SSNP504 – Contact in great slips with X-FEM for oblique cracks

Summary:

The purpose of this test is to in the case of test and validate the features of the approach great slips with X-FEM the structures 2D in plane constraints and plane deformations presenting of the oblique cracks. This approach, described in [R5.03.53], allows in particular the taking into account of the contact, with friction, on the level of the cracks introduced by method X-FEM, in the presence of great displacements but under the assumption of the small deformations. New algorithms, compared to the treatment of contact with X-FEM under the assumption of the small disturbances [R7.02.12], which is tested and validated by this CAS-test relate to the geometrical reactualization of the lips of the cracks, master-slave pairing and the creation of the new hybrid elements of contact.

One tests and validates also the operation and the effectiveness of the algorithm designed for the respect of the condition LBB, algorithm developed initially for the approach HP of method X-FEM [R7.02.12].

One considers a structure 2D, a rectangle presenting two oblique cracks the beam completely (one will speak then about interfaces). Each interface cuts several stages of elements, requirement to highlight the effectiveness of algorithm LBB. The blocking of horizontal displacements is imposed on the four corners of the rectangle, of vertical displacements are imposed on the edges inferior and superior of the rectangle in order to tighten the block medium which is seen forcing a horizontal displacement to make it slip, while going up along interfaces. Following the request of compression thus created, contact pressures appear on the zones in contact, with an evolution of their values according to the advance of the block medium.

The validation is done by comparison of the values of the contact pressure with the similar values obtained starting from a homologous test (even geometry, same boundary conditions etc), treated within the classical framework of the finite element method, with *Code_Aster*, where them interfaces are in conformity with the grid.

1 Problem of reference

1.1 Geometry

The structure is a healthy rectangle in which two interfaceS obliques are introduced. interfaceS parallel and are placed as shown on [Figure 1.1-1]. Dimensions of the structure like those concerning the geometry of interfaceS are:

$H = 9\,m$;
$L = 4\,m$;
$B = 4\,m$;
$h = 2.125\,m$;
$\alpha = 13.49$

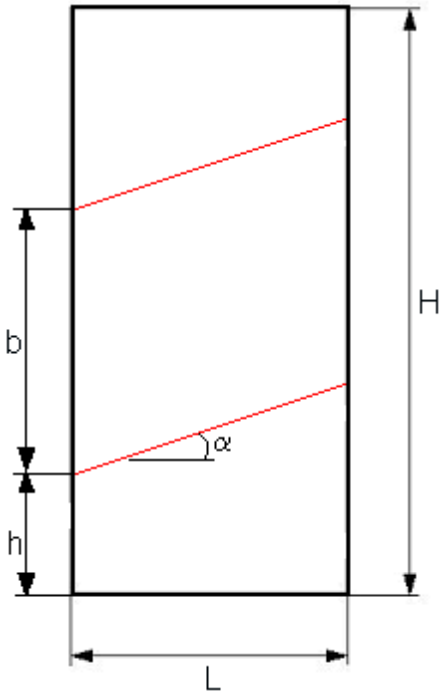

Figure 1.1-1: Geometry of the structure and positioning of interfaceS.

1.2 Properties of material

Young modulus: $E = 100\,MPa$

Poisson's ratio: $\nu = 0.3$

1.3 Boundary conditions and loadings

The blocking of horizontal displacements is imposed on the four corners of the structure (see [Figure 1.3-1]). On the edges inferior and superior of the rectangle, one imposes displacements along the axis Y who will close them interfaceS in order to generate contact pressure. The block medium is subjected to an important slip by applying a displacement controlled along the axis X on its left edge.

The digital values of imposed displacements are:

$Depl_X = 2.00\,m$;

$Depl_Y = 1.0\mathrm{E}-2\,m$.

Their application is done according to a function crawls classical, in 4 pas de charges.
The coefficient of friction of Coulomb is taken equal has $0,5$.

