Opérateur DEFI_MATERIAU

1 Drank

Définir the behavior of a material or the parameters associated with fatigue, the damage, or the simplified methods.

The allowed constitutive laws currently by this operator relate to the following fields: **Linear** mechanics **and** Thermal or not, **Métallurgique** for the modelization of steels, **Hydratation** and **Séchage** for the concretes, **Fluid** for the acoustics, **Thermo-Hydro-Mechanics** for the modelization of the porous environments saturated with thermomechanical coupled and **the Mechanics with Sols**.

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

Produit a data structure of the type MATER

Table des Matières

2 MATER142 Syntaxe

```
my [subdue] =DEFI_MATERIAU     (

       reuse = chechmate,       [subdue]
       MATER = chechmate,       [subdue]

             # Comportement Elastics Généraux [§ 3]
                 |   /ELAS  ,                          #voir  [§ 3.1]
                     /ELAS_FO  ,
                     /ELAS_FLUI   ,                   #voir  [§ 3.2]
                 |   CABLE,                           #voir  [§ 3.3]
                 |   /  ELAS_ORTH,                    #voir  [§ 3.4]
                     /ELAS_ORTH_FO,
                 |   /ELAS_ISTR   ,                   #voir  [§ 3.5]
                     /ELAS_ISTR_FO,
                 |   /ELAS_COQUE  ,                   #voir  [§ 3.6]
                     /ELAS_COQUE_FO   ,
                 |   /ELAS_MEMBRANE   ,               #voir  [§ 3.7]
                 |   /  ELAS_HYPER,                   #voir  [§ 3.8]
                 |   /  ELAS_2NDG,                    #voir  [§ 3.9]


             # General Nonlinear Mechanical Behaviors [§ 4]


                 |   TENSION,                         #voir  [§ 4.1]
                 |   /  ECRO_LINE,                    #voir  [§ 4.2]
                     /ECRO_LINE_FO,
                 |   /  PRAGER,                       #voir  [§ 4.3]
                     /PRAGER_FO   ,
                 |   /  ECRO_PUIS,                    #voir  [§ 4.4]
                     /ECRO_PUIS_FO,
                 |   /  CIN1_CHAB,                    #voir  [§ 4.5]
                     /CIN1_CHAB_FO,
                 |   /  CIN2_CHAB,                    #voir  [§ 4.6]
                     /CIN2_CHAB_FO,
                 |   /  VISCOCHAB,                    #voir  [§ 4.7]
                     /VISCOCHAB_FO,
                 |   /  MEMO_ECRO,                    #voir  [§ 4.8]
                 |   /  MEMO_ECRO_FO,                 #voir  [§ 4.8]
                 |   /  TAHERI,                       #voir  [§ 4.9]
                     /TAHERI_FO   ,
                 |      MONO_VISC1,                   #voir  [§4.10]
                 |      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,
                 |      MONO_DD_CC_ IRRA,
                 |   /  LEMAITRE,                     #voir  [§4.11]
                     /LEMAITRE_FO ,
```

```
      |      VISC_SINH,                      #voir  [§4.12]
      |      VISC_SINH_FO,                   #voir  [§4.12]
      |   /  LEMA_SEUIL,                     #voir  [§4.13]
         /LEMA_SEUIL_FO   ,
      |   VISC_IRRA_LOG,                     #voir  [§4.14]
      |   GRAN_IRRA_LOG,                     #voir  [§4.15]
      |   IRRAD3M,                           #voir  [§4.16]
      |   ECRO_COOK,                         #voir  [§4.17]
    # Comportements related to the damage and the fracture [§5]
      |   /  ROUSSELIER,                     #voir  [§ 5.1]
         /ROUSSELIER_FO   ,
      |   /  VENDOCHAB,                      #voir  [§ 5.2]
         /VENDOCHAB_FO,
      |   /  VISC_ENDO,                      #voir  [§ 5.3]
         /VISC_ENDO_FO,
      |   HAYHURST,                          #voir  [§ 5.4]
      |   NON_LOCAL,                         #voir  [§ 5.5]
      |   /  RUPT_FRAG,                      #voir  [§ 5.6]
         /RUPT_FRAG_FO,
      |   CZM_LAB_MIX,                       #voir  [§ 5.7]
      |   RUPT_DUCT,                         #voir  [§ 5.8]
      |   JOINT_MECA_RUPT,                   #voir  [§ 5.9]
      |   JOINT_MECA_FROT,                   #voir  [§ 5.10]
      |   CORR_ACIER,                        #voir  [§ 5.11]
      |   ENDO_HETEROGENE,                   #voir  [§ 5.12]
    # Behaviors Thermal [§ 6]
      |   /  THER,                           #voir  [§ 6.1]
         /THER_FO  ,
         /THER_ORTH   ,                     #voir  [§ 6.2]
         /THER_NL  ,                        #voir  [§ 6.3]
         /THER_COQU   ,                     #voir  [§ 6.4]
         /THER_COQU_FO,
    # Behaviors specific to the concretes [§ 7]
      |   THER_HYDR,                        #voir  [§ 7.1]
      |   SECH_GRANGER,                     #voir  [§ 7.2]
      |   SECH_MENSI,                       #voir  [§ 7.3]
      |   SECH_BAZANT,                      #voir  [§ 7.4]
      |   SECH_NAPPE,                       #voir  [§ 7.5]
      |   PINTO_MENEGOTTO,                  #voir  [§ 7.6]
      |   BPEL_BETON and BPEL_ACIER,        #voir  [§ 7.7]
      |   BETON_DOUBLE_BP,                  #voir  [§ 7.8]
      |   GRANGER_FP, GRANGER_FP_INDT      #voir   [§ 7.9]
                    and V_GRANGER_FP,

      |   LABORD_1D,                        #voir  [§7.10]
      |   /  MAZARS,                        #voir  [§7.11]
         /MAZARS_FO   ,
      |   BETON_UMLV_FP,                    #voir  [§7.12]
      |   ENDO_ORTH_BETON,                  #voir  [§7.13]
      |   BETON_ECRO_LINE,                  #voir  [§7.14]
      |   ENDO_SCLAIRE,                    #voir   [§7.15]
      |   GLRC_DM,                          #voir  [§7.16]
      |   JOINT_BA,                         #voir  [§7.17]

    # Behaviors Metal-worker-Mechanics [§ 8]
      |   META_ACIER,                       #VOIR  [§ 8.1]
```

```
      META_ZIRC,                    #VOIR  [§ 8.2]
|     DURT_META,                    #voir  [§ 8.3]
|     /ELAS_META    ,               #voir  [§ 8.4]
      /ELAS_META_FO,
|     META_ECRO_LINE,               #voir  [§ 8.5]
|     META_TRACTION,                #voir  [§ 8.6]
|     META_VISC_FO,                 #voir  [§ 8.7]
|     META_PT,                      #voir  [§ 8.8]
|     META_RE,                      #voir  [§ 8.9]
|     META_LEMA_ANI,                #voir  [§ 8.10]
|     META_LEMA_ANI_FO,             #voir  [§ 8.10]
```

```
                # Comportements Thermo-Hydro-Mechanics and of the grounds [§
      9]
                      COMP_THM=       /  "LIQU_SATU", #voir  [§ 9.1]
                                      /  "LIQU_GAZ",
                                      /  "GAS",
                                      /  "LIQU_GAZ_ATM",
                                      /  "LIQU_VAPE_GAZ",
                                      /  "LIQU_VAPE",
                                       / "LIQU_AD_GAZ_VAPE",
                                      /  "LIQU_AD_GAZ",
                   |  THM_INIT,                          #voir  [§ 9.2]
                   |  THM_LIQU,                          #voir  [§ 9.3]
                   |  THM_GAZ,                           #voir  [§ 9.4]
                   |  THM_VAPE_GAZ,                      #voir  [§ 9.5]
                   |  THM_AIR_DISS,                      #voir  [§ 9.6]
                   |  THM_DIFFU,                         #voir  [§ 9.7]
                   |  CAM_CLAY,                          #voir  [§ 9.8]
                   |  CJS,                               #voir  [§ 9.9]
                   |  LAIGLE,                            #voir  [§ 9.10]
                   |  LETK,                              #voir  [§ 9.11]
                   |  DRUCK_PRAGER,                      #voir  [§ 9.12]
                   |  DRUCK_PRAGER_FO,                   #voir  [§ 9.12]
                   |  VISC_DRUC_PRAG,                    #voir  [§ 9.13]
                   |  BARCELONE,                         #voir  [§ 9.14]
                   |  HUJEUX,                            #voir  [§ 9.15]
                   |  HOEK_BROWN,                        #voir  [§ 9.16]
                   |  ELAS_GONF,                         #voir  [§ 9.17]
                   |  JOINT_BANDIS,                      #voir  [§ 9.18]

                # Comportement specific to elements 1D [§ 10]
                   |  ECRO_ASYM_LINE,                    #voir  [§ 10.3]
                # Comportements private individuals [§ 11]
                   |  LEMAITRE_IRRA,                     #voir  [§ 11.1]
                   |  LMARC_IRRA,                        #voir  [§ 11.2]
                   |  DIS_) GRICRA,                      #VOIR  [§ 11.3]
                   |  GATT_MONERIE,                      #voir  [§ 11.4]
                   |  DIS_CONTACT,                       #voir  [§ 11.5]
                   |  DIS_ECRO_CINE,                     #voir  [§ 11.6]
                   |  DIS_VISC,                          #voir  [§ 11.7]
                   |  DIS_BILI_ELAS,                     #VOIR  [§ 11.8]
                   |  ASSE_CORN,                         #voir  [§ 11.9]
                   |  ARME,                              #voir  [§ 11.10]
                # Comportement fluid [§ 12]
                   |  FLUID,                          #voir  [§ 12.1]
                # Material characteristics associated with postprocessings
                # with postprocessings [§ 13]
                   |  FATIGUE,                          #voir  [§ 13.1]
                   |  DOMMA_LEMAITRE,                   #voir  [§ 13.2]
                   |  CISA_PLAN_CRIT,                   #voir  [§ 13.3]
                   |  /  WEIBULL,                       #voir  [§ 13.4]
                      /WEIBULL_FO  ,
                   |  /  RCCM,                          #voir  [§ 13.5]
```

```
    /RCCM_FO  ,
|   /  CRIT_RUPT,                    #voir  [§ 13.6]
|   /  UMAT,                         #voir  [§ 13.7]
)
```

Note:

Command DEFI_MATERIAU is D-entering but each behavior remains single. One does not allow to override a behavior already present in the 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 command variables (see commands AFFE_MATERIAU and AFFE_VARC) in the form of a function, a three-dimensions function or a formula. The parameters time ("INST"), plastic strain ("EPSI") and curvilinear abscisse ("ABSC") can be used in very particular cases, the behaviors being able to depend on these parameters explicitly specify it in their description.

3 General elastic behaviors

3.1 key Mots factor ELAS, ELAS_FO

Définition of the constant linear elastic characteristics or functions of parameter "TEMP".

3.1.1 Syntax

```
|/ ELAS = _F      ( ♦  E=yg                    ,          [R]
                   ♦  NU=nu                    ,          [R]
                   ◊  RHO=rho                     ,       [R]
                   ◊  ALPHA=dil                   ,       [R]
                   ◊AMOR_ALPHA=a_alpha            ,    [R]
                   ◊AMOR_BETA          =a_beta    ,    [R]
                   ◊AMOR_HYST          =  eta       [R]
                 )
 /ELAS_FO  = _F   ( ♦  E                 =  yg,         [function]
                   ♦  NU                 =nu ,          [function]
                   ◊RHO                  =rho       ,       [R]
                   ◊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,        [DEFAUT]
                   ◊K_DESSIC=                   / K,          [R]
                                            / 0.0,        [DEFAUT]
                   ◊B_ENDOGE             =   / E,          [R]
                                            / 0.0,        [DEFAUT]
                   ◊FONC_DESORP=f                            [function]
                  )
```

Les functions can depend on the following command variables:
"TEMP", "INST", "HYDR", "SECH", "NEUT1", "NEUT2".

3.1.2 Operands E/NU

E = yg

Modulus Young. It is checked that $E \geq 0$.

NU = naked

Poisson's ratio. It is checked that $-1. \leq \nu \leq 0.5$.

3.1.3 Operand RHO

RHO = rho

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

3.1.4 Operands ALPHA/TEMP_DEF_ALPHA/PRECISION

ALPHA = isotropic

alpha thermal Coefficient of thermal expansion.

The thermal coefficient of thermal expansion is an average coefficient of thermal expansion which can depend on the temperature T.

The values of the coefficients of thermal expansion are determined by tests of dilatometry which take place with the room temperature ($0\,°C$ or more generally $20\,°C$).

So one in general has the values of the coefficient of thermal expansion defined compared to $20\,°C$ (temperature to which one supposes the null thermal strain).

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

```
TEMP_DEF_ALPHA = Tdef       [R]
```

It is the value of the temperature to which the values of the thermal coefficient of thermal expansion were given, and were indicated under key word ALPHA.

This key word becomes compulsory as soon as ALPHA was informed.

The computation of the thermal strain is done by the formula [R4.08.01]:

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

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

Remarque:

It is not possible to use a formula for ALPHA , because them amendments to be taken into account described above. The user, if it wishes to use a formula, owes initially the tabuler using command CALC_FONC_INTERP .

```
PRECISION =  /  prec
             /1  .                [DEFAUT]
```

This key word is used when key word TEMP_DEF_ALPHA is specified.

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

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

3.1.5 Operands AMOR_ALPHA / AMOR_BETA / AMOR_HYST

```
AMOR_ALPHA = a_alpha
AMOR_BETA  = a_beta
```

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

```
AMOR_HYST = hysteretic
```

eta η Damping coefficient allowing to define the complex Young modulus (viscoelastic material) from which will be created the complex stiffness matrix allowing the computation of the harmonic response [U2.06.03] and [R5.05.04].

Note:

The presence of key words AMOR_ALPHA and AMOR_BETA associated with a zero value, can lead, in certain algorithms, to assemble a damping matrix and thus generates additional cost of computation.

3.1.6 Operands K_DESSIC / B_ENDOGE

K_DESSIC = K

Coefficient of shrinkage of dessication.

K_ENDOGE = E

endogenous Coefficient of shrinkage.

These characteristics are used with the behaviors of the concrete (see ref. [R7.01.12]).

3.1.7 Operand FONC_DESORP

curved FONC_DESORP =
F of sorption-desorption [R7.01.12] giving the hygroscopy h according to the water content C.

3.2 Key word factor ELAS_FLUI

key word ELAS_FLUI makes it possible to define the equivalent density of a tubular structure with internal and external fluid, by taking of account the effect of containment.

This operation fits in the frame 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 group of the beam. Ref. [U4.35.02]

the equivalent density of structure ρ_{eq} is defined by:

$$\rho_{eq}=\frac{1}{(d_e^2-d_i^2)}\left[\rho_{i.}d_i^2+\rho_{t.}(d_e^2-d_i^2)+\rho_{e}.d_e^2\right]$$

$$d_{eq}^2=\frac{2.Cm.d_e^2}{\pi}$$

ρ_i ρ_e, ρ_t are respectively the density of the fluid, the offsite fluid and structure.
d_e, d_i are respectively the offsite and internal diameter tube.
Cm is a coefficient of added mass (which defines containment).

3.2.1 Syntax

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

3.2.2 Opérandes RHO/E/NU

RHO = rho

Density of the material.

E = yg

Modulus Young.

NU = naked

Poisson's ratio.

3.2.3 Operands PROF_RHO_F_INT/PROF_RHO_F_EXIT/COEF_MASS_AJOU

PROF_RHO_F_INT = rhoi

Concept of the type [function] defining the profile of density of the internal fluid along the tube. This function is parameterized by the curvilinear abscisse.

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 abscisse, "ABSC".

COEF_MASS_AJOU = fonc_cm

Concept of the type [function] produced by operator FONC_FLUI_STRU [U4.35.02].

This constant function, parameterized by the curvilinear abscisse, provides the value of the coefficient of added mass C_m .

3.3 Key word factor CABLE

Définition of the elastic characteristic nonlinear, constant, for the cables: two different elastic behaviours in tension and compression, defined by the Young moduli E and EC. (modulus in compression).
The standard characteristics of the elastic material are with being informed under the key word factor ELAS.

3.3.1 Syntax

```
|  CABLE = _F    (
                ◊EC_SUR_E    =      /  ecse,      [R]
                                    /1.D-4 ,      [DEFAUT]
                )
```

3.3.2 Opérandes of elasticity

◊EC_SUR_E = ecse

Rapport of the moduli to compression and the tension. If the bulk modulus 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 Key words factor ELAS_ORTH, ELAS_ORTH_FO

Définition of the constant orthotropic elastic characteristics or functions of the temperature for the isoparametric shell elements and solid elements or the layers constitutive of a composite (confer DEFI_COMPOSITE).

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         =GLN      ,          [R]
                   ♦  NU_LT        =NULT  ,          [R]
```

```
                        ◊   NU_TN          =NUTN  ,          [R]
                        ◊   NU_LN          =NULN  ,         [R]
                        ◊   ALPHA_L        =   / dil,        [R]
                                               / 0.0,        [DEFAUT]
                        ◊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             =   / saddle-point,         [R]
                                               / 1.0,        [DEFECT]
                        ◊   YT             =   / trt,        [R]
                                               / 1.0,        [DEFECT]
                        ◊   YC             =   / cot,        [R]
                                               / 1.0,        [DEFECT]
                        ◊   S_LT           =   / cis,        [R]
                                               / 1.0,        [DEFAUT]
                        ◊AMOR_ALPHA=           alp,         [R]
                        ◊AMOR_BETA         =   Study Bureau,          [R]
                        ◊AMOR   MYST=          eta          [R]
                    )
    /ELAS_ORTH_FO   =_F    (
                        ♦   E_L                =ygl      ,       [function]
                        ♦   E_T                =ygt      ,       [function]
                        ◊   E_N                =ygn      ,       [function]
                        ♦   G_LT               =glt      ,       [function]
                        ♦   G_TN               =gtn      ,      [function]
                        ♦   G_LN               =gln      ,       [function]
                        ♦   NU_LT              =nult  ,       [function]
                        ◊   NU_TN              =nutn  ,       [function]
                        ♦NU_LN             =nuln  ,       [function]
                        ◊ALPHA_L               =dil      ,       [function]
                        ◊ALPHA_T               =dit      ,       [function]
                        ◊   ALPHA_N            =din      ,      [function]
                        ◊   RHO                =   / rho,      [R]
                                                   / 0.0,      [DEFECT]
                        ◊   TEMP_DEF_ALPHA=        Tdef,       [R]
                        ◊   PRECISION      =   /eps,       [R]
                                                   /1. ,       [DEFAUT]
                        ◊   AMOR_ALPHA=             alp ,        [R]
                        ◊AMOR_BETA             =   Study Bureau,       [R]
                        ◊AMOR   MYST=              eta       [R]
                        )
```

3.4.2 Opérandes of elasticity

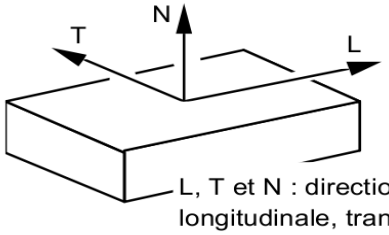
the reader will be able to refer to following documentations:

[U4.42.03] DEFI_COMPOSITE

[U4.42.01] AFFE_CARA_ELEM

to define the reference of orthotropy (L, T, N) related to the elements.

E_L = ygl longitudinal Young's modulus.



L, T et N : directions d'orthotropie longitudinale, transversale et normale

E_T = ygt transverse Young's modulus.

E_N = ygn normal Young's modulus.

GL_T = glt Shear modulus in the plane LT.

G_TN = gtn Shear modulus in the plane TN.

G_LN = gln Shear modulus in the plane LN.

Note:

For the shells, the transverse shear moduli are not compulsory; in this case, one calculates in thin shell by assigning an infinite rigidity to the transverse shears (elements DST, DSQ and Q4G).

NU_LT = nult Poisson's ratio in the plane LT.

Important remarks:

$nult$ is not equal to $nutl$. In fact, there is the relation: $nutl=\frac{ygt}{ygl}.nult$

$nult$ must be interpreted in the following way:

if one exerts a tension according to the axis L giving place to a strain according to this axis equalizes with $\varepsilon_L=\frac{\sigma_L}{ygl}$, one has a strain according to the axis T equalizes with: $\varepsilon_T=-nult.\frac{\sigma_L}{ygl}$.

The 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 non-zero strain causes a strictly positive strain energy. That results in the fact that the matrix of Hooke must be definite positive. Operator DEFI_MATERIAU computes the eigenvalues of this matrix and emits an alarm if this property is not checked.
For models 2D, as the user did not choose yet his MODELISATION (D_PLAN, C_PLAN,...), one checks the positivity of the matrix in the various cases.

NU_TN = nutn Poisson's ratio in the plane TN.

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

The remark made for NU_LT is to be applied to these the last two coefficients. There are thus the relations:

$$nunt=\frac{ygn}{ygt}.nutn$$
$$nunl=\frac{ygn}{ygt}.nuln$$

3.4.3 Typical case of cubic elasticity:

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

$$\begin{matrix} y_{1111} & y_{1122} & y_{1122} & & & \\ y_{1122} & y_{1111} & y_{1122} & & & \\ y_{1122} & y_{1122} & y_{1111} & & & \\ & & & y_{1212} & & \\ & & & & y_{1212} & \\ & & & & & y_{1212} \end{matrix}$$

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

$$E_L = E_N = E_T = E \, , G_{\mathrm{LT}} = G_{\mathrm{LN}} = G_{\mathrm{TN}} = G \, , \nu_{\mathrm{LN}} = \nu_{\mathrm{LT}} = \nu_{\mathrm{LN}} = \nu$$

To reproduce cubic elasticity with ELAS_ORTH, it is enough to calculate the coefficients of the orthotropy such that the matrix of elasticity obtained is form above:

$$y_{1111} = \frac{E(1-\nu^2)}{(1-3\nu^2-2\nu^3)}$$
$$y_{1122} = \frac{E\nu(1+\nu)}{(1-3\nu^2-2\nu^3)}$$
$$y_{1212} = G_{\mathrm{LT}} = G_{\mathrm{ln}} = G_{TN}$$

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

$\frac{y_{1122}}{y_{1111}} = \frac{\nu}{1-\nu}$ what provides $\nu = \frac{1}{1+\frac{y_{1111}}{y_{1122}}}$ then $E = y_{1111}\frac{(1-3\nu^2-2\nu^3)}{(1-\nu^2)}$

3.4.4 Opérande RHO

RHO = rho

Density.

3.4.5 Operands ALPHA_L / ALPHA_T / ALPHA_N

ALPHA_L = dil

longitudinal average thermal Coefficient of thermal expansion.

ALPHA_T = known as

transverse average thermal Coefficient of thermal expansion.

ALPHA_N = DIN

normal average thermal Coefficient of thermal expansion.

3.4.6 Operands TEMP_DEF_ALPHA / PRECISION

One will refer to the paragraph [§3.1.4]. This key word becomes compulsory as soon as ALPHA_L was informed , or ALPHA_T or ALPHA_N.

3.4.7 Rupture criteria

XT = trl

Rupture criterion in tension in the longitudinal meaning (first direction of orthotropy).

XC = saddle-point

Rupture criterion in compression in the longitudinal meaning.

YT = trt

Rupture criterion in tension in the transverse meaning (second direction of orthotropy).

YC = cot

Rupture criterion in compression in the transverse meaning.

S_LT = cis

Rupture criterion in shears in the plane LT .

3.5 Key words factor ELAS_ISTR , ELAS_ISTR_FO

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

By taking again the same notations as for the orthotropy [§3.4], the transverse isotropy means here, the isotropy in the plane (L,T) [R4.01.02].

3.5.1 Syntax

```
| /ELAS_ISTR   = _F   (
                        ♦  E_L              =YGL      ,       [R]
                        ♦  E_N              =YGN      ,       [R]
                        ♦  G_LN             =GLN      ,       [R]
                        ♦  NU_LT            =NULT  ,       [R]
                        ♦  NU_LN            =NULN  ,       [R]
                        ◊  ALPHA_L          =   / dil,     [R]
                                                / 0.0,     [DEFECT]
                        ◊  ALPHA_N          =   / DIN,     [R]
                                                / 0.0,     [DEFECT]
                        ◊  RHO              =   / rho,     [R]
                                                / 0.0,     [DEFAUT]
                    )
  /ELAS_ISTR_FO   =_F    (
                        ♦  E_L              =ygl      ,       [function]
                        ♦  E_N              =ygn      ,       [function]
                        ♦  G_LN             =gln      ,       [function]
                        ♦  NU_LT            =nult  ,       [function]
                        ♦  NU_LN            =nuln  ,       [function]
                        ◊  ALPHA_L          =dil      ,       [function]
                        ◊  ALPHA_N          =din      ,       [function]
                        ◊  RHO              =   /rho,      [R]
                                                /0.0,      [DEFECT]
                        ◊  TEMP_DEF_ALPHA   =   Tdef,      [R]
                        ◊  PRECISION        =   / eps,     [R]
                                                / 1.0      [DEFAUT]
                    )
```

3.5.2 Opérandes of elasticity

the player will be able to refer to following documentations:

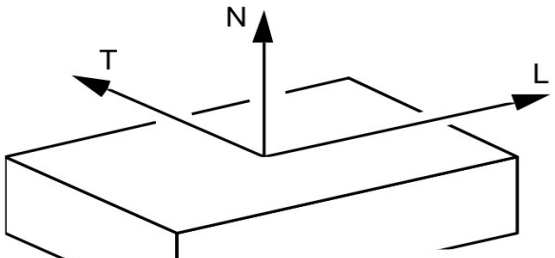
[U4.42.03] DEFI_COMPOSITE

[U4.42.01] AFFE_CARA_ELEM
[R4.01.02] Orthotropy

to define a reference (L, T, N) related to the elements and defining the transverse isotropy of the material, this last being isotropic in the plane LT.

Note:

The directions L and T are arbitrary in the plane LT.



L et T définissent le plan dans lequel le matériau a un caractère isotrope

`E_L = ygl`

Modulus Young in the plane LT.

`E_N = ygn`

normal Modulus Young.

`GL_N = gln`

Shear modulus in the plane LN.

Note:

The shear modulus in the plane LT is defined by the usual formula for the isotropic materials: $G=\frac{E}{2(1+\nu)}$ that is to say here $glt=\frac{ygl}{2(1+nult)}$.

`NU_LT = nult`

Poisson's ratio in the plane LT.

`NU_LN = nuln`

Poisson's ratio in the plane LN.

Important remarks:

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

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

$nunl$ must be interpreted in the following way:

if one exerts a tension according to the axis N giving place to a strain of tension according to this axis equalizes with $\varepsilon_N=\frac{\sigma_N}{ygn}$, one has a compression according to the axis L equalizes with: $nunl.\frac{\sigma_N}{ygn}$.

The 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 non-zero strain causes a strictly positive strain energy. That results in the fact that the matrix of Hooke must be definite positive. Operator DEFI_MATERIAU computes the eigenvalues of this matrix and emits an alarm if this property is not checked.
For models 2D, as the user did not choose yet his MODELISATION (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 = dil

average thermal Coefficient of thermal expansion in the plane LT .

ALPHA_N = DIN

normal average thermal Coefficient of thermal expansion.

3.5.5 Operands TEMP_DEF_ALPHA / PRECISION

One will refer to the paragraph [§3.1.4]. This key word becomes compulsory as soon as one informed key word ALPHA_L or ALPHA_N.

3.6 Key word factor ELAS_COQUE , ELAS_COQUE_FO

ELAS_COQUE makes it possible to the user to directly provide the coefficients of the matrix of elasticity (broken up into membrane and bending) of the orthotropic thin shells 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_LLTT=H1111                ,    [R] or [function]
                    ◊M_LLLT=H1112                ,    [R] or [function]
                    ◊M_TTTT=H2222                ,    [R] or [function]
                    ◊M_TTLT=H2212                ,    [R] or [function]
                    ◊M_LTLT=H1212                ,    [R] or [function]
                    ◊F_LLLL=A1111                ,    [R] or [function]
                    ◊F_LLLL=A1111                ,    [R] or [function]
                    ◊F_LLLT=A1112                ,    [R] or [function]
                    ◊F_TTTT=A2222                ,    [R] or [function]
                    ◊F_TTLT=A2212                ,    [R] or [function]
                    ◊F_LTLT=A1212                ,    [R] or [function]
                    ◊MF_LLLL=B1111               ,    [R] or [function]
```

```
◊MF_LLTT=B1111          ,    [R] or [function]
◊MF_LLLT=B1112          ,    [R] or [function]
◊MF_TTTT=B2222          ,    [R] or [function]
◊MF_TTLT=B2212          ,    [R] or [function]
◊MF_LTLT=B1212          ,    [R] or [function]
◊MC_LLLZ=E1111          ,    [R] or [function]
◊MC_LLTZ=E1111          ,    [R] or [function]
◊MC_TTLZ=E1112          ,    [R] or [function]
◊MC_TTTZ=E2222          ,    [R] or [function]
◊MC_LTLZ=E2212          ,    [R] or [function]
◊MC_LTTZ=E1212          ,    [R] or [function]
◊FC_LLLZ=F1111          ,    [R] or [function]
◊FC_LLTZ=F1111          ,    [R] or [function]
◊FC_TTLZ=F1112          ,    [R] or [function]
◊FC_TTTZ=F2222          ,    [R] or [function]
◊FC_LTLZ=F2212          ,    [R] or [function]
◊FC_LTTZ=F1212          ,    [R] or [function]
◊C_LZLZ=G1313           ,    [R] or [function]
◊C_TZTZ=G2323           ,    [R] or [function]
◊C_TZTZ=G1323                [R] or [function]
  )
```

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

Membrane:	Bending:	Shears:
$C=\frac{Eh}{1-\nu^2}\begin{vmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \left(\frac{1-\nu}{2}\right) \end{vmatrix}$	$D=\frac{E h^3}{12\left(1-\nu^2\right)}\begin{vmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \left(\frac{1-\nu}{2}\right) \end{vmatrix}$	$G=\frac{5Eh}{12\left(1+\nu\right)}\begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix}$

For the orthotropic shells whose elasticity moduli are obtained by a method of homogenisation, it is not possible in the general case to find a Young modulus equivalent Eeq, and an equivalent thickness heq to find the preceding statements.

The stiffness matrixes are thus given directly in the form:

Membrane: Bending: Shears:

$$C=\begin{vmatrix} C1111 & C1122 & 0 \\ C1122 & C2222 & 0 \\ 0 & 0 & C1212 \end{vmatrix} \quad D=\begin{vmatrix} D1111 & D1122 & 0 \\ D1122 & D2222 & 0 \\ 0 & 0 & D1212 \end{vmatrix} \quad G=\begin{vmatrix} G11 & 0 \\ 0 & G22 \end{vmatrix}$$

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

These coefficients are with being provided in the local coordinate system of the element. It is defined under the key word SHELL of AFFE_CARA_ELEM [U4.42.01].

Notice concerning the taking into account of the transverse shears following the models of shells:

If one wishes to use ELAS_COQUE with transverse shears modelization DST necessarily should be employed. If modelization DKT is used, the transverse shears will not be taken into account, some are the values of $G11$ and $G22$. The correspondence for an isotropic material is the following one:

- *The material ELAS_COQUE , modelization DST with $CISA\_*=5/12\times(Eh/(1+nu))$ is equivalent to the material ELAS , modelization DST.*

- *The material* ELAS_COQUE *, modelization DST with* $CISA\_*=5/12\times(Eh/(1+nu))\times N$ *, where* N *is a great number (for example* 10^5 *), is equivalent to the material* ELAS*, modelization DKT.*
- *The material* ELAS_COQUE *, modelization DKT is equivalent to the material* ELAS *, modelization DKT.*

The matrixes of behavior connecting the forces generalized to the strains for the shell elements and fascinating account the terms of coupling are in the following way defined:

Membrane:

$$HM=\begin{vmatrix} H1111 & H1122 & H1112 \\ 0 & H2222 & H2212 \\ 0 & 0 & H1212 \end{vmatrix}$$

Bending:

$$HF=\begin{vmatrix} A1111 & A1122 & A1112 \\ 0 & A2222 & A2212 \\ 0 & 0 & A1212 \end{vmatrix}$$

Shears:

$$HMF=\begin{vmatrix} B1111 & B1122 & B1112 \\ 0 & B2222 & B2212 \\ 0 & 0 & B1212 \end{vmatrix}$$

Membrane-shears:

$$HMC=\begin{vmatrix} E1113 & E1123 \\ E2213 & E2223 \\ E1213 & E1223 \end{vmatrix}$$

Bending-shears:

$$HFC=\begin{vmatrix} F1113 & F1123 \\ F2213 & F2223 \\ F1213 & F1223 \end{vmatrix}$$

Shears:

$$HC=\begin{vmatrix} G1313 & G1323 \\ G1323 & G2323 \end{vmatrix}$$

3.7 Key word factor ELAS_MEMBRANE

ELAS_MEMBRANE makes it possible to the user to directly provide the coefficients of the matrix of elasticity of the anisotropic membranes in linear elasticity.

