# SSNV512 – Block cut out by a vertical crack connecting between 2 horizontal cracks with X-FEM

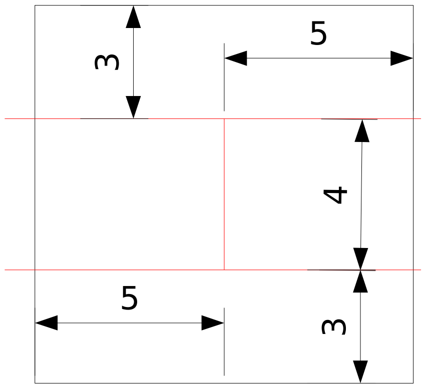
**Summarized:**

This test makes it possible to validate the approach junction with X-FEM if a crack connects on 2 distinct cracks. It is about a case test where three cracks are introduced. The first two cracks are horizontal. The third vertical crack, connects on the two first via key word JONCTION of operator DEFI_FISS_XFEM. One tests the approach with or without contact.

# 1 Problem of reference

## 1.1 Geometry

the structure is a healthy square into which one introduces three interfaces, in red on the figure 1.1-a. Two interfaces are horizontal. The third interface, vertical, are defined between the two first and connect on those. Dimensions of structure as well as the position of the interfaces are given on the figure 1.1-a and are expressed in meters [m] .



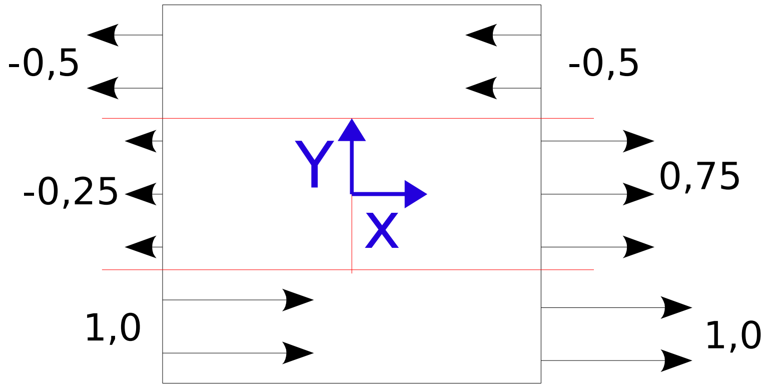

**Appear 1.1-a: Geometry of structure and positioning of the interfaces.**

## 1.2 Properties of the material

the material has elastic isotropic uncomportement whose properties are the following ones::
Young modulus: $100\,MPa$
Poisson's ratio: $0.3$

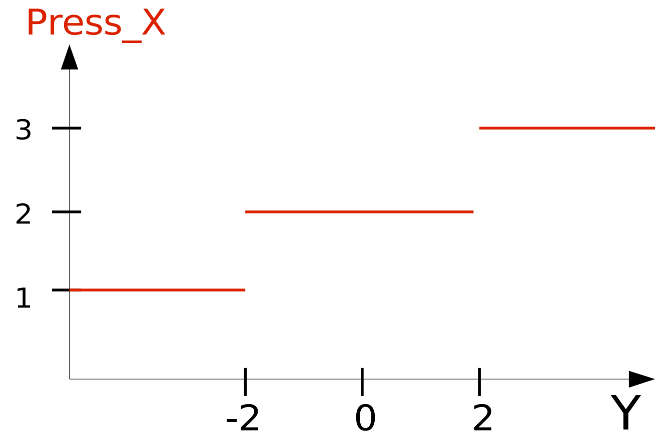
## 1.3 Boundary conditions and loadings

In the case without contact (modelizations A with E), one applies conditions in displacement to the edges left and right of structure, so that each of the 4 zones formed by the interfaces has a displacement different from the others according to $X$ . This loading is represented figure 1.3-a. One blocks displacements in $Y$ (and $Z$ for the modelizations 3D) on these same edges.

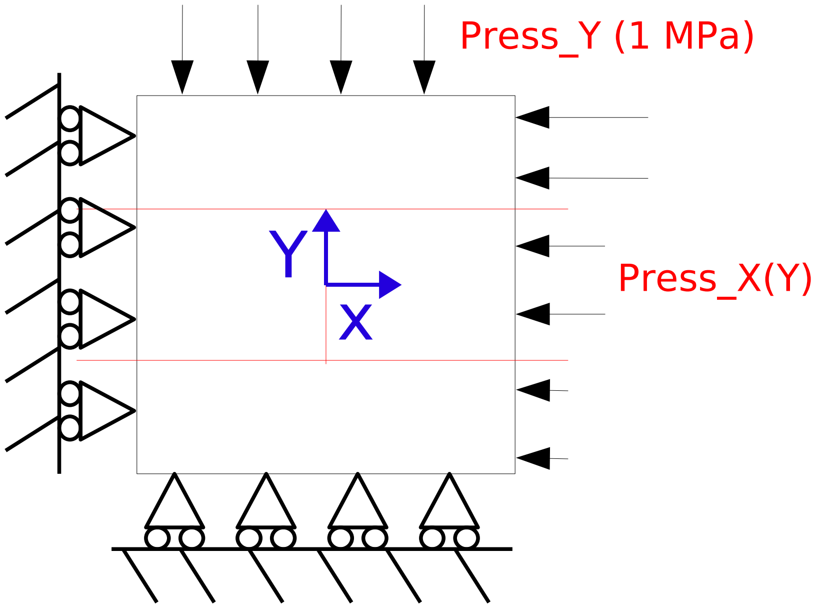



**Appear 1.3-a: Illustration of the boundary conditions and the loadings, cases without contact.**

In the case of the contact (modelizations F with J), one imposes conditions of roller on the edges left and low, one applies the pressure in staircase of the figure 1.3-b to flat rim and a uniform pressure to edge top. This loading is represented figure 1.3-c. Each block is then compressed in a uniform way according to $X$ and $Y$.




