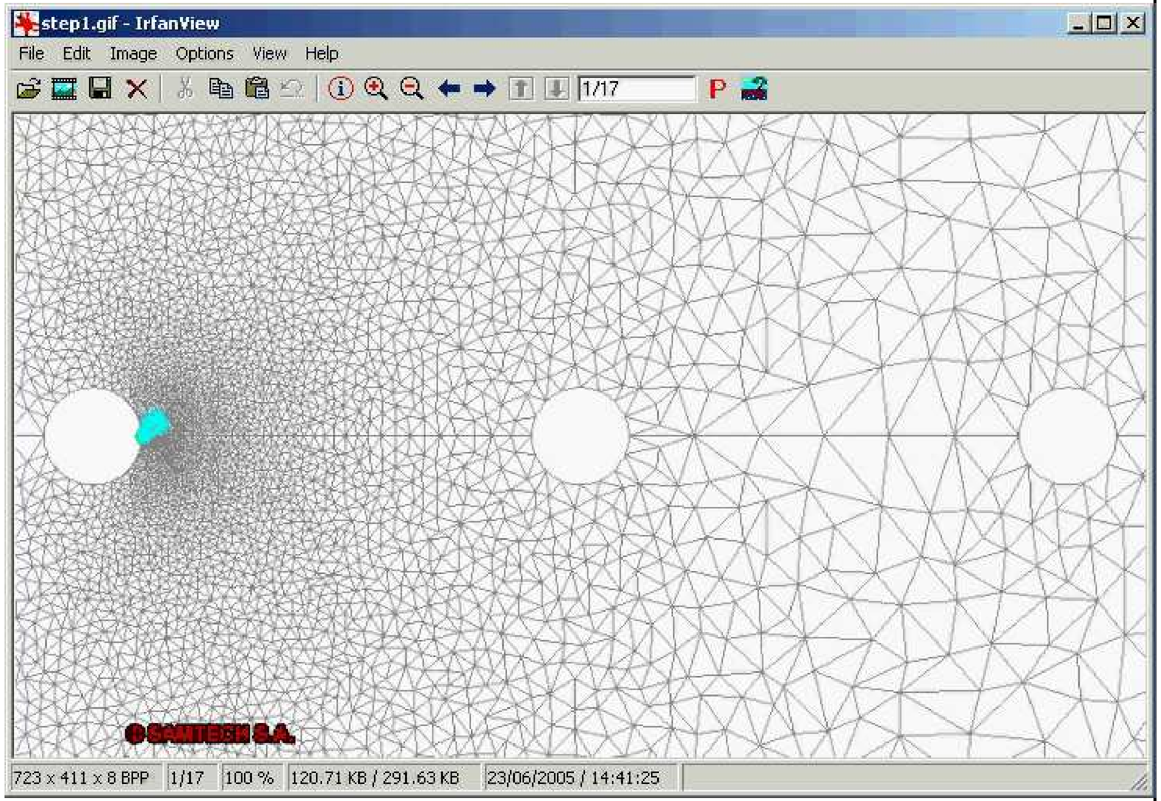
XFEM application

2D Propagation (done in 2005 for AIRBUS)





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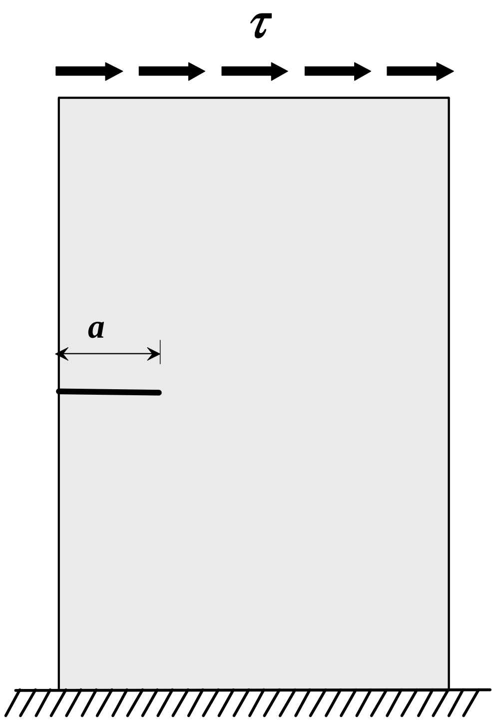
Classical benchmark (3D)