3.7.1 Syntax

```
|/ ELAS_MEMBRANE=    _F (
                     ◊RHO=rho                          ,    [R]
                     ◊ALPHA=alpha                      ,    [R]
                     ♦M_LLLL=H1111                     ,    [R]
                     ♦M_LLTT=H1111                     ,    [R]
                     ♦M_LLLT=H1112                     ,    [R]
                     ♦M_TTTT=H2222                     ,    [R]
                     ♦M_TTLT=H2212                     ,    [R]
                     ♦M_LTLT=H1212                     ,    [R]
                        )
```

the membrane stiffness matrix connecting the membrane stresses to the strains for the elements of membrane is in the following way defined:

$$HM=\begin{vmatrix} H1111 & H1122 & H1112 \\ H1122 & H2222 & H2212 \\ H1112 & H2212 & H1212 \end{vmatrix}$$

These coefficients are with being provided in the local coordinate system of the element, definite under the key word factor MEMBRANE of 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:

$$\varepsilon=\begin{vmatrix} \varepsilon_{11} \\ \varepsilon_{22} \\ \sqrt{2}\varepsilon_{12} \end{vmatrix} \qquad \sigma=\begin{vmatrix} \sigma_{11} \\ \sigma_{22} \\ \sqrt{2}\sigma_{12} \end{vmatrix}$$

The user can also indicate a thermal coefficient of thermal expansion isotropic alpha, and a mass *per unit of area* rho.

3.8 Key word factor ELAS_HYPER

Définition of the characteristics very-elastics of the type Signorini [R5.03.19]. The stresses of Piola Kirchhoff S are connected to the strains of Green-Lagrange by:

$S=\frac{\partial \Psi}{\partial E}$ with: $\Psi=C10\left(I_1-3\right)+C01\left(I_2-3\right)+C20\left(I_1-3\right)^2+\frac{1}{2}K\left(J-1\right)^2$ 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.

3.8.1 Syntax

```
|  ELAS_HYPER= _F (
                 ♦  C10       =C10   ,                [R]
                 ◊  C01       =   / c01,               [R]
                                  / 0.0,               [DEFECT]
                 ◊  C20       =   / c20,               [R]
                                  / 0.0,               [DEFECT]
                 ◊  RHO       =   / rho,               [R]
                                  / 0.0,               [DEFAUT]
                 ◊  NU        =nu ,                    [R]
                 ◊  K         =k                       [R]
                 )
```

3.8.2 Opérandes C01, C10 and C20

C01 = c01 , C10 = c10, C20 = c20

Les three coefficients of the polynomial statement of potential hyper elastic. The unit is it N/m^2 .

•If $C01$ and $C20$ are null, 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 strains if one takes $C10$ and $C01$ such as $6\left(C01+C10\right)=E$, where E is the Young's modulus.

3.8.3 Operand NU and K

NU = naked

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

K = K

Modulates compressibility.

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

$K=\frac{6\left(C01+C10\right)}{3\left(1-2\nu\right)}$.

One can take nu near to 0.5 but never strictly equal (with the accuracy machine near). If nu is too close to 0.5 , an error message invites the user to check his Poisson's ratio or its modulus of compressibility. The larger the modulus 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 type `function`). No the checking of about size.

3.9 Key word factor ELAS_2NDG

Définition 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 the modelizations of regularization second gradient (*_2DG) or second gradient of dilation (*_DIL).

3.9.1 Syntax

```
| /ELAS_2NDG  = _F (
                    ♦  A1          =a1   ,          [R]
                    ◊  A2          =a2   ,          [R]
                    ◊  A3          =a3   ,          [R]
                    ◊  A4          =a4   ,          [R]
                    ◊  A5          =a5   ,          [R]
                    )
```

3.9.2 Opérandes A1, A2, A3, A4 and A5

Ces parameters define the characteristic materials of the model described in the document [R5.04.03].

4 General nonlinear mechanical behaviors

En général, 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 Key word factor `Définition`

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

4.1.1 Syntax

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

4.1.2 Opérande `SIGM`

`SIGM = sigm_f`

Courbe σ according to the total deflection ε (it is checked that the concept function depends many only parameters `EPSI` and possibly `TEMP`).

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

Note:

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

4.2 Key words factor `ECRO_LINE` , `ECRO_LINE_FO`

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

4.2.1 Syntax

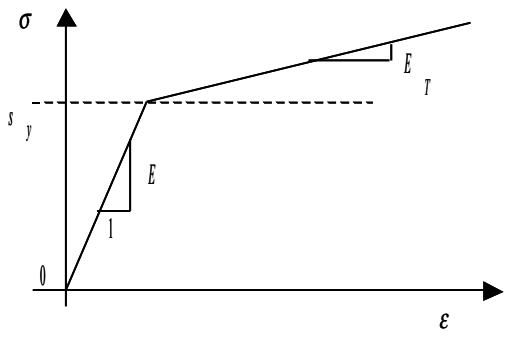
```
| / ECRO_LINE = _F (
     ♦ D_SIGM_EPSI=    dsde                                          [R]
     ♦ SY=             sigmm                                         [R]
      ◊ SIGM_ELS=      sgels                                        [R]
     ◊ EPSI_ELU=       epelu                                         [R]
     )
  / ECRO_LINE_FO = _F (
     ♦                 D_SIGM_EPSI= dsde                      [function]
     ♦ SY=             sigm                                   [function]
)
```

Les functions can depend on the following command variables: "`TEMP`", "`EPSI`", "`HYDR`", "`SECH`".

4.2.2 Operands

♦ `D_SIGM_EPSI = ds of (AND)`
Slope of the traction diagram E_T.

♦ SY = sigm
Elastic limit s_y.



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

$$R(p) = s_y + H.p$$

with $H = \dfrac{E \,.\, E_T}{E - E_T}$

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

The Young's modulus E is to be specified by key words ELAS or ELAS_FO.

◊ SIGM_ELS = sgels
Définition of the ultimate stress of service.

◊ EPSI_ELU = epelu
Définition of the ultimate limiting strain.

The operands SIGM_ELS and ESPI_ELU make it possible to define the limits which correspond to the limiting states of service and ultimate, classically used at the time of study in civil engineer. These limits are compulsory when the behavior ecro_cine _1D IS USED (confer [U4.42.07] DEFI_MATER_GC). In the other cases they are not taken into account.

4.3 Key words factor PRAGER, PRAGER_FO

Lorsque the way of loading is not monotonous any more, hardenings isotropic and kinematical are not equivalent any more. In particular, one can expect to have simultaneously a kinematical share and an isotropic share. If one seeks to precisely describe the effects of a cyclic loading, it is desirable to adopt modelizations 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 hardening, all nonthe linearities of hardening being carried by the isotropic term. That makes it possible to describe a traction diagram precisely, while representing nevertheless phenomena such as the Bauschinger effect [R5.03.16].

The characteristics of hardening are then given by a traction diagram and a constant, called of Prager, for the linear term of kinematic hardening. Key word PRAGER makes it possible to define the constant of PRAGER, used in the models with mixed hardening (kinematical 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]
                 )
```

the identification of C is described in [R5.03.16].

4.4 Key words factor ECRO_PUIS, ECRO_PUIS_FO

Model of plasticity with criterion of Von Mises and isotropic hardening following a model power.

4.4.1 Syntax

```
|   / ECRO_PUIS =_F  (
                  ♦   SY     =sigy  ,                  [R]
                  ♦A_PUIS=a         ,                    [R]
                  ♦N_PUIS=n         ,                     [R]
                   )
    / ECRO_PUIS_FO =_F       (
                  ♦SY        = sigy,                   [function]
                  ♦A_PUIS=a         ,                    [function]
                  ♦N_PUIS=n         ,                     [function]
                      )
```

4.4.2 Opérandes

SY =sigy A_PUIS=aCoefficient
Elastic limit of the model power
N_PUIS=n Exposant

the curve of hardening is deduced from the uniaxial curve connecting the strains to the stresses, whose statement is:

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

4.5 Key words factor CIN1_CHAB, CIN1_CHAB_FO

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

Briefly, these relations are:

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

$$\dot{\varepsilon}^p=\dot{\lambda}\frac{\partial F}{\partial\sigma}=\frac{3}{2}\dot{\lambda}\frac{\tilde{\sigma}-X}{(\tilde{\sigma}-X)_{eq}}$$

$$\dot{p}=\dot{\lambda}=\sqrt{\frac{2}{3}\dot{\varepsilon}^p:\dot{\varepsilon}^p} \qquad \text{éq 4.5-1}$$

$$\begin{cases}\text{si } F<0 \text{ ou } \dot{F}<0 & \dot{\lambda}=0\\ \text{si } F=0 \text{ et } \dot{F}=0 & \dot{\lambda}\geqslant 0\end{cases} \qquad \text{éq 4.5-2}$$

$$X=\frac{2}{3}C(p)\alpha \qquad \text{éq 4.5-3}$$

$$\dot{\alpha}=\dot{\varepsilon}^p-\gamma(p)\alpha\dot{p}$$

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

$$R(p)=R_\infty+(R_0-R_\infty)e^{-bp}$$
$$C(p)=C^\infty\left(1+(k-1)e^{-wp}\right)$$
$$\gamma_1(p)=\gamma^0\left(\alpha_\infty+(1-\alpha_\infty)e^{-bp}\right)$$

Note:

$\tilde{\sigma}$ represent the deviator of the stresses and $( )_{eq}$ the equivalent within the meaning of von Mises.

The definition of X in the form [éq. 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. ,                   [DEFAUT]
                  ♦    C_I=    C_I,                     [R] or [function]
                     ◊   K=    / K,                     [R] or [function]
                               / 1. ,                   [DEFECT]
                     ◊   W=    /w ,                     [R] or [function]
                               / 0. ,                   [DEFAUT]
                     ♦   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 key word factor `LEMAITRE` or `LEMAITRE_FO` , by obligatorily putting parameter `UN_SUR_M` at zero.

4.6 Key words factor CIN2_CHAB, CIN2_CHAB_FO

Comportement of the model of Chaboche (with two kinematical variables) described in the document [R5.03.04].

Briefly these relations are:

$$F(\sigma, R, X) = (\tilde{\sigma} - X_1 - X_2)_{eq} - R(p)$$

$$\dot{\varepsilon}^p = \dot{\lambda}\frac{\partial F}{\partial \sigma} = \frac{3}{2}\dot{\lambda}\frac{\tilde{\sigma} - X_1 - X_2}{(\tilde{\sigma} - X_1 - X_2)_{eq}}$$

$$\dot{p} = \dot{\lambda} = \sqrt{\frac{2}{3}\dot{\varepsilon}^p : \dot{\varepsilon}^p} \qquad \text{éq 4.6-1}$$

$$\begin{cases} \text{si } F < 0 \text{ ou } \dot{F} < 0 & \dot{\lambda} = 0 \\ \text{si } F = 0 \text{ et } \dot{F} = 0 & \dot{\lambda} \geqslant 0 \end{cases} \qquad \text{éq 4.6-2}$$

$$X_1 = \frac{2}{3}C_1(p)\alpha_1$$

$$X_2 = \frac{2}{3}C_2(p)\alpha_2 \qquad \text{éq 4.6-3}$$

$$\dot{\alpha}_1 = \dot{\varepsilon}^p - \gamma_1(p)\alpha_1\dot{p}$$

$$\dot{\alpha}_2 = \dot{\varepsilon}^p - \gamma_2(p)\alpha_2\dot{p}$$

The functions $C_1(p)$ $C_2(p)$ $\gamma_1(p)$, $\gamma_2(p)$ and $R(p)$ are defined by:

$$R(p)=R_\infty+(R_0-R_\infty)e^{-bp}$$
$$C_1(p)=C_1^\infty(1+(k-1)e^{-wp})$$
$$C_2(p)=C_2^\infty(1+(k-1)e^{-wp})$$
$$\gamma_1(p)=\gamma_1^0(\alpha_\infty+(1-\alpha_\infty)e^{-bp})$$
$$\gamma_2(p)=\gamma_2^0(\alpha_\infty+(1-\alpha_\infty)e^{-bp})$$

Note:

$\tilde{\sigma}$ represent the deviator of the stresses and $(\ )_{eq}$ 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

```
|   / 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]
                                / 0. ,                  [DEFAUT]
                  ♦    C1_I=  C1_I,              [R] or [function]
                  ♦    C2_I=  C2_I,              [R] or [function]
                  ◊    K=     / K   ,                  [R] or [function]
                                / 1. ,                  [DEFECT]
                  ◊    W=     / W,                     [R] or [function]
                                / 0. ,                  [DEFAUT]
                  ♦    G1_0=  G1_0,              [R] or [function]
                  ♦    G2_0=  G2_0,              [R] or [function]
                  ◊    A_I=     / A_I,                 [R] or [function]
                                / 1. ,                  [DEFECT]
                      )
```

Note:

A viscoplastic version of the model of Chaboche with two kinematical variables is also available (cf [R5.03.04]). It requires to define viscous characteristics using the key word factor `LEMAITRE` or `LEMAITRE_FO`, by obligatorily putting parameter `UN_SUR_M` at zero.

4.7 Key words factors VISCOCHAB, VISCOCHAB_FO

Définitions of the coefficients of the élasto-viscoplastic model of Chaboche [R5.03.12].
Briefly, the constitutive equations of the model are:

Viscous stress $\sigma_v=J_2(\tilde{\sigma}-X)-\alpha_R-k$

viscoplastic Strain rate
$$\dot{\varepsilon}^p=\frac{3}{2}\dot{p}\frac{\tilde{\sigma}-X}{J_2(\tilde{\sigma}-X)}$$

$$\dot{p}=\left\langle\frac{\sigma_v}{K_0+\alpha_k R}\right\rangle \text{x } exp\left[\alpha\left\langle\frac{\sigma_v}{K_0+\alpha_k R}\right\rangle^{n+1}\right]$$

isotropic Hardening

$$\dot{R}=b(Q-R)\,\dot{p}+\gamma_r(Q_\gamma-R)^m\,sgn(Q_\gamma-R)$$

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

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

$$\begin{cases}\dot{q}=\eta\,\mathrm{x}\,H(F)\,\mathrm{x}\,\langle n:n\rangle\,\dot{p}\\ \dot{\xi}=\sqrt{3/2}(1-\eta)\,\mathrm{x}\,H(F)\,\mathrm{x}\,\langle n:n\rangle\,\dot{p}\,n^*\end{cases}\quad\text{with: } n=\sqrt{\frac{3}{2}}\frac{\sigma-X}{J_2(\sigma-X)}\ ;\ n^*=\sqrt{\frac{3}{2}}\frac{\varepsilon^p-\xi}{J_2(\varepsilon^p-\xi)}$$

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

Kinematic hardening $X=X_1+X_2$

$$\dot{X}_i=2/3\,C_i\dot{\varepsilon}^p-\gamma_i\left[\delta_i X_i+(1-\delta_i)(X_i:n)n\right]\dot{p}-\gamma_{X_i}\left[J_2(X_i)\right]^{m_i-1}X_i+\frac{1}{C_i}\frac{\partial C_i}{\partial T}X_i\dot{T}$$

$$\gamma_i=\gamma_i^0\left[a_\infty+(1-a_\infty)e^{-bp}\right]$$

Note:

$\tilde{\sigma}$ represent the deviator of the stresses, $J_2(Y)=\sqrt{3/2(Y:Y)}$ the second invariant of the tensor Y,
$H(F)$ the function of Heavyside and $\langle..\rangle$ the hooks of Mc Cawley ($\langle x\rangle=x$ if $x\geq 0$, 0 if not).
The variables q and ξ make it possible to take into account the effect of memory of hardening under cyclic loading. If $\eta=1$, the effect of memory is not modelized and the variables q and ξ are not considered in the resolution of the system ($q=0$). If not, there is the following condition on η : $0<\eta\leq 1/2$.
From a thermodynamic point of view, the variable of hardening X_i is associated with its dual variable α_i for the relation $X_i=\frac{2}{3}C_i\alpha_i$. The term while $\dot{T}$ intervening in the equation giving $\dot{X}_i$ makes it possible to treat the cases of loadings anisothermals for C_i function of the temperature.

4.7.1 Syntax

```
|  /  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]
                  ♦ N=      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   ♦       MU=,                [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 Key words factor MEMO_ECRO

This key word makes it possible to define the parameters associated with the effect of maximum memory of hardening in the elastoplastic behaviors or élasto-visco-plastics of Chaboche (cf [R5.03.04]). This key word is usable, jointly with key words CIN1_CHAB or CIN2_CHAB, to define the parameters necessary to 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 hardening by VISC_CIN2_MEMO.

The equations of the model are written via a field representing the maximum plastic strains reached:
$F(\varepsilon^p, \xi, q) = \frac{2}{3} J_2(\varepsilon^p - \xi) - q \leq 0$ with the law of evolution $\dot{\xi} = \frac{(1-\eta)}{\eta} \dot{q}\, n^*$
q of compute the evolution of the model hardening allows $R(p)$ by:
$\dot{R} = b(Q-R)\dot{p}$, $Q = Q_0 + (Q_m - Q_0)(1 - e^{-2\mu q})$
the being written plasticity criterion: $f(\sigma, R, X) = (\tilde{\sigma} - X_1 - X_2)_{eq} - R_0 - R(p)$

4.8.1 Syntax

```
|    MEMO_ECRO=_F (
                    ♦    MU        =MU                    [R]
                    ♦    Q_M   =QM                    [R]
                    ♦    Q_0   =Q0                    [R]
                    ◊    ETA   =   / eta              [R]
                              / 0.5,               [DEFAUT]
                     )
```

4.8.2 Driven

Opérandes = driven
Cœfficient of the exponential model
Q_M = Qm
Valeur of saturation of the parameter Q representing isotropic hardening
Q_0 = Q0
Valeur intiale of the parameter Q representing isotropic hardening
ETA = eta
Valeur allowing to modify the taking into account of the memory of the maximum plastic strain: the value $eta = 1/2$ corresponds to a total taking into account.

4.9 Key words factor CIN2_NRAD

This key word 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

```
|    CIN2_NRAD=_F (
                  ♦    DELTA1   =delta1                    [R]
                  ♦    DELTA2   =delta2                    [R]
                  )
```

4.9.2 Operands

DELTA1, 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 Key words factor TAHERI, TAHERI_FO

Définition 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:

$$\begin{cases} \dot{\varepsilon}^p = \frac{3}{2}\dot{p}\frac{\tilde{\sigma}-X}{(\tilde{\sigma}-X)_{eq}} \quad \text{avec} \quad (x)_{eq} = \left(\frac{3}{2}x^t x\right)^{1/2} \\ \sigma = \Lambda(\varepsilon-\varepsilon_p) \qquad R = D\left(A\|\varepsilon\|^{\alpha}+R_0\right) \\ (\sigma-X)_{eq}-R=0 \qquad X = C\left(S\varepsilon_p-\sigma_p\varepsilon_p^n\right) \\ \dot{\sigma}_p-\dot{R}-\dot{\widetilde{(X)}}_{eq}=0 \qquad \sigma_p = \text{Max}_t\left(X_{eq}+R\right) \\ \dot{\varepsilon}_p^n=0 \qquad D = 1-me^{-bp\left(1-\frac{\sigma_p}{S}\right)} \\ \qquad\qquad C = C_{\infty}+C_1 e^{-bp\left(1-\frac{\sigma_p}{S}\right)} \end{cases}$$

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

Les various parameters can depend on the temperature, in this case one will employ key word TAHERI_FO.

4.10.1 Syntax

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

Remarque:

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

4.11 Key words factors MONO_*

Définition of the coefficients of the models of single-crystal or polycrystalline behavior [R5.03.11]. Besides these characteristics, constant the elastics must be defined under key word ELAS or ELAS_ORTH .

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

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

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

the flow MONO_VISC1 relation is:

$$\Delta\gamma_s = g(\tau_s, \alpha_s, \gamma_s, p_s) = \left\langle \frac{|\tau_s - c\alpha_s| - R(p_s)}{K} \right\rangle^n \cdot \frac{\tau_s - c\alpha_s}{|\tau_s - c\alpha_s|}$$, the parameters are: c , K , n

the flow MONO_VISC2 relation is:

$$\Delta\gamma_s = g(\tau_s, \alpha_s, \gamma_s, p_s) = \left\langle \frac{|\tau_s - c\alpha_s - a\gamma_s| - R(p_s) + \frac{c}{2\mathrm{d}}(c\alpha_s)^2}{K} \right\rangle^n \cdot \frac{\tau_s - c\alpha_s - a\gamma_s}{|\tau_s - c\alpha_s - a\gamma_s|}$$

the parameters are then: c , K , n , a , d

kinematic hardening can be form MONO_CINE1 :

$\Delta\alpha_s = h(\tau_s, \alpha_s, \gamma_s, p_s) = \Delta\gamma_s - d\,.\,\alpha_s\,.\,\Delta p_s$ with for parameter: d .

or MONO_CINE2 :

$\Delta\alpha_s = h(\tau_s, \alpha_s, \gamma_s, p_s) = \Delta\gamma_s - d\,.\,\alpha_s\,.\,\Delta p_s - \left(\frac{|c\alpha_s|}{M}\right)^m \frac{\alpha_s}{|\alpha_s|}$, the parameters being then: d , M and m .

Isotropic hardening can for example be form MONO_ISOT1: $R_s(p_s) = R_0 + Q\left(\sum_{r=1}^{N} h_{sr}\left(1 - e^{-bp_r}\right)\right)$ with h_{sr} matrixes of interaction, the parameters are h , Q , R_0 , b .

Or MONO_ISOT2 :

$R_s(p_s) = R_0 + Q_1\left(\sum_{sg} h_{sr} q^{ls}\right) + Q_2 q^{2s}$, with $dq^{is} = b_i\left(1 - q^{is}\right).dp$ the parameters are h , Q_1 , Q_2 , b_1 , b_2 , R_0 .

The equations relating to crystal models MONO_DD_KR, MONO_DD_CFC, MONO_DD_CFC_IRRA, MONO_DD_FAT, MONO_DD_CC, MONO_DD_CC_IRRA resulting from the dynamics of dislocations are described in the document [R4.03.11].

4.11.1 Syntaxe

Ces relations are accessible in *Code_Aster* in 3D, plane strains (D_PLAN), plane stresses (C_PLAN) (via the algorithm of Borst) and axisymmetric (AXIS) starting from key word COMP_INCR of command STAT_NON_LINE. The choice of the relations making it possible to build models it behavior of monocrystal is carried out via operator DEFI_COMPOR [U4.43.05].

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

 | MONO_VISC2 = _F  (
    ♦ C=C    ,          [R]
    ♦ K=K    ,         [R]
    ♦ N=n    ,          [R]
    ♦ A=a    ,         [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 the materials DC, families CUBIQUE1 and CUBIQUE2 (interaction between the 24 systems of sliding)

| MONO_DD_KR = _F (
♦ K = K, [R] Constante de Boltzmann, formulates eV/K
♦ TAUR= taur, [R] Shearing stress with $T=0\mathrm{K}$
♦ TAU0= tau0, [R] initial Critical stress of shears
♦ GAMMA0= gammap0, [R] initial Velocity D flow
♦ DELTAG0= deltaG0, [R] Gain of energy to the crossing of obstacle
♦ BSD = BsurD [R] function of the size of the grain B/Dc
♦ GCB = GCsurB [R] outdistances critical annihilation GC/Bc
♦ KDCS = K, [R] relating to the direction of dislocation
♦ P = p, [R] depend on the shape of the obstacle
♦ Q= Q, [R] depend on the shape of obstacle

Définition 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 the materials CFC, family OCTAERIQUE (interaction enters the 12 systems of sliding)

| MONO_DD_CFC = _F (
◊ GAMMA0= gammap0 [R] initial Velocity, by defect $0{,}001\,s^{-1}$
♦ TAU_F = tauf [R] Seuil, in unit of stresses
◊ A= A [R] parameter A, without unit, by defect 0.13
◊ B = B [R] parameter B, without unit, by defect 0.005
◊ N =N [R] exponent n, must be large (>50), by defect 200
♦ Y =Y [R] parameter Y, in unit of length
◊ ALPHA=a [R] hardening parameter $alpha$, by defect 0.35
◊ BETA =b [R] hardening parameter b, by defect 0.35
♦ RHO_REF = rho_ref, parameter rho_ref, in unit of length m^{-2}

Définition of the specific matrix of interaction (cf [R5.03.11])
/ ◊ H= H, [R]
/ ◊ H1= a*, [R] by defect 0.124
◊ H2 = a_colinéaire [R] by defect 0.625
◊ H3 = a_glissile, [R] by defect 0.137
◊ H4 = a_Lomer [R] by defect 0.122
◊ H5 = a_Hirth [R] by defect 0.07

| MONO_DD_CFC_IRRA = _F (same key words as MONO_DD_CFC, except:

♦DZ_IRRA = $\zeta \geq 0$ [R] parameter managing the evolution of φ_s^{voids}
♦XI_IRRA = $\xi \geq 0$ [R] parameter managing the evolution of ρ_s^{loops}
♦ALP_VOID= α_{voids} [R] parameter managing the evolution of τ_s^{forest}
♦ALP_LOOP = α_{loops} [R] parameter managing the evolution of τ_s^{forest}
♦RHO_SAT = $\rho_{sat} b^2 = \omega_{sat}$ [R] limiting with saturation of $\omega_s^{loops} = b^2 * \rho_s^{loops}$
♦PHI_SAT = φ_{sat} [R] limiting with saturation of φ_{voids}

| MONO_DD_FAT = _F (
♦ GAMMA0= gammap0 [R] initial Rate of flow in s-1

♦ TAU_F = tauf [R] Seuil, in unit of stresses
♦ BETA= B [R] Constante de Burgers b , in unit of length
♦ N =N [R] exponent n , must be large (>50)
♦ UN_SUR_D = 1/D [R] parameter function of the size of grain, in unit of 1/length
♦ GC0=gc0 [R] outdistances critical annihilation, in unit of length
♦ K = K [R] parameter relative to the mean free path of dislocations, without unit

```
# Définition of the specific matrix of interaction (cf [R5.03.11])
/  ◊  H=  H,              [R]
/  ◊  H1= a*,             [R] by defect 0.124
    ◊ H2 = a_colinéaire   [R] by defect 0.625
    ◊ H3 = a_glissile,    [R] by defect 0.137
    ◊ H4 = a_Lomer        [R] by defect 0.122
    ◊ H5 = a_Hirth        [R] by defect 0.07
```

behavior specific with materials DC with low and high temperature, family CUBIQUE1 (interaction between the 12 systems of sliding)

| MONO_DD_CC = _F (
♦B = B [R] parameter B, in unit of length
♦GH= H [R] parameter H, in unit of 1/time
♦DELTAG0 = ΔG_0 [R] energy of activation
♦TAU_0 = τ_0 [R] ultimate threshold, in unit of stresses
♦TAU_F = τ_F [R] initial threshold, in unit of stresses
♦ GAMMA0= $\dot{\gamma}_0$ [R] Vites of flow initial,
♦ N =N [R] expo sant n ,
♦ RHO_MOB= ρ_{mob} [R] density of mobile dislocations, in unit of length ** - 2
♦ D=D [R] parameter D, in unit of length
♦ BETA [R] parameter D, without unit
♦ 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] Constante de Boltzmann, in energy/K, ex: eV/K
♦DELTA1 [R] LIFO parameter allowing the variation of Y_AT with tau_eff
♦DELTA2 [R] parameter allowing the variation of a_AT with tau_eff
♦DEPDT [R] parameter/dT for the computation of DeltaG

```
    # Définition 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 with materials DC with low and high temperature, family CUBIQUE1 (interaction enters the 12 systems of sliding) with influence of “irradiation (specific densities of dislocation):

| MONO_DD_CC_IRRA = _F (same key words 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 Δp

4.12 Mots formula factor LEMAITRE, LEMAITRE_FO

Définition of the coefficients of the nonlinear relation of viscoplasticity of Lemaitre [R5.03.08].

The equations are the following ones:

$$\begin{cases} \dot{\varepsilon}_{ij}^{v} = \frac{3}{2}\dot{p}\frac{\tilde{\sigma}_{ij}}{\sigma_{eq}} \\ \dot{p} = \left[\frac{1}{K}\frac{\sigma_{eq}}{p^{1/m}}\right]^{n} \\ \sigma = \Lambda\left(\varepsilon - \varepsilon^{v}\right) \end{cases}$$

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

4.12.1 Syntax

```
| / LEMAITRE= _F (
                  ♦ N          =  N,                [R]
                  ♦ UN_SUR_K   =1 /K ,              [R]
                  ◊ UN_SUR_M   =  / 1/m,            [R]
                                  / 0.0,            [DEFAUT]
                )

  / LEMAITRE_FO = _F (
                  ♦ N          =  N,                [function]
                  ♦ UN_SUR_K   =1 /K ,              [function]
                  ♦ UN_SUR_M   =1 /m,            [function]
                    )
```

Remarque:

While taking $\frac{1}{m}=0$ (that is to say $m=+\infty$), i.e. while putting 0 behind operand UN_SUR_M, one obtains a nonlinear relation of viscoelasticity of Norton.

4.13 Key word factor VISC_SINH

Définition of the coefficients of the model of viscosity defined by the following viscoplastic potential:

$$\Phi^{vp} = \Phi^{p} - \sigma_0 \, sh^{-1}\left[\left(\frac{\dot{p}}{\dot{\varepsilon}_0}\right)^{\frac{1}{m}}\right]$$

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

$$\dot{p} = \dot{\varepsilon}_0\left[sh\left(\frac{\langle \Phi_p \rangle}{\sigma_0}\right)\right]^{m}$$

statement in which $\langle x \rangle$ indicates the positive part of x and Φ_p the plastic threshold.
This model of viscosity can be associated:

- With key word ROUSSELIER to define constitutive law ROUSS_VISC
- In key words VMIS_ISOT_TRAC and VMIS_ISOT_LINE version SIMO_MIEHE : to define constitutive laws VISC_ISOT_TRAC and VISC_ISOT_LINE.

The coefficients to be introduced are: m, ε_0 and $\sigma_0 > 0$.

4.13.1 Syntax

```
|  VISC_SINH = _F    (
                  ♦   M=m          ,
                  ♦  EPSI_0=epsi0     ,                [R]
                  ♦  SIGM_0=sigma0                     [R]
                  )
```

4.14 Key word LEMA_SEUIL

Définition of the coefficients of the nonlinear 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 the strains into an elastic part, a thermal part, an unelastic part (known) and a viscous part. The equations are then:

$$\varepsilon_{tot} = \varepsilon_e + \varepsilon_{th} + \varepsilon_a + \varepsilon_v$$
$$\sigma = A(T)\,\varepsilon_e$$
$$\dot{\varepsilon}_v = g(\sigma_{eq}, \lambda, T)\frac{3}{2}\frac{\tilde{\sigma}}{\sigma_{eq}}$$

with:

λ : cumulated viscous strain $\dot{\lambda} = \sqrt{\frac{2}{3}\dot{\varepsilon}_v : \dot{\varepsilon}_v}$

$\tilde{\sigma}$: deviator of the stresses $\tilde{\sigma} = \sigma - \frac{1}{3}Tr(\sigma)I$

σ_{eq} : equivalent stress $\sigma_{eq} = \sqrt{\frac{3}{2}\tilde{\sigma} : \tilde{\sigma}}$

$A(T)$: elasticity tensor

and:

so $D \leq 1$ then $g(\sigma, \lambda, T) = 0$ (purely elastic behavior)

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

Avec: $D = \frac{1}{S}\int_0^t \sigma_{eq}(u)\,du$

The material characteristics with informing by the user are A and S.

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

The Young modulus E and the Poisson's ratio ν are those provided under the key words factors ELAS or ELAS_FO.

4.14.1 Syntax

```
| / LEMA_SEUIL = _F (
                  ♦  A = A,                          [R]
                  ♦  S = S                           [R]
                  )
  / LEMA_SEUIL_FO =_F (
                  ♦  A = A,                          [function]
                  ♦  S = S                           [function]
                  )
```

4.15 Key word factor VISC_IRRA_LOG

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

The formulation is the following one (into uniaxial):

$$\varepsilon_f = A.\exp\left(-\frac{Q}{T}\right).\sigma.\ln\left(1+\omega.\phi t\right)+B.\exp\left(-\frac{Q}{T}\right).\sigma.\phi t$$

ε_f	axial strain of creep
Q	energy of activation
T	temperature of activation (in $°K$)
σ	stress axial applied to the tube guides
ϕt	neutron flux ($10^{+20} neutrons/cm^2$)
ω	time-constant
A, B	Syntaxe

4.15.1 constants

```
| VISC_IRRA_LOG =_F    (

                  ◊  A        =   /1.28D-1 ,       [DEFAUT]
                                  /a ,             [R]
                  ◊ B=            /  0.01159,      [DEFAUT]
                                  /b ,             [R]
                  ♦ FLUX_PHI=  phi,                [R]
                  ◊ CSTE_TPS=  W,              [R]
                  ◊ ENER_ACT=  Q,              [R]
                 )
```

4.16 Key word factor GRAN_IRRA_LOG

Définition of a creep model 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 fluence Φ_t expressed in $10^{24} neutrons/m^2$.

4.16.1 Syntax

```
| GRAN_IRRA_LOG =_F  (
                 ◊  A          =  /  1.28D-1,       [DEFAUT]
                                  /a  ,             [R]
                 ◊  B          =  /  0.01159,       [DEFAUT]
                                  /b  ,             [R]
                 ♦  FLUX_PHI=  phi,                 [R]
                 ◊  CSTE_TPS=  W,              [R]
                 ◊  ENER_ACT=  Q,              [R]
                 ◊  GRAN_FO=   Fct_g,             [function]
                 )
```

4.17 Mots key factor IRRAD3M

Constitutive law of steels under irradiation (cf [R5.03.23]).
The plastic model having to describe itself in the form $K^*(p+p_0)^n$, it is necessary of compute these parameters starting from $R02$ RM, $EPSILON_U$ and $KAPPA$ via a method of dichotomy.

4.17.1 Syntax

```
| IRRAD3M = _F   (
                 ♦ R02=           R02,                [function]
                 ♦ EPSI_U=        eps I,              [function]
                 ♦ RM=         RM                  [function]
                 ♦ AI0=           AIO                 [R]
                 ◊ ZETA_F=        y0                  [function]
                 ♦ ETAI_S=        stay,               [R]
                 ♦ RG0=           R  ,                [function]
                 ♦ ALHA=       ALPHA,              [R]
                 ♦ PHI0=       PHI0,            [R]
                 ◊ KAPPA=      /KAPPA                 [R]
                                /0.8                  [DEFAUT]
                 ◊ ZETA_G=        z0,                 [function]
                 ◊ TOLER_ET=   /inc                [R]
                                /0.15                 [DEFECT]
                )
```

4.17.2 Operands R02/RM/EPSI_U/KAPPA

```
R02=       R02
EPSI_U=    eps I _u
RM=     RM
KAPPA=  KAPPA
```

Paramètres intervening in the plastic part of the model. R02 is the elastic limit with 0.2% of plastic strain, Rm is the ultimate containte, and epsi_u is lengthening distributed.

