
Operator POST_K1_K2_K3

1 Goal

To calculate the factors of intensity of the constraints in 2D and 3D.

This operator allows to calculate $K1$, $K2$ in 2D (modelings 'D_PLAN', 'C_PLAN' and 'AXIS') and $K3$ in 3D (modeling '3D') by extrapolation of the jumps of displacements on the lips of the crack, cf [R7.02.08]. This method is applicable only for homogeneous and isotropic materials.

This operator is usable as well for a crack with a grid as for a crack nonwith a grid (method X-FEM). In the case of a crack with a grid, this one must obligatorily be plane.

The method used is theoretically less precise and more sensitive to the grid than calculation starting from the form bilinear of the rate of refund of energy and singular displacements, usable in 2D and 3D with the option CALC_K_G of the operator CALC_G [U4.82.03]. It however makes it possible to easily obtain a good estimate of the factors of intensity of the constraints.

Product a concept of the type `table`.

2 Syntax

```

tk [table] = POST_K1_K2_K3    (

    ♦ / FOND_FISS            = bottom,
    [fond_fiss]
      / CRACK                = fiss,                      [fiss_xfem]
    ♦ ABSC_CURV_MAXI        = dmax,                      [R]

# 1) If FOND_FISS is indicated:

    ♦ RESULT                = resu,                      / [evol_elas]
                                                    / [evol_noli]
                                                    / [mode_meca]
    ♦ / ALL                  = 'YES',
      / GROUP_NO            = gr_noeu,                  [l_gr_noeud]
      / SANS_GROUP_NO      = gr_noeu,                  [l_gr_noeud]

# has direction only for modelings 3D
    ♦ TYPE_MAILLAGE         = / 'RULE',                [DEFECT]
                              / 'FREE',
    ♦ NB_NOEUD_COUPE       = / 5,
                              / N,                    [I]
    ♦ PREC_VIS_A_VIS       = / 1.E-1,                  [DEFECT]
                              / epsi,                   [R]

# 2) If CRACK is indicated:

    ♦ RESULT                = resu,                      / [evol_elas]
                                                    / [evol_noli]
    ♦ NB_NOEUD_COUPE       = / 5,                      [DEFECT]
                              / N,                    [I]
    ♦ NB_POINT_FOND        = / nbnofo,                 [I]
    ♦ NUME_FOND             = / 1,                      [DEFECT]
                              / numfon,                [I]

# 3) END

    ♦ MATER                 = chechmate,                [to
subdue]

    ♦ / TOUT_ORDRE          = 'YES',
      / NUME_ORDRE          = lnuor,                    [L_I]
      / LIST_ORDRE          = lnuor,                    [listis]

      / TOUT_MODE           = 'YES',
      / NUME_MODE           = lnuor,                    [L_I]
      / LIST_MODE           = lnuor,                    [listis]

      / FREQ                = l_freq,                  [l_R]
      / LIST_FREQ           = l_freq,                  [listR8]
      / INST                = l_inst,                  [l_R]
      / LIST_INST           = l_inst,                  [listR8]
    ♦ CRITERION             = / 'RELATIVE',             [DEFECT]
    ♦ PRECISION             = / prec,                   [R]

```

Code_Aster

Version
default

Titre : Opérateur POST_K1_K2_K3
Responsable : GÉNIAUT Samuel

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```

/ 1.E-6 , [DEFECT]

/ 'ABSOLUTE' ,
  ◆ PRECISION = prec, [R]

◇ TITLE = title, [1_Kn]

◇ INFORMATION = / 1,

)
```

3 Operands

3.1 Case where the operand FOND_FISS is well informed

This case corresponds to a calculation on a crack with a grid, definite for postprocessing with the operator `DEFI_FOND_FISS`. By default, calculation is made automatically for all the nodes of the bottom of crack.

3.1.1 Operands FOND_FISS / PREC_VIS_A_VIS/GROUP_NO/SANS_GROUP_NO

