
Panorama of the tools available to carry out structural analyses of concrete Génie Civil

Summary:

The objective of this document is to provide an overall vision of the possibilities of modeling which are offered to the user according to the type of analysis that it wishes to carry out as a Génie Civil. Various choices are always possible and the goal of this document is not to substitute themselves for the analysis of the engineer but well to enable him to more easily choose the options of modeling, according to the tools available, and to direct it towards more specific documents.

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1 Introduction

Behind the word calculation of Génie Civil hides at the same time calculations on structures with dimensions and the very varied characteristics (test-tube, beams, building,...) but especially of calculations from which the finality or required information is very different: dimensioning of a structure, forecast of long-term ageing, study of the risk of cracking, checking of the seismic behaviour of a structure, revaluation of the margins. Load with the modelisator to find the best compromise between complexity, the cost of the study and the precision or the representativeness of the searched results, while choosing correctly, the type of analysis, its modeling finite elements and its models of behavior, knowing that a great choice is available in Code_Aster.

1.1 The type of analysis to be carried out

The choice of the operators is carried out in function: type of modelled phenomenon (thermal, hydrous, mechanical...) and of the required type of information (local or total information, stationary state or study of the transient,...), type of loading (static, dynamic), non-linearities to be modelled (behavior, great deformations, loading,...). The choice must be made among the following operators:

- a linear thermal calculation (`THER_LINEAIRE`) [R5.02.01] to estimate the temperature of the concrete in the linear cases;
- a non-linear calculation of thermics (`THER_NON_LINE` [R5.02.02]), when the properties or the boundary conditions are not linear, but also to model the thermo-hydratation of the concrete or the evolution of drying (under the effect of the hydrous gradient);
- a linear static calculation (`MECA_STATIQUE` [U4.51.01]) whenever the elastic concrete is considered and in the absence of any non-linearity;
- a non-linear static calculation (`STAT_NON_LINE`, [R5.03.01]), since one wants to take into account non-linearities of behavior (creep, damage,...) or of loading (prestressed, contact,...) ;
- a thermomechanical calculation, by chaining a thermal calculation (linear or not) solved with `THER_LINEAIRE` or `THER_NON_LINE` and a static calculation (linear or not) solved with `MECA_STATIQUE` or `STAT_NON_LINE`;
- a calculation coupled standard Thermo-Hydro-Mechanics porous environment, accessible via `STAT_NON_LINE`, in particular to study the exchanges of water or gas through a concrete wall (cf [R7.01.10] and [R7.01.11]);
- a vibratory calculation of dynamics with the operator `DYNA_VIBRA` [U4.53.03] which can be of type transitory or harmonic, on physical basis or modal basis (by appealing according to the case, with the historical operators `DYNA_TRAN_MODAL`, `DYNA_LINE_TRAN` and `DYNA_LINE_HARM`), with the possibility of taking into account certain localised non-linearities standard shock or friction;
- a standard calculation spectral method by modal synthesis `COMB_SISM_MODAL` [R4.05.03], to calculate the dynamic response to single or multiple imposed movements and to dimension a structure;
- a transitory dynamic calculation direct with `DYNA_NON_LINE` [R5.05.05] if one wants to model non-linearities localised E S standard friction or of great displacements or the non-linear behaviors;
- a calculation of type impact in dynamics clarifies while being used only as interface to call EUROPLEXUS (code of reference in fast dynamics) via the order `CALC_EUROPLEXUS` [U7.03.10];
- a calculation of flow of fluid in one E structure out of concrete fissured (in 2D), with `MACR_ECREVISSE` [U7.03.41].

Let us note to finish, that *Code_Aster* allows to do deterministic calculation, but that procedures were installation to make it possible to do rather easily calculations mechanic-probabilists (cf [U2.08.05]).

1.2 The type of modeling to be used:

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It is possible to use:

- voluminal elements 3D [R3.01.00] or surface 2D, when that is possible, by resorting to simplifying assumptions such as plane strains, plane stresses or axisymetry;
- elements of the type plates (DKT, DST, Q4G [R3.07.03], Q4GG [R3.07.09]), of membrane type (GRILLE_MEMBRANE, GRILLE_EXCENTREE, MEMBRANE, [R3.08.07]) or of voluminal hulls (COQUE_3D [R3.07.04], SHB [R3.07.07] or [R3.07.08]),...
- linear elements using element right beam of type Euler (POU_D_E), or of the beams of the Timoshenko type, right-hand side (POU_D_T) (cf [R3.08.01]), of the multifibre beams into small or great displacements (POU_D_EM [R3.08.08], POU_D_TGM [R3.08.09]).

These modelings can of course be used only or be combined.

To help the user to make his choice (in particular with regard to the use of the elements of structures), the reader will be able to refer to the document [U2.02.01], Note of use of the elements plates, hulls, hulls voluminal SHB, grids and membranes or with the document [U2.06.10] Realization of a study of civil engineer under seismic loading. In addition, the chapter 5 this document, details how to represent the reinforcements and the cables of prestressing, according to the choice made to represent the concrete.

1.3 The law of behavior

This one is to be chosen according to the phenomena which it is necessary to take into account, by being aware of the limits of those, the difficulty in identifying parameters realistic materials when one starts to seek to obtain very fine information, robustness of the law and impacts in terms of computing time,... The characteristics of the principal laws available are summarized in this document to facilitate the choice of the user.

The purpose of the following chapters are to list the principal possible choices in particular in terms of modeling and laws of behavior, as well as the combinations, in order to facilitate the choice.

2 Possible choices for thermal calculations

The following table specifies possible modelings according to the type of analysis.

Modeling	Type of analysis		Type of element		Example
	Linear	Non-linear	Linear	Quadratic	
3D/3D_DIAG	ok	ok	ok	ok	FORMA41
PLAN/PLAN_DIAG	ok	ok	ok	ok	FORMA21
AXIS/AXIS_DIAG	ok	ok	ok	ok	FORMA30
HULL	ok	nook	ok	ok	HPLA100
COQUE_PLAN	ok	nook	nook	ok	ZZZZ110
COQUE_AXIS	ok	nook	nook	ok	

Table 2-1: Possible types of analysis in thermics

Remarks :

Modelings *3D_DIAG*, *PLAN_DIAG* and *AXIS_DIAG*, which corresponds to the use of a matrix of lumpée or diagonalized mass (cf [R3.06.07]), results more precise give than classical modelings in the presence of thermal shock and for the linear elements.

For the hulls, the temperature variation in the thickness is inevitably parabolic (cf [R3.11.01]).

All the loadings are not applicable to modeling *HULL*, to check before use [U4.44.02].

