Nonlinear behaviors

1 Drank

This document described the nonlinear behaviors of *Code_Aster*, introduced:

• via key word COMP_INCR in operators STAT_NON_LINE, SIMU_POINT_MAT, DYNA_NON_LINE, CALC_G, CALC_META, CALC_PRECONT, CALCUL, LIRE_RESU, MACR_ASCOUF_CALC, MACR_ASPIC_CALC ;

• via key word COMP_ELAS in operators STAT_NON_LINE, SIMU_POINT_MAT, DYNA_NON_LINE, CALC_G, MACR_ASCOUF_CALC, MACR_ASPIC_CALC.

For each behavior the scopes of application, the key words are specified defining the material parameters, the contents of the local variables and the supported modelizations.

Contents

2 Syntax

```
♦  |  COMP_INCR = _F (
      ♦ RELATION =     "ELAS",                              [DEFAULT]
                     /  incremental relations described in this document
      ◊ RELATION_KIT=/  relations kit described in this document
      ◊ DEFORMATION =   "PETIT",                            [DEFAULT]
                                                           /"PETIT_REAC
",
                     /"SIMO_MIEHE",
                     /"GROT_GDEP",
                     /"GDEF_HYPO_ELAS",
                     /"GDEF_LOG"

      ◊/TOUT              = "OUI',

[DEFAULT]
        /  | GROUP_MA=lgrma                              ,
      [l_gr_maille]
           | NET =lma    ,                               [l_maille]

      ◊  ITER_CPLAN_MAXI = 1                             [DEFAULT]
                       / iter_cplan_maxi
      ◊  /RESI_CPLAN_RELA  = 1.E-6,                      [DEFAULT]
                           /resi_cplan_rela
         /RESI_CPLAN_MAXI  = resi_cplan_maxi

      ◊  PARM_THETA =     1.  ,                          [DEFAULT]
                       /theta,                           [R]
      ◊  PARM_ALPHA =     1.  ,                          [DEFAULT]
                       /alpha,                           [R]
      ◊  RESI_INTE_RELA =  1.E-6,                        [DEFAULT]
                       /resint,                          [R]
      ◊  ITER_INTE_MAXI =  10,                           [DEFAULT]
                       /iteint,                          [I]
      ◊ITER_INTE_PAS      =                              0,
[DEFAULT]
                       /itepas,                          [I]
      ◊  ALGO_INTE =      "ANALYTIQUE",                  [DEFAULT]
                        /"SECANTE",
                        /"DEKKER",
                        /"NEWTON_1D",
                        /"BRENT",
                        /"NEWTON",
                        /"NEWTON_RELI",
                        /"NEWTON_PERT",
                       /"RUNGE_KUTTA",
                       /"SPECIFIQUE"
                       /"SANS_OBJET"

      ◊  TYPE_MATR_TANG=/ "PERTURBATION",
                       /"VERIFICATION",
                          ◊  VALE_PERT_RELA =  1.E-5,    [DEFAULT]
                                              /perturb,  [R]
                       /"TANGENTE_SECANTE"
                          ◊  /SEUIL =/3       ,
[DEFAULT]
                                        /threshold,          [R]
```

```
                                 ◊   /AMPLITUDE =/1,5
[DEFAULT]
                                                 /amplitude,    [R]
                                 ◊   / TAUX_RETOUR =   0,05       [DEFAULT]
                                                    /taux_retour   [R]
                  ),

        | COMP_ELAS =_F (
          ♦RELATION         =  "ELAS",
[DEFAULT]
                            /relations    elastics described in this document
          ◊DEFORMATION      =  "PETIT,
[DEFAULT]
                            /"GROT_GDEP",

          ◊/TOUT            =       "OUI'
[DEFAULT]
             /   | GROUP_MA=lgrma
[l_gr_maille]
                 | NET =lma                              [l_maille]
          ◊  RESI_INTE_RELA =        1.E-6,                 [DEFAULT]
                                    /resint,                [R]
          ◊  ITER_INTE_MAXI =        10,                    [DEFAULT]
                                    /iteint,                [I]
),
```

3 Conventions of notation

3.1 Nomenclature of the modelizations

not to overload this document, regroupings of the various modelizations are proposed here. We will call thereafter:

Modelization 3D	=	modelizations 3D, 3D_SI
Modelization INCO	=	modelizations 3D_INCO, AXIS_INCO and D_PLAN_INCO
Modelization INCO_UP	=	modelizations 3D_INCO_UP, AXIS_INCO_UP D_PLAN_INCO_UP
Modelization INCO_GD	=	modelizations 3D_INCO_GD, AXIS_INCO_GD D_PLAN_INCO_GD
Modelization INCO_ LOG	=	modelizations 3D_INCO_LOG, AXIS_INCO_ LOG D_PLAN_INCO_ LOG
Modelization D_PLAN	=	modelizations D_PLAN and D_PLAN_SI
Modelization AXIS	=	modelizations AXIS and AXIS_SI
Modelization 2D	=	modelizations D_PLAN, D_PLAN_SI, AXIS, AXIS_SI
Modelization C_PLAN	=	modelizations C_PLAN and C_PLAN_SI
Modelization COQUE	=	modelizations COQUE_3D and DKT
Modelization PIPE	=	modelizations TUYAU_3M and TUYAU_6M
Modelization COQUE1D	=	modelizations COQUE_AXIS, COQUE_C_PLAN, COQUE_D_PLAN
Modelization CONT_PLAN	=	the modelizations C_PLAN and COQUE and PIPE and COQUE1D
Modelization 3D_DIS	=	modelizations DIS_T and DIS_TR
Modelization 2D_DIS	=	the modelizations 2D_DIS_T and 2D_DIS_TR
DISCRET Modelization	=	modelizations 3D_DIS and 2D_DIS
Modelization LOUSE	=	modelizations POU_D_E, POU_D_T, POU_D_TG
Modelization GRILL	=	modelizations GRILL and GRILLE_MEMBRANE
Modelization PMF	=	modelizations POU_D_EM and POU_D_TGM
Modelization BARS	=	the modelizations BARS and 2D_BARRE
Modelization CONT_1D	=	the modelizations BARS and PMF and GRILL
Modelization THM	=	thermo_hydro_mecanic modelizations
Modelization GRAD_EPSI	=	modelizations 3D_GRAD_EPSI, D_PLAN_GRAD_EPSI and C_PLAN_GRAD_EPSI
Modelization GRAD_VARI	=	modelizations 3D_GRAD_VARI, D_PLAN_GRAD_VARI, and AXIS_GRAD_VARI
Modelization JOINED	=	PLAN_JOINT, AXIS_JOINT

Note:

If a constitutive law is used with L" one of modelizations INCO_GD or INCO_LOG (for incompressible), it is necessary D" to use only the tangent matrix (key word" TANGENT" factor PREDICTION=, " TANGENT" MATRICE= and REAC_ITER=1 under NEWTON of STAT_NON_LINE [U4.51.03] and DYNA_NON_LINE [U4.53.01]). In the contrary case, one S" stops in fatal error.

3.2 Local variables

the local variables are described briefly in this document for each behavior. The detail of their meaning is provided in the specific reference documents of these behaviors. The name of the local variables is however visible in card-indexing it "messages" with the execution of STAT_NON_LINE/DYNA_NON_LINE.

Notice 1: in particular, the named local variable "indicating of plasticity" indicates that there was plasticity created during the computation step and the current Gauss point and not during all the transient.

4 Key word COMP_INCR

This key word factor makes it possible to define the behavior models for which L" history of the material influences its behavior: most constitutive laws (in particular in plasticity) S" write in an incremental way then. L" history seen by the material is stored in the local variables. One can incremental behaviors have in same computation certain parts of structure obeying various (COMP_INCR) and other parts obeying with various elastic behaviors (COMP_ELAS).

For the precise meaning of these various relations one will refer to various documentations of reference thus qu" with the documentation of DEFI_MATERIAU [U4.43.01].

