Note of use on the choice of the finite elements

Summary:

The purpose of this document is to give some information about the choice of the finite elements and their modeling associated in the case of studies thermal, thermomechanical or mechanical non-linear. It acts to some extent, to propose to the user a choice a priori, making it possible to avoid certain current errors. In the event of particular difficulties, other choices could be made.

1 Introduction

One gives in this document the choices a priori which can be made concerning the finite elements. One placed in the case of a thermomechanical chaining but the advices are valid on thermal or mechanical not chained calculations (linear or not). A fast justification is given. For more details on the justification of these choices, the user will be able to refer to the reference documents of *Code_Aster* like with the note [bib1].

2 Choice a priori

2.1 Grid

The elements can be indifferently:

- triangular elements or quadrangles in 2D,
- tetrahedrons or hexahedrons in 3D.

Indeed, contrary to the often spread idea, the elements of type triangle or tetrahedron give good performances, even in plasticity, **in condition of course of not using a too coarse grid**. One can also use the software LOBSTER which carries out the adaptation of grids 2D/3D for finite elements of type triangular, quadrangular, tetrahedral or hexahedral by refinement and déraffinement. One can thus obtain the optimum grid according to an indicator of error (cf [R4.10.01], [R4.10.02], [R4.10.03], or the case test TPLL01j [V4.02.01] for a demonstration) by call to the order `MACR_ADAP_MAIL` in the command file *Code_Aster*.

On the other hand, it is advised to use:

- linear elements in thermics for chained calculations and calculations of fast transitory thermics. For the other cases, one can also choose quadratic elements,
- quadratic elements in mechanics.

This choice is all the more important when one carries out thermal chained calculations then mechanical. It is then necessary to use two different grids for thermics and mechanics. Two strategies are then possible:

- that is to say independently to net the structure for thermal calculation and mechanical calculation
- that is to say to carry out a grid with linear elements then to transform it into quadratic grid thanks to the order `CREA_MAILLAGE`, keyword factor `LINE_QUAD`.

Whatever the method chosen, one can optimize each grid separately with *Lobster* thanks to the thermal and mechanical indicators of error available in Aster (cf CAS-test forma05b [V6.03.120]).

Note:

It is pointed out here that all the sizes of the type forced or deformation are calculated at the points of Gauss, and that any passage to the nodes involves a skew. That is all the more true when one then seeks to calculate standards; we thus noticed that the tetrahedrons were more sensitive than the hexahedrons to the method of calculating of the equivalent constraints for example. It is thus necessary to have an eye even more critical on the results calculated with the nodes.

2.2 Modeling

That it is for the resolution of the thermal or mechanical problems, several modelings are available in *Code_Aster*. These various modelings can be characterized by the number or it type of degrees of freedom, the number of points of integration, the particular treatments… According to calculation carried out, some of course are adapted than of others.

2.2.1 In thermics

To do a thermal calculation with *Code_Aster*, two types of modelings are accessible ([U3.23.01], [U3.24.01], [R3.06.02], [R3.06.07]):

- classical finite elements: modeling `3D`, `AXIS` or `PLAN`
- finite elements lumpés or diagonalized: modeling `3D_DIAG`, `AXIS_DIAG` or `PLAN_DIAG`

We propose like by default choice:

modeling with linear elements

Justification

In thermics, the step of time Δt cannot be unspecified, it must check a condition $\Delta t_{min} < \Delta t < \Delta t_{max}$, Δt_{min} and Δt_{max} depending on the properties materials, size of the finite elements and parameters of temporal integration (cf [R3.06.07]).

In the case of fast transitory problems of thermics, one can have to use a step of too small time. One can then observe oscillations of the solution and nonphysical temperatures due to the violation of the principle of the maximum (higher temperature at the initial temperature of a part which one cools). Modeling `DIAG`, which consists with diagonaliser the matrix of mass, allows to free itself from the condition on Δt_{min} and to avoid the associated problems.

Let us note however that this diagonalisation is not enough to remove the oscillations in all the configurations (cf [R3.06.07]). It does not guarantee the not-oscillation with the quadratic elements for example. This is why the linear elements are advised.

