To introduce a new type of mesh or a new element of reference

Summarized:

This document describes what it is necessary to do to introduce a new type of mesh into *Code_Aster* or a new element of reference.

In a few words, to add a new type of mesh and/or a new element of reference, it is necessary:

- of the mesh to define and introduce the characteristics and/or of the element of reference into the source of Code_Aster: position of the nodes, connectivity, shape functions, position of Gauss points,…
- to think of the impact on the level of the existing functionalities in Code_Aster,
- to enrich documentations and the “user” (Doc. U) documentations “reference” (Doc. R) relative to mesh file, the shape functions,…
- to enrich by the existing benchmarks in order to test your new finite element.

A complete example will be described in this document.

Contents

1 Introduction

Before thinking of introducing a new type of mesh into Code_Aster, it is necessary to have:

- consulted documentation U3.01.00 ("description of mesh file of Code_Aster") in order to know conventions of writing (order of the nodes,…),
- consulted R3.01.01 documentation ("shape functions of the isoparametric elements") in order to know the representations of the elements of references, their shape functions, the families of Gauss points existing,…

After having:

- dimensioned your element,
- placed the nodes,
- determined the shape functions and their derivatives,
- allotted one or of the families of Gauss points,

You can pass at the following stage, which consists in introducing your mesh or element of reference into Code_Aster.

This stage passes by the modification of the source of Code_Aster, i.e. the modification of:

- catalogs of elements,
- files FORTRAN.

We will explicitly describe the interventions in each file concerned.

After this stage, you will be able to carry out computations on models accepting your new type of element. It is interesting to be able to print, display and/or read again your results. It is not thus possible to restore your development without updating the commands of preprocessing and postprocessing. We will list the routines concerned.

A this stage, it remains to check that all the functionalities of Code_Aster are always operational. We will see that the source relative to other operators will need to be updated. We will list the operators routines concerned and the.

The phase of development being finalized, it remains the phase of validation. The various tests to be carried out will be presented in this document.

Lastly, it will remain to bring up to date documentations. We will enumerate various documentations with enriching.

In order to review these various stages, we will present an example illustrating the addition of a new mesh and an element of reference. With this intention, one will introduce into Code_Aster, a new finite element based on a pentaedric mesh with 18 nodes.

2 Introduction of a new type of mesh or a new element

One proposes in this example the development of a finite element based on a new mesh, a pentahedron with 18 nodes, in the field of the nonlinear mechanics. You will be able to base your realization on this one.

2.1 Presentation of the mesh and of the element of reference

a pentahedron to 18 nodes is a mesh whose nodes are localised:

- at the tops (6 nodes),
- in the middle of each edge (9 nodes),
- in the middle of the quadrangular sides (3 nodes).

A representation of element of reference associated with this mesh is the following one:

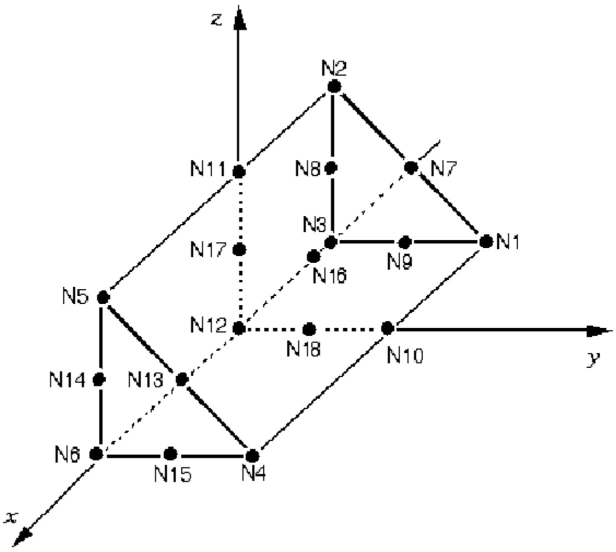

Figure 2.1-1: Element of reference

to carry out a representation of this element (dimension, position and order of the nodes,…), it is advised to consult documentation U3.01.00 ("description of mesh file of Code_Aster"). For example, a convention on the order of the nodes is presented there: one starts with ordered the nodes tops, then the nodes mediums (on the edges), and finally the nodes central (on the sides).