To continue with a mechanical calculation, one advises:

to use linear elements preferentially to solve the thermal problem with modeling , and of the quadratic elements for the mechanical problem preferably under-integrated (cf [U2.01.10]).

to check well that the law of behavior used takes into account the thermal deformation, and that modeling used accepts well L be variable of order and in particular it thermal. When she is taken into account, thermal dilation is spherical and is worth ($\epsilon_{th} = \alpha \Delta T I_d$). At present, the *S* voluminal elements and plan, elements *DKT* and *DKTG* and multifibre beams (*POU_D_EM* and *POU_D_TGM*) tolerate the temperature like variable of order.

There does not exist in Code_Aster of model describing the thermal damage of origin specifically.

3 Possible choices for calculations of hydration

There exists only one model of hydration in *Code_Aster* who allows to describe the heat emission as well as hardening, cf [R7.01.12]. It is solved via the operator *THER_NON_LINE*, and the behavior '*THER_HYDR*'. The model should comprise only the concrete, modelled using elements voluminal or surface, preferably linear. Advised modelings are *3D_DIAG*, *PLAN_DIAG* and *AXIS_DIAG* (but *3D*, *PLAN* or *AXIS* are also possible). Steps of sufficiently small times must be used with the young age (of about an hour to the thermal peak of heating, then the steps of time can be increased gradually) to obtain a solution of good quality, because an explicit discretization of the source of heat is used.

The temperature and the hydration can then be taken into account in mechanical calculation in the form of variables of order (*TEMP* and *HYDR*). In this case, it is advised to solve the thermal problem with linear elements.

An example of resolution of such a problem is treated in CAS-test *FORMA41*.

Notice :

It is possible not to solve the problem of thermohydration, and to define a field of hydration in an analytical way using the orders *CREA_CHAM* and *CREA_RESU* (In this case, the heating due to the reaction of thermohydration is neglected). Thus one usually uses the following formula, resulting from a chock *LCPC*:

$$h = \frac{t}{b+t}, \text{ with } b = 1684800 \text{ s. , if } t \text{ is the time expressed in second.}$$

(cf test SSLA103 for an example of setting in data).

4 Possible choice for calculations of drying

It is possible to model the drying of the concrete under the effect of the hydrous gradient (simplifying assumption which makes it possible to model only drying by diffusion and not by advection for example) with the operator `THER_NON_LINE`, (cf [R7.01.12]). The model should comprise only the concrete, modelled using elements voluminal or surface, preferably linear (especially if one connects with a mechanical calculation). Advised modelings are `3D_DIAG`, `PLAN_DIAG` and `AXIS_DIAG` (but `3D`, `PLAN` or `AXIS` are also possible). 4 laws are available to represent the evolution of the coefficient of diffusion D according to the concentration out of water and possibly of the temperature. The expressions of each one are given in [U4.43.01].

- `SECH_MENSI`, where D is function of the water concentration;
- `SECH_GRANGER` who is equivalent to `SECH_MENSI` but which takes into account the thermic action (i.e. the acceleration of drying when the temperature increases);
- `SECH_BAZANT`, where D is function of moisture (connected to the water concentration by the function of sorption);
- `SECH_NAPPE` who allows to define an unspecified evolution for D in the form of a tablecloth function of the water concentration and temperature.

Drying can then be taken into account in mechanical calculation in the form of a variable of order `SECH`, which corresponds to the water concentration in the concrete.

Notice

For more complex cases of drying (for example drying under the effect of a gradient of pressure), it is necessary to resort to a modeling Thermo-Hydro-Mechanics who treats the equations of the mechanics of the continuous mediums by using the theory of the porous environments possibly unsaturated and by considering that the phenomena mechanical, thermal and hydraulic are completely coupled, cf.[R7.01.10] and [U2.04.05].

The identification of the parameters materials is done starting from a curve of loss of mass. An example is given for the law `SECH_GRANGER` in test TTNV101.

5 Possible choices for mechanical calculations (static or dynamic)

A great choice of modelings but also of laws of behavior is available in *Code_Aster* for mechanical calculations. Load with the user to define the most effective strategy according to the structural features studied (pregnant, tank, flagstone, beam...), loadings applied (thermal, symmetrical, 3D...), required information (total behavior, limiting load, cracking, creep,...) but also of the speed of expected execution (complexity of setting in work, difficulty of convergence, computing time,...). The goal of this chapter is not to give advices on the choice of the most adapted modeling, but to give a synthetic sight of modelings, laws of behavior and combinations possible to facilitate the choice of the engineer.

5.1 Choice of modeling for the reinforced concrete and/or prestressed

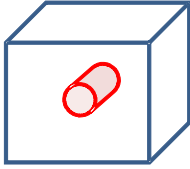
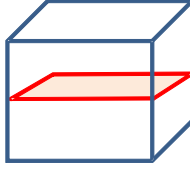
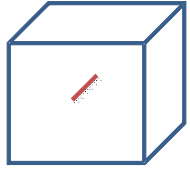
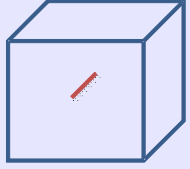
To only model the concrete, all the types of elements are usable. We make here only the synthesis of the possible combinations - or in any case classically used - to represent the concrete containing of steels. In the continuation, the entrance point of each paragraph corresponds to the choice who is done to describe the concrete: voluminal, surface or using elements of structure. For the practical details, on the setting in work calculations with the cables of prestressing, and in particular the use of the operators `DEFI_CABLE_BP` and `CALC_PRECONT`, the reader is invited to consult the document [U2.03.06].

5.1.1 Modeling of the concrete by voluminal elements 3D

Possible modelings and elements for the concrete are:

- modelings `3D` or `3D_SI` in the case general, knowing that all isoparametric elements 3D (hexahedron, tetrahedron, pentahedron, pyramid...) are usable into linear or quadratic for modeling `3D`, whereas modeling `3D_SI` allows to use only hexahedral elements (linear or quadratic) and the quadratic tetrahedrons. The quadratic elements are more expensive but give results of better quality. The use of under-integration makes it possible nevertheless cause a drop in times calculations. In the case of a thermomechanical chained calculation, it is advised to use under-integrated quadratic elements (cf [U2.01.10]).
- modeling `3D_GRAD_EPSI` if one wants to use a model of damage not-room to gradient of implicit deformation (cf [R5.04.02]). In this case the elements must be quadratic elements (HEXA20, TETRA10, PENTA15 or PYRAM13) or possibly of the linear tetrahedrons.
- modeling `3D_GRAD_VARI` if one wants to use a model of damage not-room to gradient of damage (cf [R5.04.01]). In this case, the elements must be quadratic.

