DESCRIPTION OF TEST CASES FOR THE BENCHMARK OF CODE_ASTER/MOFEM IN CRACK PROPAGATION

This document describes the proposed test cases to benchmark the capabilities and robustness of crack propagation tools in graphite bricks in response to EDF Generation's need. Full 3D crack propagation will be investigated.

Three test cases are as follows:

- test case 1: loading on a slice of brick with slot;
- test case 2: loading on a full-size brick with slot;
- test case 3: loading on a full-size brick with partial length keyways.

These test cases have been identified to benchmark three methods:

- crack propagation in Code_Aster using X-FEM;
- crack propagation in Code_Aster using ZCracks;
- crack propagation in MoFEM using configurational forces.

For each test case, the reference case is presented. In the next section, some propositions are given to study the effect of varying user-selected input parameters on the capabilities and robustness of crack propagation tools. Other values of these parameters or other parameters can be proposed and calculated by Code_Aster and MoFEM for a better understanding of the capabilities of each tool.

1. TEST CASE 1

LOADING ON A SLICE OF BRICK WITH SLOT

In order to simulate the post stress reversal configuration with non-irradiated graphite, one solution was to slot the brick and externally submit it to a traction compression field.

1.1. Geometry

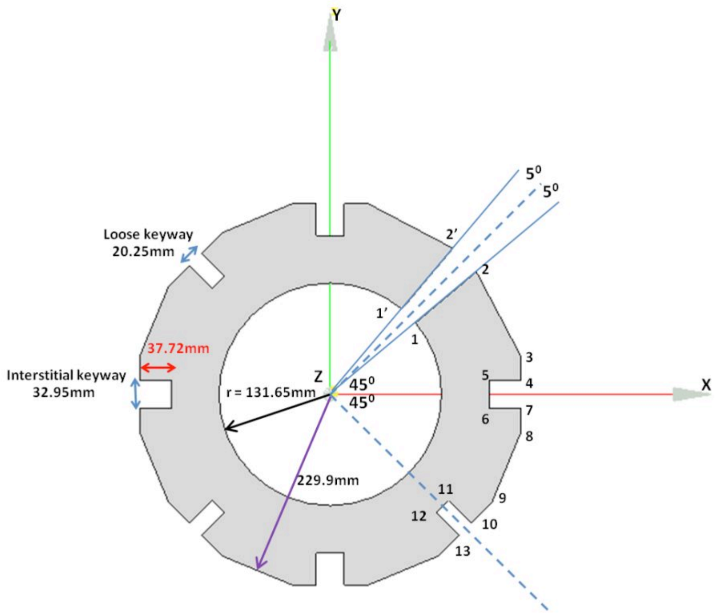

Figure 1.1

Point	X(m)	Y(m)
1	0.100850	0.084623
2	0.179564	0.150672
3	0.229900	0.045730
4	0.229900	0.016475
5	0.192180	0.016475
6	0.192180	-0.016475
7	0.229900	-0.016475
8	0.229900	-0.045730
9	0.194900	-0.130228
10	0.169723	-0.155404
11	0.143051	-0.128732
12	0.128732	-0.143051
13	0.155404	-0.169723

Table 1.1

The brick slice is 100 mm thick. Its inner radius is 131.65 mm. Its outer profile is a regular 16-sided polygon and the perpendicular distance from the centre to an edge is 229.90 mm. The width of the interstitial keyways is 32.95 mm and the width of the loose keyways is 20.25 mm. All keyways have the same depth of 37.72 mm. The slot is in the place of a loose keyway and the slot angle is 10^0. The origin of the coordinate system is at the centre of the brick, the *z* axis represents the height (positive up, z = 0 at the bottom of the brick).

1.2. Loading and boundary conditions

The forces are perpendicular to the surface of application. They have the same intensity. During the analysis, the proportion must be kept, but the value may be adapted (using arc-length control for example).

