Determination of an equivalent crack starting from a field of damage

Summary:

The order POST_ENDO_FISS carry out a postprocessing on a result resulting from the mechanics of the continuous mediums. The goal is to find the curve which represents the crack starting from a field representative and the opening of crack. The field can be the damage or another scalar field. As starter, the order uses a concept evol_noli or cham_gd, containing the field post-to be treated. This one must be a field with nodes. At exit, the order returns the grid of the crack, as well as a table containing the coordinates of nodes crack and the value of the opening on each node. The procedure applies to studies 2D.

Contents

1 Introduction

The estimate of the opening of the cracks is important in many industrial applications, for example the evaluation 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 starting from a calculation resulting from mechanics from continuous mediums. The order is used as a postprocessing and thus does not weigh down calculation in itself. The method used is able to find the way of cracking starting from the map of a field (scalar) X who represents cracking, and then to determine the opening on the crack.

The evaluation of the opening of crack thus breaks up into two stages: initially the automatic research of the way of crack, then the extraction of the opening. For the moment, the order applies to the studies 2D.

So models of damage or other lenitive laws of behavior are used for mechanical calculation, it is necessary for a correct application of the order 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 grid.

2 Research of the way of cracking

2.1 General information

It is supposed that the crack belongs to a certain group of meshs (GROUP_MA), on which the field X (damage, plastic deformation) 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 research of the way of cracking is described. We exploit the fact that, in the orthogonal plan with the crack, the field X a maximum on the crack itself has. The procedure is step by step, a new point of the crack is found with each step. It can be described by *pas-standard*, by sound *starting* and by *criteria of stop*.

2.2 Pas- standard

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

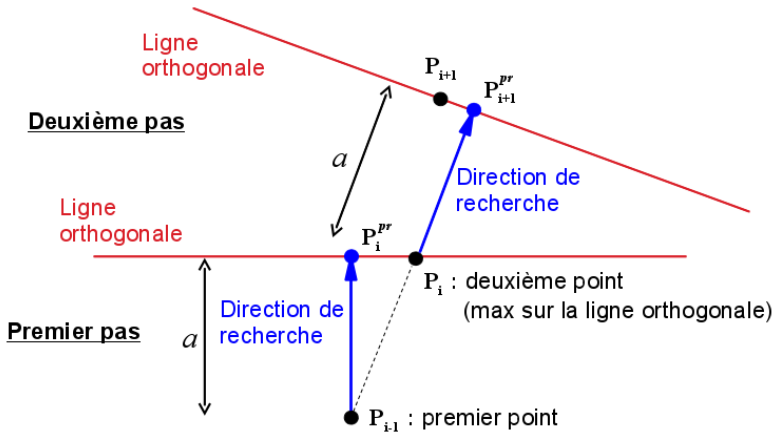

Figure 1: diagram of the not-type

With each not-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 prediction* P_i^{pr}) at the distance a starting point in the direction of research, a being it *pas d' advance;*
2. the field X is project on an orthogonal line with the direction of research and passing by the point of prediction;
3. the field project is smoothed by convolution (**éq 2.2-1**) to free itself partially of the grid (for example, if one is pressed on finite elements with linear interpolation, the field project is linear per pieces);
4. the new point of the crack P_{i+1} is that where the smoothed field reached its maximum value.

The smoothing evoked at the point 3 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. Smoothing is achieved by convolution:

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

where $\overline{X}$ is the smoothed field, l_{orth} is the length of the orthogonal line to the direction of research, s is the curvilinear X-coordinate on this line and Ψ is a function of Gauss:

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

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

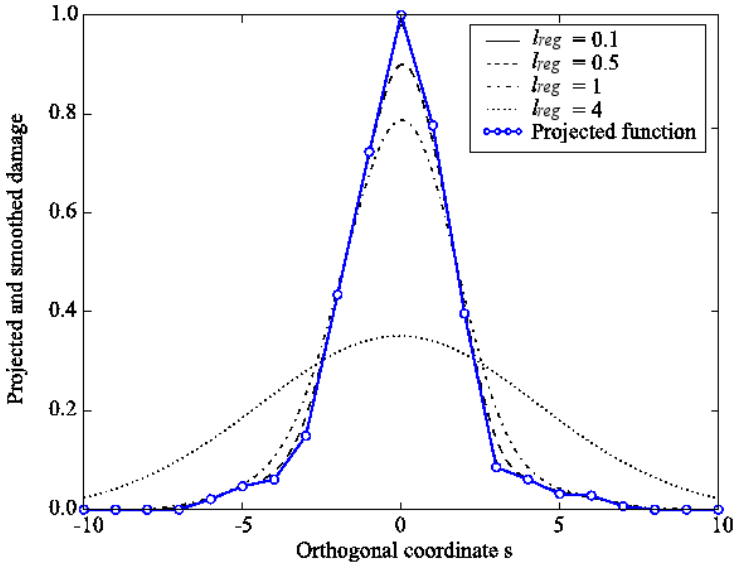

Figure 2: Smoothing of the field X project on the orthogonal line.