2.2.2 In mechanics

Four types of modelings are available to solve problems of non-linear mechanics using of the “classical” laws of behavior (of standard elastoplasticity):

- isoparametric classical finite elements: `3D`, `D_PLAN`, `C_PLAN`, `AXIS` ([U3.14.01], [U3.13.01]),
- under-integrated elements: `3D_SI`, `D_PLAN_SI`, `C_PLAN_SI`, `AXIS_SI` ([U3.14.01], [U3.13.05]),
- elements being based on an quasi-incompressible formulation with 3 fields (displacement, swelling, pressure): `3D_INCO_UPG`, `D_PLAN_INCO_UPG`, `AXIS_INCO_UPG` ([U3.14.06], [U3.13.07], [R3.06.08]),
- elements being based on an incompressible formulation with 2 fields (displacement, pressure): `3D_INCO_UP` , `D_PLAN_INCO_UP` and `AXIS_INCO_UP` for the small deformations and the great deformations (`GDEF_LOG`).

We propose like choice a priori to use:

quadratic elements

With regard to the choice of modeling, it is function of the type of elements and the need to treat the condition of incompressibility. These considerations are summarized in the table below.

	normal	quasi-incompressible (strong plasticity or $\nu > 0.45$)
triangles/tetrahedrons	**standard**	`INCO`
quadrilaterals/hexahedrons	`IF`	`IF` or `INCO`

Justifications and precautions:

- If the material is quasi-incompressible ($\nu > 0{,}45$), it is preferable to use one of the formulations INCO, because the standard formulation in displacement does not give good performances.
- The plastic flow is done with constant volume. This condition of incompressibility can cause difficulties with classical modeling of knowing a too rigid behavior and especially the appearance of oscillations on the level as of constraints. Under-integration makes it possible to improve these problems, because one then checks the condition of incompressibility in less than points of Gauss. However, **only elements QUAD8 and HEXA20 under - are really integrated,** for the other meshs, it is the classical integration which is preserved. Consequently, when phenomena of oscillations are observed for a grid made up of triangles or tetrahedrons, it is preferable to use one of the formulations INCO. This improves the result clearly but calculations will be longer.
- In the case general, under-integrated modeling gives also good performances which classical finite elements, and this for a faster computing time since one uses less points of Gauss. In the case of thermomechanical calculations, that makes it possible to limit the difficulties at the time of the passage of the thermal deformation of origin to mechanical calculation when refinements of the grids thermics and mechanics differ. However, under-integration can sometimes lead to the appearance of parasitic modes. So at the conclusion of calculation the deformation presents this kind of nonphysical modes of deformation, it is to better calculate with classical or quasi-incompressible modeling if the levels of plasticity are very important.

3 Implementation *Code_Aster*

Here the principal stages of calculation are pointed out *Aster* in the case of a calculation in plane deformations, while specifying explicitly where the specifications intervene about which one spoke. For the mechanical part, one wrote in fat what is specific to the case of a thermomechanical calculation.

3.1 Thermal study

- Reading of the thermal grid

```
MA=LIRE_MAILLAGE (UNITE=20,)
```

- Choice of the thermal model

```
MOTH2D=AFFE_MODELE (MAILLAGE=MA,
                    VERIF=' MAILLE',
                    AFFE=_F (GROUP_MA= ('GMA1', 'GMA2',…),
                            PHENOMENE=' THERMIQUE',
                            MODELISATION=' PLAN_DIAG',),)
```

- Thermal properties of material
- Thermal loading
- THER_LINEAIRE or THER_NON_LINE
  THER =…

- Possible postprocessings

3.2 Mechanical study

- Mechanical reading grid

```
MAME=LIRE_MAILLAGE ()
```

```
MAME=CRÉA_MAILLAGE (
    GRID = MY,
LINE_QUAD=_F (TOUT=' OUI'))
```

- Definition of the mechanical model

```
MOME=AFFE_MODELE (MAILLAGE=MAME,
                  VERIF=' MAILLE',
                  AFFE=_F (GROUP_MA= ('GMA1', 'GMA2',…),
                           PHENOMENE=' MECANIQUE',
                           MODELISATION=' D_PLAN_SI',),);
```

- Projection of thermal calculation if calculation chained on 2 different grids

```
CHTHER=PROJ_CHAMP (METHODE=' COLLOCATION',
                   RESULTAT=THER,
                   MODELE_1=MOTH2D,
                   MODELE_2=MOME,);
```

- Characteristics of material

```
CHMAT = AFFE_MATERIAU (GRID = MAME,
              AFFE_VARC = _F (NOM_VARC=' TEMP',
                              TEMP_REF = 20. ,
                              EVOL=CHTER or THER if not projection …)
```

- Mechanical loadings
- `STAT_NON_LINE`
- Postprocessings

4 Bibliography

1) S. MICHEL-PONNELLE, A. RAZAKANAIVO: Quality of the Studies in Mechanics of the Solids: study of the finite elements. Note EDF HT-64/02/007/B