```
◇ FOND_FISS = bottom, [fond_fiss]
◇ PREC_VIS_A_VIS = / 1.D-1, [DEFECT]
                  / epsi, [R]
◇ / ALL = 'YES',
  / GROUP_NO = gr_noeu, [l_gr_noeud]
  / SANS_GROUP_NO = gr_noeu, [l_gr_noeud]
```

The operand `FOND_FISS` allows to provide the concept `fond_fiss` (created by the order `DEFI_FOND_FISS`) in which the necessary information are stored with the automatic research of the nodes of the two lips located on normal segments at the bottom of crack. Attention, the concept `fond_fiss` must necessarily be defined such as the lips of the crack are initially stuck (`CONFIG_INIT='COLLEE'` in `DEFI_FOND_FISS` [U4.82.01])

In 3D, by default, the calculation of the stress intensity factors is done only on the nodes tops of the meshes composing the bottom of crack (thus all nodes for the linear elements, and a node on two for the quadratic elements). The user has the possibility of:

- to select certain nodes tops of the bottom of crack (keyword `GROUP_NO`);
- to exclude from the nodes of the bottom of crack (keyword `SANS_GROUP_NO`);
- to calculate on all the nodes mediums and tops of the bottom of crack (keyword `ALL`).

```
◇ ABSC_CURV_MAXI = dmax [R]
```

Maximum distance from calculation of the factors of intensity of the constraints starting from the bottom of crack. In practice, the precision of the results is less good if one is located very far from the bottom of crack [R7.02.08]. It is thus advised to choose `dmax` smallest possible (about 3 to 4 elements, or about the ray of the radiant grid, if necessary). If in a point N bottom of crack, this distance is higher than the distance from the bottom of crack in this point at the edge of the lips, the value of the factors of intensity of the constraints at the point N are obtained by constant prolongation. The value selected is that of the point of the bottom of crack nearest and for which calculation could be carried out.

The operand `ABSC_CURV_MAXI` is optional. When this operand is not indicated, the value of `ABSC_CURV_MAXI` automatically calculated starting from the maximum h sizes of the meshes connected to the nodes of the bottom of crack. These sizes of meshes in each node of the bottom are calculated in the order `DEFI_FOND_FISS` and are present in the concept `fond_fiss` [D4.10.01]. It was selected to take `ABSC_CURV_MAXI` equal to $4h$.

If one chooses the value automatically calculated for `ABSC_CURV_MAXI`, it is advisable however to make sure that its value (displayed in the file `.mess`) is coherent with dimensions of the structure.

At the time of automatic research for each node of the bottom of crack, the operator selects the nodes checking the following conditions:

- distance R compared to the bottom of crack: $R < \text{ABSC_CURV_MAXI}$,
- distance L compared to its opposite on the other lip:
$$L < \text{epsi} \cdot \text{ABSC_CURV_MAXI},$$
- and in 3D outdistances D of a node of the lips to the right-hand side perpendicular to the bottom of crack: $D < \text{epsi_fond} \cdot d$, where d is the minimal distance between two successive nodes of the bottom of crack, where epsi of the provided precision (keyword is the value PREC_VIS_A_VIS) and epsi_fond the value of the precision provided in the keyword PREC_NORM of DEFI_FOND_FISS .

By default epsi is worth 0,1. To increase the value of PREC_VIS_A_VIS (and/or of PREC_NORM in DEFI_FOND_FISS) come down to increase the number of nodes potentially retained for calculation.

Notice :

If $\text{TYPE_MAILLAGE} = \text{'REGLE'}$, this precision intervenes in the phase of projection of the result on the line of cut: a point is regarded as being out of the matter if its distance to the structure is higher than $\text{epsi} \cdot \text{ABSC_CURV_MAXI}$. It can be necessary to modify the value by default of this parameter if the crack is represented by a notch.

3.1.2 Operands RESULT

◆ $\text{RESULT} = \text{resu},$

resu is a concept of the type evol_elas , evol_noli or mode_meca containing the field of displacement on all the model.

Notice :

resu cannot be a concept of the type mode_meca that if $\text{TYPE_MAILLAGE} = \text{'REGLE'}$.

3.1.3 Operand TYPE_MAILLAGE

◇ $\text{TYPE_MAILLAGE} = / \text{'RULE'}, \quad [\text{defect}]$
 $\quad \quad \quad / \text{'FREE'},$

This keyword has direction only in 3D, for the cracks with a grid defined by FOND_FISS .

If $\text{TYPE_MAILLAGE} = \text{'REGULATES'}$, option to use by default, calculation is done by supposing that the nodes on the lips of the crack are on normal directions at the bottom and exactly in with respect to a lip with the other. Messages of alarm or error are transmitted if it is not the case.

If the grid does not meet these conditions, one can use the option $\text{TYPE_MAILLAGE} = \text{'LIBRE'}$. The principle of calculation is then the following:

1. determination of the normal directions at the bottom of crack for each node of the bottom,
2. definition on each one of these directions of NB_NOEUD_COUPE points équi-distribute between the bottom and the distance ABSC_CURV_MAXI ,
3. projection of the displacement of each lip on these nodes,
4. interpolation of the jump of displacement.

Calculation with $\text{TYPE_MAILLAGE} = \text{'LIBRE'}$ can be less precise than calculation by default.

3.1.4 Operand NB_NOEUD_COUPE

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◇ NB_NOEUD_COUPE= / 5, [DEFECT]
/ N, [I]

This operand intervenes only if `TYPE_MALLAGE= 'LIBRE'` is well informed. It makes it possible to define the number of nodes of projection of the displacement of the lips on each normal direction. The nodes of projection are équi-distribute between the bottom of crack and the distance `ABSC_CURV_MAXI`.

Notice :

The projection of the displacement of the lips on `NB_NOEUD_COUPE` points of projection does not take correctly counts of it the displacement of the nodes to the quarter (elements of Barsoum). It is thus recommended not to use these elements if `TYPE_MALLAGE= 'LIBRE'`.

3.2 Case where the operand `CRACK` is well informed

This case corresponds to a calculation on a crack nonwith a grid, definite for calculation then for postprocessing with the operator `DEFI_FISS_XFEM`.

3.2.1 Operand `CRACK`

◆ `CRACK = fiss,`

Concept of the type `fiss_xfem`, product by the order `DEFI_FISS_XFEM`.

3.2.2 Operand `RESULT`

◆ `RESULT = resu,`

Concept of the type `evol_elas` or `evol_noli` containing the field of displacement on all the model. The grid is deduced from this concept.

3.2.3 Operand `ABSC_CURV_MAXI`

◇ `ABSC_CURV_MAXI = dmax` [R]

Maximum distance from calculation of the factors of intensity of the constraints starting from the bottom of crack. In practice, the precision of the results is less good if one is located very far from the bottom of crack [R7.02.08]. It is thus advised to choose *dmax* smallest possible (about 4 to 5 elements. If in a point *N* bottom of crack, this distance is higher than the distance from the bottom of crack in this point at the edge of the lips, the value of the factors of intensity of the constraints at the point *N* are obtained by constant prolongation. The value selected is that of the point of the bottom of crack nearest and for which calculation could be carried out.

The operand `ABSC_CURV_MAXI` is optional. When this operand is not indicated, the value of `ABSC_CURV_MAXI` automatically calculated starting from the maximum *h* sizes of the meshes connected to the nodes of the bottom of crack. These sizes of meshes in each node of the bottom are calculated in the order `DEFI_FOND_FISS` and are present in the concept `fiss_xfem` [D4.10.02]. It was selected to take `ABSC_CURV_MAXI` equal to $5h$.

If one chooses the value automatically calculated for `ABSC_CURV_MAXI`, it is advisable however to make sure that its value (displayed in the file `.mess`) is coherent with dimensions of the structure.

3.2.4 Operand `NUME_FOND`

◇ `NUME_FOND` = / 1, [DEFECT]
/ numfon, [I]

Several funds of crack can be defined in only one structure of data of the type `fiss_xfem`. This operand makes it possible to select the number of the bottom on which calculation must be carried out. By default, only the first bottom is considered.

3.2.5 Operand `NB_NOEUD_COUPE`

◇ `NB_NOEUD_COUPE` = / 5, [DEFECT]
/ N, [I]

This operand makes it possible to define the number of nodes of projection of the displacement of the lips on each normal direction. The nodes of projection are équi-distribute between the bottom of crack and the distance `ABSC_CURV_MAXI`.

3.2.6 Operand `NB_POINT_FOND`

◇ `NB_POINT_FOND` = / nbnofo, [I]

By default for a crack X-FEM, calculation is done on all the points of the bottom of crack, i.e all the points of intersection between the bottom of crack and the edges of the grid. The operand `NB_POINT_FOND` allows to fix *a priori* the number of points of postprocessing, in order to limit the computing times. `nbnofo` points are équi-distribute along the bottom of crack.

3.3 Operand `MATER`

◇ `MATER` = `chechmate`, [to subdue]

Concept of type material containing the elastic characteristics of fissured material. If this optional keyword is indicated, the material `chechmate` will replace, during the execution of the order, material used for the resolution of the problem mechanical and present in `cham_mater` contents in `sd_resultat` (data under the keyword `RESULT`). The material `chechmate` must be homogeneous, isotropic and elastic linear. This material must be **constant** (obligatory use of `DEFI_MATERIAU/ELAS`). The keyword `MATER` is to be used with precaution.