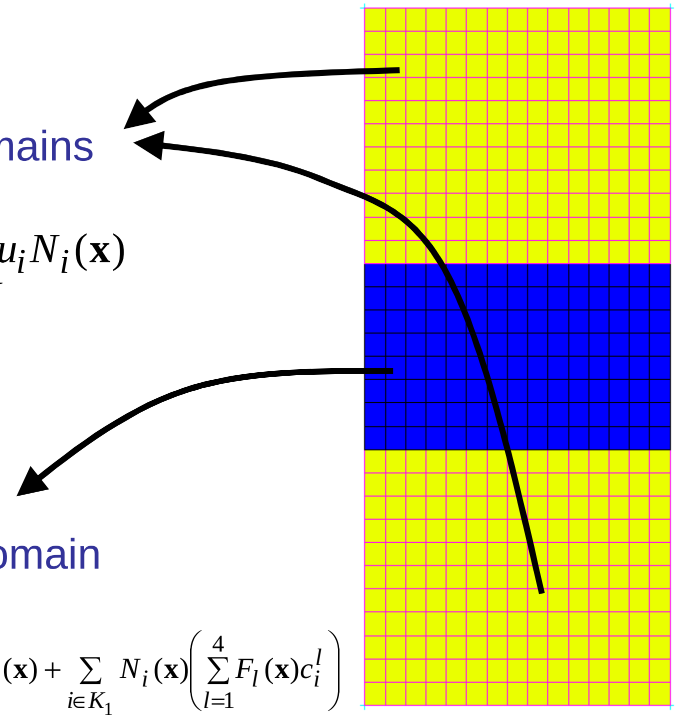
Initial finite element mesh

FEM domains

$$u(\mathbf{x}) = \sum_{i \in N} u_i N_i(\mathbf{x})$$

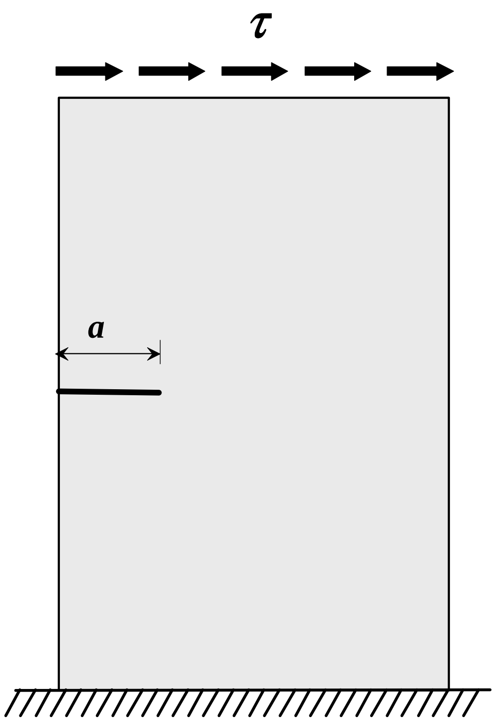
XFEM domain

$$u(\mathbf{x}) = \sum_{i \in N} u_i N_i(\mathbf{x}) + \sum_{i \in L} b_i N_i(\mathbf{x}) H(\mathbf{x}) + \sum_{i \in K_1} N_i(\mathbf{x}) \left(\sum_{l=1}^{4} F_l(\mathbf{x}) c_i^l \right)$$

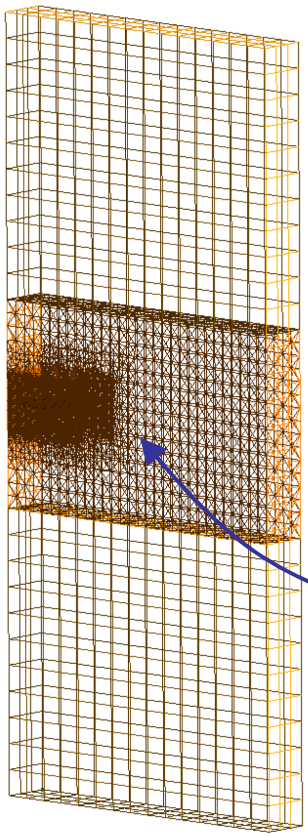


XFEM application

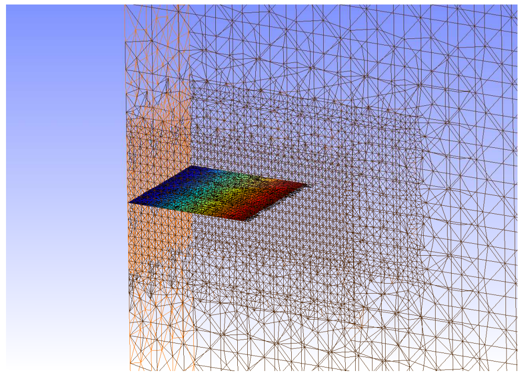
Classical benchmark (3D)



Finite element mesh



Crack (level-sets)