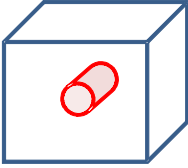
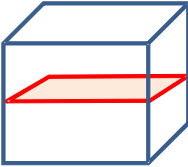
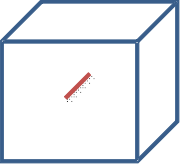
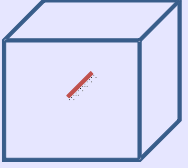
The following table synthesizes the three possible solutions to represent the reinforcements and the cables of prestressed when the concrete is modelled in 3D. As an indication, we added modeling `CABLE_GAINE` who is valid only for the cables of prestressing.

	3D (or 3D_SI)  3D/3D	GRILLE_MEMBRANE/MEMBRAN E  3D/2D	BAR POU_D_E  3D/1D	CABLE_GAINE  3D/1D
Grid usable	All voluminal, linear or quadratic elements	Triangles or quadrangles, linear or quadratic	SEG2	SEG3
Representation of a perfect steel-concrete connection	Nodes concrete and nodes steel identical	Nodes concrete and nodes steel identical	Nodes concrete and nodes steel identical or unspecified with DEFI_CABLE_BP ¹ (BAR only)	Law use CABLE_GAINE_FROT/TYPE = ' PARFAIT '
Representation of a sliding joint	not taken into account	not taken into account	not taken into account	Law use CABLE_GAINE_FROT/TYPE= ' GLISSANT '
Representation of a rubbing connection	not taken into account	not taken into account	not taken into account	Law use CABLE_GAINE_FROT/TYPE= ' FROTTANT '
Representation of a degradable steel-concrete connection²	Introduction of elements 3D_INTERFACE + law CZM_LAB_MIX between meshes steel and concrete (quadratic grid obligatory)	Introduction of elements 3D_INTERFACE+ law CZM_LAB_MIX between meshes steel and concrete (quadratic grid obligatory) ³	not taken into account	not taken into account

1 To take care however to have a level of comparable discretization between steel and concrete.

2 See §5.4 for more details.

3 Modeling MEMBRANE only.

	3D (or 3D_SI)  3D/3D	GRILLE_MEMBRANE/MEMBRANE  3D/2D	BAR POU_D_E  3D/1D	CABLE_GAINE  3D/1D
Possibility of setting in tension (cables of prestressed)	Initial deformations via EPSI_INIT or fictitious thermal deformation or equivalent pressure	Initial deformations via EPSI_INIT or fictitious thermal deformation or equivalent pressure	DEFI_CABLE_BP/CALC_PREC ONT (modeling BAR only)	DEFI_CABLE_BP/CALC_PREC ONT
Cost in terms of grid	NS	S	M / S ⁴	S
Representativeness broadly/locally	S / S	S / M	S / L	S / M
CAS-test example		FORMA40 (perfect connection) SSNS110 with CZM	SSLX103 (reinforcements) SSNV164 (cable)	ZZZZ347

Legend:

- S satisfying
- M means
- NS nonsatisfactory

Table 5.1.1-1 : Possible combinations to represent reinforced concrete and/or prestressed with elements 3D

Note:

The representation of steels by linear elements drowned in concrete modelled in 3D, pose mathematical and digital problems. However the results remain correct as long as the grid too much is not refined. In fact, their use with models of damage often induces a nonrealistic premature damage along these steels.

The modeling of the cables of prestressing when steel is modelled in 3D or with elements of the type MEMBRANE, only was little tested until now.

5.1.2 Modeling of the concrete by surface elements

Possible modelings and elements for the concrete are:


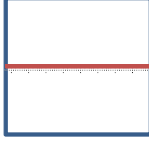
- Modeling `D_PLAN` or `D_PLAN_SI` (plane deformations, therefore thick parts),
- Modeling `C_PLAN` or `C_PLAN_SI` (plane constraints, therefore parts low thicknesses),
- Modeling `AXIS` or `AXIS_SI` (axisymetry).

(cf [U3.13.01 for the "classical" elements and [U3.13.05] for the under-integrated elements).

The elements usable can be indifferently triangles or quadrangles, linear or quadratic (to prefer `XX_SI` with quadratic elements in the case of a thermomechanical standard chained calculation).

- Modeling `D_PLAN_GRAD_EPSI` or `C_PLAN_GRAD_EPSI` if one wants to use a model of damage not-room to gradient of implicit deformation (cf [R5.04.02] and [U3.13.06]). In this case the elements usable are: triangles, linear or quadratic, or of the quadratic quadrangles.
- Modeling `D_PLAN_GRAD_VARI` or `AXIS_GRAD_VARI` if one wants to use a model of damage not-room to gradient of damage (cf [R5.04.01]). In this case, the elements must be quadratic (triangles or quadrangles).

The following table synthesizes in this case, the possible solutions to represent the reinforcements and the cables of prestressing.

	D_PLAN (_SI) C_PLAN (_SI) AXIS (_SI)  2D/2D	2D_BARRE  2D/1D
Grid usable	Triangle or quadrangle, linear or quadratic	SEG2
Representation of a perfect steel-concrete connection	Nodes concrete and nodes steel identical	Nodes concrete and nodes steel identical
Representation of a sliding joint	not taken into account	not taken into account
Representation of a rubbing connection	not taken into account	not taken into account
Representation of a degradable steel-concrete connection	Introduction of elements _PLAN_JOINT or AXIS_JOINT + law JOINT_BA between meshes steel and concrete (obligatory linear grid)	not taken into account
Possibility of setting in tension (cables of prestressed)	Initial deformations via EPSI_INIT or fictitious thermal deformation or equivalent pressure	Initial deformations via EPSI_INIT or fictitious thermal deformation or equivalent pressure
Cost in terms of grid	S	S / S
Representativeness broadly/locally	S / S	S / NS
CAS-test example		SSNL112

Legend:

S satisfying

M means

NS nonsatisfactory

Table 5.1.2-1 : Possible combinations to represent reinforced concrete and/or prestressed with elements surface

5.1.3 Modeling of the concrete by elements of structures

The elements of structure are particular elements, which with the help of a certain number of assumption make it possible to describe displacements and deformations of a particular structure in 3D, while modelling it in 2D or 1D. To arrive there, the displacement of the structure is described by degrees of freedom of displacements (classical) but also by one or of rotations. That traditionally cover

the elements known as of plate, hull or beam, cf [R3.07.03] or [R3.08.01]. They are very usually used for the dynamic studies.

Table 2-1 allows to know how to model the reinforcements and the cables of prestressing when the concrete is modelled with elements of structures, whereas it Table 5.1.3-2 give the equivalent if one chose to represent the reinforced concrete using a total model.