4.1 Modelization of the plane stresses in incremental behavior

Certain model of behaviors N" were not developed in plane stresses. In this case, one automatically uses L" algorithm of Borst [R5.03.03] which allows a taking into account of L" assumption of the plane stresses the level of L" algorithm D" balances (contrary to the models of behavior developed explicitly in plane stresses, which adopt this approach on the level of the integration of the constitutive laws). One can thus also assign an unspecified nonlinear model to the structural elements DKT, COQUE_3D and PIPE*). There still, it is necessary to use only the tangent matrix.*

In the same way, for the cases using a monodimensional stress state (POU_D_EM, POU_D_TGM, GRILL, GRILLE_MEMBRANE, BAR), to be able to use the behaviors which were not developed specifically in 1D, one automatically uses a method similar to that of Borst to integrate in 1D the behaviors available in 3D [R5.03.09].

The method of Borst is available neither for the metallurgical behaviors nor with DEFORMATION = "SIMO_MIEHE".

4.2 Local and nonlocal modelization

In the case of lenitive behaviors, the response of a model of local behavior with damage is dependant on the mesh. To be freed from this difficulty, certain models can be used in nonroom. Any model written in nonroom involves the introduction of a characteristic of the additional material, the characteristic length. For certain models, it is defined under the key word factor NON_LOCAL of operator DEFI_MATERIAU.

The response of a nonlocal modelization is more independent of the mesh. There exist four types of models in nonroom, activables in AFFE_MODELE by key word MODELISATION :

- "3D_GRAD_EPSI", "D_PLAN_GRAD_EPSI" or "C_PLAN_GRAD_EPSI". They are nonlocal models regularized on the strain. One defines a strain field regularized, related to the classical local strain by a regularizing operator who aims to limit the concentrations of strains (confer [R5.04.02]).
- "3D_GRAD_VARI", "D_PLAN_GRAD_VARI" or "AXIS_GRAD_VARI". They are nonlocal models here where the gradient of the local variables of the local model intervenes.
- "3D_GVNO", "D_PLAN_GVNO", or "AXIS_GVNO". It acts, like the preceding type, of nonlocal models where the gradient of damage intervenes. The processing of the damage is from now on nodal, like degree of freedom of the total system and either as local variable of the local model (confer [R5.04.04]).
- "D_PLAN_2DG", "D_PLAN_DIL" in complement of the model to regularize (confer [R5.04.03]). It is about a model regularized by a microstructural approach where either the strain field intervenes or the voluminal strain.

4.3 Operand RELATION

4.3.1 Model elastics and elastoplastic

Unless otherwise specified, all the models can include a dependence compared to the temperature. Moreover, they all are integrated in a purely implicit way.

4.3.1.1 "ELAS"

incremental elastic Behavior model: it makes it possible to take into account initial displacements and stresses given under key word ETAT_INIT. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under the key word:

- ELAS (_FO), with regard to isotropic elasticity,
- ELAS_ISTR (_FO), with regard to transverse isotropic elasticity,
- ELAS_ORTH (_FO), with regard to orthotropic elasticity.

The material parameters defined under ELAS are used for a certain number of behaviors, and also for the computation of the elastic stiffness matrix (PREDICTION=' ELASTIQUE', or MATRICE=' ELASTIQUE' under key word NEWTON cf [U4.51.03].

- Supported modelizations: 3D, 2D, CONT_PLAN, DISCRET, INCO, INCO_UP, INCO_LOG, POU_*, CONT_1D, SHB.
- Many local variables: 1
- Meaning: $V1$: vacuum thus is worth always zero

4.3.1.2 "ELAS_HYPER"

Behavior model hyper - elastic incremental: it makes it possible to take into account initial displacements and stresses given under key word ETAT_INIT. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word ELAS_HYPER. This relation is supported only into large displacements, rotations and large deformations (DEFORMATION=' GROT_GDEP') cf [R5.03.23].

- Supported modelizations: 3D, D_PLAN, C_PLAN
- Many local variables: 1
- Meaning: $V1$: vacuum thus is worth always zero
- Example: to see test SSNV187.

4.3.1.3 "VMIS_ISOT_TRAC"

Behavior model of elastoplasticity of Von Mises with nonlinear isotropic hardening. The simple (σ, ε) traction diagram is provided in operator DEFI_MATERIAU [U4.43.01], under the key word TENSION (cf [R5.03.02] for more details). One can possibly define several curves of tension according to the temperature. One must also inform key word ELAS (_FO) in operator DEFI_MATERIAU. If a curve of tension is provided, the modulus of YOUNG used for the behavior model is that calculated starting from the first point of curve of tension, that used for the computation of the elastic matrix (see key word NEWTON [U4.51.03]) is that given in ELAS (_FO). Example: to see test FORMA03.

- Supported local modelizations: 3D, 2D, INCO, INCO_UP, INCO_LOG, INCO_GD (if DEFORMATION=' SIMO_MIEHE') CONT_PLAN, CONT_1D, SHB. The large deformations of the type SIMO_MIEHE are available for this behavior.
  - Many local variables: 2
    - $V1$: cumulated plastic strain
    - $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic).

  Example: test SSNV501, SSNV156.

4.3.1.4 "VMIS_ISOT_PUIS"

Behavior model of elastoplasticity of Von Mises with nonlinear isotropic hardening defined by a function power. The parameters are provided in operator DEFI_MATERIAU [U4.43.01], under key word ECRO_PUIS (confer [R5.03.02] for more details). One must also inform key word ELAS (_FO) in operator DEFI_MATERIAU.

- Supported modelizations: 3D, 2D, CONT_PLAN, CONT_1D, INCO.
  - Many local variables: 2
    - Meaning: $V1$: cumulated plastic strain $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic).
  - The large deformations of the type SIMO_MIEHE are available for this behavior.

Example: to see test COMP002.

4.3.1.5 "VMIS_ISOT_LINE"

Behavior model of elastoplasticity of Von Mises with linear isotropic hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01] under key keys ECRO_LINE (_FO) and ELAS (_FO) (cf [R5.03.02]).

- Supported local modelizations: 3D, 2D, CONT_PLAN, CONT_1D, INCO, INCO_UP, INCO_LOG, INCO_GD (if DEFORMATION=' SIMO_MIEHE').
  - Many local variables: 2

    •Meaning (except modelization BARS): $V1$: cumulated plastic strain $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic).

  Example: to see test SSNP156.

  The large deformations of the type SIMO_MIEHE are available for this behavior.
- Support method IMPL_EX; in this case, the variable $V2$ represents the increment of cumulated plastic strain divided by the increment of time (either an approximation of $\dot{p}$

4.3.1.6 "VMIS_JOHN_COOK"

Behavior model of elastoplasticity of Von Mises with nonlinear isotropic hardening defined by the model of Johnson-Cook. The parameters are provided in operator DEFI_MATERIAU [U4.43.01], under key word ECRO_COOK (cf [R5.03.02] for more details). One must also inform key word ELAS (_FO) in operator DEFI_MATERIAU.

- Supported modelizations: 3D, 2D, CONT_PLAN, CONT_1D, INCO, INCO_UP, INCO_LOG.
  - Many local variables: 5
    - Meaning: $V1$: cumulated plastic strain $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic) $V3$: increment of unelastic strain $V4$: increment of time $V5$: velocity of dissipation mechanical.

Example: to see test COMP002.

4.3.1.7 "VMIS_CINE_LINE"

Behavior model of elastoplasticity of Von Mises with linear kinematic hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys ECRO_LINE (_FO) and ELAS (_FO) (confer [R5.03.02] for more details).

- Supported modelizations: 3D, 2D, INCO, INCO_UP, INCO_LOG, CONT_PLAN (method "OF BORST"), CONT_1D
- Many local variables: 7

•Meaning: $V1$ with $V6$: 6 components of the tensor of kinematic hardening X $V7$: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic).

- Many local variables for the modelizations BAR, PMF : 2
- Example: to see test SSNP14.

•For the modelizations BARS and PMF, the behavior are then 1D: 2 local variables are enough: $V1$ represent the single component of the tensor of recall, and V2 the indicator of plasticity (cf Notices 1); the 5 others are null.