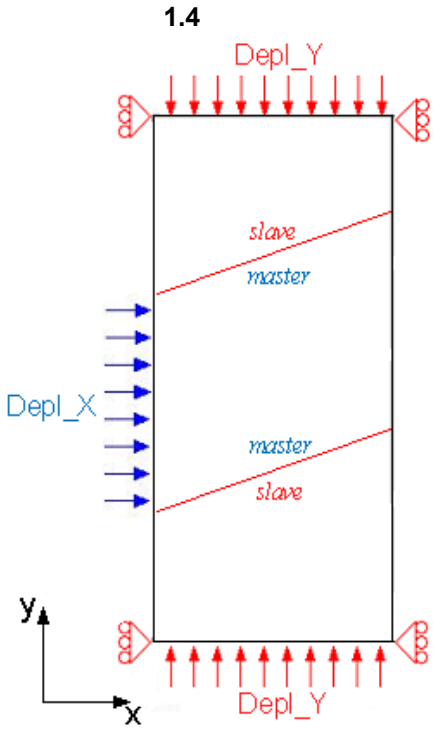

Figure 1.3-1: Illustration of the boundary conditions and the loadings.

2 Reference solution

The reference solution for this CAS-test is provided by the results resulting from a calculation *Code_Aster*, for the same structure but with interfaceS respecting the grid, realized with the method continues contact already existing within the classical framework of the finite element method [R5.03.52].

Geometry (except for the introduction interfaceS), the boundary conditions, the loadings as well as the parameters of contact are the same ones as those considered for this CAS-test modelled with method X-FEM.

3 Modeling A

3.1 Characteristics of modeling

It is about a modeling FEM, in plane deformations. The three blocks are with a grid with meshs in conformity and the conditions of contact are imposed on stop these blocks. One declares the edges Masters on the block medium and the edges slaves on the blocks inferior and superior in order to conform to [Figure 1.3-1].

3.2 Characteristics of the grid

The grid is regulated (see [Figure 3.2-1]) and comprises 3 blocks made up of meshs of the type QUAD4. The 3 blocks have each one 256 meshs.

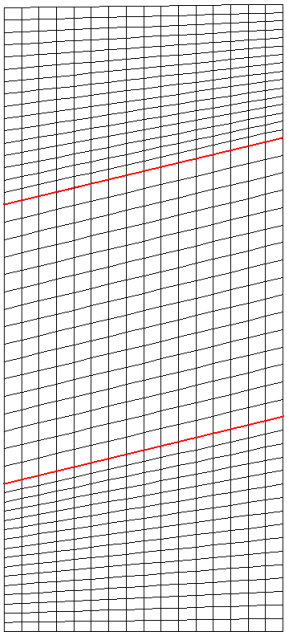

Figure 3.2-1: Grid of modeling A

3.3 Sizes tested and results

One tests contact pressures on the upper lip of the lower block, this one being declared slave, at the end of each step of load considered. The site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 3.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-6.3355792D+04	5.0%
	LAGS_C for N56	-6.0652836D+04	5.0%
	LAGS_C for N52	-5.0757743D+04	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
2	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-1.8115145E+05	5.0%
	LAGS_C for N56	-1.2479791E+05	5.0%
	LAGS_C for N52	-1.0307176E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
	LAGS_C for N10	0.0000000E+00	1.0E-12

3	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-2.0163278E+05	5.0%
	LAGS_C for N52	-1.5784447E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
4	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-3.7985867E+05	5.0%
	LAGS_C for N52	-2.2011907E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12

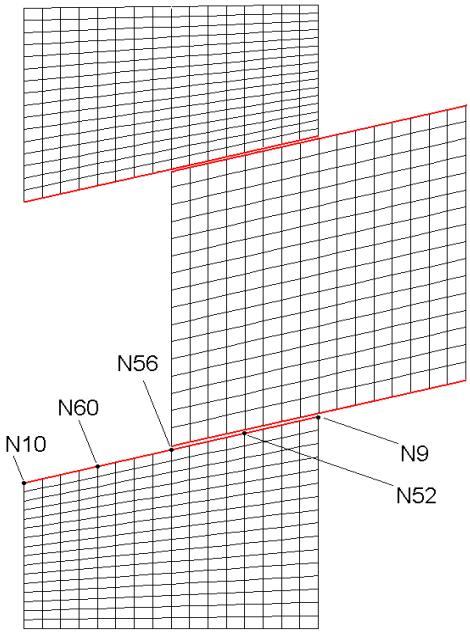

Figure 3.3-1: The site of the nodes which store the degrees of freedom of contact tested

3.4 Remarks

This test is used as reference to modeling B, it is thus normal to have residues close to zero, which correspond to the precision required in the operator IMPR_TABLE command file. It makes it possible to make sure that there is no evolution in the calculation algorithms for method FEM of contact in great slips, in which case it would then be necessary also to re-examine method X-FEM, based on this one.