```
TOLER_ET=  Inc
```

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

4.17.3 Operands AI02/ZETA_F/ETAI_S

```
AI0=       AIO,
ZETA_F=    y0  .
ETAI_S=    stay,
```

Paramètres related to the irradiation. y0 is a function of the temperature.

4.17.4 Operands RG0/ALPHA/PHI0/ZETA_G

```
ALPHA=      ALPHA,
PHI0=       PHI0,
RG0=           R,
ZETA_G=        z0
```

Paramètres related to swelling.

4.18 Key words factor ECRO_COOK, ECRO_COOK_FO

Model of plasticity with criterion of Von Mises and isotropic hardening following a model of Johnson-Cook.

4.18.1 Syntax

```
|   / ECRO_COOK =_F   (
                  ♦A=A             ,                    [R]
                  ♦B=B             ,                    [R]
                  ♦C=C             ,                    [R]
                  ♦N_PUIS=n        ,                    [R]
                  ♦M_PUIS=m        ,                    [R]
                  ♦EPSP0=epsp0        ,                 [R]
                  ♦TROOM=troom        ,                 [R]
                  ♦TMELT=tmelt        ,                 [R]
                   )
|   / ECRO_COOK_ FO =_F  (
                     ♦A=A             ,                    [function]
                     ♦B=B             ,                    [function]
                     ♦C=C             ,                    [R]
                     ♦N_PUIS=n        ,                    [R]
                     ♦M_PUIS=m        ,                    [R]
                     ♦EPSP0=epsp0        ,                 [R]
                     ♦TROOM=troom        ,                 [R]
                     ♦TMELT=tmelt        ,                 [R]
                    )
```

4.18.2 Opérandes

the curve of hardening is deduced from the uniaxial curve connecting the strains to the stresses, whose statement is:

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

This statement can be rewritten in the following way:

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

Where:

$$\dot{p}^{*}=\begin{cases}\dfrac{\dot{p}}{\dot{p}_0} & \text{si} \quad \dot{p}\geq\dot{p}_0\\ 1 & \text{si} \quad \dot{p}\leq\dot{p}_0\end{cases} \text{ and } T^{*}=\begin{cases}\dfrac{T-T_{room}}{T_{melt}-T_{room}} & \text{si} \quad T\geq T_{room}\\ 0 & \text{si} \quad T\leq T_{room}\end{cases}$$

5 Comportements related to the damage and key

5.1 the Mots fracture factor ROUSSELIER, ROUSSELIER_FO

Définition of the coefficients of the model of behavior of ductility fracture of Rousselier (cf [R5.03.06] and [R5.03.07]). This model can be used in small strains, in large deformation and in viscoplasticity (key word VISC_SINH)

Brièvement, one solves for an elastoplastic increment:

$$\begin{cases} \dfrac{\sigma_{eq}}{\rho} - R(p) + D\,\sigma_1 f \exp\left(\dfrac{\sigma_H}{\sigma_1}\rho\right) = 0 \\ \sigma = \rho\,\Lambda\left(\varepsilon - \varepsilon^p\right) \\ \dot{\varepsilon}_p = \dot{p}\,\rho\dfrac{\partial f}{\partial \sigma} \\ \dot{f} = 3(1-f)\,\varepsilon_H^p \end{cases}$$ éq 5.1-1

with
$$\begin{cases} \dfrac{\partial f}{\partial \sigma} = \dfrac{1}{\rho}\left(\dfrac{3}{2}\dfrac{\tilde{\sigma}}{\sigma_{eq}} + \dfrac{Df}{3}\exp\left(\dfrac{\sigma_H}{\sigma_1\rho}\right)\right) \\ \rho = \dfrac{1-f}{1-f_0} \end{cases}$$ éq 5.1-2

$R(p)$ input via the traction diagram (key word TENSION).

With the coefficients materials D, σ_1, f_0 specific to the model of ROUSSELIER.

These various parameters can depend on the temperature, in this case one will employ key word ROUSSELIER_FO.

It is possible to supplement models it while utilizing the following quantities:

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

  $$\dot{f} = 3\,A(1-f)\,\varepsilon_H^p \quad si\ f > f_c$$

  two additional characteristics are then necessary: f_c and A .

- the limiting porosity f_l beyond which the material is considered broken. The behavior is then overridden by an imposed fall of the stresses:

  $$\dot{\sigma} = -\lambda\,E\,\frac{\sigma}{|\sigma|}|\dot{\varepsilon}| \quad si\ f = f_l$$ (with E definite under ELAS).

  two additional characteristics are then necessary: f_1 and λ .

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

  $$\begin{cases} \dfrac{\sigma_{eq}}{\rho} - R(p) + D\,\sigma_1\left(f + A_n\,p\right)\exp\left(\dfrac{\sigma_H}{\sigma_1\rho}\right) = 0 \\ \rho = \dfrac{1-f-A_n\,p}{1-f_0} \end{cases}$$

These the last five parameters are independent of the temperature.
The following table of correspondence must be used:

Modelization	Word-keys
D	D
σ_1	SIGM_1
f_0	PORO_INIT
f_c	PORO_CRIT dp
A	PORO_ACCE
A_n	AN
f_l	PORO_LIMI
λ	D_SIGM_EPSI_NORM

Dans version SIMO_MIEHE the constitutive law requires a recutting when the increment of plastic strain is higher than the value dp provided behind key word DP_MAXI.
Key word BETA is with being informed with 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.

5.1.1 Syntax

```
| /ROUSSELIER =
  /ROUSSELIER_FO =_F (
                  ♦ D              =D     ,          [R] or [function]
                  ♦ SIGM_1         =      sigma1,    [R] or [function]
                  ♦ PORO_INIT      =f0    ,          [R] or [function]
                  ◊ PORO_CRIT=            /  1.D0,      [DEFAUT]
                                       /fc,          [R]
                  ◊ PORO_ACCE=            /  1.D0,      [DEFAUT]
                                       /A ,          [R]
                  ◊ AN=                   /  0.D0,      [DEFAUT]
                                       /An,
                  ◊ PORO_LIMI=            /  0,999,     [DEFAUT]
                                       /fl,          [R]
                  ◊ D_SIGM_EPSI_NORM=/  1.D0,       [DEFAUT]
                                        /lambda  ,    [R]
                  ◊ DP_MAXI=           /  0.1,       [DEFAUT]
                                       /dp,          [R]
                  ◊ BETA=              /  0.85,      [DEFAUT]
                                       /beta        [R]
            )
```

5.2 key Mots VENDOCHAB / VENDOCHAB_FO

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

$$\begin{cases} \sigma=(1-D)\,A\varepsilon^{e} \text{ et } \varepsilon^{e}=\varepsilon-\varepsilon^{th}-\varepsilon^{p} \\ \dot{\varepsilon}^{p}=\frac{3}{2}\,\dot{p}\,\frac{\tilde{\sigma}}{\sigma_{eq}} \text{ avec } \dot{p}=\frac{\dot{r}}{(1-D)} \\ \dot{r}=\left(\frac{\sigma_{eq}-S(1-D)}{(1-D)\,Kr^{1/M}}\right)^{N} \\ \dot{D}=\left(\frac{\chi(\sigma)}{A}\right)^{R}(1-D)^{-k(\chi(\sigma))} \end{cases}$$

with D , the scalar variable of isotropic damage and:

$$\chi(\sigma)=\alpha J_0(\sigma)+\beta J_1(\sigma)+(1-\alpha-\beta)J_2(\sigma)$$

where:

$J_0(\sigma)$ is the maximum principal stress

$J_1(\sigma)=Tr(\sigma)$

$J_2(\sigma)=\sigma_{eq}$

$\langle x\rangle$: positive part of x , $\tilde{\sigma}$ deviator of the stresses and σ_{eq} the von Mises stress.

5.2.1 Syntax

```
   | / VENDOCHAB=
     / VENDOCHAB_FO=    _F (
                      ♦ SY=SY           ,                [R]    or
[function]
                      ♦ ALPHA_D=alpha   ,          [R] or [function]
                      ♦ BETA_D=beta       ,            [R] or [function]
                      ♦ A_D=ad          ,                [R]    or
[function]
                      ♦ R_D=rd          ,                [R]    or
[function]
                      ♦ K_D=kd                           [R]    or
[function]
                    )
```

the table below summarizes the correspondences between the symbols of the equations and the key words of *Aster*.

Parameter Symbole	material in the equations	Key word in *Aster*
Seuil of viscoplasticity	S	"SY"
Coefficient 1 of the equivalent stress of creep	α	"ALPHA_D"
Coefficient 2 of the equivalent stress of creep	β	"BETA_D"
Coefficient of damage model	A	"A_D"
exposing Premier of damage model	R	"R_D"
exposing Deuxième of damage model	$k\left[\chi\left[\sigma\right]\right]$	"K_D"

Remarque:

*Parameter K_D can be defined like a constant, a function of a parameter "TEMP" or a three-dimensions function (variable of temperature and stress $\chi(\sigma)$). In this case, use DEFI_NAPPE with like first parameter "TEMP" for the temperature in $°C$ and like second parameter "X" (**compulsory**) for the stresses in $\chi(\sigma)$ MPa. If K_D depends only on $\chi(\sigma)$, it is necessary to use DEFI_NAPPE in any case by introducing for example 2 times the same data file in stress for two values different from the temperature.*

5.3 Key words VISC_ENDO / VISC_ENDO_FO

Définition of the coefficients of the viscoplastic model of Lemaître with scalar damage VISC_ENDO_LEMA cf [R5.03.15]), which corresponds to a simplified and optimized version model VENDOCHAB (cf [U4,51,11]).

$$\begin{cases} \sigma=(1-D)A\varepsilon^e \text{ et } \varepsilon^e=\varepsilon-\varepsilon^{th}-\varepsilon^p \\ \dot{\varepsilon}^p=\frac{3}{2}\dot{p}\frac{\tilde{\sigma}}{\sigma_{eq}} \text{ avec } \dot{p}=\frac{\dot{r}}{(1-D)} \\ \dot{r}=\left(\frac{\frac{\sigma_{eq}}{(1-D)}-\sigma_y}{Kr^{1/M}}\right)^N \qquad \dot{D}=\left(\frac{\sigma_{eq}}{A(1-D)}\right)^R \end{cases}$$

5.3.1 Syntax

```
   | / VISC_ENDO=
     / VISC_ENDO_FO=     _F (
                       ♦ SY=sy                          [R]    or
[function]
                       ♦ A_D=ad          ,              [R]    or
[function]
                       ♦ R_D=rd          ,              [R]    or
[function]
                     )
```

the table below summarize the correspondences between the symbols of the equations and the key words of *Aster*.

Parameter Symbole	material in the equations	Key word in *Aster*
Seuil of viscoplasticity	σ_y	"SY"
Coefficient of damage model	A	"A_D"
Premier exposing of damage model	R	"R_D"

5.4 Key word HAYHURST

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

$$
\begin{cases}
\sigma=(1-D)\,\boldsymbol{C}\,\varepsilon^{e} \text{ et } \varepsilon^{e}=\varepsilon-\varepsilon^{th}-\varepsilon^{p} \\
\dot{\varepsilon}^{p}=\dfrac{3}{2}\,\dot{p}\,\dfrac{\tilde{\sigma}}{\sigma_{eq}} \text{ avec } \dot{p}=\dot{\varepsilon}_{0}\sinh\left(\dfrac{\sigma_{eq}(1-H)}{K(1-D)(1-\phi)}\right) \quad \text{avec} \quad \dot{\phi}=\dfrac{k_{c}}{3}(1-\phi)^{4} \\
\text{si S\_EQUI\_D}=0 \quad \dot{D}=\dot{A}_{0}\sinh\left(\dfrac{\alpha<\sigma_{1}>_{+}+\sigma_{eq}(1-\alpha)}{\sigma_{0}}\right) \\
\text{si S\_EQUI\_D}=1 \quad \dot{D}=\dot{A}_{0}\sinh\left(\dfrac{\alpha<tr(\sigma)>_{+}+\sigma_{eq}(1-\alpha)}{\sigma_{0}}\right) \\
H=H_{1}+H_{2} \\
\dot{H}_{i}=\dfrac{h_{i}}{\sigma_{eq}}\left(H_{i}^{*}-\delta_{i}H_{i}\right)\dot{p} \quad i=1,2
\end{cases}
$$

5.4.1 Syntax

```
| / HAYHURST= _F (
            ♦ EPS0=      ε̇0              [R]
            ♦ K=         K ,             [R]
            ♦ H1=        h1 ,            [R]
            ♦ H2=        h2 ,            [R]
            ♦ DELTA1=    δ1 ,            [R]
            ♦ DELTA2=    δ2 ,            [R]
            ♦ H1ST=      H1* ,           [R]
            ♦ H2ST=      H2* ,           [R]
            ♦ BIGA=      Ȧ0 ,            [R]
            ♦ SIG0=      σ0 ,            [R]
            ◊ ALPHAD=      / 0           [DEFAUT]
                         / α             [R]
            ◊ KC=        / 0             [DEFAUT]
                         / kc ,          [R]
            ◊ S_EQUI_D=    / 0           [DEFAUT]
                           /1            [R]
          )
```

5.5 Key word factor RUPT_FRAG, RUPT_FRAG_FO

the theory of the fracture of Frankfurt and Marigo makes it possible to modelize the appearance and the propagation of cracks in brittle fracture. It lean on the criterion of Griffith which compares the restitution of elastic strain energy and the energy dissipated during the creation of a fissured surface, provided by key word GC. This key word, defines all alone with material RUPT_FRAG is used for the behavior of the same name. GC Associé with the other parameters of material RUPT_FRAG is intended for the cohesive constitutive laws, CZM_* (see [R7.02.11]).

5.5.1 Syntax

```
◊  |  /  RUPT_FRAG=_F      (
                    ♦ GC=gc                    ,              [R]
                    ◊ SIGM_C          =sigm  ,          [R]
                    ◊ PENA_ADHERENCE=pad     ,          [R]
                    ◊ PENA_CONTACT    =  /pco,          [R]
                                         /1. ,          [DEFECT]
                    ◊ PENA_LAGR       =  /pla           [R]
                                         /100. ,           [DEFECT]
                    ◊ RIGI_GLIS       =  /pgl,          [R]
                                         /10. ,        [DEFECT]
                    ◊ KINEMATICAL     =  /"UNILATER",   [DEFECT]
                                         /"GLIS_2D",   [TXM]
                                         /"GLIS_1D",   [TXM]
                  )
      / RUPT_FRAG_FO=_F       (
                    ♦ GC              =gc,             [function]
                    ◊ SIGM_C          =sigm  ,         [function]
                    ◊ PENA_ADHERENCE=pad     ,         [function]
                      PENA_CONTACT    =pco   ,         [function]
                    ◊ KINEMATICAL     =  /"UNILATER",   [DEFECT]
                                         /"GLIS_2D",   [TXM]
                                         /"GLIS_1D",   [TXM]
                  )
```

5.5.2 Opérande G_C

dissipated energy is proportional to the crack surface created, the proportionality factor being the density of energy critical of the material G_c .

5.5.3 Critical operand

SIGM_C Forced in the beginning from which the crack will open and the stress between the lips decrease.

5.5.4 Operand PENA_ADHERENCE

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

Note:

Parameters SIGM_C and PENA_ADHERENCE are only compulsory in the case of the modelizations 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

Petit parameter of regularization of the contact.

5.5.6 Operands PENA_LAGR and RIGI_GLIS

Paramètre of penalization of Lagrangian ($pla \geq 1.01$) and rigidity in mode of sliding.

5.5.7 KINEMATICAL operand

Détermine modes of opening authorized by the model of interface for model CZM_TAC_MIX. "UNILATER" means that two volumes on both sides of the application interface cannot interpenetrate, "GLIS_2D" that two volumes can only slide in the tangent plane with the application interface, and "GLIS_1D" which it can slide only in only one direction.

The tangent reference considered is defined via the key word factor MASSIF of AFFE_CARA_ELEM [U4.42.01]. In the case of a unidimensional sliding, the only direction of possible sliding is defined by the second vector of the swivelled reference (Oy).

5.6 Key word factor NON_LOCAL

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

5.6.1 Syntax

```
| NON_LOCAL=_F          (
                ◊  LONG_CARA=long             ,       [R]
                ◊  C_GRAD_VARI=long       ,       [R]
                ◊  COEF_RIGI_MINI=coef    ,      [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

Détermine the length characteristic or scales length internal to the material. A do not use with the damage models not room with gradient of damage GRAD_VARI.

C_GRAD_VARI = long

Paramétre of nonlocality for the formulation with gradient of intern variable, present in the free energy in the form $c/2(\nabla a)^2$. It determines the length characteristic of the area of damage. To exclusively use with the damage models not room with gradient of damage GRAD_VARI.

COEF_RIGI_MINI = coeff

A as for him an algorithmic role since it fixes, for the models of damage which degrade the rigidity of the 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.

C_GONF = gonf

Dans models it of Rousselier, the lenitive character is carried by the porosity which has a purely hydrostatic effect. To control the localization, the idea is to regularize the problem only on this part and thus to regularize the variable of swelling if modelization INCO_GD is used.

PENA_LAGR = pena

Paramètre of penalization used for the modelizations with gradients of intern 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 Gauss points (intern variable or strain).
A value by default of 1000 is established. For the modelization _DIL it is disadvised decreasing this value (loss of accuracy for the resolution). For modelization GRAD_VARI this parameter corresponds

to the multiplier r of the quadratic term of penalization in the free energy: $r/2(\alpha-a)^2$. It is to user to adjust his value according to the model used.

5.7 Key word factor CZM_LAB_MIX

This key word factor makes it possible to specify the parameters of the model of steel-concrete application 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]
                     ◊ KINEMATICAL     =  /"GLIS_1D",    [DEFECT]
                                          /"GLIS_2D",    [TXM]
                                          /"UNILATER",   [TXM]
                    )
```

5.7.2 bearable Opérande

SIGM_C Maximum stress by the steel-concrete interface.

5.7.3 Operand GLIS_C

Glissement for which the stress with the application interface is maximum.

5.7.4 Operand ALPHA and BETA

Paramètres of form of the model of steel-concrete bond. alpha varies typically between 0 and 1, while beta is positive.

5.7.5 Operands PENA_LAGR

Paramètre of penalization of Lagrangian ($pla \geq 1.01$) .

5.7.6 KINEMATICAL operand

Détermine permitted by law modes of sliding of application interface. "UNILATER" means that two volumes on both sides of the application interface cannot interpenetrate, "GLIS_2D" that two volumes can only slide in the tangent plane with the application interface, and "GLIS_1D" which it can slide only in only one direction.

The tangent reference considered is defined via the key word factor MASSIF of AFFE_CARA_ELEM [U4.42.01]. In the case of a unidimensional sliding, the only direction of possible sliding is defined by the second vector of the swivelled reference (Oy).

5.8 Key word factor RUPT_DUCT

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

5.8.1 Syntax

```
◊   |   /   RUPT_DUCT=_F       (
                     ♦ GC=gc                    ,          [R]
```

```
                    ♦ SIGM_C          =sigm  ,       [R]
                    ♦ COEF_EXTR=coee           ,       [R]
                    ♦ COEF_PLAS       =coep  ,       [R]
                    ◊ PENA_LAGR       =  /pla        [R]
                                         /100. ,       [DEFECT]
                    ◊ RIGI_GLIS       =  /pgl,       [R]
                                         /10. ,     [DEFAUT]
                  )
```

5.8.2 Opérande G_C

dissipated energy is proportional to the crack surface created, the proportionality factor being the density of energy critical of the material G_c .

5.8.3 Critical operand

SIGM_C Forced in the beginning from which the crack will open.

5.8.4 Operands COEF_EXTR and COEF_PLAS

Paramètres of form of cohesive model CZM_TRA_MIX see [R7.02.11].

5.8.5 Operands PENA_LAGR and RIGI_GLIS

Paramètre of penalization of Lagrangian ($pla \geq .01$) and rigidity in mode of sliding.

5.9 Key word factor JOINT_MECA_RUPT

the modelization of joints of the stoppings lean on this material [R7.01.25]. The hydrostatic pressure due to the possible presence of fluid in the joint is taken into account. The procedure of injection of the concrete under pressure (keying-up) is also implemented. This key word material is used by the constitutive law of the same name: JOINT_MECA_RUPT.

5.9.1 Syntax

```
◊    | JOINT_MECA_RUPT  =_F     (
                    ♦ K_N=kn                  ,          [R]
                    ◊ K_T=kt                  ,          [R]
                    ♦ SIGM_MAX=sigm           ,       [R]
                    ◊ ALPHA           =  /alpha,     [R]
                                         /1. ,       [DEFAUT]
                    ◊ PENA_RUPTURE    =   pru,       [R]
                    ◊ PENA_CONTACT    =  /pco,       [R]
                                         /1. ,       [DEFAUT]
                    ◊ PRES_FLUID=        pflu        [function]
                    ◊ PRES_CLAVAGE    =   pcla,      [function]
                    ◊ RHO_FLUIDE      =   rho,       [R]
                    ◊ VISC_FLUIDE=       vflu        [R]
                    ◊ OUV_MIN         =   oumi,      [R]
)
```

5.9.2 Opérande K_N

normal Rigidity in tension.

5.9.3 Operand K_T

Tangencial stiffness.

5.9.4 Critical operand

SIGM_MAX Forced maximum from which the crack opens and the stress between the lips decrease. This stress is often called tensile strength.

5.9.5 Operand ALPHA

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

$L_{CT} = L_C \tan(ALPHA\,\pi/4)$

5.9.6 Operand PENA_RUPTURE

Paramètre of brittle smoothing of fracture. The maximum opening before the complete fracture is given by $L_C = SIGM\_MAX(1 + PENA\_RUPTURE)/K\_N$

5.9.7 Opérande PENA_CONTACT

Rapport between normal rigidity in compression and tension.

5.9.8 Operand PRES_FLUIDE

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

5.9.9 Operand PRES_CLAVAGE

Pressure of concrete injected into the joint during the phase of keying-up (function which can depend on geometrical coordinates or time). Only valid with the modelizations joined mechanical: *_JOINT, and incompatible with RHO_FLUIDE, VISC_FLUIDE and OUV_MIN.

5.9.10 Operand RHO_FLUIDE

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

5.9.11 Operand VISC_FLUIDE

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

5.9.12 Operand OUV_MIN

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

5.10 Key word factor JOINT_MECA_FROT

the modelization of friction between the joints of the stoppings lean 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 model Mohr-Coulomb, which depends on five parameters. Two elastic parameters: tangential stiffness and normal stiffness. Two parameters characterizing the function threshold: bond and the coefficient of kinetic friction. More one parameter of regularization of the tangent matrix in sliding. This key word material is used by the constitutive law of the same name: JOINT_MECA_FROT.

5.10.1 Syntax

```
◊    | JOINT_MECA_FROT  =_F     (
                       ♦ K_N=kn                ,          [R]
                       ◊ K_T=kt                ,          [R]
```

```
♦ MU              =mu,       [R]
◊ ADHESION        =  /C,        [R]
                     /0. ,      [DEFECT]
◊ PENA_TANG       =  /pta,      [R]
                     /kt*1E-6, [DEFAUT]
◊ PRES_FLUID=        pflu       [function]
◊ RHO_FLUIDE      =   rho,      [R]
◊ VISC_FLUIDE=       vflu       [R]
◊ OUV_MIN         =   oumi,     [R]
)
```

5.10.2 Opérande K_N

normal Rigidity.

5.10.3 Operand K_T

Tangencial stiffness in the elastic domain.

5.10.4 Operand MU

Coefficient of kinetic friction.

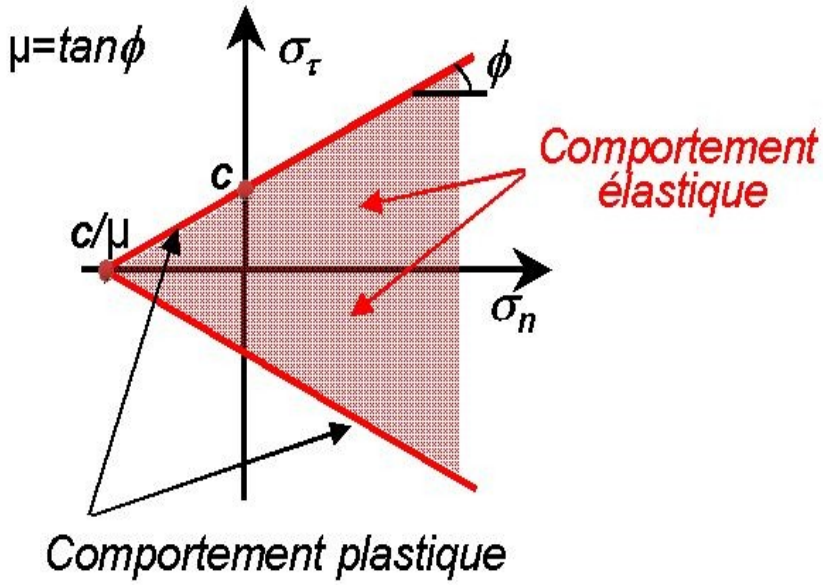
5.10.5 Operand ADHESION

Forced of friction to null normal stress. Tensile strength is given then by:

$R_T = C / \mu$

5.10.6 Operand PENA_TANG

Paramètre of regularization of the tangent matrix in sliding, 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 sliding, it should be checked that computation is not sensitive to the value of this parameter.



5.10.7 Operand PRES_FLUIDE

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

5.10.8 Operand RHO_FLUIDE

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

5.10.9 Operand VISC_FLUIDE

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

5.10.10 Operand OUV_MIN

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

5.11 Key word factor CORR_ACIER

model CORR_ACIER is a model of reaction of the steel, subjected to corrosion in reinforced concrete structures. This model is developed in 1D and elastoplastic 3D endommageable with isotropic hardening and lean on models it of Lemaître [R7.01.20].

$$\begin{cases} \dfrac{\sigma_{eq}}{1-D}-R(p)-\sigma_y>0 \\ \dot{\varepsilon}^p=\dfrac{3}{2}\dfrac{\dot{\lambda}}{1-D}\dfrac{\tilde{\sigma}}{\sigma_{eq}} \\ \dot{r}=\dot{\lambda}=\dot{p}(1-D) \\ R=kp^{1/m} \end{cases}$$

In the plastic range $D=0$, if not $D=\dfrac{Dc}{p_R-p_D}(p-p_D)$

5.11.1 Syntaxe

```
◊  |  CORR_ACIER = _F  (

                        ♦ D_CORR=dc        ,              [R]
                        ♦ ECRO_K=k         ,              [R]
                        ♦ ECRO_M=m         ,              [R]
                        ♦ SY=sy                           [R]
                        )
```

5.11.2 Opérande D_CORR

critical Coefficient of damage.

5.11.3 Operands ECRO_K, ECRO_M

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

5.11.4 Operand SY

initial Elastic limit, noted σ_y in the equations.

5.12 Key word factor ENDO_HETEROGENE

model ENDO_HETEROGENE is an isotropic model of damage representing the training and the propagation of the cracks [R5.03.24]. The presence of crack in structure is modelized by lines of

broken elements ($d=1$). The fracture of the elements can be caused either by the priming of a new crack, or by propagation. This model is adapted to the heterogeneous materials (for example clay).

5.12.1 Syntax

```
◊   | ENDO_HETEROGENE  =_F     (
                       ♦ WEIBULL=w           ,          [R]
                       ♦ SY=sy                  ,          [R]
                       ♦ KI=ki                  ,          [R]
                       ♦ EPAI=ep                ,          [R]
                       ◊ GR              =   /gr.,       [R]
                                             /1. ,       [DEFAUT]
                      )
```

5.12.2 Opérande WEIBULL

Paramètre associated with the Weibull model.

5.12.3 Operand SY

initial Elastic limit, noted σ_y in the equations.

5.12.4 Operand KI

Tenacity K_{IC} .

5.12.5 Operand EPAI

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

5.12.6 Operand GR

Graine of the random hard copy defining the initial defects. Allows to obtain a single result for each command file. If the seed is null, the hard copy will be really random and will differ with each launching. By default, the value is equal to 1.

6 Thermal behaviors

Les various behaviors thermal are excluded mutually.

6.1 Key words factor THER, THER_FO

Définition of the constant linear thermal characteristics or function defined by a concept of the standard function of 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 Opérandes LAMBDA / RHO_CP

isotropic LAMBDA =

lambda thermal Conductivity.

RHO_CP = voluminal

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

$$cp\,\dot{T} - \mathrm{div}\left(\lambda\,.\,grad\,T\right) = f$$

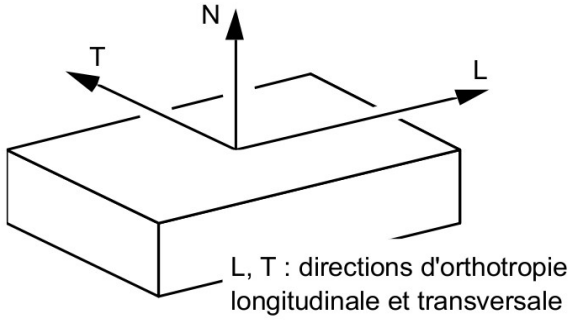
6.2 Key word factor THER_ORTH

Définition of the thermal characteristics for an orthotropic material.

The player 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 shells or the nonisotropic 3D.



L, T : directions d'orthotropie
longitudinale et transversale

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

thermal LAMBDA_L =
lal Conductivity in the longitudinal meaning.
Thermal LAMBDA_T =
lat Conductivity in the transverse meaning.
Thermal LAMBDA_N =
lan Conductivity in the normal meaning.
RHO_CP = voluminal
CP Heat.

6.3 Key word factor THER_NL

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

$$\dot{\beta} - (\lambda(T).grad\,T) = f$$

6.3.1 Syntax

```
/THER_NL   = _F   (
                / ◊    BETA=beta     ,       [function]
                 /RHO_CP     =cp     ,       [function]
                 ♦LAMBDA=lambda         ,    [function]
                )
```

6.3.2 Opérandes BETA / LAMBDA / RHO_CP

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

RHO_CP = voluminal
CP Heat.

Thermal LAMBDA =

lambda Conductivity isotropic function of the temperature.

Note:

It is not possible to use a formula for these three parameters of the material because the algorithm needs in computation er for 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 aid command CALC_FONC_INTERP.

6.4 Key words factor THER_COQUE, THER_COQUE_FO

Permet to define membrane and transverse conductivities and the heat capacity for homogenized heterogeneous thermal shells.

Directions 1 and 2 indicate those of the 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 l1, l2 and l3. The coefficients are thus defined by the user in the reference of orthotropy of the plate.

The code makes then the change of reference to find the proper values in the reference of the element.

6.4.1 Syntax

```
/ THER_COQUE
/ THER_COQUE_FO = _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 Opérandes COND_LMM / COND_LMP / COND_LPP / COND_LSI / COND_TMM / COND_TMP / COND_TPP / COND_TSI

P1, P2, P3 indicate the interpolation functions of the temperature in the thickness.
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_LMP = a1112
term related to the integral of l1*P1*P2
COND_LPP = 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 Opérandes 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_NMP = b12
term related to the integral of l3*P1*P2
COND_NPP = b22
term related to the integral of l3*P2*P2
COND_NSI = b23
term related to the integral of l3*P2*P3

6.4.4 Opérandes 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 RHOCP*P1*P1
CMAS_MP = c12
term related to the integral of RHOCP*P1*P2
CMAS_PP = c22
term related to the integral of RHOCP*P2*P2
CMAS_SI = c23
term related to the integral of RHOCP*P2*P3

7 Comportements specific to the concretes

7.1 Key word factor THER_HYDR

Permet 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].

$$\left.\begin{aligned}&\frac{d\beta}{dt}+div\,q=Q\frac{d\xi(T)}{dt}+s\\&q=-\lambda\,grad\,T\end{aligned}\right\}\quad \text{éq 7.1-1}$$

$$\frac{d\xi}{dt}=AFF(\xi,T)\qquad \text{éq 7.1-2}$$

7.1.1 Syntax

```
| THER_HYDR=_F          (
                  ♦ LAMBDA=lambda       ,       [function]
                  ◊ BETA=beta           ,       [function]
                  ♦ AFFINITE=AFF        ,       [function]
                  ♦ CHALHYDR=Q          ,          [R]
                 )
```

7.1.2 Opérandes LAMBDA / BETA

thermal LAMBDA =

lambda Conductivity isotropic function of the temperature.