Node	FX	FY
1’	-0.766	0.643
2’	0.766	-0.643

Table 1.2

The embedded surface is marked in red colour in Figure 1.2 (DX=DY=DZ=0).

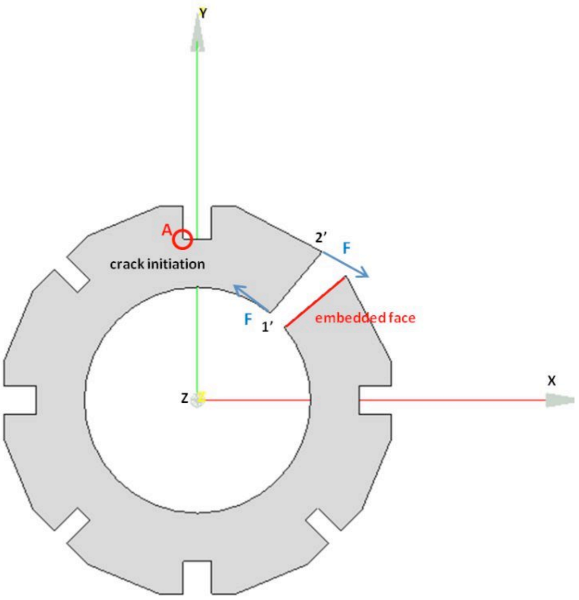

Figure 1.2

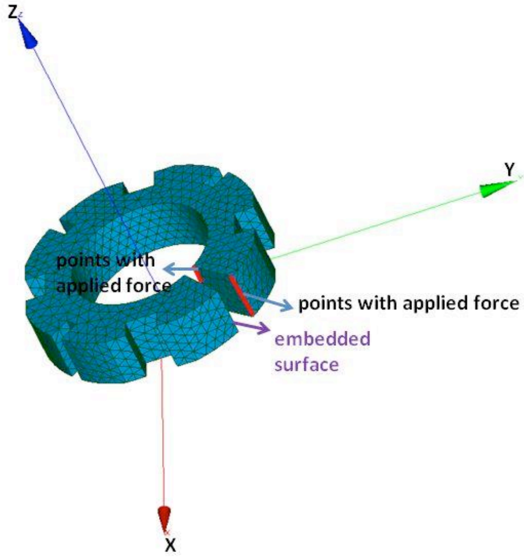

Figure 1.3

1.3. Material properties

- Young's Modulus: E = 9600 MPa
- Poisson's ratio: 0.2
- $G_c = 140 J/m^2$

1.4. Initial crack

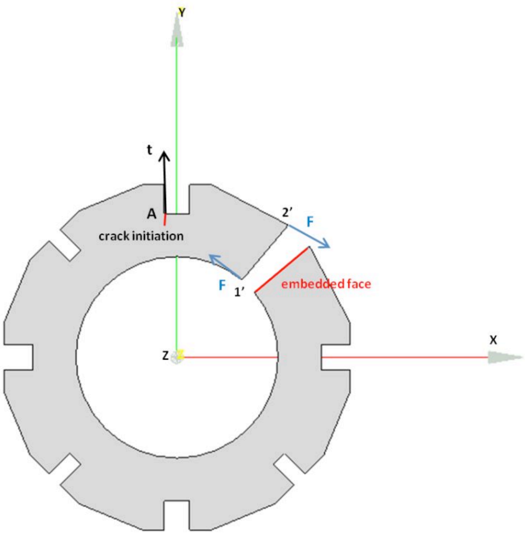

Figure 1.4

Figure 1.5

Crack initiates at point A (-0.016475; 0.192180; 0) in the keyway corner of the bottom part of the brick slice with a 180 degree angle from the At axis. Its initial shape is a quadrant of a circle of radius 10mm centred at point A.