Example of a refinement in the XFEM domain

No remeshing during the crack propagation

XFEM application

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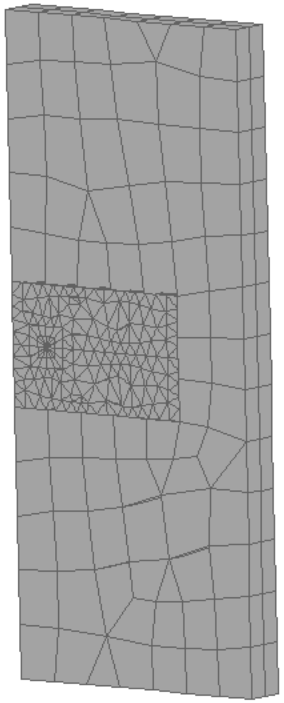
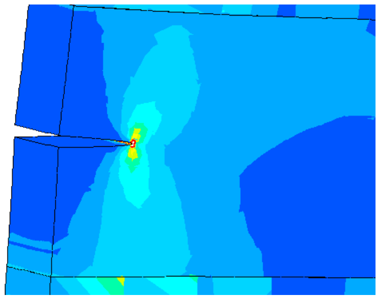
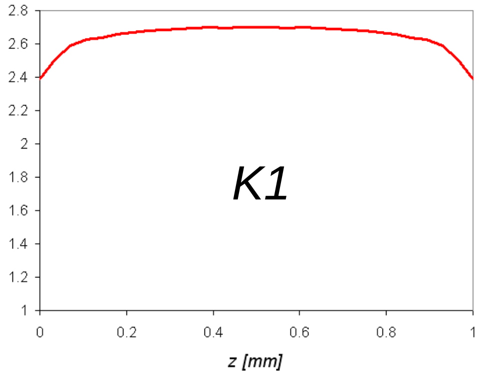
Classical benchmark (3D)

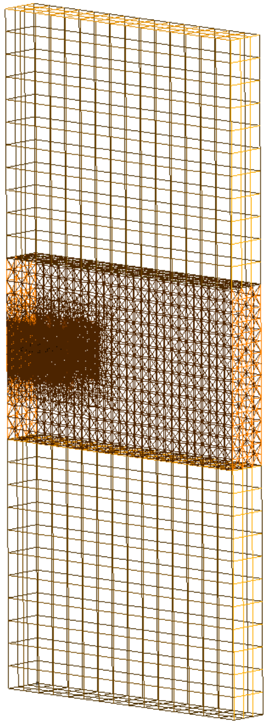
FEM (crack box)

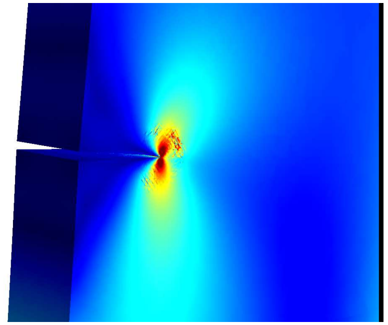


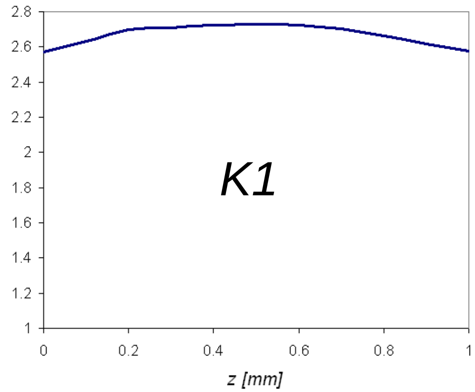




XFEM (level-sets)