Concrete	Reinforcements	Cables of prestressing
<p>Choice 1: surface modeling Model : DKT (plate or thin hull) Grid : - triangles or quadrangles, linear</p>	<p>Surface modeling Model : GRILLE_EXCENTREE (a mesh by direction of reinforcements) Grid : - triangles or quadrangles, linear Example : test FORMA40</p>	<p>Linear modeling Model: BAR Grid : SEG2, nodes identical steel and concrete or grid unspecified steel/concrete if one uses DEFI_CABLE_BP Steel-concrete connection : perfect Setting in tension : with DEFI_CABLE_BP/CALC_PRECONT Example : test SSNP108</p>
<p>Choice 2: linear modeling Model : POU_D_TGM, POU_D_EM (multifibre beams) Grid : SEG2</p>	<p>Linear modeling Possible by assigning behaviors different to the groups from fibres of type concrete and steel. Example : test SDLL130</p>	<p>(Application of a loading of compression are equivalent)</p>

Table 5.1.3-1: Possible combinations to represent reinforced concrete and/or prestressed with elements of structure

Concrete + reinforcements	Cables of prestressing
<p>Choice 1: surface modeling Modeling of the reinforced concrete in the form of elements of plate (linear element), modeling DKTG, by using a total law of behavior GLRC_DM, GLRC_DAMAGE or DHRC</p> <p>Example : test SSL106</p>	<p>Choice 1: linear modeling Model : BAR Grid : SEG2, nodes identical steel and concrete or grid unspecified steel/concrete if one uses DEFI_CABLE_BP Steel-concrete connection : perfect Setting in tension : with DEFI_CABLE_BP/CALC_PRECONT</p>
<p>Choice 2: linear modeling Modeling of the reinforced concrete using elements 1D, linear, modeling POU_D_E or POU_D_T, by using an elastic law of behavior</p> <p>Example : test SDLL130</p>	<p>(Application of a loading of compression are equivalent)</p>

Table 5.1.3-2: Possible combinations to represent reinforced concrete and/or prestressed with elements of structure using a total model

Remarks :

- It existe of other elements of structureS likelyS to model the concrete and in particular the elements COQUE_3D, SHB, COQUE_AXI,... It a priori no counter-indication to use them there but they were validatedS on these applications.
- When several types of modelings are mixed in the same structure, it is necessary to connect them. Means of connection (to be defined under AFFE_CHAR_MECA [U4.44.01]) most frequent as a Génie Civil, are the following:
 - embedded case when the grids are confused;
 - connection between voluminal/surface elements and of the beams: LIAISON_ELEM=_F (OPTION= '3D_POU' or '2D_POU') [R3.03.03];
 - connection flagstone-post LIAISON_ELEM=_F (OPTION = 'PLAQ_POUT_ORTH') ;
 - connection between a hull and a beam: LIAISON_ELEM=_F (OPTION='COQ_POU'), [R3.03.06].

For the other cases of connection, the keyword LIAISON_DDL is a practical tool.
- For practical advices on the questions of grid and setting in prestressed steels by DEFI_CABLE_BP/CALC_PRECONT to refer to the document [U2.03.06]
- Advices to choose as well as possible the type of modeling in the case of a study under seismic loading are available in Doc. [U2.06.10].

5.2 Laws of behavior usable for the concrete:

The tables below count the principal laws developed specifically to describe the concrete, by distinguishing the phenomena considered. The main features of these laws are indicated to make it possible to easily locate the law most adapted to the problem considered, but it is strongly advised to refer to the reference material before any use.

5.2.1 Description of the differed deformations :

	GRANGER_FP_V [R7.01.01]	GRANGER_FP [R7.01.01]	GRANGER_FP_INDT [R7.01.01]	BETON_UMLV_FP [R7.01.06]	BETON_BURGER_FP [R7.01.35]
Clean creep	ok	ok	ok	ok	ok
Creep of desiccation	nook	nook	nook	ok	ok
Thermal dilation endogenous Withdrawal of desiccation	nook	nook	nook	ok	ok
Thermic action	ok	ok	nook	nook	nook
Influence of "ageing" (hydration, polymerization, ...)	ok	nook	nook	nook	nook
Influence of the age of the concrete at the time of the loading	nook	nook	nook	nook	nook
Influence of the water content	ok	ok	ok	v	ok

Table 5.2.1-1: Main features of the various laws of creep

Several generations of models are available in *Code_Aster*, but all the models aim to describe long-term creep properly: they do not seek to reproduce it precisely who does to the young age, where the couplings between the phenomena are seems it, more important. The model more succeeded today is the model `BETON_BURGER_FP`, insofar as

- the model of `GRANGER` leads to a rather fast saturation of the deformations of creep,
- the model `BETON_UMLV_FP` suppose that the differed deformations evolve in a linear way in the long run, which generally results in over-estimating them in an important way. Moreover, the apparent Poisson's ratio is not controlled, and can evolve in an abnormal way, including becoming negative.
- the model `BETON_BURGER_FP` allows to describe the whole of the behaviors and in particular to find an evolution logarithmic curve according to the time which seems a phenomenon very usually observed.

Notice :

At present, no law of lawful creep is available in the code. However, if the deformation of creep to be modelled is limited to a spherical deformation ($\varepsilon_{fl} = C \times I_d$), it is possible to model it by using a variable of order. If it is proportional to the imposed deformation, it is possible to use a variable Young modulus.

5.2.2 Description of the damage/cracking of the concrete

To describe the degradation of the behavior, there exist several categories of models. In *Code_Aster*, three types are available:

- models of plasticity (which introduce unrecoverable deformations, via the cumulated plastic deformation p),
- models of damage (which introduce a scalar variable D or a tensor B , which comes to decrease the rigidity of material)

- models of cohesive zones, which make it possible to represent the cracks explicitly, but in the condition which the user introduced a priori into the grid the potential ways of cracking using elements of interface (`XX_INTERFACE`, [R3.06.13]. or [U2.05.07]).

Let us recall that since the model is lenitive (i.e. the constraint decreases starting from a certain level of deformation), if no specific treatment is carried out, the solution obtained is dependent on the network, on the one hand because the way in which the structure is with a grid directs the direction of propagation of the damage and on the other hand, because the facies of damage and the total answer depends on the sizes of the meshes (the smaller the meshes are, the more it is easy to break them). This phenomenon is valid at the same time for plasticity and the damage. Three methods make it possible to regularize the digital answer. The energy regularization suggested by Hillerborg at the end of the Seventies only makes it possible to limit the dependence in keeping with mesh but does not act on the dependence with the orientation of the grid. Not-local modelings `GRAD_EPSI` (which utilizes the gradient of the deformation) and `GRAD_VARI` (which utilizes the gradient of damage) allow as for them to regularize the problem in "spreading out" the zone damaged over several meshes. However, that implies to have sufficiently fine grids.