4.3.1.8 "VMIS_ECMI_TRAC"

Behavior model of elastoplasticity of Von Mises with combined, kinematical hardening linear and isotropic nonlinear (cf [R5.03.16] for more details). Isotropic hardening is given by a curve of tension (σ, ε) or possibly by several curves if those Ci depend on the temperature. The characteristics of the material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys PRAGER (_FO) (for kinematic hardening), TENSION (for isotropic hardening) and ELAS (_FO).

- Meaning: $V1$ with $V6$: 6 components of the tensor of kinematic hardening X $V7$: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic).
- Many local variables: 8
- Meaning: $V1$: cumulated plastic strain, V2: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic), $V3$ with $V8$: 6 components of the tensor of kinematic hardening α .
- Example: to see test SSNP102.

4.3.1.9 "VMIS_ECMI_LINE"

Behavior model of elastoplasticity of Von Mises with combined, kinematical hardening linear and isotropic linear (confer [R5.03.16] for more details). The characteristics of the material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys PRAGER (_FO) (for kinematic hardening), ECRO_LINE (_FO) (for isotropic hardening) and ELAS (_FO).

- Supported modelizations: 3D, 2D, INCO, INCO_UP, INCO_LOG, CONT_PLAN, CONT_1D (by BORST).
- Many local variables: 8
- Meaning: $V1$: cumulated plastic strain $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, 1 for plastic), $V3$ with $V8$: 6 components of the tensor of kinematic hardening α .
- Example: to see test SSNP102

4.3.1.10 "VMIS_CIN1_CHAB"

Behavior model which gives an account of the cyclic behavior of the material in elastoplasticity with a nonlinear tensor of kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variable of recall. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN1_CHAB (_F0), ELAS (_FO) (confer [R5.03.04] for more details).

- Supported modelizations: 3D, 2D, CONT_PLAN (by BORST), CONT_1D (by BORST).
- Many local variables: 8
- $V1$: cumulated plastic strain $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), $V3$ with $V8$: 6 components of the tensor of kinematic hardening α .

4.3.1.11 "VMIS_CIN2_CHAB"

Behavior model which gives an account of the cyclic behavior of the material in elastoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variable of recall. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_F0), ELAS (_FO) (confer [R5.03.04] for more details).

- Supported modelizations: 3D, 2D, CONT_PLAN (by BORST), CONT_1D (by BORST).
- Many local variables: 14
- Meaning: $V1$: cumulated plastic strain $V2$: indicator of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), $V3$ with $V8$: 6 components of the 1st tensor of the

kinematical variable α_1, $V9$ with $V14$: 6 components of the 2nd tensor of the kinematical variable α_2 .
- Example: to see test SSNV101A

4.3.1.12 "VMIS_CIN2_MEMO"

elastoplastic Behavior model of J.L.Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall and an effect of memory of greatest hardening. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO), MEMO_ECRO (_FO) (cf [R5.03 .04] for more details). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 28 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 α_1 components $V9$ $V14$ of the 2nd tensor of the kinematical variable: Function α_2 $V15$ of hardening: relative $R(p)$ $V16$ variable in memory of hardening, with: 6 q components $V17$ $V22$ of the relative tensor in memory of hardening, with: 6 ξ components $V23$ $V28$ of the tensor plastic strain. Example: to see
- test SSND105, COMP 002H "VMIS _CIN2_

4.3.1.13 NRAD" elastoplastic

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- Behavior model of Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall, and an effect of nonproportionality of the loading. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO), CIN2_NRAD (confer [R5.03 .04] for more details). Supported
- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 14 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 α_1 components $V9$ $V14$ of the 2nd tensor of the kinematical variable, Example: α_2 to see
- test SSND105D "VMIS _MEMO_

4.3.1.14 NRAD" elastoplastic

- Behavior model of Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall, and an effect of nonproportionality of the loading and an effect of memory of greatest hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO), MEMO_ECRO (_FO), CIN2_NRAD (cf [R5.03 .04] for more details). Supported
- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 28 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 α_1 components $V9$ $V14$ of the 2nd tensor of the kinematical variable: Function α_2 $V15$ of hardening: relative $R(p)$ $V16$ variable in memory of hardening, with: 6 q

components $V17$ $V22$ of the relative tensor in memory of hardening, with: 6 ξ components $V23$ $V28$ of the tensor plastic strain. Example: to see
* test SSND115 "DIS_CHOC ″

4.3.1.15 Models isothermal

contact and shock with friction of Coulomb leaning on a discrete element with 1 or 2 nodes, treated by penalization (thus of elastoplastic type). The parameters characterizing the shock and friction are provided in operator DEFI_MATERIAU [U4.43.01], under key word DIS_CONTACT [R5.03.17]. Supported

* modelizations: 3D_DIS, 2D_ SAY Many local variables
* : The 8 local variables
* describe the behavior in the tangential plane defined by the local directions and, which are y z defined compared to the normal direction of shock. Meaning x

: and: displacements $V1$ $V2$ (differential between nodes 1 and 2 if there is a mesh SEG2) in the local directions and, respectively y z, and: velocity $V3$ ($V4$ differentials between nodes 1 and 2 if there is a mesh SEG2) in the local directions and, respectively y z, and: internal forces $V5$ $V6$ in the local directions and, respectively y z: indicator $V7$ of dependancy (0 so sliding, 1 if dependancy): clearance enters $V8$ nodes 1 and 2. Example: to see
* test SDND100. "WEAPON" isothermal

4.3.1.16

elastoplastic Behavior model for the conductor arrangements. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under the key word ARMS [R5.03 .31]. Supported

* modelizations: 3D_DIS Many local variables
* : 1 Meaning
* : : maximum value $V1$ attack of the quantity in absolute value where is $(uy-ule)$ displacement uy in local direction of the mesh y SEG2 and the limiting ule displacement of the elastic domain. Example: to see
* test SSNL101. "ASSE_CORN "

4.3.1.17 isothermal

elastoplastic Behavior model for the bolted assemblies of angles of pylons. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word ASSE_CORN [R5.03.32]. Supported

* modelizations: 3D_DIS Many local variables
* : 7 Example: to see
* test SSNL102. "DIS_GOUJ2E_PLAS

4.3.1.18 ″ Models

to represent the local behavior of a net of pin of threaded assembly (discrete element). The behavior is elastic everywhere except following the local axis. In this Y direction, it is about an isothermal model of elastoplasticity of VON-MISES with nonlinear isotropic hardening (see [R5.03.17] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys TENSION (for the local direction) and ELAS. Y The curve indicated in TENSION represents actually the curved force of shear-jump of displacement of a local Y computation of a net and ELAS defines the stiffness assigned to discrete for the other directions (in fact local)). Supported X

- modelizations: 2D_DIS_T Many local variables
- : 2 Meaning
- : : plastic $V1$ displacement cumulated: indicator $V2$ of plasticity (cf Notices 1) (0 so elastic, 1 so plastic). Example: to see
- test ZZZZ120 "DIS_GOUJ2E_ELAS

4.3.1.19 " Models

to represent the local elastic behavior of a net of pin of threaded assembly (discrete element). The behavior is elastic everywhere (see [R5.03.17] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word ELAS. Supported

- modelizations: 2D_DIS_T Many local variables
- : 1 Meaning
- : : vacuum (thus $V1$ 0 are worth). "VMIS_ASYM_LINE

4.3.1.20 " uniaxial

isothermal Behavior model of elastoplasticity of VON-MISES with isotropic hardening with different elastic limits in tension and compression. This asymmetrical model of elements of bar makes it possible to model the interaction between a control or a buried cable and the soil. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word ECRO_ASYM_LINE (cf [R5.03 .09] for more details). Supported

- modelization: BAR Many local variables
- : 4 Meaning
- : : plastic strain $V1$ cumulated in tension: indicator $V2$ of plasticity (cf Notices 1) in tension: plastic strain $V3$ cumulated in compression: indicator $V4$ of plasticity (cf Notices 1) in compression. Example: to see
- test SSNL112. "DIS_ECRO_CINE