**Appear 1.3-b: Pressure imposed according to Y on flat rim, (in $[MPa]$).**




**Appear 1.3-c: Illustration of the boundary conditions and the loadings, cases with contact.**

## 2 Reference solution

Without contact, each zone must undergo a rigid body motion corresponding to the limiting condition imposed on its edge (right or left).

With contact, the 4 blocks undergo a uniform compression according to $X$ and $Y$. One can express the displacement of structure in the following way :

$$Depl_X(X,Y)=-(5+X)\frac{Press_X(Y)}{E}$$

éq 2.1-1

$$Depl_Y(Y) = -(5+Y)\frac{Press_Y}{E}$$

éq 2.1-2

# 3 Modelization A

## 3.1 Characteristic of the modelization

It acts of a modelization $\text{X-FEM}$ , in plane strains, D_PLAN. The interfaces are defined by functions of levels (level sets noted norms $\text{LN}$ ).

The equations of the functions of levels for the two horizontal interfaces and the vertical interface are respectively the following ones:

$$\text{LN}\,1 = Y - 2$$

éq 3.1-1

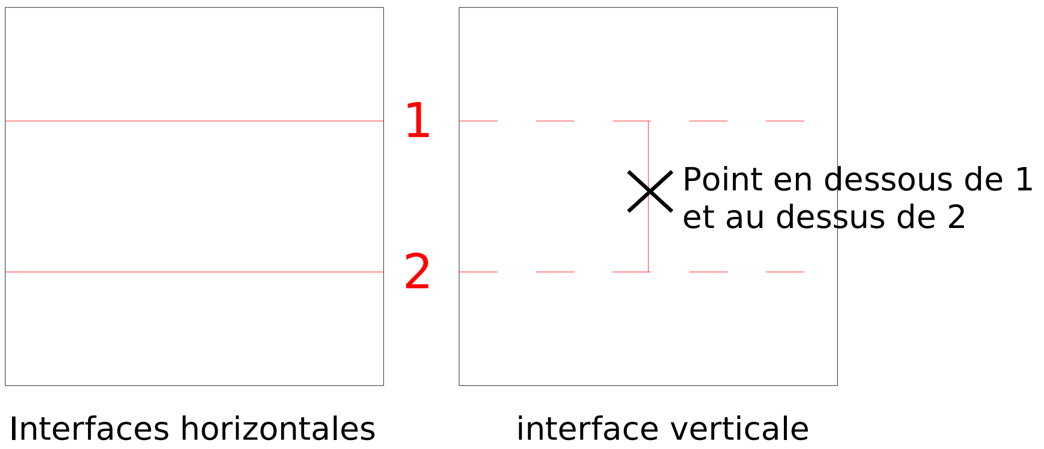
$$\text{LN}\,2 = Y + 2$$

éq 3.1-2

$$\text{LN}\,3 = X$$

éq the 3.1-3

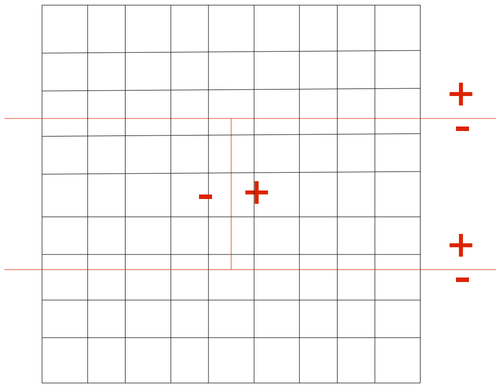
two horizontal interfaces are defined in a classical way by means of operator DEFI_FISS_XFEM with the level sets norms $\text{LN1}$ and $\text{LN2}$ .
The vertical interface is defined with the level set norm $\text{LN3}$ in DEFI_FISS_XFEM. One adds in this operator key word JONCTION. Under this key word, one gives the 2 horizontal interfaces beforehand defined in the operand FISSURES and a point which is at the same time below first crack and with the top of the second in the operand POINT (see figure 3.1-a). This point should not be necessarily positioned on $\text{LN3}$ . In this case, it can be anywhere in the delimited field enters $\text{LN1}$ and $\text{LN2}$ .




**Appear 3.1-a: Construction of the junctions.**

## 3.2 Characteristics of the mesh

The mesh which comprises 81 meshes type QUAD4 is represented on the figure 3.2-a.
One notices on this figure that some meshes are cut several times. This test thus makes it possible to validate multiple cutting.