The models of cohesive zones as for them oblige the user to apply the potential ways of cracking.

Also let us announce that the models of cracking are models always complicated to implement, and who poses problems of robustness (even if the models generally manage to reach the peak of constraint without too many difficulties). They are thus to use only when it is necessary, or to interpret in a careful way (especially on the phases post-peak). For all these question of robustness, it is advisable to refer to the notes [U2.05.06] Realization of calculations of damage into quasi-static and [U2.05.07] Note of use of the models of cohesive zones to obtain advices on the way of carrying out a calculation.

The following table gives a synthetic vision of the characteristics of the various models to facilitate the choice of this one. It is highly recommended to read associated documentation before using the model chosen, and to refer to the documents of use [U2.05.06] or [U2.05.07], which give advices on the manner of carrying out calculations with models of damage or cohesive zones.

Phenomena	BETON_DOUBLE_DP [R7.01.03]	MAZARS [R7.01.08]	GRAD_VARI [R5.03.18]	ENDO_SCALAIRE [R5.03.18]	ENDO_ISOT_BETON [R7.01.04]	ENDO_ORTH_BETON [R7.01.09]	ELAS+ ZM_OUV_MIX [R7.02.11]	BETON_RAG [R7.01.26]	BETON_REGLE_PR (X_PLAN or DKT)	MAZARS_GC (1D or C_PLAN) [R5.03.09]
Size representing cracking (and variable interns associated) ⁵ : $p_{t,c}$: plasticity $D_{t,c}$: scalar damage $B_{t,c}$: tensorial damage \square_N : jump of displacement Elas: non-linear elasticity	p_t and p_c (v1 and v2)	D (v1)	D_t (v1)	D_t (v1)	B_t (v1 with v6) and D_c (v7)	δ_n (v7)	B_t (v15 with v20) and D_c (v21)	Elas	D (v3)	
Many parameters (except elasticity)	6 (+3)	6	3 (+3)	3	6	4	31 (+2)	4	6 (+2)	
Modelings available : L: local GE: GRAD_EPSI Steam Generator: GRAD_VARI	L	L/GE	Steam Generator	L/GE/ GV	L/GE	so	L	so	L	
Energy regularization included ⁶	ok	nook	so	nook	nook	so	ok	nook	nook	
Damage in traction	ok	ok	ok	ok	ok	ok	ok	ok	ok	
Damage in compression	ok	ok	ok ⁷	ok ⁷	ok	nook (rubber band)	ok	ok	ok	
Behaviour in shearing	ok	ok	ok	ok	ok	nook	ok	nook	so / ok	
Restoration of rigidity in compression	ok	nook	nook	ok	ok	ok	ok	nook	ok(1D)/no ok(2D)	
Residual deformations (plastic)	ok	nook	nook	nook	nook	nook	nook	nook	nook	
Variable parameters with the temperature	ok	ok	nook	nook	nook	nook	nook	nook	nook	
Description of the Reaction Alkali-Aggregate (RAG)	nook	nook	nook	nook	nook	nook	ok	nook	nook	
Coupling with other laws via KIT_DDI : G: GRANGER_FP UMLV: BETON_UMLV_FP	G	UMLV	nook	UMLV	nook	nook	ok ⁸	nook	nook	
Type of adapted loading : M: monotonous C: cyclic I: impact	M	M	M	M/C	M/C	M	M	M	C/M	

5 The index t or c allows to distinguish the variable used to describe the degradation of the concrete in traction or compression, when the mechanisms are different

6 Valid only for the local models

7 Quasi-fragile afterwards σ_c

Warning : The translation process used on this website is a "Machine Translation". It may be imprecise and inaccurate in whole or in part and is provided as a convenience.

Level of degradation atteignable : - M: Moderated - R: Ruin	M	M	R	R	M	R	M	M	M
Type of Models⁹ : - R: lawful - I: engineer - E: expert testimony	E	E	E	E	E	E	E	R	I/R
Robustness (facilitated convergence)	NS	NS	M	S ¹⁰ /NS	NS	S	NS	S	M (1D)/NS (2D)

Legend:

ok	taken into account	S	satisfying
ok	field of representativeness limited	M	means
nook	not taken into account	NS	Nonsatisfactory
so	without object		

Table 5.2.2-1: Main features of the various models of cracking

- 8 Model intrinsically coupled to a model of creep and a model of swelling due to the RAG
- 9 R means that it is about a lawful model or quasi-equivalent, I: mean that it is a model relatively robust and qualified for our applications, E: mean that it is a model dedicated to expert testimonies, either because it is not very robust (difficulty of convergence), or because it is complex to implement, or because it is not yet completely validated.
- 10 By using IMPL_EX for the resolution (cf [R5.03.81])

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Remarks :

1. For lawful standard calculations, to use `BETON_REGLE_PR` or `MAZARS_GC` (which includes internal variables of postprocessing, `V1` and `V2` correspondent with an ultimate ratio forced/stress or limiting deformation/deformation, which in 1D, corresponds to criteria ELS/ELU classically used in study of civil engineer, cf [R3.05.09]).
2. The more there are ingredients in a model, the more important the number of parameters materials is and generally less the model is robust and performing: it is thus preferable to choose the simplest possible model by identifying the field well where it will be solicited.
3. More one seeks to describe cracking finely and to describe long way of cracking, more models it must be irreproachable from a mathematical point of view. From this point of view, it is the model `ENDO_SCALAIRE` more "performing".
4. Modeling `GRAD_EPSI` is not powerful when one seeks to describe multi-cracking or long propagations of cracks.
5. The model `ENDO_ISOT_BETON`, local version, perhaps solved with the method `IMPL-EX`, which guarantees to have a result, which can be interesting in certain cases, but attention the resolution depends then strongly on the discretization in time, which must be very refined (cf [R5.03.81]) and the results are not reliable in the presence of instabilities.
6. Except if cracking is represented by a model of cohesive zones, one does not have access directly to an opening of crack. Provided that the damage is sufficiently important, it is possible to have a correct order of magnitude of this opening by using the operator `POST_ENDO_FISS` in a plan, in the case of a model of damage not-room (cf [U4.86.01]), or by calculating the difference in displacement on both sides of the element damaged in the case of a local model.
7. The model `BETON_DOUBLE_DP` is the first model which was developed to describe the softening of the concrete. It has a major drawback, it is that because of the form of the criterion, it is possible in the configurations of loading bi- or three-dimensional, to exceed the ultimate stress of traction.