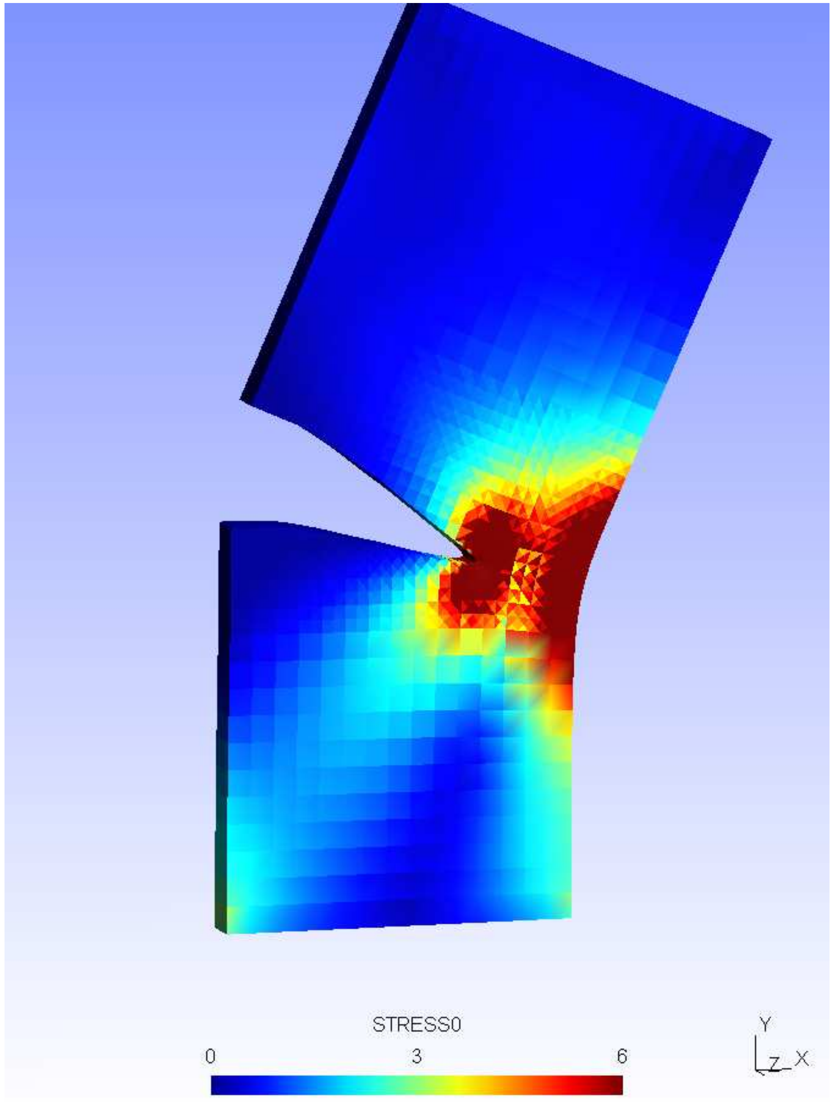


XFEM application

Classical benchmark (3D)

3D propagation

Bifurcation

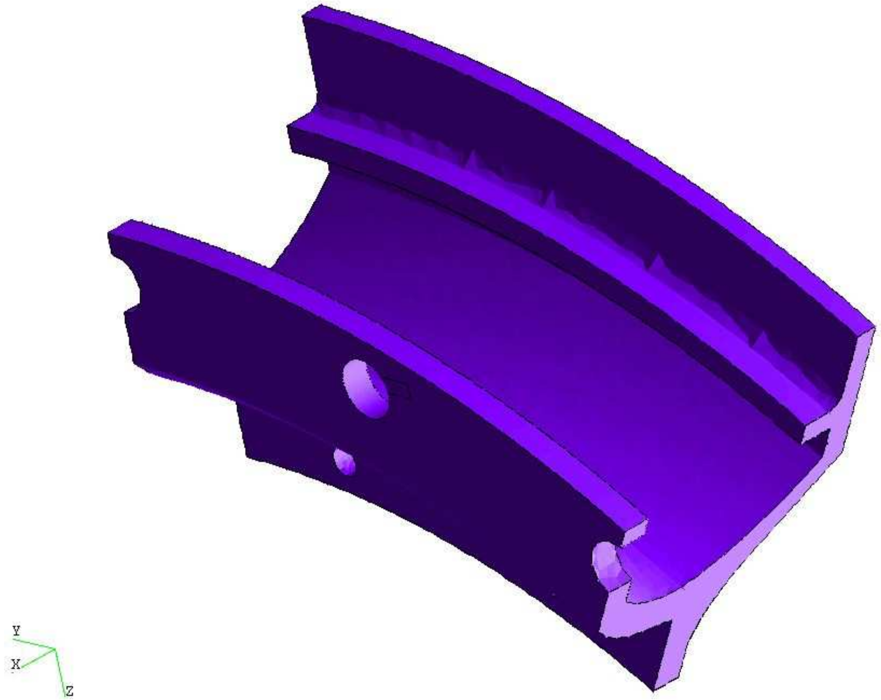


XFEM application

Industrial test case

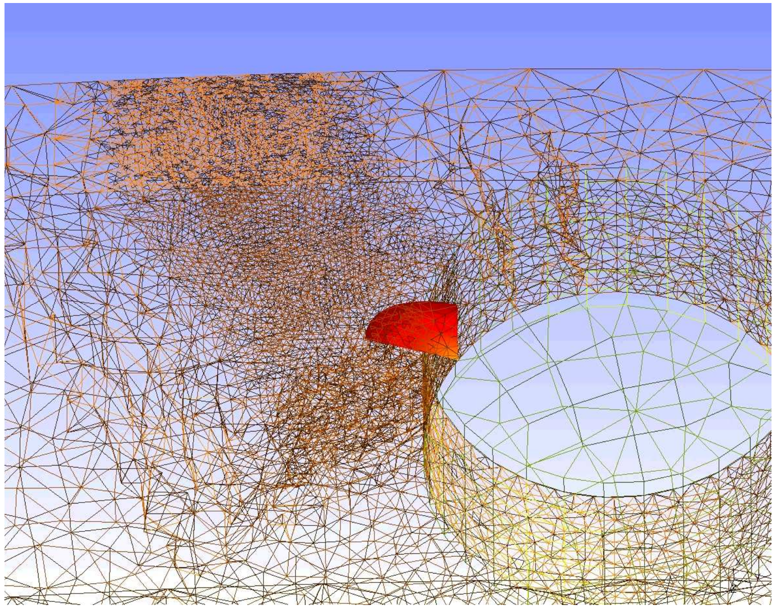
Centrifugal load

Imposed radial displacement



Location of the crack (1/4 of a circle)