The coordinates of the nodes are:

	x	y	z
N1	-1.	1.	0.
N2	-1.	0.	1.
N3	-1.	0.	0.
N4	1.	1.	0.
N5	1.	0.	1.
N6	1.	0.	0.
N7	-1.	0.5.0.5	.
N8	-1.	0.	0.5.
N9	-1.	0.5	0.
N10	0.	1.	0.
N11	0.	0.	1.
N12	0.	0.	0.
N13	1.	0.5.0.5	
N14	1.	0.	0.5
N15	1.	0.5	0.
N16	0.	0.5.0.5	
N17	0.	0.	0.5
N18	0.	0.5	0.

The shape functions of this element are the following ones:

$$w_1 = x\,y(x-1)(2y-1)/2$$
$$w_2 = x\,z(x-1)(2z-1)/2$$
$$w_3 = x(x-1)(z+y-1)(2z+2y-1)/2$$
$$w_4 = x\,y(x+1)(2y-1)/2$$
$$w_5 = x\,z(x+1)(2z-1)/2$$
$$w_6 = x(x+1)(z+y-1)(2z+2y-1)/2$$
$$w_7 = 2\,x\,y\,z(x-1)$$
$$w_8 = -2\,x\,z(x-1)(z+y-1)$$
$$w_9 = -2\,x\,y(x-1)(z+y-1)$$
$$w_{10} = y(1-x^2)(2y-1)$$
$$w_{11} = z(1-x^2)(2z-1)$$
$$w_{12} = (1-x^2)(z+y-1)(2z+2y-1)$$
$$w_{13} = 2\,x\,y\,z(x+1)$$
$$w_{14} = -2\,x\,z(x+1)(z+y-1)$$
$$w_{15} = -2\,x\,y(x+1)(z+y-1)$$
$$w_{16} = 4\,y\,z(1-x^2)$$
$$w_{17} = 4\,z(x^2-1)(z+y-1)$$
$$w_{18} = 4\,y(x^2-1)(z+y-1)$$

Figure 2.1-2: shape functions

Concerning the families of Gauss points to be associated with this element, it is convenient to consult R3.01.01 documentation (“shape functions of the isoparametric elements”). For this element, it was agreed to take again those of the pentahedron with 15 nodes.

In the following paragraph, we will answer following question:

How to introduce the new type of mesh or element of reference into the Source of Code_Aster?

2.2 Introduction of the mesh and of the element of reference into the source of Code_Aster

Before leaning on files FORTRAN, one will enrich the catalogs in question.

2.2.1 On the level of the catalogs of elements

2.2.1.1 type_maille__.catastrophes `This`

catalog Catalogues is localised in the directory `catalo` under the directory `compelem` .

It is necessary to define in this catalog, a new type of mesh, whose name must be sufficiently explicit. One chooses type PENTA18 to represent a pendaedric mesh with 18 nodes.

In this catalog, one will define new the type_maille: PENTA18 like one or more element of reference (ELREFE) which can lean on this type_maille. In general, one defines one ELREFE for a type_maille. Here it is the ELREFE P18.

`The type_maille` is purely geometrical and topological. Its definition can summarize with the diagram the representative with the local classification of its nodes.

The ELREFE relates to the finite elements which will lean on this type_maille: choice of the shape functions, choices of the families of Gauss points.