4 Modeling B

4.1 Characteristics of modeling

It is about a modeling X-FEM, in plane deformations, with definition of contact on the interfaces defined by functions of level (level sets noted LN for the level set normal) directly in the command file using the operator DEFI_FISS_XFEM [U4.82.08].

The statute main slave/for a surface of contact X-FEM is given by the sign of the normal function of level LN : surface slave is on the negative side while surface Master is positive side.

Equations of the functions of level for both interfaceS obliques are the following ones:

$$\mathrm{LN}\,1 = Y - X - \tan\alpha - 2.125 \quad \text{éq 4.1-1}$$

$$\mathrm{LN}\,2 = -Y + X - \tan\alpha + 6.125 \quad \text{éq 4.1-2}$$

No level set tangential is necessary since the keyword was used TYPE_DISCONTINUITE=' INTERFACE', which makes it possible to have a structure completely cut in three parts.

4.2 Characteristics of the grid

The grid is regulated (see [Figure 3.3-1]) and comprises 576 meshs of the type QUAD4, 16×36 along the horizontal and vertical axes, respectively. Following the definition of interfaceS, the meshs cut by those are transformed into QUAD8 in order to be able to store the degrees of freedom of contact rubbing with the nodes tops and mediums.

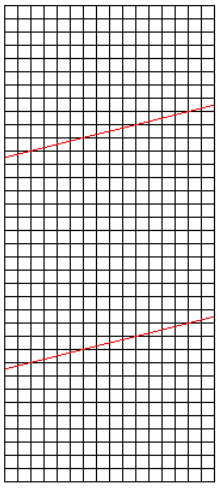

Figure 4.2-1: Grid of modeling B

As one can observe it on [Figure 3.3-1], each interface cross 5 vertical stages of meshs, which leads to a wealth of the space of multipliers of contact different from that of the space of geometrical displacements. It is in this situation that the algorithm of respect of the LBB condition will act in order to stabilize the distribution of contact pressure.

4.3 Sizes tested and results

One tests the values of contact pressure on the lip slave of the first interface, at the end of each step of load considered. The comparison compared to the results of reference is given in the following table.

The site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 4.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	-6.3355791D+04	5.0%
	LAGS_C for N249	-6.0652835D+04	5.0%
	LAGS_C for N268	-5.0757742D+04	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12
2	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	-1.8115145E+05	5.0%
	LAGS_C for N249	-1.2479791E+05	5.0%
	LAGS_C for N268	-1.0307176E+05	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12
3	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	0.0000000E+00	1.0E-12
	LAGS_C for N249	-2.0163278E+05	5.0%
	LAGS_C for N268	-1.5784447E+05	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12
4	LAGS_C for N45	0.0000000E+00	1.0E-12
	LAGS_C for N230	0.0000000E+00	1.0E-12
	LAGS_C for N249	-3.7985867E+05	5.0%
	LAGS_C for N268	-2.2011907E+05	5.0%
	LAGS_C for N83	0.0000000E+00	1.0E-12

The analysis was carried out with and without the algorithm of stabilization LBB. In absence of the algorithm, important oscillations were found in the distribution of contact pressures. On the other hand, once activated algorithm LBB, one obtains a stable solution for contact pressures.

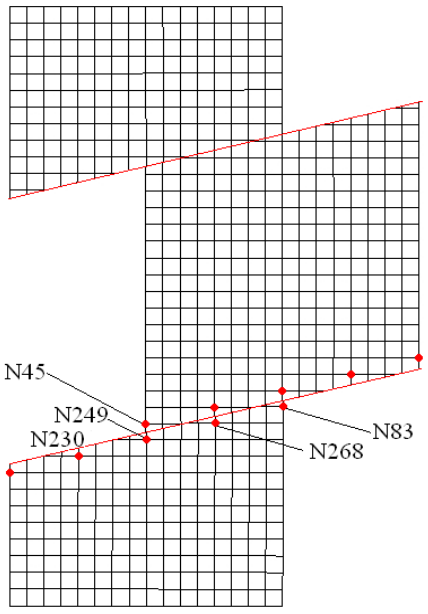

Figure 4.3-1: The site of the nodes which store the degrees of freedom of contact tested

4.4 Remarks

The results got with this modeling are close to those obtained by classical modeling. The variations are due to the different grids (the grid used for classical modeling is not regulated in order to respect

the geometry of interfaceS obliques) and with stabilization by the algorithm used for the satisfaction of the LBB.

5 Modeling C

5.1 Characteristics of modeling

They is the same characteristics of modeling as modeling A but in plane constraints.