**Appear 3.2-a: The mesh of modelization A.**

## 3.3 Fonctionnalités tested

One tests operator DEFI_FISS_XFEM if one wants to connect a crack on several different cracks. One uses the key word JONCTION which makes it possible to define crack connections with X-FEM. In this precise case one connects crack 3 on cracks 1 and 2. One in the case of tests also operator MODI_MODELE_XFEM meshes which is cut by several cracks. Multi-Heaviside and the multi-storage of Data structures ( SD ) X-FEM are of course activated.
One tests the assembly of the Heaviside degrees of freedom on the level of the matrixes and the second members of the elements connected to intersection for the option COMP_ELAS in STAT_NON_LINE.
One in the case of validates also X-FEM postprocessing multi-cutting, with operators POST_MAIL_XFEM and POST_CHAM_XFEM .

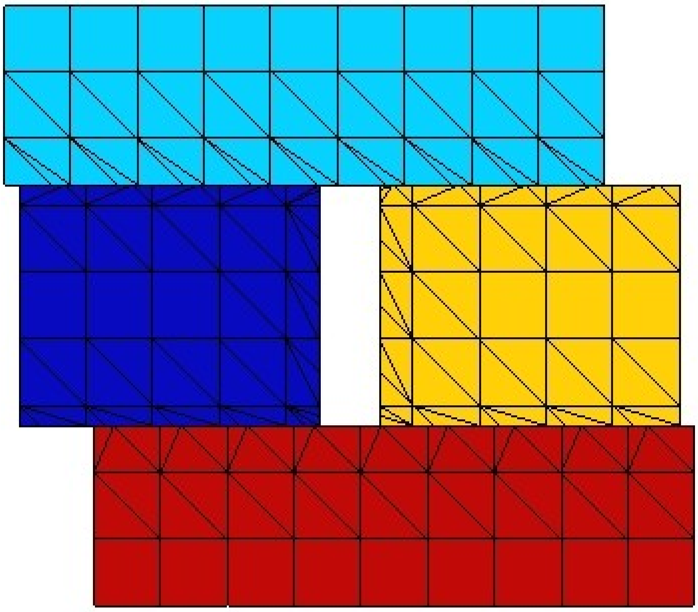
## 3.4 Quantities tested and results

One tests displacements on the level of the lips of cracks after having carried out the operations of postprocessings relative to X-FEM (POST_MAIL_XFEM and POST_CHAM_XFEM). DX displacement must correspond to the loading imposed of the figure 1.3-a on each zone and DY must be null. One tests the values minimum and maximum on the lips of each zone.

| **Identification** | | | ***Reference*** | ***% tolerance*** |
|---|---|---|---|---|
| DEPZON_1 | DX | MIN | -0.25 | 1.00E-11 |
| | | MAX | -0.25 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_2 | DX | MIN | -0.5 | 1.00E-11 |
| | | MAX | -0.5 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_3 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_4 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |

**Table 3.4-1**

the deformed shape is represented on the figure 3.4-a. The code color represents the field of displacement.



**Appear 3.4-a: Deformed shape of structure.**

### 3.5 Remarks

One gets very good results for this test, the raised error corresponding to the numerical residue.

# 4 Modelization B

## 4.1 Characteristic of the modelization

It is acted of the same modelization as the modelization A, but as plane stresses, `C_PLAN`. The junctions are built same way.

## 4.2 Characteristics of the mesh

The mesh which comprises 176 meshes type `TRIA3` is represented on the figure 4.2-a.

.

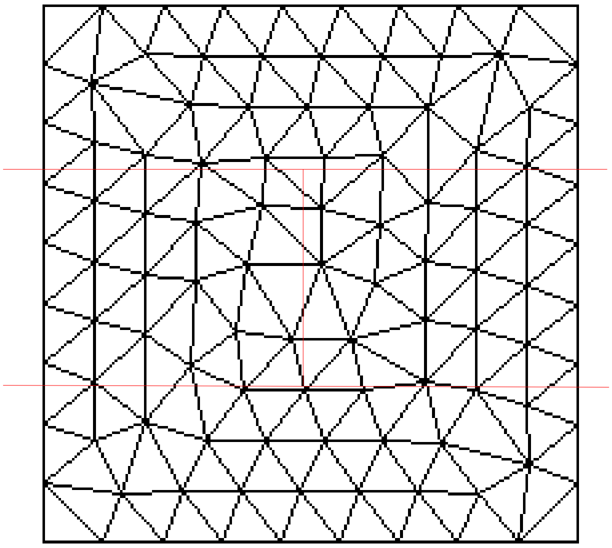


**Figure 4.2-a : The mesh of the modelization B.**

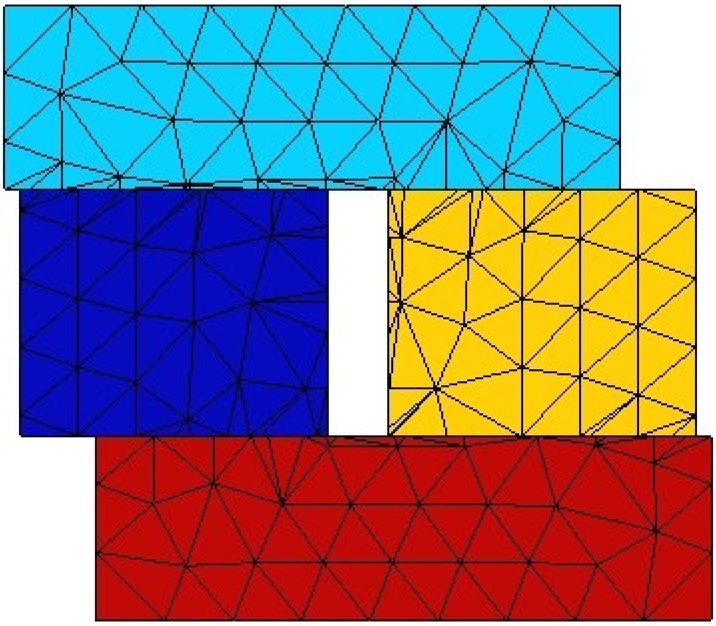
## 4.3 Quantities tested and results

the quantities tested are identical to those used for modelization A.