BETA = voluminal

Enthalpie beta 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 AFFINITE

AFFINITE = AFF

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

$\mathrm{AFF}(\xi,T)=A(\xi)\,exp\left(-\frac{E_a}{RT}\right)$ with $\mathrm{QSR\_K}=\frac{E_a}{R}$ the constant of Arrhénius expressed in Kelvin degree, and A determined by a calorimetric test of the concrete (function of quantity 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 Key word factor SECH_GRANGER

Définition 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 computation, i.e. the current C water concentration, (as thermal conductivity depended on the temperature).

7.2.1 Syntax

```
| SECH_GRANGER =_F   (
                    ♦ A=a          ,                  [R]
                    ♦ B=b          ,                  [R]
                    ♦ QSR_K=QsR          ,               [R]
                    ♦ TEMP_0_C=T0      ,                 [R]
                   )
```

7.2.2 Operands A / B / QSR_K / TEMP 0 C

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

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

A= has

Coefficient of diffusion varying from $0.5\,10^{-13}$ and $2.10^{-13}m^2/s$ for the concrete.

B= B

Coefficient about 0.05 for the concrete.

QSR_K= QsR

QsR is worth in general $4700.K$. (R is the constant of perfect gases).

TEMP_0_C= T0

Reference temperature in the model of Arrhénius. The reference temperature $T0$ is **in degrees Celsius**, and converted into Kelvin at the time of the resolution.

7.3 Key word factor SECH_MENSI

Définition 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 computation, i.e. the current C water concentration, (as thermal conductivity depended on the temperature). It is a formulation simplified of the general case, constituting the model of Mensi.

7.3.1 Syntax

```
| SECH_MENSI = _F   (
                    ♦ A =a      ,                  [R]
                    ♦ B =b      ,                  [R]
                      )
```

7.3.2 Operands A / B

Ces coefficients make it possible to express the coefficient of diffusion according to the model of Mensi:

$$D(C)=a.e^{(b.C)}$$

A= has

Coefficient of diffusion varying from $0.5.10^{-13}$ and $2.10^{-13}m^2/s$ for the concrete.

B= B

Coefficient about 0.05 for the concrete.

7.4 Key word factor SECH_BAZANT

Définition 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 computation, i.e. the current C water concentration, (as thermal conductivity depended on the temperature). This formulation constitutes the model of Bazant.

7.4.1 Syntax

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

7.4.2 Opérandes D1 / ALPHA_BAZANT / N / FONC_DESORP

Ces coefficients make it possible to express the coefficient of diffusion according to the model of Bazant:

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

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

D1 = d1

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

ALPHA_BAZANT = Coefficient

alpha varying from 0.025 with 0.1 for the concrete.

N = N

Exposant of about 6 for the concrete.

FONC_DESORP = desorp

Courbe 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 computation* C *, the concentration out of water, which is comparable for the resolution with a temperature, of type "TEMP" .*

7.5 Key word factor SECH_NAPPE

the coefficient of diffusion, characterizing the nonlinear equation of drying, is expressed using a three-dimensions function, tabulated function of the water concentration, variable of computation, and temperature, variable auxiliary of computation, given in the form of a structure of data of the evol_ther type. For the resolution of drying by operator THER_NON_LINE, the concentration out of water is comparable with a temperature, of type "TEMP".

For the coherence of the data, parameters of the three-dimensions function, i.e. the variable of computation 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

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

7.5.2 Opérande FUNCTION

the coefficient of diffusion is expressed using a tabulated function of the parameters C and T.
FUNCTION = nom_fonc

Nom of the three-dimensions function.

7.6 Key word factor PINTO_MENEGOTTO

Définitions of the coefficients of the cyclic behavior model of elastoplasticity of 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:

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

  (ε cannot exceed ε_u)

the curve $s = f\left(e\right)$ in $n^{ième}$ the cycle is defined by:

$$\sigma_L^* = b\,\varepsilon_L^* + \left(\frac{1-b}{\left(1+\left(\varepsilon_L^*\right)^R\right)^{1/R}}\right)\varepsilon_L^* \text{ with } R = R_0 - \frac{a_1 \xi}{a_2 + \xi}$$

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

where e^* is defined by: $\varepsilon^* = \frac{\varepsilon - \varepsilon_r^{n-1}}{\varepsilon_y^n - \varepsilon_r^{n-1}}$.

where σ^* is defined by: $\sigma^* = \frac{\sigma - \sigma_r^{n-1}}{\sigma_y^n - \sigma_r^{n-1}}$.

The quantity e_y^n is deducted of the cycle $n-1$ by:

$$\varepsilon_y^n = \varepsilon_r^{n-1} + \frac{\sigma_y^n - \sigma_r^{n-1}}{E}$$
$$\sigma_y^n = \sigma_y^{n-1}.sign\left(\varepsilon_y^{n-1} - \varepsilon_r^{n-1}\right) + \varepsilon_H\left(\varepsilon_r^{n-1} - \varepsilon_y^{n-1}\right)$$

The variable ξ is defined by:

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

where ε_r^{n-1} the strain reached at the end of the ème $n-1$ semi-cycle represents

and ε_y^{n-1}, ε_y^n represent the strains of end of linearity of the semi-cycles $n-1$ and n.

b represent either the value provided by the user (key word EP_SUR_E) or, with defect:

$$b=\frac{E_H}{E} \quad \text{avec} \quad E_H=\frac{\sigma_u-\sigma_y}{\varepsilon_u-\frac{\sigma_y}{E}}$$

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

- in compression one overrides b by $b_c=a\left(5.0-L/D\right)e^{\left(b\xi'\frac{E}{\sigma_y-\sigma_\infty}\right)}$
- in tension, one computes a new slope $E_r=E\left(a_5+\left(1.0-a_5\right)e^{\left(-a_6\left(\varepsilon_r^{n-1}-\varepsilon_y^{n-1}\right)\right)}\right)$ with $a_5=1+\frac{5-L/D}{7.5}$.

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

In the case of buckling, one adds to σ_y^n the value $\sigma_s^*=\gamma_s b E\frac{b-b_c}{1-b_c}$ with $\gamma_s=\frac{11-L/D}{10\left(e^{\frac{cL}{D}}-1\right)}$.

7.6.1 Syntax

```
| PINTO_MENEGOTTO = _F (
                  ♦ SY=sigm                 ,       [R]
                  ♦  EPSI_ULTM=epsu         ,       [R]
                  ♦ SIGM_ULTM=sigmu         ,       [R]
                  ◊ ELAN=         /  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        [DEFAUT]
                )
```

7.6.2 Opérandes

SY = sigm

initial Elastic limit, noted σ_y in the equations.

EPSI_ULTM = epsu, noted ε_u in the equations.

Ultimate strain.

SIGM_ULTM = sigmu, noted σ_u in the equations.

Ultimate stress.

◊ELAN = L/D

Slenderness of the bar (>5: buckling).

EPSP_HARD = epsh, noted ε_h in the equations.

Strain corresponding at the end of the plastic bearing.

◊EP_SUR_E = B

Ratio slope of 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 γ_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. per defect).

The Young modulus E and thermal coefficient of thermal expansion ALPHA are to be specified by key words ELAS or ELAS_FO.

7.7 Key words factor BPEL_BETON, BPEL_ACIER

Définition of the characteristics intervening in the model of behavior of the cables of prestressed [R7.01.02].

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

7.7.1 Syntax

```
| /BPEL_BETON      = _F    (
                  ◊ PERT_FLUA=          /  xflu,      [R]
                                      /0 . ,        [DEFECT]
                  ◊ PERT_RETR=          /  xret,      [R]
                                      /0 .         [DEFAUT]
                 )
  /BPEL_ACIER    = _F    (
                  ◊ RELAX_1000=       /  rh1000,    [R]
                                      /0 . ,        [DEFECT]
                  ◊ MU0_RELAX=          /  mu0,       [R]
                                      /0 . ,        [DEFECT]
                  ◊ F_PRG=fprg                ,       [R]
                  ◊ FROT_COURB=       /  F,         [R]
                                      /0 . ,        [DEFECT]
                  ◊ FROT_LINE=          /  phi ,      [R]
                                      /0 .         [DEFECT]
                 )
```

7.7.2 Operands

Behavior: BPEL_BETON

Word-key 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 key word factor can be used only jointly with the key word factor ELAS.

PERT_FLUA = xflu

Standard rate of loss of tension by creep of the concrete, compared to the initial tension.
$\Delta F_{flu} = x_{flu} . F_0$ where F_0 indicates 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 xflu 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 structure and r_m the average radius).

PERT_RETR = xret

Standard rate of loss of tension by shrinking of the concrete, compared to the initial tension.
$\Delta F_{ret} = x_{ret} . F_0$ where F_0 indicates 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 xret 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 structure and r_m the average radius).

Behavior: BPEL_ACIER

Word-key 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 key word factor can be used only jointly with the key word factor ELAS.

RELAX 1000 = rh1000

Relaxation 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.

MU0_RELAX = mu0

adimensional Coefficient of relieving of prestressed steel. The value by default is 0.

F_PRG = fprg

Forced guaranteed maximum loading with fracture (according to the BPEL)
If one takes account of the losses of tension by relieving of steel (RELAX 1000 informed by a non-zero value), it is obligatorily necessary to inform operand F_PRG, by a non-zero value.

FROT_COURB = F

Coefficient of kinetic friction of the cable on the partly curved concrete, in rad^{-1} . The value by default is 0.

FROT_LINE = phi

Coefficient of kinetic friction per unit of length, partly right. The value by default is 0.

7.8 Key word factor BETON_DOUBLE_DP

models It behavior 3D developed in *Code_Aster* is formulated in the frame of the thermo - plasticity, for the description of the nonlinear behavior of the concrete, in tension, and 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].

7.8.1 Syntax

```
| 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=Gt       ,          [function]
                    ♦ COEF_ELAS_COMP=phi      ,       [function]
                    ◊ LONG_CARA        =  will l_cara,   [R]
                    ◊ ECRO_COMP_P_PIC=  /"LINEAIRE" , [DEFECT]
                                         /"PARABOLE", [TXM]
                    ◊ ECRO_TRAC_P_PIC=  /"LINEAIRE", [DEFECT]
                                         /"EXPONENT" [TXM]
                  )
```

Les functions can depend on the following command variables:
"TEMP", "INST", "HYDR", "SECH".

BETON_DOUBLE_DP makes it possible to define all the characteristics associated with the constitutive law with double criterion with Drücker Prager. In complement of these characteristics, the elasticity modulus, the Poisson's ratio, and the thermal coefficient of thermal expansion α, as well as the coefficients of endogenous shrinkage and shrinkage of desiccation, must be defined under key word ELAS for the real coefficients, or ELAS_FO, for the coefficients defined by functions, or three-dimensions functions. All the characteristics of the model, $(E, nu, \alpha, f'c, f't, \beta. Gc, Gt)$ on 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 θ, which is stored for each point of Gauss, in the form of intern variable. This makes it possible to take into account the irreversible variations of these characteristics at high temperature.

7.8.2 Operands F_C / F_T / COEF_BIAX

F_C= *F'C*

Résistance in uniaxial pressing f'_c.

F_T= *F'T*

Résistance in uniaxial tension f'_t.

COEF_BIAX= *beta*

the report of the strength in biaxial compression to resistance in uniaxial pressing β.

7.8.3 Operands ENER_COMP_RUPT / ENER_TRAC_RUPT / COEF_ELAS_COMP

ENER_COMP_RUPT= *Gc*

the energy of fracture in compression G_c,

ENER_TRAC_RUPT= *WP*

the energy of fracture in tension G_t.

COEF_ELAS_COMP= *phi*

the 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.

7.8.4 Operands LONG_CARA

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

$$\kappa_u(\theta)=\frac{2.G_t(\theta)}{l_c.f_t'(\theta)}$$

In the particular case of a mesh containing of the adjacent meshes from which dimensions are very different, ultimate hardenings of 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 stress state. (This characteristic length is computed 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 computed for each mesh. The value by default of *Code_Aster* is the characteristic length computed 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 meaning of variation of the stress field, and to use the length characteristic computed automatically according to the size of the meshes. The overload by LONG_CARA must be to reserve for particular cases, when the user cannot freely intervene on the mesh.

If the user defines the characteristic length in the material, it will choose a couple $(G_t, \text{LONG\_CARA})$ such as $\frac{2.G_t(\theta)}{l_c.f_t'(\theta)}$ is worth the value which it wishes for ultimate hardening in tension κ_u. (The usual value of the strain associated with ultimate hardening in tension with an average concrete is of $5.E-4$).

7.8.5 Operands ECRO_COMP_P_PIC / ECRO_TRAC_P_PIC

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

```
ECRO_COMP_P_PIC=     /   "LINEAIRE"
                     /   "PARABOLE"
```

Forme of the curved post-peak in compression of type text, which can take values "LINEAIRE" and "PARABOLE". The nonlinear curve is then of parabolic type.

```
ECRO_TRAC_P_PIC=     /   "LINEAIRE"
                     /   "EXPONENT"
```

Forme of the curved post-peak in tension of type text, which can take values "LINEAIRE" and "EXPONENT". The nonlinear curve is then of exponential type.

7.9 Key word factor GRANGER_FP, GRANGER_FP_INDT, V_GRANGER_FP

Définition of the parameters materials for the viscoelastic model of Granger, modelizing the clean creep of the concrete. There exist 3 behavior models: the first GRANGER_FP does not take into account the phenomenon of aging, the second GRANGER_FP_INDT is identical without effect of the temperature, the third V_GRANGER_FP gives an account of the aging. Cf [R7.01.01].
In 1D and creep, models it is written: $\varepsilon_{fl}(t)=J(t,tc,T,h).\sigma_0$ with

$$J(t,t_c,T,h)=h.\frac{T-(T_{ref}-45)}{45}.k(tc_{eq}).\sum_{s=0}^{n}J_s\left(1-exp\left(\frac{t_{eq}-t_c}{\tau_s}\right)\right)$$

t_c load time indicates

$h=c^{-1}(C)$, or c is the isothermal curve of desorption make it possible to pass from drying C to the hygroscopy h.

$$t_{eq}(t)=\int_{s=t_0}^{t} exp\left(-\frac{U_c}{R}\left(\frac{1}{T(s)}-\frac{1}{293}\right)\right)ds$$

$k\left(tc_{eq}\right)=\frac{28^{0.2}+0.1}{tc_{eq}^{0.2}+1}$ if one takes into account the phenomenon of aging, $k\left(tc_{eq}\right)=1$ if not

$$tc_{eq}(t_c)=\int_{s=t_0}^{t_c} \exp\left(-\frac{u_v}{R}\left(\frac{1}{T(s)}-\frac{1}{T_{ref}}\right)\right)ds$$

Remarques:

T_{ref} is the reference temperature, it is chosen by the user using command AFFE_MATERIAU.
This behavior can be associated with the effects of dilation and thermal shrinkage defined by operands K_DESSIC and B_ENDOGE under key word ELAS_FO.

For GRANGER_FP_INDT*, the temperature does not intervene. Thus the multiplicative term* $\frac{T-(Tref-45)}{45}$ *is removed, just as the dependence of* $t_{eq}(t)$ with the temperature.

7.9.1 Syntax for clean creep

```
| GRANGER_FP = _F    (
                    ◊ J1=J1          ,                [R]
                    ◊ J2=J2          ,                [R]
                    ◊ J3=J3          ,                [R]
                    ◊ J4=J4          ,                [R]
                    ◊ J5=J5          ,                [R]
                    ◊ J6=J6          ,                [R]
                    ◊ J7=J7          ,                [R]
                    ◊ J6=J8          ,                [R]
                    ◊ TAUX_1=tau1      ,              [R]
                    ◊ TAUX_2=tau2      ,              [R]
                    ◊ TAUX_3=tau3      ,              [R]
                    ◊ TAUX_4=tau4      ,              [R]
                    ◊ TAUX_5=tau5      ,              [R]
                    ◊ TAUX_6=tau6      ,              [R]
                    ◊ TAUX_7=tau7      ,              [R]
                    ◊ TAUX_8=tau8      ,              [R]
                    ◊ QSR_K=qsr                       [R]
                   )
```

7.9.2 Opérandes 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 coefficients of “delay” of the creep function, homogeneous at a time.

QSR_K=Uc /R

Constante energy of activation intervening in equivalent the time term teq modelizing the effect of the temperature on the kinetics of creep.

7.9.3 Syntax for clean creep independent of the temperature

syntax is identical to the case with effect of the temperature, without key word QSR_K.

7.9.4 Syntax for the aging

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

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

7.9.5 Opérandes for the aging

QSR_VEIL = USR

Constante energy of activation intervening in equivalent the time term of load tceq modelizing the effect of the temperature on the aging $\frac{u_v}{R}$.

FONC_V = K (tceq)

Function of aging.

7.10 Key word LABORD_1D

This model of nonlinear behavior of the concrete is employed in situations uniaxial under the effect of monotonic loadings and cyclic. The model is described in the thermodynamic frame of formulation of the irreversible processes. It makes it possible to take account of the damage of the concrete in tension and in compression, separately, manages the opening and the Re-closing of cracks, and takes account of the nonreversible strain.

This model was developed to be employed with the multifibre beam elements [R7.01.07].

Note:

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

7.10.1 Syntax

```
◊  |  LABORD_1D=    _F  (
                    ♦ Y01=Y01            ,              [R]
                    ♦ Y02=Y02            ,              [R]
                    ♦ A1=A1        ,                 [R]
                    ♦ A2=A2        ,                 [R]
                    ♦ B1=B1        ,                 [R]
                    ♦ B2=B2        ,                 [R]
                    ♦ BETA1=beta1      ,             [R]
                    ♦ BETA2=beta2      ,             [R]
                    ♦ SIGF=sigf                      [R]
                    )
```

7.10.2 Opérandes

Y01=Y01

Seuil of evolution of the variable of damage under tension

Y02=Y02

Seuil of evolution of the variable of damage under compression

A1=A1

multiplying Paramètre describing the kinetics of evolution of the variable of damage under tension

A2=A2

multiplying Paramètre describing the kinetics of evolution of the variable of damage under compression

B1=B1

Paramètre of power describing the kinetics of evolution of the variable of damage under tension

B2=B2

Paramètre of power describing the kinetics of evolution of the variable of damage under compression

BETA1=beta1

Paramètre describing the amplitude of the anelastic strain under tension

BETA2=beta2

Paramètre describing the amplitude of the anelastic strain under compression

SIGF= sigf

Paramètre indicating the stress of opening and crack reclosing

7.11 Key word factor MAZARS, MAZARS_FO

models It 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 tension 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 shears.

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

7.11.1 Syntax

```
MAZARS= _F (
     ♦ EPSD0=        epsd0,                                    [R]
     ♦ AC=           ac,                                       [R]
     ♦ AT=           At,                                       [R]
     ♦ BC=           Bc,                                       [R]
     ♦ BT=           LT,                                       [R]
     ♦ K=            K,                                        [R]
     ♦ CHI=          chi,                                      [R]
      ◊ SIGM_ELS=    sgels                                    [R]
     ◊ EPSI_ELU=     epelu                                     [R]
)

MAZARS_FO = _F (
     ♦ EPSD0=        epsd0,                              [function]
     ♦ AC=           ac,                                 [function]
     ♦ AT=           At,                                 [function]
     ♦ BC=           Bc,                                 [function]
     ♦ BT=           LT,                                 [function]
     ♦ K=            K,                                  [function]
     ♦ CHI=          chi                                       [R]
)
```

Les functions can depend on the following command variables: "TEMP", "HYDR", "SECH".

MAZARS (or MAZARS_FO) makes it possible to define all the characteristics associated with the model with behavior with Mazars. Besides these characteristics, constant the elastics must be defined under key word 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
Seuil of damage in strain $(0.5\,10^{-4} < \varepsilon_{d0} < 1.5\,10^{-4})$.

♦ AC = ac
Coefficient allowing to fix the pace of the curved post-peak in compression. Introduced a horizontal asymptote which is the axis of ε 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 tension. Introduced a horizontal asymptote which is the axis of ε 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 stress ($BC < 10^4$) or a preliminary phase of increase in stress followed by a more or less fast decrease (generally $10^3 < Bc < 2.10^3$).

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

♦ K = K
Paramètre introducing a horizontal asymptote in pure shears. It lies between 0 and 1. Advised value $0,7$.

7.11.3 Operand CHI

♦ CHI = chi
Dans the frame of coupling BETON_UMLV_FP with the model of MAZARS. The parameter chi makes it possible 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_ELS, EPSI_ELU

◊ SIGM_ELS = sgels
Définition of the ultimate stress of service.

◊ EPSI_ELU = epelu
Définition of the ultimate limiting strain.

The operands SIGM_ELS and ESPI_ELU make it possible to define the limits which correspond to the limiting states of service and ultimate, classically used at the time of study in civil engineer. These limits are compulsory when the behavior mazars_1D IS USED (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 Key word BETON_UMLV_FP

creep model UMLV supposes a total decoupling between the spherical and deviatoric components: the strains induced by the spherical stresses are purely spherical and the strains induced by the deviatoric stresses are purely deviatoric [R7.01.06]. In addition, the clean strain of creep is supposed to be proportional to internal relative moisture:

Spherical part: $\varepsilon^s = h \cdot f\left(\sigma^s\right)$ and, left deviatoric: $\underline{\underline{\varepsilon}}^d = h \cdot f\left(\underline{\underline{\tilde{\sigma}}}\right)$

Where h indicates internal relative moisture.

The model of behavior BETON_UMLV_FP is a nongrowing old viscoelastic model developed in partnership with Université of the Marne-the-Vallée 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 stresses are at the origin of the migration of the water absorptive with the application 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 strain of creep is thus written as the sum of a reversible part and an irreversible part:

$$\varepsilon^{fs} = \underbrace{\varepsilon_r^{fs}}_{\substack{partie \\ réversible}} + \underbrace{\varepsilon_i^{fs}}_{\substack{partie \\ irréversible}}$$

The process of strain spherical of creep is controlled by the following system of equations coupled:

$$\begin{cases} \dot{\varepsilon}^{fs} = \dfrac{1}{\eta_r^s} \cdot \left[h \cdot \sigma^s - k_r^s \cdot \varepsilon_r^{fs} \right] - \dot{\varepsilon}_i^{fs} \\ \dot{\varepsilon}_i^{fs} = \dfrac{1}{\eta_i^s} \left\langle \left[k_r^s \cdot \varepsilon^{fs} - \left(k_r^s + k_i^s \right) \cdot \varepsilon_i^{fs} \right] - \left[h\,\sigma^s - k_r^s \cdot \varepsilon_r^{fs} \right] \right\rangle^+ \end{cases}$$

where k_r^s rigidity indicates connect associated with the skeleton formed by blocks with hydrates on a mesoscopic scale; η_r^s viscosity connects associated with the mechanism with diffusion within capillary porosity; k_i^s indicate rigidity connect intrinsically associated with the hydrates on a microscopic scale and η_i^s viscosity connects associated with the interfoliaceous mechanism of diffusion.

(The hooks $\langle\,\rangle^+$ appoint the operator of Mac Cauley: $\langle x \rangle^+ = \dfrac{1}{2}\left(x + |x|\right)$)

The deviatoric stresses are at the origin of a mechanism of sliding (or mechanism of quasi dislocation) of the layers of HSC in nano-porosity. Under deviatoric stress, creep is carried out with constant volume. In addition, creep model UMLV supposes the deviatoric isotropy of creep. Phénoménologiquement, the mechanism of sliding comprises a viscoelastic reversible contribution of water strongly adsorbed to the layers of HSC and a viscous irreversible contribution of free water:

$$\underbrace{\underline{\underline{\varepsilon}}^{fd}}_{\substack{déformation \\ déviatorique \\ totale}} = \underbrace{\underline{\underline{\varepsilon}}_r^{fd}}_{\substack{contribution \\ eau \\ absorbée}} + \underbrace{\underline{\underline{\varepsilon}}_i^{fd}}_{\substack{contribution \\ eau \\ libre}}$$

The jème main component of the total deviatoric strain is governed by the system of equations following:

$$\tilde{\sigma}^j \left(1 + \frac{\eta_r^d}{\eta_i^d} \right) + \frac{k_r^d}{\eta_i^d} \tilde{\sigma}^j = \eta_r^d \ddot{\varepsilon}^{d,j} + k_r^d \dot{\varepsilon}^{d,j}$$

where k_r^d indicates rigidity associated with the capacitance with water absorptive to transmit loads (*load bearing toilets*); η_r^d viscosity associated with the water adsorbed by the layers with hydrates and η_i^d indicates viscosity associated with free water.

7.12.1 Syntax

```
| BETON_UMLV_FP:   _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 Opérande

K_RS=K_RS

k_r^s rigidity connects associated with the skeleton formed by blocks with hydrates on a mesoscopic scale

K_IS=K_IS

k_i^s rigidity connect intrinsically associated with the hydrates on a microscopic scale

K_RD=K_RD

k_r^d rigidity associated with the capacity with water adsorbed to transmit loads (*load bearing toilets*)

ETA_RS=ETA_RS

η_r^s viscosity connect associated with the mechanism with diffusion within capillary porosity

ETA_IS=ETA_IS

η_i^s viscosity connect associated with the mechanism with diffusion interlamellaire

ETA_RD=ETA_RD

η_r^d viscosity associated with absorptive water by the layers of hydrates

ETA_FD=ETA_FD

allows to take into account the creep of desiccation according to the model of Bazant.

Note:

> *The curve of desorption giving the hygroscopy h according to the water concentration C must be indicated under key word ELAS_FO.*

7.13 Key word factor BETON_ECRO_LINE

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

7.13.1 Syntax

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

7.13.2 Opérandes

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

SYT = sigt
Forced maximum in simple tension.

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

Young modulus E is to be specified by key words ELAS or ELAS_FO.

7.14 Key word factor ENDO_ORTH_BETON

Définition of the parameters of constitutive law 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 meaning of the parameters and the procedure of identification.

7.14.1 Syntax

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

7.14.2 Opérande ALPHA

Constante of coupling between the evolution of the damage of tension 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
Partie constant of the function threshold. Allows to gauge the height of the peak in tension.

K1 = k1
Paramètre of the function threshold allowing to increase the threshold in compression.

K2 = k2
Paramètre of control of the shape of the envelope of fracture for biaxial tests. The value by default is 7.10^{-4}.

7.14.4 Operands ECROB / ECROD

ECROB = ecrob
Terme of locked energy (equivalent to an energy of hardening) relating to the evolution of the damage of tension. Allows to control the shape of the peak in tension.

ECROD = ecrod
Terme of locked energy (equivalent to an energy of 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 ν are to be specified by key words ELAS or ELAS_FO.
In the case of a nonlocal computation with the formulation GRAD_EPSI, the characteristic length is to be specified behind key word NON_LOCAL.

7.15 Key word factor ENDO_SCALAIRE/ENDO_SCALAIRE_FO

Définition of the parameters of the constitutive law ENDO_SCALAIRE [R5.03.25], which describes the brittle elastic fracture of a homogeneous isotropic material. This model is available only for the modelization to gradient of damage GRAD_VARI.

7.15.1 Syntax

```
 | ENDO_SCALAIRE_FO
   ENDO_SCALAIRE =_F        (
                      ♦ K                 =  K,            [R] or [function]
                      ♦ P=                   p,             [R] or [function]
                      ♦ M=                   m,             [R] or [function]
                      ◊ C_COMP=                 /c_comp   ,    [R] or
[function]
                                                /0 ,           [DEFECT]
                      ◊ C_VOLU=                 /c_volu   ,    [R] or
[function]
                                                /1 ,           [DEFECT]
                      ◊ COEF_RIGI_MINI=         /A_min ,       [R]
                                                /1E-5  ,       [DEFAUT]
                    )
```

7.15.2 Opérande K, P, M

It acts of the internal parameters of the model which define hardening, to see [R5.03.25]: k indicate one density of energy Pa, k and m are parameters without dimension. k and m can be readjusted starting from the nonlocal scales D (roughly the half-width of tape of localization) and of the following macroscopic parameters: E the Young's modulus, G_f the energy of cracking and f_t the value of the stress to the peak in simple tension. The relations of retiming are written then:

$$k=\frac{3\,G_f}{4\,D};\quad m=\frac{3\,E\,G_f}{2\,f_t^2\,D};\quad c=\frac{3}{8}D\,G_f$$

where c indicated by NON_LOCAL is the parameter = _F (C_GRAD_VARI = c), which also depends on the macroscopic response. 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

It acts of 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 (symmetric) for which the surface of load corresponds to a datum line of the density of elastic strain energy (ellipsoidal of rotation around the axis $(1,1,1)$ which 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 stress to the peak in simple tension, f_c the value of the stress to the peak in simple compression and τ the value of the stress to the peak in pure shears. The relations of retiming are the following ones:

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

7.15.4 Operands COEF_RIGI_MINI

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

The Young modulus E and the Poisson's ratio ν are to be specified by key words ELAS or ELAS_FO.
The parameter of nonlocality is indicated under key word C_GRAD_VARI behind the key word factor NON_LOCAL. It is related to the macroscopic parameters by:

7.16 Key words factor GLRC_DM

This key word factor makes it possible to define the parameters of constitutive law GLRC_DM. It is about a model of total damage of a reinforced concrete slab formulated in term of relations strain/generalized stress (membrane extension, bending and membrane force, bending moment).

7.16.1 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]
                  ◊ EF        =Ef ,             [R]
                  ◊ NUF       =Nuf  ,           [R]
                  ◊ ALPHA_C=Alfc    ,           [R]
                              /1.0  ,           [DEFAUT]
                )
```

7.16.2 Opérandes

NYT = membrane
NT Force of the threshold of damage in simple tension of a reinforced concrete slab (unit of force per length).

NYC = membrane
Nc Effort of the threshold of “damage” (fine of linearity of the curve of compression) in simple compression of a reinforced concrete slab (unit of force per length).

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

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

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 ($0<\gamma_F<1$).

EF = Ef
Modulus Young effective in bending of a reinforced concrete slab.

NUF =Nuf
effective Poisson's ratio in bending of a reinforced concrete slab.

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

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

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

7.17 Key word BETON_REGLE_PR

This key word is used to define the parameters material used by behavior BETON_REGLE_PR (rule "Parabola-Rectangle"). This behavior is usable only in 2D (plane stresses or plane strains) or in shells (modelizations DKT, COQUE_3D) (see for example the test ssnp129a). It is reduced to a unidimensional behavior, which is written, in each principal direction of tensor 2D of the strains:

•In tension:
$$\begin{cases}\sigma = E\,\varepsilon & \text{si} \quad 0<\varepsilon<\dfrac{\sigma_y^t}{E}\\ \sigma = \sigma_y^t+E_T\left(\varepsilon-\dfrac{\sigma_y^t}{E}\right) & \text{si} \quad \dfrac{\sigma_y^t}{E}<\varepsilon<\dfrac{\sigma_y^t}{E}\left(1-\dfrac{E}{E_T}\right)\\ \sigma = 0 & \text{sinon}\end{cases}$$

•In compression:
$$\begin{cases}\sigma=\sigma_y^c\left[1-\left(1-\dfrac{\varepsilon}{\varepsilon_c}\right)^n\right] & \text{si} \quad \varepsilon>\varepsilon_c\\ \sigma=\sigma_y^c & \text{sinon}\end{cases}$$

7.17.1 Syntax

```
| BETON_REGLE_PR =_F (
                     ♦ DSIGM_EPSI   =  And          [R]
                     ♦ SYT          =Syt            [R]
                     ◊ SYC          =Syc            [R]
                     ◊ EPSC         =Epsc           [R]
                     ◊ N            =N          [  R]
                    )
```

7.17.2 Opérandes

DSIGM_EPSI = And
Modulates tangent post-peak in tension E_t (negative).

Ultimate SYT =
Syt Forced in tension σ_y^t.

Ultimate SYC =

Syc Forced in compression σ_y^c. It must be given positive.

EPSC = ultimate

Epsc Strain in compression ε_c. It must be given positive.

N =n

Exposant of the model of hardening in compression.

7.18 Key word JOINT_BA

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

This model must be employed with the elements "joined" in 2D [R3.06.09]. Steel reinforcements could be modelized with plane elements (QUAD4) or unidimensional (BAR).

