Operator DEFI_MATERIAU

1 Goal

To define the behavior of a material or the parameters associated with tiredness, the damage, or the simplified methods.

The allowed laws of behavior currently by this operator relate to the following fields: Mechanics and Thermics linear or not, Metallurgical for the modeling of steels, Hydration and Drying for the concretes, Fluid for acoustics, Thermo-Hydro-mechanics for the modeling of the porous environments saturated with thermomechanical coupled and Soil mechanics.

If necessary, the same material can be defined at the time of a call to DEFI_MATERIAU with several behaviors, such as rubber band, thermics,…

Product a structure of data of the type to subdue.
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6 Thermal behaviors
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6.2 Keyword factor THER ORTH
6.3 Keyword factor THER NL
6.4 Keywords factor THER COQUE, THER_COQUE_FO

7 Behaviors specific to the concretes
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7.2 Keyword factor SECH_GRANGER
7.3 Keyword factor SECH_MENSI
7.4 Keyword factor SECH_BAZANT
7.5 Keyword factor SECH_NAPPE
7.6 Keyword factor PINTO_MENEGOTTO
7.7 Keywords factor BPEL_BETON, BPEL_ACIER
7.8 Keywords factor ETCC_BETON, ETCC_ACIER
7.9 Keyword factor CONCRETE_DOUBLE_DP
7.10 Keyword factor BETON_GRANGER, V_BETON_GRANGER
7.11 Keyword factor MAZARS, MAZARS_FO
7.12 Keyword BETON UMLV
7.13 Keyword factor BETON ECRO_LINE
7.14 Keyword factor ENDO ORTH_BETON
7.15 Keywords factor ENDO_SCALAIRE/ENDO_SCALAIRE_FO
7.16 Keyword factor ENDO_FISS_EXP/ENDO_FISS_EXP_FO
7.17 Keyword factor GLRC_DM
7.18 Keyword factor DHRC
7.19 Keyword factor BETON_REGLE_PR
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2 General syntax

my [to subdue] = DEFI_MATERIAU {
  reuse = chechmate, [to subdue]
  MATER = chechmate, [to subdue]

  # Elastic behaviors Generals [§ 3]
  | / ELAS, # to see [§ 3.1]
  | / ELAS_FO,
  | / ELAS_FLUI,
  | / CABLE,
  | / ELAS_ORTH, # to see [§ 3.4]
  | / ELAS_ORTH_FO,
  | / ELASISTR,
  | / ELASISTR_FO,
  | / ELAS_COQUE,
  | / ELAS_COQUE_FO,
  | / ELAS_MEMBRANE, # to see [§ 3.7]
  | / ELAS_HYPER, # to see [§ 3.8]
  | / ELAS_2NDG, # to see [§ 3.9]
  | / ELAS_GLRC, # to see [§ 3.10]
  | / ELAS_DHRC, # to see [§ 3.11]

  # Mechanical behaviors Non Linéaires Généraux [§ 4]
  | / TRACTION, # to see [§ 4.1]
  | / ECRO_LINE,
  | / ECRO_LINE_FO,
  | / PRAGER, # to see [§ 4.3]
  | / PRAGER_FO,
  | / ECRO_PUIS,
  | / ECRO_PUIS_FO,
  | / CIN1_CHAB,
  | / CIN1_CHAB_FO,
  | / CIN2_CHAB,
  | / CIN2_CHAB_FO,
  | / VISCOCHAB,
  | / VISCOCHAB_FO,
  | / MEMO_ECRO,
  | / MEMO_ECRO_FO,
  | / CIN2_NRAD,
  | / TAHERI,
  | / TAHERI_FO,
  | / MONO_VISC1,
  | / ECOU_VISC2,
  | / MONO_CINE1,
  | / MONO_CINE2,
  | / MONO_ISOT1,
  | / MONO_ISOT2,
  | / MONO_DD_KR,
  | / MONO_DD_CFC,
  | / MONO_DD_CFC_IRRA,
  | / MONO_DD_FAT,
  | / MONO_DD_CC,
Behaviors related to the damage and the rupture \text{[§5]}

\begin{verbatim}
| / ROUSSELIER, # to see [§ 5.1]  
| / ROUSSELIER_FO,  
| / VENDOCHAB, # to see [§ 5.2]  
| / VENDOCHAB_FO,  
| / VISC_ENDO, # to see [§ 5.3]  
| / VISC_ENDO_FO,  
| HAYHURST, # to see [§ 5.4]  
| NON_LOCAL, # to see [§ 5.5]  
| / RUPT_FRAG, # to see [§ 5.6]  
| / RUPT_FRAG_FO,  
| CZM_LAB_MIX, # to see [§ 5.7]  
| RUPT_DUCT, # to see [§ 5.8]  
| RANKINE, # to see [§ 5.9]  
| JOINT_Meca_Rupt, # to see [§ 5.10]  
| JOINT_Meca_Frot, # to see [§ 5.11]  
| CORR_ACIER, # to see [§ 5.12]  
| ENDO_HETEROGENE, # to see [§ 5.13]  
\end{verbatim}

Thermal behaviors \text{[§6]}

\begin{verbatim}
| / THER, # to see [§ 6.1]  
| / THER_FO,  
| / THER_ORTH, # to see [§ 6.2]  
| / THER_NL, # to see [§ 6.3]  
| / THER_COQU, # to see [§ 6.4]  
| / THER_COQU_FO,  
\end{verbatim}

Behaviors specific to the concretes \text{[§7]}

\begin{verbatim}
| THER_HYDR, # to see [§ 7.1]  
| SECH_GRANGER, # to see [§ 7.2]  
| SECH_MENSI, # to see [§ 7.3]  
| SECH_BAZANT, # to see [§ 7.4]  
| SECH_NAPPE, # to see [§ 7.5]  
| PINTO_MENEGOTTO, # to see [§ 7.6]  
| BPEL_BETON and BPEL_ACIER, # to see [§ 7.7]  
| ETCC_BETON and ETCC_ACIER, # to see [§ 7.8]  
| BETON_DOUBLE_BP, # to see [§ 7.9]  
| BETON_GRANGER and V_BETON_GRANGER, # to see [§7.10]  
| MAZARS # to see [§7.11]  
| BETON_UMLV, # to see [§7.12]  
| BETON_ECRO_LINE, # to see [§7.13]  
| ENDO_ORTH_BETON, # to see [§7.14]  
| ENDO_SCALAIRE, # to see [§7.15]  
| ENDO_FISS_EXP, # to see [§7.16]  
| GLRC_DM, # to see [§7.17]  
\end{verbatim}
# Behaviors Metal-worker-Mechanics [§ 8]
- META_ACIER,  # to see [§ 8.1]
- META_ZIRC,  # to see [§ 8.2]
- DURT_META,  # to see [§ 8.3]
- ELAS_META,  # to see [§ 8.4]
- META_ECRO_LINE,  # to see [§ 8.5]
- META_TRACTION,  # to see [§ 8.6]
- META_VISC_FO,  # to see [§ 8.7]
- META_PT,  # to see [§ 8.8]
- META_RE,  # to see [§ 8.9]
- META_LEMA Ansi,  # to see [§ 8.10]
- META_LEMA ANSI FO,  # to see [§ 8.10]

# Behaviors Thermo-Hydro-Mechanics and of the grounds [§ 9]

- COMP_THM = / 'LIQU SATU',  # to see [§ 9.1]
- / 'LIQU GAZ',
- / 'GAS',
- / 'LIQU GAZ ATM',
- / 'LIQU VAPE GAZ',
- / 'LIQU VAPE',
- / 'LIQU AD GAZ VAPE',
- / 'LIQU AD GAZ',

- THM INIT,  # to see [§ 9.2]
- THM LIQU,  # to see [§ 9.3]
- THM GAZ,  # to see [§ 9.4]
- THM VAPE GAZ,  # to see [§ 9.5]
- THM AIR DISS,  # to see [§ 9.6]
- THM DIFFU,  # to see [§ 9.7]
- MOHR COULOMB,  # to see [§ 9.8]
- CAM CLAY,  # to see [§ 9.9]
- CJS,  # to see [§ 9.10]
- LAIGLE,  # to see [§ 9.11]
- LETK,  # to see [§ 9.12]
- DRUCK PRAGER,  # to see [§ 9.13]
- VISC DRUC PRAG,  # to see [§ 9.14]
- BARCELONA,  # to see [§ 9.15]
- HUJEUX,  # to see [§ 9.16]
- HOEK BROWN,  # to see [§ 9.17]
- ELAS GONF,  # to see [§ 9.18]
- JOINT BANDIS,  # to see [§ 9.19]
- THM RUPT,  # to see [§ 9.20]
- Iwan,  # to see [§ 9.21]
- LKR,  # to see [§ 9.22]

# Behavior specific to the elements 1D [§ 10]
- ECRO ASYM LINE,  # to see [§ 10.1]

# Particular behaviors [§ 11]
- LEMAITRE IRA,  # to see [§ 11.1]
- DIS GRICRA,  # to see [§ 11.2]
Remarks:

The order `DEFI_MATERIAU` is D-entering but each behavior remains single. One does not allow to replace a behavior already present in material, but only to enrich the concept.

For most behaviors, it is possible to define constant characteristics or many characteristics depending on one or more variables of orders (see the orders `AFFE_MATERIAU` and `AFFE_VARC`) in the form of a function, of a tablecloth or a formula. The parameters time (`INST`), plastic deformation (`EPSI`), and curvilinear X-coordinate (`ABSC`) can be used in very particular cases, the behaviors being able to depend on these parameters explicitly specify it in their description.
3 Elastic behaviors generals

3.1 Keywords factor ELAS, ELAS_FO

Definition of the constant linear elastic characteristics or functions.

3.1.1 Syntax

```
| ELAS = _F ( ♦ E = yg, [R]
   ♦ NAKED = naked, [R]
   ♦ RHO = rho, [R]
   ♦ ALPHA = dil, [R]
   ♦ AMOR_ALPHA = a_alpha, [R]
   ♦ AMOR_BETA = a_beta, [R]
   ♦ AMOR_HYST = eta [R]
   ♦ LONG_CARA = will lcara, [R]
   ♦ COEF_AMOR = / coeam, [R]
       / 1.0, [DEFECT]

| ELAS_FO = _F ( ♦ E = yg, [function]
   ♦ NAKED = naked, [function]
   ♦ RHO = rho, [function]
   ♦ ALPHA = dil, [function]
   ♦ AMOR_ALPHA = a_alpha, [function]
   ♦ AMOR_BETA = a_beta, [function]
   ♦ AMOR_HYST = eta, [function]
   ♦ TEMP_DEF_ALPHA = Tdef, [R]
   ♦ PRECISION = / eps, [R]
       / 1.0, [DEFECT]
   ♦ K_DESSIC = / K, [R]
       / 0.0, [DEFECT]
   ♦ B_ENDOGE = / E, [R]
       / 0.0, [DEFECT]
   ♦ FONC_DESORP = F [function]
)
```

Most functions can depend on the variables of orders (see [U4.43.03]) or other parameters like time (`INST` or geometry `X`, `Y`, `Z`)

`TEMP`, `HYDR`, `SECH`, `NEUT1`, `NEUT2`, `X`, `Y`, `Z`, ...

Caution! For the geometry, there are two cases:
- Direct variables `X`, `Y`, `Z` who function only in some typical cases;
- The variable of order `GEOM` who is more general;

3.1.2 Operands E/NU

E = yg
Young modulus. It is checked that \( E \geq 0 \).

NAKED = naked
Poisson’s ratio. It is checked that \(-1. \leq \nu \leq 0.5\).

3.1.3 Operand RHO

RHO = rho
Density. No the checking of about size. Attention for modelings THM in statics, only the density homogenized well informed in THM_DIFFU (cf section 9.7.2) will be taken into account. For modelings
THM in dynamics, this value must on the other hand be here indicated and be coherent with that indicated in THM_DIFFU.

This keyword perhaps function only geometry via the variable of order 'GEOM'.

### 3.1.4 Operands ALPHA/TEMP_DEF_ALPHA/PRECISION

**ALPHA** = alpha
Isotropic thermal dilation coefficient.
The thermal dilation coefficient is an average dilation coefficient which can depend on the temperature $T$.

The values of the dilation coefficients are determined by tests of dilatometry which take place with the room temperature ($0\,^\circ\text{C}$ or more generally $20\,^\circ\text{C}$).

So one in general has the values of the dilation coefficient defined compared to $20\,^\circ\text{C}$ (temperature to which one supposes the worthless thermal deformation).

Certain studies require to take a temperature of reference different from the room temperature (worthless thermal deformation for another temperature that the room temperature). It is then necessary to carry out a change of reference mark in the calculation of the thermal deformation [R4.08.01].

**TEMP_DEF_ALPHA** = $T_{\text{def}}$  
It is the value of the temperature to which the values of the thermal dilation coefficient were given, and were indicated under the keyword **ALPHA**.

This keyword becomes obligatory as soon as one informed **ALPHA**.

For the behaviors non-THM, the calculation of the thermal deformation is done by the formula [R4.08.01]:

$$
e^{\text{th}}(T) = \hat{\alpha}(T) |T - T_{\text{ref}}|$$

with

$$
\hat{\alpha}(T) = \frac{\alpha(T)(T - T_{\text{ref}}) - \alpha(T_{\text{ref}})(T_{\text{ref}} - T_{\text{def}})}{T - T_{\text{ref}}}
$$

and

$$e^{\text{th}}(T_{\text{ref}}) = 0
$$

**Note:**

It is not possible to use a formula nor a tablecloth for **ALPHA**, because them modifications to be taken into account described above. The parameter **ALPHA** can depend ONLY on the temperature and provided that it is a function. The user, if it wishes to use a formula, owes initially the tabuler using the order CALC_FONC_INTERP.

**PRECISION** = / prec / 1.  
[DEFECT]

This keyword is used when the keyword **TEMP_DEF_ALPHA** is specified.

It is a reality which indicates with which precision a temperature $T_i$ (list of the temperatures being used for the definition of $\alpha(T_i)_{i=1,N}$) is close to the temperature of reference $T_{\text{ref}}$.

This reality is used for calculation of the function $\hat{\alpha}(T_i)$. The mathematical formula allowing the calculation of $\hat{\alpha}(T_i)$ is different according to whether $T_i \neq T_{\text{ref}}$ or $T_i = T_{\text{ref}}$.

In THM, the calculation of the thermal deformation is different (see [R4.08.01]). The thermal deformation is evaluated by the following formula:

$$e^{\text{th}}(T) = \alpha(T - T_{\text{ini}})$$

---

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In particular, one does not use TEMP_DEF_ALPHA (but one must inform it) and ALPHA cannot be a function, it is necessarily a constant. Moreover, the temperature of reference is given by THM_INIT/TEMP (see §9.2).

### 3.1.5 Operands AMOR_ALPHA / AMOR_BETA / AMOR_HYST

AMOR_ALPHA = has_alpha  
AMOR_BETA = a_beta  

Coefficients $\alpha$ and $\beta$ allowing to build a matrix of viscous damping proportional to rigidity and/or the mass $[C] = \alpha [K] + \beta [M]$. One will refer to the documents of modeling of the mechanical cushioning [U2.06.03] and [R5.05.04].

AMOR_HYST = eta  

Coefficient $\eta$ of damping hysteretic allowing to define the Young modulus complexes (viscoelastic material) from which will be created complex matrix of rigidity allowing the calculation of the harmonic answer [U2.06.03] and [R5.05.04].

**NoticeS:**

- The presence of the keywords AMOR_ALPHA and AMOR_BETA associated with a zero value, can lead, in certain algorithms, with to assemble a matrix of damping and generates additional cost of calculation thus.
- These keywords can depend on the geometry via the direct variables ‘X’, ‘Y’ and ‘Z’ but not of the variable of order ‘GEOM’.

### 3.1.6 Operands COEF_AMOR / LENGTH_CARA

For the justification of the use of these operands, one will refer to the documents of modeling of the elements of absorbing border [R4.02.05].

COEF_AMOR = coeam  

Coefficient intervening in the expression of the vector forced integrated along the absorbing border of the finite elements field and which corresponds to viscous shock absorbers distributed along this border:

$$ t_0 = coeam ( \rho c_p \frac{\partial u_3}{\partial t} e_3 + \rho c_s \frac{\partial u_e}{\partial t} ) $$

This term is affected with material constitutive of the element of absorbing border.

LONG_CARA = lcarha  

Coefficient corresponding to a characteristic dimension $L$. Associated with the coefficients of Lamé $\lambda$ and $\mu$, this coefficient intervenes in the expression of the added term of vector forced integrated along the absorbing border of the finite elements field, which corresponds to the rigidities distributed along this border of the finite elements field:

$$ t_i = \frac{\lambda + 2\mu}{L} u_i, e_3 + \frac{\mu}{L} u_e $$

This term is affected with material constitutive of the element of absorbing border.

**Note:**  
*The absence of the keyword LENGTH_CARA causes which one does not affect of rigidity added on the absorbing border.*

### 3.1.7 Operands K_DESSIC / B_ENDOGE

K_DESSIC = K  

Coefficient of withdrawal of dessication.

K_ENDOGE = E  

Endogenous coefficient of withdrawal.
These characteristics are used with the behaviors DU concrete (vto oir ref. [R7.01.12]).

3.1.8 Operand **FONC_DESORP**

\[ FONC_DESORP = F \]

curve of sorption-desorption [R7.01.12] giving the hygroscopy \( h \) according to the water content \( C \).

3.2 **Keyword factor ELAS_FLUI**

The keyword **ELAS_FLUI** allows to define the equivalent density of a tubular structure with internal and external fluid, by taking of account the effect of containment.

This operation lies within the scope of the study of the dynamic behavior of a configuration of standard “the tube bundle under transverse flow”. The study of the behavior of the beam is brought back under investigation single tube representative of the whole of the beam. Ref. [U4.35.02]

Equivalent density of the structure \( \rho_{eq} \) is defined by:

\[
\rho_{eq} = \frac{1}{(d_e^2 - d_i^2)} \left[ \rho_f d_i^2 + \rho_c (d_e^2 - d_i^2) + \rho_s d_e^2 \right] \\
d_{eq}^2 = \frac{2 C_m d_e^2}{\pi}
\]

\( \rho_f, \rho_c, \rho_s \) are respectively the density of the fluid, external fluid and structure.

\( d_e, d_i \) are respectively the external diameter and intern of the tube.

\( C_m \) is a coefficient of added mass (which defines containment).

3.2.1 **Syntax**

```
| ELAS_FLUI = _F ( 
  ♦ RHO = rho, [R]  
  ♦ E = yg, [R]  
  ♦ NAKED = naked, [R]  
  ♦ PROF_RHO_F_INT = rhoi, [function]  
  ♦ PROF_RHO_F_EXT = rhoe, [function]  
  ♦ COEF_MASS_AJOU = fonc_cm [function]  
)
```

3.2.2 **Operands RHO/E/NU**

\( \rho_f \) = rho

Density of material.

\( E = yg \)

Young modulus.

\( NAKED = naked \)

Poisson's ratio.

3.2.3 **Operands PROF_RHO_F_INT/PROFESSEUR_RHO_F_EXIT/COEF_MASS_AJOU**

**PROF_RHO_F_INT = rhoi**

Concept of the type [function] defining the profile of density of the fluid interns along the tube. This function is parameterized by the curvilinear X-coordinate.
PROF_RHO_F_EXT = rhoe
Concept of the type [function] defining the profile of density of the external fluid along the tube.
This function is parameterized by the curvilinear X-coordinate, ‘ABSC’.

COEF_MASS_AJOU = fonc_cm
Concept of the type [function] produced by the operator FONC_FLUI_STRU [U4.35.02].
This constant function, parameterized by the curvilinear X-coordinate, provides the value of the
coefficient of added mass $C_m$.

3.3 Keyword factor CABLE

Definition of the elastic characteristic nonlinear, constant, for the cables: two different elastic
behaviours in traction and compression, defined by the Young moduli $E$ and $EC$ (module in
compression).
The standard characteristics of elastic material are to be informed under the keyword factor ELAS.

3.3.1 Syntax

| CABLE = _F |
| EC_SUR_E = / ecse, [R] |
| / 1.D-4, [DEFECT] |

3.3.2 Operands of elasticity

◊ EC_SUR_E = ecse
Report of the modules to compression and traction. If the module of compression is null, the total
linear system with displacements can become singular. It is the case when a node is connected only to
cables and that those all enter in compression.

3.4 Keywords factor ELAS_ORTH, ELAS_ORTH_FO

Definition of the constant orthotropic elastic characteristics or functions of the temperature for the
isoparametric solid elements or the layers constitutive of a composite [R4.01.02].

3.4.1 Syntax

| / ELAS_ORTH = _F |
| E_L = ygl, [R] |
| E_T = ygt, [R] |
| E_N = ygn, [R] |
| G_LT = glt, [R] |
| G_TN = gtn, [R] |
| G_LN = gin, [R] |
| NU_LT = nult, [R] |
| NU_TN = nutn, [R] |
| NU_LN = nuln, [R] |
| ALPHA_L = / dil, [R] |
| / 0.0, [DEFAU] |
| ALPHA_T = / known as, [R] |
| / 0.0, [DEFECT] |
| ALPHA_N = / DIN, [R] |
| / 0.0, [DEFECT] |
| RHO = / rho, [R] |
| / 0.0, [DEFECT] |
| XT = / trl, [R] |
| / 1.0, [DEFECT] |
| XC = / collar, [R] |

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3.4.2 Operands of elasticity

To define the reference mark of orthotropism \((L, T, N)\) bound to the elements, the reader will refer:

- for the isoparametric solid elements with documentation [U4.42.01] `AFFE_CARA_ELEM` keyword `SOLID MASS`,
- for the composite elements of hulls to documentation [U4.42.01] `AFFE_CARA_ELEM` keyword `HULL` like with documentation [U4.42.03] `DEFI_COMPOSITE` keyword `ORIENTATION`.

\[
\begin{align*}
E_L &= \text{ygl} \quad \text{Longitudinal Young modulus.} \\
E_T &= \text{ygt} \quad \text{Transverse Young modulus.} \\
E_N &= \text{ygn} \quad \text{Normal Young modulus.} \\
G_LT &= \text{glt} \quad \text{Modulus of rigidity in the plan} \ L.T. \\
G_TN &= \text{gtn} \quad \text{Modulus of rigidity in the plan} \ T.N. \\
G_LN &= \text{gln} \quad \text{Modulus of rigidity in the plan} \ L.N.
\end{align*}
\]
Note:

For the hulls, the transverse moduli of rigidity are not obligatory; in this case, one calculates in thin hull by assigning an infinite rigidity to transverse shearing (elements \(\text{DST}, \text{DSQ}\) and \(Q4G\)).

\[\text{NU_LT} = \text{nult} \quad \text{coefficient of Fish in the plan } LT.\]

Important remarks:

\[\text{nult} \quad \text{is not equal to } \text{nutl}. \quad \text{In fact, there is the relation: } \text{nutl} = \frac{\sigma_L}{\gamma_{T}} \cdot \text{nult}\]

\[\text{nult} \quad \text{must be interpreted in the following way:}\]

if one exerts a traction according to the axis \(L\) causing a deformation according to this axis equalizes with \(\varepsilon_L = \frac{\sigma_L}{\gamma_{T}}\), there is a deformation according to the axis \(T\) equalize with:

\[\varepsilon_T = -\text{nult} \cdot \frac{\sigma_L}{\gamma_{T}}.\]

Various moduli of elasticity \(E_L, G_{LN}\) and \(NU_{LN}\) cannot be selected in an unspecified way: physically, it is necessary always that a nonworthless deformation causes a strictly positive deformation energy. That results in the fact that the matrix of Hooke must be definite positive. The operator \(\text{DEFI\_MATERIAU}\) calculate the eigenvalues of this matrix and emits an alarm if this property is not checked.

For the models 2D, like the user did not choose yet its \(\text{MODELING} (\text{D\_PLAN, C\_PLAN, ...})\), one checks the positivity of the matrix in the various cases.

\[\text{NU_TN} = \text{nutn} \quad \text{Poisson's ratio in the plan } TN.\]

\[\text{NU_LN} = \text{nuln} \quad \text{Poisson's ratio in the plan } LN.\]

The remark passed for \(\text{NU_LT}\) is to be applied to these the last two coefficients. There are thus the relations:

\[\text{nult} = \frac{\gamma_{G}}{\gamma_{T}} \cdot \text{nutn}\]

\[\text{nult} = \frac{\gamma_{G}}{\gamma_{T}} \cdot \text{nuln}\]

3.4.3 Case individual cubic elasticity

Cubic elasticity corresponds to a matrix of elasticity of the form:

\[
\begin{array}{cccc}
  y_{1111} & y_{1122} & y_{1122} \\
  y_{1122} & y_{1111} & y_{1122} \\
  y_{1122} & y_{1122} & y_{1111}
\end{array}
\]

\[
\begin{array}{c}
  y_{1212} \\
  y_{1212} \\
  y_{1212}
\end{array}
\]

Being given cubic symmetry, it remains to determine 3 coefficients:

\[E_L = E_N = E_T = E, \quad G_{LT} = G_{LN} = G_{TN} = G, \quad \nu_{LN} = \nu_{LT} = \nu_{LN} = \nu\]

To reproduce cubic elasticity with \(\text{ELAS\_ORTH}\), it is enough to calculate the coefficients of the orthotropism such that the matrix of elasticity obtained is form above:
\[ y_{1111} = \frac{E(1-v^2)}{(1-3v^2-2v^3)} \]
\[ y_{1122} = \frac{E\nu(1+v)}{(1-3v^2-2v^3)} \]
\[ y_{1212} = G_{LT} = G_{ln} = G_{TN} \]

Therefore, as long as \((1-3v^2-2v^3) \neq 0\) (i.e. \(\nu\) different from 0.5).

\[ \frac{y_{1122}}{y_{1111}} = \frac{\nu}{1-\nu} \quad \text{what provides} \quad \nu = \frac{1}{1 + \frac{y_{1111}}{y_{1122}}} \quad \text{then} \quad E = y_{1111} \frac{(1-3v^2-2v^3)}{(1-v^2)} \]

### 3.4.4 Operand RHO

RHO = rho
Density.

### 3.4.5 Operands ALPHA_L / ALPHA_T / ALPHA_N

ALPHA_L = dil
Thermal dilation coefficient average longitudinal.

ALPHA_T = known as
Thermal dilation coefficient average transverse.

ALPHA_N = DIN
Thermal dilation coefficient average normal.

### 3.4.6 Operands TEMP_DEF_ALPHA/PRECISION

One will refer to the paragraph [§3.1.4]. This keyword becomes obligatory as soon as one informed ALPHA_L, or ALPHA_T or ALPHA_N.

### 3.4.7 Criteria of rupture

XT = trl
Criterion of rupture in traction in the longitudinal direction (first direction of orthotropism).

XC = collar
Criterion of rupture in compression in the longitudinal direction.

YT = trt
Criterion of rupture in traction in the transverse direction (second direction of orthotropism).

YC = cot
Criterion of rupture in compression in the transverse direction.

S_LT = cis
Criterion of rupture in shearing in the plan LT.

### 3.4.8 Operands AMOR_ALPHA / AMOR_BETA / AMOR_HYST

See § 3.1.5
Rq: In the case as of multi-layer hulls, (use of DEFI_COMPOSITE) these parameters are not taken into account.

3.5 Keywords factor ELAS_ISTR, ELAS_ISTR_FO

Definition of the constant elastic characteristics or functions of the temperature in the case of the transverse isotropy for the isoparametric solid elements.

By taking again the same notations as for the orthotropism [§3.4], the transverse isotropy means here that isotropy is in the plan \((L, T)\) and that the orthotropism is thus carried by the direction \(N\) [R4.01.02]. One can draw the attention of the reader to the fact that this convention differs from a usual convention which indicates by “longitudinal direction” the direction of orthotropism of isotropic transverse materials.

3.5.1 Syntax

\[
\text{\texttt{/ ELAS_ISTR = _F \{}}}
\]

\[
\text{\bullet \ E_L = ygl, \ [R]}
\]

\[
\text{\bullet \ E_N = ygn, \ [R]}
\]

\[
\text{\bullet \ G_LN = gln, \ [R]}
\]

\[
\text{\bullet \ NU_LT = nult, \ [R]}
\]

\[
\text{\bullet \ NU_LN = nuln, \ [R]}
\]

\[
\text{\bullet \ ALPHA_L = / dil, \ [R]}
\]

\[
\text{\bullet \ ALPHA_N = / DIN, \ [R]}
\]

\[
\text{\bullet \ RHO = / rho, \ [R]}
\]

\[
\text{\bullet \ TEMP_DEF_ALPHA = Tdef, \ [R]}
\]

\[
\text{\bullet \ PRECISION = / eps, \ [R]}
\]

\[
\text{\bullet \ DEFECT}
\]

\[
\text{\texttt{\}}}
\]

\[
\text{\texttt{/ ELAS_ISTR_FO = _F \{}}}
\]

\[
\text{\bullet \ E_L = ygl, \ [function]}
\]

\[
\text{\bullet \ E_N = ygn, \ [function]}
\]

\[
\text{\bullet \ G_LN = gln, \ [function]}
\]

\[
\text{\bullet \ NU_LT = nult, \ [function]}
\]

\[
\text{\bullet \ NU_LN = nuln, \ [function]}
\]

\[
\text{\bullet \ ALPHA_L = dil, \ [function]}
\]

\[
\text{\bullet \ ALPHA_N = DIN, \ [function]}
\]

\[
\text{\bullet \ RHO = rho, \ [function]}
\]

\[
\text{\bullet \ TEMP_DEF_ALPHA = Tdef, \ [R]}
\]

\[
\text{\bullet \ PRECISION = / eps, \ [R]}
\]

\[
\text{\bullet \ DEFECT}
\]

\[
\text{\texttt{\}}}
\]

3.5.2 Operands of elasticity

To define a reference mark \((L, T, N)\) bound to the elements and defining the transverse isotropy of material, this last being isotropic in the plan \(LT\), the reader will refer to documentation [U4.42.01] AFFE_CARA_ELEM keyword SOLID MASS.

**Note:** Directions \(L\) and \(T\) are arbitrary in the plan \(LT\).
Note:
The modulus of rigidity in the plan $LT$ is defined by the usual formula for isotropic materials:

$$G = \frac{E}{2(1+v)}$$

that is to say here

$$glt = \frac{ygl}{2(1+nu lt)}.$$

NU_LN = nuln
Poisson's ratio in the plan LN.

Important remarks:

$nul = nut$ since the material is isotropic in the plane $LT$, but $nuln$ is not equal to $nunl$.

There is the relation: $nunl = \frac{ygn}{ygl} \cdot nuln$

$nunl$ must be interpreted in the following way:

if one exerts a traction according to the axis $N$ causing a deformation of traction according to this axis equals with $\varepsilon_N = \frac{\sigma_N}{ygn}$, there is a compression according to the axis $L$ equalizes with:

$$nunl \cdot \frac{\sigma_N}{ygn}.$$

Various moduli of elasticity $E_L$, $G_{LN}$ and $NU_LN$ cannot be selected in an unspecified way:

physically, it is necessary always that a nonworthless deformation causes a strictly positive deformation energy. That results in the fact that the matrix of Hooke must be definite positive.

The operator DEF_MATERIAU calculate the eigenvalues of this matrix and emits an alarm if this property is not checked.

For the models 2D, like the user did not choose yet its MODELING( D_PLAN, C_PLAN,...), one checks the positivity of the matrix in the various cases.
3.5.3 **Operand RHO**

\[ RHO = \rho \]
Density.

3.5.4 **Operands ALPHA_L / ALPHA_N**

\[ ALPHA_L = \text{dil} \]
Thermal dilation coefficient average in the plan LT.

\[ ALPHA_N = \text{DIN} \]
Thermal dilation coefficient average normal.

3.5.5 **Operands TEMP_DEF_ALPHA/PRECISION**

One will refer to the paragraph [§3.1.4]. This keyword becomes obligatory as soon as the keyword was informed ALPHA_L or ALPHA_N.

3.6 **Keyword factor ELAS_COQUE , ELAS_COQUE_FO**

**ELAS_COQUE** allows the user to directly provide the coefficients of the matrix of elasticity (broken up into membrane and inflection) of the orthotropic thin hulls in linear elasticity [R3.07.03].

3.6.1 **Syntax**

```
|/ ELAS_COQUE = _F ( 
/ ELAS_COQUE_FO=_F 
   ◦ MEMB_L = C1111 , [R] or [function] 
   ◦ MEMB_LT = C1122 , [R] or [function] 
   ◦ MEMB_T = C2222 , [R] or [function] 
   ◦ MEMB_G_LT = C1212 , [R] or [function] 
   ◦ FLEX_L = D1111 , [R] or [function] 
   ◦ FLEX_LT = D1122 , [R] or [function] 
   ◦ FLEX_T = D2222 , [R] or [function] 
   ◦ FLEX_G_LT = D1212 , [R] or [function] 
   ◦ CISA_L = G11 , [R] or [function] 
   ◦ CISA_T = G22 , [R] or [function] 
   ◦ RHO = \rho , [R] or [function] 
   ◦ ALPHA = \alpha , [R] or [function] 
   ◦ M_LLLL = H1111 , [R] or [function] 
   ◦ M_LLLT = H1122 , [R] or [function] 
   ◦ M_LLLT = H1112 , [R] or [function] 
   ◦ TTTT = H2222 , [R] or [function] 
   ◦ M_TTLT = H2212 , [R] or [function] 
   ◦ M_LTTT = H1212 , [R] or [function] 
   ◦ F_LLLL = A1111 , [R] or [function] 
   ◦ F_LLLT = A1122 , [R] or [function] 
   ◦ F_LLLL = A1112 , [R] or [function] 
   ◦ F_TTTT = A2222 , [R] or [function] 
   ◦ F_TTLT = A2212 , [R] or [function] 
   ◦ F_TTTL = A1212 , [R] or [function] 
   ◦ M_F_LLLL = B1111 , [R] or [function] 
   ◦ M_F_LLLT = B1122 , [R] or [function] 
   ◦ M_F_LLLT = B1112 , [R] or [function] 
   ◦ M_F_TTTT = B2222 , [R] or [function] 
   ◦ M_F_TTLT = B2212 , [R] or [function] 
   ◦ M_F_LTTT = B1212 , [R] or [function] 
   ◦ MC_LLLL = E1111 , [R] or [function] 
   ◦ MC_LLLT = E1122 , [R] or [function] 
   ◦ MC_LLLT = E1123 , [R] or [function] 
   ◦ MC_LTTL = E2213 , [R] or [function]
```

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The matrix of behavior intervening in the matrix of rigidity in isotropic homogeneous elasticity is form:

<table>
<thead>
<tr>
<th>Membrane:</th>
<th>Inflexion:</th>
<th>Shearing:</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ C = \frac{E_h}{1-\nu^2} \begin{bmatrix} 1 &amp; \nu &amp; 0 \ \nu &amp; 1 &amp; 0 \ 0 &amp; 0 &amp; \left(\frac{1-\nu}{2}\right) \end{bmatrix} ]</td>
<td>[ D = \frac{E_h^3}{12(1-\nu^2)} \begin{bmatrix} 1 &amp; \nu &amp; 0 \ \nu &amp; 1 &amp; 0 \ 0 &amp; 0 &amp; \left(\frac{1-\nu}{2}\right) \end{bmatrix} ]</td>
<td>[ G = \frac{5E_h}{12(1+\nu)} \begin{bmatrix} 1 &amp; 0 \ 0 &amp; 1 \end{bmatrix} ]</td>
</tr>
</tbody>
</table>

For the orthotropic hulls whose moduli of elasticity are obtained by a method of homogenisation, it is not possible in the case general to find a Young modulus equivalent \( E_{eq} \), and an equivalent thickness \( h_{eq} \) to find the preceding expressions.

The matrices of rigidity are thus given directly in the form:

\[ C = \begin{bmatrix} C_{1111} & C_{1122} & 0 \\ C_{1122} & C_{2222} & 0 \\ 0 & 0 & C_{1212} \end{bmatrix} \]
\[ D = \begin{bmatrix} D_{1111} & D_{1122} & 0 \\ D_{1122} & D_{2222} & 0 \\ 0 & 0 & D_{1212} \end{bmatrix} \]
\[ G = \begin{bmatrix} G_{11} & 0 \\ 0 & G_{22} \end{bmatrix} \]

On the other hand, one limits oneself to the cases where the thermal dilation coefficient is homogeneous isotropic.

These coefficients are to be provided in the local reference mark of the element. It is defined under the keyword \texttt{HULL} of \texttt{AFFE_CARA_ELEM} \[U4.42.01\].

Notice concerning the taking into account of transverse shearing following the models of hulls:

If one wishes to use \texttt{ELAS_COQUE} for transverse shearing it is necessarily necessary to employ DST modeling. If modeling DKT is used, transverse shearing will not be taken into account, some are the values of \( G_{11} \) and \( G_{22} \). The correspondence for an isotropic material is the following one:

- The material \texttt{ELAS_COQUE}, DST modeling with \( CISA_* = 5/12 \times (E_h/(1+\nu)) \) is equivalent to material \texttt{ELAS}, DST modeling.
- The material \texttt{ELAS_COQUE}, DST modeling with \( CISA_* = 5/12 \times (E_h/(1+\nu)) \times N \), where \( N \) is a great number (for example \( 10^5 \)), is equivalent to material \texttt{ELAS}, modeling DKT.
- The material \texttt{ELAS_COQUE}, modeling DKT is equivalent to material \texttt{ELAS}, modeling DKT.

The matrices of behavior connecting the efforts generalized to the deformations for the elements of plate and fascinating account the terms of coupling are in the following way defined:
3.7 Keyword factor ELAS_MEMBRANE

ELAS_MEMBRANE allows the user to directly provide the coefficients of the matrix of elasticity of the anisotropic membranes in linear elasticity.

3.7.1 Syntax

```c
/* ELAS_MEMBRANE = _F ( 
    ♦ RHO = rho , [R] 
    ♦ ALPHA = alpha , [R] 
    ♦ M_LLLL = H1111 , [R] 
    ♦ MLLLL = H1111 , [R] 
    ♦ M_LTTT = H1122 , [R] 
    ♦ M_LTLL = H1122 , [R] 
  )*/
```

The membrane matrix of rigidity connecting the membrane constraints to the deformations for the elements of membrane is in the following way defined:

\[
HM = \begin{bmatrix} 
H1111 & H1122 & H1112 \\
H1122 & H2222 & H2212 \\
H1112 & H2212 & H1212 \\
\end{bmatrix}
\]

These coefficients are to be provided in the local reference mark of the element, definite under the keyword factor MEMBRANE order AFFE_CARA_ELEM [U4.42.01]. These coefficients have the dimension of a force per meter. Let us recall that one uses following conventions of notation for the membrane strains and stresses, and that the coefficients of the preceding matrix must be adapted consequently:

\[
\begin{bmatrix} 
\varepsilon_{11} \\
\varepsilon_{22} \\
\sqrt{2}\varepsilon_{12} \\
\end{bmatrix} \quad \text{and} \quad \begin{bmatrix} 
\sigma_{11} \\
\sigma_{22} \\
\sqrt{2}\sigma_{12} \\
\end{bmatrix}
\]

The user can also indicate an isotropic thermal dilation coefficient alpha and a mass by unit of area rho.

3.8 Keyword factor ELAS_HYPER

Definition of the characteristics very-rubber bands of the type Signorini [R5.03.19]. Constraints of Piola Kirchhoff \( S \) are connected to the deformations of Green-Lagrange by:

\[
S = \frac{\partial \Psi}{\partial E} \quad \text{with} \quad \Psi = C10 |I_1 - 3| + C01 |I_2 - 3| + C20 |I_3 - 3|^2 + \frac{1}{2} K |J - 1|^2 \quad \text{and}
\]

\[
I_1 = I_c J^{\frac{2}{3}}, I_2 = II_c J^{\frac{4}{3}}, J = III_c \frac{1}{2},
\]

where \( I_c, II_c \) and \( III_c \) are the 3 invariants of tensor of right Cauchy-Green.

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3.8.1 Syntax

```plaintext
| ELAS_HYPER = _F ( 
  ◊ C10 = c10, [R]
  ◊ C01 = / c01, [R]
  ◊ C20 = / c20, [R]
  ◊ RHO = / rho, [R]
  ◊ NAKED = naked, [R]
  ◊ K = K [R]
 )
```

3.8.2 Operands C01, C10 and C20

C01 = c01 , C10 = c10, C20 = c20

Three coefficients of the polynomial expression of the potential hyperelastic. The unit is it N/m².

- If C01 and C20 are worthless, one obtains a material of the Néo-Hookéen type.
- If only C20 is null, one obtains a material of the Mooney-Rivlin type.

The material is elastic incompressible in small deformations if one takes C10 and C01 such as 6(C01+C10) = E, where E is the Young modulus.

3.8.3 Operand NAKED and K

NAKED = naked

Poisson's ratio. It is checked that −1 < nu < 0.5.

K = K

Module of compressibility.

These two parameters are excluded one and the other. They quantify the almost-compressibility of material One uses the module of compressibility K provided by the user, if there exists. If not one calculates K by:

\[ K = \frac{6(C01+C10)}{3(1-2v)} \]

One can take \( nu \) near to 0.5 but never strictly equal (with the precision machine near). If \( nu \) is too close to 0.5, an error message invites the user to check his Poisson's ratio or its module of compressibility. The larger the module of compressibility is, the more the material is incompressible.

3.8.4 Operand RHO

RHO = rho

Real constant density (one does not accept a concept of the type function). No the checking of about size.

3.9 Keyword factor ELAS_2NDG

Definition of the isotropic linear elastic characteristics of the model second gradient suggested by Mindlin and detailed in documentation [R5.04.03]. This behavior is mainly advised for modelings of regularization second gradient (*_2DG) or second gradient of dilation (*_DIL).

3.9.1 Syntax

```plaintext
| / ELAS_2NDG = _F ( 
```

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3.9.2 Operands A1, A2, A3, A4 and A5

These parameters define characteristic materials of the law described in the document [R5.04.03].

3.10 Keyword factor ELAS_GLRC

Definition of the constant linear elastic characteristics of a plate homogenized for the laws GLRC_DM and GLRC_DAMAGE.

3.10.1 Syntax

```plaintext
|/ ELAS_GLRC = _F ( * E_M = EM, [R] *
|/ NU_M = num, [R] *
|/ E_F = ef, [R] *
|/ NU_F = nuf, [R] *
|/ BT1 = bt1, [R] *
|/ BT2 = bt2, [R] *
|/ RHO = rho, [R] *
|/ ALPHA = dil, [R] *
|/ AMOR_ALPHA = a_alpha, [R] *
|/ AMOR_BETA = a_beta, [R] *
|/ AMOR_HYST = eta [R] )
```

3.10.2 Operands E_M/NU_M/E_F/NU_F/BT1/BT2

E_M = EM
Young modulus of membrane. It is checked that \( E_m \geq 0 \).

NU_M = num
Poisson's ratio of membrane. It is checked that \(-1 \leq \nu_m \leq 0.5\).

E_F = ef
Young modulus of inflection. It is checked that \( E_f \geq 0 \).

NU_F = nuf
Poisson's ratio of inflection. It is checked that \(-1 \leq \nu_f \leq 0.5\).

BT1 = bt1 and BT2 = bt2

If the finite elements support the calculation of the efforts cutting-edges, these operands are used to define the elastic matrix of rigidity of transverse shearing. The efforts cutting-edges \( V \) are connected to the distortions \( \gamma \) by:

\[
V = \begin{bmatrix}
BT1 & 0 \\
0 & BT2
\end{bmatrix} \gamma
\]

The other operands are identical to those of linear elasticity.
3.11 **Keyword factor ELAS_DHRC**

Definition of the constant linear elastic characteristics of a plate homogenized for the law DHRC.