3.4 Operands `INST`, `LIST_INST`, `FREQ`, `LIST_FREQ`, `TOUT_ORDRE`, `NUME_ORDRE`, `LIST_ORDRE`, `TOUT_MODE`, `NUME_MODE`, `LIST_MODE`

Cf [U4.71.00].

3.5 Operand `INFORMATION`

◇ `INFORMATION` = / 1, [DEFECT]
/ 2,

Level of messages in the file message: if `INFORMATION` is worth 2, one provides the list of all the computed values for all the treated nodes.

3.6 Operand `TITLE`

◇ `TITLE = title,`

Title which one wants to give to the result of the order.

4 Precautions and advices of use

4.1 Assumptions relating to material used for the calculation of displacements

The calculation of the factors of intensity of the constraints by extrapolation of the jumps of displacement supposes to know the linear elastic characteristics of the fissured material which was used for the resolution of the mechanical problem (calculation of the field of displacement). In practice, the order POST_K1_K2_K3 automatically recover the concept affected material on a set of meshes close to the face of crack (for a crack with a grid or X-FEM). The material must be homogeneous, isotropic and elastic linear.

This material can to be **constant** (use of `DEFI_MATERIAU/ELAS`) or **function** (use of `DEFI_MATERIAU/ELAS_FO`). The only variables of orders being able to be used for the calculation of the factors of intensity of the constraints in the case of a material function are `'TEMP'` (temperature) and `'NEUT1'`. Puses, these variables must necessarily be affected (in `AFFE_MATERIAU/AFFE_VARC`) starting from nodal fields (`cham_no`).

In the case of a material function, the elastic parameters are evaluated at the points of calculation of the bottom of crack:

- for a crack with a grid (operand `FOND_FISS` informed) these points are the nodes of the bottom of crack;
- for a crack X-FEM (operand `CRACK` informed), these points are that is to say those contained in the object `.FONDFISS` structure of data `fiss_xfem`, that is to say those resulting some by the use of the keyword `NB_POINT_FOND`.

4.2 Recall on the various methods used for extrapolation of the jumps of displacements [R7.02.08]

In each node of the bottom of crack, one uses 3 methods (alternatives) to determine K_I , K_{II} (and K_{III} in 3D).

- Method 1: for each node of the segment of interpolation, one calculates the jump of the field of displacements squared and one divides it by r . Various values of K_I (resp. K_2 , K_3) are obtained (except for a multiplicative factor) by extrapolation in $r=0$ segments of right-hand sides thus obtained.
- Method 2: one traces the jump of the field of displacements squared according to r . Approximations of K_I are (always with a multiplicative factor near) equal to the slope of the segments connecting the origin to the various points of the curve.
- Method 3: linear regression.

In each node of the bottom of crack, each method provides a value MAX and a value MIN. In each node of the bottom of crack, one thus has 6 values for K_I , 6 values for K_{II} and 6 values for K_{III} (for method 3, min and max values coincide). One notes these values as follows, the exhibitor j corresponding to the number of the method:

- for K_I (mode *I* or mode of opening): $K_I^{j,MAX}$, $K_I^{j,MIN}$, $j=1,2,3$
- for K_{II} (mode *II* or shearing plan): $K_{II}^{j,MAX}$, $K_{II}^{j,MIN}$, $j=1,2,3$
- and for K_{III} (mode *III* or shearing anti-plan): $K_{III}^{j,MAX}$, $K_{III}^{j,MIN}$, $j=1,2,3$.

4.3 Produced table

The order POST_K1_K2_K3 product a concept of the type `table`. The table can be printed by IMPR_TABLE [U4.91.03]. It contains for each node of the bottom of crack:

- values of the stress intensity factors corresponding: $K1$, $K2$ (and $K3$ if 3D)
- the value of the rate of refund of energy: G
- estimates of the error on the stress intensity factors: ERR_K1 , ERR_K2 (and ERR_K3 if 3D).

The following paragraphs detail these sizes.

4.3.1 Values of the factors of intensity of the constraints

The produced table contains, for each node (or not) of the bottom of crack, the values of the stress intensity factors corresponding to the values MAX of the method n°1 (see §4.2):

$$K1 \text{ (} = K_I^{1,MAX} \text{)}, K2 \text{ (} = K_{II}^{1,MAX} \text{)}$$

$$\text{In 3D, one has moreover } K3 \text{ (} = K_{III}^{1,MAX} \text{)}$$

One is thus printed only value of $K1$, $K2$ (and $K3$ if 3D) per node of the bottom of crack.

4.3.2 Values of the rate of refund of energy

The produced table contains, for each node (or not) of the bottom of crack, the value of the rate of refund of energy G calculated starting from the factors of intensity of the constraints by the formula of Irwin.

4.3.3 Estimate of the mistake made on the factors of intensity of the constraints