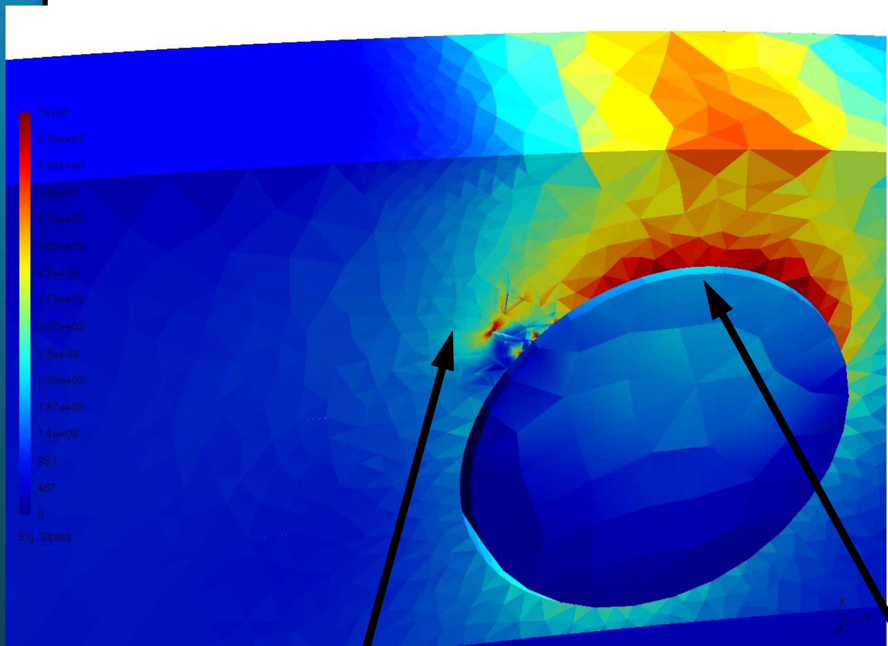
Level-sets



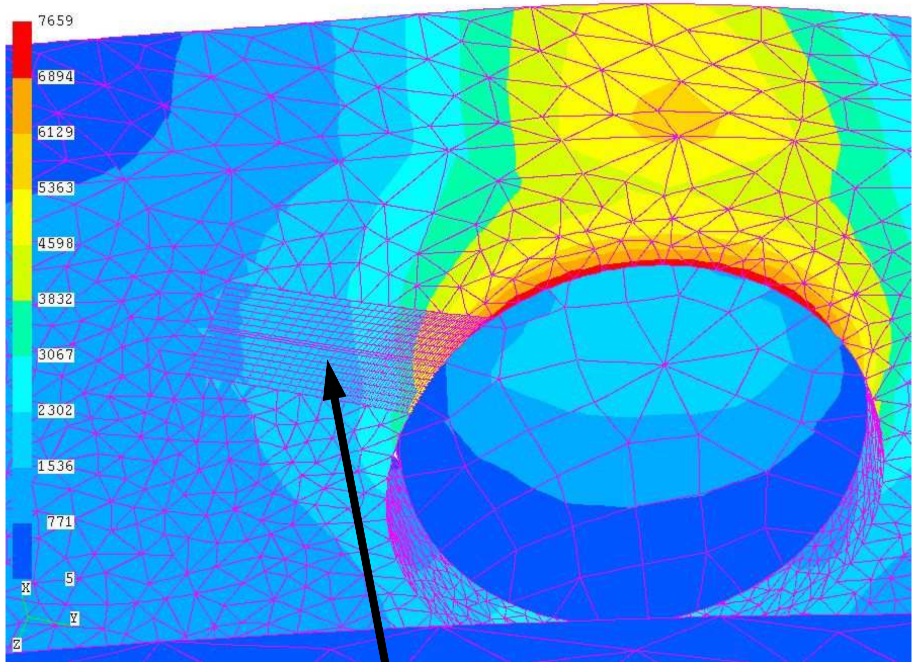
XFEM application

Industrial test case

XFEM model



FEM model



Free crack propagation

Contact

In-plane crack propagation

XFEM application