One enriches this catalog by the following block:

```
MAILLE PENTA18    18      DIM  3   CODE  “P18”
   ELREFE P18
         FAMILLE NOEU        18
         FAMILLE NOEU_S      6
         FAMILLE FPG1        1
```

```
FAMILLE FPG6        6
FAMILLE FPG6NOS     12
FAMILLE FPG8        8
FAMILLE FPG21       21
```

One notes with the reading of this block that this mesh of the type `PENTA18` is a mesh `3D` with 18 nodes. It is associated with the element of P18 `reference`.

The following stage is to use this mesh in one or more modelizations of *Code_Aster* . One will enrich the catalog by the phenomena and modelizations.

2.2.1.2 Catalogue `phenomene_modelisation__.catastrophes`

This catalog is localised in the directory `catalo` under the directory `compelem` .

It was agreed that this type_maille is used only with the modelization 3D MECHANICAL phenomenon. Thus, we added a new element to this modelization, element MECA_PENTA18. The contents of this catalog relating to the modelization 3D are the following:

```
MODELISATION “3D”              DIM 3 3   CODE “3D_”
      ATTRIBUT  NBSIGM=X6 TYPMOD=COMP3D
      MAILLE HEXA8     ELEMENT MECA_HEXA8
      MAILLE PENTA6    ELEMENT MECA_PENTA6
      MAILLE TETRA4    ELEMENT MECA_TETRA4
      …
      MAILLE PENTA15   ELEMENT MECA_PENTA15
      MAILLE PENTA18   ELEMENT MECA_PENTA18
      …
      MAILLE PYRAM13   ELEMENT MECA_PYRAM13
```

So that this element can be taken into account in elementary computations, it should be added to the catalogs of elements.

2.2.1.3 3D `catalogue`

gener_me3d_3.catastrophes the enrichment of `the modelization` with a new element (`MECA_PENTA18`) generates an impact in the catalog of element `gener_me3d_3.catastrophes` . This catalog is localised in the directory `catalo` under the directory `typelem.`

One must add to it:

- the name of the new element: MECA_PENTA18,
- its support: mesh PENTA18,
- the element of P18 reference of this element and, if necessary, elements of reference of the sides of this elements (QU9, TR6).

The block relative to this element to be added in the catalog is presented in the following form:

```
ENTETE ELEMENT MECA_PENTA18   MAILLE PENTA18
ELREFE P18  GAUSS  RIGI=FPG21  MASS=FPG21  GANO=FPG21  NOEU=NOEU
              ARLQ_4=FPG21  FPG_LISTE  MATER= (RIGI FARMHOUSE GANO NOEU)
ELREFE  QU9  GAUSS  RIGI=FPG9  MASS=FPG9   NOEU=NOEU
ELREFE  TR6  GAUSS  RIGI=FPG6  MASS=FPG6   NOEU=NOEU
```

the following stage is the seizure of the characteristics of this element of reference. It does not take place in the catalogs, but in sources FORTRAN.

2.2.2 In the level of source FORTRAN

One defines in it the coordinates of the nodes, the shape functions and their derivatives,… i.e. all the characteristics of this new element.

The table below presents the list of routines FORTRAN to be modified to take into account the new ELREFE P18 :

Routines	general
Features	elraca Characteristic of the element of reference: number and names of the families of Gauss points, coordinated nodes,…
elraga	Definition of the weights and coordinates of Gauss points
the elrfvf	Definition of the shape functions
elrfdf	Definition of derivatives of the shape functions
elrfd2	Definition of second derivative of the shape functions
inmat5	Calculates the transition matrix Gauss => nodes from the matrix Gauss => nœuds_sommets
inmat6	Calculates the transition matrix Gauss => nœuds_sommets
nuelrf	Gives the number of the routine jni00i associated with an element of reference.