2. TEST CASE 2
LOADING ON A FULL-SIZE BRICK WITH SLOT

The test case 2 has the same properties and conditions as the ones of the test case 1, but the height of the brick is 825 mm.

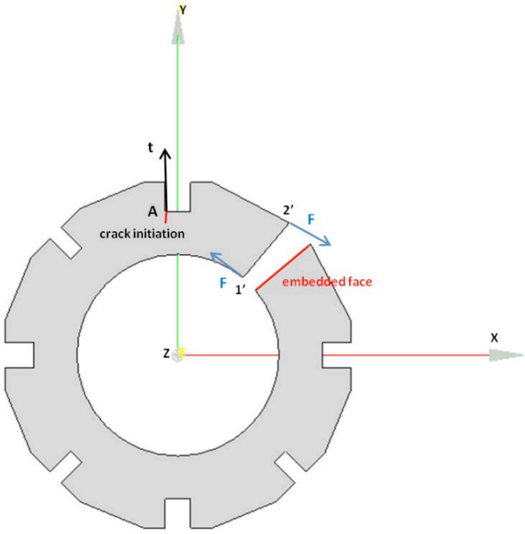

Figure 2.1

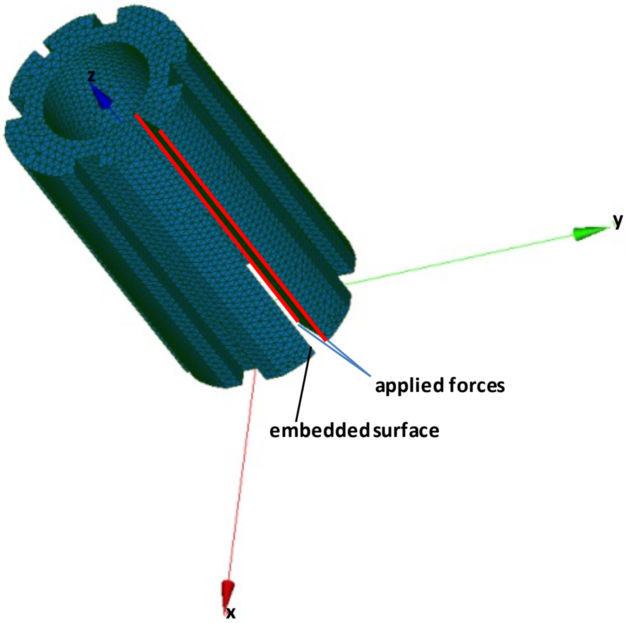

Figure 2.2

3. TEST CASE 3
LOADING ON A FULL-SIZE BRICK WITH PARTIAL LENGTH KEYWAYS

3.1. Geometry

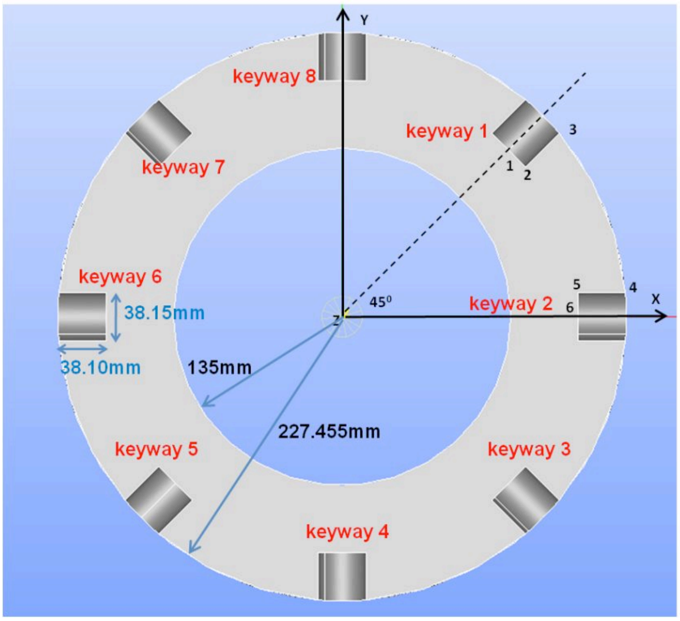

Figure 3.1 (Top part of the brick)