3.11.1 Syntax

```
|/ ELAS_DHRC = _F ( 
  ♦ A0 = a0, [l_R]
  ◊ RHO = rho, [R]
  ◊ ALPHA = dil, [R]
  ◊ AMOR_ALPHA = a_alpha, [R]
  ◊ AMOR_BETA = a_beta, [R]
  ◊ AMOR_HYST = eta      [R]
)
```

3.11.2 Operands A0

\[ A0 = a0 \]

Components (21 supra-diagonal terms) of the symmetrical tensor of elasticity \( A^0 \) membrane-inflection of the plate before damage, order 4, in the reference mark of the reinforcements \((x, y)\), in notations of Voigt, identified by homogenisation: initially out of membrane, then in inflection (unit of force per unit of length de for the terms of membrane, unit of force for the coupled terms membrane-inflection, and unit of force time unit of length for the terms of inflection):

\[
\begin{array}{cccccccc}
A_{xxxx}^{0mm} & A_{xxyy}^{0mm} & A_{xxxy}^{0mm} & A_{yyyy}^{0mm} & A_{xyxy}^{0mm} & A_{yyyy}^{0mf} & A_{xyxy}^{0mf} & A_{yyyy}^{0ff} \\
A_{xxyy}^{0mm} & A_{yyyy}^{0mm} & A_{xxxy}^{0mm} & A_{yyyy}^{0mm} & A_{xyxy}^{0mm} & A_{yyyy}^{0mf} & A_{xyxy}^{0mf} & A_{yyyy}^{0ff} \\
A_{xxxy}^{0mm} & A_{yyyy}^{0mm} & A_{xxxy}^{0mm} & A_{yyyy}^{0mm} & A_{xyxy}^{0mm} & A_{yyyy}^{0mf} & A_{xyxy}^{0mf} & A_{yyyy}^{0ff} \\
A_{yyyy}^{0mm} & A_{yyyy}^{0mm} & A_{yyyy}^{0mm} & A_{yyyy}^{0mm} & A_{xyxy}^{0mm} & A_{yyyy}^{0mf} & A_{xyxy}^{0mf} & A_{yyyy}^{0ff} \\
\end{array}
\]
4 Mechanical behaviors nonlinear generals

In general, the definition of a nonlinear mechanical behavior requires on the one hand the definition of the elastic properties and on the other hand those relating to the nonlinear aspect itself. In Code_Aster, these 2 types of data are separately defined, except some exceptions.

4.1 Keyword factor TRACTION

Definition of a traction diagram (elastoplasticity of von Mises with nonlinear isotropic work hardening or nonlinear elasticity).

4.1.1 Syntax

| TRACTION = _F(
|   ♦ SIGM = sigm_f, [function]
| )

4.1.2 Operand SIGM

SIGM = sigm_f

Curve $\sigma$ according to the total deflection $\varepsilon$ (it is checked that the concept function depends many only parameters EPSI and possibly TEMP).

The ordinate of the first point defines the yield stress of material, it is thus imperative not to define of point of worthless X-coordinate [R5.03.02].

If sigm_f depends on the two parameters EPSI and TEMP (this concept was then defined by DEFI_NAPPE), one interpolates compared to the temperature to find the traction diagram at a temperature $\theta$ data. It is highly recommended to refer to the document [R5.03.02] where the method of interpolation is explained. It will be noted that, to avoid generating important errors of approximation or to even obtain by extrapolation of bad traction diagrams, it is not to better use linear prolongation in DEFI_NAPPE.

Note:

For multiphase materials, with metallurgical phases, the characteristics of work hardening are defined by META_ECRO_LINE or META_TRACTION [R4.04.04].

4.2 Keywords factor ECRO_LINE, ECRO_LINE_FO

Definition of a linear curve of work hardening or a set of curves depending on the temperature.

4.2.1 Syntax

| /ECRO_LINE = _F ( |
|   ♦ D_SIGM_EPSI = dsde [R] |
|   ♦ SY = sigmm [R] |
|   ◊ SIGM_LIM = sglim [R] |
|   ◊ EPSI_LIM = eplim [R] |
| ) |

| /ECRO_LINE_FO = _F ( |
|   ♦ D_SIGM_EPSI = dsde [function] |
|   ♦ SY = sigm [function] |
| )

4.2.2 Operands

♦ D_SIGM_EPSI = dsde (AND)
  Slope of the traction diagram $E_T$.

♦ SY = sigm
  Elastic limit $s_y$.

The curve of work hardening used in the models of behavior is then:

$$ R(p) = s_y + H_p $$

with $H = \frac{E.E_T}{E-E_T}$

It is thus necessary to respect: $E_T < E$ (see for example [R5.03.02]).

The Young modulus $E$ is to be specified by the keywords ELAS or ELAS_FO.

♦ SIGM_LIM = sglim
  Definition of the ultimate stress.

♦ EPSI_LIM = eplim
  Definition of the limiting deformation.

Operands SIGM_LIM and EPSI_LIM allow to define the terminals in constraint and deformation of the materials, which correspond to the limiting states of service and ultimate, classically used at the time of study in civil engineer. These terminals are obligatory when the behavior is used VMIS_CINE_GC (confer [U4.42.07] DEFI_MATER_GC). In the other cases they are not taken into account.

4.3 Keywords factor PRAGER, PRAGER_FO

When the way of loading is not monotonous any more, work hardenings isotropic and kinematic are not equivalent any more. In particular, one can expect to have simultaneously a kinematic share and an isotropic share. If one seeks to precisely describe the effects of a cyclic loading, it is desirable to adopt modelings sophisticated (but easy to use) such as the model of Taheri, for example, confer [R5.03.05]. On the other hand, for less complex ways of loading, one can wish to include only one linear kinematic work hardening, all nonthe linearlities of work hardening being carried by the isotropic term. That makes it possible to follow a traction diagram precisely, while representing nevertheless phenomena such as the Bauschinger effect [R5.03.16].

The characteristics of work hardening are then given by a traction diagram and a constant, called of Prager, for the term of kinematic work hardening linear. The keyword PRAGER allows to define the constant of PRAGER, used in the models with mixed work hardening (kinematic linear compound with isotropic) VMIS_ECMI_LINE or VMIS_ECMI_TRAC.

4.3.1 Syntax

```
| / PRAGER  = _F (  
  ♦ C = C, 
) | [R] 
/ PRAGER_FO = _F (  
  ♦ C = C, 
) | [function] 
```

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Identification of $C$ is described in [R5.03.16].

### 4.4 Keywords factor ECRO_PUIS, ECRO_PUIS_FO

Law of plasticity with criterion of Von Mises and isotropic work hardening following a law power.

#### 4.4.1 Syntax

```plaintext
/ ECRO_PUIS =_F ( 
  • SY = sigy, [R]
  • A_PUIS = has, [R]
  • N_PUIS = N,
)

/ ECRO_PUIS_FO =_F ( 
  • SY = sigy, [function]
  • A_PUIS = has, [function]
  • N_PUIS = N,
)
```

#### 4.4.2 Operands

- **SY** = sigyhere Elastic limit
- **A_PUIS** = has Coefficient of the law power
- **N_PUIS** = N Exhibitor

The curve of work hardening is deduced from the uniaxial curve connecting the deformations to the constraints, whose expression is (cf [R5.03.02])

$$\varepsilon = \frac{\sigma}{E} + \frac{\alpha}{E} \left( \frac{\sigma - \sigma_y}{\sigma_y} \right)^n$$

#### 4.5 Keywords factor CIN1_CHAB, CIN1_CHAB_FO

Behavior of the model of Chaboche (with only one kinematic variable) described in the document [R5.03.04].

Briefly, these relations are:

$$F(\sigma, R, X) = |\dot{\sigma} - X|_{eq} - R(p)$$

$$\dot{\varepsilon} = \dot{\lambda} \frac{\partial F}{\partial \sigma} = \frac{\dot{\lambda}}{2} \left( \frac{\dot{\sigma} - X}{|\dot{\sigma} - X|_{eq}} \right)$$

$$\dot{p} = \dot{\lambda} = \frac{2}{3} \dot{\varepsilon} : \dot{\varepsilon}$$

$$\dot{p} = \lambda \left\{ \begin{array}{ll} \dot{\lambda} = 0 & \text{si } F < 0 \text{ ou } \dot{F} < 0 \\ \dot{\lambda} = 0 & \text{si } F = 0 \text{ et } \dot{F} = 0 \end{array} \right.$$  eq 4.5-1

$$X = \frac{2}{3} C(p) |\dot{\alpha}|$$

$$\dot{\alpha} = \dot{\varepsilon} - y(p) |\dot{p}|$$

Functions $C(p)$, $\gamma(p)$ and $R(p)$ are defined by:


\[
R(p) = R_x + \left| R_0 - R_x \right| e^{-b_p}
\]
\[
C(p) = C_x \left( 1 + 1 - \left| e^{-b_p} \right| \right)
\]
\[
\gamma_1(p) = \gamma_0 \left( \alpha_x + \left| 1 - \alpha_x \right| e^{-b_p} \right)
\]

Note:
- \( \tilde{\alpha} \) represent the diverter of the constraints and \( (\quad)_{eq} \) the equivalent within the meaning of von Mises.

The definition of \( X \) in the form [eq. 4.5-3] makes it possible to keep a formulation which takes into account the variations of the parameters with the temperature. These terms are necessary because their not taken into account would lead to inaccurate results.

### 4.5.1 Syntax

```
| / CIN1_CHAB
/ CIN1_CHAB_FO = F {
  ◁ R_0 = R_0, [R] or [function]
  ◁ R_I = R_I, (useless if B=0) [R] or [function]
  ◁ B = / B, [R] or [function]
  ◁ / 0., [DEFECT]
  ◁ C_I = C_I, [R] or [function]
  ◁ K = / K, [R] or [function]
  ◁ / 1., [DEFECT]
  ◁ W = / W, [R] or [function]
  ◁ / 0., [DEFECT]
  ◁ G_0 = G_0, [R] or [function]
  ◁ A_I = / A_I, [R] or [function]
  ◁ / 1., [DEFECT]
}
```

Note:
- A viscoplastic version of the model of Chaboche is also available (confer [R5.03.04]). It requires to define viscous characteristics using the keyword factor LEMAITRE or LEMAITRE_FO, by putting the parameter obligatorily UN_SUR_M to zero.

### 4.6 Keywords factor CIN2_CHAB, CIN2_CHAB_FO

Behavior of the model of Chaboche (with two variable kinematics) described in the document [R5.03.04].

Briefly these relations are:
\[ F(\sigma, R, X) = |\bar{\sigma} - X_1 - X_2|_{\text{eq}} - R|p| \]

\[ \dot{\varepsilon}^p = \lambda \frac{\partial F}{\partial \sigma} = \frac{3}{2} \lambda \frac{\bar{\sigma} - X_1 - X_2}{|\bar{\sigma} - X_1 - X_2|_{\text{eq}}} \]

\[ \dot{p} = \lambda = \frac{2}{3} \dot{\varepsilon}^p : \dot{\varepsilon}^p \quad \text{éq} 4.6-1 \]

\[ \begin{align*}
\text{si } F < 0 \text{ ou } \dot{F} < 0 & \quad \lambda = 0 \\
\text{si } F = 0 \text{ et } \dot{F} = 0 & \quad \lambda \geq 0
\end{align*} \quad \text{éq} 4.6-2 \]

\[ X_1 = \frac{2}{3} C_1 |p| \alpha_1 \]

\[ X_2 = \frac{2}{3} C_2 |p| \alpha_2 \quad \text{éq} 4.6-3 \]

\[ \alpha_i = \frac{\dot{\varepsilon}^p - \gamma_i |p| \alpha_i}{\dot{\varepsilon}^p} \]

\[ \dot{\alpha}_i = \frac{\dot{\varepsilon}^p - \gamma_i |p| \alpha_i}{\dot{\varepsilon}^p - \gamma_i |p| \alpha_i} \dot{p} \]

Functions \( C_1(p) \), \( C_2(p) \), \( \gamma_1(p) \), \( \gamma_2(p) \) and \( R(p) \) are defined by:

\[ R|p| = R_\infty + [R_0 - R_\infty]e^{-bp} \]

\[ C_1|p| = C_1^\infty \left[1 + \left|\frac{1}{\alpha_c} - 1\right| e^{-wp}\right] \]

\[ C_2|p| = C_2^\infty \left[1 + \left|\frac{1}{\alpha_c} - 1\right| e^{-wp}\right] \]

\[ \gamma_1|p| = \gamma_1^0 \left[\alpha_c + \left|\frac{1}{\alpha_c} - 1\right| e^{-bp}\right] \]

\[ \gamma_2|p| = \gamma_2^0 \left[\alpha_c + \left|\frac{1}{\alpha_c} - 1\right| e^{-bp}\right] \]

Note:

- \( \bar{\sigma} \) represent the diverter of the constraints and \( (\ )_{\text{eq}} \) the equivalent within the meaning of von Mises.

The definition of \( X_1 \) and \( X_2 \) in the form [éq. 4.6-3] makes it possible to keep a formulation which takes into account the variations of the parameters with the temperature. These terms are necessary because their not taken into account would lead to inaccurate results.

### 4.6.1 Syntax

```plaintext
| / CIN2_CHAB
/ CIN2_CHAB_FO = F {
  R_0 = R_0, [R] or [function]
  R_I = R_I, (useless if B=0) [R] or [function]
  B = B, [R] or [function]
  C1_I = C1_I, [R] or [function]
  C2_I = C2_I, [R] or [function]
  K = K, [R] or [function]
  W = W, [R] or [function]
  G1_0 = G1_0, [R] or [function]
  G2_0 = G2_0, [R] or [function]
  A_I = A_I, [R] or [function]
}
```

Note:

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4.7 Keywords factors VISCOCHAB, VISCOCHAB_FO

Definitions of the coefficients of the élasto-viscoplastic model of Chaboche [R5.03.12].

Viscous constraint \( \sigma_v = J_2(\bar{\alpha} - X) - \alpha_n - k \)

Viscoplastic rate of deformation

\[
\dot{\varepsilon}^p = \frac{3}{2} \frac{\bar{\sigma} - X}{J_2(\bar{\alpha} - X)}
\]

\[
\dot{\alpha} = \frac{\sigma_v}{K_0 + \alpha_k R} \times \exp \left[ \alpha \left( \frac{\sigma_v}{K_0 + \alpha_k R} \right)^{n+1} \right]
\]

Isotropic work hardening:

\[
R = b(Q - R) + y_\gamma (Q_y - R)^n \text{sgn}(Q_y - R)
\]

\[
Q = Q_0 + (Q_m - Q_0) \left[ 1 - e^{-2\mu q} \right]
\]

\[
F(\varepsilon^p, \xi, q) = \frac{2}{3} J_2(\varepsilon^p - \xi) - q \leq 0
\]

\[
\dot{q} = \eta \times H(F) \times \langle n : n \rangle \dot{p}
\]

\[
\dot{\xi} = \sqrt{3/2} (1 - \eta) \times H(F) \times \langle n : n \rangle \dot{p} n
\]

\[
Q = Q - Q_m \left[ 1 - \left( \frac{Q_m - Q}{Q_m} \right)^2 \right]
\]

Kinematic work hardening \( X = X_1 + X_2 \)

\[
X_1 = 2/3 C_i \dot{\varepsilon}^p - \gamma_i \left[ \delta_i X_i + (1 - \delta_i)(X_i : n) n \right] \dot{p} - \gamma X \left[ J_2(X_i) \right]^{m-1} X_i + \frac{1}{C_i} \frac{\partial C_i}{\partial T} X_i \dot{T}
\]

\[
\gamma_i = \gamma_i^0 \left[ a_n + (1 - a_n) e^{-\phi p} \right]
\]

Note:

- \( \bar{\sigma} \) represent the diverter of the constraints, \( J_2(Y) = \sqrt{3/2} (Y : Y) \) the second invariant of the tensor \( Y \).
- \( H(F) \) the function of Heaviside and \( \langle .. \rangle \) hooks of Mc Cawley (\( \langle x \rangle = x \) if \( x \geq 0 \), \( 0 \) if not).
- Variables \( q \) and \( \xi \) allow to take into account the effect of memory of work hardening under cyclic loading. If \( \eta = 1 \), the effect of memory is not modelled and the variables \( q \) and \( \xi \) are not considered in the resolution of the system (\( q = 0 \)). If not, there is the following condition on \( \eta : 0 < \eta \leq 1/2 \).
From a thermodynamic point of view, the variable of work hardening \( X_i \) is associated with its dual variable \( \alpha_i \) for the relation \( X_i = \frac{2}{3} C_i \alpha_i \). The term in \( \dot{T} \) intervening in the equation giving \( \dot{X}_i \) allows to treat the cases of loadings anisothermes for \( C_i \) function of the temperature.

4.7.1 Syntax

```plaintext
| / VISCOCHAB =
| / VISCOCHAB_FO = _F (  
|   ♦ K = K, [R] or [function]  
|   ♦ A_K = alphak, [R] or [function]  
|   ♦ A_R = alphar, [R] or [function]  
|   ♦ K_0 = K0, [R] or [function]  
|   ♦ NR = N, [R] or [function]  
|   ♦ ALP = alpha, [R] or [function]  
|   ♦ B = B, [R] or [function]  
|   ♦ M_R = Mr., [R] or [function]  
|   ♦ G_R = gamar, [R] or [function]  
|   ♦ DRIVEN = driven, [R] or [function]  
|   ♦ Q_0 = Q0, [R] or [function]  
|   ♦ Q_M = Qm, [R] or [function]  
|   ♦ QR_0 = Qr*, [R] or [function]  
|   ♦ ETA = eta, [R] or [function]  
|   ♦ C1 = C1, [R] or [function]  
|   ♦ M_1 = m1, [R] or [function]  
|   ♦ D1 = d1, [R] or [function]  
|   ♦ G_X1 = gx1, [R] or [function]  
|   ♦ G1_0 = g10, [R] or [function]  
|   ♦ C2 = C2, [R] or [function]  
|   ♦ M_2 = m2, [R] or [function]  
|   ♦ D2 = d2, [R] or [function]  
|   ♦ G_X2 = gx2, [R] or [function]  
|   ♦ G2_0 = g20, [R] or [function]  
|   ♦ A_I = ainfi, [R] or [function]  
```

4.8 Keywords factor MEMO_ECRO

This keyword makes it possible to define the parameters associated with the effect of maximum memory of work hardening in the elastoplastic behaviors or élasto-visco-plastics of Chaboche (cf [R5.03.04]). This keyword is usable, jointly with the keywords CIN1_CHAB or CIN2_CHAB, to define the parameters necessary to the behavior VMIS_CIN2_MEMO. Moreover, by defining the parameters of viscosity under LEMAITRE, it is possible to use a behavior visco_plastic for purpose of maximum memory of work hardening by VISC_CIN2_MEMO.

The equations of the model are written via a field representing the maximum plastic deformations reached:

\[
F[\varepsilon^p, \xi, q] = \frac{2}{3} J_2 [\varepsilon^p - \xi] - q \leq 0 \quad \text{with the law of evolution} \quad \dot{\xi} = \frac{1 - \eta}{\eta} q n^*
\]

\( q \) the evolution of the law work hardening makes it possible to calculate \( R(p) \) by:

\[
R = b |Q - R| \dot{p}, \quad Q = Q_0 + (Q_m - Q_0) \left[ 1 - e^{-2\mu q} \right]
\]

the being written criterion of plasticity:

\[
f[\sigma, R, X] = |\ddot{\sigma} - X_1 - X_2 |_{eq} - R_0 - R | \dot{p} |
\]
4.8.1 Syntax

\[
\text{MEMO\_ECRO} = \_F ( \\
\quad \text{DRIVEN} = \text{driven} \quad \text{[R]} \\
\quad \text{Q\_M} = \text{qm} \quad \text{[R]} \\
\quad \text{Q\_0} = \text{q0} \quad \text{[R]} \\
\quad \text{ETA} = \text{eta} \quad \text{[R]} \\
\quad \text{0.5, DEFECT} \\
) 
\]

4.8.2 Operands

Driven = driven
Coefficient of the exponential law

\(\text{Q\_M} = \text{qm}\)
Value of saturation of the parameter \(Q\) representing isotropic work hardening

\(\text{Q\_0} = \text{q0}\)
Value intiale of the parameter \(Q\) representing isotropic work hardening

\text{ETA} = \text{eta}
Value allowing to modify the taking into account of the memory of the maximum plastic deformation: the value \(\eta = 1/2\) corresponds to a total taking into account.

4.9 Keywords factor \texttt{CIN2\_NRAD}

This keyword makes it possible to define the parameters associated with the effect of nonproportionality of the model of Chaboche (cf [R5.03.04]).

4.9.1 Syntax

\[
\text{CIN2\_NRAD} = \_F ( \\
\quad \text{DELTA1} = \text{delta1} \quad \text{[R]} \\
\quad \text{DELTA2} = \text{delta2} \quad \text{[R]} \\
) 
\]

4.9.2 Operands

\text{DELTA1}, \text{DELTA2} : coefficients ranging between 0 and 1 allowing to take into account it not possible proportionality of the loading. The value by default of 1 cancels this effect.

4.10 Keywords factor \texttt{TAHERI}, \texttt{TAHERI\_FO}

Definition of the coefficients of the model of cyclic behavior of elastoplasticity of Saïd Taheri [R5.03.05]. Briefly, we have to solve, for an elastoplastic increment:
\[
\begin{align*}
\dot{\varepsilon}^p &= \frac{3}{2} \frac{\ddot{\sigma} - \ddot{X}}{\overline{\sigma} - \overline{X}} \quad \text{avec} \quad \overline{x}_{eq} = \left(\frac{3}{2} x^t x\right)^{1/2} \\
\sigma &= \Lambda (\varepsilon - \varepsilon_p) \\
|\sigma - \overline{X}|_{eq} - R &= 0 \\
\dot{\sigma}_p - \dot{R} - |\overline{X}|_{eq} &= 0 \\
\varepsilon_p^* &= 0 \\
\overline{X} &= C \left( S \varepsilon_p - \sigma_p \varepsilon_p^* \right) \\
R &= D \left( A \|\varepsilon\|^n + R_0 \right) \\
C &= C_{\infty} + C_1 e^{-b_p \left( 1 - \frac{\sigma_p}{S} \right)} \\
\end{align*}
\]

where the various parameters of material are \( S, C_{\infty}, C_1, b, m, A, \alpha, R_0 \)

The various parameters can depend on the temperature, in this case one will employ the keyword \texttt{TAHERI_FO}.

### 4.10.1 Syntax

```plaintext
/ TAHERI
/ TAHERI_FO = _F (   
  ♦ R_0 = R, [R] or [function]    
  ♦ ALPHA = has , [R] or [function]    
  ♦ M = m , [R] or [function]    
  ♦ With = With , [R] or [function]    
  ♦ B = B , [R] or [function]    
  ♦ C1 = C1 , [R] or [function]    
  ♦ C_INF = Cinfi, [R] or [function]    
  ♦ S = S , [R] or [function]    
)
```

**Note:**

A viscoplastic version of the model of \texttt{TAHERI} is also available (cf [R5.03.05]). It requires to define viscous characteristics using the keyword factor \texttt{LEMAITRE} or \texttt{LEMAITRE_FO}.

### 4.11 Keywords factors MONO_ *

Definition of the coefficients of the models of single-crystal or polycrystalline behavior [R5.03.11]. Besides these characteristics, constant the rubber bands must be defined under the keyword \texttt{ELAS} or \texttt{ELASORTH}.

The behavior related to each system of slip of a monocrystal or a phase of a polycrystal is (in the whole of the behaviors considered) of élasto-visco-plastic type.

The crystalline behaviors (others that those definite starting from the dynamics of dislocations) can break up into 3 types of equations:

- relation of flow: \( \Delta y_s = g (\tau_s, \alpha_s, \gamma_s, p_s) \)
- evolutions of kinematic work hardening: \( \Delta \alpha_s = h (\tau_s, \alpha_s, \gamma_s, p_s) \)
- evolution of isotropic work hardening: \( R_s (p_s), \) with \( \Delta p_s = \Delta y_s \)

---

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The relation of flow MONO_VISC1 is:

\[ \Delta \gamma_s = g \left( \tau_s, \alpha_s, \gamma_s, p_s \right) = \left( \frac{\left| \tau_s - c \alpha_s \right| - R \left| p_s \right|}{K} \right)^n \frac{\tau_s - c \alpha_s}{\left| \tau_s - c \alpha_s \right|}, \]

the parameters are: \( c, K, n \)

The relation of flow MONO_VISC2 is:

\[ \Delta \gamma_s = g \left( \tau_s, \alpha_s, \gamma_s, p_s \right) = \left( \frac{\left| \tau_s - c \alpha_s - a \gamma_s \right| - R \left| p_s \right| + \frac{c}{2d} \left( c \alpha_s \right)^2}{K} \right)^n \frac{\tau_s - c \alpha_s - a \gamma_s}{\left| \tau_s - c \alpha_s - a \gamma_s \right|}, \]

the parameters are then: \( c, K, n, a, d \)

Kinematic work hardening can be form MONO_CINE1:

\[ \Delta \alpha_s = h \left( \tau_s, \alpha_s, \gamma_s, p_s \right) \Delta \gamma_s \Delta p_s, \quad \alpha_s > 0, \Delta p_s \]

or MONO_CINE2:

\[ \Delta \alpha_s = h \left( \tau_s, \alpha_s, \gamma_s, p_s \right) \Delta \gamma_s \Delta p_s - \left( \frac{c \alpha_s}{M} \right)^m \frac{\alpha_s}{\alpha_s}, \]

parameters being then: \( d, M \) and \( m \).

Isotropic work hardening can form example be for MONO_ISOT1: \( R_s \left| p_s \right| = R_0 + Q \sum_{r=1}^{N} h_r \left( 1 - e^{-bp} \right) \)

with \( h_r \), matrices of interaction, the parameters are \( h, Q, R_0, b \).

Or MONO_ISOT2:

\[ R_s \left| p_s \right| = R_0 + Q \sum_{r=1}^{N} h_r q^r + Q_2 t^2, \quad \text{with} \quad d \left[ 1 - q^r \right], dp \]

the parameters are \( h, Q_1, Q_2, b_1, b_2, R_0 \).

Equations relating to the crystalline laws MONO_DD_KR, MONO_DD_CFC, MONO_DD_CFC_IRRA, MONO_DD_FAT, MONO_DD_CC, MONO_DD_CC_IRRA exit of the dynamics of dislocations described in the document [R4.03.11].

### 4.11.1 Syntax

These relations are accessible in Code_Aster in 3D, plane deformations (D_PLAN), forced plane (C_PLAN) (via the algorithm of Borst) and axisymmetric (AXIS) starting from the keyword BEHAVIOR order STAT NON_LINE. The choice of the relations making it possible to build the model of behavior of monocristal is carried out via the operator DEFI_COMPOR [U4.43.05].

```plaintext
| MONO_VISC1 = _F (   
  ♦ C = C, [R] 
  ♦ K = K, [R] 
  ♦ NR = N [R] ) 

| MONO_VISC2 = _F (   
  ♦ C = C, [R] 
  ♦ K = K, [R] 
  ♦ NR = N [R] 
  ♦ With has, [R] 
  ♦ D = D [R] ) 
```
MONO_ISOT1 = _F (
  ♦ R_0 = R, [R]
  ♦ Q = Q, [R]
  ♦ B = B, [R]
/  ♦ H = H, [R]
/  ♦ H1 = h1, [R]
  ♦ H2 = h2, [R]
  ♦ H3 = h3, [R]
  ♦ H4 = h4, [R]
  ♦ H5 = h5, [R]
  ♦ H6 = h6 [R]
)

MONO_ISOT2 = _F (
  ♦ R_0 = R0, [R]
  ♦ Q1 = Q1, [R]
  ♦ B1 = b1, [R]
  ♦ Q2 = Q2, [R]
  ♦ B2 = b2 [R]
/  ♦ H = H, [R]
/  ♦ H1 = h1, [R]
  ♦ H2 = h2, [R]
  ♦ H3 = h3, [R]
  ♦ H4 = h4, [R]
  ♦ H5 = h5, [R]
  ♦ H6 = h6 [R]
)

MONO_CINE1 = _F ( 
  ♦ D = D, [R] )

MONO_CINE2 = _F ( 
  ♦ D = D, [R]
  ♦ GM = M, [R]
  ♦ PM = m, [R]
  ♦ C = C [R])

# behavior of Kocks-Rauch specific to materials DC, families CUBIQUE1 and CUBIQUE2 (interaction between the 24 systems of slip)

MONO_DD_KR = _F ( 
  ♦ K = K, [R] Boltzmann constant, in $eV/K$
  ♦ TAUR = taur, [R] Shear stress with $T=0K$
  ♦ Tau0 = tau0, [R] Initial critical stress of shearing
  ♦ GAMMA0 = gammap0, [R] Initial speed D flow
  ♦ DELTAG0 = deltaG0, [R] Profit of energy to the crossing of obstacle
    ♦ BSD = Bsurd [R] function of the size of the grain $B/Dc$
  ♦ GCB = GCsurB [R] distance criticizes annihilation $GC/Bc$
  ♦ KDCS = K, [R] relating to the direction of dislocation
  ♦ P = p, [R] depending on the shape of the obstacle
  ♦ Q = Q, [R] depending on the shape of the obstacle

# Definition of the specific matrix of interaction (cf [R5.03.11])
/  ♦ H = H, [R]
/  ♦ H1 = h1, [R]
  ♦ H2 = h2, [R]
  ♦ H3 = h3, [R]
  ♦ H4 = h4, [R]
  ♦ H5 = h5, [R]
# behaviors specific to materials CFC, family OCTAERIQUE (interaction enters the 12 systems of slip)

| MONO_DD_CFC = _F {  
| ◊ GAMMA0= gammap0 [R] Initial speed, by default 0.001 s⁻¹  
| ◊ TAU_F = tauf [R] Threshold, in unit of constraints  
| ◊ A= WITH [R] parameter A , without unit, by default 0.13  
| ◊ B = B [R] parameter B , without unit, by default 0.005  
| ◊ NR =N [R] exhibitor n , must be large ( > 50 ), by default 200  
| ◊ Y =Y [R] parameter Y , in unit of length  
| ◊ ALPHA=a [R] parameter of work hardening alpha , by default 0.35  
| ◊ BETA =b [R] parameter of work hardening b , by default 0.35  
| ◊ RHO_REF = rho_ref, parameter rho_ref, in unit of length m⁻²

# Definition of the specific matrix of interaction (cf [R5.03.11])
/ ◊ H = H, [R] by default 0.124  
/ ◊ H1 = a*, [R] by default 0.625  
/ ◊ H2 = a_colinéaire [R] by default 0.137  
/ ◊ H3 = a_glissile, [R] by default 0.122  
/ ◊ H4 = a_Lomer [R] by default 0.07

| MONO_DD_CFC_IRRA = _F (same keyword as MONO_DD_CFC, except:

| ◊ DZ_IRRA = ζ ≥ 0 [R] parameter managing the evolution of loops  
| ◊ XI_IRRA = ξ ≥ 0 [R] parameter managing the evolution of forest  
| ◊ ALP_VOID = α_voids [R] parameter managing the evolution of loops  
| ◊ ALP_LOOP = α_loops [R] parameter managing the evolution of forest  
| ◊ RHO_SAT = ρ_sat b² = ω_sat [R] limit with saturation of loops  
| ◊ PHI_SAT = ϕ_sat [R] limit with saturation of loops

| MONO_DD_FAT = _F {  
| ◊ GAMMA0= gammap0 [R] Initial rate of flow in s⁻¹  
| ◊ TAU_F = tauf [R] Threshold, in unit of constraints  
| ◊ B = B [R] parameter B , in unit of length  
| ◊ GH= H [R] parameter H , in unit of 1/temps

# behavior specific to materials DC with low and high temperature, family CUBIQUE1 (interaction enters the 12 systems of slip)

| MONO_DD_CC = _F {  
| ◊ B = B [R] parameter B , in unit of length
DELTAG0 = Δ G₀ [R] energy of activation
TAU_0 = τ₀ [R] ultimate threshold, in unit of constraints
TAU_F = τ_F [R] initial threshold, in unit of constraints
GAMMA0 = γ₀ [R] Initial rate of flow,
NR = N [R] exhibitor n ,
RHO_MOB = ρ.mob [R] density of mobile dislocations, in unit of length −2
D=D [R] parameter D , in unit of length
D_LAT [R] parameter D_LAT , dependent in keeping with grain, in unit of length
Y_AT [R] parameter Y_AT in unit of length
K_F [R] parameter K_F in unit of length
K_SELF [R] parameter K_SELF in unit of length
K_BOLTZ [R] Boltzmann constant, in energy K , ex: eV / K
DEPDT [R] parameter dEps/dT for the calculation of Δ G

# Definition of the specific matrix of interaction (cf [R5.03.11])
/ ◊ H = H, [R]
/ ◊ H1 = h0 [R]
◊ H2 = h1 [R]
◊ H3 = H2, [R]
◊ H4 = h3 [R]
◊ H5 = h4 [R]
◊ H6 = h5 [R]

# behavior specific to materials DC with low and high temperature, family CUBIQUE1 (interaction enters the 12 systems of slip) with influence of 'irradiation (specific densities of dislocation):

| MONO_DD_CC_IRRA = _F ( same keyword as MONO_DD_CC, except:
| A_IRRA = a_irr [R] parameter allowing the variation of α_AT with ρ_irr
| XI_IRRA = ξ [R] parameter allowing the variation of ρ_irr with Δ p

4.12 Keywords factor LEMAITRE, LEMAITRE_FO

Definition of the coefficients of the non-linear relation of viscoplasticity of Lemaitre [R5.03.08]. The equations are the following ones:

\[
\begin{align*}
\dot{\varepsilon}_v & = \frac{3}{2} \dot{\rho} \frac{\sigma_y}{\sigma_{eq}} \\
\dot{\rho} & = \left[ \frac{1}{K} \right]^{\frac{1}{m}} \\
\sigma & = \lambda \left( \varepsilon - \varepsilon^v \right)
\end{align*}
\]

The coefficients to be introduced are: \( n > 0 \), \( \frac{1}{K} \) and \( \frac{1}{m} \geq 0 \).

4.12.1 Syntax

| / LEMAITRE= _F ( NR = N, [R]
| UN_SUR_K = 1/K , [R]
◊ UN_SUR_M = / 1/m, [R]

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Note:
While taking $\frac{1}{m} = 0$ (either $m = +\infty$), i.e. while putting 0 behind the operand $UN\_SUR\_M$, one obtains a non-linear relation of viscoelasticity of Norton.

4.13 **Keyword factor VISC\_SINH**

Definition of the coefficients of the law of viscosity defined by the following viscoplastic potential:

$$\Phi^p = \Phi_p - \sigma_0 sh^{-1}\left[\frac{p}{\varepsilon_0 \sigma_0} \right]$$

The equation defining the rate of cumulated plastic deformation is thus the following one:

$$\dot{p} = \varepsilon_0 \left[ sh\left(\frac{\Phi_p}{\sigma_0}\right) \right]^m$$

expression in which $\langle x \rangle$ indicate the positive part of $x$ and $\Phi_p$ the plastic threshold.

This model of viscosity can be associated:
- With the keyword **ROUSSELIER** to define the law of behavior **ROUSS\_VISC**
- With the keywords **VMIS\_ISOT\_TRAC** and **VMIS\_ISOT\_LINE** version **SIMO\_MIEHE** : to define the laws of behavior **VISC\_ISOT\_TRAC** and **VISC\_ISOT\_LINE**.

The coefficients to be introduced are: $m$, $\dot{\varepsilon}_0$ and $\sigma_0 > 0$.

### 4.13.1 Syntax

```c
/ VISC\_SINH = _F (  
   M = m , [R]  
   EPSI\_0 = \dot{\varepsilon}_0 , [R]  
   SIGM\_0 = \sigma_0 , [R]  
)

/ VISC\_SINH\_FO = _F (  
   M = m , [function]  
   EPSI\_0 = \dot{\varepsilon}_0 , [function]  
   SIGM\_0 = \sigma_0 , [function]  
)
```

4.14 **Keyword LEMA\_SEUIL**

Definition of the coefficients of the non-linear relation of viscoplasticity of Lemaitre with threshold [R5.03.08]. One places oneself on the assumption of the small disturbances and one divides the tensor of deformations in an elastic part, a thermal part, an unelastic part (known) and a viscous part.

The equations are then:
\[ \varepsilon_{\text{tot}} = \varepsilon_e + \varepsilon_{\text{th}} + \varepsilon_v \]
\[ \sigma = A \left| T \right| \varepsilon_e \]
\[ \dot{\varepsilon}_v = g \left( \sigma_{eq}, \lambda, T \right) \frac{3}{2} \tilde{\sigma} \]

with:

\( \lambda \) : cumulated viscous deformation  
\( \dot{\lambda} = \frac{2}{3} \varepsilon_v : \varepsilon_v \)

\( \tilde{\sigma} \) : diverter of the constraints  
\( \tilde{\sigma} = \sigma - \frac{1}{3} T \left| \sigma \right| I \)

\( \sigma_{eq} \) : equivalent constraint  
\( \sigma_{eq} = \sqrt{\frac{3}{2}} \tilde{\sigma} : \tilde{\sigma} \)

\( A \left| T \right| \) : tensor of elasticity

and:

\( \text{if } D \leq 1 \text{ then } g\left( \sigma, \lambda, T \right) = 0 \) (purely elastic behavior)

\( \text{if } D > 1 \text{ then } g\left( \sigma, \lambda, T \right) = A \left( \frac{2}{\sqrt{3}} \sigma \right) \Phi \text{ with } A \geq 0, \Phi \geq 0 \)

With:  
\( D = \frac{1}{S} \int_0^t \sigma_{eq} \left( u \right) du \)

The data materials to be informed by the user are  \( A \) and  \( S \).

As for the parameter  \( \Phi \), it is the flow of neutrons which bombards the material (quotient of the increment of fluence, defined by the keyword AFFE_VARC of AFFE_MATERIAU, by the increment of time).

The Young modulus  \( E \) and the Poisson’s ratio  \( \nu \) are those provided under the keywords factors ELAS or ELAS_FO.

### 4.14.1 Syntax

\[
/ \text{LEMA\_SEUIL} = \_F \{ \\
\quad \text{WITH} = \text{WITH}, \quad \text{[R]} \\
\quad S = S \quad \text{[R]} \\
/ \text{LEMA\_SEUIL\_FO} = \_F \{ \\
\quad \text{WITH} = \text{WITH}, \quad \text{[function]} \\
\quad S = S \quad \text{[function]} \\
\}
\]

### 4.15 Keyword factor VISC\_IRRA\_LOG

Definition of a law of creep under irradiation of the tubes guides. This law consists of a primary education type and a secondary law in logarithm of the fluence (cf [R5.03.08]).

The formulation is the following one (into uniaxial):

\[ \varepsilon_f = A \cdot \exp \left( -\frac{Q}{T} \right) \cdot \sigma \cdot \ln \left( 1 + \omega \cdot \Phi \cdot t \right) + B \cdot \exp \left( -\frac{Q}{T} \right) \cdot \sigma \cdot \Phi \cdot t \]

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\[ \varepsilon_f \] axial deformation of creep
\[ Q \] energy of activation
\[ T \] temperature
\[ \sigma \] axial stress applied to the tube guides in MPa
\[ \Phi \cdot t = \Phi_t \] Fluence \((10^{24} \text{neutrons/m}^2)\) is produced flow \(\Phi\) by time \(t\), given by the variable of order IRRA in AFFE_MATERIAU
\[ t \] time, expressed in hours
\( \omega \) Time-constant, expressed such as \(\omega \cdot \Phi \cdot t\), maybe without unit
\( A \) Constant, expressed such as \(A \cdot \sigma\), that is to say homogeneous with a deformation
\( B \) constant, expressed such as \(B \cdot \sigma \cdot \Phi \cdot t\), that is to say homogeneous with a deformation

Note: in the programming, the report \(Q/T\) is in fact taken as \(Q/(T+273.15)\), which means that the field of temperature (variable of order) must be in °C and \(Q\) in °K.

4.15.1 Syntax

| VISC_IRRA_LOG =_F  ( \\
| ♦ With = has, [R] \\
| ♦ B = B, [R] \\
| ♦ CSTE_TPS = W, [R] \\
| ♦ ENER_ACT = Q, [R] \\
| ) |

4.16 Keyword factor GRAN_IRRA_LOG

Definition of a law of creep under irradiation with growth of the tubes guides. Compared to VISC_IRRA_LOG, a term of growth is added (cf [R5.03.08]):

\[ \varepsilon_g = f(T, \Phi_t) \] where \(f\) is a function of the temperature \(T\) expressed in °C and of the fluence \(\Phi_t\), expressed in \(10^{24} \text{neutrons/m}^2\) (data by the variable of order IRRA in AFFE_MATERIAU).

4.16.1 Syntax

| GRAN_IRRA_LOG =_F  ( \\
| ♦ With = has, [R] \\
| ♦ B = B, [R] \\
| ♦ CSTE_TPS = W, [R] \\
| ♦ ENER_ACT = Q, [R] \\
| ♦ GRAN_FO = Fct_g, [function] \\
| ) |

4.17 Keywords factor IRRAD3M

Law of behavior of steels under irradiation (cf [R5.03.23]).

The plastic law having to describe itself in the form \(K (p + p_0)^n\), it is necessary to calculate these parameters from \(R02\), \(RM\), \(EPSILON_U\) and \(KAPPA\) via a method of dichotomy.
4.17.1 Syntax

\[
\text{IRRAD3M} = \_F ( \\
\text{R02} = \text{R02}, \quad \text{[function]} \\
\text{EPSI\_U} = \text{eps I}, \quad \text{[function]} \\
\text{RM} = \text{RM} \quad \text{[function]} \\
\text{A10} = \text{A10} \quad \text{[R]} \\
\text{\textcircled{ZETA\_F}} = \text{y0} \quad \text{[function]} \\
\text{ETAI\_S} = \text{stay}, \quad \text{[R]} \\
\text{\textcircled{ALHA}} = \text{ALPHA}, \quad \text{[R]} \\
\text{\textcircled{PHI0}} = \text{PHI0}, \quad \text{[R]} \\
\text{\textcircled{KAPPA}} = \text{KAPPA} \quad \text{[R]} \\
\text{\textcircled{ZETA\_G}} = \text{z0} \quad \text{[function]} \\
\text{\textcircled{TOLER\_ET}} = \text{Inc} \quad \text{[R]} \\
\text{\textcircled{KAPPA}} = \text{KAPPA} \quad \text{[DEFECT]} \\
\text{\textcircled{ZETA\_G}} = \text{z0} \quad \text{[function]} \\
\text{\textcircled{TOLER\_ET}} = \text{Inc} \quad \text{[R]} \\
\text{\textcircled{KAPPA}} = \text{KAPPA} \quad \text{[DEFECT]} \\
) 
\]

4.17.2 Operands R02/RM/EP\$I\_U/KAPPA

\[
\begin{align*}
\text{R02} &= \text{R02} \\
\text{EPSI\_U} &= \text{eps I} \\
\text{RM} &= \text{RM} \\
\text{KAPPA} &= \text{KAPPA}
\end{align*}
\]

Parameters intervening in the plastic part of the law. \(R02\) is the elastic limit with \(0.2\%\) of plastic deformation, \(Rm\) is the ultimate constraint, and \(\text{epsi}_u\) is lengthening distributed.

\text{TOLER\_ET} = \text{Inc}

This key word corresponds to the error which one authorizes on the going beyond the threshold of the creep of irradiation during digital integration. So during calculation the criterion is not respected, Code_Aster subdivides the steps of time, provided that the subdivision of the steps of time is authorized, if not the code stops.

4.17.3 Operands AI02/ZETA\_F/ETAI\_S

\[
\begin{align*}
\text{AI0} &= \text{AIO} \\
\text{ZETA\_F} &= \text{y0} \\
\text{ETAI\_S} &= \text{stay}
\end{align*}
\]

Parameters related to the irradiation. \(y0\) is a function of the temperature.

4.17.4 Operands RG0/ALPHA/PHI0/ZETA\_G

\[
\begin{align*}
\text{ALPHA} &= \text{ALPHA} \\
\text{PHI0} &= \text{PHI0} \\
\text{RG0} &= \text{R} \\
\text{ZETA\_G} &= \text{z0}
\end{align*}
\]

Parameters related to swelling.

4.18 Keywords factors \text{ECRO\_COOK}, \text{ECRO\_COOK\_FO}

Law of plasticity with criterion of Von Mises and isotropic work hardening following a law of Johnson-Cook.