Note:

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

7.18.1 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]
                    ♦ FA=alpha         ,              [R]
                    ♦ FC     =c ,                     [R]
                    ♦ EPSTR0=EPSN      ,              [R]
                    ♦ ADN    =adn      ,              [R]
                    ♦ BDN=           / bdn,           [R]
                                / 1.0               [DEFAUT]

                    )
```

7.18.2 Opérandes

HPEN=HPEN

Paramètre of penetration between surfaces by crushing of the concrete.
It is checked that $HPEN > 0.$.

GTT =GTT

Modulus of rigidity of connection.
It is checked that $G_{beton} \leq GTT \leq G_{acier}$.

GAMD0= Gam0
Seuil of perfect or limiting bond of elastic strain.
It is checked that $1.\mathrm{E}-4<Gam0<1.\mathrm{E}-2$.

AD1=ad1
Paramètre of evolution of the damage in region 1 (transition of the small strains to the great sliding).
It is checked that $1.\mathrm{E}-1<AD1<1.\mathrm{E}+1$.

BD1=bd1
Paramètre of power describing the evolution of the variable of damage in region 1 (transition of the small strains to the great sliding).
It is checked that $BD1<1.\mathrm{E}-1$.

GAMD2=Gam2
Seuil of the great sliding.
It is checked that $1.\mathrm{E}-4<Gam2<1.\mathrm{E}+0$.

AD2=ad2
Paramètre of evolution of the damage in region 2 (maximum resistance of connection and degradation in friction).
It is checked that $AD2<1.\mathrm{E}-6$.

BD2=bd2
Paramètre of power describing the evolution of the variable of damage in region 2 (maximum resistance of connection and degradation in friction).
It is checked that $BD2<1.\mathrm{E}-1$.

VIFROT=vifrot
Paramètre material describing the influence of the friction of cracks.
It is checked that $VIFROT<0.0E+0$.

FA=alpha
Paramètre material related to kinematic hardening by friction of cracks.
It is checked that $FA<0.0E+0$.

FC =c
Paramètre describing the influence of containment on the resistance of connection.
It is checked that $FC<0.0E+0$.

EPSTR0= EPSN
Seuil of elastic strain on the normal direction before the fracture. It is checked that $1.\mathrm{E}-4<EPSN<1.\mathrm{E}+0$.

ADN=adn
Paramètre of the damage in the normal direction by opening of crack.
It is checked that $ADN<1.\mathrm{E}-10$.

BDN=bdn
Paramètre of power describing the evolution of the variable of damage in the normal direction.
It is checked that $BDN<1.\mathrm{E}-1$.

7.19 Key word **BETON_RAG**

This model is used to consider the behavior long-term of structures affected by the reaction alkali-aggregate. It makes it possible to evaluate the strains and the anisotropic damage (cracking) of the works reached. It comprises a criterion of Rankine in tension 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 as Celsius, it is thus necessary to provide or of compute of the fields of temperature as Celsius.

7.19.1 Syntax

```
/BETON_RAG = F (
```

Caractéristiques of creep

```
◊ ACTIV_FL=      / creep,                          [R]
                 / 1.0,                            [DEFECT]
♦ K_RS=k1        ,                                    [R]
♦ K_IS=k2        ,                                 [R]
♦ ETA_RS=eta1s     ,                               [R]
♦ ETA_IS=eta2s       ,                                [R]
♦ K_RD=mu1         ,                                [R]
♦ K_ID=mu2         ,                                [R]
♦ ETA_RD=eta1d     ,                                [R]
♦ ETA_ID=eta2d       ,                              [R]
◊ EPS_0=         / eps0,                           [R]
                 / 0.0035,                         [DEFECT]
♦ TAU_0=tau0       ,                               [R]
◊ EPS_FL_L=      / evpmax,                         [R]
                 / 0.03,                           [DEFAUT]
```

Caractéristiques 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,                                [DEFAUT]
```

Caractéristiques of the coupling creep/skeleton and gel/skeleton

```
◊ A_VAN_GE=      / avg,                                [R]
                 / 0.0,                            [DEFECT]
◊ B_VAN_GE=      / bvg,                            [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,                            [DEFAUT]
```

Caractéristiques 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]
```

7.19.2 Opérandes

7.19.2.1 Opérandes related to the model of creep

ACTIV_FL = Variable

creep of activation of creep (necessary in a computation 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 and irreversible $k2$ part)

ETA_RS = eta1s / Spherical ETA_IS =

eta2s Viscosities ($eta1s$ for the reversible and irreversible $eta2s$ part)

K_RD = mu1 / K_ID = mu2

differed Shear moduli

ETA_RD = eta1d / ETA_ID = eta2d

deviatoric Viscosities ($eta1d$ for the reversible and irreversible $eta2d$ part)

EPS 0 = eps0

Déformation characteristic of viscoplasticity couples damage of tension. It takes the value 0.0035 by default.

TAU 0 = tau0

Temps characteristic of the orthotropic creep of tension

yield limit EPS_FL_L =

evpmax Strain orthotropic of tension. This strain is restricted to 3% by default.

7.19.2.2 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

Résistance in compression of the concrete.

F_T = rt

Résistance with the tension 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

Strain with the peak of compression.

EPS_TRAC = edpict

Strain with the peak of tension.

LC_COMP = lcc / LC_TRAC = lct

Ces terms correspond to the internal lengths of tension and of compression, they are parameters materials. They allow a management of the lenitive part of stress-strain curve. They are depend on the mesh. By defaults, it are not taken into account in the model (value 1.0).

7.19.2.3 Operands related to the model of computation of the endogenous shrinkage

A_VAN_GE = avg / B_VAN_GE = bvg

Milieu unsaturated parameters with Van Genuchten.

BIOT_EAU = bwmax / MODU_EAU = MW

saturated Milieu, number of bio and modulates bio of water.

W EAU 0 = w0

If hydrous computation in water concentration, this term indicates the maximum concentration.

HYD_PRES = hydrous

Indicateur pressure of computation by imposed pressure. Takes the value 1.0 if computation in pressure (allows to take into account overpressure), takes the value 0.0 if computation in water concentration. Attention in the case of a computation by imposed pressure, make sure of the agreement degree of saturation-pressure (via parameter of the model of Van Genuchten).

7.19.2.4 Operands related to the formation of the gel

BIOT_GEL = bchmax / MODU_GEL = mch

Assimilable with an elasticity modulus of the gel and b^g can be comparable to a coefficient of Biot for the gel.

Maximum VOL_GEL =

vg Volume of gel which can be created by the chemical reaction; it corresponds to the theoretical volume of gel created by unit volume of concrete maintained under conditions saturated during an infinite time.

AVANC_LI = a0

Avancement from which initial connected porosity is filled.

PARA_CIN = alp0

Paramètre of kinetics of reaction.

ENR_AC_G = Ea

Énergie of activation of the reaction. This value is close to $45000\,J/mol/°K$

SEUIL_SR = sr0

Seuil of saturation from which the evolution of the chemical reaction becomes possible.

7.20 Key word BETON_BURGER_FP

models It creep BETON_BURGER_FP supposes a decomposition between the spherical and deviatoric components: the strains induced by the spherical stresses are purely spherical and the strains induced by the deviatoric stresses are purely deviatoric [R7.01.35]. In addition, the clean strain of creep is supposed to be proportional to internal relative moisture:

Spherical part: $\varepsilon^s = h \cdot f\left(\sigma^s\right)$ and, left deviatoric: $\underline{\underline{\varepsilon}}^d = h \cdot f\left(\underline{\underline{\tilde{\sigma}}}\right)$

Where h indicates internal relative moisture.

The model of behavior BETON_BURGER_FP is a model based on model BETON_UMLV_FP [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 warps, warp 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).

7.20.1 Syntax

```
| BETON_BURGER_FP:     _F   (
                  ♦      K_RS=K_RS        ,          [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]
                  ♦      KAPPA=KAPPA         ,          [R]
                  ◊      ETA_FD=ETA_FD                 [R]
                  )
```

7.20.2 Opérande

K_RS=K_RS

k_r^s rigidity connects associated with the reversible spherical part of the strains of creep

K_RD=K_RD

k_r^d rigidity connect associated with the reversible deviatoric part of the strains of creep

ETA_RS=ETA_RS

η_r^s viscosity connect associated with spherical strains reversible

ETA_IS=ETA_IS

η_i^s viscosity connect associated with spherical strains irreversible

ETA_RD=ETA_RD

η_r^d viscosity with deviatoric strains reversible

ETA_ID=ETA_ID

η_i^d viscosity with deviatoric strains irreversible

KAPPA=KAPPA

κ term affecting long-term viscosity (η_i^s and η_i^d) material

ETA_FD=ETA_FD

makes it possible to take into account the creep of desiccation according to the model of Bazant.

Note:

The curve of desorption giving the hygroscopy h according to the water concentration C must be indicated under key word ELAS_FO.

8 Behaviors Metal-worker-Mechanics

Pour the metallurgical behavior (cf [R4.04.01]), two constitutive laws are available: a model characteristic of the metallurgical transformations of steel and a model 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), α

the zircaloy can comprise (with more) three different metallurgical phases (cold phase 1 = pure α phase, cold phase 2 = phase α mixes 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 the material desired while activating, in the operator STAT_NON_LINE, the key word RELATION_KIT which 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 key word META_LEMA_ANI under COMP_INCR.

8.1 Key word factor META_ACIER

Paramètres with informing for the metallurgy of steel.

8.1.1 Syntax

```
| META_ACIER = _F  (
                 ♦ TRC    =nomtrc      ,            [table_sdaster]
                 ♦ AR3    =ar3  ,                [R]
                 ♦ ALPHA  =alpha,                [R]
                 ♦ MS0    =mso  ,                [R]
                 ♦ AC1    =ac1  ,                [R]
                 ♦ AC3    =ac3     ,               [R]
                 ♦TAUX_1    =t1   ,               [R]
                 ♦TAUX_3    =t3   ,               [R]
                 ◊LAMBDA0=l0      ,               [R]
                 ◊QSR_K   =Qapp   ,             [R]
                 ◊D10       =d10     ,           [R]
                 ◊WSR_K   =Wapp   ,             [R]
                 )
```

8.1.2 Opérandes for the phase changes

TRC = nomtrc

Concept of the trc type produces by operator DEFI_TRC [U4.43.04] and containing the group of the information provided by diagrams TRC (Transformation in Refroidissement Continu) steel considered.

Quasi-static AR3 =

ar3 Temperature of beginning of decomposition of austenite to cooling.

ALPHA = Coefficient

alpha α of the model of Koïstinen-Marbürger 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 the aforementioned is total. In this case $M_s = M_{s0}$.

Quasi-static AC1 =

ac1 Temperature of beginning of transformation out of austenite to the heating.

Quasi-static AC3 =

ac3 Temperature of end of transformation out of austenite.

TAUX_1 = T1

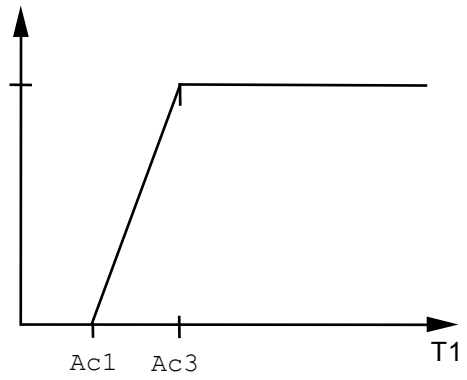
Valeur of the function “delay” (cf [R4.04.01]) $\tau(T)$ intervening in the model of transformation austenitic to temperature AC1.

TAUX_3 = T3

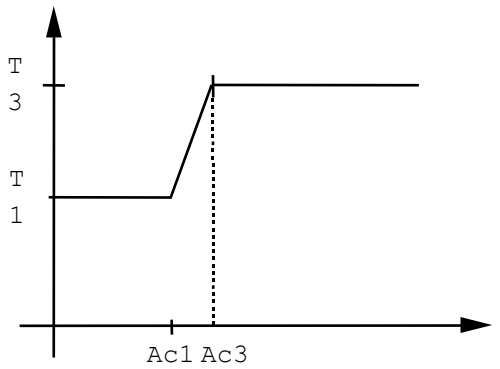
Valeur of the function “delay” (cf [R4.04.01]) $\tau(T)$ intervening in the model of transformation austenitic to temperature AC3.

The evolution of the proportion of austenite is then defined by: $\dot{Z} = \frac{Z - Z_{eq}(T)}{\tau(T)}$

with: $Z_{eq}(T)$



and $\tau(T)$



8.1.3 Opérandes for the size of grains

Les four operands following involve the computation of size of grains if they are indicated.

LAMBDA0 =l0

Paramètre material intervening in the model of evolution of size of grain below.

$$\frac{dD}{dt}=\frac{1}{\lambda}\left(\frac{1}{D}-\frac{1}{D_{\lim}}\right) \text{ avec } \left\{\begin{array}{l}\lambda=\lambda_0 exp(\frac{Q_{app}}{RT})\\ D_{\lim}=D_{10}exp(-\frac{W_{app}}{RT})\end{array}\right\}$$

QSR_K = Qapp/R

Paramètre energy of activation intervening in the model of evolution of size of grain.

D10 = D10

Paramètre material intervening in the model of evolution of size of grain.

WSR_K = Wapp/R

Paramètre energy of activation intervening in the model of evolution of size of grain.

8.2 Key word factor **META_ZIRC**

Paramètres with informing for the metallurgy of the zircaloy (cf [R4.04.04]).

8.2.1 Syntax

```
|  META_ZIRC = _F    (
                  ♦  TDEQ=teqd     ,                  [R]
                  ♦  N=n        ,                     [R]
                  ♦  K=K        ,                     [R]
                  ♦  T1C=t1c              ,                  [R]
                  ♦  T2C=t2c              ,                  [R]
                  ♦  QSR_K=qsr         ,                [R]
                  ♦  AC=Ac          ,                   [R]
                  ♦  M=m        ,                     [R]
                  ♦  T1R=t          1r,                [R]
                  ♦  T2R=t          2r,                [R]
                  ♦  AR=Ar          ,                  [R]
                  ♦  BR=Br                             [R]
                      )
```

8.2.2 Opérandes

TDEQ = teqd

Initial temperature of transformation $\alpha \Leftrightarrow \beta$ to the equilibrium

α : compact phase cold hexagonal

β : phase hot cubic centered

N = N

Paramètre material relating to the model giving the proportion of β according to the temperature, to the equilibrium.

K = K

Paramètre material relating to the model giving the proportion of β according to the temperature, to the equilibrium.

T1C = t1c
Initial temperature of transformation α in β to the heating.

T1C = t1c
Paramètre material intervening in the computation of the initial temperature of transformation α in β to the heating.

T2C = t2c

Paramètre material intervening in the computation of the initial temperature of transformation α in β to the heating.

AC = ac
Paramètre material intervening in the model of evolution of β to the heating.

M = m
Paramètre material intervening in the model of evolution of β to the heating.

T2R = t2r
Paramètre material intervening in the computation of the initial temperature of transformation β in α to cooling.

T2R = t2r
Paramètre material intervening in the computation of the initial temperature of transformation β in α to cooling.

AR = Ar
Paramètre material intervening in the model of evolution of β to cooling.

BR = Br
Paramètre material intervening in the model of evolution of β to cooling.

QSR_K = qsr
Constante d' Arrhénius expressed in Kelvin degree.

8.3 Key word factor DURT_META

Définition of the characteristics relating to the computation of hardness associated with the metallurgy with steels.
Hardness is computed by using a linear model of mixture on the microcomputer - hardness of the components:

$$HV = \sum_i z_i HV_i$$

HV_i : microhardness of the component i
z_i : proportion of the Syntaxe i

8.3.1 component

```
|   DURT_META = _F (
                  ♦F1_DURT=HVf1       ,             [R]
                  ♦  F2_DURT=HVf2     ,             [R]
                  ♦  F3_DURT=HVf3     ,             [R]
                  ♦  F4_DURT=HVf4     ,             [R]
                  ♦  C_DURT=HVa                          [R]
                  )
```

8.3.2 Opérandes

F1_DURT= HVf1
Microcomputer-hardness of the cold phase $F1$ (ferrite for steel).

F2_DURT= HVf2
Microcomputer-hardness of the cold phase $F2$ (pearlite for steel).

F3_DURT= HVf3
Microcomputer-hardness of the cold phase $F3$ (bainite for steel).

F4_DURT= Hvf4
Microcomputer-hardness of the cold phase $F4$ (martensite for steel).

C_DURT= HVf1
Microcomputer-hardness for the hot phase (austenite for steel).

8.4 Key words factor ELAS_META, ELAS_META_FO

Définition of the elastic characteristics, dilation and elastic limits for the modelization of an undergoing material of the metallurgical transformations (see [R4.04.02] or [R4.04.05]). These coefficients can be are constant compared to temperature ELAS_META, are to depend on temperature ELAS_META_FO (parameter "TEMP").
Certain coefficients depend on metallurgical structure (parameter "META").
Note:

Concerning the model META_LEMA_ANI, thermal dilation is written classically irrespective of phases. Consequently, the key words ` C_ALPHA', ` PHASE_REFE' and ` EPSF_EPSC_TREF' compulsory but are not taken into account in the equations. Only the coefficient of thermal expansion ` F_ALPHA' is considered.
This model is a model without threshold thus the elastic limits and the model of the mixtures is not useful.

Note:

Concerning the other models, for a steel one informs to the maximum 5 elastic limits, for Zircaloy one informs some to the maximum three.

8.4.1 Syntax

```
| /ELAS_META
  /ELAS_META_FO   = _F   (
                  ♦  E=young                ,       [R] or [function]
                  ♦  NU=nu                  ,       [R] or [function]
                  ♦F_ALPHA=fal              ,       [R] or [function]
                  ♦C_ALPHA=cal              ,       [R] or [function]
                  ♦  PHASE_REFE=    / "CHAUD",  [TXM]
                                    /   "FROID",
                  ♦  EPSF_EPSC_TREF=deltae,      [R]
                  ◊  TEMP_DEF_ALPHA=Tda,              [R] (_FO)
                  ◊  PRECISION=       / eps,       [R]
                                    / 1. ,       [DEFAUT]
                  ◊  F1_SY=F1sy             ,       [R] or [function]
                  ◊F2_SY=F2sy               ,       [R] or [function]
                  ◊  F3_SY=F3sy             ,       [R] or [function]
                  ◊  F4_SY=F4sy             ,       [R] or [function]
                  ◊C_SY=Fsy                 ,       [R] or [function]
                  ◊SY_MELANGE=f       ,          [function]
                  ◊F1_S_VP=F1svp            ,       [R] or [function]
```

```
◊  F2_S_VP=F2svp       ,       [R] or [function]
◊F3_S_VP=F3svp            ,       [R] or [function]
◊F4_S_VP=F4svp            ,       [R] or [function]
◊  C_S_VP=Csvp            ,       [R] or [function]
◊  S_VP_MELANGE=Svp               [function]
   )
```

8.4.2 Opérandes

E = Young
Modulus Young, identical for all metallurgical phases.

NU = naked
Poisson's ratio, identical for all the metallurgical phases.

F_ALPHA = fal
average thermal Coefficient of thermal expansion of the cold phases.

C_ALPHA = cal
average thermal Coefficient of thermal expansion of the hot phase.

PHASE_REFE= / "CHAUD"
/ "FROID"
Choix of the metallurgical phase of reference (hot phase or cold phase).
Indeed, to define the null thermal strain, it is necessary to define the reference temperature T_{ref} (defined in AFFE_MATERIAU) and the metallurgical phase of reference, so that the thermal strain is considered null in T_{ref} and in the metallurgical state of reference.

EPSF_EPSC_TREF=deltae
Strain of the phase not of reference compared to the phase of reference to the temperature T_{ref}: translated the difference in compactness between cubic crystallographic structures with centered sides (standard austenitic) and cubic centered (standard ferritic).

TEMP_DEF_ALPHA=Tda
Température compared to which one defines the coefficient of thermal expansion. If C_ALPHA is a function, this operand is compulsory.

PRECISION = eps
This reality indicates with which accuracy a temperature T is close to the reference temperature (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 model of mixture on the elastic limit of the multiphase material for a plastic behavior.

$$\sigma_y = (1 - f(z))\,\sigma_y^{\gamma} + f(z)\,\sigma_y^{\alpha}$$

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=Svp
Function used for the model of mixture on the elastic limit of the multiphase material for a viscous behavior.

$$\sigma_c = \left(1 - f\left(z\right)\right)\sigma_c^{\gamma} + f\left(z\right)\sigma_c^{\alpha}$$

8.5 Key word factor META_ECRO_LINE

Définition of five hardening moduli used in the modelization of the phenomenon of isotropic hardening linear of an undergoing material of the metallurgical phase changes (see [R4.04.02]). These moduli 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 Opérandes

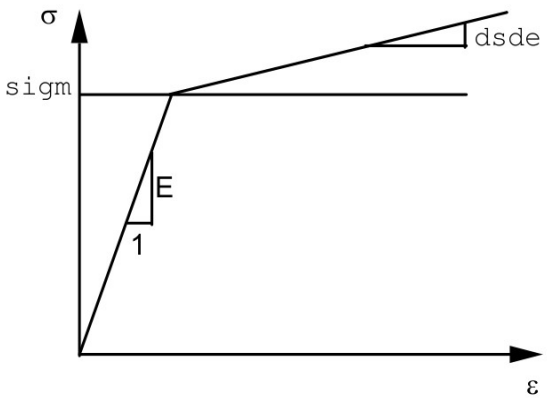
F1_D_SIGM_EPSI=dsde1
Slope of the traction diagram for the cold phase 1.

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.



The Young modulus E is to be specified by key words META_ ELAS or META_ELAS_FO.

8.6 Key word factor META_TRACTION

Définition of five traction diagrams used in the modelization of the phenomenon of isotropic hardening nonlinear of an undergoing material of the metallurgical phase changes (see [R4.04.02]). The traction diagrams can possibly depend on the temperature.

8.6.1 Syntax

```
|   META_TRACTION = _F (

                  ◊SIGM_F1       =  r_p1,           [function]
                  ◊SIGM_F2       =  r_p2,           [function]
                  ◊SIGM_F3       =  r_p3,           [function]
                  ◊SIGM_F4       =  r_p4,           [function]
                  ◊SIGM_C         =    r_pc           [function]
                  )
```

8.6.1.1 Opérandes

SIGM_F1=r_p1

Courbe hardening isotropic R according to the plastic strain cumulated p for the cold phase 1 .

SIGM_F2=r_p2

Courbe hardening isotropic R according to the plastic strain cumulated p for the cold phase 2 .

SIGM_F3=r_p3

Courbe hardening isotropic R according to the plastic strain cumulated p for the cold phase 3 .

SIGM_F4=r_p4

Courbe hardening isotropic R according to the plastic strain cumulated p for the cold phase 4 .

SIGM_C = r_p. C.

isotropic Courbe hardening R according to the plastic strain cumulated p for the hot phase.

Note:

Attention it does not act of the curved σ function of ε but of the curved R function of p . One passes from the one to the other by carrying out following computations: $R=\sigma-limite\,d'élasticité$, $p=\varepsilon-(\sigma/E)$.

8.7 Key word factor META_VISC_FO

Définition of the viscous parameters of the viscoplastic constitutive law with taking into account of the metallurgy (see [R4.04.02]). The viscoplastic model of Norton-Hoff type comprises 5 parameters; parameters conventional η , n of the flow model in power, the viscous flow yield stress, the parameters C and m relating to the restoration of hardening of viscous origin. These parameters depend on the temperature and metallurgical structure.
The parameters elastic limits are defined in 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 Opérandes F1_ETA/F2_ETA/F3_ETA/F4_ETA/C_ETA

F1_ETA=eta1

Paramètre η of the viscoplastic flow model, for the cold phase 1.

F2_ETA=eta2

Paramètre η of the viscoplastic flow model, for the cold phase 2.

F3_ETA=eta3

Paramètre η of the viscoplastic flow model, for the cold phase 3.

F4_ETA=eta4

Paramètre η of the viscoplastic flow model, for the cold phase 4.

C_ETA=etac

Paramètre η of the viscoplastic flow model, for the hot phase.

8.7.3 Operands F1 N/F2 N/F3 N/F4 N/C_N

F1_N=n1

Paramètre n of the viscoplastic flow model, for the cold phase 1.

F2_N=n2

Paramètre n of the viscoplastic flow model, for the cold phase 2.

F3_N=n3

Paramètre n of the viscoplastic flow model, for the cold phase 3.

F4_N=n4

Paramètre n of the viscoplastic flow model, for the cold phase 4.

C_N=n5

Paramètre N of the viscoplastic flow model, for the hot phase.

8.7.4 Operands F1 C/F2 C/F3 C/F4 C/C_C

F1_C=C1

Paramètre C relating to the restoration of hardening of viscous origin, for the cold phase 1.

F2_C=C2

Paramètre C relating to the restoration of hardening of viscous origin, for the cold phase 2.

F3_C=C3

Paramètre C relating to the restoration of hardening of viscous origin, for the cold phase 3.

F4_C=C4

Paramètre C relating to the restoration of hardening of viscous origin, for the cold phase 4.

C_C=C5
Paramètre C relating to the restoration of 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
Paramètre m relating to the restoration of hardening of viscous origin, for the cold phase 1.

F2_M=m2
Paramètre m relating to the restoration of hardening of viscous origin, for the cold phase 2.

F3_M=m3
Paramètre m relating to the restoration of hardening of viscous origin, for the cold phase 3.

F4_M=m4
Paramètre m relating to the restoration of hardening of viscous origin, for the cold phase 4.

C_M=m5
Paramètre m relating to the restoration of hardening of viscous origin, for the hot phase.

8.8 Key word factor META_PT

Définition of the characteristics used in the modelization of the plasticity of transformation of a material which undergoes metallurgical phase changes (see [R4.04.02]).

The model is the following: $\Delta \varepsilon^{pt} = \frac{3}{2} \sigma \sum_{i=1}^{i=4} K_i F_i^{'}(Z_i) \langle \Delta Z_i \rangle$

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]
                   ◊ F2_D_F_META=   F'p,            [function]
                   ◊ F3_D_F_META=   F'B,            [function]
                   ◊ F4_D_F_META=   F'm             [function]
                  )
```

8.8.2 Opérandes

F1_K = KF, F2_K = Kp, F3_K = KB, F4_K = km

Constantes K_i used in the model of plasticity of transformation, for the various cold phases. For steel = phase ferritic, perlitic, bainitic and martensitic.

F1_D_F_META=F'F, F2_D_F_META=F'p, F3_D_F_META=F'B,
F4_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 Key word factor META_RE

Définition of the characteristics used in the modelization of the phenomenon of restoration of hardening of a material which undergoes metallurgical phase changes (see [R4.04.02]).

8.9.1 Syntax

```
        | META_RE = _F  (

                        ◊ C_F1_THETA =Tgf     ,              [R]
                        ◊ C_F2_THETA =Tgp     ,              [R]
                        ◊ C_F3_THETA =Tgb  ,              [R]
                        ◊ C_F4_THETA =Tgm     ,              [R]
                        ◊ F1_C_THETA =Tfg  ,             [R]
                        ◊ F2_C_THETA =Tpg  ,             [R]
                        ◊ F3_C_THETA =Tbg  ,             [R]
                        ◊ F4_C_THETA =Tmg                [R]
                )
```

8.9.2 Opérandes

C_F1_THETA=Tgf, C_F2_THETA=Tgp, C_F3_THETA=Tgb, C_F4_THETA=Tgm

Constantes characterizing the rate of hardening transmitted at the time of the transformation of hot phase C in cold phase. For steel; transformation of austenite out of ferrite, pearlite, bainite and martensite. Thus, $\theta=0$ corresponds to a total restoration and $\theta=1$ a total transmission of hardening.

F1_C_THETA=Tfg, F2_C_THETA=Tpg, F3_C_THETA=Tbg, F4_C_THETA=Tmg

Constantes characterizing the rate of hardening transmitted at the time of the transformation of the cold phases in hot phase. For steel; transformation of ferrite, the pearlite, austenite bainite and martensite. Thus, $\theta=0$ corresponds to a total restoration and $\theta=1$ a total transmission of hardening.

8.10 Key word **META_LEMA_ANI**

Définition of the parameters of model META_LEMA_ANI (cf [R4.04.05]), élasto-viscous without threshold with an anisotropic behavior. Briefly, models it is written in the cylindrical coordinate system (r,θ,z):

Partition of the strains: $\varepsilon=\varepsilon^e+\alpha\Delta T\,\mathrm{Id}+\varepsilon^v$

Flow model of the viscous strain: $\dot{\varepsilon}^v=\dot{p}\dfrac{M:\sigma}{\sigma_{eq}}$

Criterion of Hill: $\sigma_{eq}=\sqrt{\sigma:M:\sigma}$

Stamp of Hill M :

$$\underline{\underline{M}}_{(r,\theta,z)}=\begin{bmatrix} M_{rrrr} & M_{rr\theta\theta} & M_{rrzz} & 0 & 0 & 0 \\ M_{rr\theta\theta} & M_{\theta\theta\theta\theta} & M_{\theta\theta zz} & 0 & 0 & 0 \\ M_{rrzz} & M_{\theta\theta zz} & M_{zzzz} & 0 & 0 & 0 \\ 0 & 0 & 0 & M_{r\theta r\theta} & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{rzrz} & 0 \\ 0 & 0 & 0 & 0 & 0 & M_{\theta z\theta z} \end{bmatrix}$$

$$\text{avec}\begin{cases} M_{rrrr}+M_{rr\theta\theta}+M_{rrzz} = 0 \\ M_{rr\theta\theta}+M_{\theta\theta\theta\theta}+M_{\theta\theta zz} = 0 \\ M_{rrzz}+M_{\theta\theta zz}+M_{zzzz} = 0 \end{cases}$$

Model of the mixtures on the matrix M :

$$M=\begin{cases} M^c & \text{si} \quad 0.00\leqslant Z_f\leqslant 0.01 \\ M^2=Z_f M^1+(1-Z_f)M^c & \text{si} \quad 0.01\leqslant Z_f\leqslant 0.99 \\ M^1 & \text{si} \quad 0.99\leqslant Z_f\leqslant 1.00 \end{cases}$$

$$Z_f=Z_1+Z_2;\quad Z_c=Z_3=1-Z_f$$

Equivalent strainrate: $\dot{p}=\left(\frac{\sigma_{eq}}{ap^m}\right)^n e^{-Q/T}$

or in an equivalent way: $\sigma_{eq}=\underbrace{a\left(e^{Q/T}\right)^{1/n}p^m\dot{p}^{1/n}}_{\text{contrainte visqueuse } \sigma_v}=\sigma_v$

Model of the mixtures on the viscous stress σ_v :

$$\sigma_{eq}=\sigma_v=\sum_{i=1}^{3} f_i(Z_\alpha)\sigma_{vi} \text{ with } \sigma_{vi}=a_i\left(e^{Q_i/T}\right)^{1/n_i}p^{m_i}\dot{p}^{1/n_i}$$

Remarque :
in the isotropic case, there is

$$M_{rrrr}=M_{\theta\theta\theta\theta}=M_{zzzz}=1$$
$$M_{r\theta r\theta}=M_{rzrz}=M_{\theta z\theta z}=0.75$$

8.10.1 Syntaxe

```
|  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=mrrrrf     ,          [R]
♦  C_MRR_RR=mrrrrc     ,          [R]
♦  F_MTT_TT=mttttf     ,          [R]
♦  C_MTT_TT=mtttfc     ,          [R]
♦  F_MZZ_ZZ=mzzzzf     ,          [R]
♦  C_MZZ_ZZ=mzzzzc     ,         [R]

♦  F_MRT_RT=mrtrtf     ,          [R]
♦  C_MRT_RT=mrtrtc     ,          [R]
♦  F_MRZ_RZ=mrzrzf     ,          [R]
♦  C_MRZ_RZ=mrzrzc     ,          [R]
♦  F_MTZ_TZ=mtztzf     ,          [R]
♦  C_MTZ_TZ=mtztzc     ,         [R]
)
```

8.10.2 Opérandes

the table below summarizes the correspondences between the symbols of the equations and the key words of *Aster*.

Symbol in the equations	Aster *Key word*
$a1 \quad a2 , \; a3$	'F1 A','F2 A','C_A'
$m1 \quad m2 , \; m3$	'F1 M','F2 M','C_M'
$n1 \quad n2 , \; n3$	'F1 N','F2 N','C_N'
$Q1 \quad Q2 , \; Q3$	'F1 Q','F2 Q','C_Q'

The matrix of Hill is known is for the cold phase (1) 'F_Mxx_xx', that is to say for the hot phase (3) 'C_Mxx_xx'.

Note:

Coefficients 'F1 Q','F2 Q' *and* 'C_Q' *are in Kelvin degree.*

9 Behaviors THERMO-HYDRO-MECANIQUES and of the grounds

9.1 Key word simple COMP_THM

Permet to select as of the definition of the material coupling law THM. The table below specifies the compulsory key words according to the selected coupling law.