5.2 Characteristics of the grid

They is the same characteristics of grid as modeling A.

5.3 Sizes tested and results

One tests contact pressures as for modeling A. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 3.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-5.6047281D+04	5.0%
	LAGS_C for N56	-5.3536786D+04	5.0%
	LAGS_C for N52	-4.4909070D+04	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
2	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	-1.6263864E+05	5.0%
	LAGS_C for N56	-1.1063071E+05	5.0%
	LAGS_C for N52	-9.1544228E+04	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
3	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-1.7966654E+05	5.0%
	LAGS_C for N52	-1.4075455E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12
4	LAGS_C for N10	0.0000000E+00	1.0E-12
	LAGS_C for N60	0.0000000E+00	1.0E-12
	LAGS_C for N56	-3.4348434E+05	5.0%
	LAGS_C for N52	-1.9708554E+05	5.0%
	LAGS_C for N9	0.0000000E+00	1.0E-12

5.4 Remarks

This test is used as reference to modeling D.

6 Modeling D

6.1 Characteristics of modeling

They is the same characteristics of modeling as modeling B but in plane constraints.

6.2 Characteristics of the grid

They is the same characteristics of grid as modeling B.

6.3 Sizes tested and results

One tests the values of contact pressure as for modeling B.

Not	Identification	Reference	Tolerance
1	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	-5.6047281E+04	5.0%
	LAGS_C for N247	-5.3536786E+04	5.0%
	LAGS_C for N266	-4.4909070E+04	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12
2	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	-1.6263864D+05	5.0%
	LAGS_C for N247	-1.1063071D+05	5.0%
	LAGS_C for N266	-9.1544228D+04	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12
3	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	0.0000000E+00	1.0E-12
	LAGS_C for N247	-1.7966654E+05	5.0%
	LAGS_C for N266	-1.4075455E+05	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12
4	LAGS_C for N43	0.0000000E+00	1.0E-12
	LAGS_C for N228	0.0000000E+00	1.0E-12
	LAGS_C for N247	-3.4348434E+05	5.0%
	LAGS_C for N266	-1.9708554E+05	5.0%
	LAGS_C for N81	0.0000000E+00	1.0E-12

7 Modeling E

7.1 Characteristics of modeling

They is the same characteristics of modeling as modeling A.

7.2 Characteristics of the grid

The grid is regulated (see [Figure 7.2-1]) and comprises 3 blocks made up of meshs of the type TRI3. It has on the whole approximately 4608 elements, 32×72 along the horizontal and vertical axes, respectively.
The grid is finer than in the preceding tests because one wants to avoid a loss of precision between the methods of contact FEM and X-FEM caused by the differences in grid. Moreover, it is built for this case (contact FEM) starting from the grid of visualization X-FEM of modeling F (homologous contact X-FEM), in order to limit the differences in grid between the two approaches of contact.

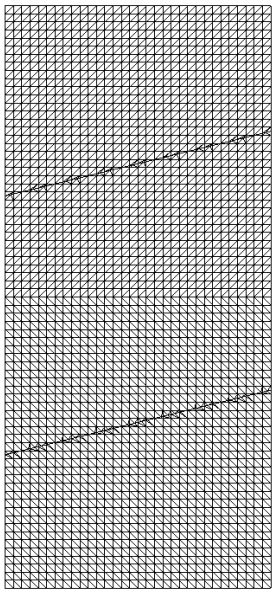

Figure 7.2-1: Grid of modeling E

7.3 Sizes tested and results

One tests the values of the contact pressure as for modeling A. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 7.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	-6.0789654D+04	5.0%
	LAGS_C for N2791	-5.9710311D+04	5.0%
	LAGS_C for N3051	-5.1197045D+04	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12
2	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	-3.9911326E+05	5.0%
	LAGS_C for N2791	-1.2010508E+05	5.0%
	LAGS_C for N3051	-1.0176447E+05	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12

3	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	0.0000000E+00	1.0E-12
	LAGS_C for N2791	-1.9289294E+05	5.0%
	LAGS_C for N3051	-1.5195304E+05	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12
4	LAGS_C for N2288	0.0000000E+00	1.0E-12
	LAGS_C for N2531	0.0000000E+00	1.0E-12
	LAGS_C for N2791	-9.4470171E+05	5.0%
	LAGS_C for N3051	-2.0680207E+05	5.0%
	LAGS_C for N3311	0.0000000E+00	1.0E-12