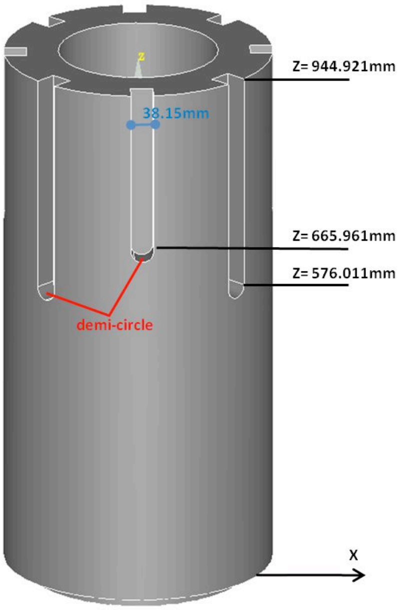

Figure 3.2

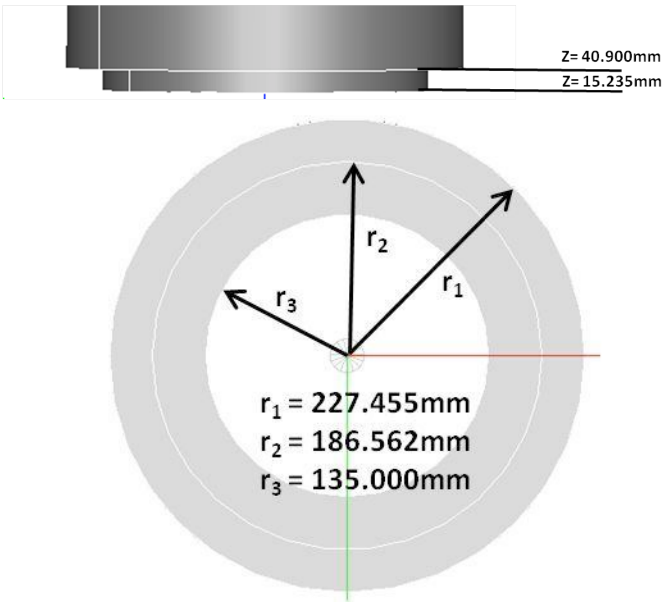

Figure 3.3 (Bottom part of the brick)

Point	X(m)	Y(m)	Z(m)
1	0.133328	0.133328	0.944921
2	0.146816	0.119840	0.944921
3	0.173756	0.146780	0.944921
4	0.226654	0.019075	0.944921
5	0.188554	0.019075	0.944921
6	0.188554	0	0.944921

Table 3.1

The height of the brick is 929.686 mm. The top part of the brick has an inner radius of 135 mm and an outer radius of 227.455 mm. The bottom part of the brick has the dimensions as indicated in Figure 3.3. All keyways have the same depth of 38.10 mm and the same width of 38.15 mm. 4 keyways (keyway 1, 3, 5, 7) have the total length of 387.985 mm and 4 others (keyway 2, 4, 6, 8) have the total length of 298.035 mm. The origin of the coordinate system is at the centre of the brick, the *z* axis represents the height (positive up, z = 0 at the bottom of the brick).

3.2. Loading and boundary conditions

The forces are perpendicular to the surface of application. They have the different intensity. During the analysis, the proportion must be kept, but the value may be adapted (using arc-length control for example).

Force	FX	FY
1	3.2	2.8
2	-1.1	-1.4

Table 3.2

The embedded surfaces are marked in red colour in Figure 3.4 (DX=DY=DZ=0).