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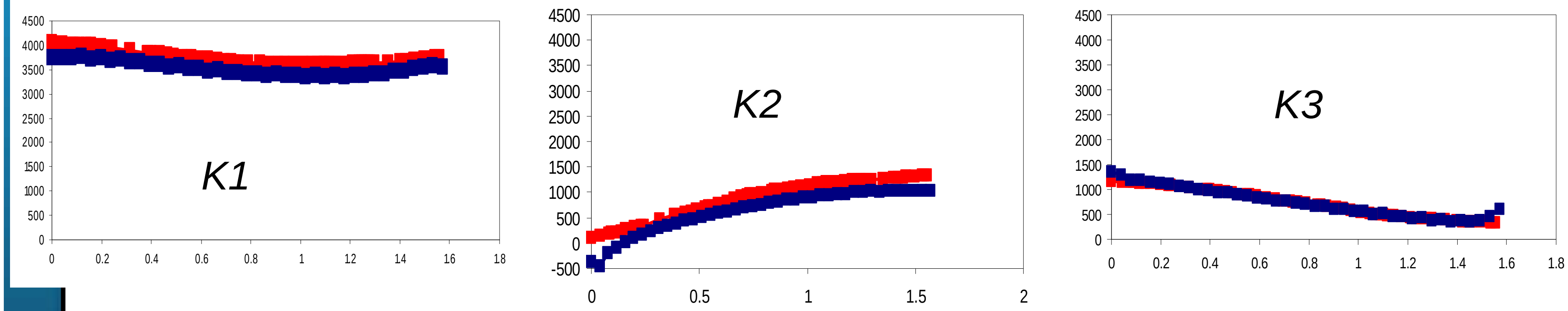
Industrial test case: comparaison of SIF

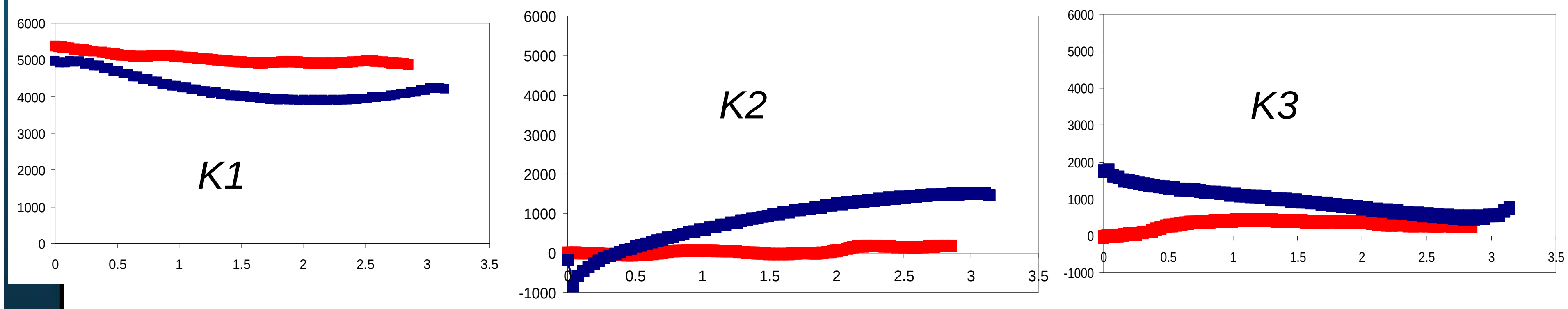
XFEM

FEM (Barsoum)

Initial crack (1/4 circle)