4.3.1.21" Models with

nonlinear kinematic hardening leaning on a discrete element with 1 or 2 nodes, independently definite on each degree of freedom (forces, moments), of the type. The parameters $F=K_e(U-U_{an})$ characterizing the yield stress, the ductile F_y plate, the constant F_u of kinematic hardening and the power k_x defining n the curvilinear part of curve of tension, are provided in operator DEFI_MATERIAU [U4.43.01], under key word DIS_ECRO_CINE , to also see [R5.03.17]; moreover, the elastic stiffness is given K_e via the command affe_cara_elem [U4.42.01]. Supported

- modelizations: DIS_T, DIS_TR , 2D_DIS_T, 2D_DIS_TR. Many local variables
- : 3. Meaning
- : : unelastic $V1$ displacement: variable U_{an} $V2$ of kinematic hardening: dissipated $\tilde{\alpha}$ $V3$ energy. Example: to see
- test SSND102 [V6.08 .102] . "DIS_BILI_ELAS

4.3.1.22 " behavior

DIS_BILI_ELAS is used to model a bilinear elastic behavior in translation. The constitutive law was conceived to be used with all the discrete elements. The behavior
is characterized by 2 slopes and a force which definite change of incline. For each degree of freedom considered, the behavior of discrete is either elastic or elastic-bilinear. So in one of the directions the bilinear behavior is not defined, the behavior in this direction is then elastic and in fact the values given in the command AFFE_CARA_ELEM are taken . Model DIS_BILI_ELAS relates to only the degrees of translation, that thus implies that the behavior is elastic for the degrees of freedom of rotation which exist for this discrete. For each direction, 3 characteristics (KDEB, KFIN, FPRE) are

provided in operator DEFI_MATERIAU [U4.43.01], under key word DIS_BILI_ELAS , to also see [R5.03.17]; they are obligatorily given in the local coordinate system of the element, it is thus necessary in the command AFFE_CARA_ELEM under the key key DISCRETE factor to specify REPERE=' LOCAL ". Quantities KDEB and KFIN are functions which depend on the temperature and can be defined in the form of function, of three-dimensions function or formula. The local coordinate system is defined in a classical way in the command AFFE_CARA_ELEM under the key key factor ORIENTATION . There is
a local variable per degree of freedom of translation. It can take 3 values: , the discrete one

- $V1=0$ was never requested in this direction. , one is in the case where
- $V1=1$, one is if $|F|\leq \text{FPREC}$
- $V1=2$ "VMIS_CINE_ $|F|>\text{FPREC}$

4.3.1.23 GC" **Behavior model**

D" elastoplasticity of Von Mises with linear kinematic hardening written in 1D, based on ECRO_LINE. The characteristics of the material are provided in operator DEFI_MATERIAU [U4.43.01], under the key key ecro_line (FOR LINEAR hardening). The modelization

supported is 1D, the number of local variables is 6 (confer [R5.03.02] "elastoplastic Integration of the behavior models of Von Mises", for more details). ◦: Criterion

$V1$ limits in stress, ◦: Criterion
$V2$ limits in strain, ◦: Kinematic hardening
$V3$, ◦: Plastic
$V4$ indicator, ◦: non
$V5$ recoverable dissipation, ◦: thermodynamic
$V6$ dissipation. Models élasto

4.3.2 - viscoplastic Unless otherwise specified

, all the models can include a dependence compared to the temperature. It is specified for each model if integration is implicit or semi-implicit. "VISC_ISOT_LINE

4.3.2.1 " **visco-elastoplastic**

Behavior model in large deformations (formulation SIMO_MIEHE only) . The model plastic is VMIS_ISOT_LINE i.e. with linear isotropic hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01] under key words ECRO_LINE (_ FO), ELAS (_FO). The model of viscosity
is a model in hyperbolic sine (confer [R5.03.21]. The viscous parameters are with being informed under key word VISC_SINH in operator DEFI_MATERIAU . Supported

- modelizations: 3D, 2D and INCO , INCO _ UP, INCO_LOG Integration
- : implicit Number of local variables
- : 3 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, 1 for plastic). Example: to see
- test SSNL129D "VISC_ISOT_TRAC

4.3.2.2 " **visco-elastoplastic**

Behavior model in large deformations (formulation SIMO_MIEHE only) . The model plastic is VMIS_ISOT_TRAC i.e. with nonlinear isotropic hardening. The simple traction diagram (σ,ε) is provided in operator DEFI_MATERIAU [U4.43.01], under the key word TENSION (confer [R5.03 .02] for more details). One can possibly define several curves of tension according to the temperature. One must also inform key word ELAS (_FO) in operator DEFI_MATERIAU . The model of viscosity is a model in hyperbolic sine (confer [R5.03.21]. The viscous parameters are with being informed under key word VISC_SINH in operator DEFI_MATERIAU . Supported

- modelizations: 3D, 2D, INCO , INCO _ UP, INCO_LOG, INCO_GD (if DEFORMATION=' SIMO_MIEHE') Integration
- : implicit Number of local variables
- : 3 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, 1 for plastic), Example: to see
- test SSNL129A "LEMAITRE "

4.3.2.3 nonlinear

viscoplastic Behavior model of Lemaitre (without threshold). A cas particulier of this relation (by cancelling parameter UN_SUR_M) gives a relation of NORTON. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys LEMAITRE (_FO) and ELAS (_FO) (confer [R5.03 .08] for more details). The correspondence of the local variables allows the sequence with a computation using an elastoplastic behavior with isotropic hardening ("VMIS_ISOT_LINE" or "VMIS_ISOT_TRAC"). The integration of this model is carried out by an semi-implicit method (PARM_THETA=0.5) or implicit (PARM_THETA=1). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, INCO_ UP, INCO_LOG, CONT_1D (by BORST) Many local variables
- : 2 Meaning
- : : cumulated $V1$ plastic strain: vacuum thus $V2$ is worth always 0. Example: to see
- test SSNA104 "NORTON "

4.3.2.4 viscoplastic

Behavior model of Norton (without threshold). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys LEMAITRE (_FO) and ELAS (_FO) (with UN_SUR _M=0) . The integration of this model is carried out by a theta-method with ALGO_INTE=' NEWTON_PERT' (PARM_THETA) or by a method clarifies (ALGO_INTE= RUNGE_KUTTA) supported

- Modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, INCO_ UP, INCO_LOG, CONT_1D (by BORST) Many local variables
- : 7 Meaning
- : with: 6 components $V1$ $V6$ of the plastic strain: indicator $V7$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic). Example: to see
- tests SSNP02E, SSNP 02D "DIS_VISC"

4.3.2.5 Models viscoelastic

nonlinear leaning on a discrete element with 1 or 2 nodes, independently definite on each degree of freedom (forces, moments), of the type, the velocity $F=C\cdot|V|^{\alpha}$ being estimated via the displacement increment (and not by the diagram). Parameters characterizing the model: constant of viscosity, and the power α of the viscous C force, are provided in operator DEFI_MATERIAU [U4.43.01], under key word DIS_VISC, to also see [R5.03.17]; moreover, one needs an elastic stiffness, which is used K_e for the phase of prediction of the nonlinear algorithm, given via the command affe_cara_elem [U4.42.01]. Supported

- modelizations: DIS_T, DIS_TR , 2D_DIS_T, 2D_DIS_TR. Many local variables
- : 2. Meaning
- : : force corresponding $V1$ to: dissipated CV^{α} $V2$ energy. Example: to see
- test SSND101 [V6.08 .101] . "VISC_CIN1_CHAB

4.3.2.6 " **Behavior model**

of Chaboche (account of the cyclic behavior of the material returns) in élasto-viscoplasticity with a nonlinear tensor of kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variable of recall and taking into account of viscosity. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN1_CHAB (_ F0), ELAS (_FO) (see [R5.03 .04] for more details) and LEMAITRE for viscosity . Integration is completely implicit. Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, INCO_ UP, INCO_LOG, CONT_1D (by BORST) Many local variables
- : 8 Meaning
- : : cumulated $V1$ viscoplastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), V3 with V8: 6 components of the tensor of kinematic hardening. Example: α to see
- test HSNV124 "VISC_CIN2_CHAB