In order to evaluate the mistake made on the factors of intensity of the constraints in each node of the bottom, one evaluates the difference between the 6 values given by the 3 methods (see §4.2). That gives an absolute deviation concerning $K1$, $K2$ (and $K3$ if 3D). Pour to obtain a relative variation easier to interpret, one standardizes the absolute deviations by a value K who is the maximum value of all them K in this node of the bottom of crack.

More precisely, the mistake made on $K_i (i=1,2,3)$, i being mode of request of the crack and j the number of the method, is in the following way defined:

$$\text{erreur}(K_i) = \frac{\max_{j=1,2,3} (K_i^{j,MAX} - K_i^{j,MIN})}{K}, \text{ with } K = \max_{j=1,2,3} (K_I^{j,MAX}, K_{II}^{j,MAX}, K_{III}^{j,MAX})$$

Erreurs on $K1$, $K2$ (and $K3$ if 3D) soundT printed in the table: ERR_K1 , ERR_K2 (and ERR_K3 if 3D) for each node of the bottom of crack.

4.4 Additional impressions

If INFORMATION is worth 2, all intermediate calculations are displayed in the file message. It is announced that the column entitled SAUT_DX (resp. SAUT_DY and SAUT_DZ) in the tables of the file message corresponds to the jump of displacement following the axis $X1$ (respectively $X2$ and $X3$), multiplied by a coefficient depend on material, the whole with the square [R7.02.08].

4.5 Precautions and advices

The assumptions necessary to the validity of this method are:

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- 1) the crack must be sufficiently regular (either the bottom and the lips do not present a geometrical singularity);
- 2) the behavior must be elastic, linear, isotropic and homogeneous;
- 3) the structure must be isothermal (or, has minimum, the variations in temperature on the lips can be neglected in the zone of interpolation).

The method used is theoretically less precise and more sensitive to the grid than the method of singular displacements [R7.02.05]. In a general way, one can advise to compare in the studies the results of POST_K1_K2_K3 and those of CALC_G [U4.82.03], which is a good indicator of the quality of the got result.

The Councils in the case fissures with a grid: the grid must be preferably quadratic and comprise sufficient nodes perpendicular to the bottom of crack. In addition, the results are clearly improved if, if the grid is composed of quadratic elements, one moves nodes mediums (edges which touch the bottom of crack), with the quarter of these edges by bringing closer them to the bottom to crack. This is made possible by the keyword MODI_MAILLE (option 'NOEUD_QUART') order MODI_MAILLAGE [U4.23.04].

Calculation by interpolation of the jumps of displacement requires to have at least 3 nodes on the normal at the bottom of crack. If the number of nodes is not sufficient, an alarm is emitted and the lines corresponding to this node of the bottom are put at 0 in table result. Calculation continues then, if necessary, for the following node of the bottom of crack. One can in this case:

- that is to say to increase the maximum curvilinear X-coordinate ABSC_CURV_MAXI to go to seek nodes further away from the bottom of crack;
- that is to say to increase the parameter PREC_VIS_A_VIS (and possibly PREC_NORM in DEFI_FOND_FISS), which comes down to being less demanding in the selection of the nodes for calculation.

The Councils in the case fissures nonwith a grid: Lprecision of the method has is sensitive to the choice of the zone of enrichment of method X-FEM (parameter RAYON_ENRI of DEFI_FISS_XFEM). In the ideal, the ray of enrichment and the maximum curvilinear X-coordinate ABSC_CURV_MAXI are about three times the size of the minimal edge of the grid.

Calculations are possible on a nonplane crack, but the user must take care that it remains sufficiently regular so that the design assumptions are valid: one should not have a geometrical singularity on the bottom or the lips. Typically, calculation is licit for an axisymmetric crack, but not for a corner.

Calculation by interpolation jumps of displacement requires to have at least 3 nodes on the normal at the bottom of crack. The number of points of interpolation is normally equal to NB_NOEUD_COUPE but can be lower in a case:

- if the geometry of the bottom and the structure is such as part of the points of interpolation leaves the matter. It is necessary in this case to reduce ABSC_CURV_MAXI (while remaining coherent with the smoothness of the grid) and/or to increase NB_NOEUD_COUPE.

Calculations are rather consuming in time and memory if there are many points on the bottom of crack. The use of the keyword NB_POINT_FOND allows to limit postprocessing to a certain number of points équi-distribute along the bottom (for example about twenty points is often sufficient).

5 Example 1: regulated grid

Circular crack in a block 3D (test SSLV134D).