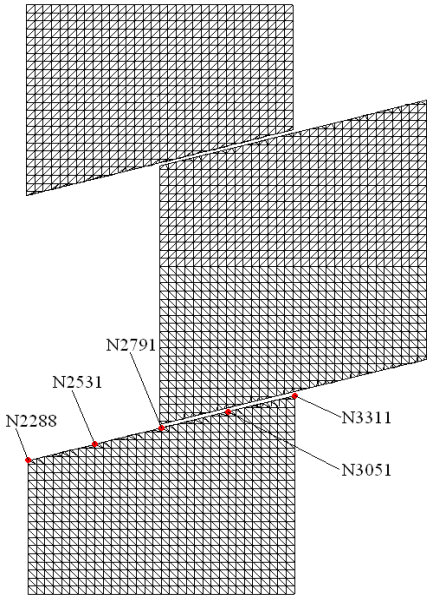

Figure 7.3-1: The site of the nodes which store the degrees of freedom of contact tested

7.4 Remarks

This test is used as reference to modeling F.

8 Modeling F

8.1 Characteristics of modeling

They is the same characteristics of modeling as modeling B.

8.2 Characteristics of the grid

The grid is regulated (see [Figure 8.2-1]) and comprises 4608 meshs of the type TRI3. Following the definition of interfaceS, the cut meshs store with their nodes the degrees of freedom of contact friction.

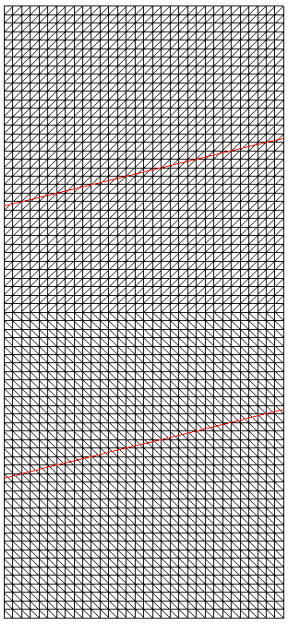

Figure 8.2-1: Grid of modeling F

8.3 Sizes tested and results

One tests the values of contact pressure as for modeling B. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on [Figure 8.3-1]. One compares graphically on [Figure 8.3-2] results of approaches FEM and X-FEM for the last step of load.

Not	Identification	Reference	Tolerance
1	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-6.0789654D+04	5.0%
	LAGS_C for N710	-5.9710311D+04	5.0%
	LAGS_C for N1008	-5.1197045D+04	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
2	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-3.9911326E+05	5.0%
	LAGS_C for N710	-1.2010508E+05	5.0%
	LAGS_C for N1008	-1.0176447E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12

3	LAGS_C for N710	-1.9289294E+05	5.0%
	LAGS_C for N1008	-1.5195304E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
4	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12
	LAGS_C for N710	-9.4470171E+05	5.0%
	LAGS_C for N1008	-2.0680207E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12

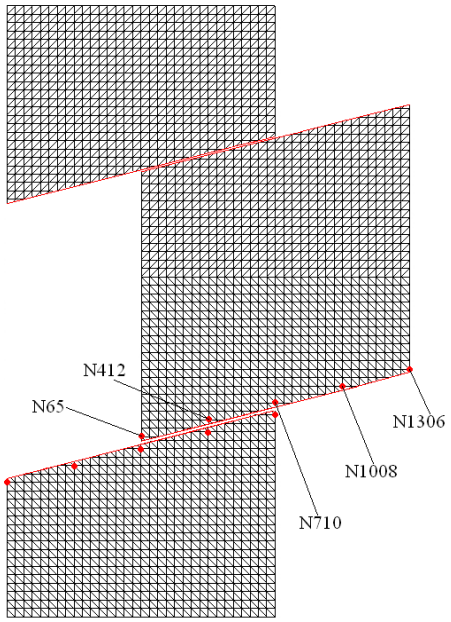

Figure 8.3-1: The site of the nodes which store the degrees of freedom of contact tested