4.18.1 Syntax

\[
/\text{ECRO\_COOK} = \_F ( \\
\text{With} = \text{With}, \quad \text{[R]} \\
\text{B} = \text{B}, \quad \text{[R]} \\
\text{C} = \text{C}, \quad \text{[R]} \\
\text{N\_PUIS} = \text{N}, \quad \text{[R]}
) 
\]

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4.18.2 Operands

The curve of work hardening is deduced from the uniaxial curve connecting the deformations to the constraints, whose expression is:

\[
\sigma(p, \dot{p}) = (A + Bp^n) \left[ 1 + C \ln \left( \frac{\dot{p}}{\dot{p}_0} \right) \right] \left[ 1 - \left( \frac{T - T_{room}}{T_{melt} - T_{room}} \right)^m \right]
\]

This expression can be rewritten in the following way:

\[
\sigma(p, \dot{p}) = (A + Bp^n) \left[ 1 + C \ln \left( \dot{p}^* \right) \left[ 1 - T^* \right]^m \right]
\]

Where:

\[
\dot{p}^* = \begin{cases} 
\frac{\dot{p}}{\dot{p}_0} & \text{if } \dot{p} \geq \dot{p}_0 \text{ and } T^* = \begin{cases} 
\frac{T - T_{room}}{T_{melt} - T_{room}} & \text{if } T \geq T_{room} \\
0 & \text{if } T \leq T_{room}
\end{cases}
\end{cases}
\]

\[
1 & \text{if } p \leq p_0
\]
5 Behaviors related to the damage and the rupture

5.1 Keywords factor ROUSSELIER, ROUSSELIER FO

Definition of the coefficients of the model of ductile behavior of rupture of Rousselier (cf [R5.03.06] and [R5.03.07]). This model can be used in small deformations, great deformations and viscoplasticity (keyword VISC_SINH)

Briefly, one solves for an elastoplastic increment:

\[
\frac{\sigma_{eq}}{\rho} - R(p) + D \sigma_1 f \exp \left( \frac{\sigma_H}{\sigma_1 \rho} \right) = 0 \quad \text{éq 5.1-1}
\]

\[
\sigma = \rho \Lambda (\varepsilon - \varepsilon^p)
\]

\[
\dot{\varepsilon}_p = \dot{p} \rho \frac{\partial f}{\partial \sigma} = \frac{3}{2} \frac{\dot{\varepsilon}_{eq}}{\rho}
\]

\[
\dot{f} = 3 (1 - f) \dot{\varepsilon}_{eq}^p
\]

\[
\frac{\partial f}{\partial \sigma} = \frac{1}{\rho} \left[ \frac{3}{2} \frac{\dot{\varepsilon}_p}{\sigma_{eq}} + Df \exp \left( \frac{\sigma_H}{\sigma_1 \rho} \right) \right]
\]

with

\[
\rho = \frac{1 - f}{1 - f_0}
\]

éq 5.1-2

\[ R(p) \text{ entry via the traction diagram (keyword TRACTION).} \]

With the coefficients materials \( D, \sigma_1, f_0 \) specific to the model of ROUSSELIER.

These various parameters can depend on the temperature, in this case one will employ the keyword ROUSSELIER FO.

It is possible to supplement the model while utilizing the following quantities:

- critical porosity \( f_c \) beyond which the growth of the cavities is accelerated:

\[
\dot{f} = 3 A (1 - f) \dot{\varepsilon}_{eq}^p \quad \text{si} \quad f > f_c
\]

two additional characteristics are then necessary: \( f_c \) and \( A \).

- limiting porosity \( f_l \) beyond which the material is considered broken. The behavior is then replaced by an imposed fall of the constraints:

\[
\dot{\sigma} = -\lambda E \frac{\sigma}{|\sigma|} |\varepsilon| \quad \text{si} \quad f = f_l \quad \text{(with} \ E \ \text{defined under ELAS)}.
\]

two additional characteristics are then necessary: \( f_l \) and \( \lambda \).

- the voluminal rate of germination of cracks of cleavages \( A_n \), modifying as follows the equations [éq 5.1-1] and [éq 5.1-2].

\[
\frac{\sigma_{eq}}{\rho} - R(p) + D \sigma_1 (f + A_n p) \exp \left( \frac{\sigma_H}{\sigma_1 \rho} \right) = 0
\]

\[
\rho = \frac{1 - f - A_n p}{1 - f_0}
\]
These the last five parameters are independent of the temperature. The following table of correspondence must be used:

<table>
<thead>
<tr>
<th>Modeling</th>
<th>Keywords</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D$</td>
<td>$D$</td>
</tr>
<tr>
<td>$\sigma_1$</td>
<td>SIGM_1</td>
</tr>
<tr>
<td>$f_0$</td>
<td>PORO_INIT</td>
</tr>
<tr>
<td>$f_c$</td>
<td>PORO_CRIT $dp$</td>
</tr>
<tr>
<td>$A$</td>
<td>PORO_ACCE</td>
</tr>
<tr>
<td>$A_n$</td>
<td>YEAR</td>
</tr>
<tr>
<td>$f_i$</td>
<td>PORO_LIMI</td>
</tr>
<tr>
<td>$\lambda$</td>
<td>$D_SIGM_EPSI_NORM$</td>
</tr>
</tbody>
</table>

In the version SIMO_MIEHE law of behavior has requires a recutting when the increment of plastic deformation is higher than the value $dp$ provided behind the keyword $DP\_MAXI$. The keyword $BETA$ is to be informed with the behaviors $ROUSS\_PR$ or $ROUSS\_VISC$ to take into account the adiabatic heating: it fixes the plastic proportion of energy which is actually transformed into heat.

The choice is given to the user via the keyword $PORO\_TYPE$ to change the formulation of porosity according to the plastic deformation or the total deflection. It was noticed that for an initial porosity $f_0$ weak, the behavior at the beginning of evolution strongly changes according to this parameter. Thus $PORO\_TYPE$ is affected of 1 (porosity in plastic deformation), 2 (porosity in total deflection).

### 5.1.1 Syntax

```plaintext
| / ROUSSELIER =
  / ROUSSELIER_FO=_F ( 
  ♦ $D$ = $D$, [R] or [function] 
  ♦ SIGM_1 = sigmal, [R] or [function] 
  ♦ PORO_INIT = $f_0$, [R] or [function] 
  ♦ PORO_CRIT = / 1.0D0, [DEFECT] 
  / FC, [R] 
  ♦ PORO_ACCE = / 1.0D0, [DEFECT] 
  / With, [R] 
  ♦ YEAR = / 0.0D0, [DEFECT] 
  / Year, 
  ♦ PORO_LIMI = / 0.999, [DEFECT] 
  / fl, [R] 
  ♦ $D\_SIGM\_EPSI\_NORM$ = / 1.0D0, [DEFECT] 
  / lambda, [R] 
  ♦ DP_MAXI = / 0.1, [DEFECT] 
  / $dp$, [R] 
  ♦ $BETA$ = / 0.85, [DEFECT] 
  / beta [R] 
  ♦ PORO_TYPE = / 1 [DEFECT] 
  / 2 [R] )
```

### 5.1.2 Assistance with the use

The model of Rousselier was the object of many developments and has several named alternatives $ROUSSELIER$, $ROUSS\_PR$ and $ROUSS\_VISC$ (these models are available in order $STAT\_NON\_LINE$ via the keyword $RELATION$). Thus each one of its models requires a particular knowledge from the
point of view “user”. In order to clarify that, a summary table below exposed, is accompanied by various remarks.

<table>
<thead>
<tr>
<th>BEHAVIOR</th>
<th>ROUSSELIER [R5.03.06]</th>
<th>ROUSS_PR [R5.03.07]</th>
<th>ROUSS_VISC [R5.03.07]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIMO_MIEHE</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDEF_LOG</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PETIT_REAC</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3D</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Axisymmetric</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>CP</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>DP</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>INCOMPRESSIBLE</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

(xxx_inco_ugp)

**Note:**
When one uses the incompressible elements (to refer to Doc. [R3.06.08]), keyword C_GONF must be indicated in DEFI_MATERIAU under operand NON_LOCAL (to refer to the §5.6 and with the CAS-test ssnp122a).
For a formulation with three fields UPG, it is preferable to use solver MUMPS to solve the linear systems. Moreover, the user must be informed that it is advised to regard as convergence criteria, convergence criteria by constraint of reference S on the keyword RESI_REFE_RELA.

### 5.2 Keywords VENDOCHAB / VENDOCHAB_FO

Definition of the coefficients of the viscoplastic model with scalar damage of Chaboche confer [R5.03.15]). It is a multiplicative behavior with work hardening-viscosity coupled to isotropic damage. Briefly, the relations are:

\[
\begin{align*}
\sigma &= (I-D)A\varepsilon^e \quad \text{et} \quad \varepsilon^e = \varepsilon - \varepsilon^h - \varepsilon^p \\
\varepsilon^p &= \frac{3}{2} p \frac{\bar{\sigma}}{\sigma_{eq}} \quad \text{avec} \quad p = \frac{\dot{\varepsilon}}{1-D} \\
\dot{\varepsilon} &= \left( \frac{\sigma_{eq} - S}{1-D} \right)^N \\
D &= \left( \frac{\chi(|\sigma|)}{A} \right)^R \left(1-D\right)^{-k|x|} \\
\end{align*}
\]

with \( D \), the scalar variable of isotropic damage and:

\[
\chi(|\sigma|) = \alpha J_\theta(|\sigma|) + \beta J_1(|\sigma|) + (1-\alpha-\beta)J_2(|\sigma|)
\]
where:

\[ J_0(\sigma) \] is the maximum principal constraint

\[ J_1(\sigma) = Tr(\sigma) \]

\[ J_2(\sigma) = \sigma_{eq} \]

\( \langle x \rangle \) : positive part of \( x \), \( \tilde{\sigma} \) diverter of the constraints and \( \sigma_{eq} \) the constraint of Von Mises.

### 5.2.1 Syntax

<table>
<thead>
<tr>
<th>/VENDOCHAB</th>
<th>=</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>♦ SY =</td>
<td>SY, [R] or [function]</td>
<td></td>
</tr>
<tr>
<td>♦ ALPHA_D =</td>
<td>alpha, [R] or [function]</td>
<td></td>
</tr>
<tr>
<td>♦ BETA_D =</td>
<td>beta, [R] or [function]</td>
<td></td>
</tr>
<tr>
<td>♦ A_D =</td>
<td>AD, [R] or [function]</td>
<td></td>
</tr>
<tr>
<td>♦ R_D =</td>
<td>rd, [R] or [function]</td>
<td></td>
</tr>
<tr>
<td>♦ K_D =</td>
<td>kd [R] or [function]</td>
<td></td>
</tr>
</tbody>
</table>

The table below summarizes the correspondences between the symbols of the equations and the keywords of Aster.

<table>
<thead>
<tr>
<th>Parameter material</th>
<th>Symbol in the equations</th>
<th>Keyword in Aster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of viscoplasticity</td>
<td>( S )</td>
<td>'SY'</td>
</tr>
<tr>
<td>Coefficient 1 of the equivalent constraint of creep</td>
<td>( \alpha )</td>
<td>'ALPHA_D'</td>
</tr>
<tr>
<td>Coefficient 2 of the equivalent constraint of creep</td>
<td>( \beta )</td>
<td>'BETA_D'</td>
</tr>
<tr>
<td>Coefficient of the law of damage</td>
<td>( A )</td>
<td>'A_D'</td>
</tr>
<tr>
<td>First exhibitor of the law of damage</td>
<td>( R )</td>
<td>'R_D'</td>
</tr>
<tr>
<td>Second exhibitor of the law of damage</td>
<td>( k \langle \chi</td>
<td>\sigma \rangle )</td>
</tr>
</tbody>
</table>

Note:

The parameter \( K_D \) can be defined like a constant, a function of a parameter 'TEMP' or a tablecloth (variable of temperature and constraint \( \chi | \sigma \)). In this case, to use \text{DEFI\_NAPPE} with like first parameter 'TEMP' for the temperature in °C and like second parameter '\( \chi \)' (obligatory) for the constraints in \( \chi | \sigma \) MPa. If \( K_D \) depends only on \( \chi | \sigma \), it is necessary to use \text{DEFI\_NAPPE} in any event by introducing for example 2 times same data file in constraint for two values different from the temperature.

### 5.3 Keywords VISC_ENDO / VISC_ENDO_FO

Definition of the coefficients of the viscoplastic model of Lemaître with scalar damage \text{VISC\_ENDO\_LEMA} (cf [R5.03.15]), which corresponds to a simplified and optimized version model \text{VENDOCHAB} (cf [U4.51.11]).

\[
\begin{align*}
\sigma &= |I - D| A \varepsilon^e \quad \text{et} \quad \varepsilon^e = \varepsilon - \varepsilon^\text{th} - \varepsilon^p \\
\varepsilon^p &= \frac{3}{2} \frac{\dot{\sigma}}{\sigma_{eq}} \quad \text{avec} \quad \dot{\rho} = \frac{\dot{\gamma}}{|I - D|} \\
\dot{\gamma} &= \frac{\sigma_{eq}}{K_D^{1/2}} \\
\dot{D} &= \frac{\sigma_{eq}}{A |I - D|}^R
\end{align*}
\]
5.3.1 Syntax

```plaintext
| /VISC_ENDO =   F (  
|   ♦ SY = sy [R] or [function]  
|   ♦ A_D = AD, [R] or [function]  
|   ♦ R_D = rd, [R] or [function]  
)
```

The table below summarizes the correspondences between the symbols of the equations and the keywords of Aster.

<table>
<thead>
<tr>
<th>Parameter material</th>
<th>Symbol in the equations</th>
<th>Keyword in Aster</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold of viscoplasticity</td>
<td>σ_y</td>
<td>'SY'</td>
</tr>
<tr>
<td>Coefficient of the law of damage</td>
<td>A</td>
<td>'A_D'</td>
</tr>
<tr>
<td>First exhibitor of the law of damage</td>
<td>R</td>
<td>'R_D'</td>
</tr>
</tbody>
</table>

5.4 Keyword HAYHURST

Definition of the coefficients of the viscoplastic model of Hayhurst, to describe the élasto-viscoplastic behavior of the austenitic steels, with a scalar damage in hyperbolic sine, function of the maximum principal constraint, an isotropic work hardening and a viscous law in hyperbolic sine:

\[
\begin{align*}
\sigma &= |I - D| C \varepsilon^e \quad \text{et} \quad \varepsilon^e &= \varepsilon^h - \varepsilon^p \\
\varepsilon^p &= \frac{3}{2} \frac{p}{\sigma_{eq}} \quad \text{avec} \quad p = \varepsilon_0 \sinh \left( \frac{\sigma_{eq}(1-H)}{K(I-D)(1-\phi)} \right) \\
&\quad \text{avec} \quad \dot{\phi} = \frac{k_c}{3} (1-\phi) \\
\text{si} \quad S_{EQUI_D} = 0 \quad \dot{D} = \dot{A}_0 \sinh \left( \frac{\alpha < \sigma^\alpha >_i + \sigma_{eq}(1-\alpha)}{\sigma_0} \right) \\
\text{si} \quad S_{EQUI_D} = 1 \quad \dot{D} = \dot{A}_0 \sinh \left( \frac{\alpha < \text{tr}(\sigma) >_i + \sigma_{eq}(1-\alpha)}{\sigma_0} \right) \\
H &= H_1 + H_2 \\
\dot{H}_i &= \frac{h_i}{\sigma_{eq}} \left( H_i^\ast - \delta_i H_i \right) \dot{p} \quad i = 1,2
\end{align*}
\]

5.4.1 Syntax

```plaintext
| /HAYHURST =   F (  
|   ♦ EPS0  =  \varepsilon_0, [R]  
|   ♦ K     =  \frac{\sigma}{\varepsilon_0}, [R]  
|   ♦ H1    =  \frac{h_1}{\sigma_0}, [R]  
|   ♦ H2    =  \frac{h_2}{\sigma_0}, [R]  
|   ♦ DELTA1 = \frac{\delta_1}{\sigma_0}, [R]  
|   ♦ DELTA2 = \frac{\delta_2}{\sigma_0}, [R]  
|   ♦ H1ST  =  \frac{H_1^\ast}{\sigma}, [R]  
|   ♦ H2ST  =  \frac{H_2^\ast}{\sigma}, [R]  
|   ♦ BIGA  =  A_0, [R]  
```
5.5 **Keyword factor RUPT_FRAG, RUPT_FRAG_FO**

The theory of the rupture of Frankfurt and Marigo makes it possible to model the appearance and the propagation of cracks in brittle fracture. It is based on the criterion of Griffith who compares the elastic restitution of energy and the energy dissipated during the creation of a fissured surface, provided by the keyword GC. In fact the concepts are used to describe the rupture in the models of cohesive zones, with the help of the definition of other concepts specific to certain laws. RUPT_FRAG is the keyword used to define the parameters materials of the cohesive laws of behavior, CZM_* (except for CZM_TRA_MIX and CZM_LAB_MIX) (see [R7.02.11]).

5.5.1 **Syntax**

\[
\begin{align*}
\text{◊} & \quad / \text{RUPT_FRAG} \quad = \quad _F ( \begin{align*}
\text{◊} & \quad \text{GC} \quad = \quad gc, \quad [R] \\
\text{◊} & \quad \text{SIGM_C} \quad = \quad sigm, \quad [R] \\
\text{◊} & \quad \text{PENA_ADHERENCE} \quad = \quad pad, \quad [R] \\
\text{◊} & \quad \text{PENA_CONTACT} \quad = \quad \text{/pco, } \quad [R] \\
\text{◊} & \quad \text{PENA_LAGR} \quad = \quad \text{/pla } \quad [R] \\
\text{◊} & \quad \text{RIGI_GLIS} \quad = \quad \text{/pgl, } \quad [R] \\
\text{◊} & \quad \text{KINEMATICS} \quad = \quad \text{/'UNILATER‘, } \quad [\text{DEFECT}] \\
\text{◊} & \quad / \text{GLIS_2D‘, } \quad [\text{TXM}] \\
\text{◊} & \quad / \text{GLIS_1D‘, } \quad [\text{TXM}] \\
\end{align*}
) \\
\text{◊} & \quad / \text{RUPT_FRAG_FO} \quad = \quad _F ( \begin{align*}
\text{◊} & \quad \text{GC} \quad = \quad gc, \quad [\text{function}] \\
\text{◊} & \quad \text{SIGM_C} \quad = \quad sigm, \quad [\text{function}] \\
\text{◊} & \quad \text{PENA_ADHERENCE} \quad = \quad pad, \quad [\text{function}] \\
\text{◊} & \quad \text{PENA_CONTACT} \quad = \quad \text{pco, } \quad [\text{function}] \\
\text{◊} & \quad \text{PENA_LAGR} \quad = \quad \text{pla } \quad [R] \\
\text{◊} & \quad \text{RIGI_GLIS} \quad = \quad \text{pgl, } \quad [R] \\
\text{◊} & \quad \text{KINEMATICS} \quad = \quad \text{/'UNILATER‘, } \quad [\text{DEFECT}] \\
\text{◊} & \quad / \text{GLIS_2D‘, } \quad [\text{TXM}] \\
\text{◊} & \quad / \text{GLIS_1D‘, } \quad [\text{TXM}] \\
\end{align*}
) 
\end{align*}
\]

5.5.2 **Operand G_C**

Dissipated energy is proportional to the surface of crack created, the proportionality factor being the density of energy critical of material \( G_c \).
5.5.3 **Operand SIGM_C**

Critical stress in the beginning from which the crack will open and the constraint between the lips to decrease.

5.5.4 **Operand PENA_ADHERENCE**

Small parameter of regularization of the constraint in zero (for more details to see [R7.02.11]).

**Note:**
Parameters `SIGM_C` and `PENA_ADHERENCE` in the case of modelings are only obligatory for `xxx_JOINT`. They are not used for the criterion of Griffith, this is why they appear optional on the level of the catalogue.

5.5.5 **Operand PENA_CONTACT**

Small parameter of regularization of the contact.

5.5.6 **Operands PENA_LAGR and RIGI_GLIS**

Parameter of penalization of Lagrangian (\( pla \geq 1.01 \)) and rigidity in mode of slip.

5.5.7 **Operand KINEMATICS**

Determine the modes of opening authorized by the law of interface for the law `CZM_TAC_MIX`. ‘UNILATER’ mean that two volumes on both sides of the interface cannot interpenetrate, ‘GLIS_2D’ that two volumes can only slide in the tangent plan with the interface, and ‘GLIS_1D’ that it can slide only in only one direction.

The tangent reference mark considered is defined via the keyword factor `SOLID MASS` of `AFFE_CARA_ELEM` [U4.42.01]. In the case of a unidimensional slip, the only direction of possible slip is defined by the second vector of the swivelled reference mark (\( Oy \)).

5.6 **Keyword factor NON_LOCAL**

This keyword factor makes it possible to inform the characteristics necessary to the use of nonlocal models of behavior for which the answer of material is not defined any more at the level of the material point but in that of the structure, to also see `AFFE_MODELE` [U4.41.01] and the booklet [R5.04].

5.6.1 **Syntax**

```plaintext
| NON_LOCAL = _F (_
  ◆ LONG_CARA = length, [R]
  ◆ C_GRAD_VARI = length, [R]
  ◆ COEF_RIGI_MINI = coeff, [R]
  ◆ C_GONF = gonf, [R]
  ◆ PENA_LAGR = pena, [R]
) |
```

5.6.2 **Operands LONG_CARA/C_GRAD_VARI/COEF_RIGI_MINI/C_GONF/PENA_LAGR**

**LONG_CARA** = long

Determine the length characteristic or scale length internal to material. With not using with the laws of nonlocal damage with gradient of damage `GRAD_VARI`.

**C_GRAD_VARI** = long
Parameter of nonlocality for the formulation with gradient of variable internal, present in the free energy in the form $c/2|\nabla a|^2$. It determines the length characteristic of the zone of damage. With to use exclusively with the laws of nonlocal damage with gradient of damage GRAD_VARI.

\[ \text{COEF_RIGI_MINI} = \text{coef} \]

With as for him an algorithmic role since it fixes, for the models of damage which degrade the rigidity of material, the proportion of initial rigidity (Young modulus) defines under ELAS (0.1% for example) in on this side which one stops the damage mechanism: this residual rigidity makes it possible to preserve the character posed well of the elastic problem.

\[ \text{C_GONF} = \text{gonf} \]

In the model of Rousselier, the lenitive character is carried by the porosity which has an effect pure lies hydrostatic. To control the localization, the idea is to regularize the problem only on this part and thus to regularize the variable of swelling if one uses modeling INCO_UPG.

\[ \text{PENA_LAGR} = \text{pena} \]

Parameter of penalization used for modelings with gradients of internal variables (_GRAD_VARI_) and second gradient (_DIL_), which makes it possible to control coincidence between a field with the nodes (degrees of freedom specific to nonthe room) and a field at the points of Gauss (variable intern or deformation).

A value by default of 1000 is established. For modeling _DIL_ it is disadvised decreasing this value (loss of precision for the resolution). For modeling _GRAD_VARI_ this parameter corresponds to the multiplier $r$ quadratic term of penalization in the free energy: $r/2(\alpha-a)^2$. It is to user to adjust his value according to the law used.

### 5.7 Keyword factor CZM_LAB_MIX

This keyword factor makes it possible to specify the parameters of the law of steel-concrete interface CZM_LAB_MIX (see [R7.02.11]).

#### 5.7.1 Syntax

```
| CZM_LAB_MIX = _F (  
  ♦ SIGM_C = sigm, [R]  
  ♦ GLIS_C = glis, [R]  
  ◊ ALPHA = /alpha, [R]  
  ◊ /0.5, [DEFECT]  
  ◊ BETA = /beta, [R]  
  ◊ /1. , [DEFECT]  
  ◊ PENA_LAGR = /pla [R]  
  ◊ /100. , [DEFECT]  
  ◊ KINEMATICS = /'GLIS_1D', [DEFECT]  
  ◊ /'GLIS_2D', [TXM]  
  ◊ /'UNILATER', [TXM]  
)
```

#### 5.7.2 Operand SIGM_C

Bearable maximum constraint by the steel-concrete interface.

#### 5.7.3 Operand GLIS_C

Slip for which the constraint with the interface is maximum.
5.7.4 **Operand ALPHA and BETA**

Parameters of form of the law of steel-concrete adherence. \( \alpha \) vary typically between 0 and 1, while \( \beta \) is positive.

5.7.5 **Operands PENA_LAGR**

Parameter of penalization of Lagrangian \( (pla \geq 1.01) \).

5.7.6 **Operand KINEMATICS**

Determine the modes of slip authorized by the law of interface. ‘UNILATER’ mean that two volumes on both sides of the interface cannot interpenetrate, ‘GLIS_2D’ that two volumes can only slide in the tangent plan with the interface, and ‘GLIS_1D’ that it can slide only in only one direction.

The tangent reference mark considered is defined via the keyword factor SOLID MASS of AFFE_CARAELEM [U4.42.01]. In the case of a unidimensional slip, the only direction of possible slip is defined by the second vector of the swivelled reference mark \( (Oy) \).

5.8 **Keyword factor RUPT_DUCT**

This material is intended to define the behavior of a ductile cohesive crack with the law of behavior CZM_TRA_MIX to see [R7.02.11].

5.8.1 **Syntax**

\[
\Diamond | / RUPT_DUCT = _F ( \begin{align*}
\Diamond & GC = gc, \quad [R] \\
\Diamond & SIGM_C = sigm, \quad [R] \\
\Diamond & COEF_EXTR = coee, \quad [R] \\
\Diamond & COEF_PLAS = coep, \quad [R] \\
\Diamond & PENA_LAGR = /pla \quad [R] \\
& \quad /100., \quad [DEFECT] \\
\Diamond & RIGI_GLIS = /pgl, \quad [R] \\
& \quad /10., \quad [DEFECT] 
\end{align*} )
\]

5.8.2 **Operand G_C**

Dissipated energy is proportional to the surface of crack created, the proportionality factor being the density of energy critical of material \( G_c \).

5.8.3 **Operand SIGM_C**

Critical stress in the beginning from which the crack will open.

5.8.4 **Operands COEF_EXTR and COEF_PLAS**

Parameters of form of the cohesive law CZM_TRA_MIX to see [R7.02.11].

5.8.5 **Operands PENA_LAGR and RIGI_GLIS**

Parameter of penalization of Lagrangian \( (pla \geq 0.1) \) and rigidity in mode of slip.
5.9 Keyword factor RANKINE

The simplified modeling of joints of the concrete dams is pressed on this material [R7.01.39]. It is about a criterion of perfect plasticity in traction relating to the components of the principal constraints: \( \sigma_{i=1,2,3} \leq \sigma_t \). When a principal constraint reaches the value threshold \( \sigma_t \), the joint opens in this direction. It should be noted that the plastic deformation thus created is not reversible, the model thus does not make it possible to represent refermeture of the joint and is valid only on one way of monotonous loading.

5.9.1 Syntax

\[
◊ | RANKINE = _F ( \\
\quad ◊ SIGMA_T = sigm, [R] 
) 
\]

5.9.2 Operand SIGMA_T

Threshold in traction (positive value).

5.10 Keyword factor JOINT_MECA_RUPT

The modeling of joints of the stoppings is pressed on this material [R7.01.25]. The hydrostatic pressure due to the possible presence of fluid in the joint is taken into account. Two industrial procedures are also implemented: keying-up - the injection of the concrete under pressure enters the studs of the work and sawing – the sawing of stopping in order to slacken the compressive stresses. This keyword material is used by the law of behavior of the same name: JOINT_MECA_RUPT.

5.10.1 Syntax

\[
◊ | JOINT_MECA_RUPT = _F ( \\
\quad ◊ K_N = kN, [R] \\
\quad ◊ K_T = kt, [R] \\
\quad ◊ SIGM_MAX = sigm, [R] \\
\quad ◊ ALPHA = /alpha, [R] \\
\quad \quad /1., [DEFECT] \\
\quad ◊ PENA_RUPTURE = pru, [R] \\
\quad ◊ PENA_CONTACT = /pco, [R] \\
\quad \quad /1., [DEFECT] \\
\quad ◊ PRES_FLUID = pflu [function] \\
\quad ◊ PRES_CLAVAGE = pcla, [function] \\
\quad ◊ SAWING = sawed, [function] \\
\quad ◊ RHO_FLUIDE = rho, [R] \\
\quad ◊ VISC_FLUIDE = vflu [R] \\
\quad ◊ OUV_MIN = oumi, [R] 
) 
\]

5.10.2 Operand K_N

Normal rigidity in traction.

5.10.3 Operand K_T

Tangential rigidity.

5.10.4 Operand SIGM_MAX

Maximum critical stress from which the crack opens and the constraint between the lips decrease. This constraint is often called tensile strength.
5.10.5 **Operand ALPHA**

Parameter of regularization of the tangential damage. The critical length of opening from which tangential rigidity falls towards zero is as follows defined:

\[ L_{CT} = L_C \tan \left( \frac{\text{ALPHA} \pi}{4} \right) \]

5.10.6 **Operand PENA RUPTURE**

Parameter of brittle smoothing of fracture. The maximum opening before the complete rupture is given by

\[ L_C = \text{SIGM}_\text{MAX} \left( 1 + \text{PENA RUPTURE} \right) / K_N \]

5.10.7 **Operand PENA_CONTACT**

Relationship between normal rigidity in compression and traction.

5.10.8 **Operand PRES_FLUIDE**

Pressure on the lips of the crack due to the presence of fluid (function which can depend on geometrical coordinates or the moment). Only valid with modelings mechanical joint: *_JOINT, and incompatible with RHO_FLUIDE, VISC_FLUIDE and OUV_MIN.

5.10.9 **Operand PRES_CLAVAGE**

Concrete pressure injected into the joint during the phase of keying-up (function which can depend on geometrical coordinates or the moment). Only valid with modelings mechanical joint: *_JOINT, and incompatible with RHO_FLUIDE, VISC_FLUIDE and OUV_MIN.

5.10.10 **Operand SAWING**

Size of saw used during the phase of sawing. Only valid with modelings mechanical joint: *_JOINT, and incompatible with RHO_FLUIDE, VISC_FLUIDE and OUV_MIN.

5.10.11 **Operand RHO_FLUIDE**

Density of the fluid (real positive [mass]/[volume]), only valid for hydro-mechanical coupled modelings: *_JOINT_HYME and incompatible with PRES_FLUIDE and PRES_CLAVAGE.

5.10.12 **Operand VISC_FLUIDE**

Dynamic viscosity of the fluid (real strictly positive [pressure] [time]), only valid for hydro-mechanical coupled modelings: *_JOINT_HYME and incompatible with PRES_FLUIDE and PRES_CLAVAGE.

5.10.13 **Operand OUV_MIN**

Opening of regularization at a peak of crack (strictly positive reality [length]), only valid for hydro-mechanical coupled modelings: *_JOINT_HYME and incompatible with PRES_FLUIDE and PRES_CLAVAGE.

5.11 **Keyword factor JOINT_MECA_FROT**

The modeling of friction between the joints of the stoppings is pressed on this material [R7.01.25]. The hydrostatic pressure due to the possible presence of fluid in the joint is taken into account. It is an elastoplastic version of the law Mohr-Coulomb, which depends on five parameters. Two parameters rubber bands: tangential stiffness and normal stiffness. Two parameters characterizing the function threshold: adherence and the coefficient of friction. More one parameter of regularization of the
tangent matrix in slip. A procedure industrial is also implemented: the sawing of stopping in order to slacken the compressive stresses. This keyword material is used by the law of behavior of the same name: JOINT_MEC_FROT.

5.11.1 Syntax

◊ | JOINT_MEC_FROT = _F ( 
 ◊ K_N = kN, [R] 
 ◊ K_T = kt, [R] 
 ◊ DRIVEN = driven, [R] 
 ◊ ADHESION = /c, [R] 
 ◊ AMOR_NOR = year, [R] 
 ◊ AMOR_TAN = At, [R] 
 ◊ COEF_AMOR = that, [R] 
 ◊ PENA_TANG = /pta, [R] 
 ◊ SAWING = sawed, [function] 
 ◊ PRES_FLUID = pflu [function] 
 ◊ RHO_FLUIDE = rho, [R] 
 ◊ VISC_FLUIDE = vflu [R] 
 ◊ OUV_MIN = oumi, [R] 
 )

5.11.2 Operand K_N
Normal rigidity.

5.11.3 Operand K_T
Tangential rigidity in the elastic range.

5.11.4 Operand DRIVEN
Coefficient of friction.

5.11.5 Operand ADHESION
Constraint of friction to worthless normal constraint. Tensile strength is given then by:

\[ R_T = C / \mu \]
5.11.6 Operand AMOR_NOR

Surface density of normal damping integrated on the surface of a face of element 3D_JOINT then distributed like characteristic of discrete on each segment uniting each couple of nodes tops in with respect to vis-a-vis the other of the element. These characteristics are affected with their full value only if the element of joint is in compression: maybe if the seventh component of variable interns behavior JOINT_MECA_FROT is negative.

5.11.7 Operand AMOR_TAN

Surface density of tangential damping integrated on the surface of a face of element 3D_JOINT then distributed like characteristic of discrete on each segment uniting each couple of nodes tops in with respect to vis-a-vis the other of the element. These characteristics are affected with their full value only if the element of joint is in compression: maybe if the seventh component of variable interns behavior JOINT_MECA_FROT is negative.

5.11.8 Operand COEF_AMOR

If the element of joint is not in compression when the seventh component of variable interns behavior JOINT_MECA_FROT is not negative, the preceding characteristics of damping normal or tangential are not affected with their full value but with a coefficient indicated by the keyword COEF_NOR.

5.11.9 Operand PENAT_TANG

Parameter of regularization of the tangent matrix in slip, is introduced to make the matrix tangent elementary invertible. One fixes it by default at a small value compared to tangent rigidity. If the structure is subjected to very important slips, it should be checked that calculation is not sensitive to the value of this parameter.

5.11.10 Operand SAWING

Size of saw used during the phase of sawing. Only valid with modelings mechanical joint: *_JOINT, and incompatible with RHO_FLUIDE, VISC_FLUIDE and OUV_MIN.
5.11.11 Operand `PRES_FLUIDE`

Pressure on the lips of the crack due to the presence of fluid (function which can depend on geometrical coordinates or the moment). Only valid with modelings mechanical joint: `*_JOINT`, and incompatible with `RHO_FLUIDE`, `VISC_FLUIDE` and `OUV_MIN`.

5.11.12 Operand `RHO_FLUIDE`

Density of the fluid (real positive [mass]/[volume]), only valid for hydro-mechanical coupled modelings: `*_JOINT_HYME` and incompatible with `PRES_FLUIDE`.

5.11.13 Operand `VISC_FLUIDE`

Dynamic viscosity of the fluid (real strictly positive [pressure]. [time]), only valid for hydro-mechanical coupled modelings: `*_JOINT_HYME` and incompatible with `PRES_FLUIDE`.

5.11.14 Operand `OUV_MIN`

Opening of regularization at a peak of crack (strictly positive reality [length]), only valid for hydro-mechanical coupled modelings: `*_JOINT_HYME` and incompatible with `PRES_FLUIDE`.

5.12 Keyword factor `CORR_ACIER`

The law `CORR_ACIER` is a model of behavior of the steel, subjected to corrosion in the reinforced concrete structures. This model is developed in 1D and elastoplastic 3D endommageable with isotropic work hardening and is based on the model of Lemaître [R7.01.20].

\[
\begin{align*}
\frac{\sigma_{eq}}{1-D} & = R(p) - \sigma_y > 0 \\
\dot{\varepsilon} & = \frac{3}{2} \frac{\dot{\lambda}}{1-D} \frac{\sigma_{eq}}{R} \\
\dot{\varepsilon} & = \dot{\lambda} = p[1-D] \\
R & = kp^{1/m}
\end{align*}
\]

In the plastic range $D=0$, if not $D = \frac{Dc}{p - p_D}$

5.12.1 Syntax

\begin{verbatim}
◊ | CORR_ACIER = _F ( \\
  |   D_CORR = cd., [R] \\
  |   ECRO_K = K, [R] \\
  |   ECRO_M = m, [R] \\
  |   SY = sy [R] \\
 )
\end{verbatim}

5.12.2 Operand `D_CORR`

Critical coefficient of damage.

5.12.3 Operands `ECRO_K`, `ECRO_M`

Coefficients of the law of work hardening $R = kp^{1/m}$.

5.12.4 Operand `SY`

Initial elastic limit, noted $\sigma_y$ in the equations.

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5.13 **Keyword factor ENDO_HETEROGENE**

The law **ENDO_HETEROGENE** is an isotropic model of damage representing the formation and the propagation of the cracks [R5.03.24]. The presence of crack in the structure is modelled by lines of broken elements \( \ell = 1 \). The rupture of the elements can be caused either by the starting of a new crack, or by propagation. This law is adapted to heterogeneous materials (for example clay).

### 5.13.1 Syntax

\[
\begin{align*}
\text{◊} & | \text{ENDO\_HETEROGENE} = _F ( \\
\star & \text{WEIBULL} = w, \quad [R] \\
\star & \text{SY} = sy, \quad [R] \\
\star & \text{KI} = ki, \quad [R] \\
\star & \text{EPAI} = ep, \quad [R] \\
\diamond & \text{GR.} = /gr, \quad [R] \\
\diamond & /1. \ , \quad \text{[DEFECT]} \\
\end{align*}
\]

### 5.13.2 Operand **WEIBULL**

Parameter associated with the model with Weibull.

### 5.13.3 Operand **SY**

Initial elastic limit, noted \( \sigma_y \) in the equations.

### 5.13.4 Operand **KI**

Tenacity \( K_{IC} \).

### 5.13.5 Operand **EPAI**

Thickness of the sample represented. Attention, if this value is purely geometrical, it is necessary for this law of behavior.

### 5.13.6 Operand **GR.**

Seed of random pulling defining the initial defects. Allows to get a single result for each command file. If the seed is worthless, pulling will be really random and will differ with each launching. By default, the value is equal to 1.
6 Thermal behaviors

The various thermal behaviors are excluded mutually.

6.1 Keywords factor THER, THER_FO

Definition of the constant linear thermal characteristics or function defined by a concept of the type function parameter 'INST'.

6.1.1 Syntax

/ THER = _F ( 
  ◊ RHO_CP = CP, [R] 
  ♦ LAMBDA = lambda [R] 
) / THER_FO = _F ( 
  ◊ RHO_CP = CP, [function] 
  ♦ LAMBDA = lambda [function] 
)

6.1.2 Operands LAMBDA / RHO_CP

LAMBDA = lambda
Isotropic thermal conductivity.

RHO_CP = CP
Voluminal heat with constant pressure (voluminal specific heat and bulk product). It is the coefficient appearing in the equation:

\[ cp \dot{T} - \text{div}\left(\lambda \cdot \text{grad} T\right) = f \]

6.2 Keyword factor THER_ORTH

Definition of the thermal characteristics for an orthotropic material.

The reader will be able to refer to following documentations:

[U4.42.03] DEFI_COMPOSITE
[U4.42.01] AFFE_CARA_ELEM

to define the longitudinal direction associated with the hulls or the nonisotropic 3D.

6.2.1 Syntax

/ THER_ORTH = _F ( 
  ◊ RHO_CP = CP, [R] 
  ♦ LAMBDA_L = lal, [R] 
  ♦ LAMBDA_T = lat, [R] 
  ◊ LAMBDA_N = lan, [R] 
)
6.2.2 Operands LAMBDA/RHO_CP

LAMBDA_L = lal
Thermal conductivity in the longitudinal direction.

LAMBDA_T = lat
Thermal conductivity in the transverse direction.

LAMBDA_N = lan
Thermal conductivity in the normal direction.

RHO_CP = CP
Voluminal heat.

6.3 Keyword factor THER_NL

Allows to describe the thermal characteristics depending on the temperature. The formulation utilizes the voluminal enthalpy (cf [R5.02.02]).

\[ \dot{\beta} - \nabla \cdot (\lambda(T) \nabla T) = f \]

6.3.1 Syntax

/ THER_NL = _F ( \\
  / BETA = beta, [function] \\
  / RHO_CP = CP , [function] \\
  ♦ LAMBDA = lambda, [function] \\
)

6.3.2 Operands AVERAGE BETA// RHO_CP

BETA = beta
Voluminal enthalpy function of the temperature. For the enthalpy, the prolongations of the function are necessarily linear.

RHO_CP = CP
Voluminal heat.
If the enthalpy is not provided by the user, it will be calculated by integration of RHO_CP and will not be prolonged on the left. RHO_CP must thus be defined on all the beach of calculation what means that the prolongation on the left RHO_CP is ignored for the estimate of the enthalpy.

LAMBDA = lambda
Thermal conductivity isotropic function of the temperature.

Note:

It is not possible to use a formula for these three parameters of material because the algorithm needs in calculation er of many times the derivative, which is more easily accessible for a linear function per pieces. Thus, the user, if it wishes to use a formula rather than a function, owes initially the tabuler with the assistance the order CALC_FONC_INTERP.

6.4 Keywords factor THER_COQUE, THER_COQUE_FO

Allows to define membrane and transverse conductivities and the heat capacity for homogenized heterogeneous thermal hulls.
Directions 1 and 2 indicate those of plan of the plate, direction 3 is perpendicular. It is admitted that the tensor of conductivity in each point is diagonal and that its eigenvalues are $l_1$, $l_2$ and $l_3$. The coefficients are thus defined by the user in the reference mark of orthotropy of the plate.

The code makes then the change of reference mark to find the correct values in the reference mark of the element.
6.4.1 Syntax

```plaintext
/ THER_COQUE
/ THER_COQUE_PO = _F { 
  ♦ COND_LMM = a1111, [R] or [function]
  ♦ COND_TMM = a2211, [R] or [function]
  ♦ COND_LMP = a1111, [R] or [function]
  ♦ COND_TMP = a2211, [R] or [function]
  ♦ COND_LPP = a1111, [R] or [function]
  ♦ COND_TPP = a2211, [R] or [function]
  ♦ COND_LSI = a1111, [R] or [function]
  ♦ COND_TSI = a2211, [R] or [function]
  ♦ COND_NMM = b1, [R] or [function]
  ♦ COND_NMP = b12, [R] or [function]
  ♦ COND_NPP = b22, [R] or [function]
  ♦ COND_NSI = b23, [R] or [function]
  ◊ CMAS_MM = c11, [R] or [function]
  ◊ CMAS_MP = c12, [R] or [function]
  ◊ CMAS_PP = c22, [R] or [function]
  ◊ CMAS_SI = c23, [R] or [function]
}
```

6.4.2 Operands

COND_LMM/COND_LMP/COND_LPP/COND_LSI/COND_TMM/COND_TMP/COND_TPP/COND_TSI

P1, P2, P3 the functions of interpolation of the temperature in the thickness indicate.

If has is the matrix of surface average conductivity defined in the note [R3.11.01], one has then for the membrane tensor of conductivity:

COND_LMM = a1111
  term related to the integral of l1*P1*P1
COND_LMF = a1112
  term related to the integral of l1*P1*P2
COND_LPF = a1122
  term related to the integral of l1*P2*P2
COND_LSI = a1123
  term related to the integral of l1*P2*P3
COND_TMM = a2211
  term related to the integral of l2*P1*P1
COND_TMP = a2212
  term related to the integral of l2*P1*P2
COND_TPP = a2222
  term related to the integral of l2*P2*P2
COND_TSI = a2223
  term related to the integral of l2*P2*P3

6.4.3 Operands

COND_NMM/COND_NMP/COND_NPP/COND_NSI

If B is the tensor which describes transverse conduction and the exchanges on surfaces omega+ and Omega, defined in the note [R3.11.01], one has for the transverse tensor of conductivity:

COND_NMM = b11
  term related to the integral of l3*P1*P1
COND_NMF = b12
  term related to the integral of l3*P1*P2
COND_NPF = b22
  term related to the integral of l3*P2*P2

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6.4.4 Operands CMAS_MM/CMAS_MP/CMAS_PP/CMAS_SI

One has finally for the tensor of heat capacity.

- CMAS_MM = c11  
  term related to the integral of \( \rho_1 \cdot c_{P1} \cdot P1 \)
- CMAS_MP = c12  
  term related to the integral of \( \rho_1 \cdot c_{P1} \cdot P2 \)
- CMAS_PP = c22  
  term related to the integral of \( \rho_1 \cdot c_{P2} \cdot P2 \)
- CMAS_SI = c23  
  term related to the integral of \( \rho_1 \cdot c_{P2} \cdot P3 \)
7 Behaviors specific to the concretes

7.1 Keyword factor THER_HYDR

Allows to define the behavior associated with the hydration with the concrete. The hydration of the concrete is a phenomenon which is accompanied by a heat emission depend on the temperature [R7.01.12].

\[
\frac{d \beta}{dt} + \text{div} q = Q \frac{d \xi}{dt} + s \\
q = -\lambda \text{grad} T \\
\frac{d \xi}{dt} = \text{AFF} \{\xi, T\}
\]

\[\text{eq 7.1-1}\]

\[\text{eq 7.1-2}\]

7.1.1 Syntax

\[
\text{THER_HYDR} = _F (\text{LAMBDA}, \text{BETA}, \text{AFFINITY}, \text{CHALHYDR})
\]

7.1.2 Operands LAMBDA / BETA

LAMBDA = average

Thermal conductivity isotropic function of the temperature.

BETA = beta

Voluminal enthalpy function of the temperature. The prolongations are has minimum linear, the voluminal enthalpy being able to be defined as the integral of voluminal heat.

7.1.3 Operand AFFINITY

AFFINITY = AFF

Function of the degree of hydration and the temperature. In general, one uses:

\[
\text{AFF} \{\xi, T\} = A \xi \exp \left( - \frac{E_a}{RT} \right) \text{ with } \text{QSR}_K = \frac{E_a}{R}
\]

the constant of Arrhenius expressed in Kelvin degree, and determined by a calorimetric test of the concrete (function of the size HYDR).

7.1.4 Operand CHAL_HYDR

CHAL_HYDR = Q

Heat released per unit of hydration (presumedly constant), this function depends on the type of concrete.