After a 1mm propagation



XFEM application

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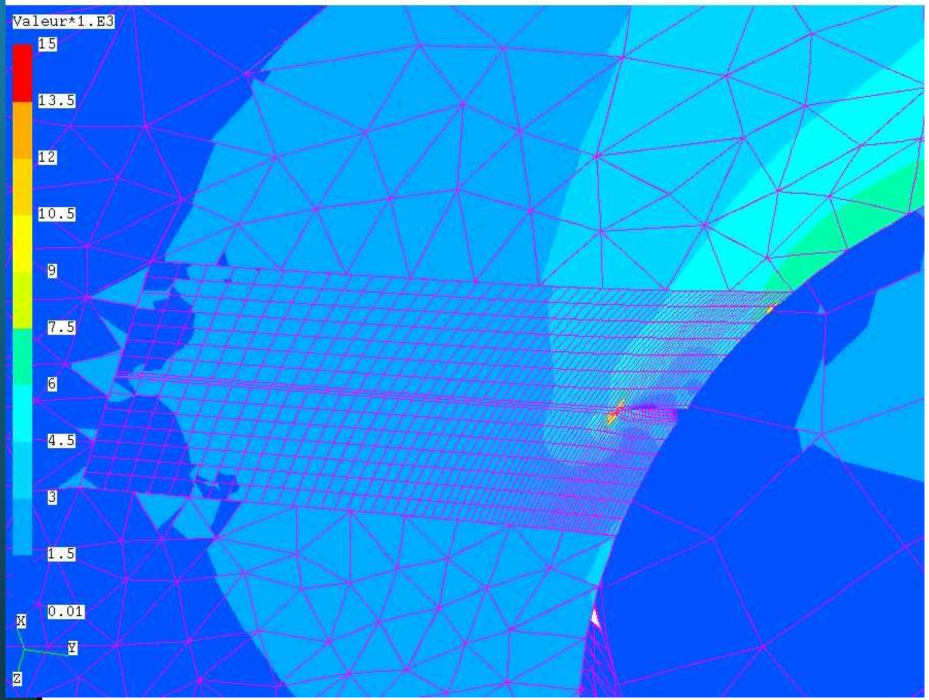
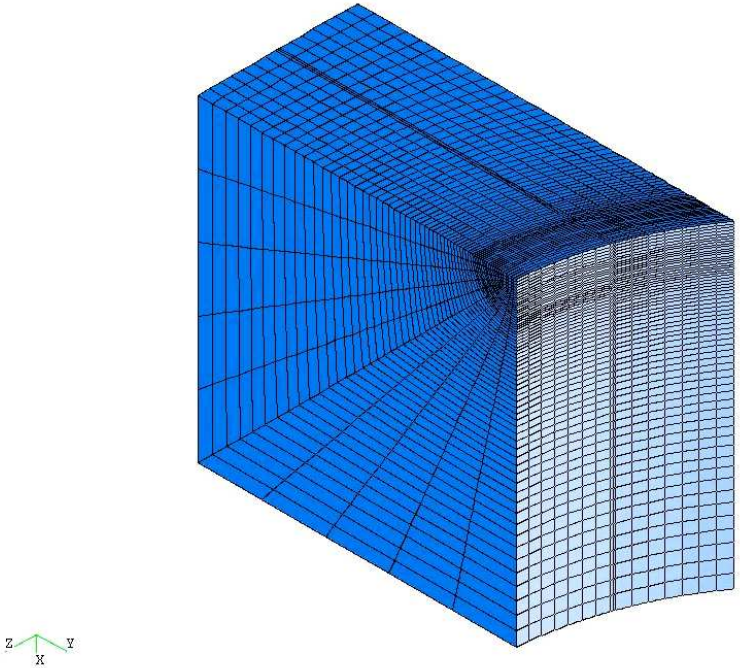
Industrial test case: FEM and Barsoum elements

Elliptical cack propagation in a plane

Parameterized model with a crack box





XFEM application

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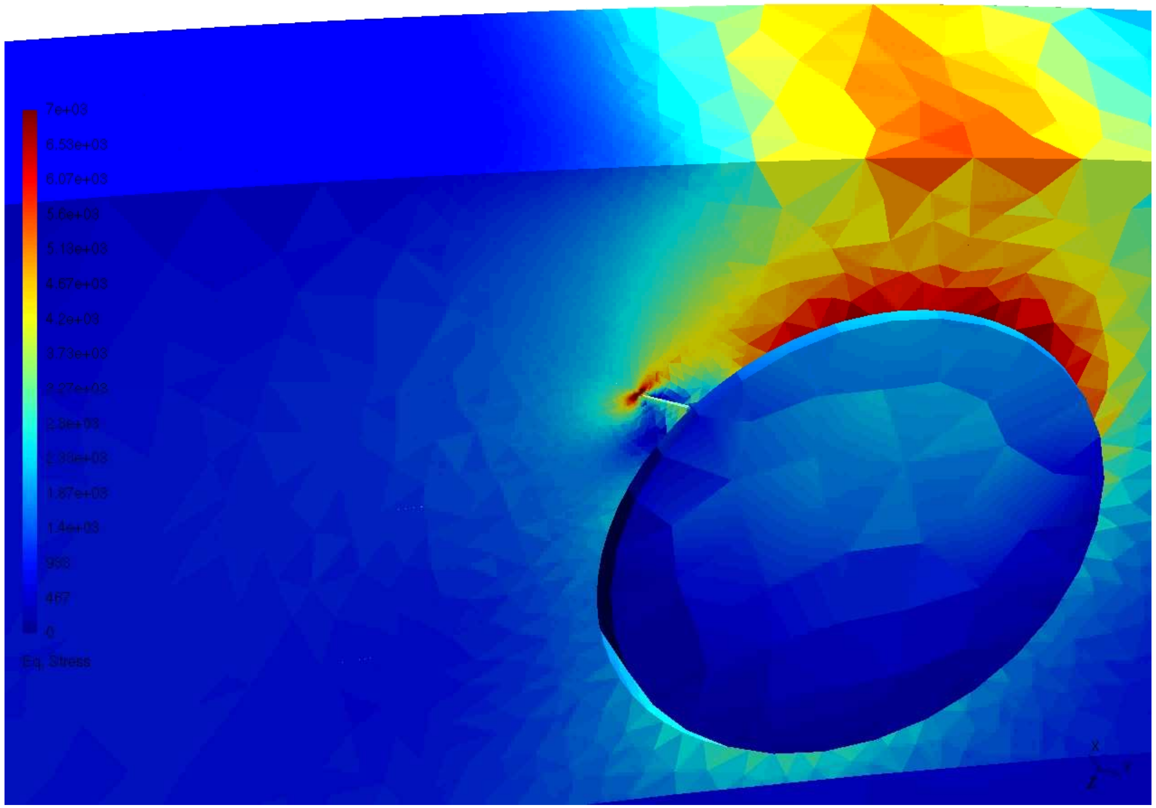
Industrial test case: XFEM (initial crack of 1mm)

