Determination of an equivalent crack from a field of Summarized

damage:

Command POST_ENDO_FISS carries out a postprocessing on result resulting from the mechanics of the continuums. The goal is to find the curve which represents crack from a field representative and the crack opening. The field can be the damage or another scalar field. As starter, the command uses a concept evol_noli or cham_gd, containing the field with post-treating. This one must be a field at nodes . In output, the command returns the mesh of crack, as well as an array containing the coordinates of the nodes of crack and the value of the opening on each node. The procedure applies to studies 2D.

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1 Introduction

the estimate of the opening of cracks are important in many industrial applications, for example the evaluating of the permeability in structures having function to guarantee the sealing.

The goal of `POST_ENDO_FISS` [U4.86.01] is to extract the opening from crack from a computation resulting from the mechanics from continuums. The command is used as a postprocessing and thus does not weigh down computation in itself. The method used is able to find the way of cracking from the card of a field (scalar) X which represents cracking, and then to determine the opening on crack.

The evaluating of the crack opening thus breaks up into two stages: initially the automatic search of the crack path, then the extraction of the opening. For the moment, the command applies to the studies 2D.

So models of damage or other lenitive constitutive laws are used for mechanical computation, it is necessary for a correct application of the command that methods of regularization are employed: that will make it possible to obtain fields distributed well on several finite elements. Also, the methods of regularization will avoid any dependence of the results to the mesh.

2 Searching for way of cracking

2.1 General information

One supposes that the crack belongs to a certain mesh group (`GROUP_MA`), on which the field X (damage, plastic strain) is defined. The crack is identified by a zone where the values of this field are especially high, and normally higher than a certain value: damage higher than 0 for example.

In the continuation, the procedure of search of the path of cracking is described. We exploit the fact that, in the orthogonal plane with crack, the field X has a maximum on crack itself. The procedure is step by step, a new point of crack is found with each step. It can be described by *the PAS-type*, its *starting* and *the stopping criteria*.

2.2 PAS-type

With each stage, the search requires two points. The last found point P_i is *the starting point* and the vector $\overrightarrow{P_{i-1}P_i}$ (P_{i-1} being the not found last but one) gives *the direction of search*.

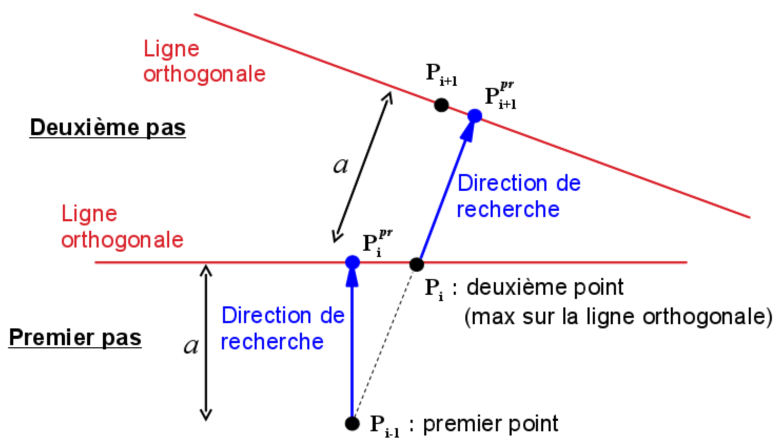

Figure 1: diagram of the PAS-type

A each PAS-type, the following actions are carried out (see also the diagram of Figure 1):

1. the position of the following point is initially estimated (*not of prediction* P_i^{pr}) with the distance a from the starting point in the direction of search, a being *the step of advance;*
2. the champest X project on line orthogonal with the direction of search and passing by the point of prediction;
3. the field project is smoothed by convolution (**éq 2.2-1**) to be freed partially of the mesh (for example, if one leans on of the finite elements with linear interpolation, the field project is linear per pieces);
4. the new point of the fissureest P_{i+1} that where the smoothed field reached its maximum value.

The lissage evoked as in point 4 is necessary: for example, if the field project on the orthogonal profile is linear per pieces, its maximum is forcing on the edge of an element. The lissage is achieved by convolution:

$$\overline{X}(s)=\frac{\int_{l_{orth}} X(\zeta)\Psi(|\zeta-s|)d\zeta}{\int_{l_{orth}} \Psi(|\zeta-s|)d\zeta}$$ **éq 2.2-1**

where $\overline{X}$ is the smoothed field, l_{orth} is the length of line orthogonal with the direction of search, s is the curvilinear abscisse on this line etest Ψ a function of Gauss:

$$\Psi(|\zeta-s|)=\exp\left(-\left(\frac{2(\zeta-s)}{l_{reg}}\right)^2\right)$$ **éq 2.2-2**

an example of the fields X and $\overline{X}$ according to the parameter l_{reg} is given in Figure 2.