7.2 Keyword factor SECH_GRANGER

Definition of the parameters characterizing the coefficient of diffusion \( D(C, T) \) intervening in the nonlinear equation of drying proposed by Granger (cf [R7.01.12]). These characteristics are constants, while the coefficient of diffusion depends on the variable of calculation, i.e. the concentration \( C \) current out of water, (as thermal conductivity depended on the temperature).
7.2.1 Syntax

```cpp
| SECH_GRANGER = _F (  
  ♦ With = has,  
  ♦ B = B,  
  ♦ QSR_K = QsR,  
  ♦ TEMP_0_C = T0,  
)  
```

7.2.2 Operands With / B / QSR_K / TEMP_0_C

These coefficients make it possible to express the coefficient of diffusion in its form most usually used in the literature and suggested by Granger:

\[
D(C, T) = a \cdot e^{b \cdot C} \cdot \frac{T}{T_0} e^{-\frac{Q}{R} \left(\frac{1}{T} - \frac{1}{T_0}\right)}
\]

A= has

Coefficient of diffusion varying from \(0.5 \times 10^{-13}\) and \(2 \times 10^{-13} \text{ m}^2/\text{s}\) for the concrete.

B= B

Coefficient about \(0.05\) for the concrete.

QSR_K= QsR

QsR is worth in general \(4700 \text{ K}\). (\(R\) is the constant of perfect gases).

TEMP_0_C= T0

Temperature of reference in the law of Arrhenius. The temperature of reference \(T0\) is in degrees Celsius, and converted into Kelvin at the time of the resolution.

7.3 Keyword factor SECH_MENSI

Definition of the parameters characterizing the coefficient of diffusion intervening in the nonlinear equation of drying proposed by Mensi (cf [R7.01.12]). These characteristics are constants, while the coefficient of diffusion depends on the variable of calculation, i.e. the concentration \(C\) current out of water, (as thermal conductivity depended on the temperature). It is a formulation simplified of the case general, constituting the law of Mensi.

7.3.1 Syntax

```cpp
| SECH_MENSI = _F (  
  ♦ With = has,  
  ♦ B = B,  
)  
```

7.3.2 Operands With / B

These coefficients make it possible to express the coefficient of diffusion according to the law of Mensi:

\[
D(C) = a \cdot e^{b \cdot C}
\]

A= has

Coefficient of diffusion varying from \(0.5 \times 10^{-13}\) and \(2 \times 10^{-13} \text{ m}^2/\text{s}\) for the concrete.

B= B

Coefficient about \(0.05\) for the concrete.
7.4 **Keyword factor SECH_BAZANT**

Definition of the parameters characterizing the coefficient of diffusion intervening in the nonlinear equation of drying proposed by Bazant (confer [R7.01.12]). These characteristics are constants, while the coefficient of diffusion depends on the variable of calculation, i.e. the concentration $C$ current out of water, (as thermal conductivity depended on the temperature). This formulation constitutes the law of Bazant.

7.4.1 Syntax

```plaintext
| SECH_BAZANT = _F (  
  ♦ D1           = d1,  [R]  
  ♦ ALPHA_BAZANT = alpha, [R]  
  ♦ NR            = N,   [R]  
  ♦ FONC_DESORP  = desorp , [function]  
 )
```

7.4.2 **Operands D1 / ALPHA_BAZANT / NR / FONC_DESORP**

These coefficients make it possible to express the coefficient of diffusion according to the law of Bazant:

$$D(h) = d_1 \left( \alpha + \frac{1-\alpha}{1+\left(\frac{1-h}{1-0.75}\right)^\alpha} \right)$$

where $h$ is the degree of hydration, related to the water concentration by the curve of desorption.

- **D1** = $d_1$
  Coefficient of diffusion which is about $3.10^{-13} m^2/s$ for the concrete.

- **ALPHA_BAZANT** = $\alpha$
  Coefficient varying from 0.025 with 0.1 for the concrete.

- **NR** = $N$
  Exposing about 6 for the concrete.

- **FONC_DESORP** = $desorp$
  Curve of desorption, allowing to pass from the water concentration to the degree of hydration $h$.

**Notice important:**

- $desorp$ is a function of the variable of calculation, $C$, water concentration, which is comparable for the resolution at a temperature, of type ‘TEMP’.

7.5 **Keyword factor SECH_NAPPE**

The coefficient of diffusion, characterizing the nonlinear equation of drying, is expressed using a tablecloth, function tabulée of the concentration out of water, variable of calculation, and temperature, variable auxiliary of calculation, given in the form of a structure of data of the type `evol_ther`. For the resolution of drying by the operator `THER_NON_LINE`, the water concentration is comparable at a temperature, of type ‘TEMP’.

For the coherence of the data, parameters of the tablecloth, i.e. the variable of calculation and the auxiliary variable cannot be of the same type. A new type of variable was added in `DEFI_NAPPE`, the “type of the temperature calculated prior to drying”, ‘TSEC’, which corresponds indeed to a temperature.
7.5.1 Syntax

```plaintext
| SECH_NAPPE = _F ( 
  ° FUNCTION = nom_fonc, [function] 
)
```

7.5.2 Operand FUNCTION

The coefficient of diffusion is expressed using a tabulée function of the parameters $C$ and $T$.

FUNCTION = nom_fonc

Name of the tablecloth.

7.6 Keyword factor PINTO_MENEGOTTO

Definitions of the coefficients of the relation of cyclic behavior of elastoplasticity of the steel reinforcements in the reinforced concrete according to the model of Pinto-Menegotto (cf [R5.03.09]).

The initial traction diagram (beginning of the loading) is defined by:

- $\sigma = E\varepsilon$ as long as $\sigma \leq \sigma_y$ ; $E$ defined under ELAS
- $\sigma = \sigma_y$ for $\frac{\sigma}{E} \leq \varepsilon \leq \varepsilon_h$
- $\sigma = \sigma_u - (\sigma_u - \sigma_y) \left( \frac{\varepsilon_u - \varepsilon}{\varepsilon_u - \varepsilon_h} \right)^4$ for $\varepsilon_h \leq \varepsilon \leq \varepsilon_u$

$(\varepsilon$ cannot exceed $\varepsilon_u)$

The curve $s = f(e)$ with $n_{inc}$ cycle is defined by:

$$\sigma^*_{L} = b\varepsilon^*_{L} + \left( \frac{1-b}{1+\varepsilon^*_{L} R} \right)^{1/R} \varepsilon^*_{L} \text{ with } R = R_0 - \frac{a_1 \xi}{a_2 + \xi}$$

and $b = \frac{E_h}{E}$, $E_h$ : asymptotic slope of work hardening

where $\varepsilon^*$ is defined by:

$$\varepsilon^* = \frac{\varepsilon - \varepsilon_r^{n-1}}{\varepsilon_y^{n-1} - \varepsilon_r^{n-1}}.$$

where $\sigma^*$ is defined by:

$$\sigma^* = \frac{\sigma - \sigma_r^{n-1}}{\sigma_y^{n-1} - \sigma_r^{n-1}}.$$

Quantity $\varepsilon_y^n$ is deduced from the cycle $n-1$ by:

$$\varepsilon_y^n = \varepsilon_y^{n-1} + \frac{\sigma_y^n - \sigma_y^{n-1}}{E}$$

$$\sigma_y^n = \sigma_y^{n-1} \cdot \text{sign} (\varepsilon_y^{n-1} - \varepsilon_y^{n-1}) + \varepsilon_y^n (\varepsilon_y^{n-1} - \varepsilon_y^{n-1}).$$

The variable $\xi$ is defined by:

$$\xi = \frac{\varepsilon_y^{n-1} - \varepsilon_y^{n-1}}{\varepsilon_y^n - \varepsilon_y^{n-1}}$$

where $\varepsilon_r^{n-1}$ represent the deformation reached at the end of $n-1$ semi-cycle and $\varepsilon_y^{n-1}, \varepsilon_y^n$ the deformations of end of linearity of the semi-cycles represent $n-1$ and $n$.

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\[ b = \frac{E_H}{E} \] avec \[ E_H = \frac{\sigma_u - \sigma_y}{\varepsilon_u - \frac{E}{\sigma_y}} \]

In the event of buckling, (if \( L/D > 5 \)):

- in compression one replaces \( b \) by \( b = a(5.0 - L/D) e^{\left(\frac{b - b_c}{E} \sigma_y \right)} \)
- in traction, a new slope is calculated \( E_r = E \left( a_5 + 1.0 - a_5 \right) e^{\left( \frac{\sigma_y}{\varepsilon_u - \varepsilon_y^n} \right)} \) with \( a_5 = 1 + \frac{5 - L/D}{7.5} \).

\( \xi' \) represent the greatest “plastic excursion” during the loading: \( \xi' = \max_n \left( \varepsilon^n - \varepsilon_y^n \right) \) and \( \sigma_\infty = 4 \frac{\sigma_y}{L/D} \)

In the case of buckling, one adds to \( \sigma_y^n \) the value \( \sigma_y^* = Y_s b E \frac{b - b_c}{1 - b_c} \) with \( Y_s = \frac{11 - L/D}{10(\frac{a}{\varepsilon_p} - 1)} \).

### 7.6.1 Syntax

```
| PINTO_MENEGOTTO = _F ( |
| ♦ SY = sigm, [R] |
| ♦ EPSI_ULTM = epsu, [R] |
| ♦ SIGM_ULTM = sigmu, [R] |
| ◇ DASH = / L/D, [R] |
| ◇ / 4., [DEFECT] |
| ♦ EPSP_HARD = epsh, [R] |
| ◇ R_PM = / R0, [R] |
| ◇ / 20., [DEFECT] |
| ◇ EP_SUR_E = / B, [R] |
| ◇ A1_PM = / a1, [R] |
| ◇ / 18.5, [DEFECT] |
| ◇ A2_PM = / a2, [R] |
| ◇ / 0.15, [DEFECT] |
| ◇ A6_PM = / a6, [R] |
| ◇ / 620., [DEFECT] |
| ◇ C_PM = / C, [R] |
| ◇ / 0.5, [DEFECT] |
| ◇ A_PM = / has, [R] |
| ◇ / 0.006, [DEFECT] |
```

### 7.6.2 Operands

SY = sigm
Initial elastic limit, noted \( \sigma_y \) in the equations.

EPSI_ULTM = epsu, noted \( \varepsilon_u \) in the equations. Ultimate deformation.

SIGM_ULTM = sigmu, noted \( \sigma_u \) in the equations. Ultimate constraint.

DASH = L/D
Twinge of the bar (>5: buckling).
EPSP_HARD = epsh, noted $\varepsilon_h$ in the equations.
Deformation corresponding at the end of the plastic stage.

◊ EP_SUR_E = B

Ratio slope of work hardening/Young modulus (if no value is given, one takes $b = \frac{E_H}{E}$).

A1_PM = a1
Coefficient defining the traction diagram of the model.

A2_PM = a2
Coefficient defining the traction diagram of the model.

A6_PM = a6
Coefficient defining the traction diagram of the model in the event of buckling.

C_PM = C used in $\gamma_s$
Coefficient defining the traction diagram of the model in the event of buckling.

A_PM = has
Coefficient defining the traction diagram of the model in the event of buckling.

R_PM =
Coefficient $R_O$ (20. by defaults).

The Young modulus $E$ and the thermal dilation coefficient $\text{ALPHA}$ are to be specified by the keywords ELAS or ELAS_FO.

7.7 **Keywords factor BPEL_BETON, BPEL_ACIER**

Definition of the characteristics intervening in the model of behavior of the cables of prestressed within the regulation framework of the BPEL [R7.01.02].

The linear elastic characteristics of the material concrete and the material steel must be simultaneously defined under the keyword ELAS.

7.7.1 **Syntax**

```plaintext
| / BPEL_BETON = F (  
  ◊ PERT_FLUA = / xflu, [R]  
  ◊ PERT_RETR = / xret, [R]  
)  
/ BPEL_ACIER = F (  
  ◊ RELAX_1000 = / rh1000, [R]  
  ◊ MU0_RELAX = / mu0, [R]  
  ◊ F_PRG = fprg, [R]  
  ◊ FROT_COURB = / F, [R]  
  ◊ FROT_LINE = / phi, [R]  
)  
```

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7.7.2 Operands

Behavior: BPEL_BETON
Keyword factor for the definition of the parameters characteristic of the material concrete which intervene in the estimate of the losses of tension along the cables of prestressing. This keyword factor can be used only jointly with the keyword factor ELAS.

\[ \text{PERT\_FLUA} = x_{\text{flu}} \]
Standard rate of loss of tension by creep of the concrete, compared to the initial tension.
\[ \Delta F_{\text{flu}} = x_{\text{flu}} \cdot F_0 \] where \( F_0 \) indicate the initial tension defines by DEFI\_CABLE\_BP. [U4.42.04]
The value by default is 0: in this case, one does not take account of the losses of tension by creep of the concrete.
Attention, this value will not be affected by the information of the coefficient of relieving \( R_J \) in DEFI\_CABLE\_BP. The value \( x_{\text{flu}} \) must thus take account of this effect (multiplication by \( r(t) = \frac{t}{t+9r_m} \), \( t \) corresponding to the date on which one wants to estimate the state of the structure and \( r_m \) the average radius).

\[ \text{PERT\_RETR} = x_{\text{ret}} \]
Standard rate of loss of tension by shrinking of the concrete, compared to the initial tension.
\[ \Delta F_{\text{ret}} = x_{\text{ret}} \cdot F_0 \] where \( F_0 \) indicate the initial tension.
The value by default is 0: in this case, one does not take account of the losses of tension by shrinking of the concrete.
Attention, this value will not be affected by the information of the coefficient of relieving \( R_J \) in DEFI\_CABLE\_BP. The value \( x_{\text{ret}} \) must thus take account of this effect (multiplication by \( r(t) = \frac{t}{t+9r_m} \), \( t \) corresponding to the date on which one wants to estimate the state of the structure and \( r_m \) the average radius).

Behavior: BPEL_ACIER
Keyword factor for the definition of the parameters characteristic of the material steel which intervene in the estimate of the losses of tension along the cables of prestressing. This keyword factor can be used only jointly with the keyword factor ELAS.

\[ \text{RELAX\_1000} = rh_{1000} \]
Relieving of steel at 1000 hours, expressed in %.
The value by default is 0: in this case, one does not take account of the losses of tension by relieving of steel.

\[ \text{MU0\_RELAX} = \mu_0 \]
Adimensional coefficient of relieving of prestressed steel. The value by default is 0.

\[ \text{F\_PRG} = f_{\text{prg}} \]
Guaranteed constraint of the maximum loading with rupture (according to the BPEL)
If one takes account of the losses of tension by relieving of steel (RELAX\_1000 informed by a nonworthless value), the operand should obligatorily be informed F\_PRG, by a nonworthless value.

\[ \text{FROT\_COURB} = F \]
Coefficient of friction enters the cable and the sheath, partly curved, in \( rad^{-1} \). The value by default is 0.

\[ \text{FROT\_LINE} = \phi \]
Coefficient of friction per unit of length \( m^{-1} \), partly right. The value by default is 0. Note:
\[ \text{FROT\_LINE} = \text{FROT\_COURB} \times \text{PERT\_LIGNE} . \]
7.8 Keywords factor ETCC_BETON, ETCC_ACIER

Definition of the characteristics intervening in the model of behavior of the cables of prestressing, within the regulation framework of the ETCC [R7.01.02].
The linear elastic characteristics of the material concrete and the material steel must be simultaneously defined under the keyword ELAS.

7.8.1 Syntax

```
| / ETCC_BETON  = _F  |
| / ETCC_ACIER  = _F  |

◊ RELAX_1000 = / rh1000, [R]
◊ F_PRG = fprg, [R]
◊ COEF_FROT = / F, [R]
◊ PERT_LIGNE = / phi, [R]
```

7.8.2 Operands

**Behavior: ETCC_BETON**

Keyword factor to indicate to be able to calculate the tension in the cables according to the formulas of the ETCC. No information is necessary. This keyword factor can be used only jointly with the keyword factor ELAS.

**Behavior: ETCC_ACIER**

Keyword factor for the definition of the parameters characteristic of the material steel which intervene in the estimate of the losses of tension along the cables of prestressing. This keyword factor can be used only jointly with the keyword factor ELAS.

RELAX_1000 = rh1000
Relieving of steel at 1000 hours, expressed in %.
The value by default is 0: in this case, one does not take account of the losses of tension by relieving of steel.

F_PRG = fprg
Guaranteed constraint of the maximum loading with rupture (according to the ETCC).
If one takes account of the losses of tension by relieving of steel (RELAX_1000 informed by a nonworthless value), the operand should obligatorily be informed F_PRG, by a nonworthless value.

COEF_FROT = F
Coefficient of friction enters the cable and its partly curved sheath, in \( \text{rad}^{-1} \). The value by default is 0.

PERT_LIGNE = phi
Loss ratio on line in \( \text{rad} \cdot \text{m}^{-1} \). The value by default is 0.

Note:

```
PERT_LIGNE = FROT_LINE/FROT_COURB.
```

7.9 Keyword factor CONCRETE_DOUBLE_DP

The model of behavior 3D developed in Code_Aster is formulated within the framework of the thermo-plasticity, for the description of the nonlinear behavior of the concrete, in traction, and in
compression, with the taking into account of the irreversible variations of the thermal and mechanical characteristics of the concrete, particularly sensitive at high temperature [R7.01.03].

7.9.1 Syntax

```plaintext
| BETON_DOUBLE_DP = _F(
  ♦ F_C  = f' C ,  [function]
  ♦ F_T  = f' T ,  [function]
  ♦ COEF_BIAX = beta,  [function]
  ♦ ENER_COMP_RUPT = Gc,  [function]
  ♦ ENER_TRAC_RUPT = WP,  [function]
  ♦ COEF_ELAS_COMP = phi,  [R]
  ◊ LONG_CARA = will l_cara,  [R]
  ◊ ECRO_COMP_P_PIC =/'LINEAR',  [DEFECT]
                     /'PARABOLA',  [TXM]
  ◊ ECRO_TRAC_P_PIC =/'LINEAR',  [DEFECT]
                     /'EXPONENT'  [TXM]
)
```

The functions can depend on the variables of following orders: 'TEMP', 'INST', 'HYDR', 'SECH'.

BETON_DOUBLE_DP allows to define all the characteristics associated with the law with behavior with double criterion with Drücker Prager. In complement of these characteristics, the modulus of elasticity, the Poisson's ratio, and the thermal dilation coefficient $\alpha$, as well as the coefficients of endogenous withdrawal and withdrawal of desiccation, must be defined under the keyword ELAS for the real coefficients, or ELAS_FO, for the coefficients defined by functions, or tablecloths. All characteristics of the model, $(E, nu, \alpha, f'c, f't, \beta, Gc, Gt)$ of type [function] can depend on one or two variables among the temperature, the hydration and drying. When they depend on the temperature, they are functions of the maximum of the temperature reached during the history of loading $\theta$, which is stored for each point of Gauss, in the form of internal variable. This makes it possible to take into account the irreversible variations of these characteristics at high temperature.

7.9.2 Operands $F_C$ / $F_T$ / COEF_BIAX

- $F_C = f' C$
  Resistance in uniaxial pressing $f'c$.

- $F_T = f' T$
  Resistance in uniaxial traction $f't$.

- COEF_BIAX = beta
  The report of the strength in biaxial compression to resistance in uniaxial pressing $\beta$.

7.9.3 Operands ENER_COMP_RUPT / ENER_TRAC_RUPT / COEF_ELAS_COMP

- ENER_COMP_RUPT = $Gc$
  The energy of rupture in compression $Gc$.

- ENER_TRAC_RUPT = WP
  The energy of rupture in traction $Gt$.

- COEF_ELAS_COMP = phi
  Elastic limit in compression, given by a proportionality factor expressed as a percentage of resistance to the peak $f'_c(\theta)$ is in general about 30% for the standard concretes. It is important to stress that this parameter is a reality and not a function.
7.9.4 Operands LONG_CARA

This operand makes it possible to overload the automatically calculated characteristic length, for each mesh, according to its dimensions (starting from its surface in 2D, starting from its volume in 3D). The automatically calculated characteristic length makes it possible, when the smoothness of the grid evolves from one calculation to another, to preserve stable results by avoiding the phenomena of localization. This length calculated automatically or given by the user, conduit with the value of ultimate work hardening in traction according to the formula (for a linear work hardening post-peak):

\[ \kappa_u(0) = \frac{2 \cdot G_t(0)}{l_c \cdot \varepsilon'_t(0)} \]

In the typical case of a grid containing of the adjacent meshes from which dimensions are very different, ultimate work hardenings of the model BETON_DOUBLE_DP calculated starting from the length characteristic of the meshes are consequently very different, which can generate problems of convergence or lead to a not very physical state of stresses. (This characteristic length is calculated starting from the volume of the current mesh). For this reason, one proposes to give the possibility to the user of defining an average length which overloads the characteristic length calculated for each mesh. The value by default of Code_Aster is the characteristic length calculated for each mesh.

To choose an arbitrary and identical length for all the meshes can also generate difficulties of convergence. The best solution consists in creating a network whose variations of the mesh sizes respect the direction of variation of the stress field, and to use the length characteristic calculated automatically according to the size of the meshes. The overload by LONG_CARA must be to reserve for typical cases, when the user cannot freely intervene on the grid.

If the user defines the characteristic length in material, it will choose a couple \((G_t, \text{LONG_CARA})\) such as \(\frac{2 \cdot G_t(0)}{l_c \cdot \varepsilon'_t(0)}\) the value is worth which it wishes for ultimate work hardening in traction \(\kappa_u\). (The usual value of the deformation associated with ultimate work hardening in traction with an average concrete is of \(5.E^{-4}\)).

7.9.5 Operands ECRO_COMP_P_PIC / ECRO_TRAC_P_PIC

The parameters making it possible to define the curve of softening in compression and traction are optional, and have values by default.

- \(\text{ECRO_COMP_P_PIC} = \) \{'LINEAR', 'PARABOLA'
- \(\text{ECRO_TRAC_P_PIC} = \) \{'LINEAR', 'EXPONENT'

The shape of the curved post-peak in compression of type text, which can take the values ‘LINEAR’ and ‘PARABOLA’. The nonlinear curve is then of parabolic type.

The shape of the curved post-peak in traction of type text, which can take the values ‘LINEAR’ and ‘EXPONENT’. The nonlinear curve is then of exponential type.

7.10 Keyword factor BETON_GRANGER, V_BETON_GRANGER

Definition of the parameters materials for the viscoelastic model of Granger, modelling the clean creep of the concrete. There exist 2 relations of behavior: the first \((\text{BETON_GRANGER})\) does not take into account the phenomenon of ageing but models the effect of hygroscopy. The second \((\text{BETON_GRANGER_V})\) takes into account the effects of ageing and hygroscopy (cf [R7.01.01]).

In 1D and due to a constant constraint \(\sigma_0\), deformation of creep according to time and the moment of loading \(l_c\) is written: \(\varepsilon_p(t) = J(t, l_c) \cdot \sigma_0\)

The function of creep \(J(t, l_c)\) is worth:

---

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\[ J(t, t_c) = k(a(t_c)) \sum_{s=0}^{n} J_s \left( 1 - \exp\left( \frac{t - t_c}{\tau_s} \right) \right) \]

where \( a \) is old material, i.e. the past time of the installation of the concrete. It is about an internal variable of the model.

The function \( k(a(t_c)) \) who appears in \( J(t, t_c) \) is used to model ageing because it introduces the direct dépendence at the moment of loading. One can use for example the curve CEB which models ageing due to the hydration:

\[ k(a(t_c)) = 28 \frac{0.2 + 0.1 a^{0.2} + 0.1}{a^{0.2} + 0.1} \]

Without ageing this function is constant and is worth 1, the function of creep depends in this case only on the time passed as of loading \( t - t_c \).

The hygroscopy is taken into account by the means of an equivalent constraint \( S = h \cdot \sigma \), \( h \) being relative umidity of material. It is thus necessary to inform the isothermal curve of desorption \( c \) who allows to pass from the water content \( C \) with \( h : h = c^{-1} |C| \). This curve is provided to Code_Aster under the keyword \textbf{ELAS_FO} (\texttt{ELAS_FO} and \texttt{ELAS_FO} to see § 3.1.8).

\[ \text{Note:} \]

\[ This \ behavior \ can \ be \ associated \ with \ the \ withdrawals \ of \ drying \ and \ thermohydration \ defined \ by \ the \ operands \ K_DESSIC, B_ENDOGE \ and \ ALPHA \ under \ the \ keyword \ \textbf{ELAS_FO}. \]

For the law \texttt{BETON_GRANGER}, the parameters of the law are to be informed under the keyword: \texttt{BETON_GRANGER}. For the law \texttt{BETON_GRANGER_V} the keyword also should be informed \texttt{BETON_GRANGER} but he is necessary to add the keyword to it \texttt{V_BETON_GRANGER} for the parameters specific to growing old law.

The internal variables of the law of behavior are described in [R7.01.01].

7.10.1 Syntax for clean creep

\begin{verbatim}
| BETON_GRANGER = _F { 
  \phi J1 = J1, [R] 
  \phi J2 = J2, [R] 
  \phi J3 = J3, [R] 
  \phi J4 = J4, [R] 
  \phi J5 = J5, [R] 
  \phi J6 = J6, [R] 
  \phi J7 = J7, [R] 
  \phi J8 = J8, [R] 
  \phi TAUX_1 = tau1, [R] 
  \phi TAUX_2 = tau2, [R] 
  \phi TAUX_3 = tau3, [R] 
  \phi TAUX_4 = tau4, [R] 
  \phi TAUX_5 = tau5, [R] 
  \phi TAUX_6 = tau6, [R] 
  \phi TAUX_7 = tau7, [R] 
  \phi TAUX_8 = tau8, [R] 
  \phi QSR_K = qsr [R] 
}
\end{verbatim}

7.10.2 Operands for clean creep

\[ J1 = J1 \]
... 
J8 = J8

8 coefficients materials of the function of creep, homogeneous at a time.

TAUX_1 = tau1
...
TAUX_8 = tau8

8 time lags of the function of creep.

### 7.10.3 Syntax for ageing

If one uses the relation of behavior which then takes into account the phenomenon of ageing it is necessary to inform moreover:

```
|   V_BETON_GRANGER = _F ( 
    ◊ QSR_VEIL = USR,       [R]
    ◊ FONC_V = K (Tc),      [function, formula] 
) |
```

### 7.10.4 Operands for ageing

FONC_V = K (a)

Function of ageing.

### 7.11 Keyword factor MAZARS, MAZARS_FO

The model of behavior of Mazars is an elastic model of behavior endommageable making it possible to describe the softening behavior of the concrete. It distinguishes behaviour in traction and compression, but uses only one variable of scalar damage (confer [R7.01.08]). Implemented the Mazars model corresponds to the version of 2012 i.e. reformulation improving behaviour in bi-compression and pure shearing.

The parameters can be a function of the temperature, to use then MAZARS_FO. Attention, in practice, one considers that the parameters depend on the maximum temperature seen by material.

### 7.11.1 Syntax

```
MAZARS = _F ( 
    ◆ EPSD0 = epsd0,       [R]
    ◆ AC = ac,             [R]
    ◆ AT = At,             [R]
    ◆ BC = Bc,             [R]
    ◆ BT = BT,             [R]
    ◆ K = K,              [R]
    ◆ CHI = chi,          [R]
    ◆ SIGM_LIM = sqlim,    [R]
    ◆ EPSI_LIM = eplim,    [R]
)
```

```
MAZARS_FO = _F ( 
    ◆ EPSD0 = epsd0,       [function]
    ◆ AC = ac,             [function]
    ◆ AT = At,             [function]
    ◆ BC = Bc,             [function]
    ◆ BT = BT,             [function]
    ◆ K = K,              [function]
    ◆ CHI = chi,          [R]
```
The functions can depend on the variables of following orders: ‘TEMP’, ‘HYDR’, ‘SECH’. On the other hand for the multifibre beams, the functions can depend only on the temperature: the deformations due to the hydration and drying are not taken into account.

MAZARS (or MAZARS_FO) allows to define all the characteristics associated with the model with behavior with Mazars. Besides these characteristics, constant the rubber bands must be defined under the keyword ELAS for the real coefficients or ELAS_FO for the coefficients depending on the temperature.

7.11.2 Operands EPSD0 / AC / AT / BC / BT / K

- EPSD0 = epsd0
  Threshold of damage in deformation \(0.5 \times 10^{-4} < \varepsilon_{\text{d0}} < 1.5 \times 10^{-4}\).

- AC = ac
  Coefficient allowing to fix the pace of the curved post-peak in compression. Introduced a horizontal asymptote which is the axis of \(\varepsilon\) for \(AC = 1\) and the horizontal one for passer by the peak for \(AC = 0\) (generally \(1 < AC < 1.5\)).

- AT = At
  Coefficient allowing to fix the pace of the curved post-peak in traction. Introduced a horizontal asymptote which is the axis of \(\varepsilon\) for \(AC = 1\) and the horizontal one passing by the peak for \(AC = 0\) (generally \(0.7 < AT < 1\)).

- BC = bc
  Coefficient allowing to fix the pace of the curved post-peak in compression. According to its value can correspond to a sharp fall of the constraint \((BC < 10^4)\) or a preliminary phase of increase in constraint followed by a more or less fast decrease (generally \(10^3 < Bc < 2 \times 10^3\)).

- BT = BT
  Coefficient allowing to fix the pace of the curved post-peak in traction. According to its value can correspond to a sharp fall of the constraint \((BC < 10^4)\) or a preliminary phase of increase in constraint followed by a more or less fast decrease (generally \(10^4 < Bt < 10^5\)).

- K = K
  Parameter introducing a horizontal asymptote in pure shearing. It lies between 0 and 1. Advised value 0.7.

7.11.3 Operand CHI

- CHI = chi
  Within the framework of the coupling BETON_UMLV with the law of MAZARS. The parameter \(\chi\) allows to define the importance of the coupling:
  \(CHI = 0\) : no coupling,
  \(CHI = 1\) : total coupling.
  The total coupling generates a premature appearance of the concrete, this is why the value to be used is rather around \(0.4/0.7\).

7.11.4 Operand SIGM_LIM, EPSI_LIM

- SIGM_LIM = sglim
  Definition of the ultimate stress.
Definition of the limiting deformation.

Operands SIGM_LIM and ESPI_LIM allow to define the terminals in constraint and deformation which correspond to the limiting states of service and ultimate, classically used at the time of study in civil engineer. These terminals are obligatory when the behavior is used MAZARS (confer [R7.01.08] Model of damage of MAZARS, [U4.42.07] DEFI_MATER_GC). In the other cases they are not taken into account.

7.12 Keyword BETON_UMLV

The law of creep UMLV supposes a total decoupling between the spherical and deviatoric components: the deformations induced by the spherical constraints are purely spherical and the deformations induced by the deviatoric constraints are purely deviatoric [R7.01.06]. In addition, the clean deformation of creep is supposed to be proportional to internal relative moisture:

Spherical part: \( \varepsilon_s^s = h \cdot f(\sigma_s) \) and, left deviatoric: \( \varepsilon_d^d = h \cdot f(\sigma_d) \)

Where \( h \) indicate internal relative moisture.

The model of behavior BETON_UMLV is a nongrowing old viscoelastic model developed in partnership with the University of Marne-the-Valley to describe the clean creep of the concretes. It is particularly adapted to the multiaxial configurations by not presupposing the value of the Poisson's ratio of creep.

The spherical constraints are at the origin of the migration of the water absorptive with the interfaces between the hydrates on the level of the macroporosity and absorptive within microporosity in capillary porosity. The diffusion of the inter-lamellate water of the pores of hydrates towards capillary porosity is carried out in an irreversible way. The total spherical deformation of creep is thus written as the sum of a reversible part and an irreversible part:

\[
\varepsilon_s^s = \varepsilon_s^{s,r} + \varepsilon_s^{s,i}
\]

The process of deformation spherical of creep is controlled by the system of equations coupled according to:

\[
\begin{align*}
\dot{\varepsilon}_s^{s,r} &= \frac{1}{\eta_s^{s,r}} \left[ h \cdot \sigma_s - k_s^{s,r} \varepsilon_s^{s,r} \right] - \dot{\varepsilon}_s^{s,i} \\
\dot{\varepsilon}_s^{s,i} &= \frac{1}{\eta_s^{s,i}} \left[ k_s^{s,i} \cdot \varepsilon_s^{s,i} - \left( k_s^{s,i} + k_i^{s,i} \right) \cdot \varepsilon_i^{s,i} \right] - \left[ h \sigma_s - k_s^{s,i} \varepsilon_s^{s,i} \right]^{+}
\end{align*}
\]

where \( k_s^{s,r} \) indicate rigidity connect associated with the skeleton formed by blocks with hydrates on a mesoscopic scale; \( \eta_s^{s,r} \) viscosity connects associated with the mechanism with diffusion within capillary porosity; \( k_i^{s,i} \) indicate rigidity connect intrinsically associated with the hydrates on a microscopic scale and \( \eta_i^{s,i} \) viscosity connects associated with the interfoliaceous mechanism of diffusion.

(Hooks \( \langle \cdot \rangle^+ \) appoint the operator of Mac Cauley: \( \langle x \rangle^+ = \frac{1}{2} \left( x + |x| \right) \))

The deviatoric constraints are at the origin of a mechanism of slip (or mechanism of quasi dislocation) of the layers of HSC in nano-porosity. Under deviatoric constraint, creep is carried out with constant volume. In addition, the law of creep UMLV supposes the deviatoric isotropy of creep. Phénoménologiquement, the mechanism of slip comprises a viscoelastic reversible contribution of water strongly adsorbed to the layers of HSC and a viscous irreversible contribution of free water.
The principal component of the total deviatoric deformation is governed by the system of equations following:

\[
\tilde{\varepsilon}_{ij} = 1 + \frac{\eta_j}{\eta_i} \tilde{\eta}_j + k^d \tilde{\eta}_j = \eta^d_i \varepsilon^d_i + k^d \varepsilon^d_i
\]

where \( k^d_r \) indicate rigidity associated with the capacity with water absorptive to transmit loads (load bearing toilets); \( \eta^d_i \) viscosity associated with the water adsorbed by the layers with hydrates and \( \eta^d_i \) indicate viscosity associated with free water.

### 7.12.1 Syntax

```plaintext
| BETON_UMLV: _F (  
    ♦ K_RS = K_RS, [R]  
    ♦ K_IS = K_IS, [R]  
    ♦ K_RD = K_RD, [R]  
    ♦ ETA_RS = ETA_RS, [R]  
    ♦ ETA_IS = ETA_IS, [R]  
    ♦ ETA_RD = ETA_RD, [R]  
    ♦ ETA_ID = ETA_ID, [R]  
    ◊ ETA_FD = ETA_FD [R]  
)
```

### 7.12.2 Operand

- \( K_{RS} = K_{RS} \)
- \( K_{IS} = K_{IS} \)
- \( K_{RD} = K_{RD} \)
- \( \eta_{RS} = \eta_{RS} \)
- \( \eta_{IS} = \eta_{IS} \)
- \( \eta_{RD} = \eta_{RD} \)
- \( \eta_{FD} = \eta_{FD} \)

Allows to take into account the creep of desiccation according to the law of Bazant.

**Note:**

The curve of desorption giving the hygroscopy \( h \) according to the water concentration \( C \) must be well informed under the keyword `ELAS_FO`.
7.13 **Keyword factor BETON_ECRO_LINE**

Definition of a linear curve of work hardening with taking into account of containment in the case specific to the concrete. In order to improve behaviour in compression one defines a threshold of reversibility ([R7.01.04] model ENDO_ISOT_BETON).

7.13.1 **Syntax**

```plaintext
| BETON_ECRO_LINE = _F (  
  ♦ D_SIGM_EPSI = dsde, [R]  
  ♦ SYT = sigt, [R]  
  ◊ SYC = sigc, [R]  
)
```

7.13.2 **Operands**

- **D_SIGM_EPSI** = dsde (AND)
  Slope of the traction diagram.

- **SYT** = sigt
  Maximum constraint in simple traction.

- **SYC** = sigc
  Maximum constraint in simple compression (it does not exist for a Poisson's ratio $\nu = 0$, in this case one does not specify **SYC**)

The Young modulus $E$ is to be specified by the keywords **ELAS** or **ELAS_FO**.

7.14 **Keyword factor ENDO_ORTH_BETON**

Definition of the parameters of the law of behavior ENDO_ORTH_BETON, allowing to describe the anisotropy induced by the damage of the concrete, as well as the unilateral effects [R7.01.09]. One will refer to the documents [R7.01.09] and [V6.04.176] for the precise significance of the parameters and the procedure of identification.

7.14.1 **Syntax**

```plaintext
| ENDO_ORTH_BETON = _F (  
  ◊ ALPHA = / alpha, [R]  
  / 0.9, [DEFECT]  
  ♦ K0 = k0, [R]  
  ♦ K1 = k1, [R]  
  ◊ K2 = / k2, [R]  
  / 0.0007, [DEFECT]  
  ♦ ECROB = ecrob, [R]  
  ♦ ECROD = ecrod [R]  
)
```

7.14.2 **Operand ALPHA**

Constant of coupling between the evolution of the damage of traction and that of the damage of compression. It must be taken enters 0 and 1, rather near to 1. The value by default is 0.9.

7.14.3 **Operands K0 / K1 / K2**

- **K0** = k0
  Constant part of the function threshold. Allows to gauge the height of the peak in traction.

- **K1** = k1

---

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Parameter of the function threshold allowing to increase the threshold in compression.

\[ K_2 = k_2 \]

Parameter of control of the shape of the envelope of rupture for biaxial tests. The value by default is \( 7.10^{-4} \).

### 7.14.4 Operands ECROB / ECROD

\( \text{ECROB} = \text{ecrob} \)

Term of blocked energy (equivalent to an energy of work hardening) relating to the evolution of the damage of traction. Allows to control the shape of the peak in traction.

\( \text{ECROD} = \text{ecrod} \)

Term of blocked energy (equivalent to an energy of work hardening) relating to the evolution of the damage of compression. Allows to control the shape of the peak in compression.

The Young modulus \( E \) and the Poisson's ratio \( \nu \) are to be specified by the keywords \text{ELAS} or \text{ELAS\_FO}.

In the case of a nonlocal calculation with the formulation \text{GRAD\_EPSI}, the characteristic length is to be specified behind the keyword \text{NON\_LOCAL}.

### 7.15 Keywords factor ENDO\_SCALAIRE/ENDO\_SCALAIRE\_FO

Definition of the parameters of the law of behavior \text{ENDO\_SCALAIRE} [R5.03.25], which describes the elastic rupture fragile of a homogeneous isotropic material. This law is available only for modeling to gradient of damage \text{GRAD\_VARI}.

#### 7.15.1 Syntax

\[
\begin{align*}
\text{ENDO\_SCALAIRE\_FO} & = _F ( \\
\text{ENDO\_SCALAIRE} & = \text{F} ( \\
\quad & \text{K} = k, \quad [\text{R}] \text{ or } [\text{function}] \\
\quad & \text{P} = p, \quad [\text{R}] \text{ or } [\text{function}] \\
\quad & \text{M} = m, \quad [\text{R}] \text{ or } [\text{function}] \\
\quad & \text{C\_COMP} = \text{/} c\_\text{comp}, \quad [\text{R}] \text{ or } [\text{function}] \\
\quad & \text{C\_VOLU} = \text{/} c\_\text{volu}, \quad [\text{R}] \text{ or } [\text{function}] \\
\quad & \text{COEF\_RIGI\_MINI} = \text{/} A\_\text{min}, \quad [\text{R}] \\
\quad & \text{E}\_5 = \text{/} 1E\text{-}5, \quad [\text{DEFECT}] \\
\end{align*}
\]

#### 7.15.2 Operand \text{K}, \text{P}, \text{M}

They are the internal parameters of the model which define work hardening, to see [R5.03.25]: \( k \) indicate a density of energy \( Pa \), \( k \) and \( m \) are parameters without dimension. \( k \) and \( m \) can be readjusted starting from the nonlocal scale \( D \) (roughly the half-width of band of localization) and of the following macroscopic parameters: \( E \) the Young modulus, \( G_f \) the energy of cracking and \( f_t \) the value of the constraint to the peak in simple traction. The relations of retiming are written then:

\[
\begin{align*}
K &= \frac{3 \cdot G_f}{4D} ; \quad m = \frac{3E \cdot G_f}{2f_t^2 D} ; \quad c = \frac{3}{8} \cdot DG_f
\end{align*}
\]

where \( c \) is the parameter indicated by \text{NON\_LOCAL} = _F (\text{C\_GRAD\_VARI} = c), who also depends on the macroscopic answer. As for the parameter \( p \), higher than 1, it controls the curvature of the response post-peak.
7.15.3 Operands C_COMP, C_VOLU

They are the internal parameters of the model, without dimension, which define the form of the surface of load (except for a homothety), to see [R5.03.25]. The values by default make it possible to find the energy model (symmetrical) for which the surface of load corresponds to a datum line of the density of elastic energy (ellipsoidal of rotation around the axis \((1,1,1)\) who is centered at the beginning of coordinates).

In the case more general the surface of ellipsoidal load (always the axis \((1,1,1)\) not-centered, perhaps defined by three parameters more accessible to measurement: \(f_t\), the value of the constraint to the peak in simple traction, \(f_c\), the value of the constraint to the peak in simple compression and \(\tau\) the value of the constraint to the peak in pure shearing. The relations of retiming are the following ones:

\[
c_{\text{comp}} = \frac{1 + \nu}{1 - 2\nu} \frac{(f_c - f_t)\tau \sqrt{3}}{2f_t f_c} ; \quad c_{\text{vola}} = \frac{2(1 + \nu)}{1 - 2\nu} \left[ \frac{((f_c + f_t)\tau \sqrt{3})^2}{2f_t f_c} - 1 \right]
\]

7.15.4 Operands COEF_RIGI_MINI

COEF_RIGI_MINI

It is the parameter of regularization of the tangent matrix to the rupture, to avoid the worthless pivots if cracking were to cut out the part in several pieces not maintained by the boundary conditions. It does not depend on the variables of order.

The Young modulus \(E\) and the Poisson's ratio \(\nu\) are to be specified by the keywords ELAS or ELAS_FO.

The parameter of nonlocality is indicated under the keyword C_GRAD_VARI behind the keyword factor NON_LOCAL. It is related to the macroscopic parameters by:

7.16 Keyword factor ENDO_FISS_EXP/ENDO_FISS_EXP_FO

Definition of the parameters of the law of behavior ENDO_FISS_EXP [R5.03.27], which describes the elastic rupture fragile of a homogeneous isotropic material. This law is available only for modeling to gradient of damage GRAD_VARI.

7.16.1 Syntax

```plaintext
| ENDO_FISS_EXP_FO
ENDO_FISS_EXP = _F {
    K = K, [R] or [function]
    M = m, [R] or [function]
    P = p, [R] or [function]
    Q = / Q, [R] or [function]
    / 0, [DEFECT]
    TAU = tau, [R] or [function]
    SIG0 = sig0, [R] or [function]
    BETA = / beta, [R]
    / 1E-1, [DEFECT]
    REST_RIGIDITE = gamma, [R]
    / 1E-5, [DEFECT]
}
```

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7.16.2 Operand $K$, $M$, $P$, $Q$

They are the internal parameters of the model which define work hardening, to see [R5.03.27]. Their identification is assumption of responsibility by the order DEFI_MATER_GC [U4.42.07], starting from accessible sizes in experiments.

7.16.3 Operands $\tau$, $\sigma_0$, $\beta$

They are the internal parameters of the model which define the form of the surface of load (except for a homothety), to see [R5.03.27]. It is based on the constraint of Von Mises and the exponential one of the tensor of the constraints and is compared well with experimental results on concrete in biaxial loading. The parameter $\beta$ is of digital nature and has like interest only to return the field of elasticity limited, including for hydrostatic compressions; the value by default fills this office well, without incidence on the form of the field in the zones of interest.

There too, the order DEFI_MATER_GC [U4.42.07] allows to identify these parameters starting from accessible sizes in experiments (limiting in traction and compression).

7.16.4 Operand REST_RIGIDITE

The restoration of rigidity is active for the directions of deformation in compression. To avoid a brutal regime change at the time of the passage of traction to compression, a function regularizes the jump of rigidity, to see [R5.03.27]. The parameter REST_RIGIDITE, positive, comes to control this regularization; it corresponds to the coefficient $\gamma$ function. A value of 0 conduit not to restore rigidity (i.e the model is without restoration of rigidity) while a very large value amounts being freed almost from the regularization. The order DEFI_MATER_GC [U4.42.07] the quantification of this parameter facilitates while stipulating which proportion of rigidity is restored for a level of deformation corresponding to the initial threshold in compression.