Free crack propagation, with bifurcation



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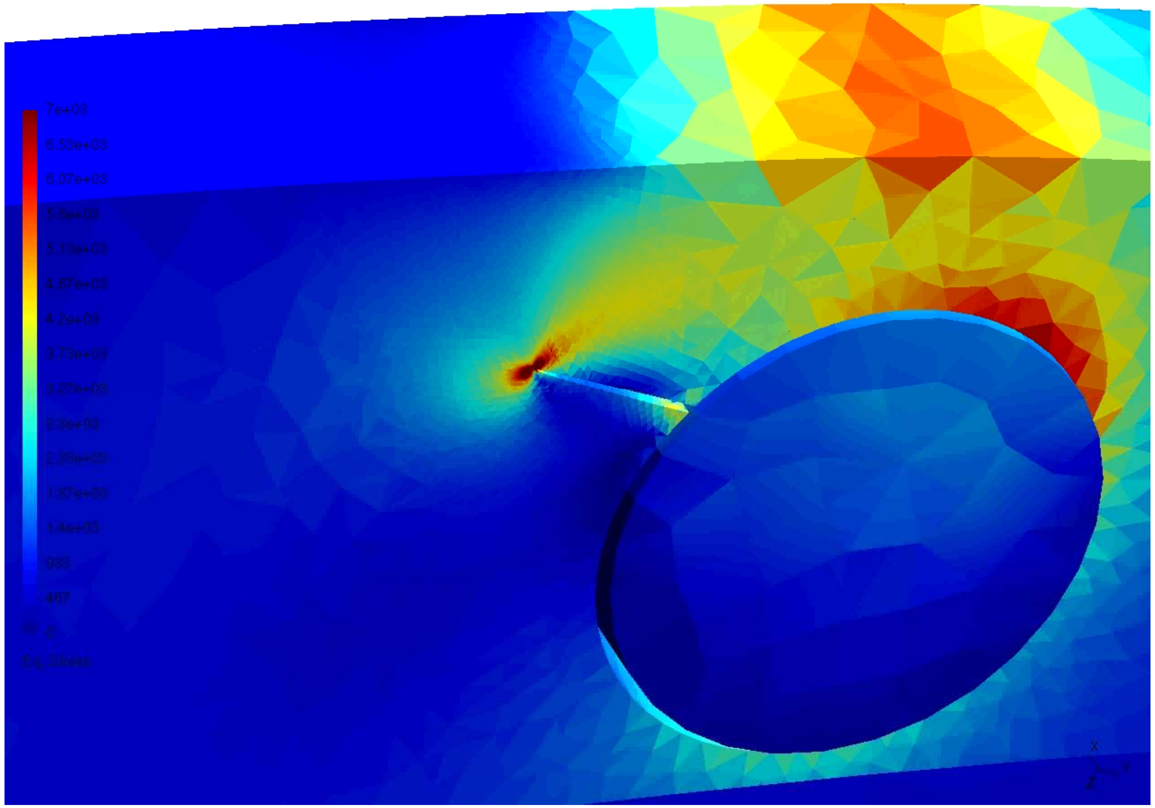
Industrial test case: XFEM (initial crack of 3mm)

Free crack propagation, with bifurcation



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Conclusions

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- ☞ XFEM is a powerful method for fracture mechanics
- ☞ XFEM simplifies the life of the analyst for fracture mechanics problems
- ☞ XFEM available in SAMCEF for 2D and 3D fracture mechanics problems
  - *Crack modelled in a very simple way*
  - *Automatic crack propagation (3D problems)*
- ☞ XFEM in SAMCEF is still under improvements for/with our industrial partners
- ☞ XFEM is a easy, ready and the best solution for fracture mechanics

Thank you

Dr. Michael Bruyneel
Project Manager
Michael.bruyneel@samtech.com
Tel: +32.4.361.69.69