4.3.2.7 " **Behavior model**

of Chaboche (account of the cyclic behavior of the material returns) in élasto-viscoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variable of recall and taking into account of viscosity. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO) (see [R5.03 .04] for more details) and LEMAITRE for viscosity . Integration is completely implicit. Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST]), INCO, INCO_ UP, INCO_LOG, CONT_1D (by BORST) Many local variables
- : 14 Meaning
- : : cumulated $V1$ viscoplastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 α_1 components $V9$ $V14$ of the 2nd tensor of the kinematical variable. Example: α_2 to see
- test HSNV124 "VISC_CIN2_MEMO

4.3.2.8 " **elastoviscoplastic**

Behavior model of Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in élasto-viscoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall and an effect of memory of greatest hardening. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO), MEMO_ECRO (_FO), LEMAITRE for viscosity . Integration is completely implicit. (see [R5.03 .04] for more details). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 28 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 components α_1 $V9$ $V14$ of the 2nd tensor of the kinematical variable: Function α_2 $V15$ of hardening: relative $R(p)$ $V16$ variable in memory of hardening, with: 6 q components $V17$ $V22$ of the relative tensor in memory of hardening, with: 6 ξ components $V23$ $V28$ of the tensor plastic strain. Example: to see
- test SSND105, COMP 002H, SSNV118 "VISC_CIN2_

4.3.2.9 NRAD″ elastoviscoplastic

- Behavior model of Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in élasto-viscoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall, and an effect of nonproportionality of the loading. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO), CIN2_NRAD (confer [R5.03 .04] for more details). Supported
- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 14 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 α_1 components $V9$ $V14$ of the 2nd tensor of the kinematical variable, Example: α_2 to see
- test SSND105D "VISC _MEMO

4.3.2.10 _NRAD ″ elastoplastic

- Behavior model of Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in élasto-viscoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall, and an effect of nonproportionality of the loading and an effect of memory of greatest hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CIN2_CHAB (_ F0), ELAS (_FO), MEMO_ECRO (_FO), CIN2_NRAD (confer [R5.03 .04] for more details). Supported
- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 28 Meaning
- : : cumulated $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1) (0 for elastic, nombre of iterations interns for plastic), with: 6 components $V3$ $V8$ of the 1st tensor of the kinematical variable, with: 6 α_1 components $V9$ $V14$ of the 2nd tensor of the kinematical variable: Function α_2 $V15$ of hardening: relative $R(p)$ $V16$ variable in memory of hardening, with: 6 q components $V17$ $V22$ of the relative tensor in memory of hardening, with: 6 ξ components $V23$ $V28$ of the tensor plastic strain. Example: to see
- test SSND115 "VISCOCHAB ″

4.3.2.11 elastoviscoplastic

Behavior model of Chaboche with 2 kinematical variables which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic hardening, a nonlinear isotropic hardening, an effect of hardening on the tensorial variables of recall, an effect of memory of greatest hardening, and effects of restoration. All the constants of the material can possibly depend on the temperature. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys VISCOCHAB (_ F0), ELAS (_FO). Integration is either implicit, or clarifies (RUNGE_KUTTA) (cf [R5.03 .12] for more details). Supported

- modelizations: 3D, 2D, CONT _1D (by BORST). Many local variables
- : 28 Meaning
- : with: 12 components $V1$ $V12$ of the 2 tensors kinematics; : cumulated X_1 X_2 $V13$ plastic strain: Function $V14$ of hardening: relative $R(p)$ $V15$ variable in memory of hardening, relative q variable in memory of hardening, with: 6 q components $V16$ $V21$ of the relative tensor in memory of hardening: indicator ξ $V22$ of plasticity (cf Notices 1) (0 for elastic, 1 for plastic), with: 6 components $V23$ $V28$ of the tensor plastic strain (only in the explicit case). Example: to see
- test HSNV125D, COMP 002I, SSNV118 "NORTON_HOFF

4.3.2.12 ″ Behavior model

of viscosity independent of the temperature, to use for the computation of structure Yield-point loads, with threshold of Von Mises. The only material parameter is the elastic limit with informing in operator DEFI_MATERIAU [U4.43.01] under key word ECRO_LINE (confer [R7.07 .01] and [R5.03.12] for more details). For the computation of the Yield-point load, there exists a specific key word under CONTROL for this model (see key word CONTROL: " ANA_LIM" of STAT_NON_LINE [U4.51.03]) . It is strongly advised to employ linear search (see key word RECH_LINEAIRE of STAT_NON_LINE [U4.51.03]) . Indeed, the computation of the Yield-point load requires many iterations of linear search (about 50) and of iterations of Newton (about 50). Supported

- modelization: INCO, INCO_ UP, INCO_LOG Many local variables
- : 1 Meaning
- : : vacuum thus $V1$ is worth 0. Example: to see
- test SSNV124 "VISC_TAHERI

4.3.2.13 " Behavior model

(visco) - plastic modelling the response of materials under cyclic plastic loading, and in particular allowing to represent the effects of ratchet. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys TAHERI (_FO) for the description of hardening, LEMAITRE (_FO) for viscosity and ELAS (_FO) (confer [R5.03 .05] for more details). In the absence of LEMAITRE, the model is purely elastoplastic. Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, INCO_ UP, INCO_LOG, CONT_1D (by BORST). Many local variables
- : 9 Meaning
- : : cumulated $V1$ plastic strain: stress $V2$ of peak, with: 6 plastic $V3$ $V8$ components of the strain tensor to the last discharge: discharge $V9$ /loadmeter (0 for elastic discharge, 1 if classical plastic load, 2 if plastic load on two surfaces, 3 if pseudo-discharge). Example: to see
- tests SSNV102 (without viscosity) and SSNV170 (with viscosity). "MONOCRISTAL

4.3.2.14 " ♦ COMPOR

= comp [compor] This model

makes it possible to describe the behavior of a monocrystal whose behavior models are provided via the concept compor, resulting from DEFI_COMPOR . The number of

local variables is function of the choices carried out in DEFI_COMPOR : The six first

are the 6 components of the viscoplastic strain: : with E^{vp}_{ij}

$$E^{vp}=\sum_t \left(\Delta E^{vp}\right) \quad \Delta E^{vp}=\sum_s \mu_s \Delta\gamma_s$$

$V_1=E^{vp}_{xx}$ $V_2=E^{vp}_{yy}$ $V_3=E^{vp}_{zz}$, $V_4=\sqrt{(2)}E^{vp}_{xy}$ are $V_5=\sqrt{(2)}E^{vp}_{xz}$ $V_6=\sqrt{(2)}E^{vp}_{yz}$

V_7 V_8 the values V_9 of for the system α_1 γ_1 p_1 of sliding, correspond $s=1$
V_{10} V_{11} V_{12} to the system, and so on $s=2$, where: represent

- α_s the kinematical variable of the system in the case of s the phenomenologic models, and the density of dislocations in a model resulting from the DD; represent
- γ_s the plastic sliding of the system represents s
- p_1 the cumulated plastic sliding of the system Taken into account s

of the irradiation: in case

- DD_CC_IRRA, it is necessary to add local variables $n_{irra}=12$: with contain V_{6+3n_s+1} V_{6+3n_s+12} for each system of sliding the density of dislocations related to the irradiation in case ρ^{irr}_s

- DD_CFC_IRRA , `it is necessary to add` local variables $n_{irra}=24$: with contain V_{6+3n_s+1} V_{6+3n_s+12} for each system of sliding with contain ρ_s^{loops} V_{6+3n_s+13} V_{6+3n_s+24} for each system of sliding One stores then ϕ_s^{voids}

cissions them for each system of sliding: ,… If τ_1 τ_{n_s}

one takes into account the rotation of the crystal lattice, local variables should be added $n_{rota}=16$: with are