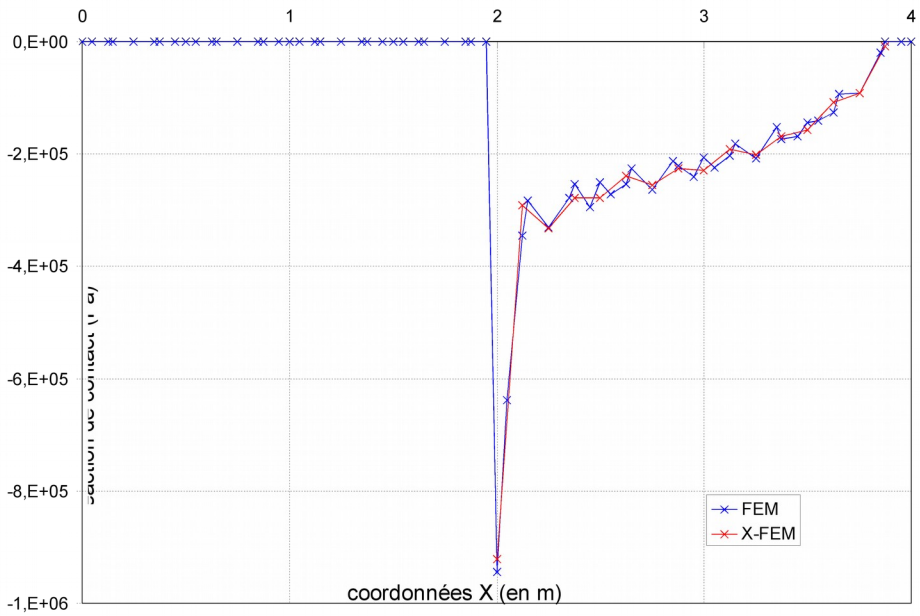

Figure 8.3-2: SSNP503-e and F: Comparison of the reactions of contact (last step of load), for methods FEM (in blue) and XFEM (in red).

8.4 Remarks

These results validate in 2D the management of the integration of the contact with slipping friction when a relation of equality between the degrees of freedom of contact friction is imposed on the way contacting/not contacting by the algorithm of stabilization of the LBB (see [R5 03 53] and [D9 05 06]). So that results of the two approaches (methods of contact X-FEM and Classical FEM) corresponds, one recovered the grid of the postprocessing of approach X-FEM to build the grid for approach FEM (modeling E). The positions of the nodes of the grid (except interface) are then the same ones, the integration of rigidity is done on the same triangles and the integration of the contact is done on the same segments.
However, according to this approach of construction of grid, the interfaces of method of contact FEM have almost twice more degrees of freedom (contact and displacement) that those of method of contact X-FEM. One thus does not solve exactly the same digital problem in the 2 cases.
The convergence of the test of comparison on the profile of the reaction of contact is checked with a maximum tolerance of 12% in one of the points. This relatively great tolerance takes account of the oscillations (see [Figure 8.3-2]) which comes from the irregularity of the size of the segments on which one integrates the contact. It is noticed that these oscillations are of less great amplitude in case X-FEM because of the algorithm of management of condition LBB.

9 Modeling G

9.1 Characteristics of modeling

They is the same characteristics of modeling as modeling F, but in penalized formulation.

9.2 Characteristics of the grid

It is the same grid as that of modeling F.

9.3 Sizes tested and results

One tests the values of contact pressure with the same references and tolerances that modeling F. the site of the nodes which store the degrees of freedom of contact, which one tests the values, is illustrated on it [Figure 8.3-1].

Not	Identification	Reference	Tolerance
1	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-6.0789654D+04	5.0%
	LAGS_C for N710	-5.9710311D+04	5.0%
	LAGS_C for N1008	-5.1197045D+04	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
2	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	-3.9911326E+05	5.0%
	LAGS_C for N710	-1.2010508E+05	5.0%
	LAGS_C for N1008	-1.0176447E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
3	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12
	LAGS_C for N710	-1.9289294E+05	5.0%
	LAGS_C for N1008	-1.5195304E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12
4	LAGS_C for N65	0.0000000E+00	1.0E-12
	LAGS_C for N412	0.0000000E+00	1.0E-12
	LAGS_C for N710	-9.4470171E+05	5.0%
	LAGS_C for N1008	-2.0680207E+05	5.0%
	LAGS_C for N1306	0.0000000E+00	1.0E-12

10 Summary of the results

The goals of this test are achieved.

- It is a question of showing the feasibility of the taking into account of the contact on the oblique lips of cracks with the approach great slips X-FEM. Only the case of the cracks crossing the structure completely was considered (interface).
- One also shows in 2D the effectiveness of the algorithms implemented to improve the results when the relations of equalities introduced on the degrees of freedom of contact by algorithm LBB enter in conflict with a contacting change of status/not contacting (modeling F).
- The approach was validated with the taking into account of frictions in 2D (plane strains and plane stresses, elements QUAD4 and TRI3)