7.16.5 Operands COEF_RIGI_MINI

It is the parameter of regularization of the tangent matrix to the rupture, to avoid the worthless pivots if cracking were to cut out the part in several pieces not maintained by the boundary conditions. It does not depend on the variables of order.

The Young modulus $E$ and the Poisson's ratio $\nu$ are to be specified by the keywords ELAS or ELAS_FO.

The parameter of nonlocality is indicated under the keyword C_GRAD_VARI behind the keyword factor NON_LOCAL; the order DEFI_MATER_GC [U4.42.07] allows to identify it starting from accessible sizes in experiments.

7.17 Keyword factor GLRC_DM

This keyword factor makes it possible to define the parameters of the law of behavior GLRC_DM. It is about a model of total damage of a reinforced concrete flagstone formulated in term of generalized relations forced deformation/(membrane extension, inflection and membrane effort, bending moment).

7.17.1 Syntax

```
| GLRC_DM = _F (  
  ♦ NYT = NT,  [R]  
  ◊ NYC = Nc, [R]  
  ♦ MYF = MF,  [R]  
  ♦ GAMMA_T = GMT,  [R]  
  ◊ GAMMA_C = Gmc, [R]  
  ♦ GAMMA_F = Gmf,  [R]  
  ◊ ALPHA_C = Alfc, [R]  
  /  1.0,  [DEFECT]  )  
```

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7.17.2 Operands

NYT = NT
Membrane effort of the threshold of damage in simple traction of a reinforced concrete flagstone (unit of force per length).

NYC = Nc
Membrane effort of the threshold of "damage" (fine of linearity of the curve of compression) in simple compression of a reinforced concrete flagstone (unit of force per length).

MYF = MF
Bending moment of the threshold of damage in pure bending of a reinforced concrete flagstone (unit of force).

GAMMA_T = GMT
Slope damaging relative compared to the elastic slope in simple traction ($0 < \gamma_{MT} < 1$).

GAMMA_C = Gmc
Slope damaging relative compared to the elastic slope in simple compression ($0 < \gamma_{MC} < 1$).

GAMMA_F = Gmf
Slope damaging relative compared to the elastic slope in pure bending ($0 < \gamma_F < 1$).

ALPHA_C = Alfc
Parameter of modulation of the function of damage in compression to introduce a decoupling of the thresholds in traction and compression and inducing a curve of the curve of compression. The function of damage out of membrane is written:

$$\xi_m(x, d_1, d_2) = \frac{1}{2} \left[ \left( \frac{1 + \gamma_{mt} d_1}{1 + d_1} + \frac{1 + \gamma_{mt} d_2}{1 + d_2} \right) H(x) + \frac{\alpha_c + \gamma_{mc} d_1}{\alpha_c + d_1} + \frac{\alpha_c + \gamma_{mc} d_2}{\alpha_c + d_2} \right] H(-x)$$

One can refer to the reference material [R7.01.32] section § 3.2.4 where a summary of the identification of the parameters of the model is exposed.

7.18 Keyword factor DHRC

This keywords factor makes it possible to define the parameters of the law of behavior DHRC. It is about a model of total damage of a reinforced concrete flagstone formulated using a method of homogenisation, in terms of generalized relations forced deformation/(membrane extension, inflection and membrane effort, bending moment) and comprising internal variables of state of damage and slip to the steel-concrete interface, to see [R7.01.36].

258 parameters of the law to be identified, by homogenisation and the method of least squares on various values of damage, correspond:

- with the parameters controlling the components of the tensors of elastic rigidity endommageable $\Lambda$, of coupling deformations generalize-slips $B$ and of energy stored in slip $C$, for which one does not have analytical expression;
- with the macroscopic parameters of thresholds which are related to the parameters of the microscopic thresholds.

7.18.1 Syntax

```
| DHRC = _F ( ♦ NYD = nyd, [l_R] ♦ SCRIT = scrit, [l_R])
```

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7.18.2 Operands

NYD = nyd
List of the two thresholds of damage $G^c,_{crit}$ in simple traction of the reinforced concrete

SCRIT = scrit
List of the four thresholds of slip $\Sigma^\alpha,_{crit}$ steel-concrete are equivalent

$AA_C = \alpha_Ac$ $[l_R]$

$GA_C = \gamma_Ac$ $[l_R]$

$AB = \alpha_B$ $[l_R]$

$C0 = \gamma_C, [l_R]$

$AC = \alpha_C$ $[l_R]$

$AC = \gamma_C, [l_R]$

$AA_T = \alpha_At$ $[l_R]$

$GA_T = \gamma_At$ $[l_R]$

$GB = \gamma_B$ $[l_R]$

$AC = \gamma_C, [l_R]$

In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes $(x, y)$, one will have:

| AAC131 = 1., AAC161 = 1., AAC231 = 1., AAC261 = 1., AAC341 = 1., AAC351 = 1., AAC461 = 1., AAC561 = 1., |
| AAC461 = 1., AAC561 = 1., AAC132 = 1., AAC162 = 1., AAC232 = 1., AAC262 = 1., |
| AAC342 = 1., AAC352 = 1., AAC462 = 1., AAC562 = 1., |

$AA_T = \alpha_At$

Parameters (42) $\alpha_{Ac}^{dt}$ dependences in variables of damage of the components (21 supra-diagonal terms) of the tensor of order 4 symmetrical $A$ membrane-inflexion of the plate, in the traction field, the reference mark of the reinforcements $(x, y)$, in notations of Voigt, identified by homogenisation and the method of least squares on various values of $D_{\rho}$, in higher zone (1) then lower (2):

$$A^0_{\beta\delta\tau\upsilon}(D_{\rho}) = A^0_{\beta\delta\tau\upsilon} \left( \frac{\alpha_{\delta\sigma}^{Ac} + \gamma_{\delta\sigma}^{Ac} D_{\rho}}{\alpha_{\delta\sigma}^{Ac} + D_{\rho}} \right)$$

Note:

In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes $(x, y)$, one will have:

| AAT131 = 1., AAT161 = 1., AAT231 = 1., AAT261 = 1., AAT341 = 1., AAT351 = 1., |
| AAT461 = 1., AAT561 = 1., AAT132 = 1., AAT162 = 1., AAT232 = 1., AAT262 = 1., |
| AAT342 = 1., AAT352 = 1., AAT462 = 1., AAT562 = 1., |
Parameters \( \gamma^{i4c} \) dependences in variables of damage of the components (21 supra-diagonal terms) of the tensor of order 4 symmetrical \( \mathbf{A} \) membrane-inflection of the plate, in the compression field, the reference mark of the reinforcements \((x, y)\), in notations of Voigt, identified by homogenisation and the method of least squares on various values of \( D_\rho \), in higher zone (1) then lower (2).

Note: In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes \((x, y)\), one will take:

\[
\begin{align*}
GAC131 &= 1., GAC161 = 1., GAC231 = 1., GAC261 = 1., GAC341 = 1., GAC351 = 1., \\
GAC461 &= 1., GAC561 = 1.; GAC132 = 1., GAC162 = 1., GAC232 = 1., GAC262 = 1., \\
GAC342 &= 1., GAC352 = 1., GAC462 = 1., GAC562 = 1.
\end{align*}
\]

GA_T = \( \gamma^{i4t} \) dependences in variables of damage of the components (21 supra-diagonal terms) of the tensor of order 4 symmetrical \( \mathbf{A} \) membrane-inflection of the plate, in the traction field, the reference mark of the reinforcements \((x, y)\), for the slips out of higher grid (1) or lower (2), in notations of Voigt, identified by homogenisation and the method of least squares on various values of \( D_\rho \), in higher zone (1) then lower (2).

Note: In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes \((x, y)\), one will take:

\[
\begin{align*}
GAT131 &= 1., GAT161 = 1., GAT231 = 1., GAT261 = 1., GAT341 = 1., GAT351 = 1., \\
GAT461 &= 1., GAT561 = 1.; GAT132 = 1., GAT162 = 1., GAT232 = 1., GAT262 = 1., \\
GAT342 &= 1., GAT352 = 1., GAT462 = 1., GAT562 = 1.
\end{align*}
\]

AB = \( \alpha^{i3} \) dependences in variables of damage of the components (24 supra-diagonal terms) of the tensor of order 3 symmetrical \( \mathbf{B} \) of coupling membrane-inflection-slip of the plate, in the reference mark of the reinforcements \((x, y)\), for the slips out of higher grid (1) then lower (2), in notations of Voigt, identified by homogenisation and the method of least squares on various values of \( D_\rho \) :

\[
\begin{bmatrix}
B^\text{m1}_{1x} & B^\text{m1}_{1y} & B^\text{m1}_{1xy} & B^\text{m1}_{1yy} \\
B^\text{m1}_{2x} & B^\text{m1}_{2y} & B^\text{m1}_{2xy} & B^\text{m1}_{2yy} \\
B^\text{m2}_{1x} & B^\text{m2}_{1y} & B^\text{m2}_{1xy} & B^\text{m2}_{1yy} \\
B^\text{m2}_{2x} & B^\text{m2}_{2y} & B^\text{m2}_{2xy} & B^\text{m2}_{2yy}
\end{bmatrix}
\]

with: \( B^{\gamma b}_{\gamma c} (D_\rho) = \frac{\gamma^{\gamma b}_{\gamma c} D_\rho}{\alpha^{\gamma b}_{\gamma c}} \) ; \( B^{\gamma b}_{\gamma c} (D_\rho) = \frac{\gamma^{\gamma b}_{\gamma c} D_\rho}{\alpha^{\gamma b}_{\gamma c}} \)

Note: In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes \((x, y)\), one will take:

\[
\begin{align*}
AB311 &= 1., AB321 = 1., AB611 = 1., AB621 = 1., \\
AB312 &= 1., AB322 = 1., AB612 = 1., AB622 = 1.
\end{align*}
\]
\( \text{GB} = \gamma_B \)

Parameters (24) \( \gamma^B \) dependences in variables of damage of the components (24 supra-diagonal terms) of the tensor of order 3 symmetrical \( \mathbf{B} \) of coupling membrane-inflection-slip of the plate, in the reference mark of the reinforcements \((x, y)\), for the slips out of higher grid (1) then lower (2), in notations of Voigt, identified by homogenisation and the method of least squares on various values of \( D_p \).

**Note:** In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes \((x, y)\), one will take:

\[
\begin{align*}
&\text{GB311} = 0, \text{GB321} = 0, \text{GB611} = 0, \text{GB621} = 0, \\
&\text{GB312} = 0, \text{GB322} = 0, \text{GB612} = 0, \text{GB622} = 0.
\end{align*}
\]

\( \text{C0} = C_0 \)

Components (6 nonworthless supra-diagonal terms) of the tensor of order 2 symmetrical of free energy of steel-concrete slip \( C^0 \) plate before damage, according to the directions of the slips considered, in the reference mark of the reinforcements \((x, y)\), out of higher grid (1) or lower (2), in notations of Voigt, identified by homogenisation:

\[
\begin{pmatrix}
C_{xx}^{01} & C_{xy}^{01} & 0 & 0 \\
C_{xy}^{01} & C_{yy}^{01} & 0 & 0 \\
C_{xx}^{02} & C_{xy}^{02} & C_{yy}^{02} & 0
\end{pmatrix}
\]

**Note:** In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes \((x, y)\), one will have: \( \text{C0211} = 0, \text{C0212} = 0 \).

\( \text{AC} = \alpha_C \)

Parameters (6) \( \alpha^C \) dependences in variables of damage of the components (6 supra-diagonal terms) of the symmetrical tensor \( \mathbf{C} \) identified by homogenisation and the method of least squares on various values of \( D_p \):

\[
C_{\beta\delta}^p(D_p) = C_{\beta\delta}^{00} + \frac{\alpha_{\beta\delta}^{Cp} + \gamma_{\beta\delta}^{Cp} D_p}{\alpha_{\beta\delta}^{Cp} + D_p}
\]

**Note:** In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes \((x, y)\), like: \( \text{C0211} = 0, \text{C0212} = 0 \), one will take: \( \text{AC211} = 1, \text{AC212} = 1 \).

\( \text{GC} = \gamma_C \)

Parameters (6) \( \gamma^C \) dependences in variables of damage of the components (6 supra-diagonal terms) of the symmetrical tensor \( \mathbf{C} \) identified by homogenisation and the method of least squares on various values of \( D_p \).
Note: In practice current, because of the isotropy of the concrete and the orientation of steels according to the axes $(x, y)$, like: $C_{0211} = 0, C_{0212} = 0$, one will take: $G_{C211} = 1,$ $G_{C212} = 1.

One can refer to the reference material [R7.01.36] where a summary of the identification of the parameters of the model is exposed.

### 7.19 Keyword factor BETON_REGLE_PR

This keyword is used for to define the parameters material used by the behavior `BETON_REGLE_PR` (rule "Parabola-Rectangle"). This behavior is usable only in 2D (forced plane or plane deformations) or in hulls (modelings `DKT`, `COQUE_3D`) (see for example the test `ssnp129a`). It is reduced to a unidimensional behavior, which is written, in each principal direction of the tensor 2D of the deformations:

- **In traction:**
  \[
  \begin{align*}
  \sigma &= E \varepsilon \quad &\text{si} & 0 < \varepsilon < \frac{\sigma_y^t}{E} \\
  \sigma &= \sigma_y^t + E_T \left( \varepsilon - \frac{\sigma_y^t}{E} \right) \quad &\text{si} & \frac{\sigma_y^t}{E} \leq \varepsilon < \frac{\sigma_y^t}{E} \left( \frac{1 - E}{E_T} \right) \\
  \sigma &= 0 \quad &\text{sinon}
  \end{align*}
  \]

- **In compression:**
  \[
  \begin{align*}
  \sigma &= \sigma_y^c \left( 1 - \frac{\varepsilon}{\varepsilon_y^c} \right)^n \quad &\text{si} & \varepsilon < \varepsilon_y^c \\
  \sigma &= \sigma_y^c \quad &\text{sinon}
  \end{align*}
  \]

#### 7.19.1 Syntax

```plaintext
| BETON_REGLE_PR = F (  
  ♦ DSIGM_EPSI = And [R]  
  ♦ SYT = Syt [R]  
  ◊ SYC = Syc [R]  
  ◊ EPSC = Epsc [R]  
  ◊ NR = NR [ R]  
)
```

#### 7.19.2 Operands

- **DSIGM_EPSI** = And
  Tangent module post-peak in traction $E_t$ (negative).

- **SYT** = Syt
  Ultimate constraint in traction $\sigma_y^t$.

- **SYC** = Syc
  Ultimate constraint in compression $\sigma_y^c$. It must be given positive.

- **EPSC** = Epsc
  Ultimate deformation in compression $\varepsilon_y^c$. It must be given positive.
Exhibitor of the law of work hardening in compression.

7.20 **Keyword JOINT_BA**

This model of nonlinear behavior of the steel-concrete connection is employed for the fine calculation of the reinforced concrete structures where the prediction of the cracks and the redistribution of the constraints in the concrete are very important. Available for analyses under the effect of monotonous and cyclic loadings, the model is written within the thermodynamic framework of formulation of the irreversible processes. It makes it possible to take account of the damage of the interface in shearing, in combination with the effects of the friction of the cracks, as well as unrecoverable deformations. The document [R7.01.21] described the corresponding details.

This model must be used with the elements "joint" in 2D [R3.06.09]. The steel reinforcements could be modelled with elements plans (QUAD4) or unidimensional (BAR).

**Note:**

The taking into account of the effect of a thermal loading is not possible for the moment.

7.20.1 **Syntax**

```
◊ | JOINT_BA = _F (

♦ HPEN = / HPEN, [R]
   / 1.0, [DEFECT]
♦ GTT = GTT, [R]
♦ GAMD0 = Gam0, [R]
♦ AD1 = ad1, [R]
♦ BD1 = / bd1, [R]
   / 0.5, [DEFECT]
♦ GAMD2 = Gam2, [R]
♦ AD2 = ad2, [R]
♦ BD2 = / bd2, [R]
   / 1.0 [DEFECT]
♦ VIFROT = vifrot, [R]
♦ F = alpha, [R]
♦ FC = C, [R]
♦ EPSTR0 = EPSN, [R]
♦ DNA = DNA, [R]
♦ BDN = / bdn, [R]
   / 1.0 [DEFECT]
)
```

7.20.2 **Operands**

- **HPEN** = HPEN
  Parameter of penetration between surfaces by crushing of the concrete.
  It is checked that \( HPEN > 0 \). 

- **GTT** = GTT
  Module of rigidity of the connection.
  It is checked that \( G_{\text{beton}} \leq GTT \leq G_{\text{acier}} \).

- **GAMD0** = Gam0
  Threshold of perfect adherence or limit of elastic strain.
  It is checked that \( 1.E^{-4} < \text{Gam0} < 1.E^{-2} \).
Parameter of evolution of the damage in area 1 (passage of the small deformations to the great slips).
It is checked that \( 1.E-1 < AD1 < 1.E+1 \).

Parameter of power describing the evolution of the variable of damage in area 1 (passage of the small deformations to the great slips).
It is checked that \( BD1 < 1.E-1 \).

Threshold of the great slips.
It is checked that \( 1.E-4 < Gam2 < 1.E+0 \).

Parameter of evolution of the damage in area 2 (maximum resistance of the connection and degradation in friction).
It is checked that \( AD2 < 1.E-6 \).

Parameter of power describing the evolution of the variable of damage in area 2 (maximum resistance of the connection and degradation in friction).
It is checked that \( BD2 < 1.E-1 \).

Parameter material describing the influence of the friction of the cracks.
It is checked that \( VIFROT < 0.0 E+0 \).

Parameter material related to kinematic work hardening by friction of the cracks.
It is checked that \( FA < 0.0 E+0 \).

Parameter describing the influence of containment on the resistance of the connection.
It is checked that \( FC < 0.0 E+0 \).

Threshold of elastic strain on the normal direction before the rupture. It is checked that \( 1.E-4 < EPSN < 1.E+0 \).

Parameter of the damage in the normal direction by opening of the crack.
It is checked that \( ADN < 1.E-10 \).

Parameter of power describing the evolution of the variable of damage in the normal direction.
It is checked that \( BDN < 1.E-1 \).

7.21 Keyword BETON_RAG

This model is used to consider the behavior long-term of the structures affected by the reaction alkali-aggregate. It makes it possible to evaluate the deformations and the anisotropic damage (cracking) of the works reached. It comprises a criterion of Rankine in traction and a criterion of Drücker-Prager in compression. The two criteria are associated with a law of evolution leading to a lenitive behavior. This model functions only with temperatures into Centigrade, it is thus necessary to provide or calculate fields of temperature into Centigrade.

7.21.1 Syntax

\[ /BETON_RAG = F ( \]
Characteristics of creep

◊ ACTIV_FL = / creep, [R]
   / 1.0, [DEFECT]

♦ K_RS = k1, [R]
♦ K_IS = k2, [R]
♦ ETA_RS = etal1s, [R]
♦ ETA_IS = etal2s, [R]
♦ K_RD = mu1, [R]
♦ K_ID = mu2, [R]
♦ ETA_RD = etad1, [R]
♦ ETA_ID = etad2, [R]
◊ EPS_0 = / eps0, [R]
   / 0.0035, [DEFECT]
♦ TAU_0 = tau0, [R]
◊ EPS_FL_L = / evpmax, [R]
   / 0.03, [DEFECT]

Characteristics of the damage

◊ ACTIV_LO = / room, [R]
   / 1.0, [DEFECT]
♦ F_C = rc, [R]
♦ F_T = rt, [R]
◊ ANG_CRIT = / delta, [R]
   / 8.594367, [DEFECT]
♦ EPS_COMP = edpicc, [R]
♦ EPS_TRAC = edpict, [R]
◊ LC_COMP = / lcc, [R]
   / 1.0, [DEFECT]
◊ LC_TRAC = / lct, [R]
   / 1.0, [DEFECT]

Characteristics of the coupling creep/skeleton and freezing/skeleton

◊ A_VAN_GE = / avg, [R]
   / 0.0, [DEFECT]
◊ B_VAN_GE = / bvgs, [R]
   / 1.9, [DEFECT]
◊ BIOT_EAU = / bwmax, [R]
   / 0.3, [DEFECT]
◊ MODU_EAU = / MW, [R]
   / 0.0, [DEFECT]
◊ W_EAU_0 = / w0, [R]
   / 1.0, [DEFECT]
◊ HYD_PRES = / pressure, [R]
   / 0.0, [DEFECT]

Characteristics of the formation of the gels

♦ BIOT_GEL = / bchmax, [R]
♦ MODU_GEL = / mch, [R]
♦ VOL_GEL = / vg, [R]
♦ AVANC_LI = / a0, [R]
♦ PARA_CIN = / alp0, [R]
♦ ENR_AC_G = / Ea, [R]
♦ SEUIL_SR = / sr0, [R]

7.21.2 Operands

7.21.2.1 Operands related to the model of creep

ACTIV_FL = creep

Variable of activation of creep (necessary in a calculation RAG). Takes the value 1.0 if the taking into account of creep is activated.
K_RS = k1/K_IS = k2

Modules of compressibility differ (k1 for the reversible part and k2 irreversible)

ETA_RS = etals/ETA_IS = eta2s

Spherical viscosities (eta1s for the reversible part and eta2s irreversible)

K_RD = mu1/K_ID = mu2

Differed moduli of rigidity

ETA_RD = eta1d/ETA_ID = eta2d

Deviatoric viscosities (eta1d for the reversible part and eta2d irreversible)

EPS_0 = eps0

Deformation characteristic of viscoplasticity couples damage of traction. It takes the value 0.0035 by default.

TAU_0 = tau0

Time characteristic of the orthotropic creep of traction

EPS_FL_L = evpmx

Yield limit deformation orthotropic of traction. This deformation is limited to 3% by default.

### 7.21.2.2 Operands related to the model of damage

**ACTIV_LO = local**

Variable of activation of the localization. Takes the value 1.0 if the taking into account of the localization is activated.

**F_C = rc**

Resistance in compression of the concrete.

**F_T = rt**

Tensile strength of the concrete.

**ANG_CRIT = delta**

This term is a characteristic of the criterion of compression, it indicates the angle in degrees of the criterion of Drucker Prager. By default it is allowed that it takes the value 8.594367 degrees (what is equivalent to 0.15 radians).

**EPS_COMP = edpicc**

Deformation with the peak of compression.

**EPS_TRAC = edpict**

Deformation with the peak of traction.

**LC_COMP = lcc/LC_TRAC = lct**

These terms correspond to the internal lengths of traction and of compression, they are parameters materials. They allow a management of the lenitive part of the forced curved deformation. They are depend on the grid. By defaults, it are not taken into account in the model (value 1.0).

### 7.21.2.3 Operands related to the model of calculation of the endogenous withdrawal

**A_VAN_GE = avg/B_VAN_GE = bvg**

Medium unsaturated parameters with Van Genuchten.

**BIOT_EAU = bwmax/MODU_EAU = MW**

Saturated medium, number of organic and modulate the organic one of water.

**W_EAU_0 = w0**

If hydrous calculation in water concentration, this term indicates the maximum concentration.

**HYD_PRES = pressure**

Hydrous indicator of calculation by imposed pressure. Takes the value 1.0 if calculation in pressure (allows to take into account overpressure), takes the value 0.0 if calculation in water concentration. Attention in the case of a calculation by imposed pressure, to make sure of the agreement degree of saturation-pressure (via parameter of the law of Van Genuchten).

### 7.21.2.4 Operands related to the formation of the gel

**BIOT_GEL = bchmax/MODU_GEL = mch**

Comparable to a modulus of elasticity of freezing and b can be comparable to a coefficient of Biot for freezing.

**VOL_GEL = vg**
Maximum volume of freezing which can be created by the chemical reaction; it corresponds to the theoretical volume of freezing created by unit volume of concrete maintained under conditions saturated during an infinite time.

AVANC_LI = a0
Advance from which initial connected porosity is filled.
PARA_CIN = alp0
Parameter of kinetics of reaction.
ENR_AC_G = Ea
Energy of activation of the reaction. This value is close to 45000 J/mol°K
SEUIL_SR = sr0
Threshold of saturation from which the evolution of the chemical reaction becomes possible.

7.22 Keyword BETON_BURGER

The model of creep BETON_BURGER suppose a decomposition between the spherical and deviatoric components: the deformations induced by the spherical constraints are purely spherical and the deformations induced by the deviatoric constraints are purely deviatoric [R7.01.35]. In addition, the clean deformation of creep is supposed to be proportional to internal relative moisture:

\[ \varepsilon^s = h \cdot f(\sigma^s) \] and, left deviatoric: \[ \varepsilon^d = h \cdot f(\tilde{\sigma}) \]

Where \( h \) indicate internal relative moisture.

The model of behavior BETON_BURGER is a model based on the model BETON UMLV [R7.01.06] to describe the clean creep of the concretes. It is particularly adapted to the multiaxial configurations by not presupposing the value of the Poisson's ratio of creep. The evolutions brought relate to the taking into account of a consolidation of creep translated by a nonlinear term on the behavior to the long-term of the model. Moreover, the spherical and deviatoric parts are now built in an identical way, leaving the possibility of controlling the apparent Poisson's ratio of creep.
The spherical and deviatoric parts are described by equivalent rheological chains, chain known as of Burger. This model is initially built according to a stage of Kelvin Voigt (left reversible) coupled in series with a body of Maxwell (left irreversible).
The model also makes it possible to take into account the effect of the temperature on the deformations of creep via a law of the Arrhenius type.

7.22.1 Syntax

\[
| \text{BETON_BURGER: } _F ( \\
\quad \text{K_RS} = \text{K_RS}, \quad [R] \\
\quad \text{K_RD} = \text{K_RD}, \quad [R] \\
\quad \text{ETA_RS} = \text{ETA_RS}, \quad [R] \\
\quad \text{ETA_IS} = \text{ETA_IS}, \quad [R] \\
\quad \text{ETA_RD} = \text{ETA_RD}, \quad [R] \\
\quad \text{ETA_ID} = \text{ETA_ID}, \quad [R] \\
\quad \text{KAPPA} = \text{KAPPA}, \quad [R] \\
\quad \text{QRK_K} = \text{QSR_K}, \quad [R] \\
\quad \text{TEMP_0_C} = \text{TEMP_0_C}, \quad [R] \\
\quad \text{ETA_FD} = \text{ETA_FD} \quad [R] 
) 
\]

7.22.2 Operand

\[ K_{RS} = \text{K_RS} \]
\( k_r^s \) rigidity connects associated with the reversible spherical part of the deformations of creep

\[ K_{RD} = \text{K_RD} \]
\( k_r^d \) rigidity connects associated with the reversible deviatoric part of the deformations of creep

\[ \text{ETA_RS} = \text{ETA_RS} \]
\( \eta_r^s \) viscosity connects associated with the reversible spherical deformations
ETA_IS = ETA_IS

\eta_i^r \text{ viscosity connects associated with the irreversible spherical deformations}

ETA_RD = ETA_RD

\eta_i^d \text{ viscosity with the reversible deviatoric deformations}

ETA_ID = ETA_ID

\eta_i^d \text{ viscosity with the irreversible deviatoric deformations}

KAPPA = KAPPA

\kappa \text{ term affecting long-term viscosity (} \eta_i^r \text{ and } \eta_i^d \text{) material}

QSR_K = \frac{E_ac}{R}

\frac{E_ac}{R} \text{ is worth in general } 4700. K \text{. (} R \text{ is the constant of perfect gases).}

TEMP_0_C = T0

Temperature of reference in the law of Arrhenius. The temperature of reference \( T0 \) is \textbf{in degrees Celsius}, and converted into Kelvin at the time of the resolution.

ETA_FD = ETA_FD

allows to take into account the creep of desiccation according to the law of Bazant.

\textbf{Note:}

The curve of desorption giving the hygroscopy \( \bar{h} \) according to the water concentration \( C \) must be well informed under the keyword \texttt{ELAS_FO}.
Behaviors métallo-mecanic

For the metallurgical behavior (cf [R4.04.01]), two laws of behavior are available: a law characteristic of the metallurgical transformations of steel and a law characteristic of zirconium alloys.

Note: Steel can comprise (with more) five different metallurgical phases (cold phase 1 = ferrite, cold phase 2 = pearlite, cold phase 3 = bainite, cold phase 4 = martensite and a hot phase = austenite).

The zircaloy can comprise (with more) three different metallurgical phases (cold phase 1 = phase pure, cold phase 2 = phase mixture and a hot phase = phase β).

For the mechanical behavior with the taking into account of the metallurgical transformations, there exist two models. The first model (cf [R4.04.02]) is usable for steel and Zircaloy. One chooses material desired while activating, in the operator STAT NON LINE, the keyword RELATION KIT who is worth ‘STEEL’ or ‘ZIRC’. The various relations relative to this model are identical for these two materials (one treats the same phenomena) but the number of involved phases is different.

The second model (cf [R4.04.05]) is only available for Zircaloy (RELATION KIT='ZIRC') and corresponds to the keyword META_LEMA_ANI under BEHAVIOR.

8.1 Keyword factor META_ACIER

Parameters to be informed for the metallurgy of steel.

8.1.1 Syntax

\[
\text{META_ACIER} = _F(\text{TRC} = \text{nomtrc}, \text{AR3} = \text{ar3}, \text{ALPHA} = \text{alpha}, \text{MS0} = \text{mso}, \text{AC1} = \text{ac1}, \text{AC3} = \text{ac3}, \text{TAUX_1} = \text{T1}, \text{TAUX_3} = \text{T3}, \text{LAMBDA}_0 = 10, \text{QSR}_K = \text{Qapp}, \text{D10}^- = \text{d10}, \text{WSR}_K = \text{Wapp}, \text{WSR}_K = \text{Wapp})
\]

8.1.2 Operands for the phase shifts

TRC = nomtrc

Concept of the type trc product by the operator DEFI_TRC [U4.43.04] and containing the whole of the furnished information by the diagrams TRC (Transformation into Continuous Cooling) of steel considered.

AR3 = ar3

Quasi-static temperature of beginning of decomposition of austenite to cooling.

ALPHA = alpha

Coefficient \( \alpha \) law of Koistinen-Marburger expressing the quantity of martensite formed according to the temperature:
$Z_m = 1 - \exp(\alpha |M_s - T|)$

MSO = mso
Martensitic initial temperature of transformation when this one is total. In this case $M_s = M_{s0}$.

AC1 = ac1
Quasi-static temperature of beginning of transformation into austenite with the heating.

AC3 = ac3
Quasi-static temperature of end of transformation into austenite.

TAUX_1 = T1
Value of the function “delay” (cf [R4.04.01]) $\tau(T)$ intervening in the austenitic model of transformation at the temperature $AC1$.

TAUX_3 = T3
Value of the function “delay” (cf [R4.04.01]) $\tau(T)$ intervening in the austenitic model of transformation at the temperature $AC3$.

The evolution of the proportion of austenite is then defined by:

$\dot{Z} = \frac{Z - Z_{eq}(T)}{\tau(T)}$

with: $Z_{eq}(T)$

$1$

Ac1 Ac3 $T$

3 1

and $\tau(T)$

Ac1 Ac3 $T$
8.1.3 Operands for the size of grains

The four operands following involve the calculation of size of grains if they are indicated.

\[
\text{LAMBDAA0} = 10
\]

Parameter material intervening in the model of evolution of size of grain below.

\[
\frac{dD}{dt} = \frac{1}{\lambda} \left( \frac{1}{D} - \frac{1}{D_{\text{lim}}} \right) \quad \text{with} \quad \begin{cases} 
\lambda = \lambda_0 \exp \left( \frac{Q_{\text{app}}}{RT} \right) \\
D_{\text{lim}} = D_{10} \exp \left( - \frac{W_{\text{app}}}{RT} \right) 
\end{cases}
\]

\[
\text{QSR}_K = \frac{Q_{\text{app}}}{R}
\]

Parameter energy of activation intervening in the model of evolution of size of grain.

\[
D_{10} = D_{10}
\]

Parameter material intervening in the model of evolution of size of grain.

\[
\text{WSR}_K = \frac{W_{\text{app}}}{R}
\]

Parameter energy of activation intervening in the model of evolution of size of grain.

8.2 Keyword factor META_ZIRC

Parameters to be informed for the metallurgy of Zircaloy (cf. [R4.04.04]).

8.2.1 Syntax

```
| META_ZIRC = _F ( 
  ♦ TDEQ = teqd, [R] 
  ♦ NR = N, [R] 
  ♦ K = K, [R] 
  ♦ T1C = t1c, [R] 
  ♦ T2C = t2c, [R] 
  ♦ QSR_K = qsr, [R] 
  ♦ AC = Ac, [R] 
  ♦ M = m, [R] 
  ♦ T1R = t1r, [R] 
  ♦ T2R = t2r, [R] 
  ♦ AR = Ar, [R] 
  ♦ Br = Br [R] )
```

8.2.2 Operands

\[
\text{TDEQ} = \text{teqd}
\]

Initial temperature of transformation \( \alpha \leftrightarrow \beta \) with balance

\( \alpha \) : compact phase cold hexagonal

\( \beta \) : phase hot cubic centered

\[
\text{NR} = \text{N}
\]

Parameter material relating to the model giving the proportion of \( \beta \) according to the temperature, with balance.

\[
\text{K} = \text{K}
\]
Parameter material relating to the model giving the proportion of $\beta$ according to the temperature, with balance.

$T1C = t1c$

Initial temperature of transformation $\alpha$ in $\beta$ with the heating.

$T1C = t1c$

Parameter material intervening in the calculation of the initial temperature of transformation $\alpha$ in $\beta$ with the heating.

$T2C = t2c$

Parameter material intervening in the calculation of the initial temperature of transformation $\alpha$ in $\beta$ with the heating.

$AC = ac$

Parameter material intervening in the model of evolution of $\beta$ with the heating.

$M = m$

Parameter material intervening in the model of evolution of $\beta$ with the heating.

$T2R = t2r$

Parameter material intervening in the calculation of the initial temperature of transformation $\beta$ in $\alpha$ with cooling.

$T2R = t2r$

Parameter material intervening in the calculation of the initial temperature of transformation $\beta$ in $\alpha$ with cooling.

$AR = Ar$

Parameter material intervening in the model of evolution of $\beta$ with cooling.

$Br = Br$

Parameter material intervening in the model of evolution of $\beta$ with cooling.

$QSR_K = qsr$

Constant of Arrhenius expressed in Kelvin degree.

### 8.3 Keyword factor DURT_META

Definition of the characteristics relating to the calculation of hardness associated with the metallurgy with steels. Hardness is calculated by using a linear law of mixture on the microphone - hardness of the components:

$$HV = \sum z_iHV_i$$

$HV_i$ : microhardness of the component $i$

$z_i$ : proportion of the component $i$

### 8.3.1 Syntax

```
| DURT_META = _F (    
| \ F1_DURT = HVf1,  [R]  
| \ F2_DURT = HVf2,  [R]  
| \ F3_DURT = HVf3,  [R]  
| \ F4_DURT = HVf4,  [R]  
```

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8.3.2 Operands

\[
\begin{align*}
&\text{F}_1_{\text{DURT}} = \text{HV}f_1 \\
&\text{F}_2_{\text{DURT}} = \text{HV}f_2 \\
&\text{F}_3_{\text{DURT}} = \text{HV}f_3 \\
&\text{F}_4_{\text{DURT}} = \text{HV}f_4 \\
&\text{C}_{\text{DURT}} = \text{HV}f_1
\end{align*}
\]

Microhardness of the cold phase \( F_1 \) (ferrite for steel).

Microhardness of the cold phase \( F_2 \) (pearlite for steel).

Microhardness of the cold phase \( F_3 \) (bainite for steel).

Microhardness of the cold phase \( F_4 \) (martensite for steel).

Microhardness for the hot phase (austenite for steel).

8.4 Keywords factor ELAS_META, ELAS_META_FO

Definition of the elastic characteristics, dilation and elastic limits for the modeling of an undergoing material of the metallurgical transformations (see [R4.04.02] or [R4.04.05]). These coefficients can be are constant compared to the temperature ELAS_META, are to depend on the temperature ELAS_META_FO (parameter ‘TEMP’).

Certain coefficients depend on the metallurgical structure (parameter ‘META’).

Notice:
Concerning the model META_LEMA_ANI, L has thermal dilation is written classically irrespective of phases. Consequently, keywords ‘C_ALPHA’, ‘PHASE_REFE’ and ‘EPSF_EPSC_TREF’ obligatory but are not taken into account in the equations. Only the dilation coefficient ‘F_ALPHA’ is considered.

This model is a law without threshold thus the limits elastic and the law of the mixtures is not useful.

Notice:
Concerning the other models, pour a steel one informs to the maximum 5 elastic limits, for Zircaloy one informs some to the maximum three.

8.4.1 Syntax

\[
\begin{align*}
&/ \text{ELAS}_\text{META} \\
&/ \text{ELAS}_\text{META}_\text{FO} = \_F \ ( \\
&\begin{align*}
&\text{E} = \text{Young}, \ [R] \text{or } [\text{function}] \\
&\text{NAKED} = \text{naked}, \ [R] \text{or } [\text{function}] \\
&\text{F}_\text{ALPHA} = \text{fal}, \ [R] \text{or } [\text{function}] \\
&\text{C}_\text{ALPHA} = \text{cal}, \ [R] \text{or } [\text{function}] \\
&\text{PHASE}_\text{REFE} = / \text{‘HOT’}, \ [\text{TXM}] \\
&\quad \text{‘COLD’}, \\
&\text{EPSF}_\text{EPSC}_\text{TREF}=\text{deltae}, \ [R] \\
&\text{TEMP}_\text{DEF}_\text{ALPHA}=\text{Tda}, \ [R] \ (\_\text{FO}) \\
&\text{PRECISION} = / \text{eps}, \ [R] \\
&\quad / \_1., \ [\text{DEFECT}] \\
&\text{F}_1\text{SY} = \text{F}_1\text{sy}, \ [R] \text{or } [\text{function}] \\
&\text{F}_2\text{SY} = \text{F}_2\text{sy}, \ [R] \text{or } [\text{function}] \\
&\text{F}_3\text{SY} = \text{F}_3\text{sy}, \ [R] \text{or } [\text{function}] \\
&\text{F}_4\text{SY} = \text{F}_4\text{sy}, \ [R] \text{or } [\text{function}] \\
&\text{C}\text{SY} = \text{Fsy}, \ [R] \text{or } [\text{function}] \\
\end{align*}
\end{align*}
\]

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8.4.2 Operands

E = Young
Young modulus, identical for all the metallurgical phases.

NAKED = naked
Poisson's ratio, identical for all the metallurgical phases.

F_ALPHA = fa
Thermal dilation coefficient average of the cold phases.

C_ALPHA = ca
Thermal dilation coefficient average of the hot phase.

PHASE_REFE = / ‘HOT’
/ ‘COLD’
Choice of the metallurgical phase of reference (hot phase or cold phase).
Indeed, to define the worthless thermal deformation, it is necessary to define the temperature of reference \( T_{ref} \) (defined in AFFE_MATERIAU) and the metallurgical phase of reference, so that the thermal deformation is considered worthless with \( T_{ref} \) and in the metallurgical state of reference.

EPSF_EPSC_TREF = deltae
Deformation of the phase not of reference compared to the phase of reference to the temperature \( T_{ref} \): translated the difference in compactness between the cubic crystallographic structures with centered faces (standard austenitic) and cubic centered (standard ferritic).

TEMP_DEF_ALPHA = Tda
Temperature compared to which one defines the dilation coefficient. If C_ALPHA is a function, this operand is obligatory.

PRECISION = eps
This reality indicates with which precision a temperature \( T \) is close to the temperature of reference (cf. [§3.1.4]).

F1_SY = F1sy
Elastic limit of the cold phase 1 for a plastic behavior.

F2_SY = F2sy
Elastic limit of the cold phase 2 for a plastic behavior.

F3_SY = F3sy
Elastic limit of the cold phase 3 for a plastic behavior.

F4_SY = F4sy
Elastic limit of the cold phase 4 for a plastic behavior.

C_SY = Fsy
Elastic limit of the hot phase for a plastic behavior.
SY_MELANGE  =  F
Function used for the law of mixture on the elastic limit of multiphase material for a plastic behavior.
\[ \sigma_y = (1 - f(z)) \sigma_y^p + f(z) \sigma_y^a \]

F1_S_VP  =  F1svp
Elastic limit of the cold phase 1 for a viscous behavior.

F2_S_VP  =  F2svp
Elastic limit of the cold phase 2 for a viscous behavior.

F3_S_VP  =  F3svp
Elastic limit of the cold phase 3 for a viscous behavior.

F4_S_VP  =  F4svp
Elastic limit of the cold phase 4 for a viscous behavior.

C_S_VP  =  Csvp
Elastic limit of the hot phase for a viscous behavior.

S_VP_MELANGE  =  Please
Function used for the law of mixture on the elastic limit of multiphase material for a viscous behavior.
\[ \sigma_c = (1 - f(z)) \sigma_c^p + f(z) \sigma_c^a \]

8.5 **Keyword factor META_ECRO_LINE**

Definition of five modules of work hardening used in the modeling of the phenomenon of isotropic work hardening linear of an undergoing material of the metallurgical phase shifts (see [R4.04.02]). These modules depend on the temperature.

8.5.1 **Syntax**

```
| META_ECRO_LINE = _F ( 

    ◦ F1_D_SIGM_EPSI= dsde1, [function]
    ◦ F2_D_SIGM_EPSI= dsde2, [function]
    ◦ F3_D_SIGM_EPSI= dsde3, [function]
    ◦ F4_D_SIGM_EPSI= dsde4, [function]
    ◦ C_D_SIGM_EPSI= dsdec, [function]
)
```

8.5.2 **Operands**

- **F1_D_SIGM_EPSI**  =  dsde1
  Slope of the traction diagram for the cold phase 1.
- **F2_D_SIGM_EPSI**  =  dsde2
  Slope of the traction diagram for the cold phase 2.
- **F3_D_SIGM_EPSI**  =  dsde3
  Slope of the traction diagram for the cold phase 3.
- **F4_D_SIGM_EPSI**  =  dsde4
  Slope of the traction diagram for the cold phase 4.
- **C_D_SIGM_EPSI**  =  dsdec
  Slope of the traction diagram for the hot phase.
8.6 **Keyword factor META_TRACTION**

Definition of five traction diagrams used in the modeling of the phenomenon of isotropic work hardening nonlinear of an undergoing material of the metallurgical phase shifts (see [R4.04.02]). The traction diagrams can possibly depend on the temperature.

8.6.1 **Syntax**

\[
\text{META_TRACTION} = \_F ( \\
\hspace{1em} \text{SIGM}_F1 = r_p1, \quad \text{SIGM}_F2 = r_p2, \quad \text{SIGM}_F3 = r_p3, \quad \text{SIGM}_F4 = r_p4, \quad \text{SIGM}_C = r_pc)
\]

8.6.1.1 **Operands**

- **SIGM_F1** = \( r_p1 \)
  Isotropic curve work hardening \( R \) according to the cumulated plastic deformation \( p \) for the cold phase 1.

- **SIGM_F2** = \( r_p2 \)
  Isotropic curve work hardening \( R \) according to the cumulated plastic deformation \( p \) for the cold phase 2.

- **SIGM_F3** = \( r_p3 \)
  Isotropic curve work hardening \( R \) according to the cumulated plastic deformation \( p \) for the cold phase 3.

- **SIGM_F4** = \( r_p4 \)
  Isotropic curve work hardening \( R \) according to the cumulated plastic deformation \( p \) for the cold phase 4.

- **SIGM_C** = \( r_pC \)
  Isotropic curve work hardening \( R \) according to the cumulated plastic deformation \( p \) for the hot phase.
Note:
Attention it does not act of the curve $\sigma$ function of $\varepsilon$ but of the curve $R$ function of $p$. One passes from the one to the other by carrying out following calculations:

$$R = \sigma - \lim_{\varepsilon} d \eta \text{élasticité}, p = \varepsilon - (\sigma / E).$$

### 8.7 Keyword factor META_VISC_FO

Definition of the viscous parameters of the viscoplastic law of behavior with taking into account of the metallurgy (see [R4.04.02]). The viscoplastic model of Norton-Hoff type comprises 5 parameters; the parameters classic $\eta$, $n$ law of flow in power, yield stress of flow viscous, parameters $C$ and $m$ relating to the restoration of work hardening of viscous origin. These parameters depend on the temperature and the metallurgical structure.

The limit elastic parameters are defined in \texttt{ELAS_META}.