5.2.3 Description of the damage/cracking of the reinforced concrete

The following table recapitulates same manner the characteristics of the laws making it possible to describe the damage of the reinforced concrete via laws known as total, i.e. describing the behavior of the concrete and steels simultaneously. One of the main advantages of these laws is to make it possible not to have lenitive models more and thus to free themselves from the associated problems (dependence with the grid, difficulty of convergence,...).

	GLRC_DM [R7.01.32]	DHRC [R7.01.33]	GLRC_DAMAGE [R7.01.31]
Damage in extension	ok	ok	ok
Damage in compression	ok	ok	ok
Damage in shearing	ok	ok	ok
Membrane	ok	ok	ok
Inflection	ok	ok	ok
Refermeture of cracks	ok	ok	nook
Transverse shearing	nook	nook	ok
Residual deformations (plastic)	nook	ok	ok
Taking into account of the withdrawals	ok (only ϵ^{th})	ok (only ϵ^{th})	nook
Coupling	VMIS_CINE_LINE (membrane only)	so	so
Type of adapted loading: M: monotonous C: cyclic I: impact	M/C	C	I
Level of degradation atteignable: - M: Moderated - R: Ruin	M		R
Robustness	S	S	S
Reliability/Validation	S	NS	S

Legend

X	taken into account	S	satisfying
X	field of representativeness limited	M	means
nook	not taken into account	NS	Nonsatisfactory
so	without object		

Table 5.2.3-1 : Main features of the total reinforced concrete models

Notice :

The total laws were developed with for objective being powerful for the dynamic studies (seismic loadings for GLRC_DM and DHRC, standard loading impact for GLRC_DAMA).

5.2.4 Compatibility laws of behavior/modeling

All the laws of behavior are not available for all modelings. The purpose of the following table is to help the user to choose, is the modeling which it can adopt according to the law of behavior chosen, that is to say to know the laws of behavior usable according to modeling that it wishes to adopt.

	3D 3D_SI D_PLAN D_PLAN_S I	C_PLAN C_PLAN_S I	AXIS AXIS_SI	X_GRAD_EP SI	X_GRAD_V ARI	DKT	POU_D_X	COQUE_3D	DKTG	X_INTERFACE
ELAS	ok	ok	ok	nook	nook	ok	ok	ok	nook	nook
GRANGER_FP GRANGER_FP _V GRANGER_FP _INDT	ok	ok	ok	nook	nook	nook	ok	nook	nook	nook
BETON_UMLV _FP	ok	ok	ok	nook	nook	nook	nook	nook	nook	nook
BETON_BURG ER_FP	ok	ok	ok	nook	nook	nook	nook	nook	nook	nook
BETON_DOUB LE_DP	ok	ok	ok	nook	nook	ok	ok	ok	nook	nook
MAZARS	ok	ok	ok	ok	nook	ok	nook	ok	nook	nook
ENDO_SCALA IRE	nook	nook	nook	nook	ok	nook	nook	nook	nook	nook
ENDO_ISOT_ BETON	ok	ok	ok	ok	ok	ok	ok	ok	nook	nook
ENDO_ORTH_ BETON	ok	ok	ok	ok	nook	ok	nook	ok	nook	nook
ELAS+CZM_O UV_MIX	nook	nook	nook	nook	nook	nook	nook	nook	nook	ok
BETON_RAG	ok	ok	ok	nook	nook	nook	nook	nook	nook	nook
BETON_REGL E_PR	ok(PLA N only)	ok	nook	nook	nook	ok	nook	ok	nook	nook
MAZARS_GC	nook	ok	nook	nook	nook	ok	ok	ok	nook	nook
GLRC_DM	nook	nook	nook	nook	nook	nook	nook	nook	ok	nook
GLRC_DAMA	nook	nook	nook	nook	nook	nook	nook	nook	ok	nook

Table 5.2.4-1: Laws of behavior usable according to selected modeling

5.3 Laws of behavior usable for steel

In practice, almost all the laws established in 3D are available for voluminal and plane modelings but also for modelings DKT and COQUE_3D (natively, if the law is programmed in plane constraints, via the algorithm DeBorst [R5.03.03] if it is not the case) and for the elements whose behavior is 1D (BAR, POU_D_EM, POU_D_TGM, GRILLE_MEMBRANE, GRILLE_EXCENTREE) thanks to the algorithm DeBorst1D [R3.03.09].

In the table below, one mentions the laws most usually used.

	Elasticity	Plasticity isotropic hardening with work	Plasticity kinematic hardening with work	Plasticité+effet Bauschinger ¹¹	Plasticité+Endommagement couplé with corrosion
Voluminal elements or plans	ELAS	VMIS_ISOT_LINE VMIS_ISOT_TRAC VMIS_ISOT_PUIS	VMIS_ISOT_CINE		CORR_ACIER
DKT	ELAS	VMIS_ISOT_LINE VMIS_ISOT_TRAC VMIS_ISOT_PUIS	VMIS_ISOT_CINE		CORR_ACIER
COQUE_3D	ELAS	VMIS_ISOT_LINE VMIS_ISOT_TRAC VMIS_ISOT_PUIS	VMIS_ISOT_CINE		CORR_ACIER
MEMBRANE	ELAS				
GRILLE_MEMBRANE	ELAS	GRILLE_ISOT_LIN E	GRILLE_CINE_LINE	GRILLE_PINTO_ MEN	
GRILLE_EXCENTREE	ELAS	GRILLE_ISOT_LIN E	GRILLE_CINE_LINE	GRILLE_PINTO_ MEN	
POU_D_TGM POU_D_EM	ELAS	VMIS_ISOT_LINE VMIS_ISOT_TRAC VMIS_ISOT_PUIS	VMIS_ISOT_CINE	PINTO_MENEGOT TO	CORR_ACIER
BARRE/2D_BARRE	ELAS	VMIS_ISOT_LINE VMIS_ISOT_TRAC VMIS_ISOT_PUIS	VMIS_CINE_LINE	PINTO_MENEGOT TO	CORR_ACIER

Table 5.3-1: Models of behavior usable for steel according to selected modeling

5.4 Models of behavior usable for the steel-concrete connection

In most case, it is sufficient to consider that the connection between steel and the concrete is perfect. In this case, it is enough that the meshes steel and the meshes concrete rest on the same ones nodes. If the grids are not compatible, then it is necessary to create connections kinematics between nodes of the two materials (what weighs down calculations of course. These connections kinematics are generated automatically by the operator DEFI_CABLE_BP.

Nevertheless, it can happen that one wishes to take into account this phenomenon, for example to simulate a situation where adherence between steel and the concrete is very degraded or because one wishes to search local information such as spacings and openings of cracks. Models are thus available in Code_Aster, but let us announce that the characterization of the steel-concrete connection, and consequently the identification of the parameters of the laws of behavior, remain difficult access.