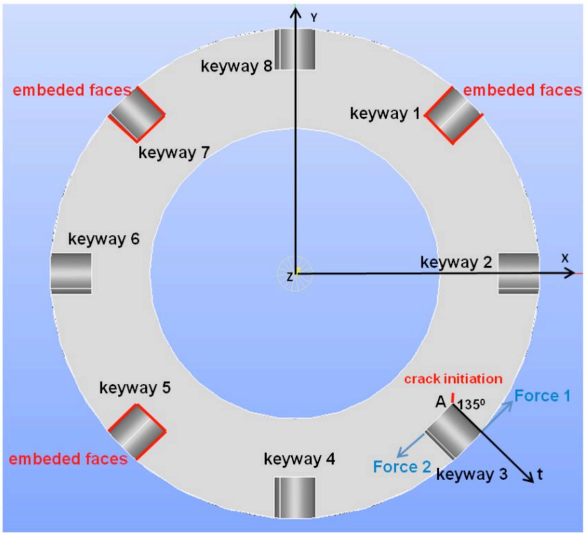

Figure 3.4

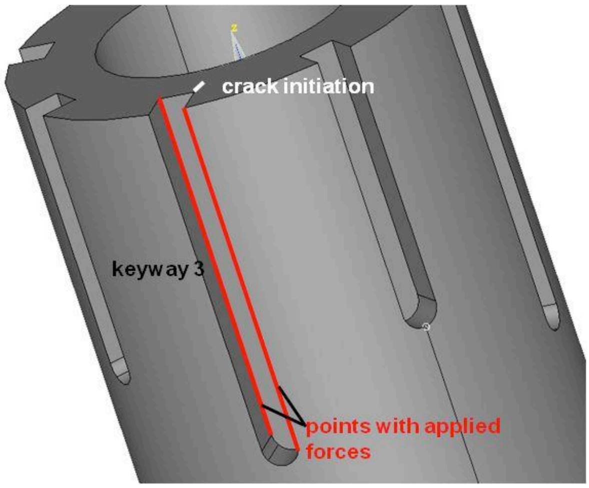

Figure 3.5

3.3. Material properties

- Young's Modulus: E = 9600 MPa
- Poisson's ratio: 0.2
- $G_c = 140 J/m^2$

3.4. Initial crack

Crack initiates at point A (0.146816; -0.11984; 0.944921) in the keyway corner of the top part of the brick with a 135 degree angle from the At axis. Its initial shape is a quadrant of a circle of radius 10mm centred at point A.

STUDY OF THE EFFECT OF INPUT PARAMETER FOR EACH TEST

The description of the test cases of the benchmark is given for a reference initial crack path. However it must be noted that:

- If, for any reason, the proposed initial crack shape does not enable to have interesting results for the method considered, it is possible to slightly alter the initial crack shape. The reason why it has been changed must be explained.
- In any case, it would be interesting to test the variability of the results depending on the initial crack shape. Mesh sensitivity may also be tested as well as sensitivity to user parameters (if any).
- Results may vary as well depending on the parameters (mesh, size, order of the elements, method of calculation, propagation criteria, …). A variability study would therefore be appreciated.

Important note: for MoFEM, it would be interesting to concentrate most of the work on second order elements. The use of higher order elements to demonstrate the increase in accuracy may also be considered.

OUTPUT OF INTEREST FOR EACH TEST CASE

1. Robustness (successively updates in a typical time step the history field, the crack phase field and finally the displacement field; accurate results are obtained in all cases).
2. Evolution of crack path (position of crack front for every step of calculation with coordinates of different points on the crack front).
3. Capacity of full propagation (full separation of the specimen).
4. Computational time required (with computer information, parallel computing or not, ...)
5. Load displacement curves.

DEADLINES AND REPORTS

For each method, a report describing the results for the reference configuration of each test case should be delivered. It may contain an alternative solution if the suggested crack shape does not provide any result of interest. It may contain as well a sensitivity study. This report should be delivered to all partners before 31st July 2015.