Table 2.2.2-1: Routines suitable for the development of a new ELREFE

Note:

During the introduction of the ELREFE P18, it was also necessary to modify (but for "essential" reasons less: ECLA_PG, PROJ_CHAMP,…) following routines: ecla3d, forme0, forme1, pj3dtr, pjxxut, elref7, I smali

It is necessary to be very vigilant when a new type of mesh is added because the list of the type_maille (or at least their number) is known in "tough" in many sources. The list is the following one: iradhs.f, ircam1.f, ircame.f, ircmpe.f, ircmva.f, irmhdf.f, irmmf2.f, irmmma.f, irmpga.f, lrcame.f, lrfmed.f, lrmhdf.f, lrmmdi.f, lrmmf1.f, lrmmf3.f, lrmmfa.f, lrmmma.f, lrmtyp.f, lrvemo.f. By way of an example, here the list of the routines

modified to take into account new type_maille PENTA18: momaba.f, forme0.f, forme1.f, pjtyma.f, pjxxut.f, ermes 3.f, gmgnre.f, lrmtyp.f, cm1518.f, cm2027.f, cmlqlq.f, cmqlql.f, inigms.f, iradhs.f, ircam1.f, irceca.f, ircecs.f, ircers.f, ircmpr.f, irgmtb.f, irmac2.f, irmaca.f, irmasu.f, irmmma.f, lrvemo.f, creaco.f, utidea.f. A this stage, one can build executable who can correspond to our need. But two questions

remain outstanding: What are they the features the pre one and postprocessing to make evolve to be able to generate

- a mesh made up of PENTA18 and to be able to print and display the results resulting from elementary computation? What are they the other features which would be likely to be impacted (even broken) by this
- evolution? Update of the commands the pre one and post processing in Code_Aster Operator CREA_MAILLAGE Option

2.3 QUAD_LINE This option makes it possible to transform a quadratic mesh *into*

2.3.1 linear mesh . In

2.3.1.1 our case , mesh

PENTA18 is quadratic, it is thus concerned with this option. Without intervention in the source FORTRAN, the use of this option in the presence of this kind of mesh should lead to a brutal stop of Code_Aster in this operator. Routines functionalities cmqlql Transformation of meshes quadratic into linear cmqlma Creation of

objects	TYPMAIL and CONNEX
cmqlnm	Recovery of the nodes mediums cm2027 cm27ma cm
27na cm	27nd Updated of the option HEXA20_27
2.3.1.1	Table - 1: Impacted routines
of the command	CREA_MAILLAGE/QUAD_LINE Operator IMPR_RESU

to be able 2.3.1.1-1 the results calculated from a made up model inter alia

2.3.1.2elements

MECA_PENTA18, it is essential to update source FORTRAN of this operator. The following table presents the routines concerned: Format Routines Comments ENSIGHT iniens Writing

of the names of meshes the irmaen Writing of mesh

GMSH irgmsh	Writing	of a field
irgmor	Turns over	the order of printing of the elements
		. irgmma, irgmm3 Transforms
		meshes into the meshes linear ones
		irgmcg, irgmce Printing of a cham_elem irgmtb
	Turns over	the table of cutting of the elements irmgms
	Writing of the mesh	to format GMSH CASTEM
	irmac	2 Turns over the type of mesh gibi irceca Writing
	of	a cham_elem irmaca Writing of the mesh
IDEAS	ircers	, ircecs Writing of a cham_
	elem irmasu	Writing of mesh
	MED irmmma	Writing of meshes
the ircam	1, ircame Writing	of a field ircmpe
	, ircmpn	, ircmpr Writing of
the profiles	of	the fields ircmpva Writing
	of the values	irmhdf Writing of
	the mesh irmmf2 Writing	of the families irmpga Writing
	of Gauss points	2.3.1.2
	Table	- 1: Routines of the command
		IMPR_RESU impacted Operators
		LIRE_RESU, LIRE_CHAMP the modification