¹¹ Translated the fact that if one plasticizes a metal in a given direction, then that one deforms it in opposite direction in the same direction, one observes that the elastic limit decreased.

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For a modeling in `AXIS` or `D_PLAN`, steel and the concrete can be with a grid explicitly and connected by an element of joint (modeling `AXIS_JOINT` or `PLAN_JOINT`, [U3.13.14]), to which the law of behavior `JOINT_BA` [R7.01.21] is affected. However, let us announce that it is about a model very rich but complicated to implement, and who can have not very physical results for great slips (taken again important of rigidity).

For a modeling of the concrete in `3D`, and a representation of steels, is in `3D`, that is to say in the form of `MEMBRANE`, it is possible to describe the steel-concrete connection using elements of interface placed between the 2 materials (modeling `3D_INTERFACE` [U3.13.14]) to which the law of behavior `CZM_LAB_MIX` is affected [R7.02.11].

Lastly, let us announce that it is possible to represent cables rubbing in `1D`, using modeling `CABLE_GAINE` [R3.08.10] and of the law of behavior `CABLE_GAINE_FROT`. The model of friction is of type Coulomb (cf test `ZZZZ347E`).

5.5 Modeling of the interaction ground – structure and Interaction structure - ground - structure

The taking into account of the interaction ground-structure (ISS) and the interaction structure-ground-structure (I3S) is equivalent considering the energy dissipated in the ground and the effects of coupling between the ground and the close buildings at the time of dynamic stresses (earthquake). In statics, it makes it possible to have boundary conditions more realistic than a perfect embedding. Several methods exist to model the interaction between (S) the structure (S) studied (S) and the ground:

- To explicitly model the ground with isoparametric elements (to be noted that, in *Code_Aster*, only the elastoplastic model of behavior known as of “Hujeux” [R7.01.23] is able to take into account a cyclic loading. It makes it possible to consider the behavior of géomatériaux granular, sandy clays normally consolidated E S or on-consolidated E S, low registers,....) . In statics, one can be satisfied to model the ground in rubber band or with a law of Mohr-Coulomb [R7.01.28] ;
- To use springs of ground for lawful calculations of ISS, to take into account separation and the reduction amongst modes of a foundation (cf. [U2.06.08]).
- To use `MISS3D` (cf [U2.06.07] for the classical cases (elastic range) and [U3.06.21] for the more complex cases at the time of the taking into account of space variability in the seismic analyses [U2.06.12]).
It should be noted that: `MISS3D` allows to model at the same time rigid or flexible foundations, heterogeneous grounds - with an extension particular to the laminated grounds (of not taken into account of the dip) - and foundation rafts of an unspecified form, and thus to allow calculations of dynamic interaction with one or more unspecified structures (I3S).
The chaining *Code_Aster* – `MISS3D` is based on a coupling of the type BEM-FEM which makes it possible to take into account the ISS and the I3S in dynamic calculations in seismic analysis. Nevertheless, the resolution being in frequency, only the problems linear could be treated until now with this approach.
- To use `MISS3D` for the complex cases. A new method Laplace-time, which also passes by the calculation of the impedances of ground with `MISS3D`, then makes it possible to carry out non-linear transitory calculations (with the use of `DYNA_NON_LINE`).

The table below makes it possible to easily compare the characteristics and the field of validity of various modelings.

	Column of ground (géomechanics)	RIGI_PARASOL (calculation of ISS in Code_Aster pure)	CALC_MISS (calculation of ISS with MISS3D)
Separation	so	ok (calculation of the impedances with MISS3D)	ok (mechanical calculation with Code_Aster)
Shallow foundation	ok	ok	ok
Buried foundation	ok	ok	ok
Floor covering (S) /rigide (R)	S	R and S	R and S
Space variability (DYNA_ISS_VARI)	nook	ok (precondition to a calculation of modes of foundation unspecified)	ok
Type of loadings: SL: linear statics SNL: Statics non-linear DL: linear dynamics DNL; non-linear dynamics	ok SL, SNL, DL, DNL	ok SL, SNL, DL, DNL	ok SL, DL ok SNL, DNL with use of the method Laplace/time
Type of Models ¹² : - R: lawful - I: engineer - E: expert testimony	I and E	R, I and E	R, I and E

Table 5.5-1: Comparison of various modelings of the interaction ground-structure

Legend

- ok taken into account
- ok field of representativeness limited
- nook not taken into account
- so without object

6 Others

6.1 Calculation of reinforcement

It is possible to calculate the reinforcement of one structure using the operator `CALC_FERRAILLAGE` [U4.81.42]. The method used is that of Capra and Maury [R7.04.05]

6.2 Macro of assistance to the identification of the parameters materials

For a certain number of laws of behavior, the identification of the parameters materials can prove relatively complex. Also, some macros were developed to help the users to carry out this stage. It is about:

- `DEFI_GLRC` [U4.42.06] for the total laws `GLRC_DM` and `GLRC_DAMAGE`, which makes it possible to obtain the properties of the concrete homogenized starting from the physical and geometrical characteristics of the reinforced concrete
- `DEFI_MATER_GC` [U4.42.07] for the law of `MAZARS` or `MAZARS_GC` while making use of the rules resulting from Eurocode 2

¹² R means that it is about a lawful model or quasi-equivalent, I: mean that it is a model relatively robust and qualified for our applications, E: mean that it is a model dedicated to expert testimonies, either because it is not very robust (difficulty of convergence), or because it is complex to implement, or because it is not yet completely validated.

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The reference material remains in any event, an essential information source knowing that in complement, for certain laws, there exists in-house EDF, of the Model Cards of Identities which clarify the techniques of identification.

6.3 Pre/Postprocessing

6.3.1 Checking put in data

One often needs to check the setting in data, to be sure for example to have affected the good geometrical characteristics with elements of structures, to have directed them well, that the affected material fields were indeed assigned to the good groups of meshes,...

Tools for visualization can be interesting to help with the checking of the setting in data;

- to visualize the elements of structures in 3D. This is possible under SaloméMeca/GEOM as one can see it on the following figure by publishing the command file thanks to EFICAS/View3D, cf [U1.04.10].