- V_{6+3n_s+1} the 9 V_{6+3n_s+9} components of the matrix of rotation, with are $\mathbf{Q}$
- V_{6+3n_s+10} the 3 V_{6+3n_s+12} components of, with are $\Delta\boldsymbol{\omega}^{\mathbf{p}}$
- V_{6+3n_s+13} the 3 V_{6+3n_s+15} components of, represents $\Delta\boldsymbol{\omega}^{\mathbf{e}}$
- V_{6+3n_s+16} the antepenultimate Θ

local variable is the stress of cleavage: Before last $\max_s(\Sigma.n):n$

local variable contains the total cumulated plastic strain, defined by: with the last

$$V_{p-1}=\sum \Delta E_{eq}^{vp} \quad \Delta E_{eq}^{vp}=\sqrt{\frac{2}{3}(\Delta\mathbf{E}^{vp}:\Delta\mathbf{E}^{vp})}$$

local variable, (, being Vp $p=6+3n_s+n_{rota}+3$ the nombre total n_s of sliding systems) is an indicator of plasticity (cf Notices 1) (threshold exceeded in at least a system of sliding to time step running). If it is null, there no was increase in local variables at current time. If not, it contains the nombre of iterations of local Newton (for an implicit resolution) which were necessary to obtain convergence. For more

precise details to consult [R5.03.11]. Supported

- modelizations: 3D, 2D, CONT _PLAN (`by BORST`). `Example:` to see
- test SSNV194 "POLYCRISTAL

4.3.2.15 " ♦ COMPOR

= comp [compor] This model

makes it possible to describe the behavior of a polycrystal whose behavior models are provided via the concept compor, resulting `from DEFI_COMPOR . The number` of

local variables is, being $p=7+6m+\sum_{g=1,m}(3n_{s(g)})+6m+1$ the number m of phases and being the number $n_s(g)$ of sliding systems of the phase) the first six g

- local variables are the components of the macroscopic viscoplastic strain: E^{vp}

$$V_1=E_{xx}^{vp} \quad V_2=E_{yy}^{vp};\ V_3=E_{zz}^{vp} \quad V_4=\sqrt{(2)}E_{xy}^{vp} \text{ the seventh } V_5=\sqrt{(2)}E_{xz}^{vp} \quad V_6=\sqrt{(2)}E_{yz}^{vp}$$

- is the cumulated equivalent viscoplastic strain macroscopic: with; then P

$$V_7=\sum \Delta E_{eq}^{vp} \text{ , for } \Delta E_{eq}^{vp}=\sqrt{\frac{2}{3}(\Delta\mathbf{E}^{vp}:\Delta\mathbf{E}^{vp})}$$

- each phase, one finds the 6 components of the viscoplastic strains or the tensor of the phase β : ; then, $\{\varepsilon_{xx}^{vp}(g),\varepsilon_{yy}^{vp}(g),\varepsilon_{zz}^{vp}(g),\sqrt{(2)}\varepsilon_{xy}^{vp}(g),\sqrt{(2)}\varepsilon_{xz}^{vp}(g),\sqrt{(2)}\varepsilon_{yz}^{vp}(g)\}_{g=1,m}$ for

- each phase: for each
  - system of sliding of the phase, one finds the values of; if α_s γ_s p_s
  - the behavior takes into account irradiation (currently MONO_DD_CC_ IRRA), local variables should then be added 12 : densities of dislocations due to the irradiation. then, for
- each phase, one finds the 6 components of the stresses of the phase: ; the last $\{\sigma_{xx}(g), \sigma_{yy}(g), \sigma_{zz}(g), \sqrt{(2)}\sigma_{xy}(g), \sqrt{(2)}\sigma_{xz}(g), \sqrt{(2)}\sigma_{yz}(g)\}_{g=1,m}$
- local variable is an indicator of plasticity (cf Notices 1) (threshold exceeded in at least a system of sliding to time step running). For more

precise details to consult [R5.03.11]. Supported

- modelizations: 3D Example : to see
- test SSNV171 Behaviors

4.3.3 specific to the fuel pins and metals under irradiation "VISC_IRRA_LOG

4.3.3.1 " Creep model

axial under irradiation of the fuel assemblies. It makes it possible to model primary education and secondary creep, parameterized by the neutron fluence (cf [R5.03.09]) the parameters are provided in operator DEFI_MATERIAU [U4.43.01], under key keys VISC_IRRA_LOG . The field of fluence is defined by the key word AFFE_VARC of the command AFFE_MATERIAU . Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D. Many local variables
- : 2. : cumulated $V1$ equivalent viscoplastic strain: memorizing $V2$ of the history of irradiation (fluence). Example: to see
- test SSNV113 "GRAN_IRRA_LOG

4.3.3.2 " Behavior model

of creep and growth under irradiation for the fuel assemblies, similar to model VISC_IRRA_LOG for the viscoplastic , and integral strain in more one strain of growth under irradiation (cf [R5.03.09]). The field of fluence is defined by the key word AFFE_VARC of the command AFFE_MATERIAU . The characteristics of the behavior are provided in operator DEFI_MATERIAU [U4.43.01], under key word GRAN_IRRA_LOG . The growth being done only according to one direction, it is necessary in 3D case and 2D to give to the direction of the growth by operand ANGL_REP of key word MASSIF of L "operator AFFE_CARA_ELEM . Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D. Many local variables
- : 3. : cumulated $V1$ equivalent viscoplastic strain: memorizing $V2$ of the history of irradiation (fluence): strain $V3$ of growth. Example: to see
- test SSNL128 "GATT_MONERIE

4.3.3.3 " the thermomechanical

constitutive law of fuel "GATT-Monerie" makes it possible to simulate tests of indentation (cf [R5.03.08]). This constitutive law is an isotropic élasto-viscoplastic model without hardening whose specificities are: the potential

- of dissipation is the sum of two potentials of the type Norton (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. Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : The 2 two local variables
- of this model are the cumulated plastic strain and the voluminal fraction of porosity, Example: to see

- test SSNA114. "LEMAITRE_IRRA

4.3.3.4 " Behavior model

of creep and growth under irradiation for the fuel assemblies. The field of fluence is defined by the key word AFFE_VARC of the command AFFE_MATERIAU . The characteristics of the behavior are provided in L" operator DEFI_MATERIAU [U4.43.01], under key word LEMAITRE_IRRA . The growth being done only according to one direction, it is necessary in 3D case and 2D to give to the direction of the growth by operand ANGL_REP of key word MASSIF of L "operator AFFE_CARA_ELEM . For the beams, creep and growth N" take place that in the axial meaning of beam: in the other directions, the behavior is elastic. The diagram of integration is implicit or semi-implicit, but one advises to use an semi-implicit integration i.e. PARM_THETA= 0.5. Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 3. : cumulated $V1$ plastic strain: null: $V2$ strain $V3$ of growth. For the modelization
- LOUSE: : cumulated $V1$ plastic strain: value of $V2$ the irradiation at the Gauss point considered: strain $V3$ of growth. Example: to see
- test SSNL121. "LMARC_IRRA

4.3.3.5 " Behavior model

of viscoplasticity of the LMARC with taking into account of the irradiation for the fuel assemblies. The field of fluence is defined by the key word AFFE_VARC of the command AFFE_MATERIAU . The characteristics of the behavior are provided in operator DEFI_MATERIAU [U4.43.01], under key word LMARC_IRRA. For the beams, creep takes place only in the axial meaning of beam: in the other directions, the behavior is elastic. Supported

- modelizations: LOUSE (only POU_D_T and POU_D_E). Many local variables
- : 6 three variables
- of viscoplastic kinematic hardening $X , X1 , X2$
- cumulated strain value of L p
- "irradiation at the Gauss point considered. Strain
- of growth Example: to see
- test SSNL109 "LEMA_SEUIL

4.3.3.6 " viscoplastic

Behavior model with threshold under irradiation for the fuel assemblies (cf [R5.03.08]). The field of fluence is defined by the key word AFFE_VARC of the command AFFE_MATERIAU . The characteristics of the growth are provided in L" operator DEFI_MATERIAU [U4.43.01], under key word LEMA_SEUIL . The integration of the model is carried out by a method semi - implicit or implicit. Supported