An additional parameter is given by the number of points on the orthogonal line, N_{orth} . That determines the precision of the discrete product of convolution, as well as the precision $\delta_{orth}=l_{orth}/N_{orth}$ (distance enters the points).
The discrete convolution is carried out E by the function *convolve* bookstore python *numpy* . The function S $X(s)$ and $\Psi(s)$ are sample ée S on l_{orth} at the constant distance δ_{orth} . While calling

$\mathbf{X}$, $\mathbf{\Psi}$ two sampled vectors, the point $\overline{X}_j$ vector $\overline{\mathbf{X}}$ who approximates by points the smoothed function $\overline{X}(s)$ will be given by:

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

2.3 Initialization

The goal of initialization is to obtain the first two points, to continue as described afterwards in the not-type. A diagram of the procedure of initialization is given in Figure 3 :

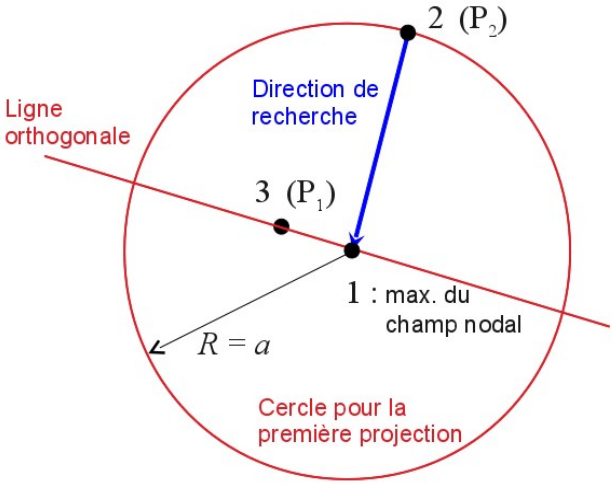

Figure 3: diagram of the procedure of initialization.

In detail:

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

2.4 Criteria of stop

The research of the way 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 order under the operand BORNE_MIN keyword factor RESEARCH.
- the point of prediction is apart from the matter.

2.5 Fields for the research of the way of cracking

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

It happens sometimes that the field of damage is too “flat”, and that he presents to rupture 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. One can then choose other relevant fields: a component of principal deformation, an equivalent deformation…

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

3 Opening of crack

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

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),
- pace of displacements on this line, in particular the component of displacement in the same direction,
- coordinates of the two points P_g, P_d to operate the difference in displacement DN .

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

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

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

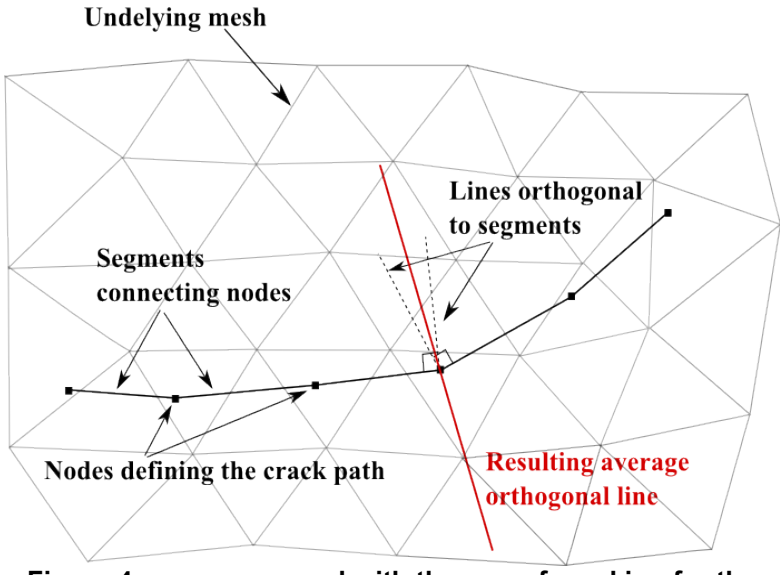

Figure 4: average normal with the way of cracking for the calculation of the opening of crack.

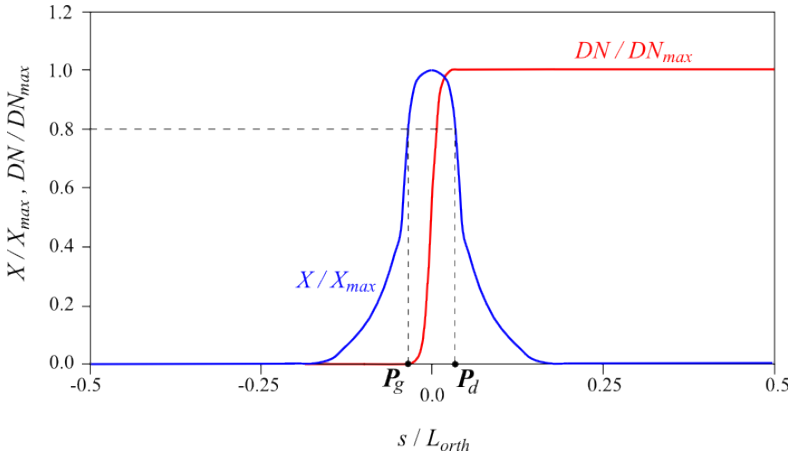

Figure 5 : Projection of displacement DN and field X on the normal with the way of the crack (standardized values); determination of P_g, P_d .

4 Features and validation

4.1 The Councils for the use of the parameters

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

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

to inform under the keyword factor RESEARCH. The beach of advised use is the following one:

- l_{orth} must be higher or equal to the damaged bandwidth, from the good performances are already obtained by adopting twice this width;
- l_{reg} can be in the interval $0.5\Delta \leqslant l_{reg} \leqslant 2\Delta$, Δ being size of the finite elements in the damaged zones (compromised between a sufficient smoothing and the risk to lose too much information of the profile of damage not smoothed);
- a depends on the curve of the way and of how much points the user wishes to describe the crack, as an indication one can also take it in an interval $0.5\Delta \leqslant a \leqslant 2\Delta$;
- the choice of N_{orth} must guarantee at least 10 points per finite element;
- BORNE_MIN is the value of the field for which research 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 calculation of the opening fissures, the parameter BORNE_M AX must be lower than 0.8, S I the field X is the damage.

4.2 Validation

The order is validated by the CAS-test zzzz264 [V1.01.264].

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

In modeling B, C, one searches the way of cracking and the opening on a mechanical result, got by using laws of damage 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