#### 8.7.1 Syntax

```
| META_VISC_FO = _F (  
  ◊ F1_ETA = eta1, [function]  
  ◊ F2_ETA = eta2, [function]  
  ◊ F3_ETA = eta3, [function]  
  ◊ F4_ETA = eta4, [function]  
  ◊ C_ETA = etac, [function]  
  ◊ F1_N = n1, [function]  
  ◊ F2_N = n2, [function]  
  ◊ F3_C = C1, [function]  
  ◊ F2_C = C2, [function]  
  ◊ F3_C = C3, [function]  
  ◊ F4_C = C4, [function]  
  ◊ C_C = C5, [function]  
  ◊ F1_M = m1, [function]  
  ◊ F2_M = m2, [function]  
  ◊ F3_M = m3, [function]  
  ◊ F4_M = m4, [function]  
  ◊ C_M = m5, [function]  
)
```

#### 8.7.2 Operands $F1_ETA$/$F2_ETA$/$F3_ETA$/$F4_ETA$/$C_ETA$

- $F1_ETA$ = eta1
  Parameter $\eta$ viscoplastic law of flow, for the cold phase 1.
- $F2_ETA$ = eta2
  Parameter $\eta$ viscoplastic law of flow, for the cold phase 2.
- $F3_ETA$ = eta3
  Parameter $\eta$ viscoplastic law of flow, for the cold phase 3.
- $F4_ETA$ = eta4
  Parameter $\eta$ viscoplastic law of flow, for the cold phase 4.
- $C_ETA$ = etac
  Parameter $\eta$ viscoplastic law of flow, for the hot phase.

#### 8.7.3 Operands $F1_N$/$F2_N$/$F3_N$/$F4_N$/$C_N$

- $F1_N$ = n1
  Parameter $n$ viscoplastic law of flow, for the cold phase 1.
F2_N = n2
Parameter n viscoplastic law of flow, for the cold phase 2.

F3_N = n3
Parameter n viscoplastic law of flow, for the cold phase 3.

F4_N = n4
Parameter n viscoplastic law of flow, for the cold phase 4.

C_N = n5
Parameter N of the viscoplastic law of flow, for the hot phase.

8.7.4 Operands F1_C/F2_C/F3_C/F4_C/C_C

F1_C = C1
Parameter C relating to the restoration of work hardening of viscous origin, for the cold phase 1.

F2_C = C2
Parameter C relating to the restoration of work hardening of viscous origin, for the cold phase 2.

F3_C = C3
Parameter C relating to the restoration of work hardening of viscous origin, for the cold phase 3.

F4_C = C4
Parameter C relating to the restoration of work hardening of viscous origin, for the cold phase 4.

C_C = C5
Parameter C relating to the restoration of work hardening of viscous origin, for the hot phase.

8.7.5 Operands F1_M/F2_M/F3_M/F4_M/C_M

F1_M = m1
Parameter m relating to the restoration of work hardening of viscous origin, for the cold phase 1.

F2_M = m2
Parameter m relating to the restoration of work hardening of viscous origin, for the cold phase 2.

F3_M = m3
Parameter m relating to the restoration of work hardening of viscous origin, for the cold phase 3.

F4_M = m4
Parameter m relating to the restoration of work hardening of viscous origin, for the cold phase 4.

C_M = m5
Parameter m relating to the restoration of work hardening of viscous origin, for the hot phase.

8.8 Keyword factor META_PT

Definition of the characteristics used in the modeling of the plasticity of transformation of a material which undergoes metallurgical phase shifts (see [R4.04.02]).

The model is the following: \[ \Delta \varepsilon^{pt} = \frac{3}{2} \sigma \sum_{i=1}^{4} K_i F_i' |Z_i| \langle Z_i \rangle \]

8.8.1 Syntax

| META_PT = _F ( |
| F1_K = KF, [R] |
| F2_K = Kp, [R] |
| F3_K = KB, [R] |
| F4_K = km, [R] |
| F1_D_F_META = F' F, [function] |

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8.8.2 Operands

\[ F_1_K = KF, \quad F_2_K = Kp, \quad F_3_K = KB, \quad F_4_K = km \]

Constants \( K_i \) used in the model of plasticity of transformation, for the various cold phases. For steel:
- phase ferritic, perlitic, bainitic and martensitic.

\[ F_1_D_F_META = F'_F, \quad F_2_D_F_META = F'_p, \quad F_3_D_F_META = F'_B, \quad F_4_D_F_META = F'_m, \]

Functions \( F'_i \) used in the model of plasticity of transformation, for the various cold phases. For steel:
- phase ferritic, perlitic, bainitic and martensitic.

8.9 Keyword factor META_RE

Definition of the caractéristique used in the modeling of the phenomenon of restoration of work hardening of a material which undergoes metallurgical phase shifts (see [R4.04.02]).

8.9.1 Syntax

\[ META_RE = _F \]

\[ C_F1\_THETA = Tgf, \quad C_F2\_THETA = Tgp, \quad C_F3\_THETA = Tgb, \quad C_F4\_THETA = Tgm \]

\[ F1\_C\_THETA = Tfg, \quad F2\_C\_THETA = Tpg, \quad F3\_C\_THETA = Tbg, \quad F4\_C\_THETA = Tmg \]

8.9.2 Operands

\[ C_F1\_THETA = Tgf, \quad C_F2\_THETA = Tgp, \quad C_F3\_THETA = Tgb, \quad C_F4\_THETA = Tgm \]

Constants characterizing the rate of work hardening transmitted at the time of the transformation of the hot phase \( C \) into cold phase. For steel; transformation of austenite into ferrite, pearlite, bainite and martensite. Thus, \( \theta = 0 \) corresponds to a total restoration and \( \theta = 1 \) with a total transmission of work hardening.

\[ F1\_C\_THETA = Tfg, \quad F2\_C\_THETA = Tpg, \quad F3\_C\_THETA = Tbg, \quad F4\_C\_THETA = Tmg \]

Constants characterizing the rate of work hardening transmitted at the time of the transformation of the cold phases into hot phase. For steel; transformation of ferrite, the pearlite, austenite bainite and martensite. Thus, \( \theta = 0 \) corresponds to a total restoration and \( \theta = 1 \) with a total transmission of work hardening.
8.10 Keyword META_LEMA_ANI

Definition of the parameters of the law META_LEMA_ANI (cf. [R4.04.05]), élasto-viscous without threshold with an anisotropic behavior. Briefly, the model is written in the cylindrical reference mark \((r, \theta, z)\), that is to say in the Cartesian reference mark \((Ox, Oy, Oz)\):

Partition of the deformations: \(\varepsilon = \varepsilon^e + \alpha \Delta T \, T \, \text{id} + \varepsilon^v\)

Law of flow of the viscous deformation: \(\dot{\varepsilon}^v = \dot{p} \, M : \dot{\alpha} / \sigma_{eq}\)

Criterion of Hill: \(\sigma_{eq} = \sqrt{\alpha : M : \alpha}\)

Matrix of Hill \(M\) into cylindrical:

\[
M_{(r, \theta, z)} = \begin{bmatrix}
M_{rr} & M_{ \theta \theta} & M_{rz} & 0 & 0 & 0 \\
M_{ \theta \theta} & M_{\theta \theta z} & M_{ \theta zz} & 0 & 0 & 0 \\
M_{rz} & M_{ \theta zz} & M_{zzz} & 0 & 0 & 0 \\
0 & 0 & 0 & M_{r \theta \theta} & 0 & 0 \\
0 & 0 & 0 & 0 & M_{rzz} & 0 \\
0 & 0 & 0 & 0 & 0 & M_{z \theta \theta}
\end{bmatrix}
\]

\[
\begin{cases}
M_{rr} + M_{ \theta \theta} + M_{rz} = 0 \\
M_{ \theta \theta} + M_{\theta \theta z} + M_{ \theta zz} = 0 \\
M_{rz} + M_{ \theta zz} + M_{zzz} = 0
\end{cases}
\]

or, into Cartesian:

\[
M_{(x, y, z)} = \begin{bmatrix}
M_{xxx} & M_{xxy} & M_{xxz} & 0 & 0 & 0 \\
M_{xxy} & M_{yyy} & M_{yxz} & 0 & 0 & 0 \\
M_{xxz} & M_{yxz} & M_{zzz} & 0 & 0 & 0 \\
0 & 0 & 0 & M_{xyy} & 0 & 0 \\
0 & 0 & 0 & 0 & M_{zzz} & 0 \\
0 & 0 & 0 & 0 & 0 & M_{yzz}
\end{bmatrix}
\]

\[
\begin{cases}
M_{xxx} + M_{xxy} + M_{xxz} = 0 \\
M_{xxy} + M_{yyy} + M_{yxz} = 0 \\
M_{xxz} + M_{yxz} + M_{zzz} = 0
\end{cases}
\]

Law of the mixtures on the matrix \(M\):

\[
M = \begin{cases}
M^c & \text{si } 0.00 \leq Z_f \leq 0.01 \\
M^2 = Z_f \, M^1 + (1 - Z_f) \, M^c & \text{si } 0.01 \leq Z_f \leq 0.99 \\
M^1 & \text{si } 0.99 \leq Z_f \leq 1.00
\end{cases}
\]

\[
Z_f = Z_1 + Z_2; \quad Z_e = Z_3 = 1 - Z_f
\]

Speed of equivalent deformation: \(\dot{p} = \left(\frac{\sigma_{eq}}{\alpha p}ight)^n \, e^{-Q/T}\)
or in an equivalent way:
\[
\sigma_{eq} = \frac{a_i e^{Q_i/T_i}}{p^m p_i^{1/n_i}} = \sigma_v
\]

Law of the mixtures on the viscous constraint \( \sigma_v \):
\[
\sigma_{eq} = \sigma_v = \sum_{i=1}^{3} f_i(Z_\alpha) \sigma_{vi} \quad \text{with} \quad \sigma_{vi} = a_i e^{Q_i/T_i} p^m p_i^{1/n_i}
\]

Notice:
In the isotropic case, one a:
\[
\begin{align*}
M_{rrr} & = M_{\theta\theta\theta} = M_{zzz} = 1 \\
M_{r\theta\theta} & = M_{zzr} = M_{\theta z\theta} = 0.75 \\
M_{xxx} & = M_{yyz} = M_{zzz} = 1 \\
M_{xyy} & = M_{zxz} = M_{zzc} = 0.75
\end{align*}
\]

### 8.10.1 Syntax

The choice of the type of coordinates (cylindrical or Cartesian) is done respectively by the detection of keyword `F_MRR_RR` or keyword `F_MXX_XX`.

**Into cylindrical:**

```plaintext
| META_LEMA_ANI = _F ( \\
|   ♦ F1_A       = a1 [R]   \\
|   ♦ F2_A       = a2 [R]   \\
|   ♦ C_A        = ac [R]    \\
|   ♦ F1_M       = m1 [R]    \\
|   ♦ F2_M       = m2 [R]    \\
|   ♦ C_M        = mc [R]    \\
|   ♦ F1_N       = n1, [R]   \\
|   ♦ F2_N       = N2, [R]   \\
|   ♦ C_N        = nc, [R]   \\
|   ♦ F1_Q       = q1, [R]   \\
|   ♦ F2_Q       = q2, [R]   \\
|   ♦ C_Q        = qc, [R]   \\
|   ♦ F_MRR_RR   = mrrrf, [R] \\
|   ♦ C_MRR_RR   = mrrrc, [R] \\
|   ♦ F_MTT_TT   = mtttf, [R] \\
|   ♦ C_MTT_TT   = mtttc, [R] \\
|   ♦ F_MZZ_ZZ   = mzzzf, [R] \\
|   ♦ C_MZZ_ZZ   = mzzzc, [R] \\
|   ♦ F_MRT_RT   = mrttf, [R] \\
|   ♦ C_MRT_RT   = mrttc, [R] \\
|   ♦ F_MRZ_RZ   = mrzzf, [R] \\
|   ♦ C_MRZ_RZ   = mrzzc, [R] \\
|   ♦ F_MTZ_TZ   = mtztf, [R] \\
|   ♦ C_MTZ_TZ   = mtztc, [R] 
)
```

**Into Cartesian:**

```plaintext
| META_LEMA_ANI = _F ( \\
|   ♦ F1_A       = a1 [R]   \\
|   ♦ F2_A       = a2 [R]   \\
|   ♦ C_A        = ac [R]    
```

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8.10.2 Operands

The table below summarizes the correspondences between the symbols of the equations and the keywords of Aster.

<table>
<thead>
<tr>
<th>Symbol in the equations</th>
<th>Keyword Aster</th>
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</thead>
<tbody>
<tr>
<td>( a_1, a_2, a_3 )</td>
<td>‘( F_1_A )’, ‘( F_2_A )’, ‘( C_A )’</td>
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<tr>
<td>( m_1, m_2, m_3 )</td>
<td>‘( F_1_M )’, ‘( F_2_M )’, ‘( C_M )’</td>
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<td>( n_1, n_2, n_3 )</td>
<td>‘( F_1_N )’, ‘( F_2_N )’, ‘( C_N )’</td>
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<tr>
<td>( Q_1, Q_2, Q_3 )</td>
<td>‘( F_1_Q )’, ‘( F_2_Q )’, ‘( C_Q )’</td>
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</table>

The matrix of Hill is known is for the cold phase (1) ‘\( F_M \) ** _**’, that is to say for the hot phase (3) ‘\( C_M \) ** _**’.

Note:

Coefficients ‘\( F_1_Q \)’, ‘\( F_2_Q \)’ and ‘\( C_Q \)’ are in Kelvin degree.
# Behaviors thermo-hydro-mechanics and of the grounds

## 9.1 Simple keyword COMP_THM

Allows to select as of the definition of material the mixing rate THM. The table below specifies the obligatory keywords according to the selected mixing rate.

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<td>CP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>VISC</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D VISC TEMP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
9.2 Keyword factor THM_INIT

For all the ThermoHydroMécaniques behaviors, it makes it possible to describe the initial state of the structure (cf. [R7.01.11] and [R7.01.14]).

9.2.1 Syntax

```plaintext
| THM_INIT = _F ( 
|   ◊ TEMP = temp, [R]
|   ◊ PRE1 = pre1, [R]
|   ◊ PRE2 = pre2, [R]
|   ◊ PORO = poro, [R]
|   ◊ PRES_VAPE = pvap, [R]
|   ◊ DEGR_SATU = DS, [R]
| )
```

For understanding these data well, it is necessary to distinguish the unknown factors with the nodes, which we call \( \{u\}_{ddl} \) and values defined under the keyword THM_INIT that we call \( p_{ref} \) and \( T_{ref} \).

\[
\begin{align*}
\|u\|_{ddl} &= \begin{bmatrix} u_x \\ u_y \\ u_z \\ PRE1_{ddl}^{diff} \\ PRE2_{ddl}^{diff} \end{bmatrix} \\
\end{align*}
\]

Significance of the unknown factors PRE1 and PRE2 vary according to the models. While noting:

- \( p_w \) water pressure,
- \( p_{ad} \) dissolved air pressure,
- \( p_l \) pressure of liquid,
- \( p_i = p_w + p_{ad} \) the air pressure dryness,
- \( p_g = p_{ad} + p_{vp} \) total gas pressure and
- \( p_c = p_g - p_l \) the capillary pressure (also called suction),

one has the following meanings of the unknown factors PRE1 and PRE2:

<table>
<thead>
<tr>
<th>Behavior KIT</th>
<th>LIQU_S ATU</th>
<th>LIQU_VAPE</th>
<th>LIQU_GAZ ATM</th>
<th>GAS</th>
<th>LIQU_VAPE GAZ</th>
<th>LIQU_GAZ</th>
<th>LIQU_AD GAZ VAPE FE</th>
<th>LIQU_AD_GAZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRE1</td>
<td>( p_i )</td>
<td>( p_i )</td>
<td>(-p_l)</td>
<td>( p_g )</td>
<td>( p_c = p_g - p_l )</td>
<td>( p_c = p_g - p_l )</td>
<td>( p_c = p_g - p_l )</td>
<td></td>
</tr>
<tr>
<td>PRE2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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One will be able to refer to [§4.4.3] documentation [U4.51.11].

One then defines the “total” pressures and the temperature by:

\[ p = p_{\text{ddl}} + p_{\text{ref}}^*; T = T_{\text{ddl}} + T_{\text{ref}}^* \]

Values written by \texttt{IMPR\_RESU} are the nodal unknown factors \( p_{\text{ddl}} \) et \( T_{\text{ddl}} \). In the same way the boundary conditions must be expressed compared to the nodal unknown factors.

On the other hand, in fact the pressures and the total air temperature are used in the laws of behavior

\[ \frac{P}{\rho} = \frac{R}{M} T \quad \text{for perfect gases,} \quad \frac{d \rho_i}{\rho_i} - \frac{dp_i}{K_i} - 3 \alpha_i dT \quad \text{for the liquid and in the relation capillary saturation/pressure.} \]

Let us note that the nodal values can be initialized by the keyword \texttt{ETAT\_INIT} order \texttt{STAT\_NON\_LINE}.

The user must be very careful in the definition of the values of \texttt{THM\_INIT}: indeed, the definition of several materials with values different from the quantities defined under \texttt{THM\_INIT} led to discontinuous values initial of the pressure and temperature, which is not in fact not compatible with the treatment general which is made of these quantities. We thus advise with the user the following approach:

- so at the beginning, there is a uniform field of pressure or of temperature, one returns it directly by the keyword \texttt{THM\_INIT},
- if there is a nonuniform field, one enters for example a reference by the keyword \texttt{THM\_INIT} order \texttt{DEFI\_MATERIAU}, and initial values compared to this reference by the keyword \texttt{ETAT\_INIT} order \texttt{STAT\_NON\_LINE}.

### 9.2.2 Operand \texttt{TEMP}

Temperature of reference \( T_{\text{ref}}^* \).

Attention this value is expressed in Kelvin and must be strictly positive.

The value of the temperature of reference entered behind the keyword \texttt{VALE\_REF} order \texttt{AFFE\_VARC} is ignored.

### 9.2.3 Operand \texttt{PRE1}

For the behaviors: \texttt{LIQU\_SATU}, \texttt{LIQU\_VAPE} pressure of liquid of reference.

For the behavior: \texttt{GAS} nonworthless standard gas pressure.

For the behavior: \texttt{LIQU\_GAZ\_ATM} pressure of liquid of changed reference of sign.

For the behaviors: \texttt{LIQU\_VAPE\_GAZ}, \texttt{LIQU\_AD\_GAZ\_VAPE}, \texttt{LIQU\_AD\_GAZ} and \texttt{LIQU\_GAZ} capillary pressure of reference.

### 9.2.4 Operand \texttt{PRE2}

For the behaviors: \texttt{LIQU\_VAPE\_GAZ}, \texttt{LIQU\_AD\_GAZ\_VAPE}, \texttt{LIQU\_AD\_GAZ} and \texttt{LIQU\_GAZ} nonworthless standard gas pressure.

### 9.2.5 Operand \texttt{PORO/PRES\_VAPE/DEGR\_SATU}

\begin{verbatim}
PORO     = poro
Initial porosity.

PRES\_VAPE = pvap
For the behaviors: LIQU\_VAPE\_GAZ, LIQU\_VAPE, LIQU\_AD\_GAZ\_VAPE and LIQU\_GAZ initial steam pressure.
\end{verbatim}
9.3 **Keyword factor THM_LIQU**

This keyword relates to all behaviors THM utilizing a liquid (cf. [R7.01.11]).

### 9.3.1 Syntax

```
| THM_LIQU= _F (  
  ♦ RHO = rho,           [R]
  ♦ UN_SUR_K = usk,       [R]
  ◊ ALPHA = alp,          [function]
  ◊ CP = CP,             [R]
  ◊ VISC = VI,            [function]
  ♦ D_VISC_TEMP = dvi,    [function]
)
```

### 9.3.2 Operand RHO

Density of the liquid for the pressure defined under the keyword PRE1 keyword factor THM_INIT.

### 9.3.3 Operand UN_SUR_K

Opposite of the compressibility of the liquid: $K_l$.

### 9.3.4 Operand ALPHA

Dilation coefficient of the liquid: $\alpha_l$

If $p_l$ indicate the pressure of the liquid, $\rho_l$ its density and $T$ the temperature, the behavior of the liquid is:

$$
\frac{d\rho_l}{\rho_l} = \frac{dp_l}{K_l} - 3\alpha_l dT
$$

### 9.3.5 Operand CP

Specific heat with constant pressure of the liquid.

### 9.3.6 Operands VISC/D_VISC_TEMP

- **VISC** = VI
  
  Viscosity of the liquid. Function of the temperature.

- **D_VISC_TEMP** = dvi
  
  Derived from the viscosity of the liquid compared to the temperature. Function of the temperature. The user must ensure coherence with the function associated with VISC.

9.4 **Keyword factor THM_GAZ**

This keyword factor relates to all behaviors THM utilizing a gas (cf [R7.01.11]). For the behaviors utilizing at the same time a liquid and a gas, and when one takes into account the evaporation of the liquid, the coefficients indicated here relate to dry gas. The properties of the vapor are indicated under the keyword THM_VAPE_GAZ.
9.4.1 Syntax

\[
| \text{THM}_\text{GAZ} = _F ( \\
\quad \Diamond \text{MASS}_\text{MOL} = M_{gs}, [R] \\
\quad \Diamond \text{CP} = \text{CP}, [R] \\
\quad \Diamond \text{VISC} = \text{VI}, \text{[function]} \\
\quad \Diamond \text{D}_\text{VISC}_\text{TEMP} = \text{dvi}, \text{[function]} \\
) \\
\]

9.4.2 Operand MASS_MOL

Molar mass of dry gas \( M_{gs} \).

If \( p_{gs} \) indicate the pressure of dry gas, \( \rho_{gs} \) its density, \( R \) the constant of perfect gases and \( T \) the temperature, the reaction of dry gas is:

\[
\frac{p_{gs}}{\rho_{gs}} \frac{\rho_{gs}}{M_{gs}} = RT. 
\]

9.4.3 Operand CP

Specific heat with constant pressure of dry gas.

9.4.4 Operand VISC

Viscosity of dry gas. Function of the temperature.

9.4.5 Operand D_VISC_TEMP

Derived compared to the temperature from viscosity from dry gas. Function of the temperature.

The user must ensure coherence with the function associated with VISC.

9.5 Keyword factor THM_VAPE_GAZ

This keyword factor relates to all behaviors THM utilizing at the same time a liquid and a gas, and fascinating of account the evaporation of the liquid (confer [R7.01.11]). The coefficients indicated here relate to the vapor.

9.5.1 Syntax

\[
| \text{THM}_\text{VAPE}_\text{GAZ} = _F ( \\
\quad \Diamond \text{MASS}_\text{MOL} = m, [R] \\
\quad \Diamond \text{CP} = \text{CP}, [R] \\
\quad \Diamond \text{VISC} = \text{VI}, \text{[function]} \\
\quad \Diamond \text{D}_\text{VISC}_\text{TEMP} = \text{dvi}, \text{[function]} \\
) \\
\]

9.5.2 Operand MASS_MOL

Molar mass of the vapor \( M_{vp} \).

If is \( M_{vp} \) indicate the pressure of the vapor, \( \rho_{vp} \) its density, the constant \( R \) perfect gases and \( T \) the temperature, the behavior of the vapor is:

\[
\frac{p_{vp}}{\rho_{vp}} \frac{\rho_{vp}}{M_{vp}} = RT. 
\]

9.5.3 Operand CP

\[
\text{CP} = \text{CP} \]
Specific heat with constant pressure of the vapor.

### 9.5.4 Operand VISC

\[ \text{VISC} = v \]

Viscosity of the vapor. Function of the temperature.

### 9.5.5 Operand D_VISC_TEMP

\[ \text{D\_VISC\_TEMP} = dvi \]

Derived compared to the temperature from viscosity from the vapor. Function of the temperature. The user must ensure coherence with the function associated with VISC.

### 9.6 Keyword factor THM_AIR_DISS

This keyword factor relates to behavior THM THM_AD_GAZ_VAPE taking into account the dissolution of the air in the liquid (cf [R7.01.11]). The coefficients indicated here relate to the dissolved air.

#### 9.6.1 Syntax

\[
\text{THM\_AD\_GAZ\_VAPE} = _F( \\
\quad \ast \text{CP} = \text{CP}, \quad [R] \\
\quad \ast \text{COEF\_HENRY} = \text{H}, \quad \text{[function]} \\
) 
\]

#### 9.6.2 Operand CP

\[ \text{CP} = \text{CP} \]

Specific heat with constant pressure of the dissolved air.

#### 9.6.3 Operand COEF_HENRY

\[ \text{COEF\_HENRY} = \text{H} \]

Constant of Henry \( K_H \), function of the temperature, allowing to connect the molar concentration of dissolved air \( C_{ad} \) (moles/m^3) with the air pressure dryness:

\[
C_{ad} = \frac{p_{as}}{K_H}
\]

### 9.7 Keyword factor THM_DIFFU

Obligatory for all behaviors THM (cf [R7.01.11]). The user must make sure of the coherence of the functions and their derivative.

#### 9.7.1 Syntax

\[
\text{THM\_DIFFU} = _F( \\
\quad \ast \text{R\_GAZ} = \text{rgaz}, \quad [R] \\
\quad \ast \text{RHO} = \text{rho}, \quad [R] \\
\quad \ast \text{CP} = \text{CP}, \quad [R] \\
\quad \ast \text{BIOT\_COEF} = \text{organic}, \quad [R] \\
\quad \ast \text{BIOT\_L} = \text{bion}, \quad [R] \\
\quad \ast \text{BIOT\_T} = \text{biot}, \quad [R] \\
\quad \ast \text{PESA\_X} = \text{px}, \quad [R] \\
\quad \ast \text{PESA\_Y} = \text{py}, \quad [R] \\
) 
\]
PESA_Z = pz, [R]
PESA_MULT = fpesa, [function]
PERM_IN = leave, [function]
PERMIN_L = permL, [function]
PERMIN_T = permT, [function]
PERMIN_N = permN, [function]
SATU_PRES = sp, [function]
D_SATU_PRES = dsp, [function]
PERM_LIQU = perML, [function]
D_PERM_LIQU_SATU = dpermL, [function]
PERM_GAZ = permG, [function]
D_PERM_GAZ_SATU = dpags, [function]
PERMIN_L = perml, [function]
D_PERMIN_L = permL, [function]
PERMIN_T = permt, [function]
D_PERMIN_T = permT, [function]
PERMIN_N = permn, [function]
D_PERMIN_N = permN, [function]
SATU_PRES = sp, [function]
D_SATU_PRES = dsp, [function]
PERM_LIQU = perML, [function]
D_PERM_LIQU_SATU = dpermL, [function]
PERM_GAZ = permG, [function]
D_PERM_GAZ_SATU = dpags, [function]
PERMIN_L = perml, [function]
D_PERMIN_L = permL, [function]
PERMIN_T = permt, [function]
D_PERMIN_T = permT, [function]
PERMIN_N = permn, [function]
D_PERMIN_N = permN, [function]
VG_N = vgn, [R]
VG_PR = Pr, [R]
VG_SR = Sr, [R]
VG_SMAX = smax, [R]
VG_SATUR = stur, [R]
FICKV_T = fvt, [function]
FICKV_PV = /fvpv, [function] /1, [DEFECT]
FICKV_PG = /fvgp, [function] /1, [DEFECT]
FICKV_S = /fvs, [function] /1, [DEFECT]
D_FV_T = /dfvt, [function] /0, [DEFECT]
D_FV_PG = /dfvgp, [function] /0, [DEFECT]
FICKA_T = conceited, [function]
FICKA_PA = /fapv, [function] /1, [DEFECT]
FICKA_PL = /fapg, [function] /1, [DEFECT]
FICKA_S = /fas, [function] /1, [DEFECT]
D_FA_T = /dfat, [function] /0, [DEFECT]
LAMB_T = /lambt, [function]
LAMB_TL = /lambtl, [function]
LAMB_TN = /lambtn, [function]
LAMB_TT = /lambtt, [function] /0, [DEFECT]
LAMB_S = /lambS, [function] /1, [DEFECT]
LAMB_PHI = /lambp, [function] /1, [DEFECT]
LAMB_CT = /lambct, [function]
LAMB_C_T = /lambctt, [function]
LAMB_C_L = /lambctl, [function]
LAMB_C_N = /lambctn, [function] /0, [DEFECT]
D_LB_S = /dlambS, [function] /0, [DEFECT]
D_LB_T = /dlambt, [function]
D_LB_TT = /dlambtt, [function]
D_LB_TL = /dlambtl, [function]
D_LB_TN = /dlambtn, [function] /0, [DEFECT]
9.7.2 Operands R_GAZ/RHO/CP/BIOT_COEF

R_GAZ = rgaz
Constant of perfect gases.

RHO = rho
For the hydraulic behaviors, homogenized density. In the static cases, it is useless to inform the density in the elastic behavior (cf section 3.1.3).

CP = CP
For the thermal behaviors specific heat with constant constraint of the solid alone.

BIOT_COEF = organic
Coefficient of Biot.

9.7.3 Operands BIOT_L/BIOT_T/BIOT_N

Replace BIOT_COEF in the anisotropic case. For the definition of the plans of isotropy one will refer to 3.4 and 3.5. In the case of the transverse isotropy (3D), BIOT_L and BIOT_N are respectively the coefficients of Biot in the directions L and NR (perpendicular to the plan of isotropy). In the orthotropic case in 2D, one will define the coefficients of Biot in the three directions L, T, NR: BIOT_L, BIOT_T and BIOT_N.

9.7.4 Operands SATU_PRES/D_SATU_PRES

For the unsaturated material behaviors (LIQU_VAPE_GAZ, LIQU_VAPE, LIQU_AD_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ, LIQU_GAZ_ATM).

SATU_PRES = sp
Isotherm of saturation function of the capillary pressure.

D_SATU_PRES = dsp
Derived from saturation compared to the pressure.

9.7.5 Operands PESA_X/PESA_Y/PESA_Z/PESA_MULT

PESA_X = px, PESA_Y = py, PESA_Z = pz,
Gravity according to x, y or z, used only if the modeling chosen in AFFE_MODELE 1 or 2 includes variable of pressure.

PESA_MULT = fpesa
Temporal function in factor of the components of gravity PESA_X, PESA_Y and PESA_Z. Optional, it is by default constant and equal to 1.

9.7.6 Operand PERM_IN

Intrinsic permeability: function of porosity (in the isotropic case). In the studies, the dependence of the intrinsic permeability to ϕ can express itself classically by the following cubic law:

\[
\frac{k(\phi)}{k_0} = \begin{cases} 
   1 & \text{if } \phi - \phi_0 < 0 \\
   \sin(\phi - \phi_0) & \text{if } 0 < \phi - \phi_0 < 10^{-2} \\
   1 + \chi(\phi - \phi_0)^3 & \text{if } 10^{-2} < \phi - \phi_0 < 10^{-4} \\
   1 + \chi \times 10^{-6} & \text{if } \phi - \phi_0 > 10^{-4}
\end{cases}
\]

Other laws are of course possible.
The permeability to the classical direction $K$, of which dimension is that a speed is calculated in the following way:

$$K = \frac{K_{\text{int}} K_{\text{rel}}}{\mu} \rho_l g$$

where $K_{\text{int}}$ is the intrinsic permeability, $K_{\text{rel}}$ the relative permeability, $\mu$ viscosity, $\rho_l$ density of the liquid and $g$ the acceleration of gravity. $K_{\text{int}}$ is in fact a diagonal tensor, in the isotropic case its three components are equal to the well informed value.

9.7.7 OperandsPERMIN_L/PERMIN_T/PERMIN_N
For the definition of the plans of isotropy one will refer to 3.4 and 3.5. In the case of the transverse isotropy (3D), PERMIN_L and PERMIN_T are respectively the intrinsic permeabilities in the directions L and NR (perpendicular to the plan of isotropy). In the orthotropic case in 2D, one will define the permeabilities in the plans L and T : PERMIN_L and PERMIN_T.

9.7.8 OperandsPERM_LIQU/D_PERM_LIQU_SATU
For the unsaturated material behaviors (LIQU_VAPE_GAZ, LIQU_VAPE, LIQU_AD_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ, LIQU_GAZ_ATM).
Permeability and derived from the permeability relating to the liquid: function of saturation.

9.7.9 OperandsPERM_GAZ/D_PERM_SATU_GAZ
For the unsaturated material behaviors (LIQU_VAPE_GAZ, LIQU_VAPE, LIQU_AD_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ).
Permeability and derived from the permeability relating to gas: function of the saturation and the gas pressure.

9.7.10 OperandsVG_N/VG_PR/VG_SR
For the unsaturated material behaviors liquid gas with two components and two unknown factors (LIQU_VAPE_GAZ, LIQU_AD_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ,) and if the hydraulic law is HYDR_VGM or HYDR_VGC (see Doc. U4.51.11), indicate respectively parameters $N$, $Pr$, and $Sr$ law of Mualem Van-Genuchten being used to define the capillary pressure and the permeabilities relating to water and gas.

9.7.11 OperandsVG_SMAX/VG_SATUR
For the unsaturated material behaviors liquid gas with two components and two unknown factors (LIQU_VAPE_GAZ, LIQU_AD_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ,) and if the hydraulic law is HYDR_VGM or HYDR_VGC (see document [U4.51.11]).
VG_SMAX = smax indicate the maximum saturation for which one applies the law of Mualem Van-Genuchten. Beyond this saturation the curves of Mualem-Van Genuchten are interpolated (see document [R7.01.11]). This value must be very close to 1.
VG_SATUR = stur Beyond the saturation defined by VG_SMAX, saturation is multiplied by this corrective factor. This value must be very close to 1 (see document [R7.01.11]).

9.7.12 OperandsD_PERM_PRES_GAZ
Derived from the permeability to gas by report has the gas pressure: function of the saturation and the gas pressure.
9.7.13 Operands FICKV_T/FICKV_S/FICKV_PG/FICKV_PV
For the behaviors LIQU_VAPE_GAZ and LIQU_AD_GAZ_VAPE, coefficient of Fick function of the
temperature for the diffusion of the vapor in the gas mixture. The coefficient of Fick which can be a
function of saturation, the temperature, the pressure of gas and the steam pressure, one defines it as
a product of 4 functions: FICKV_T, FICKV_S, FICKV_PG, FICKV_VP. In the case of LIQU_VAPE_GAZ
and LIQU_AD_GAZ_VAPE, only FICKV_T is obligatory.

9.7.14 Operands D_FV_TD_FV_PG
For the behaviors LIQU_VAPE_GAZ and LIQU_AD_GAZ_VAPE.
Derived from the coefficient FICKV_PG compared to the gas pressure.

9.7.15 Operands FICKA_T/FICKA_S/FICKA_PA/FICKA_P
For the behavior LIQU_AD_GAZ_VAPE, coefficient of Fick function of the temperature for the diffusion
of the air dissolved in the liquid mixture. The coefficient of Fick which can be a function of saturation,
the temperature, the dissolved air pressure and the pressure of liquid, one defines it as a product of 4
functions: FICKA_T, FICKA_S, FICKA_PA, FICKA_PL. In the case of LIQU_AD_GAZ_VAPE, only
FICKA_T is obligatory.

9.7.16 Operand D_FA_T
For the behavior LIQU_AD_GAZ_VAPE, derived from the coefficient FICKA_T compared to the
temperature.

9.7.17 Operands LAMB_T/LAMB_S/LAMB_PHI/LAMB_CT
LAMB_T = lambt
Multiplicative part of the thermal conductivity of the mixture depend on the temperature (cf
[R7.01.11]). This operand is obligatory in the case of modeling with thermics.
LAMB_S = lambs, LAMB_PHI = lambp
Multiplicative part (to 1 by default equalizes) thermal conductivity of the mixture depending
respectively on saturation, of porosity.
LAMB_CT = lambct
Part of the thermal of the constant mixture and additive conductivity (confer [R7.01.11]). This constant
is equal to zero by default.

9.7.18 Operands LAMB_TL/LAMB_TN/LAMB_TOUT
Replace LAMB_T in the anisotropic case. In the case of the transverse isotropy (3D), LAMB_TL and
LAMB_TT are respectively conductivities in the directions L and NR (perpendicular to the plan of
isotropy). In the orthotropic case in 2D, one will define conductivities in the plans L and T : LAMB_TL
and LAMB_TN.

9.7.19 Operands LAMB_C_L/LAMB_C_N/LAMB_C_T
Replace LAMB_CT in the anisotropic case. In the case of the transverse isotropy (3D), LAMB_C_L and
LAMB_C_T are respectively conductivities in the directions L and NR (perpendicular to the plan of
isotropy). In the orthotropic case in 2D, one will define conductivities in the plans L and T : LAMB_C_L
and LAMB_C_N.

9.7.20 Operands D_LB_T/D_LB_S/D_LB_PHI
D_LB_T = dlambt

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Derived from the part of thermal conductivity of the mixture depend on the temperature compared to the temperature.

\[ D_{LB\_S} = \text{dlambs}, \quad D_{LB\_PHI} = \text{dlambp} \]

Derived from the part of thermal conductivity of the mixture depending respectively on saturation, porosity.

### 9.7.21 Operands \( D\_LB\_TL/D\_LB\_TN/D\_LB\_TOUT \)

In the anisotropic case, derived compared to the temperature from respectively \( \text{LAMB\_TL}, \text{LAMB\_TN} \) and \( \text{LAMB\_TT} \).

### 9.7.22 Operand \( \text{EMMAG} \)

Coefficient of storage. This coefficient is taken into account only in the cases of modeling without mechanics. It connects the variation of porosity to the variation of pressure of liquid.

### 9.7.23 Operand \( \text{PERM\_END} \)

Permeability function of the damage, used by the mechanical behaviors with damage.

### 9.8 Keyword \( \text{MOHR\_COULOMB} \)

The model of Mohr-Coulomb is an elastoplastic model used in soil mechanics and is especially adapted to sandy materials. The document \([R7.01.28]\) described the corresponding equations. This model can be used independently of behaviors THM. The elastic characteristics must be defined under the keyword \( \text{ELAS} \).

#### 9.8.1 Syntax

\[
\text{MOHR\_COULOMB} = \_F \quad ( \\
\quad \bullet \quad \text{PHI} = \phi, \quad [R] \\
\quad \bullet \quad \text{ANGDIL} = \text{angdil}, \quad [R] \\
\quad \bullet \quad \text{COHESION} = \text{cohes}, \quad [R] \\
) \\
\]

#### 9.8.2 Operands \( \text{PHI/ANGDIL/COHESION} \)

\( \text{PHI} = \phi \)  
Angle of friction (in degrees). The value must be ranging between 0 and 60 degrees.  
\( \text{ANGDIL} = \text{angdil} \)  
Angle of dilatancy (in degrees). The value must be ranging between 0 and 60 degrees.  
\( \text{COHESION} = \text{cohes} \)  
Cohesion of material (in a PASCAL – if unit IF).

### 9.9 Keyword \( \text{CAM\_CLAY} \)

The Camwood-Clay model is an elastoplastic model used in soil mechanics and is especially adapted to argillaceous materials. The model presented here is called modified Camwood-Clay. The document \([R7.01.14]\) described the corresponding equations. This model can be used independently of behaviors THM. The elastic characteristics must be defined under the keyword \( \text{ELAS} \).

#### 9.9.1 Syntax

\[
\text{CAM\_CLAY} = \_F \quad ( \\
\quad \bullet \quad \text{DRIVEN} = \text{driven}, \quad [R] \\
\quad \bullet \quad \text{LAMBDA} = \lambda, \quad [R] \\
\quad \bullet \quad \text{KAPA} = \kappa, \quad [R] \\
\quad \bullet \quad \text{M} = m, \quad [R] \\
) \\
\]

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.
9.9.2 Operands MU/LAMBDA/KAPA

DRIVEN = driven
Elastic module of shearing.
LAMBDA = average
Coefficient of compressibility (plastic slope in a hydrostatic test of compression).
KAPA = kapa
Elastic coefficient of swelling (elastic slope in a hydrostatic test of compression).

9.9.3 Operand M
Slope of the right-hand side of critical condition.

9.9.4 Operand PORO
Initial porosity. If CAM_CLAY is used under RELATION_KIT, the keyword PORO informed under CAM_CLAY and under THM_INIT must be the same one.

9.9.5 Operands PRES_CRIT/KCAM

PRES_CRIT = prescr
The critical pressure equalizes with half of the pressure of consolidation.
KCAM = kcam
Initial pressure corresponding to initial porosity generally equal to the atmospheric pressure. This parameter must be positive (kcam > 0.).

9.9.6 Operand PTRAC
Quantity of the hydrostatic constraint of traction tolerated or shift of the ellipse towards the left on the axis of the hydrostatic constraints. This parameter must be negative (ptrac < 0.).

9.10 Keyword factor CJS

The law (Cambou, Jaffani, Sidoroff) is a law of behavior for the grounds. It comprises three mechanisms, one corresponds to nonlinear elasticity, another corresponds to a plasticization for states of isotropic stresses, and the third mechanism corresponds to a plasticization related to a state of stress déviatoire. The document [R7.01.13] described with precision the corresponding equations.
The elastic characteristics must be defined under the keyword ELAS.

Law CJS recovers three possible forms (CJS1, CJS2 and CJS3), according to whether one authorizes or not the activation of the nonlinear mechanisms.
Table Ci below gives the mechanisms activated for three levels CJS1, CJS2 and CJS3:

<table>
<thead>
<tr>
<th>Elastic mechanism</th>
<th>Isotropic plastic mechanism</th>
<th>Plastic mechanism déviatoire</th>
</tr>
</thead>
<tbody>
<tr>
<td>CJS1</td>
<td>linear</td>
<td>not activated</td>
</tr>
<tr>
<td>CJS2</td>
<td>nonlinear</td>
<td>activated</td>
</tr>
<tr>
<td>CJS3</td>
<td>nonlinear</td>
<td>activated</td>
</tr>
</tbody>
</table>

Note: By adopting the correspondence of the parameters for the limiting states, it is possible to use behavior CJS1 to model a law of Mohr Coulomb in soil mechanics.
9.10.1 Syntax

\[
\text{CJS} = \_F \left( \\
\bullet \text{BETA\_CJS} = \text{beta}, \\
\bullet \text{RM} = \text{rm}, \\
\bullet \text{N\_CJS} = \text{N}, \\
\bullet \text{KP} = \text{kp}, \\
\bullet \text{RC} = \text{rc}, \\
\bullet \text{A\_CJS} = \text{has}, \\
\bullet \text{B\_CJS} = \text{B}, \\
\bullet \text{C\_CJS} = \text{C}, \\
\bullet \text{GAMMA\_CJS} = \text{G}, \\
\bullet \text{MU\_CJS} = \text{driven}, \\
\bullet \text{PCO} = \text{pco}, \\
\bullet \text{Pa} = \text{Pa}, \\
\bullet \text{Q\_INIT} = \text{Q}, \\
\bullet \text{R\_INIT} = \text{R} \\
\right)
\]

The various coefficients are to be informed or not according to the level which one wants to use, in accordance with table Ci below (F for optional, O for obligatory and nothing for without object).

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Q_init</th>
<th>R_init</th>
<th>n</th>
<th>K_p</th>
<th>y</th>
<th>(\beta)</th>
<th>R_c</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Keyword</td>
<td>Q_INIT</td>
<td>R_INIT</td>
<td>N_CJS</td>
<td>KP</td>
<td>PCO</td>
<td>BETA_CJS</td>
<td>RC</td>
<td>A_CJS</td>
</tr>
<tr>
<td>CJS1</td>
<td>F</td>
<td>O</td>
<td>O</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CJS2</td>
<td>F</td>
<td>F</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td>O</td>
</tr>
<tr>
<td>CJS3</td>
<td>F</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td></td>
<td>O</td>
</tr>
</tbody>
</table>

\[
\text{BETA\_CJS} = \text{beta} \\
\text{RM} = \text{rm} \\
\]

Parameter \(\beta\) : Control plastic variation of volume in the mechanism déviatoire.

We draw the attention of the user to the fact that, for the same material, the same coefficient can take different values according to the level used. The level used is never indicated, it is indicated by the fact that certain coefficients are indicated or not.

In addition, the keyword \text{ELAS} must be obligatorily well informed when law CJS is used (under one of its three levels). The definition of the Young modulus and the Poisson's ratio make it possible to calculate the coefficients \(K_c\) and \(G_a\).
Maximum value of opening of the field of reversibility déviatoire.

9.10.3 Operands N_CJS/KP/RC

For levels CJS2 and CJS3.

\( N_{CJS} = N \)

Control dependence of the modulus of elasticity with the average constraint:

\[
K = K^o \left( \frac{I_J + Q_{init}}{3P_a} \right)^n
\]

\( KP = kp \)

Plastic module of compressibility:

\[
\dot{Q}_{iso} = K^p \dot{q} = K^p_o \left( \frac{Q_{init}}{P_a} \right)^n \dot{q}
\]

\( RC = rc \)

Value criticizes variable \( R \):

\[
\dot{e}_v^{dp} = -\beta \left[ \frac{s_{II}}{s_{II}^3} - 1 \right] \left[ s_{II} e_v^{dp} \right]_{s_{II}} = \frac{R_c I_1}{h} \left( \theta_s \right)
\]

9.10.4 Operands A_CJS/R_INIT

For levels CJS2.