- modelizations: 3D, 2D, PLANE CONT _ (by BORST), CONT_1D (by BORST). Many local variables
- : 2: cumulated
- $V1$ plastic strain: represent
- $V2$ the current threshold Example: to see
- test SSNA104 "IRRAD3M " elastoplastic

4.3.3.7

Behavior model under irradiation of the stainless steels 304 and 316, materials of which the structures internal reactor vessels of the nuclear engines are made up. The field of fluence is defined by the key word AFFE_VARC of the command AFFE_MATERIAU . The model takes into account plasticity, creep under irradiation, swelling under neutron flux. The characteristics are provided in operator DEFI_MATERIAU [U4.43.01], under key word IRRAD3M. The integration of the model is carried out by an implicit scheme in time (cf [R5.03.13]). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST). Many local variables
- : 5: cumulated
  - $V1$ equivalent plastic strain: threshold for
  - $V2$ the creep of irradiation: equivalent
  - $V3$ plastic strain of irradiation: swelling
  - $V4$: indicator
  - $V5$ of plasticity (cf Notices 1) Example: to see
- test SSNA118 "DIS_GRICRA

4.3.3.8 " behavior

DIS_GRICRA makes it possible to model connections between grids and pencils of the fuel assemblies. It leans on discrete elements with 2 nodes, with 6 d.o.f. per node (translation+rotation). The constitutive law on each subsystem (sliding - axial friction, rotation in the plane, and rotation except plane) is of standard plasticity with positive hardening in the tangential directions with discrete to model the sliding, and of the unilateral elastic type in the direction of discrete to model the contact. The parameters of DIS_GRICRA, characterizing the contact and friction, are directly stiffness in rotation and thresholds in rotation (standard critical angles). These parameters are provided in operator DEFI_MATERIAU [U4.43.01], under key word DIS_GRICRA . Contrary to the other discrete ones, one does not take into account the characteristics of stiffness of AFFE_CARA_ELEM . The stiffness matrix of discrete must thus be taken null in AFFE_CARA_ELEM . The stiffness is only resulting from the parameters in DEFI_MATERIAU . The unilateral contact takes place in the direction given by X mesh SEG2 of the discrete element , and the sliding takes place in the direction given by Y key word ORIENTATION of AFFE_CARA_ELEM (confer [R5.03 .17] for more details). The tangent matrix is symmetric. Supported

- modelizations: DIS_TR Many local variables
- : 6: plastic
  - $V1$ displacement cumulated: indicator
  - $V2$ of contact/friction (1 so sliding, 0 so not sliding): indicator
  - $V3$ of separation in rotation: plastic angle
  - $V4$ (sliding): cumulated plastic
  - $V5$ angle: memorizing
  - $V6$ of the history of irradiation (fluence) Example: to see
- mechanical test SSNL131 Model

4.3.4 with effects of the metallurgical transformations the following

behavior models apply to a material which undergoes metallurgical phase changes (confer [R4.04.02] for more detail). One can activate

by key word RELATION_KIT two types of material, is ACIER which comprises with more the 5 different metallurgical phases, that is to say ZIRC which comprises with more the 3 different metallurgical phases. Moreover,

the name of the behavior model is META_x_yy_zzz form , with the following possibilities: x=PouVyy=IL

or INL ouC L

zzz =PT or

RE ouP T _RE the meaning

of the letters defined above is the following one: P = plastic

behavior V = viscoplastic
behavior IT = linear
isotropic hardening INL = isotropic
hardening nonlinear CL = linear
kinematic hardening Pt = plasticity
of transformation RE = restoration
of metallurgical hardening of origin Examples:

COMP_INCR =
```
    (RELATION =   '  META_P_      INL'    RELATION_KIT
                   = ' ZIRC'     )    COMP_INCR     =

    (RELATION =   '  META_V_         CL_PT_RE' RELATION_KIT
                   = ' ACIER'    )    See also
```

the tests: HSNV101, HSNV 1202, HSNV103, HSNV104, HSNV105, HTNA100. In more this

these models, META_LEMA_ANI is an anisotropic viscoplastic constitutive law taking into account the metallurgy, for Zirconium only [R4.04.05] (and the tests HSNV134 and HSNV135). The characteristics
are: taking into account

- of the 3 metallurgical phases of Zircaloy. viscosity
- of the Lemaitre type, without threshold anisotropy
- with criterion of Hill Notices on

the matrix of Hill: the user must give it in the reference. In 3D, (R, T, Z) a change of variable is made (it is considered that the axis of 3D is Z the axis of the tube). The supported

modelizations are: 3D, 2D, INCO . For all *the metallurgical models, the plane stresses are impossible even with the method OF BORST.* Mechanical computations

taking into account the metallurgy lean on a computation of evolution of the metallurgical phases (see command CALC_META [U4.85.01]). The material characteristics

necessary to mechanical computation are to be defined for each metallurgical phase in presence in the material. They are provided in operator DEFI_MATERIAU [U4.43.01] : Type of behavior

Key word of	elastoplastic DEFI_MATERIAU P =
behavior ELAS_META (_	FO) follow-up of a hardening… V = viscoplastic
behavior META_VISC_FO	and the given elastoplastic IT = isotropic
hardening linear ELAS_META (_	FO) and META_ECRO_LINE INL = hardening
isotropic nonlinear ELAS_META (_	FO) and META_TRACTION (*) linear CL =
kinematic hardening ELAS_META (_	FO) and META_ECRO_LINE Pt = plasticity
of transformation META_PT RE	= restoration
of hardening of metallurgical origin META_RE (*)	Note

: Attention, under META_TRACTION , it is necessary to not inform stress-strain curve but curved isotropic hardening according to the plastic strain cumulated For the model

META_LEMA_ANI , the coefficients material are defined in operator DEFI_MATERIAU under "ELAS_META ", "META_LEMA_ANI". Many local variables

and meanings One gather

here the information on the local variables because their number varies according to the type of hardening (isotropic or kinematical), of the type of material (ACIER or ZIRC) and of the type of strains (PETIT, PETIT_REAC, GROT_GDEP or SIMO_MIEHE) . The phases

are arranged in the following order: For steel

: 1 to 4 = cold phases, 5 = hot phase For Zircaloy
: 1 and 2 = cold phases, 3 = hot phase Strain

isotropic	Hardening Kinematic hardening		ACIER ZIRC	
	ACIER	ZIRC	PETIT,	PETIT_REAC
and GROT_GDEP with : variables	$V1$ $V5$ related to isotropic hardening for the 5 phases on: variables	$V1$ $V3$ related to isotropic hardening for the 3 phases on: variables	$V1$ $V30$ related to kinematic hardening for the 5 α phases on: variables	$V1$ $V18$ related to kinematic hardening for the 3 α phases: indicator
	$V6$ of plasticity (cf Notices 1) (0 so elastic, 1 so plastic): indicator	$V4$ of plasticity (cf Notices 1) (0 so elastic, 1 so plastic) with: average	$V31$ $V36$ kinematic hardening with: average X	$V19$ $V24$ kinematic hardening: average X
	$V7$ isotropic hardening: average	$V5$ isotropic hardening: indicator	$V37$ of plasticity (cf Notices 1) (0 so elastic, 1 so plastic): indicator	$V25$ of plasticity (cf Notices 1) (0 so elastic, 1 so plastic) SIMO_MIEHE
: trace	$V8$ elastic strain divided by 3 used into large deformations: trace	$V6$ elastic strain Does not exist divided by 3 used into large deformations	Does not exist	For the model

META_LEMA_ANI , the 2 local variables by phase are: : cumulated
- $V1$ viscous strain: the indicator
- $V2$ of plasticity (cf Notices 1) (0 or 1) Model buildings

4.3.5 and nonlocal of damage “ENDO_FRAGILE

4.3.5.1 ” brittle

elastic Behavior model. It is about a modelization to scalar damage and negative linear isotropic hardening (see [R5.03.18] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys ECRO_LINE (_ FO) (negative DSDE) and ELAS (_FO). Supported

local modelizations: 3D, 2D, CONT _PLAN , INCO, INCO_ UP, INCO_LOG. Many local variables
- : 2 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 if the damage is worth 0,1 if the damage is higher than 0). Example: to see
- test SSNV147 supported

nonlocal Modelization: GRAD_EPSI Many local variables
- for modelization GRAD_EPSI: 2. Meaning