| Identification | | | *Reference* | *% tolerance* |
|---|---|---|---|---|
| DEPZON_1 | DX | MIN | -0.25 | 1.00E-11 |
| | | MAX | -0.25 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_2 | DX | MIN | -0.5 | 1.00E-11 |
| | | MAX | -0.5 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_3 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_4 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |

**Table 4.3-1**

the deformed shape is represented on the figure 4.4-a.



**Appear 4.4-a: Deformed shape of structure.**

## 4.4 Remarks

the remarks are identical to those specified for modelization A.

# 5 Modélisation C

## 5.1 Characteristic of the modelization

It acts of the same modelization as the modelization A, but in 3D. The junctions are built same way.

## 5.2 Characteristics of the mesh

The mesh which comprises 81 meshes type HEXA8 is represented on the figure 5.2-a.

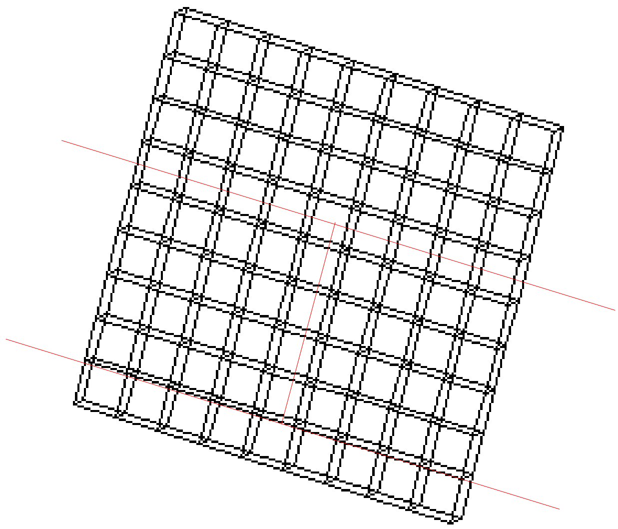


**Figure 5.2-a : The mesh of the modelization C.**

## 5.3 Quantities tested and results

the quantities tested are identical to those used for modelization A. One adds tests on DZ.

| Identification | | | *Reference* | *% tolerance* |
|---|---|---|---|---|
| DEPZON_1 | DX | MIN | -0.25 | 1.00E-11 |
| | | MAX | -0.25 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_2 | DX | MIN | -0.5 | 1.00E-11 |
| | | MAX | -0.5 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_3 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_4 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |

**Table 5.3-1**

the deformed shape is represented on the figure 5.4-a.

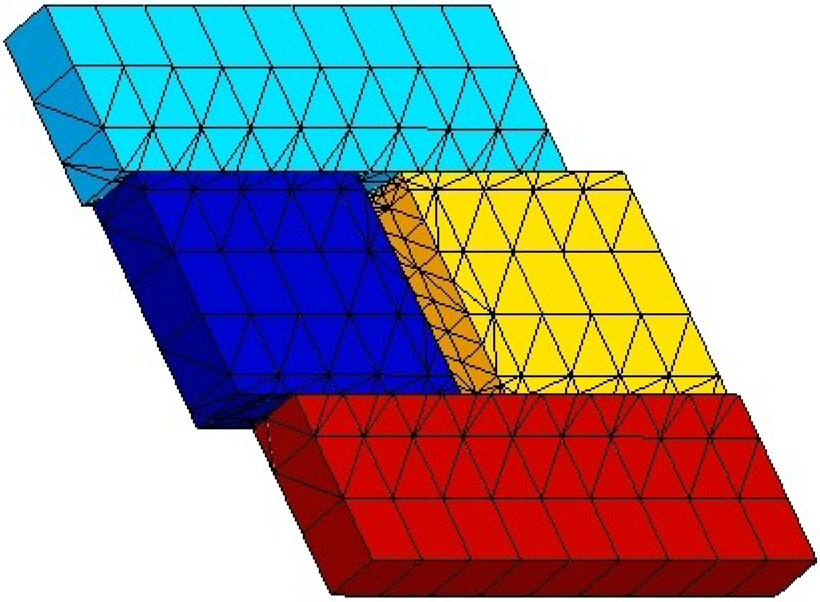


**Figure 5.4-a : Deformed shape of structure.**

## 5.4 Remarks

the remarks are identical to those specified for modelization A.