	LIQU_SATU	LIQU_GAZ	GAS	LIQU_GAZ_ATM	LIQU_VAPE_GAZ	LIQU_AD_GAZ_VAPE	LIQU_VAPE
THM_INIT	***O***	***O***	***O***	***O***	***O***	***O***	***O***
PRE1	O	O	O	O	O	O	O
PRE2		O			O	O	
PORO	O	O	O	O	O	O	O
TEMP	T	O	O	T	O	O	O
PRES_VAPE					O	O	O
THM_DIFFU	***O***	***O***	***O***	***O***	***O***	***O***	***O***
R_GAZ		O	O		O	O	O
RHO	O	O	O	O	O	O	O
BIOT_COEF	O	O	O	O	O	O	O
PESA_X	O	O	O	O	O	O	O
PESA_Y	O	O	O	O	O	O	O
PESA_Z	O	O	O	O	O	O	O
SATU_PRES				O		O	O
D_SATU_PRES				O		O	O
PERM_LIQU				O		O	O
D_PERM_LIQU_SATU				O		O	O
PERM_GAZ						O	O
D_PERM_SATU_GAZ						O	O
D_PERM_PRES_GAZ						O	O
VG_N / VG_PR / VG_SR							
VG_SMAX / VG_SATUR							
EMMAG							
FICKV_T					O	O	
FICKV_PV							
FICKV_PG							
FICKV_S							
D_FV_T							
D_FV_PG							
FICKA_T						O	
FICKA_PA							
FICKA_PL							
FICKA_S							
D_FA_T							
CP	T	T	T	T	T	T	T
PERM_IN/PERM_END/ PERM_X	O	O	O	O	O	O	O
PERM_Y							
PERM_Z							
LAMB_T	T	T	T	T	T	T	T
LAMB_S							
LAMB_PHI							
LAMB_CT							
D_LB_T							
D_LB_S							
D_LB_PHI							
THM_LIQU	***O***	***O***		***O***	***O***	***O***	***O***
RHO	O	O		O	O	O	O
UN_SUR_K	O	O		O	O	O	O
VISC	O	O		O	O	O	O
D_VISC_TEMP	O	O		O	O	O	O
ALPHA	T	T		T	T	T	T
CP	T	T		T	T	T	T
THM_GAZ		***O***	***O***	***O***	***O***	***O***	
MASS_MOL		O	O	O	O	O	
VISC		O	O	O	O	O	
D_VISC_TEMP		O	O	O	O	O	
CP		T	T	T	T	T	
THM_VAPE_GAZ					***O***	***O***	***O***
MASS_MOL					O	O	O
CP					O	O	O
VISC					O	O	O
D_VISC_TEMP					O	O	O
THM_AIR_DISS						***O***	
Compulsory						CP	
O						COEF_HENRY	

O O Key word

T compulsory Key word in Thermal
Inutile Key word for this kind of coupling law

syntax is the following one:

```
◊COMP_THM  = / ` LIQU_SATU `          ,
             / ` LIQU_GAZ `           ,
             / ` GAS `                   ,
             / ` LIQU_GAZ_ATM `       ,
             / "LIQU_VAPE_GAZ `    ,
             / "LIQU_AD_GAZ `   ,
             / "LIQU_AD_GAZ_VAPE `  ,
             / "LIQU_VAPE `         ,
```

9.2 Key word factor THM_INIT

Pour all the behaviors ThermoHydroMécaniques, it makes it possible to describe the initial state of the structure (cf [R7.01.11] and [R7.01.14]).

9.2.1 Syntax

```
| THM_INIT = _F   (
                  ◊ TEMP=      temp,          [R]
                  ♦ PRE1=      pre1,          [R]
                  ◊ PRE2=      pre2,          [R]
                  ♦ PORO=      poro,          [R]
                  ◊ PRES_VAPE=    pvap,          [R]
                  ◊DEGR_SATU=     ds,               [R]
          )
```

Pour to understand well these data, it is necessary to distinguish the unknown factors with the nodes, which we call $\{u\}^{ddl}$ and the values defined under key word THM_INIT that we call p^{ref} and T^{ref}.

$$\{u\}^{ddl}=\begin{Bmatrix} u_x \\ u_y \\ u_z \\ PRE1^{ddl} \\ PRE2^{ddl} \end{Bmatrix}$$

The meaning of the unknown factors $PRE1$ and $PRE2$ varies according to the models. By noting p_w the water pressure, p_{ad} the dissolved air pressure, p_l the pressure of liquid $p_l=p_w+p_{ad}$, p_{as} the air pressure dryness p_{vp} the steam pressure, $p_g=p_{as}+p_{vp}$ the gas stagnation 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 $PRE2$:

Comportement KIT	LIQU_SATU	LIQU_GAZ_ATM	GAS	LIQU_VAPE_GAZ	LIQU_GAZ	LIQU_AD_GAZ_VAPE	LIQU_AD_GAZ
$PRE1$	p_l	$-p_l$	p_g	$p_c=p_g-p_l$	$p_c=p_g-p_l$	$p_c=p_g-p_l$	$p_c=p_g-p_l$
$PRE2$				p_g	p_g	p_g	p_g

One will be able to refer to [§4.4.3] documentation [U4.51.11].

One then defines the “total” pressures and the temperature by:

$$p=p^{ddl}+p^{ref};T=T^{ddl}+T^{ref}$$

The values written by IMPR_RESU are the nodal unknown factors p^{ddl} et T^{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 constitutive laws $\frac{P}{\rho}=\frac{R}{M}T$ for perfect gases, $\frac{d\rho_l}{\rho_l}=\frac{dp_l}{K_l}-3\alpha_l dT$ the liquid and in the relation saturation/capillary pressure.

Let us note that the nodal values can be initialized by key word ETAT_INIT of command STAT_NON_LINE.

The user must be very careful in the definition of the values of THM_INIT : indeed, the definition of several materials with values different from the quantities defined under THM_INIT leads to discontinuous values initial of the pressure and temperature, which is not in fact not compatible with the general processing which is made of these quantities. We thus advise with the user the following step:

- so at the beginning, there is a uniform field of pressure or of temperature, one re-enters it directly by key word THM_INIT,
- if there is a nonuniform field, one enters for example a reference by key word THM_INIT of command DEFI_MATERIAU, and the initial values compared to this reference by key word ETAT_INIT of command STAT_NON_LINE.

9.2.2 Operand TEMP

Reference temperature T^{ref}.
Attention this value is expressed in Kelvin and must be strictly positive.
The value of the reference temperature input behind key word VALE_REF of command AFFE_VARC is ignored.

9.2.3 Operand PRE1

Pour behaviors: LIQU_SATU and pressure of liquid of reference.
For the behavior: GAS pressure of non-zero standard gas.
For the behavior: LIQU_GAZ_ATM pressure of liquid of changed reference of sign.
For the behaviors: LIQU_VAPE_GAZ , LIQU_AD_GAZ_VAPE and capillary LIQU_GAZ pressure of reference.

9.2.4 Operand PRE2

Pour behaviors: LIQU_VAPE_GAZ, LIQU_AD_GAZ_VAPE and LIQU_GAZ pressure of non-zero standard gas.

9.2.5 Operand PORO/PRES_VAPE/Initial

DEGR_SATU PORO=
poro Porosité.

PRES_VAPE= pvap
Pour behaviors: LIQU_VAPE_GAZ, LIQU_AD_GAZ_VAPE and LIQU_GAZ and initial steam pressure.

DEGR_SATU= DS
Pour all unsaturated behaviors: initial degree of saturation.

9.3 Key word factor THM_LIQU

This key word 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,            [R]
                 ◊  CP=           CP,             [R]
                 ♦  VISC=         VI,             [function]
                 ♦  D_VISC_TEMP=  dvi,            [function]
                 )
```

9.3.2 Opérande RHO

Density of the liquid for the pressure defined under key word PRE1 of the key word factor THM_INIT.

9.3.3 Operand UN_SUR_K

Inverse of the compressibility of the liquid: K_l.

9.3.4 Operand ALPHA

Coefficient of thermal expansion of the liquid: α_l

If p_l the pressure of the liquid indicates, ρ_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 Key word factor THM_GAZ

This key word 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 key word THM_VAPE_GAZ.

9.4.1 Syntax

```
| THM_GAZ = _F   (
                 ◊  MASS_MOL=         Mgs,            [R]
                 ◊  CP=               CP,             [R]
                 ◊  VISC=             VI,             [function]
                 ◊  D_VISC_TEMP=      dvi,            [function]
               )
```

9.4.2 Opérande MASS_MOL

Molar mass of dry gas M_{gs}.

If p_{gs} the pressure of dry gas indicates, ρ_{gs} its density, R the constant of perfect gases etla T temperature, the reaction of dry gas is: $\frac{p_{gs}}{\rho_{gs}}=\frac{RT}{M_{gs}}$.

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 the viscosity of dry gas. Function of the temperature.
The user must ensure coherence with the function associated with VISC.

9.5 Key word factor THM_VAPE_GAZ

This key word 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

```
| THM_VAPE_GAZ = _F     (
                  ◊ MASS_MOL=      m ,              [R]
                  ◊ CP=            CP,              [R]
                  ◊ VISC=          VI,              [function]
                  ◊ D_VISC_TEMP=   dvi,             [function]
                 )
```

9.5.2 Opérande MASS_MOL

MASS_MOL= m

Molar mass of the vapor M_{vp}.

If east M_{vp} indicates the pressure of the vapor, ρ_{vp} its density, the constant R of perfect gases and T the temperature, the behavior of the vapor is: $\frac{p_{vp}}{\rho_{vp}}=\frac{RT}{M_{vp}}$.

9.5.3 Operand CP

CP= CP

Specific heat with constant pressure of the vapor.

9.5.4 Operand VISC

VISC= v

Viscosity of the vapor. Function of the temperature.

9.5.5 Operand D_VISC_TEMP

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 Key word factor THM_AIR_DISS

This key word factor relates to fascinating behavior THM THM_AD_GAZ_VAPE of 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

```
| THM_AD_GAZ_VAPE = _F  (
                    ♦  CP=            CP,              [R]
                    ♦  COEF_HENRY=    H,             [function]
                    )
```

9.6.2 Opérande CP

CP= CP

Specific heat with constant pressure of the dissolved air.

9.6.3 Operand COEF_HENRY

COEF_HENRY= H

Constante of Henry K_H, function of the temperature, allowing to connect the molar concentration of dissolved air C_{ad}^{ol} ($moles/m^3$) to the air pressure dryness:

$$C_{ad}^{ol}=\frac{p_{as}}{K_H}$$

9.7 Key word Compulsory factor

THM_DIFFU 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

```
| THM_DIFFU = _F  (
                  ♦ R_GAZ=            rgaz,     [R]
                  ♦ RHO=                rho,          [R]
                  ◊ CP=               CP,           [R]
                  ♦ BIOT_COEF=          bio,          [R]
                  ♦ PESA_X=             px,           [R]
                  ♦ PESA_Y=             py,           [R]
                  ♦ PESA_Z=             pz,           [R]
                  ◊ PESA_MULT=          fpesa,        [function]
                  ◊ PERM_IN=          perm,     [function]
                  ◊PERMIN_X=            OX,           [function]
                  ◊ PERMIN_Y=         OX,           [function]
                  ◊ PERMIN_Z=         OX,           [function]
                  ◊PERMINXY=            OX,           [function]
                  ◊ PERMINYZ=         OX,           [function]
                  ◊ PERMINZX=         OX,           [function]
                  ◊ SATU_PRES=          sp,           [function]
                  ◊ D_SATU_PRES=      dsp,          [function]
                  ◊ PERM_LIQU=          perml,        [function]
                  ◊ D_PERM_LIQU_SATU=   dperm,        [function]
                  ◊ PERM_GAZ=         permg,        [function]
                  ◊ D_PERM_SATU_GAZ=  dpsg  ,       [function]
                  ◊ D_PERM_PRES_GAZ=  dppg  ,       [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=          /fvpg,      [function]
                     /1,         [DEFECT]
◊ FICKV_S=           /fvs,       [function]
                     /1,         [DEFECT]
◊ D_FV_T=               /dfvt,      [function]
                     /0,         [DEFECT]
◊ D_FV_PG=           /dfvgp,     [function]
                     /0,         [DEFAUT]
conceited   ◊         FICKA_T=,           [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]
                     /0        [DEFECT]
◊ LAMB_S=               /lambs,     [function]
                     /1,         [DEFECT]
◊ LAMB_PHI=          /lambp,     [function]
                     /1,         [DEFECT]
◊ LAMB_CT=           /lambct,    [function]
                     /0,         [DEFECT]
◊ D_LB_S=               /dlambs,    [function]
                     /0,         [DEFECT]
◊ D_LB_T=               /dlambt,    [function]
                     /0,         [DEFECT]
◊ D_LB_PHI=          /dlambp,    [function]
                     /0,         [DEFAUT]
◊ EMMAG=           EM,           [R]
◊ PERM_END=        perment     [function]
)
```

9.7.2 Opérandes R_GAZ/RHO/CP/BIOT_COEF

R_GAZ = rgaz
Constante of perfect gases.

RHO = rho
Pour hydraulic behaviors homogenized density.

CP= CP
Pour thermal behaviors specific heat with constant stress of solid alone.

Organic BIOT_COEF=
Coefficient de Biot.

9.7.3 Operands SATU_PRES/D_SATU_PRES

Pour behaviors of unsaturated materials (LIQU_VAPE_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ, LIQU_GAZ_ATM).
SATU_PRES= sp

Isotherme of saturation function of the capillary pressure.

D_SATU_PRES= dsp
Derived from saturation compared to the pressure.

9.7.4 Operands PESA_X/PESA_Y/PESA_Z/PESA_MULT

PESA_X = px, PESA_y = py, PESA_z = pz,
Pesanteur according to x, y or z, used only if the modelization chosen in AFFE_MODELE includes 1 or 2 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.

9.7.5 Intrinsic operand

PERM_IN Permeability: function of porosity (in the isotropic case). In the studies, the dependence of the intrinsic permeability with φ can be expressed classically by the following cubic model:

$$\frac{k(\varphi)}{k_0} = \begin{cases} si\ \varphi-\varphi_0<0 \ :\ 1 \\ si\ 0<\varphi-\varphi_0<10^{-2}:\ 1+\chi(\varphi-\varphi_0)^3 \\ si\ 10^{-2}<\varphi-\varphi_0 \ :\ 1+\chi*10^{-6} \end{cases}$$

Other models are of course possible.

The permeability with the conventional meaning K, whose dimension is that a velocity is computed in the following way:
$K=\frac{K_{\text{int}}K_{rel}}{\mu}\rho_l g$ where K_{int} is the intrinsic permeability, K_{rel} the relative permeability, μ viscosity, ρ_l the density of the liquid and g the acceleration of gravity. K_{int} is in fact a diagonal tensor, in the isotropic case its three components are equal to the well informed value.

9.7.6 Operands PERMIN_X/PERMIN _Y/PERMIN _Z

Dans the orthotropic case, component in x, y and z of the intrinsic tensor of permeability. In this case, PERMIN_Y and PERMIN_Z are compulsory.

9.7.7 Operands PERMINXY/PERMINYZ/PERMINZX

In the case of the volumes finished and only in this case, extradiagonaux terms of the tensor of intrinsic permeability orthotropic. These values are null by default.

9.7.8 Operands PERM_LIQU/D_PERM_LIQU_SATU

Permeability and derived from the permeability relating to the liquid: function of saturation.

9.7.9 Operands PERM_GAZ/D_PERM_SATU_GAZ

Permeability and derived from the permeability relating to gas: function of the saturation and the gas pressure.

9.7.10 Operands VG_N/VG_PR/VG_SR

Pour the behaviors of unsaturated materials (LIQU_VAPE_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ, LIQU_GAZ_ATM) and if the hydraulic model is HYDR_VGM or HYDR_VGC (see Doc. U4.51.11), indicate the parameters respectively N Pr, and Sr of the model of Mualem Van-Genuchten being used to define the capillary pressure and the permeabilities relating to water and gas.

9.7.11 Operands VG_SMAX/VG_SATUR

Pour behaviors of unsaturated materials (LIQU_VAPE_GAZ, LIQU_AD_GAZ_VAPE, LIQU_GAZ, LIQU_GAZ_ATM) and if the hydraulic model is HYDR_VGM or HYDR_VGC (see document [U4.51.11]).

VG_SMAX = smax
indicates the maximum saturation for which one applies the model 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
Au delà de 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 Opérandes D_PERM_PRES_GAZ

Dérivée 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

Pour 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 compulsory.

9.7.14 Operands D_FV_T/D_FV_PG

Pour behaviors LIQU_VAPE_GAZ and LIQU_AD_GAZ_VAPE.
Derived from coefficient FICKV_T compared to the temperature.
Derived from coefficient FICKV_PG compared to the gas pressure.

9.7.15 Operands FICKA_T/FICKA_S/FICKA_PA/FICKA_P

Pour 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, FICKV_PA, FICKV_PL. In the case of LIQU_AD_GAZ_VAPE, only FICKA_T is compulsory.

9.7.16 Operand D_FA_T

Pour behavior LIQU_AD_GAZ_VAPE, derived from coefficient FICKA_T compared to the temperature.

9.7.17 Operands LAMB_T/LAMB_S/LAMB_PHI/LAMB_CT

LAMB_T = lambt
Pour multiplicative behavior THER_POLY left the thermal conductivity of the mixture depend on the temperature (cf [R7.01.11]).
For thermal behavior THER_HOMO conductivity of the mixture. This operand is compulsory in the thermal case.

LAMB_S = lambs , LAMB_PHI = lambp
Pour multiplicative behavior THER_POLY left (equal to 1 by default) the thermal conductivity of the mixture depending respectively on saturation, porosity.

LAMB_CT = lambct
Pour behavior THER_POLY left 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 D_LB_T/D_LB_S/D_LB_PHI

D_LB_T = dlambt
Pour behavior THER_POLY derived from the part of thermal conductivity of the mixture depend on the temperature compared to the temperature.
For behavior THER_HOMO derived from the thermal conductivity of the mixture by report the temperature has.

D_LB_S = dlambs, D_LB_PHI = dlambp
Pour behavior THER_POLY derived from the part of thermal conductivity of the mixture depending respectively on saturation, porosity.

9.7.19 Operand EMMAG

Coefficient of storage. This coefficient is taken into account only in the cases of the modelization without mechanics. It connects the variation of porosity to the variation of pressure of liquid.

9.7.20 Operand PERM_END

Permeability function of the damage, used by the mechanical behaviors with damage.

9.8 Key word CAM_CLAY

models It Camwood-Clay is an elastoplastic model used in soil mechanics and is especially adapted to the 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 key word ELAS.

9.8.1 Syntax

```
| CAM_CLAY = _F    (
                  ♦   MU=mu           ,                [R]
                  ♦   LAMBDA=lambda          ,         [R]
                  ♦   KAPA=kapa       ,             [R]
                  ♦   M=m           ,                [R]
                  ♦   PORO=poro       ,             [R]
                  ♦   PRES_CRIT=prescr    ,         [R]
                  ◊   KCAM=kcam       ,             [R]
                  ◊   PTRAC=ptrac         ,             [R]
                  )
```

9.8.2 Operands MU/LAMBDA/KAPA

MU = driven
Elastic modulus of shears.
LAMBDA = lambda
Coefficient of compressibility (plastic slope in a hydrostatic compression test).
Elastic KAPA =
kapa Coefficient of swelling (elastic slope in a hydrostatic compression test).

9.8.3 Operand M

Slope critical line of state.

9.8.4 Initial operand

PORO Porosité. If CAM_CLAY is used under RELATION_KIT, key word PORO informed under CAM_CLAY and THM_INIT must be the same one.

9.8.5 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 ($kcam > 0.$).

9.8.6 Operand PTRAC

Quantité of the hydrostatic stress of tension tolerated or shift of the ellipse towards the left on the axis of the hydrostatic stresses. This parameter must be negative (ptrac < 0.).

9.9 Key word factor CJS

the model (Cambou, Jaffani, Sidoroff) is a constitutive law for the grounds. It comprises three mechanisms, one corresponds to nonlinear elasticity, another corresponds to a plasticization for isotropic stress states, and the third mechanism corresponds to a plasticization related to a stress state déviatoire. The document [R7.01.13] described with accuracy the corresponding equations.
The elastic characteristics must be defined under key word ELAS.

Model 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:

	Elastic mechanism	plastic Mécanisme isotropic	Mécanisme plastic déviatoire
CJS1	linear	not activated	activated, perfect plasticity
activated	nonlinear	CJS2	activated, isotropic hardening
activated	nonlinear	CJS3	activated, Remarque

kinematic hardening:

By adopting the correspondence of the parameters for the limiting states, it is possible to use behavior CJS1 to modelize a model of Mohr Coulomb in soil mechanics.

9.9.1 Syntax

```
|  CJS = _F  (
                ♦ BETA_CJS  = beta,              [R]
                ♦  RM=          rm,                 [R]
                ◊ N_CJS=     N  ,                [R]
                ◊ KP=        kp,                 [R]
                ◊ RC=        rc,                 [R]
                ◊ A_CJS=     has   ,                [R]
                ◊  B_CJS=       B  ,                [R]
                ◊ C_CJS=     C  ,                [R]
                ♦  GAMMA_CJS=   G  ,                [R]
               driven   ◊       MU_CJS=,                 [R]
               ◊ PCO=           pco,                [R]
               ♦  PA=           AP,                 [R]
               ◊ Q_INIT=        Q  ,                [R]
               ◊ R_INIT=        R                   [R]
             )
```

Les various coefficients are with being informed or not according to the level which one wants to use, in accordance with the table Ci below (F for optional, O for compulsory and nothing for without object).

Symbol	Q_{init}	R_{init}	n	K^p	γ	β	R_c	A
Key word	Q_INIT	R_INIT	N_CJS	KP	PCO=	BETA_CJS	RC	A_CJS

					pcoGAMMA_CJS			
CJS1	F				O	O		
CJS2	F	F	O	O	O	O	O	O
CJS3	F		O	O	O	O	O	

Symbole	b	R_m	μ	p_{co}	c	P_a
Key word	B_CJS	RM	M_CJS	PCO	C_CJS	PA
CJS1		O				O
CJS2		O				O
CJS3	O	O	O	O	O	O

Nous let us 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, key word ELAS must be obligatorily indicated when model CJS is used (under one of its three levels). The definition of the Young modulus and the Poisson's ratio allow of compute the coefficients K_o^e and G_o .

9.9.2 Operands BETA_CJS/RM

Pour levels CJS1, CJS2 CJS3.
BETA_CJS = Paramètre
beta β . Control the plastic variation of volume in the mechanism déviatoire.
Maximum RM=
rm Valeur of opening of the field of reversibility déviatoire.

9.9.3 Operands N_CJS/KP/RC

Pour levels CJS2 and CJS3.
N_CJS= N
Controls the dependence of the elasticity modulus with the mean stress:

$$K = K_o^e \left(\frac{I_1 + Q_{init}}{3P_a} \right)^n \quad G = G_o \left(\frac{I_1 + Q_{init}}{3P_a} \right)^n$$

KP= kp
plastic Module of compressibility:

$$\dot{Q}_{iso} = K^p \dot{q} = K_o^p \left(\frac{Q_{iso}}{P_a} \right)^n \dot{q}$$

Critical RC =
rc Valeur of the variable R :

$$\dot{e}_v^{dp} = -\beta \left(\frac{s_{II}}{s_{II}^c} - 1 \right) \frac{\left| s_{ij} \dot{e}_{ij}^{dp} \right|}{s_{II}} \quad s_{II}^c = -\frac{R_c I_1}{h(\theta_s)}$$

9.9.4 Operands A_CJS/R_INIT

Pour levels CJS2.
A_CJS= has
Contrôle the isotropic hardening of the mechanism déviatoire;

$$R=\frac{AR_m r}{R_m+Ar}$$

Initial R_INIT=
R Valeur of the variable R. At the first CPU time, if the initial value of R is null, either that one did not define an initial state of the intern variables by key word ETAT_INIT of STAT_NON_LINE, or that this initial state or no one, one will take as initial value that definite by key word R_INIT of DEFI_MATERIAU.

9.9.5 Operands B_CJS/C_CJS/PCO/MU_CJS

Pour levels CJS3.
B_CJS= B
Controls the kinematic hardening of the mechanism déviatoire:

$$\dot{X}_{ij}=-\frac{1}{b}\dot{\lambda}^d\left[dev\left(\frac{\partial f^d}{\partial X_{ij}}\right)-I_1 f X_{ij}\right]\left(\frac{I_1}{3P_a}\right)^{-1.5}$$

C_CJS= C
Controls the 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
Check out the value of fracture of the variable R : $R_r=R_c+m\,ln\left(\frac{3p_c}{I_1}\right)$

9.9.6 Operands GAMMA_CJS/PA/Q_INIT

Pour levels CJS1, CJS2 and CJS3.
GAMMA_CJS= G
Controls the form of the criterion: $h\left(\theta_s\right)=\left(1+\gamma\,cos\left(3\theta_s\right)\right)^{1/6}=\left(1+\gamma\sqrt{54}\frac{det\left(\underline{s}\right)}{s_{II}^3}\right)^{1/6}$
PA = AP
Atmospheric pressure. Must be given negative.
Q_INIT = Q
Paramètre numerical allowing to make acceptable a null stress state. Can also be used to define a cohesion, at least for level CJS1. The formula will be used: $Q_{init}=-3c\,cotan\left(\varphi\right)$

9.10 Key word factor LAIGLE

the model of LAIGLE [R7.01.15] is a rheological model of behavior for the modelization 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 large deformation. This parameter depends on the level of deterioration of the rock,
- s which 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 key word ELAS.

9.10.1 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]
                )
```

9.10.2 Operands GAMMA_ULT/GAMMA_E

GAMMA_ULT= gamma_ult

Paramètre γ_{ult} : Plastic strain déviatoire corresponding to the bearing.

GAMMA_E =gamma_e

Parameter γ_e : Plastic strain déviatoire corresponding to the complete disappearance of cohesion.

9.10.3 Operand M_ULT/M_E/A_E/M_PIC

M_ULT= m_ult

Paramètre m_{ult} : Value of m ultimate criterion reached γ_{ult}.

M_E =m_e

Parameter m_e : Value of m intermediate criterion reached in γ_e.

A_E =a_e

Parameter a_e : Value of a intermediate criterion reached in γ_e.

M_PIC=m_pic

Parameter m_{pic} : Value of m criterion of peak reached with the peak of stress.

9.10.4 Operands A_PIC/ETA/SIGMA_C

A_PIC=a_pic

Parameter a_{pic} : Value of the exponent a to the peak of stress.

ETA =eta

Parameter η : Exponent controlling hardening.

SIGMA_C = sigma_c

Paramètre s_c : Resistance in simple compression.

9.10.5 Operands GAMMA/KSI

GAMMA = gamma, KSI = ksi

Paramètres γ and ξ : Parameters regulating dilatancy.

A condition to respect is that the report γ/ξ remains lower than 1. In the case of the very resistant stones hard, subjected to relatively low stresses of containment, the variation of dilatancy $\sin\psi$ (according to the state of the stresses - see [R7.01.15]) can tend towards γ/ξ, which justifies this condition.

9.10.6 Operand GAMMA_CJS

Parameter γ_{cjs} : parameter of form of the surface of load in the déviatoire plane.

9.10.7 Operand SIGMA_P1

Parameter σ_{pl} : intersection of the intermediate criterion and the criterion of peak.

9.10.8 Operand PA

Atmospheric pressure. Must be given positive.

Note:

Parameters M_E , A_E , A_PIC , SIGMA_P1 , SIGMA_C and MPIC are dependent from/to each other by the relation: $m_e = \frac{\sigma_c}{\sigma_{pl}} \left(m_{pic} \frac{\sigma_{pl}}{\sigma_c} + 1 \right)^{\frac{a_{pic}}{a_e}}$. *This dependence is checked within the code.*

9.11 Key word factor LETK

rheological model L&K (Laigle and Kleine) is a called viscoplastic constitutive law élasto LETK in Code_Aster [R7.01.24]. It lean on concepts of elastoplasticity and viscoplasticity. Elastoplasticity is characterized by a positive hardening in pre peak and a negative hardening in post peak.
One finds among the parameters:

- parameters which intervene in the functions of hardening relative to the various elastoplastic or viscous thresholds, like a , s and m ,
- of the parameters related to the viscous criteria,
- the parameters related to dilatancy,
- the parameters related to the resistance of the material in compression and tension.

The elastic characteristics must be defined under key word ELAS.

9.11.1 Syntax

```
| LETK=_F          (
                ♦  PA          =  AP,            [R]
                ♦  NELAS       =nelas ,           [R]
                ♦  SIGMA_C     =  sigc,           [R]
                ♦  H0_EXT      =  h0,             [R]
                ♦  GAMMA_CJS=gcjs    ,            [R]
                ♦  XAMS=xams           ,            [R]
                ♦  ETA=eta           ,            [R]
                ♦  A_0=a0            ,              [R]
                ♦  A_E=ae            ,              [R]
                ♦  A_PIC=ap          ,              [R]
                ♦  S_0=s0            ,              [R]
                ♦  S_E=se            ,              [R]
                ♦  M_0=m0            ,              [R]
                ♦  M_E=me            ,              [R]
                ♦  M_PIC=mp          ,              [R]
                ♦  M_ULT=mult          ,            [R]
                ♦  XI_ULT=xiult      ,            [R]
                ♦  XI_E=xie          ,            [R]
                ♦  XI_PIC=xip        ,            [R]
                ♦  MV_MAX=mvmx       ,            [R]
```

```
♦    XIV_MAX=xivmx          ,              [R]
♦    A=A                    ,              [R]
♦    N=n                    ,              [R]
♦    SIGMA_P1=sp1           ,          [R]
♦    MU0_V=mu0v             ,              [R]
♦    XI0_V=xi0v             ,              [R]
♦    MU1=mu1                ,          [R]
♦    XI1=xi1                               [R]
)
```

9.11.2 Operands PA/ NELAS/SIGMA_C/H0_EXT

PA = AP S_0=s0

Paramètre Pa : atmospheric pressure.

NELAS =nelas

Parameter n_{elas} : exponent of the model of variation of the elastic moduli K and G.

SIGMA_C = sigc

Paramètre σ_c : resistance in simple compression (the unit of a stress).

H0_EXT = h0

Paramètre H_{0ext} : parameter controlling the tensile strength

9.11.3 Opérande GAMMA_CJS/XAMS

GAMMA_CJS=gcjs

Parameter γ_{cjs} : parameter of form of the criterion in the déviatoire plane (between 0 and 1).

XAMS=xams

Parameter x_{ams} : non-zero parameter intervening in the models of hardening pre-peak.

9.11.4 Operand ETA/A 0/A_E/A_PIC

ETA=eta

Parameter h : non-zero parameter intervening in the models of hardening post-peak.

A_0=a0

Parameter a_0 : value of a on the threshold of damage.

A_E=ae

Parameter a_e : value of a on the intermediate threshold.

A_PIC=ap

Parameter a_{pic} : value of a on the threshold of peak.

9.11.5 Operands S 0/S_E/M 0/M_E/M_PIC/M_ULT

S_0=s0

Parameter s_0 : value of s on the threshold of damage.

S_E=se

Parameter s_e : value of s on the intermediate threshold.

M_0=m0

Parameter m_0 : value of m on the threshold of damage.

M_E=me

Parameter m_e : value of m on the intermediate threshold.

M_PIC=mp

Parameter m_{pic} : value of m on the threshold of peak.

M_ULT=mult

Parameter m_{ult} : value of m on the residual threshold.

9.11.6 Operands XI_E/XI_PIC/MV_MAX/XIV_MAX

XI_E=xie

Parameter ξ_e : level of hardening on the intermediate threshold.

XI_PIC=xip

Parameter ξ_{pic} : level of 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 ξ_{v-max} : level of hardening to reach the maximum viscoplastic threshold.

9.11.7 Operands A/N

A=A

Parameter A : parameter characterizing the amplitude velocity of creep (in s^{-1} or $jour^{-1}$).

N=n

Parameter n : exponent intervening in the formula controlling the kinetics of creep.

9.11.8 Operand SIGMA_P1

SIGMA_P1=sp1

Parameter σ_{P1} : corresponds to the X-coordinate of the point of intersection of the limit of cleavage and threshold of peak.

9.11.9 Operands MU0 V and XI0 V

MU0_V=mu0v , XI0_V=xi0v

Paramètres μ_{0v} and ξ_{0v} : parameters regulating the dilatancy of the mechanisms pre peak and viscoplastic

Les conditions to respect on these parameters are:

$\mu_{0v}<\xi_{0v}$ or $\begin{cases}\mu_{0v}>\xi_{0v}\\ \dfrac{s_{pic}^{a_{pic}}}{s_0^{a_0}}\leq\dfrac{1+\mu_{0v}}{\mu_{0v}-\xi_{0v}}\end{cases}$ with $s^{pic}=1$

9.11.10 Opérandes MU1 and XI1

MU1 =mu1 , XI1 = xi1

Paramètres μ_1 and ξ_1 : parameters regulating the dilatancy of the mechanisms post peak. A condition to respect is that the report μ_1/ξ_1 remains lower or equal to 1.

9.12 Key word factor DRUCK_PRAGER

the model 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

σ_{eq} is a function of the deviator of the effective stresses σ' ,

$I_1=Tr(\sigma')$ is the trace of the effective stresses,

α is a coefficient of dependence in pressure,

$R(p)$ is a function of the cumulated plastic strain.