2.3.1.2-1 IMPR_RESU goes from pair with that of

2.3.2 LIRE_RESU (or LIRE_CHAMP). Indeed

, if one prints a field one must be able to read again it. This is why , an intervention

in these operators is to be envisaged. Routines Standard Comments Irmtyp of meshes for med Irmpga Localization of Gauss points the Irvemo Checks

	coherence
between the model	provided and the given
lrcame	Reading of a field lrmhdf Reading
	of the mesh lrmmdi Reading of dimensions of the mesh lrmmf1, lrmmf
3,	lrmmfa Reading of
the families	lrmmma Reading of
meshes	the op0150 Reading of result a Table
2.3.2-1: Routines	of the operators LIRA
_RESU	and LIRE_CHAMP impacted
In	the following paragraph

, us 2.3.2-1 operators indirectly impacted by the addition of a new

mesh or a new element of reference. Update of the other operators of Code_Aster It is not easy to draw up an exhaustive list.

2.4 We proceeded by: a search *of* “

the P15”, character strings “PENTA” in FORTRAN via

“grep” to leave the list

- files FORTRAN related to the pentahedrons. a meticulous analysis of each one of them in order to determine those which must be adjusted. The list is
- the following one: Operators Routines Features AFFE_CARA_ELEM: option: LIAISON_GROUP

panbno Calculates the number

of nodes tops	**, edges**	**of a mesh**
CREA_MAILLAGE: ECLA_PG ecla 3D 3D	To break up	the types of the elements into under elements DEFI_GROUP: CREA_GROUP_NO
gmgnre To fill out	the list	of the nodes under subjacent with the list of mesh PROJ_CHAMP
pjxxut meshes Prepares		the list of and the lists of nodes useful for projection pjtyma and the
Turns over	the type	of element starting from the mesh pj3dco Created the correspondence between
	the nodes	meshes pj3dtr Transforms the corresp_2_maillage
	into corresp	_2_maillage_final MODI_MAILLAGE: MODI_MAILLE (option
	"NOEU_	QUART") momaba Modification of meshes via Barsum barpen Processing
of meshes (Barsum) the AFFE_CARA_ELEM op0019	Addition	of element MECA_PENTA18 CREA_MAILLAGE:
		LINE_QUAD cmlqlq PRE_GMSH inigms
Initialization	of the types	of meshes for transition GMSH
towards Aster DEFI_PART_PA	_OPS creaco	
Creation	of	the connectivity of meshes the CALC_ERREUR: OPTION=' QIRE_ELEM "te0368
, ermes3 Calculates	of the estimator	of error in mechanics 3D CALC_ERREUR
: OPTION=' ERME_ELNO" te375	3D Calculates of	the estimator of error in mechanics Table 2.4 – 1:
List other operators and	routines	impacted Validation the validation consisted

with: to test 2.4-1the development on a benchmark interns made up of

2.5 a linear computation

of mechanics on an element

- whose type of the mesh is a PENTA18. One could compare the results with those of the similar study based on PENTA15, test the development on a benchmark of reference in linear mechanics (ZZZZ238B), to test
- the development on a benchmark of reference in nonlinear mechanics (SSNP121Q), to test
- key word QUAD_LINE of operator CREA_MAILLAGE (benchmark ZZZZ206A), to test PENTA15_18 the key word
- of operator CREA_MAILLAGE, to test the IMPR_RESU with the various formats
- , like LIRE_RESU and LIRE_CHAMP. The transition of the short list
- was carried out to check all the features of Code_Aster

. Documentations the representation of your new mesh must appear in documentation *U3.01.00*

2.6 (“description

- of mesh file of Code_Aster”), the shape functions associated with the new element with reference must be presented in
- the R3.01.01 document (“shape functions of the isoparametric elements”), the addition of element MECA_PENTA18 in the modelization 3D U3.14.01 generates a documentary work in
- the document (Modelizations 3D and 3D_SI mechanical) the development of the option PENTA15_18 of CREA_MAILLAGE is accompanied by enrichment by the document
- U4.23.02 (operator CREA_MAILLAGE) documentations by the benchmarks by validation must be updated . Here , it is the documents V
- 6.03.121 (SSNP121) and V1.01.238 (ZZZZ238).