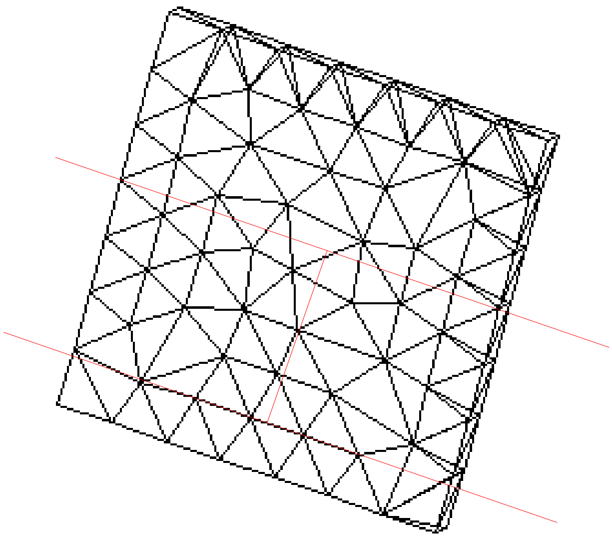
# 6 Modélisation D

## 6.1 Characteristic of the modelization

It acts of the same modelization as the modelization C.

## 6.2 Characteristic of the mesh

The mesh which comprises 312 meshes type `TETRA4` is represented on the figure 6.2-a.



**Appear 6.2-a: The mesh of modelization D.**

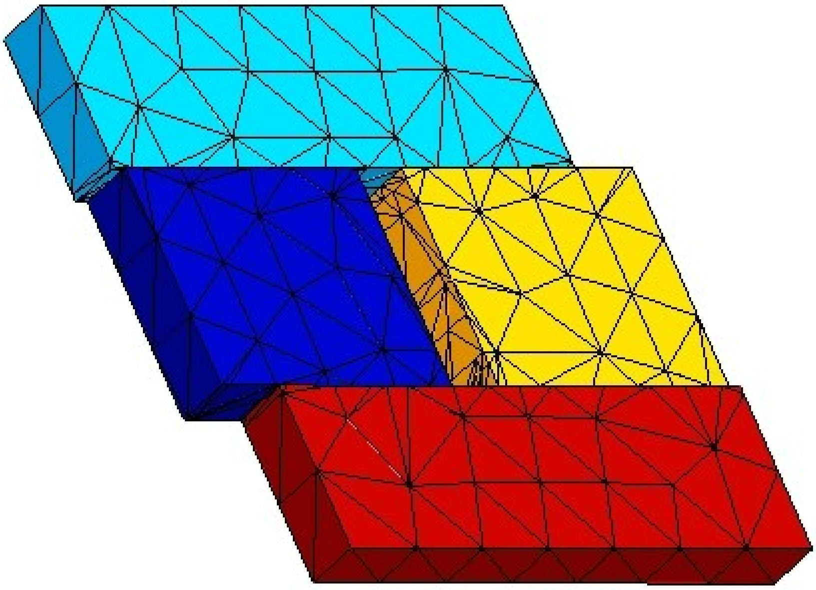
## 6.3 Grandeurs tested and results

the quantities tested are identical to those used for the modelization C.

| Identification | | | *Reference* | *% tolerance* |
|---|---|---|---|---|
| DEPZON_1 | DX | MIN | -0.25 | 1.00E-11 |
| | | MAX | -0.25 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_2 | DX | MIN | -0.5 | 1.00E-11 |
| | | MAX | -0.5 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_3 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |
| DEPZON_4 | DX | MIN | 0.75 | 1.00E-11 |
| | | MAX | 0.75 | 1.00E-11 |
| | DY | MIN | 0 | 1.00E-11 |
| | | MAX | 0 | 1.00E-11 |

**Table 6.3-1**

the deformed shape is represented on the figure 6.4-a.



**Appear 6.4-a: Deformed shape of structure.**

## 6.4 Remarks

the remarks are identical to those specified for modelization A.

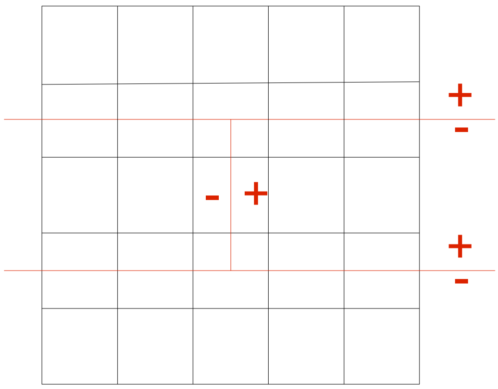
# 7 Modélisation E

## 7.1 Characteristic of the modelization

It acts of the same modelization as modelization A.

## 7.2 Caractéristiques of the mesh

The mesh which comprises 25 meshes type QUAD4 is represented on the figure 7.2-a. The mesh is refined less than that of the modelization A, so that certain elements see two horizontal cracks.