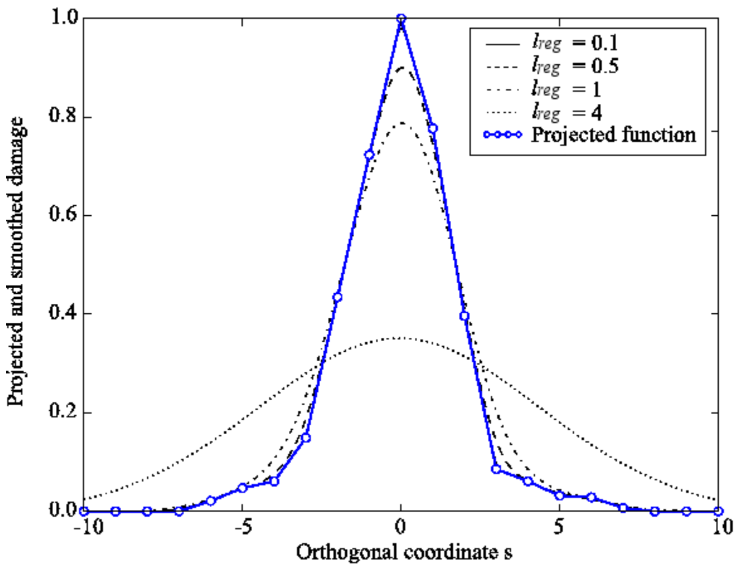

Figure 2: Lissage of the field X project on the line orthogonal one.

An additional parameter is given by the number of points on the line orthogonal one, N_{orth} . That determines the accuracy of the discrete product of convolution, as well as the accuracy $\delta_{orth}=l_{orth}/N_{orth}$ (distance between the points).
The discrete convolution is carried out E by the function *convolve* of the library python *numpy* . The function S $X(s)$ and $\Psi(s)$ are sample ée S on l_{orth} at the constant distance δ_{orth} . By calling $\mathbf{X}$, $\boldsymbol{\Psi}$ the two sampled vectors, the point $\overline{X}_j$ vector $\overline{\mathbf{X}}$ which approximates by points the smoothed function $\overline{X}(s)$ will be given by:

$$\overline{X}_j = \frac{\sum_i \Psi_i X_{i+j}}{\sum_i \Psi_i} \quad \text{éq 2.2-3}$$

2.3 Initialization

the goal of the initialization is to obtain the first two points, to continue as described afterwards in the PAS-type. A diagram of the procedure of initialization is given in Figure 3 :

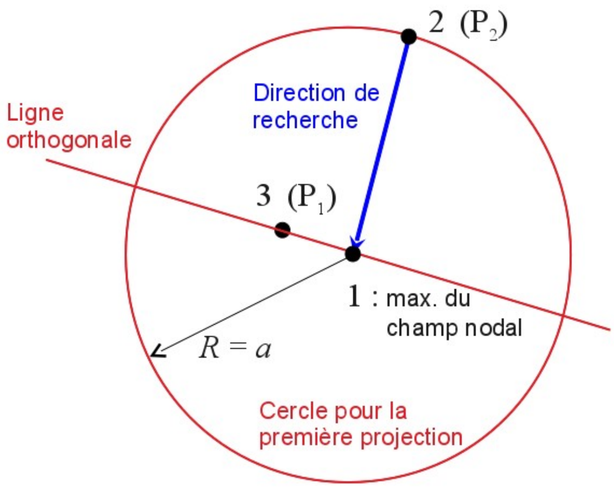

Figure 3: diagram of the procedure of initialization.

In detail:

1) the field X is project on a circle of radius a and center on the node 1 where the field with the node has its maximum on `the GROUP_MA` selected;
2) the field X is smoothed on the circle via discrete product of convolution (**éq. 2.2-3**), the second point of crack P_2 is the point of the circle where $\overline{X}$ is maximum;
3) one corrects the position of the point 1 by projection and lissage of the field $\overline{X}$ on line orthogonal with $\overrightarrow{P_2 1}$ and passing by P_2 : the new point $3 = P_1$ is found;
4) two possible directions of search are thus determined: $\overrightarrow{P_1 P_2}$ and $\overrightarrow{P_2 P_1}$.

2.4 Stopping criteria

the search of the path of cracking is accomplished in the two directions $\overrightarrow{P_1 P_2}$ and $\overrightarrow{P_2 P_1}$ until stop, in one of the following cases:

- the value of the field corresponding to the new point is lower than a threshold value, a priori definite. This value must be indicated among the parameters of the command under operand `BORNE_MIN` of factor key word `the SEARCH`.
- the point of prediction is apart from the matter.

2.5 Fields for the search of the way of cracking

the described method can be applied to all scalar fields which represent the cracking of the materials. Typically, it is the damage d which can be used.