In the linear case, the function R is given by: $\begin{array}{ll}0<p<p_{ult} & R(p)=hp+\sigma_y\\ p\geq p_{ult} & R(p)=h\,p_{ult}+\sigma_y\end{array}$

In the parabolic case, $R(p)=\sigma_y f(p)$ where the function $f(p)$ is given by:

$$0<p<p_{ult} \quad f(p)=\left(1-\left(1-\sqrt{\frac{\sigma_{y\,ult}}{\sigma_y}}\right)\frac{p}{p_{ult}}\right)^2$$

$$p\geq p_{ult} \qquad f(p)=\frac{\sigma_{y\,ult}}{\sigma_y}$$

9.12.1 Syntax

```
      |      DRUCK_PRAGER= _F (
                        ♦ ECROUISSAGE=  /"LINEAIRE `  ,
                                        /"PARABOLIQUE `,        [TXM]
                        ♦ ALPHA=alpha          ,              [R]
                        ♦ P_ULTM=p_ult         ,              [R]
                        ♦ SY=sy              ,                [R]
                        ◊ H=h              ,                  [R]
                        ◊ SY_ULTM=sy_ult       ,            [R]
                        ◊ DILAT=ang          ,                [R]
                    )
```

9.12.2 Operand ECROUISSAGE

ECROUISSAGE= /"LINEAIRE `,/"PARABOLIQUE `
Permet to define the type of desired hardening.

9.12.3 Operand ALPHA

ALPHA= Désigne
alpha the coefficient of dependence in pressure. It is reminded the meeting that operand ALPHA is connected to the friction angle φ by the relation: $\alpha = \frac{2.sin(\varphi)}{3-sin(\varphi)}$.

9.12.4 Operand P_ULTM

P_ULTM= p_ult
Désigne ultimate cumulated plastic strain.

9.12.5 Operand SY

SY= sy
Désigne the plastic stress. This operand is related to the combination of the binding fraction C with the friction angle φ in the following way: $SY = \frac{6C\,cos(\varphi)}{3-sin(\varphi)}$.

9.12.6 Operand H

H =h
Désigne the hardening modulus, $h<0$ if the model is lenitive. This operand is compulsory for hardening of a linear type (operand ECROUISSAGE = ` LINEAIRE `).

9.12.7 Operand SY_ULTM

SY_ULTM =sy_ult Désigne the ultimate stress. This operand is compulsory for hardening of a parabolic type (operand ECROUISSAGE = ` PARABOLIQUE `).

9.12.8 Operand DILAT

DILAT = ang
Désigne the angle of dilatancy (by defect equal to zero).

9.13 Key word factor VISC_DRUC_PRAG

rheological model VISC_DRUC_PRAG is a constitutive law élasto-visco-plastic in Code_Aster [R7.01.22]. It is characterized by a viscoplastic mechanism which is hammer-hardened between three thresholds: elastic, of peak and ultimate. Elastoplasticity is of type Drucker Prager with a positive hardening in pre peak and a negative hardening in post-peak and viscoplasticity is a model power of the Perzyna type.

One finds among the parameters:

- parameters which intervene in the functions of hardening relative to the various thresholds elastic, of peak and ultimate " α ", " R " and " β ",
- of the parameters related to the creep model " A " and " n ",
- the cumulated viscoplastic strains corresponding to each threshold p_{pic} and p_{ult} ;
- a pressure of reference " P_{ref} "

Les elastic characteristics must be defined under key word ELAS.

9.13.1 Syntax

```
| VISC_DRUC_PRAG=_F          (
                  ♦   PREF        =  pref,          [R]
                  ♦   N           =  N,             [R]
                  ♦   A           =  has,              [R]
                  ♦   P_PIC       =  peak,           [R]
                  ♦   P_ULT       =  pult,           [R]
                  ♦   ALPHA_0     =  alpha0,         [R]
                  ♦   ALPHA_PIC   =  alphapic,       [R]
                  ♦   ALPHA_ULT   =  alphault,       [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]
)
```

9.13.2 Opérandes PREF/ N/A/P_PIC/P_ULT

PREF = pref
Paramètre P_{ref} : pressure of reference (unit of a stress)
N =n
Paramètre n : exponent of the model D creep
A = has
Paramètre A : viscoplastic parameter (in s^{-1} or $jour^{-1}$)
P_PIC = Paramètre
peak p_{pic} : viscoplastic strain cumulated on the level of the threshold of peak
P_ULT = pult
Paramètre p_{ult} : viscoplastic strain cumulated on the level of the ultimate threshold

9.13.3 Opérandes ALPHA_0/ALPHA_PIC /ALPHA_ULT

ALPHA_0 = alpha0
Paramètre α_0 : parameter of the function of cohesion $\alpha(p)$ on the level of the elastic threshold
ALPHA_PIC = alphapic
Paramètre α_{pic} : parameter of the function of cohesion $\alpha(p)$ on the level of the threshold of peak
ALPHA_ULT = alphault
Paramètre α_{ult} : parameter of the function of cohesion $\alpha(p)$ on the level of the ultimate threshold

9.13.4 Opérandes R 0 /R_PIC /R_ULT

R 0 = r0
Paramètre R_0 : parameter of the function of hardening $R(p)$ on the level of the elastic threshold (in Pa or in MPa)
R_PIC = rpic
Paramètre R_{pic} : parameter of the function of hardening $R(p)$ on the level of the threshold of peak (in Pa or in MPa)

R_ULT = rult
Paramètre R_{ult} : parameter of the function of hardening $R(p)$ on the level of the ultimate threshold (in Pa or in MPa)

9.13.5 Opérandes BETA_0 /BETA_PIC /BETA_ULT

BETA_0 = beta0
Paramètre β_0 : parameter of the function of dilatancy $\beta(p)$ on the level of the elastic threshold
BETA_PIC = betapic
Paramètre β_{pic} : parameter of the function of dilatancy $\beta(p)$ on the level of the threshold of peak
BETA_ULT = betault
Paramètre β_{ult} : parameter of the function of dilatancy $\beta(p)$ on the level of the ultimate threshold

9.14 Key word factor BARCELONE

models It of Barcelona described 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 mechanical plasticity criterion (that of Camwood-Clay) and a hydrous criterion controlled by suction (or capillary pressure). It can be used only in the frame of behaviors THHM and HHM. The characteristics necessary to the model must be given under this key word and key words CAM_CLAY and ELAS.
It is thus compulsory to inform the parameters of key words CAM_CLAY and ELAS.

9.14.1 Syntax

```
| BARCELONE = _F  (
                    ♦ MU=mu              ,              [R]
                    ♦ PORO=poro          ,           [R]
                    ♦ LAMBDA=lambda                     [R]
                    ♦ KAPA=kapa          ,           [R]
                    ♦ M=m                ,           [R]
                    ♦ PRES_CRIT=pc       ,              [R]
                    ♦ PA=pa              ,              [R]
                    ♦ R=r                ,           [R]
                    ♦ BETA=beta          ,           [R]
                    ♦ KC=kc              ,              [R]
                    ♦ PC0_INIT=Pc0        (0),       [R]
                    ♦ KAPAS=Kappas          ,       [R]
                    ♦ LAMBDAS=Lambdas       ,       [R]
                    ◊ ALPHAB=alphab                [R]
               )
```

9.14.2 Operands MU/PORO/LAMBDA/KAPA/M

MU = driven
Elastic modulus of shears.
PORO =poro

Porosité associated with a pressure initial and related to the initial index of the vacuums: $n=\frac{e_0}{1+e_0}$.

LAMBDA= Coefficient
lambda of compressibility (plastic slope in a hydrostatic compression test).
Elastic KAPA
=kapa Coefficient of swelling (elastic slope in a hydrostatic compression test).
M =m
Pente critical line of state.

9.14.3 Operands PRES_CRIT and PA

PRES_CRIT= PC, critical PA
=pa Pression equalizes with half of the pressure of consolidation and atmospheric pressure.

9.14.4 Operands R/BETA/KC

R =r , BETA =beta

Coefficients adimensional intervening in the statement: $\lambda(p_c)=\lambda(0)\left[(1-r)\exp(-\beta p_c)+r\right]$

KC=kc

Paramètre adimensional controlling the increase in cohesion with suction (capillary pressure).

9.14.5 Operands PCO_INIT/KAPAS/LAMBDAS/ALPHAB

PC0_INIT= Pc0 (0)

Seuil initial of the capillary pressure (homogeneous with stresses).

KAPAS= Kappas

Coefficient of rigidity adimensional associated with the change of suction in the elastic domain.

LAMBDAS =Lambdas

Coefficient of compressibility related to a variation of suction in the plastic range. (adimensional).

ALPHAB= alphab

Coefficient of correction of the normality of yielding [R7.01.17].

Optional and adimensional corrective term allowing to better take into account experimental results. By default, it is computed by *Code_Aster* according to the slope of the straight line of critical condition, the coefficient of swelling and the coefficient of compressibility.

9.15 Key word elastoplastic factor

HUJEUX Constitutive law 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, NU, and ALPHA must be defined in parallel under key word ELAS. The model of Hujeux exhibant a nonlinear elastic behavior, the values of these parameters are associated with the pressure of reference PREF of the model of Hujeux.

9.15.1 Syntax

```
| HUJEUX = _F    (
                 ♦  N=n          ,              [R]
                 ♦  BETA=beta       ,           [R]
                 ♦  B=b          ,              [R]
                 ♦  D=d          ,              [R]
                 ♦  PHI=phi            ,           [R]
                 ♦  ANGDIL=angdil      ,           [R]
                 ♦  PCO=pco            ,           [R]
                 ♦  PREF=pref       ,              [R]
                 ♦  ACYC=acyc       ,              [R]
                 ♦  AMON=amon       ,              [R]
                 ♦  CCYC=ccyc       ,              [R]
                 ♦  CMON=cmon       ,              [R]
                 ♦  RD_ELA=rdela       ,           [R]
                 ♦  RI_ELA=riela       ,           [R]
                 ♦  RHYS=rhys       ,              [R]
                 ♦  RMOB=rmob       ,              [R]
                 ♦  XM=xm           ,              [R]
                 ♦  RD_CYC=rdcyc       ,           [R]
                 ♦  RI_CYC=ricyc       ,           [R]
```

```
    ♦     DILA=dila        ,              [R]
    ◊ PTRAC=           /ptrac,            [R]
                       /0.0             [DEFECT]
)
```

9.15.2 Operands N/BETA/B/D/PHI

N = N
Valeur of the parameter characteristic of the nonlinear model elastic power, ranging between 0 and 1.
BETA =beta
Valeur of the coefficient of plastic compressibility voluminal or critical state model, (positive).
B=b
Valeur of the parameter influencing the loading function in the plane (P',Q), ranging between 0 (Mohr-Coulomb) and 1 (Camwood-Clay).
D = D
Valeur of the parameter characterizing the distance enters the critical line of state and the isotropic line of consolidation, (positive).
PHI =phi
Valeur of the parameter characterizing the internal friction angle, in degree.

9.15.3 Operands ANGDIL/PCO/PREF

ANGDIL =angdil
Valeur of the parameter characterizing the angle of dilatancy, in degree.
PCO =pco
critical Valeur pressure of initial reference, (negative).
PREF =pref
Valeur confining pressure of reference, (negative).

9.15.4 Operands ACYC/AMON/CCYC/CMON

ACYC = acyc, AMON = amon, CCYC = ccyc, CMON = cmon
Valeurs of the hardening parameters of the plastic mechanisms déviatoires, into cyclic and monotonous, and of the plastic mechanisms of consolidation, into cyclic and monotonous, respectively.

9.15.5 Operands RD_ELA/RI_ELA

RD_ELA = rdela, RI_ELA = riela,
Valeurs of the initial radii of the thresholds of the mechanisms déviatoire monotonous and monotonous consolidation, respectively, ranging between 0 and 1.
RD_ELA = rdela, RI_ELA = riela,
Valeurs of the initial radii of the thresholds of the mechanisms déviatoire monotonous and monotonous consolidation, respectively, ranging between 0 and 1.

9.15.6 Operands RD_CYC/RI_CYC

RD_CYC = rdcyc, RI_CYC = ricyc
Valeurs of the initial radii of the thresholds of the mechanisms déviatoire cyclic and cyclic consolidation, respectively, ranging between 0 and 1.

9.15.7 Operands RHYS/RMOB/XM/DILA/PTRAC

RHYS = rhys
Valeur of the parameter defining the size of the hysteretic field.
RMOB = rmob
Valeur of the parameter defining the size of the mobilized field.
XM = xm
Valeur of the parameter of control in the hysteretic field.
DILA = dila
Valeur of the coefficient of dilatancy, ranging between 0 and 1.

PTRAC = ptrac
cohesion of the material, homogeneous with a stress (positive or null value). Allows to shift the surface of load towards $p>0$ in order to taking into account a light tension in the material.

9.16 Key word factor HOEK_BROWN

Constitutive law in rock mechanics of type model of modified HOEK-BROWN (Cf. [R7.01.18]
Les elastic mechanical characteristics E, NU, and ALPHA must be defined in parallel under key word ELAS.

9.16.1 Syntax

```
| HOEK_BROWN = _F (
                  ♦ GAMMA_RUP=grup          ,          [R]
                  ♦ GAMMA_RES=gres          ,          [R]
                  ♦ S_END=send              ,          [R]
                  ♦ S_RUP=srup              ,          [R]
                  ♦ M_END=mend              ,          [R]
                  ♦ M_RUP=mrup              ,          [R]
                  ♦ BETA=beta           ,          [R]
                  ♦ ALPHAHB=alphahb         ,       [R]
                  ♦ PHI_RUP=prup        ,          [R]
                  ♦ PHI_RES=pres        ,          [R]
                  ◊ PHI_END=phiend               [R]
                 )
```

9.16.2 Operands GAMMA_RUP/GAMMA_RES

GAMMA_RUP = grup
Valeur of the hardening parameter to the fracture of the material.
GAMMA_RES = Valeur
sandstone of the hardening parameter at the beginning of residual resistance.

9.16.3 Operands S_END/S_RUP/M_END/M_RUP

S_END = send
Valeur of the product S*SIGMA_c ** 2 attack with the initiation of damage.
S_RUP = srup
Valeur of the product S*SIGMA_c ** 2 attack in GAMMA_RUP.
M_END = mend
Valeur of the M*SIGMA_c product reached with the initiation of damage.
M_RUP = mrup
Valeur of the M*SIGMA_c product reached in GAMMA_RUP.

9.16.4 Operand BETA/ALPHAB

BETA = Paramètre
beta characterizing the behavior post-fracture of the material.
ALPHAHB = alphahb
Paramètre characterizing the behavior post-fracture of the material.

9.16.5 Operand PHI_RUP/PHI_RES/PHI_END

PHI_RUP = prup
Valeur of the friction angle reached in GAMMA_RUP.
PHI_RES = close
Valeur of the friction angle reached in GAMMA_RES.
PHI_END = phiend
Valeur of the friction angle to the initiation of damage (taken null by defect).

9.17 Key word factor ELAS_GONF

Constitutive law in rock mechanics allowing to describe the behavior of “the inflating” clay materials type (bentonite). This model was developed with the LAEGO. It is about a nonlinear elastic model connecting the clear stress to the pressure of swelling which it even depends on suction (or capillary pressure). It can be used only in the frame of behaviors THHM and HHM.
Elastic mechanical characteristics E, NU, and ALPHA must be defined in parallel under key word ELAS.
Model ELAS_GONF is a model of behavior for inflating clays (standard bentonite), it is defined by the relation:

$$d\tilde{\sigma} = K_0\, d\varepsilon_V + b\left(1+\frac{s}{A}\right)e^{-\beta_m\left(\frac{s}{A}\right)^2} ds$$

with $\tilde{\sigma}$: clear stress (trace) $\sigma = \tilde{\sigma} - p_g$

Dans 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 of incompressibility of the material is the coefficient
b of Biot is a homogeneous
A parameter with a pressure is a parameter
$beta_m$ without dimension there suction
s (or capillary pressure is the modulus

) A partir de, the identification is done by seeking the pressure of swelling.

Either P_{gf} pressure of swelling expected and or $P_{gf}(s_0)$ pressure of swelling found by the model when one Re-saturates a sample in a test with locked strain and on the basis of a suction s_0 .

It is easy to see that: $\frac{P_{gf}(s_0)}{A} = \frac{\sqrt{\pi}}{2\sqrt{\beta_m}} Erf\left(\frac{s_0}{A}\sqrt{\beta_m}\right) + \frac{1}{2\beta_m}\left(1-e^{-\beta_m\left(\frac{s_0}{A}\right)^2}\right)$

One must have $P_{gf} = P_{gf}^{\infty}$. It is known that $Erf(\infty) = 1$ and thus: $\frac{P_{gf}(s_0)}{A} = \frac{\sqrt{\pi}}{2\sqrt{\beta_m}} + \frac{1}{2\beta_m}$

In Aster, the model 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:

$$PG(Pc) = \begin{cases} A\left(\frac{\sqrt{\pi}}{2\sqrt{\beta_m}}\right) Erf\left(\frac{s_0}{A}\sqrt{\beta_m}\right) + \frac{1}{2\beta_m}\left(1-e^{-\beta_m\left(\frac{s_0}{A}\right)^2}\right) & \text{si } S<1 \\ Pc \text{ si } S=1 \end{cases}$$

9.17.1 Syntax

```
| ELAS_GONF  = _F (
                  ♦  BETAM   = betam,                  [R]
                  ♦  PREF    = pref              [R]
                   ),
```

9.17.2 Opérande BETAM

Paramètre material without dimension corresponding to β_m model above. The identification is done by seeking the pressure of swelling.

9.17.3 Homogeneous operand

PREF Paramètre with a pressure corresponding to A model above.

9.18 Key word factor JOINT_BANDIS

Constitutive law of a water seal in rock mechanics.

In the normal direction with the joint, the behavior is given by

$$d\,\sigma'_n = -K_{\mathrm{ni}} \frac{dU}{\left(1-\frac{U}{U_{max}}\right)^{\gamma}}$$

σ'_n is the normal effective stress
K_{ni} is normal initial rigidity
U is the crack closing (opening to null loading minus current opening)
U_{max} is the asymptotic closing of crack (with infinite stress)
γ is a parameter material

Dans the tangential direction, the behavior is elastic linear

$$\sigma'_t = K_t [[u_t]]$$

9.18.1 Syntaxe

```
| JOINT_BANDIS  = _F (
                      ♦  K    = K,                  [R]
                      ♦  DMAX     = dmax,           [R]
                      ♦  GAMMA=gamma        ,           [R]
                      ◊  KT=          /kt,          [R]
                                      /1.E12        [DEFAUT]
                      ),
```

9.18.2 Opérande K

normal Rigidity with null loading K_{ni} (stress per unit of length).

9.18.3 Asymptotic operand

DMAX Fermeture D_{max} (length).

9.18.4 Operand GAMA

Paramètre material γ without dimension.

9.18.5 Operand KT

Tangencial stiffness K_t (forced per unit of length).

9.19 Key word factor THM_RUPT

Constitutive law for cracks with hydro-mechanical coupling (see [R7.02.15]).

When the surrounding solid masses the crack are impermeable, flow is not well any more defined on the elements of nonopen joints. In this case, one overrides the jump of displacement by a fictitious crack opening ε_{fict} which makes it possible to regularize 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 modulus of Biot N for the cohesive area.

9.19.1 Syntax

```
| THM_RUPT  = _F (
                    ♦  OUV_FICT   = ouv_fict,        [R]
                    ◊  UN_SUR_N   = /1/n     ,       [R]
                                    /0.0           [DEFAUT]
                          ),
                    ),
```

9.19.2 Opérande OUV_FICT

Ouverture fictitious of crack ε_{fict} (length).

9.19.3 Operand UN_SUR_N

Inverse of the modulus of Biot of crack N (forced per unit of length).

10 Behaviors specific to elements 1D

10.1 Key word factor ECRO_ASYM_LINE (cf [R5.03.09])

It makes it possible to modelize a behavior with linear isotropic hardening, but with elastic limits and different hardening moduli in tension and compression. This is used by the model of behavior 1D VMIS_ASYM_LINE, usable for elements of bar.
Elastic behaviour in tension and compression is the same one: even Young modulus.
There are two fields of isotropic hardening defined by R_T and R_C. The two fields are independent one of the other. We adopt an index T for the tension and C compression.

σ_{YT}	Limiting force in tension. In absolute value.
σ_{YC}	Limiting force in compression. In absolute value.
p_T	Plastic strain cumulated in tension. Algebraic value.
p_C	Plastic strain cumulated in compression. Algebraic value.
E_{TT}	Slope of hardening in tension.
E_{TC}	Slope D ` hardening in compression.

The equations of the model of behavior are:

$$\begin{cases} \dot{\varepsilon}^p=\dot{\varepsilon}-\dot{\overbrace{E^{-1}\sigma}}-\dot{\varepsilon}^{th} & \text{avec} \\ \dot{\varepsilon}^p=\dot{\varepsilon}_C^p+\dot{\varepsilon}_T^p & \begin{cases} \dot{p}_C=0 \text{ si } -\sigma-R_C(p_C)<0 \\ \dot{p}_C\geq 0 \text{ si } -\sigma=R_C(p_C) \\ \dot{p}_T=0 \text{ si } \sigma-R_T(p_T)<0 \\ \dot{p}_T\geq 0 \text{ si } \sigma=R_T(p_T) \end{cases} \\ \dot{\varepsilon}_C^p=\dot{p}_C\dfrac{\sigma}{|\sigma|} & \\ \sigma-R_T(p_T)\leq 0 & \\ -\sigma-R_C(p_C)\leq 0 & \end{cases}$$

where:
$\dot{\varepsilon}_C^p$: plastic strainrate in compressions
$\dot{\varepsilon}_T^p$: plastic strainrate in tension.
ε_{th} : thermal strain of origin: $\varepsilon_{th}=\alpha(T-T_{ref})$. α is defined under ELAS.

It is noticed that one cannot have simultaneously plasticization in tension and compression: either $\dot{p}_C=0$, or $\dot{p}_T=0$, or both are null.

10.1.1 Syntax

```
| ECRO_ASYM_LINE = _F (
                 ♦  DT_SIGM_EPSI=RT     ,            [R]
                 ♦  SY_T=sigmayT           ,      [R]
                 ♦  DC_SIGM_EPSI=RC     ,            [R]
                 ♦  SY_C=             sigma yC       [R]
                 )
```

11 Comportements private individuals

11.1 Key word factor LEMAITRE_IRRA

Caractéristiques (specific with the irradiation) of the creep of the pencils or fuel assemblies (behavior LEMAITRE_IRRA).
The elastic characteristics must be defined under key word ELAS or ELAS_FO.

The uniaxial form of the model of growth is:

$$\varepsilon_g(t)=f(T,\Phi_t)$$

where f is a function of the temperature T expressed in $°C$ and expressed Φ_t fluence in 1024 neutrons/m2.

If one adopts a modelization 1D (the behavior is then applied to a beam element in the axial direction, confer [R5.03.09]), this uniaxial form is used such as it is.

On the other hand, for modelizations 2D and 3D, the model of growth is written (confer [R5.03.08]):

$$\varepsilon_g(t)=f(T,\Phi_t)\varepsilon_g^0$$

with: $\varepsilon_g^0=\begin{pmatrix}1&0&0\\0&0&0\\0&0&0\end{pmatrix}_{R_1}$

One must then define using operand ANGL_REP of key word MASSIF of operator AFFE_CARA_ELEM the local axes corresponding to the reference R_1 (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 key word GRAN_FO.
One informs four key words QSR_K, BETA, PHI_ZERO, L (the other parameters of creep are identical to those of behavior LEMAITRE) and behaviour in creep are then according to:

$$\dot{p}=\left[\frac{\sigma_{eq}}{p^{1/m}}\right]^n\left(\frac{1}{K}\frac{\Phi}{\Phi_0}+L\right)^{\beta}e^{\frac{-Q}{R(T+T_0)}}\qquad(T_O=273{,}15°)$$

where F is the neutron flow computed starting from the fluence (see [R5.03.08] or [R5.03.09] according to the modelization). T is in $°C$.

If it is wished that the behavior not depend on the fluence, but comprises nevertheless the term in $\exp(-Q/RT)$, it is possible, only for modelizations 2D and 3D, to use key word LEMAITRE_IRRA in STAT_NON_LINE by informing key word LEMAITRE_IRRA in DEFI_MATERIAU. It is then necessary imperatively to affect UN_SUR_K, A, B, S with zero and PHI_ZERO with one. Under these conditions, it is not necessary to define a field of fluence.

11.1.1 Syntax

```
| LEMAITRE_IRRA=  _F (
                  ♦ N          =  N,                 [R]
                  ♦  UN_SUR_K     =1  /K  ,          [R]
                  ◊  UN_SUR_M     =  /   1/m,        [R]
                                  /0.0   ,           [DEFECT]
                  ◊ QSR_K=        /  Q/R,            [R]
                                  /0.0   ,           [DEFECT]
                  ◊ BETA=         /  beta,           [R]
                                  /0.O   ,           [DEFECT]
                  ◊ PHI_ZERO=     /  phi0,           [R]
                                  /1.10E +20,        [DEFECT]
                  ◊ L=            /  L,              [R]
                                  /0.0   ,           [DEFAUT]
                  ◊ GRAN_FO=       Fct_g,            [function]
                 )
```

11.2 Key word élasto-viscoplastic Model

factor LMARC_IRRA developed with the LMA-RC to describe the orthotropic viscoplastic behavior of the tubes of claddings of the fuel pin [R5.03.10], supplemented by the parameters of growth provided behind key word GRAN_FO.

Briefly, the behavior models are:

$$\begin{cases} f=\left|\tilde{\sigma}-X\right|-R_0=\sqrt{\frac{3}{2}\left(\tilde{\sigma}-X\right)^t M\left(\tilde{\sigma}-X\right)} \\ \dot{\varepsilon}^{vp}=\dot{v}\frac{\partial f}{\partial \sigma}=\frac{3}{2}\dot{v}\frac{M\left(\tilde{\sigma}-X\right)}{\left|\tilde{\sigma}-X\right|} \qquad \dot{v}=\sqrt{\frac{2}{3}\left(\dot{\varepsilon}^{vp}\right)^t M^{-1}\dot{\varepsilon}^{vp}}=\dot{\varepsilon}_0\left\{sinh\left(\frac{\left|\tilde{\sigma}-X\right|}{K}\right)\right\}^n \\ \dot{X}=p\left(\frac{2}{3}Y(v)\,N\,\dot{\varepsilon}^{vp}-Q\left(X-X^{(1)}\right)\dot{v}\right)-\left\{r_m sinh\left(\left(\frac{\left|X\right|}{X_0}\right)^m\right)\right\}N\,R\frac{\left|X\right|}{X} \\ X^{(1)}=p_1\left(\frac{2}{3}Y(v)\,N\,\dot{\varepsilon}^{vp}-Q\left(X^{(1)}-X^{(2)}\right)\dot{v}\right) \qquad X^{(2)}=p_2\left(\frac{2}{3}Y(v)\,N\,\dot{\varepsilon}^{vp}-Q\,X^{(2)}\dot{v}\right) \end{cases}$$

with: $Y(v)=Y_\infty+\left(Y_0-Y_\infty\right)e^{bv}$ $\quad |X|=\sqrt{\frac{3}{2}X^t N X}$

Note:

$\tilde{\sigma}$ represent the deviator of the stresses and $\left|\tilde{\sigma}-X\right|$ the equivalent within the meaning of Hill.
The matrixes M, N, R and Q make it possible to describe the viscoplastic anisotropy of behavior.

11.2.1 Syntax

```
|   LMARC_IRRA= _F   (

                    ♦ R_0=          R0,                 [R]
                    ♦ DE_0=      eps 0,               [R]
                    ♦ N=         N,                  [R]
                    ♦ K=         K,                  [R]
                    ♦ Y_0=          y0,                 [R]
                    ♦ Y_I=          yinfi,              [R]
                    ♦ B=         B ,                 [R]
                    ♦ A_0=          X0,                 [R]
                    ♦ RM=        rm,                 [R]
                    ♦ M=         m ,                 [R]
                    ♦ P=         p ,                 [R]
                    ♦ P1=        p1,                 [R]
                    ♦ P2=        p2,                 [R]
                    ♦ M11=          M11,                [R]
                    ♦ M22=          M22,                [R]
                    ♦ M33=          M33,                [R]
                    ♦ M66=          M66,                [R]
                    ♦ N11=          N11,                [R]
                    ♦ N22=          M22,                [R]
                    ♦ N33=          N33,                [R]
                    ♦ N66=          N66,                [R]
                    ♦ Q11=          Q11,                [R]
                    ♦ Q22=          Q22,                [R]
                    ♦ Q33=          Q33,                [R]
                    ♦ Q66=          Q66,                [R]
                    ♦ R11=          R11,                [R]
                    ♦ R22=          R22,                [R]
                    ♦ R33=          R33,                [R]
                    ♦ R66=          R66,                [R]
                    ◊ GRAN_FO=   Fct_g,              [function]
                   )
```

11.3 Key word factor DIS_GRICRA

This key word makes it possible to define the parameters associated with the nonlinear behavior with connection between the grid and the pencil in a fuel assembly modelized by a discrete element (cf [R5.03.17]). The behavior usable in commands STAT_NON_LINE and DYNA_NON_LINE starting from these parameters is DIS_GRICRA .

The parameters of input of this model are the following:

•Behavior in axial sliding: 5 parameters (of which an arbitrary, purely numerical parameter):

1.normal rigidity of discrete the KN_AX ;
2.tangencial stiffness (in the direction of the sliding) KT_AX ;
3.coefficient of kinetic friction of Coulomb COUL_AX ;
4.force tightening F_SER (limit of sliding = COUL_AX X F_SER);
5.hardening parameter ET_AX (the constitutive law can be comparable with perfect plasticity. The hardening parameter is only used to ensure the convergence of computation; a value by default of 10^{-7} him is affected);

•Behaviour in rotation: 6 parameters (of which a purely numerical parameter)

1.successive slopes PEN1, PEN2 and PEN3 of the curve $Moment = f(angle)$;
2.angles ANG1 and ANG2 of the points of inflection of the curve;
3.hardening parameter ET_ROT (parameter being used only to ensure the convergence of computation; a value by default of 10^{-7} him is affected).

The gripping forces can vary according to the temperature and from the irradiation. These dependences are affected on slopes PEN1 and PEN2 for behaviour in rotation and on the gripping force F_SER for the behavior in axial sliding. The functions of dependence are directly defined in the form of a FORMULA in the command file.

- behavior which lean on a discrete element with 2 nodes (modelization DIS_TR) with degrees of freedom in translation and rotation
- contact with friction of Coulomb for the degrees of translation, modelized by an elastoplastic model
- nonlinear constitutive law in rotation based on geometrical and physical considerations (cf [R5.03.17])

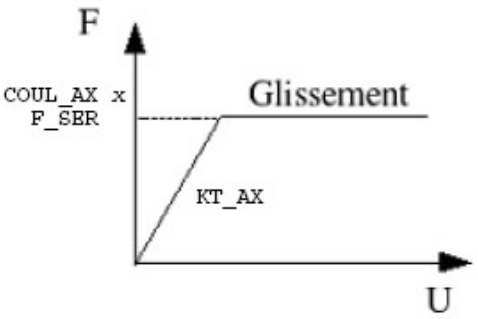
Les names of the followed parameters by the suffix _FO make it possible to inform the value in the form of a function.
A certain number of parameters additional, available for this behavior but which do not appear in this document, are clarified in [V6.04.131].

11.3.1 Syntax

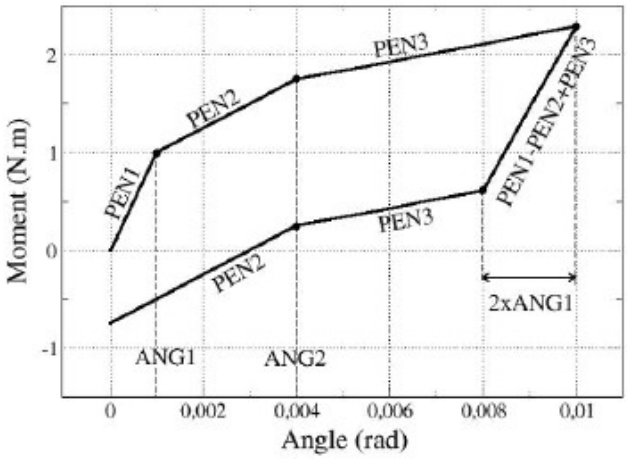
```
    | DIS_GRICRA= _F (

% Behavior "DIS_GRICRA'

                    ♦ KN_AX=       kn_bossette,     [R]
                    ♦ KT_AX=       kt_bossette,     [R]
                    ♦ COUL_AX=        kt_bossette,     [R]
                    ◊ F_SER=       kt_bossette,     [R]
```



(a) Comportement en translation



(b) Comportement en flexion

```
                    ◊ F_SER_FO=    kt_bossette,     [function]
                    ◊ ET_AX=      /kt_bossette,     [R]
                                   /1.0E-7,            [DEFECT]
                    ◊ ET_ROT=     /kt_bossette ,       [R]
                                   /1.0E-7,            [DEFAUT]
                    ◊ ANG1=           kt_ressort,         [R]
                    ◊ ANG2=           kt_ressort,         [R]
                    ◊ ANG1_FO=        mu_bossette ,       [function]
                    ◊ ANG2_FO=        mu_ressort,         [function]
                    ◊ PEN1_FO=        gamma_bossette  ,   [function]
                    ◊ PEN2_FO=        gamma_ressort,      [function]
                    ◊ PEN3_FO=        forc_serrage       [function]
                )
```

11.4 Key word thermomechanical factor

GATT_MONERIE Constitutive law of fuel “GATT-Monerie” in order to simulate tests of indentation [R5.03.08]. This constitutive law is an isotropic élasto-viscoplastic model without hardening whose specifities are:

- the potential of dissipation is the sum of two potentials of the Norton type (without threshold),
- the fuel having a residual porosity likely to evolve in compression (thickening), this potential depends, besides the equivalent stress, of the hydrostatic stress.