**Appear 7.2-a: The mesh of the modelization E.**

## 7.3 Functionalities tested

As for the other modelizations, the vertical crack connects on two horizontal cracks, but certain elements see 3 cracks.
Even if it is possible to connect crack 3 on cracks 1 and 2, it is not possible locally i.e the algorithm set up can attach crack 3 only to only one another crack within the same element: it thus confusion enters there cracks 1 and 2.
To solve this problem, one forces the user in DEFI_FISS_XFEM. to bind crack 2 to crack 1 via key word JONCTION Crack 3 will be thus explicitly related to the crack 2 which is related to the first. Crack 3 will be thus also implicitly related to the first. Quantities

## 7.4 tested and results

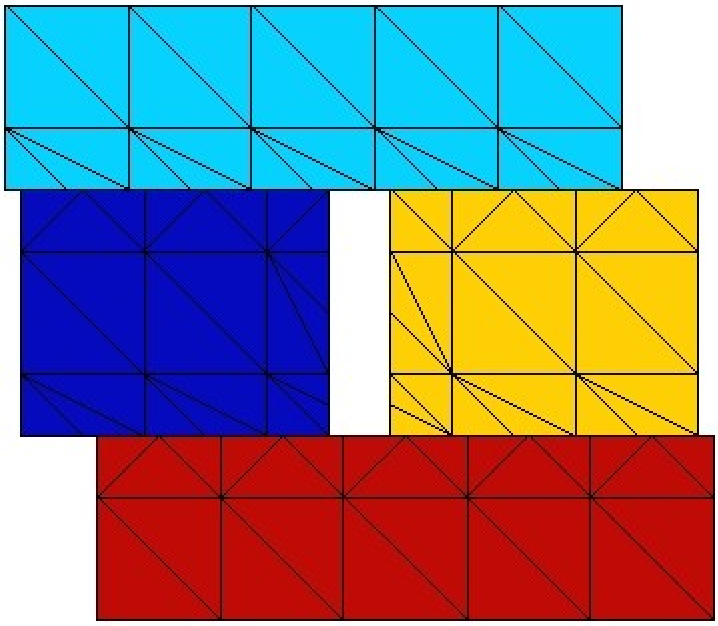
the quantities tested are identical to those used for modelization A. Identification

| | **Reference** | | **%** | ***tolerance DEPZON*** |
|---|---|---|---|---|
| _1 DX | MIN | -0.25 | 1.00 | E-11 MAX |
| _1 DX | | -0.25 | 1.00 | E-11 DY |
| _1 DX | MIN | 0 | 0 | E-11 MAX |
| _1 DX | | 0 | 0 | E-11 DEPZON |
| _2 DX | MIN | -0.5 | 1.00 | E-11 MAX |
| _2 DX | | -0.5 | 1.00 | E-11 DY |
| _2 DX | MIN | 0 | 0 | E-11 MAX |
| _2 DX | | 0 | 0 | E-11 DEPZON |
| _3 DX | MIN | 0.75 | 1.00 | E-11 MAX |
| _3 DX | | 0.75 | 1.00 | E-11 DY |
| _3 DX | MIN | 0 | 0 | E-11 MAX |
| _3 DX | | 0 | 0 | E-11 DEPZON |

| Reference | | | % | tolerance DEPZON |
|---|---|---|---|---|
| _4 DX | MIN | 0.75 | 1.00 | E-11 MAX |
| | | 0.75 | 1.00 | E-11 DY |
| | MIN | 0 | 0 | E-11 MAX |
| | | 0 | 0 | E-11 Table |

**7.4 7.4-1**

the deformed shape is represented on the figure 7.4-a. Appear



**7.4-a: Deformed shape of structure. Remarks**

### 7.5

the remarks are identical to those specified for modelization A. Modélisation

# 8 F Characteristic

## 8.1 of the modelization It

acts of the same modelization that the modelization A, but the conditions of loading in contact are applied. The junctions are built with X-FEM and the functions of levels in the same way as for modelization A. Caractéristiques

## 8.2 of the mesh The mesh

identical to that of the modelization A, figure 3.2-a is represented. Functionalities

## 8.3 tested One

tests the functionality already presented for modelization A. One tests also the contact X-FEM in the case of junctions with X-FEM via operator DEFI `_CONTACT. Quantities`

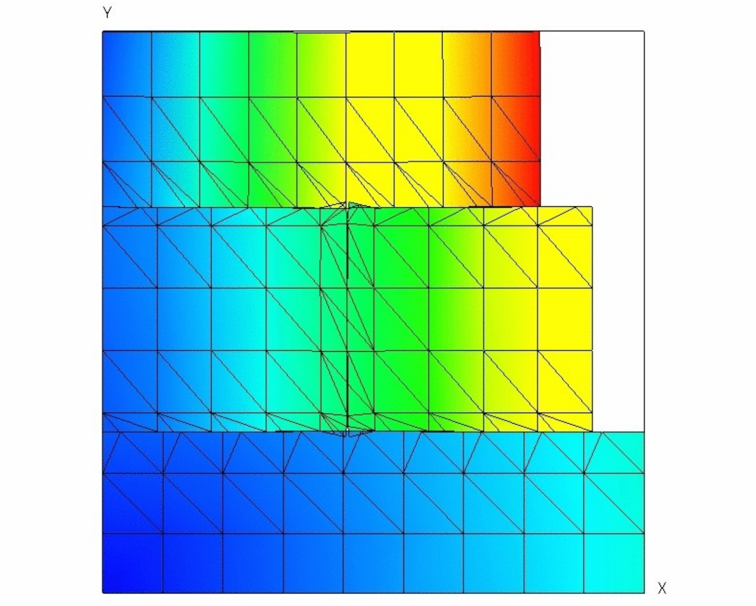
## 8.4 tested and results One

tests displacements on the level of the lips of cracks after having carried out the operations of postprocessings relative to (POST X-FEM _MAIL_XFEM and POST _CHAM_XFEM). DX displacement must follow the function of $Depl_X$ equation 2.1-1. Displacement DY must follow the function of $Depl_Y$ equation 2.1-2. One obtains the deformed shape of the figure 8.4-a. Identification

| Reference | | | tolerance | DEPZON |
|---|---|---|---|---|
| _1 DX | - MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _2 DX | - MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _3 DX | - MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _4 DX | - MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | Table |