It happens sometimes that the field of damage is too “flat”, and that he presents to fracture a plate with $d=1$. As there would not be then a well defined maximum, procedure described in paragraphs 2.2 - 2.3 could not give the desired results. It is the case for example damage models regularized in deformation gradient [R5.04.02]. One can then choose other relevant fields: a component of principal strain, an equivalent strain…

An example of choice of the relevant field is given by the zzzz264b benchmarks, C [V1.01.264].

3 Crack opening

the opening of crack is found by difference of déplacementformule DN in the normal direction with the way of cracking, between two points P_g, P_d this norm.

It is then necessary to determine:

- line normal with way of cracking (taking into account the fact that the crack is known in a discrete way by points),
- the pace of displacements on this line, in particular the component of displacement in the same direction,
- the coordinates of the two points P_g, P_d to operate the difference in displacement DN .

The norm is given on each node of crack like the bisectrix of the angle formed by the two norms with the segments which have the joint node (see Figure 4).

Once the norm n given on a node of the way of cracking, one carries out a change of reference on the field of displacements, of the total reference to the reference (n,t) (t is the tangent vector), in particular the component DN is calculated.

The points P_g, P_d are those for which the following relation is satisfied: $X\geqslant$ BORNE_MAX (BORNE_MAX is a parameter with informing like operand under the key word SEARCHES). The projection of the field $X\geqslant$ on the line normal one with the way is thus necessary to the determination of P_g, P_d (see Figure 5).
Normally for the damage models, the value $X=d=0.8$ is sufficient to collect the jump of displacement (see [V1.01.264]).

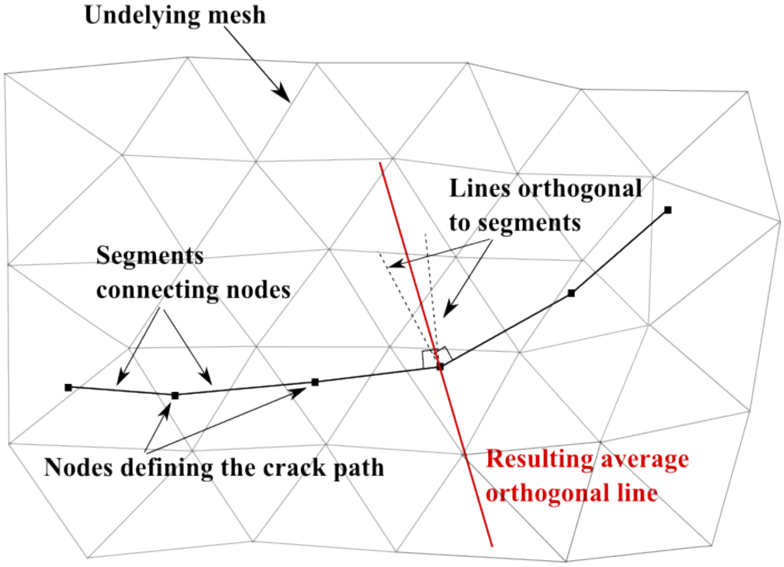

Figure 4: average norm with the way of cracking for the computation of the crack opening.

4 Features and validation

4.1 the Councils for the use of the parameters

In short, for the search of **the way of cracking** the parameters necessary are:

• l_{orth} (LONG_ORTH)
• l_{reg} (LONG_REG)
• a (NOT)
• N_{orth} (NB_POINT)
•BORNE_MIN

with informing under factor key word the SEARCH. The beach of advised use is the following one:

• l_{orth} to be higher or equal to the damaged bandwidth, from the good performances is already obtained by adopting twice this width;
• l_{reg} can be in the interval $0.5\Delta\leqslant l_{reg}\leqslant 2\Delta$, Δ the size of the finite elements in the damaged zones (compromised between a sufficient lissage and the risk to lose too much information of the profile of damage not smoothed);
• a of the curvature of the way and of how much points the user wishes to describe crack, as an indication one can also take it in an interval $0.5\Delta\leqslant a\leqslant 2\Delta$;
•the choice N_{orth} to guarantee at least 10 points per finite element;
•BORNE_MIN is the value of the field for which the search is stopped in a direction; in the case of the damage one takes values >0.5 to be sure that the crack is well formed.

Concerning the computation of the opening fissures, parameter BORNE_M AX must be lower than 0.8, S I the field X is the damage.

4.2 Validation

the command is validated by the zzzz264 benchmark [V1.01.264].

In the modelization A one searches a way of cracking and one compares it with an analytical way.

In the modelization B, C, one searches the way of cracking and the opening on result mechanical, obtained by means of damage models of *Code_Aster* .

5 Description of the versions of the document

Version Aster	Author (S) Organization (S)	Description of the modifications
11.2	Mr. BOTTONI	initial Text