\( A_{CJS} = \) has

Control the isotropic work hardening of the mechanism déviatoire:

\[
R = \frac{AR_m r}{R_m + Ar}
\]

\( R_INIT = R \)

Initial value of the variable \( R \). At the first computing time, if the initial value of \( R \) is worthless, that is to say that one did not define an initial state of the internal variables by the keyword \( \text{ETAT INIT} \) of \( \text{STAT NON LINE} \), either that this initial state or no one, one will take as initial value that definite by the keyword \( R_INIT \) of \( \text{DEFI_MATERIAU} \).

9.10.5 Operands B_CJS/C_CJS/PCO/MU_CJS

For levels CJS3.

\( B_{CJS} = B \)

Control the kinematic work hardening of the mechanism déviatoire:

\[
\dot{X}_y = -\frac{1}{b} \dot{e}_v^{dp} \left[ \text{dev} \left( \frac{\partial f}{\partial X_y} \right) - I_1 f X_y \right] \left( \frac{I_1}{3P_a} \right)^{-1.5}
\]

\( C_{CJS} = C \)

Control evolution of the critical pressure: \( p_c = p_{co} \exp \left( -c \varepsilon_v \right) \).

\( PCO = pco \)

Initial critical pressure: \( p_c = p_{co} \exp \left( -c \varepsilon_v \right) \).

\( MU_CJS = \) driven

Control the value of rupture of the variable \( R \):

\[
R_r = R_c + m \ln \left( \frac{3 p_r}{I_1} \right)
\]
9.10.6 Operands $\text{GAMMA_CJS}/PA/Q\_INIT$

For levels CJS1, CJS2 and CJS3.

$\text{GAMMA_CJS} = G$

Control the form of the criterion:

$$h(\theta_s) = \left| 1 + \gamma \cos \left( 3 \theta_s \right) \right|^{1/6} = \left( 1 + \gamma \sqrt{\frac{54 \det(s)}{s_{ll}^3}} \right)^{1/6}$$

$Pa = Pa$

Atmospheric pressure. Must be given negative.

$Q\_INIT = Q$

Digital parameter allowing to make acceptable a null state of stress. Can also be used to define a cohesion, at least for the level CJS1. The formula will be used: $Q_{init} = -3c \cotan(\varphi)$

9.11 Keyword factor $\text{LAIGLE}$

The law of LAIGLE [R7.01.15] is a rheological model of behavior for the modeling of the rocks. Those are characterized by the three following parameters:

- $a$ who defines the influence of the component of dilatancy in the behavior in the great deformations. This parameter depends on the level of deterioration of the rock,
- $s$ who defines the cohesion of the medium. It is thus representative of the damage of the rock,
- $m$ is function of the mineralogical nature of the rock, and is associated with an important experience feedback.

The elastic characteristics must be defined under the keyword $\text{ELAS}$.

9.11.1 Syntax

```
| LAIGLE = _F ( 
  ✦ GAMMA_ULT = gamma_ult, [R] 
  ✦ GAMMA_E = gamma_e, [R] 
  ✦ M_ULT = m_ult, [R] 
  ✦ M_E = m_e, [R] 
  ✦ A_E = a_e, [R] 
  ✦ M_PIC = m_pic, [R] 
  ✦ A_PIC = a_pic, [R] 
  ✦ ETA = eta, [R] 
  ✦ SIGMA_C = sigma_c, [R] 
  ✦ GAMMA = gamma, [R] 
  ✦ KSI = ksi, [R] 
  ✦ GAMMA_CJS = gamma_cjs, [R] 
  ✦ SIGMA_P1 = sigma_p1, [R] 
  ✦ Pa = Pa [R] 
) 
```

9.11.2 Operands $\text{GAMMA_ULT}/\text{GAMMA_E}$

$\text{GAMMA_ULT} = \text{gamma_ult}$

Parameter $\gamma_{\text{ult}}$: Plastic deformation déviatoire corresponding to the stage.

$\text{GAMMA_E} = \text{gamma_e}$

Parameter $\gamma_e$: Plastic deformation déviatoire corresponding to the complete disappearance of cohesion.

9.11.3 Operand $\text{M_ULT}/\text{M_E}/\text{A_E}/\text{M_PIC}$

$\text{M_ULT} = \text{m_ult}$

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Parameter $m_{\text{ult}}$ : Value of $m$ ultimate criterion reached $\gamma_{\text{ult}}$.

$M_E = m_e$

Parameter $m_\epsilon$ : Value of $m$ intermediate criterion reached in $\gamma_\epsilon$.

$A_E = a_\epsilon$

Parameter $a_\epsilon$ : Value of $a$ intermediate criterion reached in $\gamma_\epsilon$.

$M\_\text{PIC} = m\_\text{pic}$

Parameter $m_{\text{pic}}$ : Value of $m$ criterion of peak reached with the peak of constraint.

### 9.11.4 Operands A\_PIC/ETA/SIGMA\_C

- $A\_\text{PIC} = a_{\text{pic}}$
- Parameter $a_{\text{pic}}$ : Value of the exhibitor $a$ with the peak of constraint.
- $ETA = \eta$
- Parameter $\eta$ : Exhibitor controlling work hardening.
- $SIGMA\_\text{C} = \sigma_c$
- Parameter $\sigma_c$ : Resistance in simple compression.

### 9.11.5 Operands GAMMA/KSI

- $GAMMA = \gamma$, $KSI = \kappa$
- Parameters $\gamma$ and $\kappa$ : Parameters regulating dilatancy.
- A condition to respect is that the report $\gamma/\kappa$ remain lower than 1. In the case of very resistant hard stones, subjected to constraints of containment relatively low, the variation of dilatancy $\sin \psi$ (according to the state of the constraints - to see [R7.01.15]) can tend towards $\gamma/\kappa$, which justifies this condition.

### 9.11.6 Operand GAMMA\_CJS

Parameter $\gamma_{\text{cjs}}$ : parameter of form of the surface of load in the déviatoire plan.

### 9.11.7 Operand SIGMA\_PL

Parameter $\sigma_{\text{pl}}$ : intersection of the intermediate criterion and the criterion of peak.

### 9.11.8 Operand $\mathbf{P}_a$

Atmospheric pressure. Must be given positive.

Note: Parameters $M_E$, $A_E$, $A\_\text{PIC}$, $SIGMA\_\text{PL}$, $SIGMA\_\text{C}$ and $MPIC$ from/to each other are dependent by the relation: $m_\epsilon = \frac{\sigma_c}{\sigma_{\text{pl}}} \left( m_{\text{pic}} \frac{\sigma_{\text{pl}}}{\sigma_c} + 1 \right)^{\frac{a_{\text{pic}}}{a_\epsilon}}$. This dependence is checked within the code.

### 9.12 Keyword factor L\&K

Rheological model L&K (Laigle and Kleine) is a called viscoplastic law of behavior élasto L\&K in Code_Aster [R7.01.24]. It is based on concepts of elastoplasticity and viscoplasticity. Elastoplasticity is characterized by a positive work hardening in pre peak and a negative work hardening in post peak. One finds among the parameters:

- parameters which intervene in the functions of work hardening relative to the various elastoplastic or viscous thresholds, like $a$, $s$ and $m$. 

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.
- parameters related to the viscous criteria,
- parameters related to dilatancy,
- parameters related to the resistance of material in compression and traction.

The elastic characteristics must be defined under the keyword `ELAS`.

### 9.12.1 Syntax

```latex
\text{LETK} = \_F \left( \begin{array}{l}
\text{Pa} \quad = \quad \text{Pa}, \quad \text{[R]} \\
\text{NELAS} \quad = \quad \text{nelas}, \quad \text{[R]} \\
\text{SIGMA\_C} \quad = \quad \text{sigc}, \quad \text{[R]} \\
\text{H0\_EXT} \quad = \quad \text{h0}, \quad \text{[R]} \\
\text{GAMMA\_CJS} \quad = \quad \text{gcjs}, \quad \text{[R]} \\
\text{XAMS} \quad = \quad \text{xams}, \quad \text{[R]} \\
\text{ETA} \quad = \quad \text{eta}, \quad \text{[R]} \\
\text{A\_0} \quad = \quad \text{a0}, \quad \text{[R]} \\
\text{A\_E} \quad = \quad \text{ae}, \quad \text{[R]} \\
\text{A\_PIC} \quad = \quad \text{ap}, \quad \text{[R]} \\
\text{S\_0} \quad = \quad \text{s0}, \quad \text{[R]} \\
\text{S\_E} \quad = \quad \text{se}, \quad \text{[R]} \\
\text{M\_0} \quad = \quad \text{m0}, \quad \text{[R]} \\
\text{M\_E} \quad = \quad \text{me}, \quad \text{[R]} \\
\text{M\_PIC} \quad = \quad \text{mp}, \quad \text{[R]} \\
\text{M\_ULT} \quad = \quad \text{mult}, \quad \text{[R]} \\
\text{XI\_ULT} \quad = \quad \text{xiult}, \quad \text{[R]} \\
\text{XI\_E} \quad = \quad \text{11th}, \quad \text{[R]} \\
\text{XI\_PIC} \quad = \quad \text{xiip}, \quad \text{[R]} \\
\text{MV\_MAX} \quad = \quad \text{vmvmx}, \quad \text{[R]} \\
\text{XI\_MAX} \quad = \quad \text{xi1vmx}, \quad \text{[R]} \\
\text{With} \quad = \quad \text{With}, \quad \text{[R]} \\
\text{NR} \quad = \quad \text{N}, \quad \text{[R]} \\
\text{SIGMA\_PI} \quad = \quad \text{sp1}, \quad \text{[R]} \\
\text{MU0\_V} \quad = \quad \text{mu0v}, \quad \text{[R]} \\
\text{XI0\_V} \quad = \quad \text{xi0v}, \quad \text{[R]} \\
\text{MU1} \quad = \quad \text{mu1}, \quad \text{[R]} \\
\text{XI1} \quad = \quad \text{x1}, \quad \text{[R]} \\
\end{array} \right)
```

### 9.12.2 Operands \text{Pa} NELAS/SIGMA\_C/H0\_EXT

- **\text{Pa}**: pressure atmosphérique.
- **NELAS**: exhibitor of the law of variation of the elastic modules $K$ and $G$.
- **SIGMA\_C**: resistance in simple compression (the unit of a constraint).
- **H0\_EXT**: parameter controlling the tensile strength.

### 9.12.3 Operands GAMMA\_CJS/XAMS

- **GAMMA\_CJS**: parameter of form of the criterion in the déviatoire plan (between 0 and 1).
- **XAMS**: parameter not no one intervening in the laws of work hardening pre-peak.
9.12.4 Operand ETA/A_0/A_E/A_PIC

\[ \text{ETA} = \eta \]
Parameter \( h \) : parameter not no one intervening in the laws of work hardening post-peak.

\[ A_0 = a_0 \]
Parameter \( a_0 \) : value of \( a \) on the threshold of damage.

\[ A_E = a_e \]
Parameter \( a_e \) : value of \( a \) on the intermediate threshold.

\[ A_PIC = a_{pic} \]
Parameter \( a_{pic} \) : value of \( a \) on the threshold of peak.

9.12.5 Operands S_0/S_E/M_0/M_E/M_PIC/M_ULT

\[ S_0 = s_0 \]
Parameter \( s_0 \) : value of \( s \) on the threshold of damage.

\[ S_E = s_e \]
Parameter \( s_e \) : value of \( s \) on the intermediate threshold.

\[ M_0 = m_0 \]
Parameter \( m_0 \) : value of \( m \) on the threshold of damage.

\[ M_E = m_e \]
Parameter \( m_e \) : value of \( m \) on the intermediate threshold.

\[ M_PIC = m_{pic} \]
Parameter \( m_{pic} \) : value of \( m \) on the threshold of peak.

\[ M_ULT = m_{ult} \]
Parameter \( m_{ult} \) : value of \( m \) on the residual threshold.

9.12.6 Operands XI_E/XI_PIC/MV_MAX/XIV_MAX

\[ XI_E = 11th \]
Parameter \( \xi_e \) : level of work hardening on the intermediate threshold.

\[ XI_PIC = xip \]
Parameter \( \xi_{pic} \) : level of work hardening on the threshold of peak.

\[ MV_MAX = mvmx \]
Parameter \( m_{v(max)} \) : value of \( m \) on the threshold of viscoplasticity.

\[ XIV_MAX = xivmx \]
Parameter \( \xi_{v(max)} \) : level of work hardening to reach the maximum viscoplastic threshold.

9.12.7 Operands A/N

\[ A = \text{With} \]
Parameter \( A \) : parameter characterizing the amplitude the speed of creep (in \( s^{-1} \) or \( \text{jour}^{-1} \)).

\[ NR = N \]
Parameter \( N \) : exhibitor intervening in the formula controlling the kinetics of creep.

9.12.8 Operand SIGMA_P1

\[ SIGMA_P1 = sp1 \]
Parameter \( \sigma_{p1} \) : corresponds to the X-coordinate of the point of intersection of the limit of cleavage and threshold of peak.
9.12.9 Operands MU0_V and XI0_V

\[ \begin{align*}
  & \text{MU0}_V = \mu_{0v}, \ XI0_V = \xi_{0v} \\
  \text{Parameters } \mu_{0v} \text{ and } \xi_{0v} : \text{parameters regulating the dilatancy of the mechanisms pre-peak and viscoplastic} \\
  \text{The conditions to respect on these parameters are:}
  \begin{cases} 
    & \mu_{0v} > \xi_{0v} \\
    & \frac{s^{\text{pic}}}{s_0} \leq 1 + \mu_{0v} \\
    & \mu_{0v} - \xi_{0v} \ \\
  \end{cases} \\
  \text{with } s^{\text{pic}} = 1
\end{align*} \]

9.12.10 Operands MU1 and XI1

\[ \begin{align*}
  & \text{MU1} = \mu_{1}, \ XI1 = \xi_{1} \\
  \text{Parameters } \mu_{1} \text{ and } \xi_{1} : \text{parameters regulating the dilatancy of the mechanisms post-peak. A condition to respect is that the report } \frac{\mu_{1}}{\xi_{1}} \text{ remain lower or equal to 1.}
\end{align*} \]

9.13 Keyword factor DRUCK_PRAGER

The law of DRUCK_PRAGER [R7.01.16] is a model of behavior for the soil mechanics, it is defined by the relation:

\[ \sigma_{eq} + \alpha I_1 - R(p) \leq 0 \]

where

\[ \sigma_{eq} \] is a function of the diverter of the effective constraints \( \sigma' \),

\[ I_1 = \text{Tr} \left( \sigma' \right) \] is the trace of the effective constraints,

\[ \alpha \] is a coefficient of dependence in pressure,

\[ R(p) \] is a function of the cumulated plastic deformation.

In the linear case, the function \( R(p) \) is given by:

\[ 0 < p < p_{ult} \quad R(p) = hp + \sigma_y \]

\[ p \geq p_{ult} \quad R(p) = h p_{ult} + \sigma_y \]

In the parabolic case, \( R(p) = \sigma_y f(p) \) where the function \( f(p) \) is given by:

\[ 0 < p < p_{ult} \quad f(p) = \left( 1 - \left( 1 - \frac{\sigma_{y,ult}}{\sigma_y} \right) \frac{p}{p_{ult}} \right)^2 \]

\[ p \geq p_{ult} \quad f(p) = \frac{\sigma_{y,ult}}{\sigma_y} \]

9.13.1 Syntax

\[ \text{DRUCK_PRAGER = _F (} \]

\[ \begin{align*}
  & \text{\{ WORK HARDENING = 'LINEAR ', 'PARABOLIC ', [TXM] } \]
  & \text{\{ ALPHA = alpha, [R] } \]
  & \text{\{ P_ULTM = p_ult, [R] } \]
  & \text{\{ SY = sy, [R] } \]
  & \text{\{ H = H, [R] } \]
  & \text{\{ SY_ULTM = sy_ult, [R] } \]
  & \text{\{ DILAT = ang, [R] } \]
\]
9.13.2 Operand WORK HARDENING

```plaintext
WORK HARDENING = 'LINEAR',/'PARABOLIC'
```

Allows to define the type of desired work hardening.

9.13.3 Operand ALPHA

```plaintext
ALPHA = alpha
```

Indicate the coefficient of dependence in pressure. It is pointed out that the operand ALPHA is connected to the angle of friction $\phi$ by the relation:

$$\alpha = \frac{2 \sin(\phi)}{3 - \sin(\phi)}.$$

9.13.4 Operand P_ULTM

```plaintext
P_ULTM = p_ult
```

Indicate the ultimate cumulated plastic deformation.

9.13.5 Operand SY

```plaintext
SY = sy
```

Indicate the plastic constraint. This operand is related to the combination of the binding fraction $C$ with the angle of friction $\phi$ in the following way:

$$SY = \frac{6C \cos(\phi)}{3 - \sin(\phi)}.$$

9.13.6 Operand H

```plaintext
H = H
```

Indicate the module of work hardening, $h < 0$ if the law is lenitive. This operand is obligatory for work hardening of a linear type (operand WORK HARDENING = ‘LINEAR’).

9.13.7 Operand SY_ULTM

```plaintext
SY_ULTM = sy_ult
```

Indicate the ultimate constraint. This operand is obligatory for work hardening of a parabolic type (operand WORK HARDENING = ‘PARABOLIC’).

9.13.8 Operand DILAT

```plaintext
DILAT = ang
```

Indicate the angle of dilatancy (by default equal to zero).

9.14 Keyword factor VISC_DRUC_PRAG

The rheological model VISC_DRUC_PRAG is a law of behavior élasto-visco-plastic in Code_Aster [R7.01.22]. It is characterized by a viscoplastic mechanism which is hammer-hardened between three thresholds: rubber band, of peak and ultimate. Elastoplasticity is of type Drucker Prager with a positive work hardening in pre peak and a negative work hardening in post-peak and viscoplasticity is a law power of the Perzyna type.

One finds among the parameters:

- parameters which intervene in the functions of work hardening relative to the various thresholds rubber band, of peak and ultimate $\alpha$, $\beta$, $R$ and $n$,
- parameters related to the law of creep $A$ and $n$,
- cumulated viscoplastic deformations corresponding to each threshold $p_{pic}$ and $p_{ult}$;
- a pressure of reference $P_{ref}$.
The elastic characteristics must be defined under the keyword \texttt{ELAS}.

\subsection{Syntax}

\begin{verbatim}
| VISC_DRUC_PRAG = _F (  
  • PREF = pref, [R]
  • NR = N, [R]
  • With = has, [R]
  • P_PIC = peak, [R]
  • P_ULT = pult, [R]
  • ALPHA_0 = alpha0, [R]
  • ALPHA_PIC = alphapic, [R]
  • ALPHA_ULT = alpault, [R]
  • R_0 = r0, [R]
  • R_PIC = rpic, [R]
  • R_ULT = rult, [R]
  • BETA_0 = beta0, [R]
  • BETA_PIC = betapic, [R]
  • BETA_ULT = betault, [R]
)
\end{verbatim}

\subsection{Operands \texttt{PREF}/ \texttt{NR}/\texttt{P_PIC}/\texttt{P_ULT}}

\begin{itemize}
  \item \texttt{PREF} = pref
  \begin{itemize}
    \item Parameter $P_{\text{ref}}$ : pressure of reference (unit of a constraint)
  \end{itemize}
  \item \texttt{NR} = N
  \begin{itemize}
    \item Parameter $n$ : exhibitor of the law D creep
  \end{itemize}
  \item With = has
  \begin{itemize}
    \item Parameter $A$ : viscoplastic parameter (in $s^{-1}$ or $jour^{-1}$)
  \end{itemize}
  \item \texttt{P_PIC} = peak
  \begin{itemize}
    \item Parameter $p_{\text{pic}}$ : viscoplastic deformation cumulated on the level of the threshold of peak
  \end{itemize}
  \item \texttt{P_ULT} = pult
  \begin{itemize}
    \item Parameter $p_{\text{ult}}$ : viscoplastic deformation cumulated on the level of the ultimate threshold
  \end{itemize}
\end{itemize}

\subsection{Operands \texttt{ALPHA_0}/\texttt{ALPHA_PIC} /\texttt{ALPHA_ULT}}

\begin{itemize}
  \item \texttt{ALPHA_0} = alpha0
  \begin{itemize}
    \item Parameter $\alpha_0$ : parameter of the function of cohesion $\alpha(p)$ on the level of the elastic threshold
  \end{itemize}
  \item \texttt{ALPHA_PIC} = alphapic
  \begin{itemize}
    \item Parameter $\alpha_{\text{pic}}$ : parameter of the function of cohesion $\alpha(p)$ on the level of the threshold of peak
  \end{itemize}
  \item \texttt{ALPHA_ULT} = alpault
  \begin{itemize}
    \item Parameter $\alpha_{\text{ult}}$ : parameter of the function of cohesion $\alpha(p)$ on the level of the ultimate threshold
  \end{itemize}
\end{itemize}

\subsection{Operands \texttt{R_0} /\texttt{R_PIC} /\texttt{R_ULT}}

\begin{itemize}
  \item \texttt{R_0} = r0
  \begin{itemize}
    \item Parameter $R_0$ : parameter of the function of work hardening $R(p)$ on the level of the elastic threshold (in $Pa$ or in $MPa$)
  \end{itemize}
  \item \texttt{R_PIC} = rpic
  \begin{itemize}
    \item Parameter $R_{\text{pic}}$ : parameter of the function of work hardening $R(p)$ on the level of the threshold of peak (in $Pa$ or in $MPa$)
  \end{itemize}
  \item \texttt{R_ULT} = rult
  \begin{itemize}
    \item Parameter $R_{\text{ult}}$ : parameter of the function of work hardening $R(p)$ on the level of the ultimate threshold (in $Pa$ or in $MPa$)
  \end{itemize}
\end{itemize}
9.14.5 **Operands BETA_0 /BETA_PIC /BETA_ULT**

\[
\begin{align*}
BETA_0 & = beta0  \\
\text{Parameter } \beta_0 & : \text{ parameter of the function of dilatancy } \beta( p) \text{ on the level of the elastic threshold}  \\
BETA_PIC & = betapic  \\
\text{Parameter } \beta_{pic} & : \text{ parameter of the function of dilatancy } \beta( p) \text{ on the level of the threshold of peak}  \\
BETA_ULT & = betault  \\
\text{Parameter } \beta_{ult} & : \text{ parameter of the function of dilatancy } \beta( p) \text{ on the level of the ultimate threshold}
\end{align*}
\]

9.15 **Keyword factor BARCELONA**

The model of Barcelona describes the elastoplastic behavior of the unsaturated grounds coupled with the hydraulic behavior (cf [R7.01.17] for more detail). This model is reduced to the Camwood-Clay model in the saturated case. Two criteria intervene: a criterion of plasticity mechanical (that of Camwood-Clay) and one hydrous criterion controlled by suction (or capillary pressure). It cannot be used that within the framework of the behaviors THHM and HHHM. The characteristics necessary to the model must be given under this keyword and the keywords CAM_CLAY and ELAS.

It is thus obligatory to inform the parameters of the keywords CAM_CLAY and ELAS.

9.15.1 **Syntax**

```plaintext
| BARCELONA = _F (  
| ◆ DRIVEN = driven,  
| ◆ PORO = poro,  
| ◆ LAMBDA = lambda  
| ◆ KAPA = kapa,  
| ◆ M = m,  
| ◆ PRES_CRIT = PC,  
| ◆ Pa = Pa,  
| ◆ R = R,  
| ◆ BETA = beta,  
| ◆ KC = kc,  
| ◆ PC0_INIT = PC0(0),  
| ◆ KAPAS = Kappas,  
| ◆ LAMBDAS = Lambdas,  
| ◆ ALPHAB = alphab  
| )
```

9.15.2 **Operands MU/PORO/LAMBDA/KAPA/M**

\[
\begin{align*}
\text{DRIVEN} & = \text{driven}  \\
\text{Elastic module of shearing} & .  \\
\text{PORO} & = \text{poro}  \\
\text{Porosity associated with a pressure initial and related to the initial index of the vacuums: } n = \frac{e_0}{I + e_0}.  \\
\text{LAMBDA} & = \text{average}  \\
\text{Coefficient of compressibility (plastic slope in a hydrostatic test of compression).}  \\
\text{KAPA} & = \text{kapa}  \\
\text{Elastic coefficient of swelling (elastic slope in a hydrostatic test of compression).}  \\
\text{M} & = m  \\
\text{Slope of the right-hand side of critical condition.}
\end{align*}
\]

9.15.3 **Operands PRES_CRIT and Pa**

\[
\begin{align*}
PRES\_CRIT & = \text{PC, Pa} = \text{Pa}  \\
\text{Pcritical ression equalizes with half of the pressure of consolidation and atmospheric pressure.}
\end{align*}
\]
9.15.4 Operands R/BETA/KC

\( R = R, \ \text{BETA} = \beta \)

Adimensional coefficients intervening in the expression:
\[
\lambda(p_c) = \lambda(0) \left[ (1 - r) \exp(-\beta p_c) + r \right]
\]

\( KC = k_c \)

Adimensional parameter controlling the increase in cohesion with suction (capillary pressure).

9.15.5 Operands PCO_INIT/KAPAS/LAMBDAS/ALPHAB

\( PCO\_INIT = PC\ 0(0) \)

Initial threshold of the capillary pressure (homogeneous with constraints).

\( KAPAS = Kappas \)

Adimensional coefficient of rigidity associated with the change of suction in the elastic range.

\( LAMBDAS = \Lambda\text{mbdas} \)

Coefficient of compressibility related to a variation of suction in the plastic range. (adimensional).

\( ALPHAB = alphab \)

Coefficient of correction of the normality of the plastic flow [R7.01.17].

Optional and adimensional corrective term allowing to better take into account experimental results. By default, it is calculated by Code_Aster according to the slope of the right-hand side of critical condition, coefficient of swelling and coefficient of compressibility.

9.16 Keyword factor HUJEUX

Elastoplastic law of behavior in soil mechanics (géomatériaux granular: sandy, normally consolidated or on-consolidated, serious clays...). This model is a multicriterion model which comprise a nonlinear elastic mechanism, 3 plastic mechanisms déviatoires and an isotropic plastic mechanism (see [R7.01.23]).

Elastic mechanical characteristics \( E, \text{NAKED}, \text{AND ALPHA} \) must be defined in parallel under the keyword ELAS. The law of Hujeux displaying a non-linear elastic behavior, the values of these parameters are associated with the pressure of reference \( \text{PREF} \) law of Hujeux.

9.16.1 Syntax

\[ \text{HUJEUX} = \_F \ ( \]

\[
\begin{align*}
\text{NR} & = N, & [R] \\
\text{BETA} & = beta, & [R] \\
\text{B} & = B, & [R] \\
\text{D} & = D, & [R] \\
\text{PHI} & = phi, & [R] \\
\text{ANGDIL} & = angdil, & [R] \\
\text{PCO} & = pco, & [R] \\
\text{PREF} & = pref, & [R] \\
\text{ACYC} & = acyc, & [R] \\
\text{AMON} & = amon, & [R] \\
\text{CCYC} & = ccyc, & [R] \\
\text{CMON} & = cmon, & [R] \\
\text{RD\_ELA} & = rdela, & [R] \\
\text{RI\_ELA} & = riela, & [R] \\
\text{RHYS} & = rhys, & [R] \\
\text{RMOC} & = rmob, & [R] \\
\text{XM} & = xm, & [R] \\
\text{RD\_CYC} & = rdyc, & [R] \\
\text{RI\_CYC} & = ricyc, & [R]
\end{align*}
\]

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9.16.2 Operands N/BETA/B/D/PHI

NR = N
Value of the parameter characteristic of the non-linear law elastic power, ranging between 0 and 1.

BETA = beta
Value of the coefficient of plastic compressibility voluminal or law of critical condition, (positive).

B = B
Value of the parameter influencing the function of load in the plan (\( P', Q \)), ranging between 0 (Mohr-Coulomb) and 1 (Camwood-Clay).

D = D
Value of the parameter characterizing the distance enters the line of critical condition and the isotropic line of consolidation, (positive).

PHI = phi
Value of the parameter characterizing the natural angle of repose, in degree.

9.16.3 Operands ANGDIL/PCO/PREF

ANGDIL = angdil
Value of the parameter characterizing the angle of dilatancy, in degree.

PCO = pco
Value pressure criticizes initial reference, (negative).

PREF = pref
Value confining pressure of reference, (negative).

Operands ACYC/AMON/CCYC/CMON
ACYC = acyc, AMON = amon, CCYC = ccyc, CMON = cmon
Values of the parameters of work hardening of the plastic mechanisms déviatoires, into cyclic and monotonous, and of the plastic mechanisms of consolidation, into cyclic and monotonous, respectively.

9.16.4 Operands RD_ELA/RI_ELA

RD_ELA = rdela, RI_ELA = riela,
Values of the initial rays of the thresholds of the mechanisms déviatoire monotonous and monotonous consolidation, respectively, ranging between 0 and 1.

RD_ELA = rdela, RI_ELA = riela,
Values of the initial rays of the thresholds of the mechanisms déviatoire monotonous and monotonous consolidation, respectively, ranging between 0 and 1.

9.16.5 Operands RD_CYC/RI_CYC

RD_CYC = rdcyc, RI_CYC = ricyc
Values of the initial rays of the thresholds of the mechanisms déviatoire cyclic and cyclic consolidation, respectively, ranging between 0 and 1.

9.16.6 Operands RHYS/RMOB/XM/DILA/PTRAC

RHYS = rhys
Value of the parameter defining the hysteretic size of the field.

RMOB = rmob
Value of the parameter defining the size of the mobilized field.

XM = xm
Valor of the parameter of control in the field hysteretic.
DILA = dila
Value of the coefficient of dilatancy, ranging between 0 and 1.
PTRAC = ptrac
cohesion of material, homogeneous with a constraint (positive or worthless value). Allows to shift the
surface of load towards \( p > 0 \) in order to take into account a light traction in material.

9.17 Keyword factor HOEK_BROWN

Law of behavior in rock mechanics of type law of modified HOEK-BROWN (cf [R7.01.18])
Elastic mechanical characteristics \( E, NAKED, \) and \( ALPHA \) must be defined in parallel under the
keyword ELAS.

9.17.1 Syntax

\[
\text{HOEK\_BROWN} = \_F ( \nonumber \\
\text{\textbullet \ GAMMA\_RUP} = \text{grup,} & [R] \\
\text{\textbullet \ GAMMA\_RES} = \text{sandstone,} & [R] \\
\text{\textbullet \ S\_END} = \text{send,} & [R] \\
\text{\textbullet \ S\_RUP} = \text{srup,} & [R] \\
\text{\textbullet \ M\_END} = \text{mend,} & [R] \\
\text{\textbullet \ M\_RUP} = \text{mrup,} & [R] \\
\text{\textbullet \ BETA} = \text{beta,} & [R] \\
\text{\textbullet \ ALPHAB} = \text{alphahb,} & [R] \\
\text{\textbullet \ PHI\_RUP} = \text{prup,} & [R] \\
\text{\textbullet \ PHI\_RES} = \text{near,} & [R] \\
\text{\textbullet \ PHI\_END} = \text{phiend} )
\]

9.17.2 Operands GAMMA\_RUP/GAMMA\_RES

GAMMA\_RUP = grup
Value of the parameter of work hardening to the rupture of material.
GAMMA\_RES = sandstone
Value of the parameter of work hardening at the beginning of residual resistance.

9.17.3 Operands S\_END/S\_RUP/M\_END/M\_RUP

S\_END = send
Value of the product \( S*SIGMA\_c ** 2 \) attack with the initiation of damage.
S\_RUP = srup
Value of the product \( S*SIGMA\_c ** 2 \) attack in GAMMA\_RUP.
M\_END = mend
Value of the product \( M*SIGMA\_c \) attack with the initiation of damage.
M\_RUP = mrup
Value of the product \( M*SIGMA\_c \) attack in GAMMA\_RUP.

9.17.4 Operand BETA/ALPHAB

BETA = beta
Parameter characterizing the behavior post-rupture of material.
ALPHAB = alphahb
Parameter characterizing the behavior post-rupture of material.

9.17.5 Operand PHI\_RUP/PHI\_RES/PHI\_END

PHI\_RUP = prup
Value of the angle of friction reached in GAMMA\_RUP.
PHI\_RES = near

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Value of the angle of friction reached in \( \text{GAMMA\_RES} \).

\( \text{PHI\_END} = \text{phiend} \)

Value of the angle of friction to the initiation of damage (taken worthless by default).

### 9.18 **Keyword factor ELAS\_GONF**

Law of behavior in rock mechanics allowing to describe the behavior of “inflating” clay materials type (bentonite). This model was developed with the LAEGO. It is about a non-linear elastic model connecting the clear constraint to the pressure of swelling which it even depends on suction (or capillary pressure). It cannot be used within the framework as of behaviors THHM and HHM.

Elastic mechanical characteristics \( E, \text{NAKED}, \) and \( \text{ALPHA} \) must be defined in parallel under the keyword \( \text{ELAS} \).

The law \( \text{ELAS\_GONF} \) is a model of behavior for inflating clays (standard bentonite), it is defined by the relation:

\[
d \tilde{\sigma} = K_0 d \varepsilon_v + b \left( 1 + \frac{s}{A} \right) e^{-\beta_m \left( \frac{s}{A} \right)} ds
\]

with \( \tilde{\sigma} \): clear constraint (trace) \( \sigma = \tilde{\sigma} - p_g \)

In the saturated field:

\[
d \tilde{\sigma} = K_0 d \varepsilon_v - b dp_w + dp_g
\]

Or:

\[
d \tilde{\sigma} = K_0 d \varepsilon_v - b dp_c + (1 - b) dp_g
\]

\( K_0 \) is the module of incompressibility of material

\( b \) is the coefficient of Biot

\( A \) is a homogeneous parameter with a pressure

\( \beta_m \) is a parameter without dimension

\( s \) suction (or capillary pressure)

From there, the identification is done by searching the pressure of swelling.

That is to say \( P_{gf} \) the pressure of swelling expected and is \( P_{gf} (s_0) \) pressure of swelling found by the model when one Re-saturates a sample in a test with blocked deformation and on the basis of a suction \( s_0 \).

It is easy to see that:

\[
\frac{P_{gf} (s_0)}{A} = \frac{\sqrt{\pi}}{2 \sqrt{\beta_m}} \text{Erf} \left( \frac{s_0}{A \sqrt{\beta_m}} \right) + \frac{l}{2 \beta_m} \left( 1 - e^{-\beta_m \left( \frac{s_0}{A} \right)} \right)
\]

One must have \( P_{gf} = P_{gf}^\infty \). It is known that \( \text{Erf} (\infty) = 1 \) and thus:

\[
\frac{P_{gf} (s_0)}{A} = \frac{\sqrt{\pi}}{2 \sqrt{\beta_m}} + \frac{l}{2 \beta_m}
\]

In Aster, the law is programmed in an incremental way in the form:

\[\Delta \tilde{\sigma} = K_0 \Delta \varepsilon_v + b \Delta PG\]

by introducing the function pressure of swelling with of saturated and unsaturated:

\[
PG(P_c) = \begin{cases} 
    A \left( \frac{\sqrt{\pi}}{2 \sqrt{\beta_m}} \right) \text{Erf} \left( \frac{s_0}{A \sqrt{\beta_m}} \right) + \frac{l}{2 \beta_m} \left( 1 - e^{-\beta_m \left( \frac{s_0}{A} \right)} \right) & \text{si } S < 1 \\
    P_c \text{si } S = 1 
\end{cases}
\]
9.18.1 Syntax

```plaintext
| ELAS_CONF = _F (  
  ♦ BETAM = betam,  [R]  
  ♦ PREF = pref  [R]  
),
```

9.18.2 Operand BETAM

Parameter material without dimension corresponding to $\beta_m$ law above. The identification is done by searching the pressure of swelling.

9.18.3 Operand PREF

Homogeneous parameter with a pressure corresponding to $A$ law above.

9.19 Keyword factor JOINT_BANDIS

Law of behavior of a water seal in rock mechanics. In the normal direction with the joint, the behavior is given by

$$
d \sigma' = -K_{ni} \frac{d U}{1 - \frac{U}{U_{max}}}$$

- $\sigma'$ is the normal effective constraint
- $K_{ni}$ is normal initial rigidity
- $U'$ is the closing of crack (opening to null loading minus current opening)
- $U_{max}$ is the asymptotic closing of the crack (with infinite constraint)
- $\gamma$ is a parameter material

In the tangential direction, the behavior is elastic linear

$$
\sigma' = K_t [u_t]
$$

9.19.1 Syntax

```plaintext
| JOINT_BANDIS = _F (  
  ♦ K = K,  [R]  
  ♦ DMAX = dmax,  [R]  
  ♦ GAMMA = gamma,  [R]  
  ◊ KT = /kt,  [R]  
  ◊ /1.E12 [DEFECT]
),
```

9.19.2 Operand K

Normal rigidity with null loading $K_{ni}$ (constraint per unit of length).

9.19.3 Operand DMAX

Asymptotic closing $D_{max}$ (length).

9.19.4 Operand GAMMA

Parameter material $\gamma$ without dimension.
9.19.5 **Operand KT**

Tangential rigidity $K_t$ (constraint per unit of length).

9.20 **Keyword factor THM_RUPT**

Law of behavior for the cracks with hydro-mechanical coupling (see [R7.02.15]).

When the surrounding solid masses the crack are impermeable, the flow is not well any more defined on the elements of nonopen joints. In this case, one replaces the jump of displacement by an opening of fictitious crack $\epsilon_{fict}$ who allows to regularize the flow and to defer to the forefront of crack the boundary condition written at the end of the way of cracking.

One can also define a module of Biot $N$ for the cohesive zone.

9.20.1 **Syntax**

```
| THM_RUPT = _F ( 
  ♦ OUV_FICT = ouv_fict, [R]
  ◊ UN_SUR_N = \(\frac{1}{n}\), \(\frac{0.0}{0.0}\) [DEFECT]
 ),
```

9.20.2 **Operand OUV_FICT**

Fictitious opening of crack $\epsilon_{fict}$ (length).

9.20.3 **Operand UN_SUR_N**

Opposite of the module of Biot of the crack $N$ (constraint per unit of length).

9.21 **Keyword factor Iwan**

Elastoplastic law of behavior in soil mechanics adapted for the cyclic behavior deviatoric. The law of behavior of Iwan [R7.01.38] makes it possible to reproduce the curves of degradation of the modulus of rigidity. The law is gauged starting from the parameters of a hyperbolic model of the form:

$$G = \frac{1}{\left(1 - \frac{\gamma}{\gamma_{ref}}\right)^n}$$

Elastic mechanical characteristics $E$ and NAKED must be defined in parallel under the keyword ELAS.

9.21.1 **Syntax**

```
| Iwan = _F ( 
  ♦ YoungModulus = Young, [R]
  ♦ PoissonRatio = fish, [R]
  ♦ GammaRef = gammaref, [R]
  ♦ N = N [R]
 ),
```

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9.21.2 **Operand YoungModulus**

*Young modulus.*

9.21.3 **Operand PoissonRatio**

Coefficient of Fish.

9.21.4 **Operand GammaRef**

Value of the shearing strain $\gamma_{ij}^2$ hyperbolic law. It is the value for which $G = G_{\text{max}}/2$ in the curve of behavior.

9.21.5 **Operand N**

Exhibitor of the hyperbolic law.

9.22 **Keyword factor LKR**

The model LKR (Laigle, Kleine and Raude) is a law of thermo-élasto behavior (visco) plastic [R7.01.40]. It is based on concepts resulting from the theories of elastoplasticity and viscoplasticity. The plastic mechanism is characterized by a positive in mode pre-peak and negative work hardening in mode post-peak. The temperature influences work hardenings plastic and viscoplastic.

The elastic characteristics must be defined under the keyword ELAS.

The reader will refer to the reference material [R7.01.40] for the significance, the intervals of definition and the values by default (if optional parameter, ◇) of each parameter suitable for the keyword factor LKR whose syntax is detailed in the paragraph 9.22.1.

9.22.1 **Syntax**

```
| LKR = _F ( ◆ Pa            = Pa,            [R]  
 ◆ NELAS         = nelas,         [R]  
◆ SIGMA_C       = sigma_c,        [R]  
◆ BETA          = beta,          [R]  
◆ GAMMA         = gamma,         [R]  
◆ V_1           = v_1,           [R]  
◆ V_2           = v_2,           [R]  
◆ A_2           = a_2,           [R]  
◆ M_0           = m_0,           [R]  
◆ M_1           = m_1,           [R]  
◆ Q_I           = q_i,           [R]  
◆ XI_1          = xi_1,          [R]  
◆ XI_2          = xi_2,          [R]  
◆ XI_5          = xi_5,          [R]  
◆ F_P           = f_p,           [R]  
◆ A             = has,           [R]  
◆ NR             = N,             [R]  
◆ RHO_1         = rho_1,         [R]  
◆ RHO_2         = rho_2,         [R]  
◆ RHO_4         = rho_4,         [R]  
◆ R_Q           = r_q,           [R]  
◆ R_M           = r_m,           [R]  
◆ R_S           = r_s,           [R]  
◆ R_X1          = r_x1,          [R]  
◆ R_X2          = r_x2,          [R]  
◆ R_X5          = r_x5,          [R]  
◆ Z             = Z,             [R]  
◆ COUPLAGE_P_VP = couplage_p_vp, [R]  |
```

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10 Behaviors specific to the elements 1D

10.1 Keyword factor ECRO_ASYM_LINE (cf. [R5.03.09])

It makes it possible to model a behavior with linear isotropic work hardening, but with elastic and different module limits of work hardening in traction and compression. This is used by the model of behavior 1D VMIS_ASYM_LINE, usable for elements of bar.

Elastic behaviour in traction and compression is the same one: even Young modulus.

There are two fields of isotropic work hardening defined by \( R_T \) and \( R_C \). The two fields are independent one of the other. We adopt an index \( T \) for traction and \( C \) for compression.

- \( \sigma_{YT} \): Effort limits in traction. In absolute value.
- \( \sigma_{YC} \): Effort limits in compression. In absolute value.
- \( p_T \): Plastic deformation cumulated in traction. Algebraic value.
- \( p_C \): Plastic deformation cumulated in compression. Algebraic value.
- \( E_{TT} \): Slope of work hardening in traction.
- \( E_{TC} \): Slope of work hardening in compression.

The equations of the model of behavior are:

\[
\begin{align*}
\dot{\varepsilon}^p &= \dot{\varepsilon} - E^{-1} \sigma - \dot{\varepsilon}^{th} \\
\dot{\varepsilon} &= \dot{\varepsilon}^p + \dot{\varepsilon}^p \sigma \\
\dot{\varepsilon}^p &= \dot{p} \left[ \frac{\sigma}{\sigma} \right] \\
\sigma - R_T(p_T) &\leq 0 \\
-\sigma - R_C(p_C) &\leq 0 \\
\end{align*}
\]

avec

- \( \dot{p}_C = 0 \) si \( \sigma - R_C(p_C) < 0 \)
- \( \dot{p}_C = 0 \) si \( \sigma = R_C(p_C) \)
- \( \dot{p}_T = 0 \) si \( \sigma = R_T(p_T) \)
- \( \dot{p}_T = 0 \) si \( \sigma - R_T(p_T) < 0 \)

where:

- \( \dot{\varepsilon}^p \): speed of plastic deformation in compressions,
- \( \dot{\varepsilon}^p \): speed of plastic deformation in traction.
- \( \varepsilon^{th} \): thermal deformation of origin: \( \varepsilon^{th} = \alpha(T - T_{ref}) \cdot \alpha \) is defined under ELAS.

It is noticed that one cannot have simultaneously plasticization in traction and compression: that is to say \( \dot{p}_C = 0 \), that is to say \( \dot{p}_T = 0 \), that is to say both are worthless.

10.1.1 Syntax

```plaintext
| ECRO_ASYM_LINE = _F {
    DT_SIGM_EPSI = RT, [R]
    SY_T = sigmayT, [R]
    DC_SIGM_EPSI = RC, [R]
    SY_C = sigma yC [R]
}
```

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11 Particular behaviors

11.1 Keyword factor LEMAITRE_IRRA

Characteristics (specific to the irradiation) of the creep of the pencils or fuel assemblies (behavior LEMAITRE_IRRA).

The elastic characteristics must be defined under the keyword ELAS or ELAS_FO.

The uniaxial form of the law of growth is:

$$\varepsilon_g(t) = f(T, \Phi_t)$$

where $f$ is a function of the temperature $T$ expressed in °C and of the fluence $\Phi_t$ expressed into $10^{24}$ neutrons/m².

For modelings 2D and 3D, the law of growth is written (confer [R5.03.08]):

$$\varepsilon_g(t) = f(T, \Phi_t) \varepsilon_g^0$$

with: $\varepsilon_g^0 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix}$

One must then define using the operand ANGL_REP keyword SOLID MASS of the operator AFFE_CARA_ELEM local axes corresponding to the reference mark $R_i$ (see [U4.42.01]). This operand expects 3 nautical angles of which one uses only the 2 first (the third can thus be unspecified).