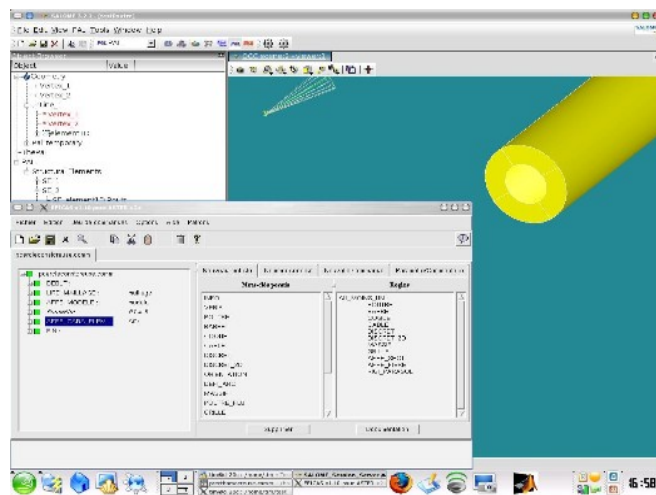


Figure 6.3.1-a: example of visualization 3D of a beam

- To visualize the orientation of the elements of structures under SaloméMeca. This is possible by printing with format MED (cf [U7.05.21]) the local reference mark and by visualizing these concepts under SaloméMeca. An example is shown below.

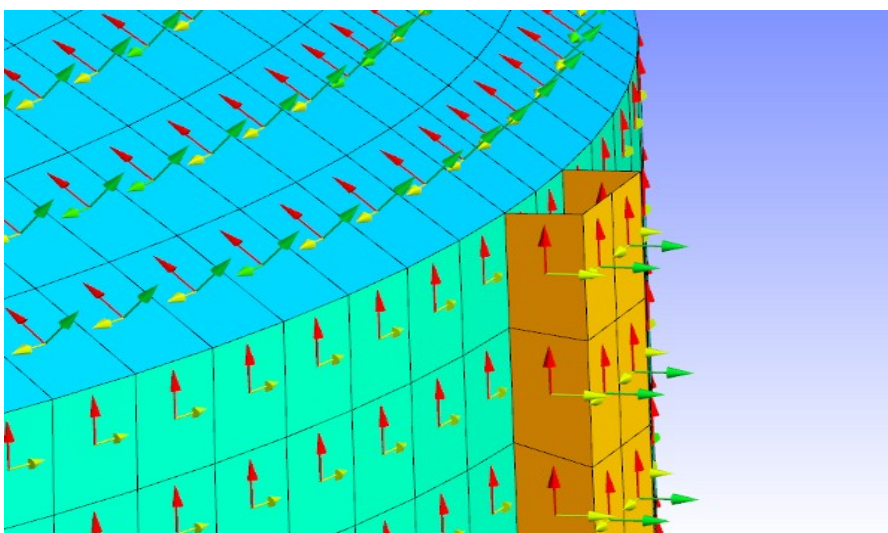


Figure 6.3.1-b: example of visualization of the orientation of the local reference mark

- To visualize with different colors, the groups of mesh having a different thickness, having been affected by different materials, etc For that, it is advisable to print the field desired with format MED (cf [U7.05.21]), for example:

```
IMPR_RESU ( FORMAT=' MED',  
CONCEPT= (_F ( CHAM_MATER = CHMAT),  
_F (CARA_ELEM = CARELE),  
_F (LOAD = CHAR1),),),);
```

One obtains then in a file med, a field called CHMAT_CHAMP_MAT having a value by mesh among: 0,1,2,... the correspondence enters the values: 1,2,3... and the names of materials is written in the files of message and result.

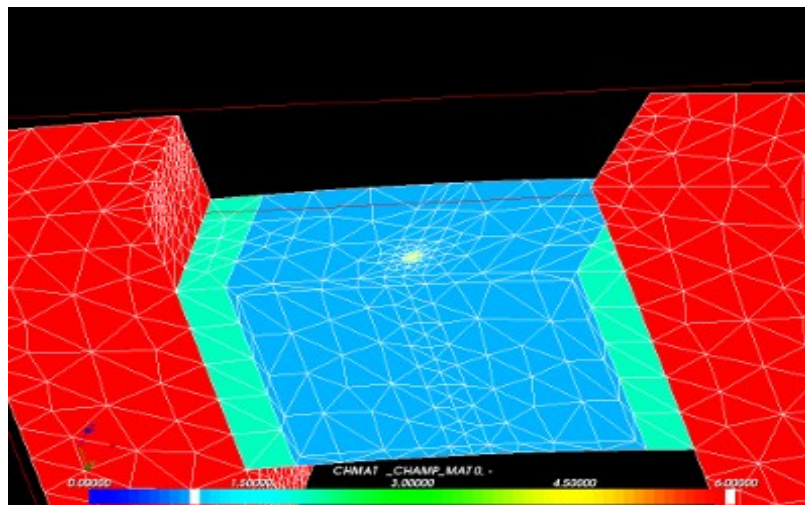


Figure 6.3.1-c: example of visualization under Salomé of the material assignments

6.3.2 Postprocessings

For postprocessings, many opportunities are given to the user, which cannot be detailed. Let us quote simply some options specific to Génie Civil:

- Thanks to the operator CALC_CHAMP [U4.81.04], of many options are available according to the modeling or of the law of behavior used, among which one can quote:
 - to isolate the deformations related to clean creep EPFP_XXXX or of desiccation EPFD_XXXX ;
 - to isolate the thermal deformations, the endogenous withdrawal or of desiccation EPVC_XXXX ;
 - to calculate constraints projected on the skin of a volume (for example on the facings of a hydraulic work) SIRO_ELEM ;
 - to calculate dissipated energies DISS_XXXX, ECIN_ELEM.
- To visualize data on a hull multi-layer thanks to the operator IMPR_RESU /FORMAT_MED, NIVE_COUCHE.
- To extract from the efforts or the deformations in an unspecified point of a hull thanks to the operator POST_COQUE [U4.81.23].
- To trace the way of cracking and to calculate the opening of crack (2D only starting from one calculation of damage not-room (GRAD_EPSI or GRAD_VARI) thanks to the operator POST_ENDO_FISS [U4.86.01].
- Construction of curve of brittleness with POST_DYNA_ALEA, [U4.84.04] and [U2.08.05].

7 What Code_Aster cannot (still) do

No model is available in a direct way in *Code_Aster* to represent:

- the damage of the concrete at high temperature (not of damage of thermal origin),
- Thermal Transient Creep (unrecoverable deformation which occurs when one heats the concrete with more 100°C whereas it is subjected to loading of compression),
- phenomena of RSI (Sulfatique Reaction Interns),
- carbonation of the concrete,
- the cracking of the concrete to the young age,
- taking into account of the thermal radiation in calculations,
- the coupling hydration-drying,
- a model of creep adapted specifically to the young age or the higher temperatures with 80°C.
- a law of behavior allowing to simulate the relieving of the cables of prestressed in the course of time,
- taking into account of drying and the hydration for the elements of structure.