**8.4 8.4-1**

the deformed shape is represented on the figure 8.4-a. The code color represents the field of displacement. Appear




**8.4-a: Deformed shape of the structure (exaggeration 10). Remarks**

## 8.5

a high error is obtained. Indeed the implementation of the recutting of the facets of contact was not implemented. The forces of contact on these facets are not taken into account in computation. The zone affected relates to in particular the junction points (which one does not test) as well as the elements the container. Let us note that the results are clearly to improve when the mesh is refined. Modelization

# 9 G Characteristic

## 9.1 of the modelization It

is acted of the same modelization as the modelization F, but as plane stresses, C_PLAN . The junctions are built same way. Characteristics

## 9.2 of the mesh The mesh

identical to that of the modelization B, is represented on the figure 4.2-a. Quantities

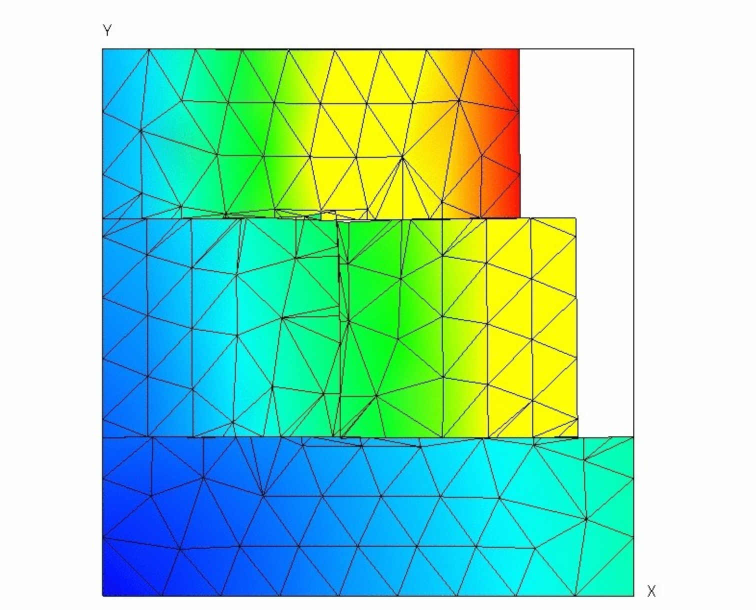
## 9.3 tested and results

the quantities tested are identical to those presented for the modelization E. Identification

| Reference | | | *tolerance* | *DEPZON* |
|---|---|---|---|---|
| _1 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _2 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _3 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _4 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | Table |

**9.3 9.3-1**

the deformed shape is represented on the figure 9.4-a. Appear




**9.4-a: Deformed shape of the structure (exaggeration 10). Remarks**

## 9.4

the remarks are identical to those specified for the modelization F. Modelization

# 10 H Characteristic

## 10.1 of the modelization It

acts of the same modelization as the modelization F, but in 3D . The junctions are built same way. Characteristics

## 10.2 of the mesh The mesh

identical to that of the modelization C, is represented on the figure 5.2-a. Quantities

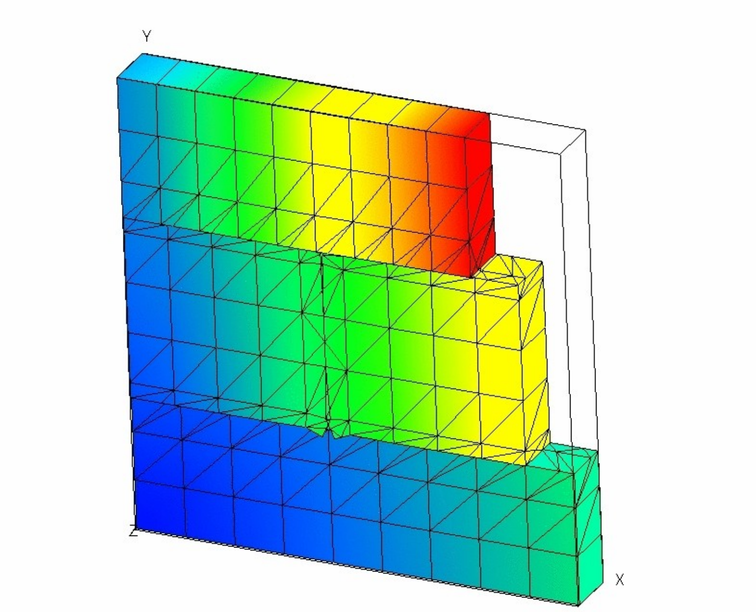
## 10.3 tested and results

the quantities tested are identical to those used for the modelization F. One adds tests on DZ . Identification

| Reference | | | tolerance | DEPZON |
|---|---|---|---|---|
| _1 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _2 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _3 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _4 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | Table |

**10.3 10.3-1**

the deformed shape is represented on the figure 10.4-a. Appear




**10.4-a: Deformed shape of the structure (exaggeration 10). Remarks**

## 10.4

the remarks are identical to those specified for the modelization F. Modelization