The two intern variables of this model are the cumulated plastic strain and the voluminal fraction of porosity.

11.4.1 Syntax

```
◊  | GATT_MONERIE  = _F   (

                    ♦ D_GRAIN=d_grain          ,          [R]
                    ♦ PORO_INIT=poro_init        ,        [R]
                    ◊ EPSI_01=          /eps1,            [R]
                                      /2.7252E-10,      [DEFECT]
                    ◊ EPSI_02=          /eps2,            [R]
                                      /9.1440E-41      [DEFAUT]
                   )
```

with

D_GRAIN	:	cut combustible grain
PORO_INIT	:	initial porosity
EPSI 01	:	coefficient strainrate low stress
EPSI 02	:	coefficient strainrate strong stress

Les elastic characteristics must be indicated under key word ELAS.

11.5 Key word factor DIS_CONTACT

This key word makes it possible to define the parameters associated with nonlinear behavior DIS_CHOC of shock with friction with Coulomb associated with the discrete elements (cf [R5.03.17]) for modelizations DIS_T, DIS_TR, 2D DIS T, 2D_DIS_TR lean on meshes POI1 or SEG2 (discrete element with 1 or 2 nodes).

11.5.1 Syntax

```
◊  | DIS_CONTACT=    _F  (
                  ◊ RIGI_NOR=       kN,                 [R]
                  ◊ RIGI_TAN=       /Kt   ,               [R]
                                     /0.0 ,             [DEFECT]
                  ◊ AMOR_NOR=       /Cn   ,               [R]
                                     /0.0 ,             [DEFECT]
                  ◊ AMOR_TAN=       /Ct   ,               [R]
                                     /0.0 ,             [DEFECT]
                  ◊ COULOMB=           /mu   ,                 [R]
                                     /0.0 ,             [DEFECT]
                  ◊ DIST_1=         /dist1   ,           [R]
                                     /0.0 ,             [DEFECT]
                  ◊ DIST_2=         /dist2   ,           [R]
                                     /0.0 ,             [DEFECT]
                  ◊ JEU=            /d0   ,              [R]
                                     /0.0                [DEFECT]
                  )
```

11.5.2 Operands RIGI_NOR/RIGI_TAN/AMOR_NOR/AMOR_TAN

RIGI_NOR = kN
Valeur 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 command AFFE_CARA_ELEM with key words DISCRET , 2D_DISCRET or RIGI_PARASOL).

RIGI_TAN = Kt
Valeur of the tangencial stiffness of shock.

AMOR_NOR = Cn
Valeur of the normal damping of shock.

AMOR_TAN = Ct
Valeur of the tangential damping of shock.

11.5.3 Operands COULOMB/DIST_1/DIST_2/CLEARANCE

COULOMB = driven
Valeur of the coefficient of kinetic 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).

CLEARANCE = d0
Distance enters the node of shock and an obstacle not modelized (case of a shock between a mobile structure and an indeformable and motionless obstacle).

11.6 Key word factor DIS_ECRO_CINE

Ces parameters of elastoplastic material behavior to nonlinear kinematic hardening, cf [R5.03.17], are to be used with discrete elements 2D_DIS_TR, 2D_DIS_T, DIS_TR, DIS_T (cf operator AFFE_MODELE [U4.41.01]). The model is built component by component of the torsor of the resulting forces on the discrete element: there is no coupling between the components of forces (forces and couples), on which one can define different characteristics; only the diagonal characteristics are affected by the behavior. The elastic stiffness K_e (which is also used for the nonlinear algorithm for the prediction) of this constitutive law is given via key words K_T_D_L, K_TR_D_L, K_T_D_N, K_TR_D_N of the command AFFE_CARA_ELEM [U4.42.01]:

The quantities all are expressed in the local coordinate system of the element; it is compulsory to specify the key word REPERE='ROOM" in AFFE_CARA_ELEM [U4.42.01]. The directional sense of discrete can be done in AFFE_CARA_ELEM with the usual rules by using the key word DIRECTIONAL SENSE.

The use of the constitutive law is done in STAT_NON_LINE or DYNA_NON_LINE under the key word COMP_INCR [U4.51.11] with RELATION = "DISC_ECRO_CINE".

11.6.1 Syntax

```
◊   | DIS_ECRO_CINE=    _F (

                ◊/ ♦ LIMY_DX=          fy_dx,          [R]
                   ♦ KCIN_DX=          kx_dx,          [R]
                   ◊/ ♦ PUIS_DX=       n_dx,       [R]
                      ♦ LIMU_DX=       fu_dx,          [R]
                ◊/ ♦ LIMY_DY=          fy_dy,          [R]
                   ♦ KCIN_DY=          kx_dy,          [R]
                   ◊/ ♦ PUIS_DY=       n_dy,       [R]
                      ♦ LIMU_DY=       fu_dy,          [R]
                ◊/ ♦ LIMY_DZ=          fy_dz,          [R]
                   ♦ KCIN_DZ=          kx_dz,          [R]
                   ◊/ ♦ PUIS_DZ=       n_dz,       [R]
                      ♦ LIMU_DZ=       fu_dz,          [R]
                ◊/ ♦ LIMY_RX=          fy_rx,          [R]
                   ♦ KCIN_RX=          kx_rx,          [R]
                   ◊/ ♦ PUIS_RX=       n_rx,       [R]
                      ♦ LIMU_RX=       fu_rx,          [R]
                ◊/ ♦ LIMY_RY=          fy_ry,          [R]
                   ♦ KCIN_RY=          kx_ry,          [R]
                   ◊/ ♦ PUIS_RY=       n_ry,       [R]
                      ♦ LIMU_RY=       fu_ry,          [R]
                ◊/ ♦ LIMY_RZ=          fy_rz,          [R]
                   ♦ KCIN_RZ=          kx_rz,          [R]
                   ◊/ ♦ PUIS_RZ=       n_rz,       [R]
                      ♦ LIMU_RZ=       fu_rz         [R]
                )
```

11.6.2 Opérandes

LIMY_DX = fy_dx

F_y^x : yield stress in the direction of force x

KCIN_DX = kx_dx

k_x : "stiffness" of kinematic hardening in the direction of force x

PUIS_DX = n_dx

n_x : power, defining the shape of the monotonous curve in the direction of force

LIMU_DX = fu_dx

F_u^x : limit of kinematic hardening, defining the plate of the monotonous curve in the direction of force x

11.7 Key word factor DIS_VISC

Ces parameters of nonlinear viscoelastic behavior are to be used with discrete elements (cf [R5.03.17]) 2D_DIS_TR, 2D DIS T, DIS_TR, DIS_T (cf operator AFFE_MODELE [U4.41.01]). The model is built component by component of the torsor of the resulting forces on the discrete element: there is no coupling between the components of forces (forces and couples), 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 also used for the nonlinear algorithm for the prediction) of this constitutive law is given via key words K_T_D_L, K_TR_D_L, K_T_D_N, K_TR_D_N of the command AFFE_CARA_ELEM [U4.42.01].

This viscous constitutive law is usable with operators STAT_NON_LINE and DYNA_NON_LINE, under the key word COMP_INCR [U4.51.11] with RELATION = "DISC_VISC".

The quantities all are expressed in the local coordinate system of the element; it is compulsory to specify REPERE='ROOM" in AFFE_CARA_ELEM [U4.42.01]. The directional sense of discrete can be done in AFFE_CARA_ELEM with the usual rules by using the key word DIRECTIONAL SENSE.

11.7.1 Syntax

```
| DIS_VISC = _F (
                ◊/ ♦ COEF_DX=          a_dx,        [R]
                   ♦ PUIS_DX=          c_dx,        [R]
                ◊/ ♦ COEF_DY=          a_dy,        [R]
                   ♦ PUIS_DY=          c_dy,        [R]
                ◊/ ♦ COEF_DZ=          a_dz,        [R]
                   ♦ PUIS_DZ=          c_dz,        [R]
                ◊/ ♦ COEF_RX=          a_rx,        [R]
                   ♦ PUIS_RX=          c_rx,        [R]
                ◊/ ♦ COEF_RY=          a_ry,        [R]
                   ♦ PUIS_RY=          c_ry,        [R]
                ◊/ ♦ COEF_RZ=          a_rz,        [R]
                   ♦ PUIS_RZ=          c_rz        [R]
                )
```

11.7.2 Opérandes

the constitutive law is form $F=-CV^{\alpha}$ and requires 2 characteristics. Their units must be in agreement with those of the force or the couple considered: F is homogeneous with a force (*respectively* Couple), V is homogeneous at a velocity (*respectively* angular velocity).

COEF_DX = c_dx
C_x : damping coefficient (this value can be different from the stiffness K_e) in the direction of force x

PUIS_DX = a_dx
α_x : power of the model of damping of velocity in the direction of force x

11.8 Key word factor DIS_BILI_ELAS

This word key factor makes it possible 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 model is built component by component, it thus does not have there coupling between the components of forces, 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 constitutive law is given via key words K_T_D_L, K_T_D_N of the command AFFE_CARA_ELEM [U4.42.01].

This constitutive law is usable with operators STAT_NON_LINE and DYNA_NON_LINE, under the key word COMP_INCR [U4.51.11] with RELATION = "DISC_BILI_ELAS".

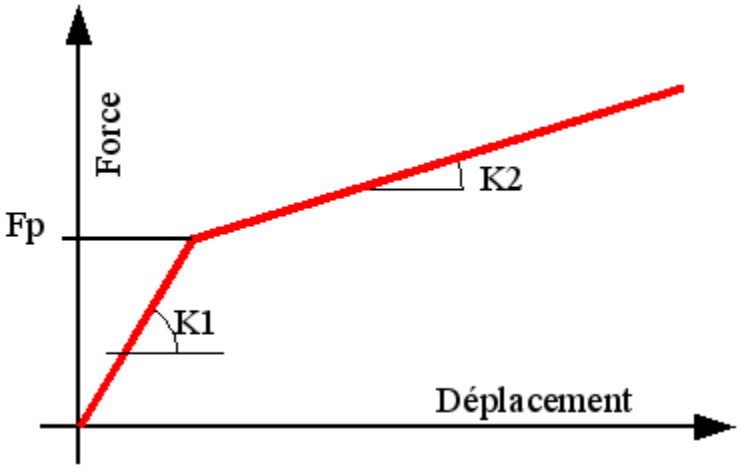
The quantities all are expressed in the local coordinate system of the element. The directional sense of discrete can be done in the command AFFE_CARA_ELEM with the usual rules by using the key word DIRECTIONAL SENSE.

11.8.1 Syntax

```
| DIS_BILI_ELAS = _F (
                ◊/ ♦ KDEB_DX=          k1_dx,          [function]
                   ♦         KFIN_DX= k2_dx,         [function]
                   ♦ FPRE_DX=           fp_dx,          [R]
                ◊/ ♦ KDEB_DY=          k1_dy,          [function]
                   ♦         KFIN_DY= k2_dy,         [function]
                   ♦ FPRE_DY=           fp_dy,          [R]
                ◊/ ♦ KDEB_DZ=          k1_dz,          [function]
                   ♦         KFIN_DZ= k2_dz,         [function]
                   ♦ FPRE_DZ=           fp_dz          [R]
                   )
```

11.8.2 Opérandes

the constitutive law is bilinear elastic and requires 3 characteristics. The units of the characteristics must be in agreement with those of the analyzed problem: $k1$ and $k2$ are homogeneous with a force by displacement, Fp is homogeneous with a force.



KDEB_DX = k1_dx, KDEB_DY = k1_dy, KDEB_DZ = k1_dz
stiffness of the behavior when the force in the discrete one is lower Fp .
KFIN_DX = k2_dx, KFIN_DY = k2_dy, KFIN_DZ = k2_dz
stiffness of the behavior when the force in the discrete one is higher than Fp .
FPRE_DX = fp_dx, FPRE_DY = fp_dy, FPRE_DZ = fp_dz
the force which definite the transition enters the 2 linear behaviors.

11.9 Key word factor ASSE_CORN

Description of the characteristics material associated with the behavior with a bolted assembly [R5.03.32].

11.9.1 Syntax

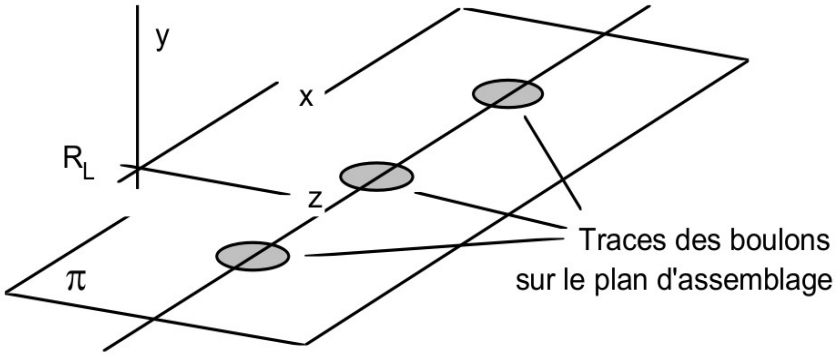
```
|   ASSE_CORN = _F    (

                ♦   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,               [R]
                  /1.E-4
)
```

11.9.2 Sur

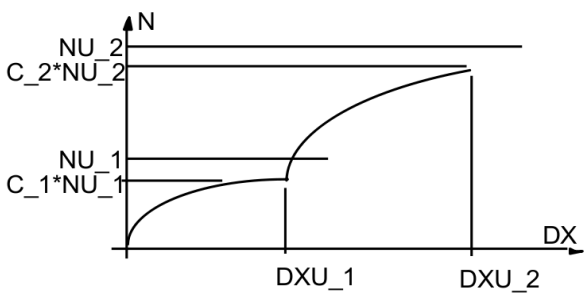
Operands the following figure, the plane π represents the plan of the assembly. The axis of the bolts is perpendicular to this plane. The player will refer to [U4.42.01] AFFE_CARA_ELEM for the directional sense of the reference R_L defining the plan of the assembly.

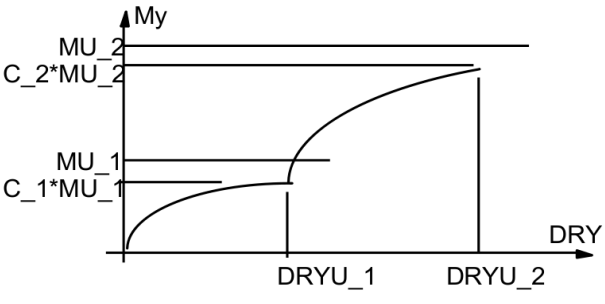


The behavior model of the assembly is:

- nonlinear in translation according to x and in rotation around y.
- linear according to the other degrees of freedom: DY , DZ , DRX , DRZ

Behaviours in tension along the axis x and rotation around the axis y.





The behavior of 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

11.10 Key word factor ARME

Description of the characteristics material associated with the behavior with an air conductor arrangement.
The arm of each armament of broken phase, represented by a discrete element, has a nonlinear behavior forces of it - displacement consisted the difference between maximum displacement dlp of the end of the armament in the plastic phase and limiting elastic displacement dle.

11.10.1 Syntax

```
| ARME = _F (
                ♦ KYE=kye , [R]
                ♦ DLE=dle , [R]
                ♦ KYP=kyp , [R]
                ♦ DLP=dlp , [R]
                ♦ KYG=kyg [R]
              )
```

11.10.2 Operands KYE/DLE

elastic KYE =
kye Slope until a limiting force.

Limiting DLE =
dle Displacement of the elastic strain.

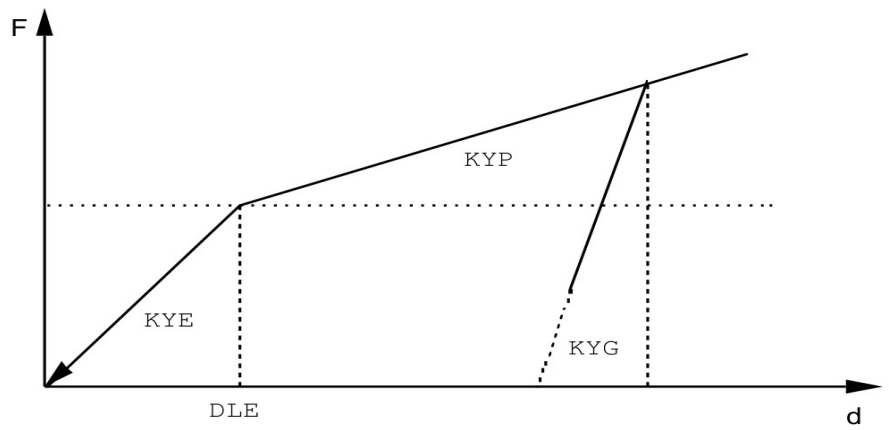
11.10.3 Operand KYP/DLP

plastic KYP =
kyp Slope until limiting displacement DLP.

Limiting DLP =
dlp Displacement of plastic strain 0.

11.10.4 Operand KYG

KYG = kyg
Slope of discharge.



12 Fluid behavior

12.1 Key word FLUID factor

Définitions of the constant fluid characteristics.

12.1.1 Syntax

```
|   FLUID = _F   (

                ♦  RHO       =rho      ,             [R]
                ◊  CELE_R    =celr  ,            [R]
                ◊  CELE_C    =celc  ,            [C]
                 ◊ PESA_Z=pz        ,             [R]
                )
```

12.1.2 Opérande RHO

RHO =rho
Density of the fluid. No the checking.

12.1.3 Operands CELE_R/ CELE_C

CELE_R =celr
Célérité of propagation acoustic waves in the fluid environment (standard reality).
No the checking of about size.

CELE_C =celc

Célérité of propagation acoustic waves in the fluid environment (standard complex in particular for a porous environment). No the checking of about size.

For a modelization in PHENOMENE: ACOUSTICS (command AFFE_MODELE [U4.41.01]) only the definition of celerity using key word CELE_C are valid.

The definition using key word CELE_R leads to a stop in error.

12.1.4 Opérande PESA_Z

PESA_z = pz,
Accélération of gravity according to z, used only and compulsory if the modelization chosen in AFFE_MODELE is 2D_FLUI_PESA.

13 Material characteristics associated with postprocessings

13.1 Key word factor FATIGUE

One will be able to refer to [R7.04.01] and [R7.04.03].

13.1.1 Syntax

```
| FATIGUE = _F  (
                /◊  WOHLER=f_wohl            ,    [function]
                /◊ A_BASQUIN=a             ,          [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 Opérande WOHLER

Cet operand makes it possible to introduce the curve of Wöhler of the material in a point by point discretized form. This function gives the number of cycles to the fracture N_{rupt} according to the half-amplitude of stress $\frac{\Delta\sigma}{2}$.

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 fracture and on half - amplitude of the stress (formula of Basquin per pieces),
- LIN LIN : linear interpolation on the number of cycles to the fracture and on the half amplitude of the stress (this interpolation is disadvised because the curve of Wöhler is absolutely not linear in this reference),
- LIN LOG : interpolation into linear on the half-amplitude of stress, and logarithmic curve on the number of cycles to the fracture, which corresponds to the statement 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

A_BASQUIN= has
BETA_BASQUIN= beta
Ces operands make it possible to introduce the curve of Wöhler of the material in the analytical form of BASQUIN [R7.04.01].

$D = A\,Salt^{\beta}$ where A and β are two constants of the material,

$Salt$ = forced alternate of the cycle = $\frac{\Delta\sigma}{2}$ and D the elementary damage.

13.1.4 Operands A0 / A1 / A2 / A3 / SL

A0= a0, A1= a1, A2= a2, A3= a3, SL= SL
Ces operands allow to define in analytical form the curve of Wöhler in “current area” [R7.04.01].

$Salt$ = alternate stress = $\frac{1}{2}\frac{E_C}{E}\Delta\sigma$

$X = log_{10}(Salt)$

$N_{rupt} = 10^{a0+a1x+a2x^2+a3x^3}$

$D = \begin{cases} 1/N \text{ si} Salt \geq SL \\ 0. \text{ sinon} \end{cases}$

Cette lists operands makes it possible to introduce the various parameters of this analytical form.

$a0$ $a1$, $a2$ and $a3$ constants of the material,

Sl limit of endurance of the material.

The Young modulus E is introduced into DEFI_MATERIAU (key word factor ELAS operand E).

The value of Ec , Young modulus associated with the curve with fatigue with the material is also introduced into DEFI_MATERIAU under the key word factor FATIGUE, operand E_REFE.

13.1.5 Operand MANSON_COFFIN

MANSON_COFFIN = f_mans
Cet operand makes it possible to introduce the curve of Manson-Coffin of the material in a point by point discretized form. This function gives the number of cycles to the fracture according to the half-amplitude of strains $\frac{\Delta\varepsilon}{2}$.

13.1.6 Operand E_REFE

E_REFE = EC.
Cet operand makes it possible to specify the value of the Young modulus associated with the curve with fatigue with the material. This value allows amongst other things, to define the curve of Wöhler in “current area” [R7.04.01].

13.1.7 Operands D0/TAU0

D0 = d0
Permet to specify the value of the limit of endurance in alternate pure traction and compression. This value is used in the computation of the criteria of Crossland and Dang Van Papadopoulos [R7.04.01] by the ordering of POST_FATIGUE [U4.83.01].

TAU0 = tau0
Permet to specify the value of the limit of endurance in alternate pure shears. This value is used in the computation of the criteria of Crossland and Dang Van Papadopoulos [R7.04.01] by the ordering of POST_FATIGUE [U4.83.01].

13.2 Key word factor DOMMA_LEMAITRE

Sous this key word factor are gathered all the characteristics material necessary to the computation of the damage of Lemaitre and the model 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                 [DEFAUT]
                     )
```

13.2.2 Opérande S

S = S

S is a parameter material necessary to the computation of the damage of Lemaitre. S must be a function of the parameter $TEMP$.

13.2.3 Operand EPSP_SEUIL

EPSP_SEUIL = Pseuil

Permet to specify the value of the threshold of damage pd, necessary to the computation of the damage of Lemaitre.

13.2.4 Operand EXP_S

EXP_S = Pd

Permet to define the model of Lemaitre-Sermage, the default value (1.0) corresponds to the computation of the damage of Lemaitre.

13.3 Key word factor CISA_PLAN_CRIT

Sous this key word factor are gathered all the characteristics material necessary to the implementation of the criteria with critical planes [R7.04.04].

13.3.1 Syntax

```
◊   | CISA_PLAN_CRIT = _F    (

                    ♦ CRITERE =/ "MATAKE_MODI_AC",         [TXM]
                               / " DANG_VAN_MODI_AC ",     [TXM]
                               / "MATAKE_MODI_AV",         [TXM]
                               / "DANG_VAN_MODI_AV",       [TXM]
                               / "FATESOCI_MODI_AV",       [TXM]

                #Si CRITERE == "MATAKE_MODI_AC" OR "MATAKE_MODI_AV":

                      ♦ MATAKE_A = has,                       [R]
                      ♦ MATAKE_B = B,                         [R]
                      ♦ COEF_FLEX_TORS = c_flex_tors,         [R]
                #FinSi

                #Si CRITERE == "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]
                #FinSi

                #Si CRITERE ==" FATESOCI_MODI_AV":

                      ♦ FATSOC_A = has,                       [R]
                      ♦ COEF_CISA_TRAC = c_cisa_trac,         [R]
```

```
#FinSi
      )
```

13.3.2 Opérande MATAKE_A

MATAKE_A = has,

Permet to specify the value of the coefficient without dimension a, present in 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,

Permet to specify the value of the coefficient B , present in 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,

Permet to specify the value of the report of the limits of endurance in bending and alternating torsion, 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,

Permet to specify the value of the coefficient without dimension a, present in 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,

Permet to specify the value of the coefficient b, present in 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,

Permet to specify the value of the report of the limits of endurance in bending and alternating torsion, 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,

Permet to specify the value of the coefficient a, present in criterion FATESOCI_MODI_AV, confer [R7.04.01] and [U4.83.02].

13.4 Key word factor WEIBULL, WEIBULL_FO

Définition of the coefficients of the Weibull model [R7.02.06].
Briefly, the probability of cumulated fracture of fracture P_r of a structure is written, in the case of a monotonic loading:

$$P_r = 1 - \exp\left[-\sum_{V_p} \left(\left(\frac{\sigma_I}{\sigma_u} \right)^m \frac{V_p}{V_0} \right) \right]$$

where the summation relates to maillesplastifiées V_p (i.e cumulated plastic strain higher than a value chosen arbitrarily p_s) and m, s_u, V_0 are the parameters of the Weibull model.

In the case of an unspecified way of loading:

$$P_r(t) = 1 - \exp\left[-\left(\frac{\sigma_w}{\sigma_u} \right)^m \right]$$

with:

$$\sigma_{\omega^m} = \sum_V \left[\max_{[u<t,\ \dot{p}(u)>0]} \left\{ \tilde{\sigma}_I(u) \right\} \right]^m \frac{V}{V_0},$$

$\dot{p}$ indicating plastic strain rate cumulated, $\tilde{\sigma}_I$ the greatest principal stress at time t [R7.02.06].

Lastly, if the stress of cleavage depends on temperature (WEIBULL_FO):

$$P_r(t) = 1 - exp\left[-\left(\frac{\sigma_\omega^0}{\sigma_u^0} \right)^m \right],$$

σ_ω^0 indicating the stress of Weibull defined conventionally for σ_u^0 data:

$$\sigma_\omega^{0^m} = \sum_V \max_{[u<t,\ \dot{p}(u)>0]} \left[\frac{\sigma_u^0 . \sigma_I(u)}{\sigma_u(\theta(u))} \right]^m \frac{V}{V_0} A^{p^m},$$

$\theta(u)$ indicating the temperature in the element δV.

13.4.1 Syntax

```
| / WEIBULL= _F (

                ♦   M=m                      ,          [R]
                ♦   SIGM_REFE=sigmu          ,       [R]
                ♦   VOLU_REFE=V0          ,          [R]
                ◊   SEUIL_EPSP_CUMU=         /PS ,       [R]
                                           /10-6     [DEFAUT]
                )
 / 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,     [DEFAUT]
                )
```

13.4.2 Opérandes

M = m, SIGM_REFE = sigmu, SIGM_CNV = sigm0u, VOLU_REFE = V0

Paramètres associated with the Weibull model.

SEUIL_EPSP_CUMU=ps

cumulated Plastic strain threshold.

13.5 Key words factor RCCM, RCCM_FO

Définition of the quantities necessary to the use of the methods simplified defined in payment RCC-M [R7.04.03]. These quantities are constant or function of parameter "TEMP".

13.5.1 Syntax

```
|    /  RCCM     = _F (
                   ◊  SY_02=sy          ,                  [R]
                   ◊SM=sm               ,                  [R]
                   ◊  SU=su             ,                  [R]
                   ◊  SC=sc             ,                  [R]
                   ◊  SH=sh             ,                  [R]
                   ◊  N_KE=h         ,                  [R]
                   ◊  M_KE=m         ,                  [R]
                   ◊  A_AMORC=a      ,                  [R]
                   ◊  B_AMORC=b      ,                  [R]
                   ◊  D_AMORC=d      ,                  [R]
                   ◊  R_AMORC=r      ,                  [R]
                    )
       /  RCCM_FO = _F (
                   ◊   SY_02=sy         ,                  [function]
                   ◊   SM=sm            ,                  [function]
                   ◊  SU=su             ,                  [function]
                   ◊  S          =s ,                  [function]
                   ◊  SH=sh             ,                  [function]
                   ◊  N_KE=h         ,                  [function]
                   ◊  M_KE=m         ,                  [function]
                   ◊  A_AMORC=a      ,                  [function]
                   ◊  B_AMORC=b      ,                  [function]
                   ◊  D_AMORC=d      ,                  [function]
                   ◊  R_AMORC=r      ,                  [function]
                    )
```

13.5.2 Opérande SY 02

SY_02= sy
Elastic limit to 0.2% of plastic strain to the temperature of computation. This operand can vary according to the temperature.

13.5.3 Operands SM/SU/SH

SM = acceptable
Sm Equivalent stress of the material to the temperature of computation. This operand can vary according to the temperature.

SU= known
Résistance with the tension of the material to the temperature of computation. This operand can vary according to the temperature.

Working Sh=
HS Stress of the material to the ambient temperature, confer POST_RCCM [U4.83.11]
working Stress of the material to the maximum temperature, confer POST_RCCM [U4.83.11]

13.5.4 working Opérande

SC
SC=sc Stress of the material to the ambient temperature, confer POST_RCCM [U4.83.11]

13.5.5 working Opérande

S S
=s Stress of the 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, M_KE = m

Ces operands make it possible to define the values of n and m two constants of the material.

These characteristics are necessary for the computation of the elastoplastic coefficient of concentration K_e, which is defined by the RCC-M as being the relationship between the amplitude of real strain and the amplitude of strain determined by the elastic analysis.

$$\begin{cases} K_e = 1 & \text{si} \quad \Delta\sigma \le 3\,S_m \\ K_e = 1+(1-n)\left(\dfrac{\Delta\sigma}{3S_m}-1\right)(n(m-1)) & \text{si} \quad 3S_m < \Delta\sigma \le 3\,S_m \\ K_e = \dfrac{1}{n} & \text{si} \quad 3mS_m \le \Delta\sigma \end{cases}$$

13.5.7 Operands A_AMORC/B_AMORC

A_AMORC = has, B_AMORC = B

Coefficients of the model of priming.

13.5.8 Operand D_AMORC

D_AMORC =d
Distance of extraction of the stresses.

13.5.9 Operand R_AMORC

R_AMORC =r
Paramètre of the relation between stress and effective stress.

13.6 Key word factor CRIT_RUPT

Définition of the quantities necessary to the rupture criterion in critical stress implemented by key word POST_ITER/CRIT_RUPT under COMP_INCR. If the greatest average principal stress in an element exceeds a threshold given sigc, the Young modulus is divided by the coefficient coeff.
This criterion available for constitutive laws VISCOCHAB, VMIS_ISOT_TRAC (_LINE) and VISC_ISOT_TRAC (_LINE) , and is validated by tests SSNV226A, B, C.

13.6.1 Syntaxe

```
CRIT_RUPT    = _F ( ◊ SIGM_C=sigc         ,                [R]
                    ◊COEF        =coef  ,              [R]    )
```

13.6.2 Opérandes SIGM_C, COEF

Valeur of the stress threshold sigc (in unit of stresses) and of the coefficient coeff (without unit).

13.7 Key word factor VERI_BORNE

This key word allows a checking of the field of validity of the parameters of a constitutive law. Indeed, the identification of the parameters of these models is always made in a certain range of strain and temperature. The objective is to so inform the user in his study it leaves this field where the parameters were identified. These limits are defined under key word VERI_BORNE . The overflow of the limits during computation, results in the emission of an alarm.

13.7.1 Syntax

```
VERI_BORNE = _F (   ◊  EPSI_MAXI=epsi                          [R]
                    ◊VEPS_MAXI       =veps  ,              [R]
                    ◊TEMP_MINI       =tmin  ,              [R]
                    ◊TEMP_MAXI       =tmax  ,              [R]
)
```

13.7.2 Opérandes

Valeur of S limits in terms of maximum total deflection, strainrate, and temperatures extreme.

13.8 Key words factor UMAT, UMAT_FO

Définition of the parameters allowing to the use of a constitutive law “user”, i.e. whose routine of integration of the behavior is provided by the user, confer [U2.10.01]. These quantities are constant or function of parameter "TEMP". It is possible to provide up to 50 parameters.

13.8.1 Syntax

```
   |    /  UMAT     = _F (
                     ◊  C1=C1            ,                [R]
                     ◊  C2=C2            ,                [R]
                        …                          [R]
                     ◊  C50=C50             ,             [R]
                      )
        /  UMAT_FO = _F (
                     ◊  C1=C1            ,                [function]
                     ◊C2=C2              ,                [function]
                        …                             [function]
                     ◊  C50       =C50                   [function]
                      )
```

13.9 Key word simple MATER

command DEFI_MATERIAU can be D-entering but each behavior remains single. One does not allow indeed to override a behavior already present in the material but only to enrich structure of data by additional characteristics material.

Example of use:
Only the characteristics thermal of the 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,),);

RESUT=MECA_STATIQUE (MODELE=MODMECA,…
```