Note of use on the choice of the Résumé

finite elements:

The purpose of this document is giving some information on the choice of the finite elements and their modelization associated in the case of studies thermal, thermomechanical or mechanical nonlinear. 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 sequence but the advices are valid on thermal or mechanical not chained computations (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 to the note [bib1].

2 Choices a priori

2.1 the mesh

Les 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, **with condition of course not using a too coarse mesh**. One can also use the software HOMARD which carries out mesh adaptation 2D/3D for finite elements of type the triangular, quadrangular, tetrahedral or hexahedral by refinement and coarsening. One can thus obtain the optimum mesh 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 command `MACR_ADAP_MAIL` in the command file *Code_Aster*.

On the other hand, it is advised to use:

- linear elements in thermal for chained computations and computations of fast transient thermal. 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 computations then mechanical. It is then necessary to use two different meshes for the thermal and the mechanics. Two strategies are then possible:

- either independently net structure for thermal computation and mechanical computation
- or carry out a mesh with linear elements then to transform it into quadratic mesh thanks to the command `CREA_MAILLAGE`, key word factor `LINE_QUAD`.

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

Note:

It is reminded the meeting here that all the quantities of the type forced or strain are computed at the Gauss points, and that any transition with the nodes involves a skew. That is all the more true when one seeks then with compute of the norms; we thus noticed that the tetrahedrons were more sensitive than the hexahedrons to the method of calculating of the equivalent stresses for example. It is thus necessary to have an eye even more critical on the results computed with the nodes.

2.2 The modelization

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

2.2.1 In Pour

thermal to make a thermal computation with *Code_Aster*, two types of modelizations are accessible ([U3.23.01], [U3.24.01], [R3.06.02], [R3.06.07]):

- conventional finite elements: modelization `3D`, `AXIS` or `PLANE`
- lumped or diagonalized finite elements: modelization `3D_DIAG, AXIS_DIAG` or `PLAN_DIAG`

Nous let us propose like choice by defect:

modelization with linear elements

Justification

In thermal, the pitch of tempsne Δt can be unspecified, it must check a condition $\Delta t_{min} < \Delta t < \Delta t_{max}$, Δt_{min} and Δt_{max} depend 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 thermal, one can have to use a too small time step. One can then observe oscillations of the solution and nonphysical temperatures due to the violation of the principle of the maximum (higher temperature to the initial temperature of a part which one cools). The modelization `DIAG`, which consists with diagonalise the mass matrix, makes it possible to be freed from the condition on Δt_{min} and to avoid the associated problems.

Let us note however that this diagonalization 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

Quatre types of modelizations are available to solve problems of nonlinear mechanics using of the “conventional” constitutive laws (standard elastoplasticity):

- isoparametric conventional finite elements: `under-integrated 3D, D_PLAN, C_PLAN,` AXIS ([U3.14.01], [U3.13.01])
- , elements: `3D SI, D_PLAN_SI, C_PLAN_SI, AXIS_SI` ([U3.14.01], [U3.13.05]),
- elements lean on an quasi-incompressible formulation at 3 fields (displacement, swelling, pressure) : `3D_INCO, D_PLAN_INCO, AXIS_INCO` for the small strains, `3D_INCO_GD, D_PLAN_INCO_GD, AXIS_INCO_GD` for the large deformation with the formalism of `SIMO_MIEHE` and `3D_INCO_LOG, D_PLAN_INCO_LOG` and `AXIS_INCO_LOG` for the large deformation with the formalism of `GDEF_LOG` ([U3.14.06], [U3.13.07], [R3.06.08]),
- elements lean on an incompressible formulation at 2 fields (displacement, pressure): `3D_INCO_UP` , `D_PLAN_INCO_UP` and `AXIS_INCO_UP` for the small strains,

Nous let us propose like choice a priori to use:

quadratic elements

En ce qui concerne the choice of the modelization, 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/standard	**tetrahedrons**	`INCO`
quadrilateral/hexahedrons	`IF`	`IF` or `INCO`

Justifications and precautions:

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

3 In Code_Aster work *One*

bets points out here the main stages of Aster *computation* in the case of a computation in plane strains, while specifying explicitly where the specifications intervene about which one spoke. For the mechanical part, one wrote in fat what is specific with the case of a thermomechanical computation.

3.1 Thermal study

- Lecture of thermal mesh

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

- Choix of thermal model

```
MOTH2D=AFFE_MODELE (MAILLAGE=MA,
                    VERIF='NET',
                    AFFE=_F (GROUP_MA= (“GMA1', “GMA2',…),
                             PHENOMENE='THERMAL”,
                             MODELISATION='PLAN_DIAG”,),)
```

- thermal Properties of the thermal
- material Loading
- `THER_LINEAIRE` or `THER_NON_LINE`
  `THER =…`
- possible Post-processing

3.2 mechanical Étude

- Lecture mechanical mesh

```
MAME=LIRE_MAILLAGE ()
```

```
MAME=CREA_MAILLAGE (
    MESH = MY,
LINE_QUAD=_F (TOUT='OUI'))
```

- Definition of mechanical model

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

- Projection of thermal computation if computation chained on 2 meshes various

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

- Characteristics of the material

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

- Mechanical loadings
- `STAT_NON_LINE`
- Post-processing

4 Bibliographie

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