# 11 I Characteristic

## 11.1 of the modelization It

acts of the same modelization as the modelization H. Caractéristiques

## 11.2 of the mesh The mesh

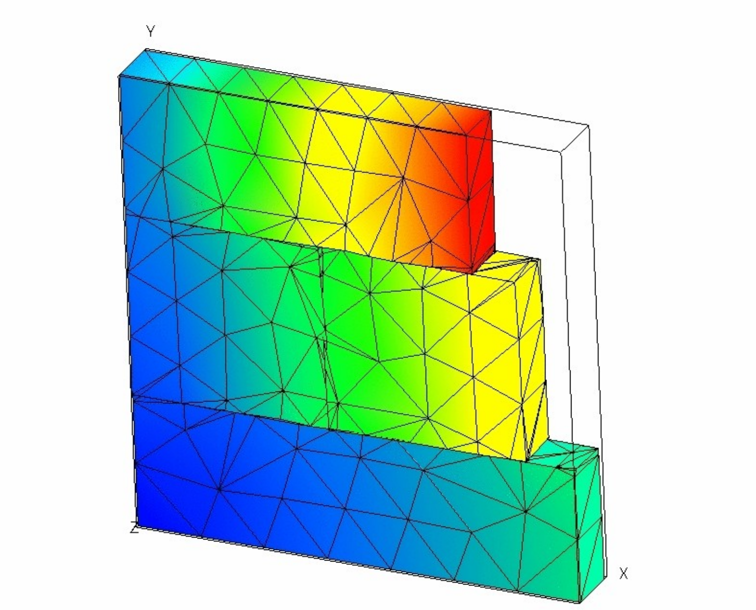
identical to that of the modelization D, is represented on the figure 6.2-a. Quantities

## 11.3 tested and results Identification

| Reference | | | **tolerance** | ***DEPZON*** |
|---|---|---|---|---|
| _1 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _2 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _3 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _4 DX | - MIN | 0 | 0,05 | MAX |
| | $Depl_X$ | 0 | 0,05 | DY |
| | - MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | Table |

**11.3 11.3-1**

the deformed shape is represented on the figure 11.4-a. Appear




**11.4-a: Deformed shape of the structure (exaggeration 10). Remarks**

## 11.4

the remarks are identical to those specified for the modelization F. Modelization

# 12 J Characteristic

## 12.1 of the modelization It

acts of the same modelization as the modelization F. Characteristic

## 12.2 of the mesh The mesh

identical to that of the modelization E, is represented on the figure 7.2-a. The mesh is refined less than that of the modelization F, so that certain elements see two horizontal cracks. Quantities

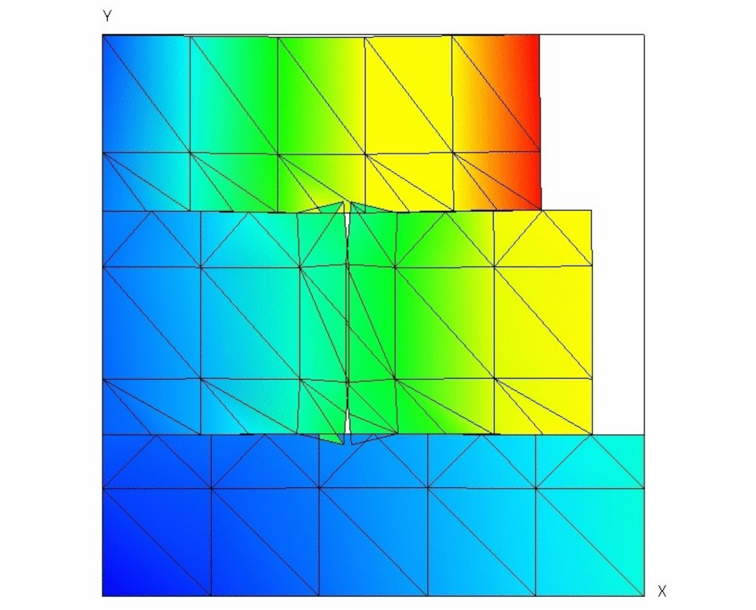
## 12.3 tested and results

the quantities tested are identical to those used for the modelization F. Identification

| Reference | | | *tolerance* | *DEPZON* |
|---|---|---|---|---|
| _1 DX | – MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | – MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _2 DX | – MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | – MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _3 DX | – MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | – MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | DEPZON |
| _4 DX | – MIN | 0 | 0,07 | MAX |
| | $Depl_X$ | 0 | 0,07 | DY |
| | – MIN | 0 | 0 | MAX |
| | $Depl_Y$ | 0 | 0 | Table |

**12.3 12.3-1**

the deformed shape is represented on the figure 12.4-a. Appear




**12.4-a: Deformed shape of the structure (exaggeration 10). Remarks**

## 12.4

the remarks are identical to those specified for the modelization F. Summary

# 13 of the results

the kinematics of opening of a crack connected with several other cracks is possible with. X-FEM It is necessary nevertheless in certain cases to bind these cracks between them via key word JONCTION , even if these cracks are not a priori connected one on the other.

The approach was validated in for 2D modelizations C_PLAN and D_PLAN and the elements of the type QUAD4 and SORTED 3. One also validated the approach in for 3D elements HEXA 8 and TETRA 4, with or without contact.