```
MY = LIRE_MALLAGE ( )
```

LEVINF1, LEVINFS are the groups containing the surface meshes located on the upper lips and lower of the crack. One creates the groups of associated nodes:

```
MY = DEFI_GROUP ( GRID = MY,  
                  CREA_GROUP_NO = _F (GROUP_MA= ( ' LEVINFS ',  
                                                  ' LEVINFS ',))
```

Displacement of the nodes to the quarter of the edges:

```
MY = MODI_MALLAGE (GRID = MY, reuse = MY,  
                  MODI_MAILLE = _F (OPTION = 'NOEUD_QUART',  
                                     GROUP_MA_FOND = 'LFF1',)  
                  )
```

Calculation with MECA_STATIQUE...

```
FISS = DEFI_FOND_FISS (GRID = MY,  
                      FOND_FISS = _F ( GROUP_MA = 'LFF1',  
                                       GROUP_NO_ORIG = 'NFF1',  
                                       GROUP_NO_EXTR = 'NFF2',  
                                       ),  
                      LEVRE_SUP = _F (GROUP_MA = 'LEVINFS'),  
                      LEVRE_INF = _F (GROUP_MA = 'LEVINF1'),  
                      DTAN_ORIG = ( 1. , 0. , 0. ),  
                      DTAN_EXTR = ( 0. , 1. , 0. ),  
                      PREC_NORM = 0.1,  
                      )
```

```
TABK1K3 = POST_K1_K2_K3 ( INFO=2,  
                          FOND_FISS = FISS,  
                          RESULT = RESU1,  
                          ABSC_CURV_MAXI = 0,539,  
                          PREC_VIS_A_VIS = 0.1,  
                          )
```

6 Example 2: free grid

In 3D, if the grid is not regulated in bottom of crack, there can not be sufficient nodes on normal directions at the bottom for the interpolation. In this case, one must use the option `TYPE_MALLAGE=' LIBRE '`.

With this option, the principle of calculation is the following

- [1] determination of the normal directions at the bottom of crack for each node of the bottom,
- [2] definition on each one of these directions of `NB_NOEUD_COUPE` points, équi-distribute between the bottom and the distance `ABSC_CURV_MAXI`,
- [3] projection of the displacement of each lip on these nodes and interpolation of the jump of displacement.

The option `TYPE_MALLAGE=' LIBRE '` is not available in 2D. The only case where that could be useful is the case of the nodes not coincidents between the two lips.

Figure 6a: Free grid of the lips of the crack – Definition of the points of projection

```
TABK = POST_K1_K2_K3 ( INFO=2,  
  ABSC_CURV_MAXI TYPE_MALLAGE = 'FREE',  
  FOND_FISS = FISS,  
  RESULT = RESU_MECA,  
  ABSC_CURV_MAXI = 0,539,  
  NB_NOEUD_COUPE = 5,  
)
```