The parameters of growth are provided behind the keyword GRAN_FO.

The four keywords are informed QSR_K, BETA, PHI_ZERO, L (the other parameters of creep are identical to those of the behavior LEMAITRE) and behaviour in creep is then according to:

$$\dot{p} = \sigma_{eq} \left[ \frac{I_1}{p} \right]^{\frac{m}{p}} \left( \frac{L \Phi}{\Phi_0} + L \right) \frac{-Q}{R[T+T_0]} e^{-\frac{-Q}{RT}}$$

where $F$ is the neutron flow calculated starting from the fluence (see [R5.03.08]). $T$ is in °C.

If it is wished that the behavior not depend on the fluence, but comprises the term nevertheless in $e^{-\frac{-Q}{RT}}$, it is possible to use the keyword LEMAITRE_IRRA in STAT_NON_LINE by informing the keyword LEMAITRE_IRRA in DEFI_MATERIAU. It is then necessary imperatively to affect UN_SUR_K, with, B, S to zero and PHI_ZERO with one. Under these conditions, it is not necessary to define a field of fluence.
11.1 Syntax

\[
\text{LEMAITRE_IRRA} = \_F (\)
\begin{align*}
\addprime{\text{NR}} &= \text{N}, & \text{[R]} \\
\addprime{\text{UN\_SUR\_K}} &= 1/K, & \text{[R]} \\
\addprime{\text{UN\_SUR\_M}} &= 1/m, & \text{[R]} \\
\addprime{\text{QSR\_K}} &= Q/R, & \text{[R]} \\
\addprime{\text{BETA}} &= \text{beta}, & \text{[R]} \\
\addprime{\text{PHI\_ZERO}} &= \phi_0, & \text{[R]} \\
\addprime{\text{L}} &= \text{L}, & \text{[R]} \\
\addprime{\text{GRAN\_FO}} &= \text{Fct\_g}, & \text{[function]} \\
\end{align*}
\]

11.2 Keyword factor DIS_GRICRA

This keyword makes it possible to define the parameters associated with the nonlinear behavior with the connection between the grid and the pencil in a fuel assembly modelled by a discrete element (cf [R5.03.17]). The behavior usable in the orders STAT_NON_LINE and DYNA_NON_LINE starting from these parameters is DIS_GRICRA.

The parameters of entry of this law are the following:

- **Behavior in axial slip**: 5 parameters (of which an arbitrary, purely digital parameter):
  1. Normal rigidity of the discrete one \( \text{KN\_AX} \);
  2. Tangential rigidity (in the direction of the slip) \( \text{KT\_AX} \);
  3. Coefficient of friction of Coulomb \( \text{COUL\_AX} \);
  4. Gripping force \( \text{F\_SER} \) (limit of slip = \( \text{COUL\_AX} \times \text{F\_SER} \));
  5. Parameter of work hardening \( \text{ET\_AX} \) (the law of behavior can be comparable to perfect plasticity. The parameter of work hardening is only used to ensure the convergence of calculation; a value by default of \( 10^{-7} \) he is affected);

- **Behaviour in rotation**: 6 parameters (of which a purely digital parameter)
  1. Successive slopes \( \text{PEN1}, \text{PEN2} \) and \( \text{PEN3} \) curve \( \text{Moment} = f(\text{angle}) \);
  2. Angles \( \text{ANG1} \) and \( \text{ANG2} \) points of inflection of the curve;
  3. Parameter of work hardening \( \text{ET\_ROT} \) (parameter being used only to ensure the convergence of calculation; a value by default of \( 10^{-7} \) he is affected).

The gripping forces can vary according to the temperature and from the irradiation. These dependences are affected on the slopes \( \text{PEN1} \) and \( \text{PEN2} \) for behaviour in rotation and on gripping force \( \text{F\_SER} \) for the behavior in axial slip. The functions of dependence are directly defined in the form of one FORMULA in the command file.

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• behavior being pressed on a discrete element with 2 nodes (modeling DIS_TR) with degrees of freedom in translation and rotation
• contact with friction of Coulomb for the degrees of translation, modelled by an elastoplastic model
• nonlinear law of behaviour in rotation based on geometrical and physical considerations (cf [R5.03.17])

Names of the followed parameters by the suffix _FO allow to inform the value in the form of a function.
A certain number of parameters additional, available for this behavior but which do not appear in this document, are clarified in [V6.04.131].

11.2.1 Syntax

```plaintext
| DIS_GRICRA = _F ( % Behavior 'DIS_GRICRA'
  ♦ KN_AX = kn_bossette, [R]
  ♦ KT_AX = kt_bossette, [R]
  ♦ COUL_AX = kt_bossette, [R]
  ♦ F_SER = kt_bossette, [R]
  ◊ F_SER_FO = kt_bossette, [function]
  ◊ ET_AX =/kt_bossette, [R]
  ◊ ET_ROT =/kt_bossette, [R]
  ◊ ET_ANG =/kt_bossette, [R]
  ◊ ET_ANG1 = kn_ressort, [R]
  ◊ ET_ANG2 = kt_ressort, [R]
  ◊ ET_ANG1_FO = mu_bossette, [function]
  ◊ ET_ANG2_FO = mu_ressort, [function]
  ◊ PEN1_FO = gamma_bossette,
  ◊ PEN2_FO = gamma_ressort, [function]
  ◊ PEN3_FO = forc_serrage, [function]
```

11.3 Keyword factor DIS_CONTACT

This keyword makes it possible to define the parameters associated with the behavior DIS_CHOC nonlinear of shock with friction of Coulomb associated with the discrete elements (cf [R5.03.17]) for modelings DIS_T, DIS_TR, 2D_DIS_T, 2D_DIS_TR being pressed on meshes POII or SEG2 (discrete element with 1 or 2 nodes).

11.3.1 Syntax

```plaintext
◊ | DIS_CONTACT = _F ( ◊ RIGI_NOR = kN, [R]
  ◊ RIGI_TAN =/Kt, [R]
  ◊ AMOR_NOR =/Cn, [R]
  ◊ AMOR_TAN =/Ct, [R]
  ◊ COULOMB =/driven, [R]
  ◊ DIST_1 =/dist1, [R]
```

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11.3.2 Operands RIGI_NOR/RIGI_TAN/AMOR_NOR/AMOR_TAN

**RIGI_NOR = kN**

Value of the normal rigidity of shock. If RIGI_NOR is present it is this value which is taken into account. If it is not present, the discrete elements to which one affects this material must have their stiffness defined in addition (for example using the order **AFFE_CARA_ELEM** with the keywords **DISCRETE**, **2D_DISCRET** or **RIGI_PARASOL**).

**RIGI_TAN = Kt**

Value of the tangential rigidity of shock.

**AMOR_NOR = Cn**

Value of the normal damping of shock.

**AMOR_TAN = Ct**

Value of the tangential damping of shock.

11.3.3 Operands COULOMB/DIST_1/DIST_2/JEU

**COULOMB = driven**

Value of the coefficient of friction.

**DIST_1 = dist1**

Distance characteristic of matter surrounding the first node of shock.

**DIST_2 = dist2**

Distance characteristic of matter surrounding the second node of shock (shock between two mobile structures).

**GAME = d0**

Distance enters the node of shock and an obstacle not modelled (case of a shock between a mobile structure and an indeformable and motionless obstacle).

11.4 Keyword factor **DIS_ECRO_CINE**

These parameters of elastoplastic behavior material to nonlinear kinematic work hardening, cf [R5.03.17], are to be used with the discrete elements **2D_DIS_TR, 2D_DIS_T, DIS_TR, DIS_T** (cf operator **AFFE_MODELE** [U4.41.01]). The law is built component by component of the torque of the resulting efforts on the discrete element: there is no coupling between the components of efforts (forces and couples), on which one can define different characteristics; only the diagonal characteristics are affected by the behavior. Elastic stiffness $K_e$ (which is also used for the nonlinear algorithm for the prediction) of this law of behavior is given via the keywords **K_T_D_L, K_TR_D_L, K_T_D_N, K_TR_D_N order AFFE_CARA_ELEM** [U4.42.01]:

The sizes all are expressed in the local reference mark of the element; it is obligatory to specify the keyword **REFERENCE MARK=’LOCAL’** in **AFFE_CARA_ELEM** [U4.42.01]. The orientation of discrete can be done in **AFFE_CARA_ELEM** with the usual rules by using the keyword **ORIENTATION**.

The use of the law of behavior is done in **STAT_NON_LINE** or **DYNA_NON_LINE** under the keyword **BEHAVIOR** [U4.51.11] with **RELATION = ‘DISC_ECRO_CINE’**.
11.4.1 Syntax

\[ \text{◊} | \text{DIS_ECRO_CINE} = \_F ( \text{\_} ) \]

\[ \text{◊} / \text{◊} | \text{LIMY_DX} = \text{fy_dx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{KCIN_DX} = \text{vx_dx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{PUIS_DX} = \text{n_dx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMU_DX} = \text{fu_dx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMY_DY} = \text{fy_dy}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{KCIN_DY} = \text{kx_dy}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{PUIS_DY} = \text{n_dy}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMU_DY} = \text{fu_dy}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMY_DZ} = \text{fy_dz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{KCIN_DZ} = \text{kx_dz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{PUIS_DZ} = \text{n_dz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMU_DZ} = \text{fu_dz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMY_RX} = \text{fy_rx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{KCIN_RX} = \text{kx_rx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{PUIS_RX} = \text{n_rx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMU_RX} = \text{fu_rx}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMY_RY} = \text{fy_ry}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{KCIN_RY} = \text{kx_ry}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{PUIS_RY} = \text{n_ry}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMU_RY} = \text{fu_ry}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMY_RZ} = \text{fy_rz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{KCIN_RZ} = \text{kx_rz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{PUIS_RZ} = \text{n_rz}, \text{[R]} \]
\[ \text{◊} / \text{◊} | \text{LIMU_RZ} = \text{fu_rz}, \text{[R]} \]

11.4.2 Operands

\[ \text{LIMY_DX} = \text{fy_dx}, \text{[R]} \]
\[ \text{F}^y_{\text{x}} : \text{yield stress in the direction of effort} \text{ } \text{x} \]
\[ \text{KCIN_DX} = \text{kx_dx}, \text{[R]} \]
\[ \text{k}_{\text{x}} : \text{“stiffness” of kinematic work hardening in the direction of effort} \text{ } \text{x} \]
\[ \text{PUIS_DX} = \text{n_dx}, \text{[R]} \]
\[ \text{n}_{\text{x}} : \text{power, defining the shape of the monotonous curve in the direction of effort} \text{ } \text{x} \]
\[ \text{LIMU_DX} = \text{fu_dx}, \text{[R]} \]
\[ \text{F}^y_{\text{x}} : \text{kinematic limit of work hardening, defining the plate of the monotonous curve in the direction of effort} \text{ } \text{x} \]

11.5 Keyword factor DIS_VISC

This nonlinear viscoelastic behavior is to be used with the discrete elements (cf [R5.03.17]) 2D_DIS_TR, 2D_DIS_T, DIS_TR, DIS_T (cf operator AFFE_MODELE [U4.41.01]). This behavior affects only the degree of freedom \( dx \) room of the element. The value of the elastic stiffness \( K_x \) (which is also used for the nonlinear algorithm for the prediction) is given via the keywords K_T_D_L, K_TR_D_L, K_T_D_N, K_TR_D_N order AFFE_CARAELEM [U4.42.01].

This viscous law of behavior is usable with the opérateurs STAT_NON_LINE and DYNA_NON_LINE, under the keyword BEHAVIOR [U4.51.11] with RELATION = ‘DIS_VISC’.

The sizes all are expressed in the local reference mark of the element; it is obligatory to specify REFERENCE_MARK = ‘LOCAL’ in AFFE_CARA_ELEM [U4.42.01]. The orientation of discrete can be done in AFFE_CARA_ELEM with the usual rules in utilisant the keyword ORIENTATION.
11.5.1 Syntax

◇ | DIS_VISC = _F ( 
     ◇/ K1 = k1,         [R]
     / UNSUR_K1 = usk1,  [R]
     ◇/ K2 = k2,         [R]
     / UNSUR_K2 = usk2,  [R]
     ◇/ K3 = k3,         [R]
     / UNSUR_K3 = usk3,  [R]
     ◇ C = C,           [R]
     ◇ PUIS_ALPHA = alpha, [R]
 )

11.5.2 Operands

The behavior DIS_VISC is a nonlinear viscoelastic rheological behavior, of type Zener extended, allowing to schematize the behavior of a uniaxial shock absorber, applicable to axial degree of freedom of the discrete elements with two nodes (mesh SEG2) or and of the discrete elements to a node (mesh POI1).

For the local direction \( x \) (and only that one) of the discrete element, one provides 5 coefficients. Their units must be in agreement with the unit of the efforts, the unit lengths and the unit of time of the problem.
- \( K1 \): elastic stiffness of element 1 of the rheological model,
- \( K2 \): elastic stiffness of element 2 of the rheological model,
- \( K3 \): elastic stiffness of element 3 of the rheological model,
- \( UNSUR_K1 \): elastic flexibility of element 1 of the rheological model,
- \( UNSUR_K2 \): elastic flexibility of element 2 of the rheological model,
- \( UNSUR_K3 \): elastic flexibility of element 3 of the rheological model,
- \( PUIS_ALPHA \): power of the viscous behavior of the element \( \alpha \)
- \( C \): coefficient of the viscous behavior of the element.

The conditions to respect for these coefficients are (in particular to ensure the positivity and the finitude of the tangent matrix):
\[
E_1 \geq 10^{-8} \quad ; \quad 1/E_1 \geq 0 \quad ; \quad E_2 \geq 10^{-8} \quad ; \quad 1/E_3 \geq 0 \quad ; \quad 1/E_2 \geq 10^{-8} \quad ; \quad E_2 \geq 0 \quad ; \quad C \geq 10^{-8} \quad ; \\
10^{-8} \leq \alpha \leq 1
\]

Moreover, one cannot have at the same time: \( 1/E_1 = 0 \), \( 1/E_3 = 0 \) and \( E_2 = 0 \) i.e. the case of the shock absorber alone.
11.6 Keyword factor DIS_ECRO_TRAC

The behavior DIS_ECRO_TRAC is a nonlinear behavior, allowing to schematize the behavior of a uniaxial device, only according to the degree of freedom $\text{DX}$ room of the discrete elements with two nodes (mesh SEG2) or of the discrete elements to a node (mesh POI1).

The non-linear behavior is given by a curve $F_x = f(\Delta u_x)$:
- for one SEG2, $\Delta u_x$ represent the relative displacement of the 2 nodes in the local reference mark of the element.
- for one POI1, $\Delta u_x$ represent the absolute displacement of the node in the local reference mark of the element.
- for one SEG2 or one POI1, $F_x$ represent the effort expressed in the local reference mark of the element.

This law of behavior is usable with the opérateurs STAT_NON_LINE and DYNA_NON_LINE, under the keyword BEHAVIOR [U4.51.11] with RELATION = 'DIS_ECRO_TRAC'.

The sizes all are expressed in the local reference mark of the element. The orientation of discrete can be done in AFFE_CARA_ELEM with the usual rules in utilissuant the keyword ORIENTATION.

11.6.1 Syntax

◊ | DIS_ECRO_TRAC = _F (
   ◊ | / FX = fx,
   ◊ | )

11.6.2 FX operand

The only data necessary is the function describing the non-linear behavior. This function must respect the criteria according to:
- It is a function within the meaning of Code_Aster: defined with the operator DEFI_FONCTION,
- The interpolations on the ordinate and x-axes are linear,
- The name of the X-coordinate at the time of the definition of the function is $\text{DX}$,
- The prolongations on the left and on the right of the function are excluded,
- The function must be defined by at least 3 points,
- The first point is $(0.0,0.0)$ and must be given,
- The function must be strictly increasing.
- The derivative of the function must be lower or equal to its derivative to the point $(0.0,0.0)$.

Examples of definition of the function:

$\text{LesX} = (0.0, 0.2, 0.3)$
$\text{LesY} = (0.0, 500.0, 800.0)$

```plaintext
fctsy1 = DEFI_FONCTION ( NOM_PARA= 'DX',
   X-COORDINATE = LesX,
   ORDINATE = LesY,
 )
```

```plaintext
fctsy2 = DEFI_FONCTION ( NOM_PARA= 'DX',
   VALE = (0.0, 0.0, 0.2, 500.0, 0.3, 800.0 ),
 )
```

The first two points of the function make it possible to define the elastic slope in the behavior. The units of the X-coordinates and the ordinates must be coherent with those of the problem:
- The unit of the X-coordinates must be homogeneous with displacements,
- The unit of the function must be homogeneous with efforts.
11.7  **Keyword factor DIS_BILI_ELAS**

This key word Factor allows to assign a bilinear elastic behavior to the discrete ones in the 3 directions of translation.

This behavior is to be used with the discrete elements (cf [R5.03.17]), 2D_DIS_T, DIS_T (cf operator AFFE_MODELE [U4.41.01]). The law is built component by component, it thus does not have there coupling between the components of efforts, on which one can define different characteristics; only the diagonal characteristics are affected by the behavior. The value of the elastic stiffness $K_e$ (which is used only for the nonlinear algorithm for the prediction) of this law of behavior is given via the keywords K_T_D_L, K_T_D_N order AFFE_CARAREL [U4.42.01].

This law of behavior is usable with the operators STAT_NON_LINE and DYNA_NON_LINE, under the keyword BEHAVIOR [U4.51.11] with RELATION = ‘DISC_BILI_ELAS’.

The sizes all are expressed in the local reference mark of the element. The orientation of discrete can be done in the order AFFE_CARAREL with the usual rules by using the keyword ORIENTATION.

**11.7.1 Syntax**

```
| DIS_BILI_ELAS =  _F ( 
  0/   KDEB_DX = k1_dx, [function]  
  *   KFIN_DX = k2_dx,  
  *   FPRE_DX = Fp_dx,  [ R ] 
  0/   KDEB_DY = k1_dy, [function]  
  *   KFIN_DY = k2_dy,  
  *   FPRE_DY = Fp_dy,  [ R ] 
  0/   KDEB_DZ = k1_dz, [function]  
  *   KFIN_DZ = k2_dz,  
  *   FPRE_DZ = Fp_dz,  [ R ] 
) 
```

**11.7.2 Operands**

The law of behavior is bilinear rubber band and requires 3 characteristics. The units of the characteristics must be in agreement with those of the analyzed problem: $k_1$ and $k_2$ are homogeneous with a force by displacement, $F_p$ is homogeneous with a force.
The effort which defines the transition between the 2 linear behaviors.

11.8 **Keyword factor ASSE_CORN**

Description of the characteristics material associated with the behavior with a bolted assembly [R5.03.32].

11.8.1 **Syntax**

```
| ASSE_CORN = _F ( 
  ♦ NU_1 = nu1, [R] 
  ♦ MU_1 = mu1, [R] 
  ♦ DXU_1 = dxu1, [R] 
  ♦ DRYU_1 = dryu1, [R] 
  ♦ C_1 = c1, [R] 
  ♦ NU_2 = nu2, [R] 
  ♦ MU_2 = mu2, [R] 
  ♦ DXU_2 = dxu2, [R] 
  ♦ DRYU_2 = dryu2, [R] 
  ♦ C_2 = c2, [R] 
  ♦ KY = ky, [R] 
  ♦ KZ = kz, [R] 
  ♦ KRX = krx, [R] 
  ♦ KRZ = krz, [R] 
  ◊ R_P0 = /rp0, /1.E-4 
 )
```

11.8.2 **Operands**

On the following figure, the plan \( \pi \) represent the plan of the assembly. The axis of the bolts is perpendicular to this plan. The reader will refer to [U4.42.01] **AFFE_CARA_ELEM** for the orientation of the reference mark \( R_L \) defining the plan of the assembly.

The relation of behaviour of the assembly is:
- non-linear in translation according to \( x \) and in rotation around \( y \).
- linear according to the other degrees of freedom: \( D_Y, D_Z, D_RX, D_RZ \)
Behaviours in traction along the axis $x$ and in rotation around the axis $y$.

The behavior of the connection is considered linear in the other directions:
- $KY$: stiffness in translation according to $Y$
- $KZ$: stiffness in translation according to $Z$
- $KRX$: stiffness in rotation around $X$
- $KRZ$: stiffness in rotation around $Z$
- $R\_P0$: Slope in the beginning or of discharge

11.9 **Keyword factor WEAPON**

Description of the characteristics material associated with the behavior with an armament with airline. The arm of each armament of broken phase, represented by a discrete element, has a non-linear behavior forces of it - displacement consisted the difference between maximum displacement $dlp$ end of the armament in the plastic phase and limiting elastic displacement $dle$.

11.9.1 **Syntax**

```plaintext
| WEAPON = _F (  
  ♦ KYE = kye,  [R]  
  ♦ DLE = dle,  [R]  
  ♦ KYP = kyp,  [R]  
  ♦ DLP = dlp,  [R]  
  ♦ KYG = kyg  [R]  
```

11.9.2 **Operands** $KYE/DLE$

- **KYE** = kye
  Elastic slope until a limiting effort.
- **DLE** = dle
  Displacement limits elastic strain.

11.9.3 **Operand** $KYP/DLP$

- **KYP** = kyp
  Plastic slope until limiting displacement $DLP$.
- **DLP** = dlp
  Displacement limits plastic deformation 0.

11.9.4 **Operand** $KYG$

- **KYG** = kyg
  Slope of discharge.
11.10 Keyword factor CABLE_GAINE_FROT

This material relates to only the elements CABLE_GAINE. It makes it possible to define the behavior of friction enters a cable and its sheath or between a cable and the neighbouring concrete. It is possible to consider a slipping, rubbing cable or member. For its use, to see the behavior KIT.CG in U4.51.11.

11.10.1 Syntax

```plaintext
| CABLE_GAINE_FROT = _F (   
  ♦ TYPE = '/SLIPPING ', 
     '/RUBBING ', [TXM]
  ♦ PENAL_LAGR = PEN, [R] 
  # if TYPE='FROTANT': 
  ♦ FROT_LINE = fl , [R] 
     = 0.d0, [DEFECT] 
  ♦ FROT_COURB= FC , [R] 
     = 0.d0, [DEFECT] 
)
```

11.10.2 Operands TYPE

♦ TYPE = '/SLIPPING ',
   '/RUBBING ',
   '/MEMBER', [TXM]

This operand makes it possible to determine whether it is about a cable slipping, rubbing or adherent.

11.10.3 Operand PENAL_LAGR

♦ PENAL_LAGR = PEN,

This operand defines the coefficient of penalization to be taken into account. (See R3.08.10, §6.1 for more details).

11.10.4 Operands FROT_LINE and FROT_COURB

♦ FROT_LINE = fl ,
  Rectilinear coefficient of friction.

♦ FROT_COURB= FC ,
  Curved coefficient of friction.

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12 Fluid behavior

12.1 Keyword factor FLUID

Definitions of the constant characteristics of fluid.

12.1.1 Syntax

\[
\text{FLUID} = _F \left( \begin{array}{c}
\bullet \text{RHO} = \rho, \\
\diamond \text{CELE\_R} = \text{celr}, \\
\diamond \text{CELE\_C} = \text{celc}, \\
\diamond \text{PESA\_Z} = \text{pz},
\end{array} \right) [R]
\]

12.1.2 Operand RHO

\[
\text{RHO} = \rho
\]

Density of the fluid. No the checking.

12.1.3 Operands CELE\_R/CELE\_C

\[
\text{CELE\_R} = \text{celr}
\]
Celerity of propagation acoustic waves in the fluid environment (standard reality).
Pas de checking of about size.

\[
\text{CELE\_C} = \text{celc}
\]
Celerity of propagation acoustic waves in the fluid environment (standard complex in particular for a porous environment). No the checking of about size.

For a modeling in \text{PHENOMENON: ACOUSTICS} (order \text{AFFE\_MODELE [U4.41.01]}) only the definition of celerity using the keyword \text{CELE\_C} is valid.

The definition using the keyword \text{CELE\_R} conduit with a stop in error.

Note: when one uses modeling of a fluid type (3D\_FLUIDE for example) and that one puts RHO=0. and CELE\_R=0., one obtains matrices of really worthless mass and rigidity by \text{CALC\_MATR\_ELEM}.
(see [R4.02.02]).

12.1.4 Operand PESA\_Z

\[
\text{PESA\_Z} = \text{pz},
\]
Acceleration of gravity according to z, only used and obligatory if the modeling chosen in \text{AFFE\_MODELE is 2D\_FLUI\_PESA}.
13 Data matériaux associated with postprocessings

13.1 Keyword factor TIREDNESS

One will be able to refer to [R7.04.01] and [R7.04.03].

13.1.1 Syntax

```plaintext
| TIREDNESS = _F (  
|   /◊ WOHLER = f_wohl,  [function] 
|   /◊ A_BASQUIN = With,      [R] 
|   ◊ BETA_BASQUIN = beta,    [R] 
|   ◊ A0     = a0,            [R] 
|   ◊ A1     = a1,            [R] 
|   ◊ A2     = a2,            [R] 
|   ◊ A3     = a3,            [R] 
|   ◊ SL     = SL,            [R] 
|   ◊ MANSON_COFFIN = f_mans, [function] 
|   ◊ E_REFE = EC,            [R] 
|   ◊ D0     = d0,            [R] 
|   ◊ TAU0   = tau0,          [R] 
) 
```

13.1.2 Operand WOHLER

This operand makes it possible to introduce the curve of Wöhler of material in a point by point discretized form. This function gives the number of cycles to the rupture \( N_{rupt} \) according to the half-amplitude of constraint \( \frac{\Delta \sigma}{2} \).

The curve of Wöhler is a function for which the user chooses the mode of interpolation:

- **LOG LOG**: interpolation logarithmic curve on the number of cycles to the rupture and on the half-amplitude of the constraint (formula of Basquin per pieces),
- **LIN LIN**: linear interpolation on the number of cycles to the rupture and on the half-amplitude of the constraint (this interpolation is disadvised because the curve of Wöhler is absolutely not linear in this reference mark),
- **FLAX LOG**: interpolation into linear on the half-amplitude of constraint, and logarithmic curve on the number of cycles to the rupture, which corresponds to the expression given by Wöhler.

The user must also choose the type of prolongation of the function on the right and on the left.

13.1.3 Operands A_BASQUIN / BETA_BASQUIN

```plaintext
A_BASQUIN = A 
BETA_BASQUIN = beta 
```

These operands make it possible to introduce the curve of Wöhler of material in the analytical form of BASQUIN [R7.04.01].

\[
D = A Salt^\beta \quad \text{where} \quad A \quad \text{and} \quad \beta \quad \text{are two constants of material,}
\]

\[
Salt = \text{alternate constraint of the cycle} = \frac{\Delta \sigma}{2} \quad \text{and} \quad D \quad \text{elementary damage.}
\]
13.1.4 Operands A0 / A1 / A2 / A3 / SL

A0 = a0, A1 = a1, A2 = a2, A3 = a3, SL = SL

These operands make it possible to define in analytical form the curve of Wöhler in “current zone” [R7.04.01].

\[ Salt = \text{alternate constraint} = \frac{1}{2} \frac{E_c}{E} \Delta \sigma \]

\[ X = \log_{10}(Salt) \]

\[ N_{rupt} = 10^{a0 + a1x + a2x^2 + a3x^3} \]

\[ D = \begin{cases} 1/N & \text{si } Salt \geq SL \\ 0 & \text{sinon} \end{cases} \]

This list of operands makes it possible to introduce the various parameters of this analytical form.

\( a0, a1, a2, \) and \( a3 \) constantS of material,

\( SL \) limit of endurance of material.

The Young modulus \( E \) is introduced into DEFI_MATERIAU (keyword factor ELAS operand \( E \)).

The value of \( E_c \), Young modulus associated with the curve with tiredness with material is also introduced into DEFI_MATERIAU under the keyword factor TIREDNESS, operand E_REFE.

13.1.5 Operand MANSON_COFFIN

MANSON_COFFIN = f_mans

This operand makes it possible to introduce the curve of Manson-Whetstone sheath of material in a point by point discretized form. This function gives the number of cycles to the rupture according to the half-amplitude of deformations \( \frac{\Delta \varepsilon}{2} \).

13.1.6 Operand E_REFE

E_REFE = EC

This operand makes it possible to specify the value of the Young modulus associated with the curve with tiredness with material. This value allows amongst other things, to define the curve of Wöhler in “current zone” [R7.04.01].

13.1.7 Operands D0/TAU0

D0 = d0

Allows to specify the value of the limit of endurance in alternate pure traction and compression. This value is used in the calculation of the criteria of Crossland and Dang Van Papadopoulos [R7.04.01] by the order of POST_FATIGUE [U4.83.01].

TAU0 = tau0

Allows to specify the value of the limit of endurance in alternate pure shearing. This value is used in the calculation of the criteria of Crossland and Dang Van Papadopoulos [R7.04.01] by the order of POST_FATIGUE [U4.83.01].
13.2 **Keyword factor DOMMA_LEMAITRE**

Under this keyword factor are gathered all the characteristics material necessary to the calculation of the damage of Lemaitre and the law of Lemaitre-Sermage (option ENDO_ELGA of CALC_CHAMP, [U4.81.04]).

13.2.1 **Syntax**

| DOMMA_LEMAITRE = _F (  
| ♦ S = S, [function]  
| ♦ EPSP_SEUIL = Pseuil, [function]  
| ◊ EXP_S = Pd, [R] / 1.0 [DEFECT]  
| )

13.2.2 **Operand S**

S = S

S is a parameter material necessary to the calculation of the damage of Lemaitre. S must be a function of the parameter TEMP.

13.2.3 **Operand EPSP_SEUIL**

EPSP_SEUIL = Pseuil

Allows to specify the value of the threshold of damage pd, necessary to the calculation of the damage of Lemaitre.

13.2.4 **Operand EXP_S**

EXP_S = Pd

Allows to define the law of Lemaitre-Sermage, the value by default (1.0) corresponds to the calculation of the damage of Lemaitre.

13.3 **Keyword factor CISA_PLAN_CRIT**

Under this keyword factor are gathered all the characteristics material necessary to the implementation of the criteria with critical plans [R7.04.04].

13.3.1 **Syntax**

◊ | CISA_PLAN_CRIT = _F (  
| ♦ CRITERION = ‘MATAKE_MODI_AC’, [TXM]  
| /’ DANG_VAN_MODI_AC ’, [TXM]  
| /’ MATAKE_MODI_AV’, [TXM]  
| /’ DANG_VAN_MODI_AV’, [TXM]  
| /’ FATESOCI_MODI_AV’, [TXM]  
|  
| #SI CRITERION == ‘MATAKE_MODI_AC’ OR ‘MATAKE_MODI_AV’:  
| ♦ MATAKE_A = has, [R]  
| ♦ MATAKE_B = B, [R]  
| ♦ COEF_FLEX_TORS = c_flex_tors, [R]  
|  
| #FinSi  

#SI CRITERION == ‘DANG_VAN_MODI_AC’ OR ‘DANG_VAN_MODI_AV’:  
| ♦ D_VAN_A = has, [R]  
| ♦ D_VAN_B = B, [R]  
| ♦ COEF_CISA_TRAC = c_cisa_trac, [R]  

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### 13.3.2 Operand MATAKE_A

MATAKE_A = has,

Allows to specify the value of the coefficient without dimension $a$, present in the criteria MATAKE_MODI_AC and MATAKE_MODI_AV, confer [R7.04.01] and [U4.83.02].

### 13.3.3 Operand MATAKE_B

MATAKE_B = B,

Allows to specify the value of the coefficient $b$, present in the criteria MATAKE_MODI_AC and MATAKE_MODI_AV, confer [R7.04.01] and [U4.83.02].

### 13.3.4 Operand COEF_FLEX_TORS

COEF_FLEX_TORS = c_flex_tors,

Allows to specify the value of the coefficient without dimension $a$, present in the criteria MATAKE_MODI_AC and MATAKE_MODI_AV, confer [R7.04.01] and [U4.83.02]. This value must be higher or equal to one and lower or equal to $\sqrt{3}$. This operand is to be used in the criteria: MATAKE_MODI_AC and MATAKE_MODI_AV.

### 13.3.5 Operand D_VAN_A

D_VAN_A = has,

Allows to specify the value of the coefficient without dimension $a$, present in the criteria DANG_VAN_MODI_AC and DANG_VAN_MODI_AV, confer [R7.04.01] and [U4.83.02].

### 13.3.6 Operand D_VAN_B

D_VAN_B = B,

Allows to specify the value of the coefficient $b$, present in the criteria DANG_VAN_MODI_AC and DANG_VAN_MODI_AV, confer [R7.04.01] and [U4.83.02].

### 13.3.7 Operand COEF_CISA_TRAC

COEF_CISA_TRAC = c_cisa_trac,

Allows to specify the value of the coefficient without dimension $a$, present in the criteria DANG_VAN_MODI_AC, DANG_VAN_MODI_AV and FATESOCI_MODI_AV, confer [R7.04.01] and [U4.83.02]. This value must be higher or equal to one and lower or equal to $\sqrt{3}$. This operand is to be used in the criteria: DANG_VAN_MODI_AC, DANG_VAN_MODI_AV and FATESOCI_MODI_AV, confer [R7.04.01] and [U4.83.02].

### 13.3.8 Operand FATSOC_A

FATSOC_A = has,

Allows to specify the value of the coefficient $a$, present in the criterion FATESOCI_MODI_AV, confer [R7.04.01] and [U4.83.02].
13.4 Keyword factor WEIBULL, WEIBULL_FO

Definition of the coefficients of the model of Weibull [R7.02.06].
Briefly, probability of cumulated rupture of rupture $P_r$ of a structure is written, in the case of a monotonous loading:

$$P_r = 1 - \exp \left[ - \sum_{V_p} \left( \frac{\sigma_{V_p}}{\sigma_u} \right)^m \right]$$

where the summation relates to the meshes $V_p$ plasticized (i.e. cumulated plastic deformation higher than a value chosen arbitrarily $p_s$) and $m, \sigma_u, V_0$ are the parameters of the model of Weibull.

In the case of an unspecified way of loading:

$$P_r(t) = 1 - \exp \left[ - \left( \frac{\sigma_{V_p}}{\sigma_u} \right)^m \right]$$

with:

$$\sigma_{V_p} = \sum_{V} \max_{\nu < r, \rho(u) > \theta} \left| \tilde{\sigma}_I(u) \right|^m \frac{V}{V_0},$$

$p$ indicating the rate of cumulated plastic deformation, $\tilde{\sigma}_I$ the greatest principal constraint at the moment $t$ [R7.02.06].

Lastly, if the constraint of cleavage depends on the temperature (WEIBULL_FO):

$$P_r(t) = 1 - \exp \left[ - \left( \frac{\sigma_{V_p}}{\sigma_u} \right)^m \right]$$

$\sigma_{V_p}$ indicating the constraint of Weibull defined conventionally for $\sigma_u^0$ data:

$$\sigma_{V_p}^0 = \sum_{V} \max_{\nu < r, \rho(u) > \theta} \left[ \frac{\sigma_{\nu, \sigma_I(u)}}{\sigma_{V_p}} \right]^m \frac{V}{V_0} A^\theta,$$

$\theta(u)$ indicating the temperature in the element $\delta V$.

13.4.1 Syntax

```plaintext
| / WEIBULL = _F { 
  ♦ M = m, [R] 
  ♦ SIGM_REFE = sigmu, [R] 
  ♦ VOLU_REFE = V0, [R] 
  ◊ SEUIL_EPSP_CUMU = /ps, [R] 
    /10-6 [DEFECT] 
} 

/ WEIBULL_FO = _F { 
  ♦ M = m, [R] 
  ♦ SIGM_REFE = sigmu, [function] 
  ♦ SIGM_CNV = sigm0u, [R] 
  ♦ VOLU_REFE = V0, [R] 
  ◊ SEUIL_EPSP_CUMU = /ps, [R] 
    /10-6, [DEFECT] 
}
```

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13.4.2 Operands

\[ M = m, \text{SIGM\_REFE} = \text{sigmU}, \text{SIGM\_CNV} = \text{sigm0u}, \text{VOLU\_REFE} = V0 \]

Parameters associated with the model with Weibull.

\[ \text{SEUIL\_EPS\_CUMU} = PS \]

Cumulated plastic deformation threshold.

13.5 Keywords factor RCCM, RCCM_FO

Definition of the sizes necessary to the use of the methods simplified defined in regulation RCC-M [R7.04.03]. These sizes are constant or function of the parameter ‘TEMP’.

13.5.1 Syntax

\[
\text{RCCM} = \_F ( \\
\quad \text{SY\_02} = sy, [R] \\
\quad \text{SM} = Sm, [R] \\
\quad \text{KNOWN} = \text{known}, [R] \\
\quad \text{SC} = Sc, [R] \\
\quad \text{HS} = HS, [R] \\
\quad \text{N\_KE} = H, [R] \\
\quad \text{M\_KE} = m, [R] \\
\quad \text{A\_AMORC} = \text{has}, [R] \\
\quad \text{B\_AMORC} = B, [R] \\
\quad \text{D\_AMORC} = D, [R] \\
\quad \text{R\_AMORC} = R, [R] \\
\)
\]

\[
\text{RCCM\_FO} = \_F ( \\
\quad \text{SY\_02} = sy, \text{[function]} \\
\quad \text{SM} = Sm, \text{[function]} \\
\quad \text{KNOWN} = \text{known}, \text{[function]} \\
\quad \text{S} = S, \text{[function]} \\
\quad \text{HS} = HS, \text{[function]} \\
\quad \text{N\_KE} = H, \text{[function]} \\
\quad \text{M\_KE} = m, \text{[function]} \\
\quad \text{A\_AMORC} = \text{has}, \text{[function]} \\
\quad \text{B\_AMORC} = B, \text{[function]} \\
\quad \text{D\_AMORC} = D, \text{[function]} \\
\quad \text{R\_AMORC} = R, \text{[function]} \\
\)
\]

13.5.2 Operand SY\_02

\[ \text{SY\_02} = sy \]

Limit elastic with 0.2% of plastic deformation at the temperature of calculation. This operand can vary according to the temperature.

13.5.3 Operands SM/SU/SH

\[ \text{SM} = Sm \]

Acceptable constraint equivalent of material to the temperature of calculation. This operand can vary according to the temperature.

\[ \text{KNOWN} = \text{known} \]

Tensile strength of material at the temperature of calculation. This operand can vary according to the temperature.

\[ \text{HS} = HS \]
13.5.4 Operand SC
\[
SC = Sc
\]
Working stress of material to the room temperature, confer POST_RCCM [U4.83.11]

13.5.5 Operand S
\[
S = S
\]
Working stress of material. This operand varies according to the temperature, confer POST_RCCM [U4.83.11].

13.5.6 Operands N_KE/M_KE
\[
N_KE = N, \quad M_KE = m
\]
These operands make it possible to define the values of \( n \) and \( m \) two constants of material.

These characteristics are necessary for the calculation of the elastoplastic coefficient of concentration \( K_e \), which is defined by the RCC-M as being the relationship between the amplitude of real deformation and the amplitude of deformation determined by the elastic analysis.

\[
\begin{align*}
K_e &= 1 & \text{si} & \Delta \sigma \leq 3 S_m \\
K_e &= 1 + (1 - n) \left( \frac{\Delta \sigma}{3 S_m} - 1 \right) \left( n(m - 1) \right) & \text{si} & 3 S_m < \Delta \sigma \leq 3 S_m \\
K_e &= \frac{1}{n} & \text{si} & 3 m S_m \leq \Delta \sigma
\end{align*}
\]

13.5.7 Operands A_AMORC/B_AMORC
\[
A_{AMORC} = \text{has}, \quad B_{AMORC} = B
\]
Coefficients of the law of starting.

13.5.8 Operand D_AMORC
\[
D_{AMORC} = D
\]
Distance from extraction of the constraints.

13.5.9 Operand R_AMORC
\[
R_{AMORC} = R
\]
Parameter of the relation between constraint and effective constraint.

13.6 Keyword factor CRIT_RUPT
Definition of the quantities necessary to the criterion of rupture in critical stress implemented by the keyword POST_ITER/CRIT_RUPT under BEHAVIOR. If the greatest average principal constraint in an element exceeds a given threshold \( \text{sigc} \), the Young modulus is divided by the coefficient \( \text{coeff} \).

This criterion is available for the laws of behavior VISCOCHAB, VMIS_ISOT_TRAC (_LINE) and VISC_ISOT_TRAC (_LINE), and validated by the tests SSNV226A, B, C.
13.6.1 Syntax

\[
\text{CRIT RUPT} = \_F ( \Diamond \text{SIGM} \_C = \text{sigc}, \quad [R] \\
\Diamond \text{COEFF} = \text{coeff}, \quad [R])
\]

Operands SIGM\_C, COEFF
Value of the constraint threshold \text{sigc} (in unit of constraints) and of the coefficient \text{coeff} (without unit).

13.7 Keyword factor REST\_ECRO

Definition of the data necessary to the taking into account of the phenomenon of restoration of work hardening implemented by the keyword \text{POST INCR/’REST ECRO’} under BEHAVIOR. At the end of each step of computing time, the variables of work hardenings are multiplied by the function \text{foncmult}, with actual values in [0.1], and which depends on the temperature and possibly on time. This criterion is available for the laws of behavior \text{VMIS ISOT TRAC ( LINE), VMIS CINE LINE, VMIS ECM1 LINE, VMIS CIN1 CHAB and VMIS CIN2 CHAB}, and for modelings 3D, AXIS, D\_PLAN and C\_PLAN.

13.7.1 Syntax

\[
\text{REST ECRO} = \_F ( \Diamond \text{FONC\_MULT} = \text{foncmult}, \quad \text{[function]} \n\]

13.7.2 Operand FONC\_MULT
Parameters of restoration of work hardening defined in the function \text{foncmult} (without unité).

13.8 Keyword factor VERI\_BORNE

This keyword allows a checking of the field of validity of the parameters of a law of behavior. Indeed, the identification of the parameters of these laws is always made in a certain range of deformation and temperature. objective the user in his study it is to so inform leaves this field where the parameters were identified. These terminals are defined under the keyword \text{VERI BORNE}. The going beyond the terminals during calculation, results in emission of an alarm.

13.8.1 Syntax

\[
\text{VERI BORNE} = \_F ( \Diamond \text{EPSI MAXI} = \text{epsi} \quad [R] \\
\Diamond \text{VEPS MAXI} = \text{veps}, \quad [R] \\
\Diamond \text{TEMP MINI} = \text{tmin}, \quad [R] \\
\Diamond \text{TEMP MAXI} = \text{tmax}, \quad [R])
\]

13.8.2 Operands
Value of S terminals in terms of maximum total deflection, speed of deformation, and temperatures extreme.

13.9 Keywords factor MFRONT, MFRONT\_FO

Definition of the parameters relative to a law of behavior “user” defined in the formalism MFront [U2.10.02]. These sizes are constant or function of the parameter ‘TEMP’. It is possible to provide up to 197 parameters.
13.9.1 Syntax

|   | / MFRONT = _F ( ♦ LISTE_COEF = (c1, c2,...) [l_R] ) |
|   | / MFRONT_FO = _F ( ♦ LISTE_COEF = (c1, c2,...) [l_fonction] ) |

13.10 Keywords factor UMAT, UMAT_FO

Definition of the parameters relative to a law of behavior “user”, i.e. whose routine of integration of the behavior is provided by the user [U2.10.01]. These sizes are constant or function of the parameter 'TEMP'. It is possible to provide up to 197 parameters.

13.10.1 Syntax

|   | / UMAT = _F ( ♦ LISTE_COEF = (c1, c2,...) [l_R] ) |
|   | / UMAT_FO = _F ( ♦ LISTE_COEF = (c1, c2,...) [l_fonction] ) |

14 Simple keyword MATER

The order DEFI_MATERIAU can be D-entering but each behavior remains single. One does not allow indeed to replace a behavior already present in material but only to enrich the structure of data by additional characteristics material.

Example of use:
Only the characteristics thermics of material are initially defined. Then, after the thermal resolution, one adds the mechanical properties under ELAS:

ACIER_TH=DEFI_MATERIAU ( THER=_F ( LAMBDA=54.6, RHO_CP=3710000.0),);

CHM=AFFE_MATERIAU ( MAILLAGE=MAIL, AFFE=_F ( TOUT=' OUI', MATER=ACIER_TH, TEMP_REF=20.0),);

... TEMPE= THER_LINEAIRE ( MODELE=MODETH,...

... ACIER_TH=DEFI_MATERIAU ( reuse=ACIER_TH, MATER=ACIER_TH, ELAS=_F ( E=204000000000.0, NU=0.3, ALPHA=1.092e-05),);

RESULT=MEECA_STATIQUE (MODELE=MODMEECA,...