- : : value of $V1$ the damage: indicator $V2$ of damage (0 if the damage is worth 0,1 if the damage is higher than 0). Example: to see
- test SSNV157 Supports

method IMPL_EX (in `its local` version only); in this case, the variable represents the increment of damage divided by the increment of time (that is to say an approximation of) "ROUSSELIER $\dot{d}$

4.3.5.2", "ROUSS_PR", "ROUSS_VISC" Note:

Three following

models "ROUSSELIER " (models elastoplastic), "ROUSS_PR " (models elastoplastic) and "ROUSS_VISC " (models elastoviscoplastic) are three versions different from the model of Rousselier. This model is a behavior model élasto (visco) plastic which makes it possible to give an account of the growth of the cavities and to describe the ductility fracture in steels. Apart from with dimensions viscous plastic/, the essential difference lies in the way in which the large deformations are treated. For the model "ROUSSELIER " it is about a standard formulation Simo_Miehe (DEFORMATION : "SIMO_MIEHE") and for the two others of a standard formulation "PETIT_REAC " (DEFORMATION : "PETIT_REAC"). On various examples treated in plasticity , one noted that the model "ROUSS_PR " needs much more iterations of Newton to converge compared to model "ROUSSELIER ". It should be also noted
that these three models treat in a different way the broken material. In models "ROUSS_PR " and "ROUSS_VISC ", when porosity reaches a limiting porosity, one considers the broken material. The behavior is then replaced by an imposed fall of the stresses. To activate this modelization of the broken material, it is then necessary to inform in operator DEFI_MATERIAU [U4.43.01], under the key word ROUSSELIER (_FO), two coefficients "PORO_LIMI " and "D_SIGM_EPSI_NORM ". For " ROUSSELIER ", one does nothing in particular because the stress tends naturally towards zero when porosity tends towards one. The two preceding parameters can be indicated but do not have impact on the model. "ROUSSELIER

" elastoplastic

Behavior model. It makes it possible to give an account of the growth of the cavities and to describe the ductility fracture. This model gets busy exclusively with the key word DEFORMATION = "SIMO_MIEHE"). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys ROUSSELIER (_FO) and ELAS (_FO) (cf [R5.03 .06] for more details). To facilitate the integration of this model, it is advised systematically to use the total recutting of time step (see STAT_NON_LINE [U4.51.03], key word INCREMENT). This model is not developed in plane stress. Moreover, with key word SIMO_MIEHE, one cannot use the plane stresses by the method OF BORST. Supported

local modelizations: 3D, 2D, INCO , INCO_ GD (if DEFORMATION=' SIMO_MIEHE') Many local variables

- : 9 Meaning
- : : cumulated $V1$ plastic strain: value of $V2$ porosity, with: 6 components $V3$ $V8$ of an eulerian tensor in large deformations of elastic strain: indicator $V9$ of plasticity (cf Notices 1) (0 so elastic, 1 so plastic with regular solution, 2 so plastic with singular solution). Example: to see
- test SSNV147. Supported

nonlocal modelization: to use modelizations INCO with length interns Many local variables

- : 12 Meaning
- : : cumulated
  - $V1$ plastic strain, with: gradient
  - $V2$ $V4$ of the plastic strain cumulated along the axes, respectively x, y, z , V5: porosity
  - , with: elastic strain

  - $V6$ $V11$ used for SIMO_MIEHE : indicator
  - $V12$ from plasticity (cf Notices 1) (0 so elastic, 1 so plastic and regular solution, 2 so plastic and singular solution). Example: to see
- test SSNP122 "ROUSS_PR ″

elastoplastic

Behavior model. It makes it possible to give an account of the growth of the cavities and to describe the ductility fracture. This model gets busy exclusively with key keys DEFORMATION : "PETIT_REAC ″ or "PETIT ", (to use preferably the modelization "PETIT_REAC ″ because it is a model large deformations). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys ROUSSELIER (_FO) and ELAS (_FO) (cf [R5.03 .06] for more details). One can also take into account the nucleation of the cavities. It is then necessary to inform the parameter AN (key word not activated for the model ROUSSELIER and ROUSS_VISC) under ROUSSELIER (_FO) to facilitate the integration of this model, it is advised to use the local automatic recutting of time step (key word ITER_INTE_PAS) . Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, INCO_ UP, INCO_LOG. Many local variables
- : 5 Meaning
- : : cumulated $V1$ plastic strain: value of $V2$ porosity: indicator $V3$ of dissipation, = stored $V4$ energy, = indicating $V5$ of plasticity (cf Notices 1) Example: test
- SSNV103 "ROUSS_VISC

″ Behavior model

élasto-visco-plastic. It makes it possible to give an account of the growth of the cavities and to describe the ductility fracture. This model gets busy exclusively with the key keys DEFORMATION = ' PETIT_REAC' or "PETIT ", (to take the modelization "PETIT_REAC ″ because it is a model large deformations). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys VISC_SINH, ROUSSELIER (_FO) and ELAS (_FO) (cf [R5.03 .06] for more details). To facilitate the integration of this model, it is advised to use the local automatic recutting of time step, key word ITER_INTE_PAS) . For the integration of this model, a - method θ is available and one advises to use an integration semi - implicit i.e.: PARM_THETA= 0.5 supported

- Modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO. Many local variables
- : 5 Meaning
- : : cumulated $V1$ plastic strain: value of $V2$ porosity: indicator $V3$ of dissipation, = stored $V4$ energy, = indicating $V5$ of plasticity (cf Notices 1) Example: test
- SSNP117. "HAYHURST ″

4.3.5.3 Models élasto

- viscoplastic of Hayhurst, to describe the austenitic steel reaction of, with a scalar damage in hyperbolic sine, function of the maximum principal stress or trace of the stresses, an isotropic hardening and a viscous model in hyperbolic sine. This model
gets busy with the key keys DEFORMATION = PETIT or PETIT_REAC . or GDEF_LOG. The data necessary are defined in DEFI_MATERIAU under key keys HAYHURST and ELAS. Supported

- modelizations: 3D, 2D, INCO , INCO_ UP, INCO_LOG. Many local variables
- : 12 Meaning
- : with: 6 components $V1$ $V6$ of the viscoplastic strain: cumulated $V7$ plastic strain, and: variables $V8$ $V9$ of hardening and: variable H_1 H_2 $V10$: damage ϕ $V11$: indicator $V12$. Example: test
- SSNV222 "VENDOCHAB ″

4.3.5.4 Models viscoplastic

coupled with the isotropic damage of Lemaitre-Chaboche [R5.03.15]. This model gets busy with the key keys DEFORMATION = PETIT or PETIT_REAC . The data necessary are defined in DEFI_MATERIAU under key keys VENDOCHAB (_FO), LEMAITRE (_ FO) and ELAS (_ FO). Supported

- modelizations: 3D, 2D, INCO , INCO_ UP, INCO_LOG. Many local variables
- : 9 Meaning
- : with: viscoplastic $V1$ $V6$ strain: cumulated $V7$ plastic strain: isotropic $V8$ hardening: damage $V9$. Example: test
- SSNV183 “VISC_ENDO_LEMA

4.3.5.5 ” Models viscoplastic

coupled with the isotropic damage of Lemaitre-Chaboche, corresponding to a simplified version of model VENDOCHAB if coefficients ALPHA_D and BETA_D are null and K_D = R_D. cf [R5.03.15]. This model gets busy with the key keys DEFORMATION = PETIT or PETIT_REAC . The data necessary are defined in DEFI_MATERIAU under key keys VISC_ENDO (_ FO), LEMAITRE (_FO) and ELAS (_ FO). Supported

- modelizations: 3D, 2D, INCO , INCO_ UP, INCO_LOG. Many local variables
- : 9 Meaning
- : with: viscoplastic $V1$ $V6$ strain: cumulated $V7$ plastic strain: isotropic $V8$ hardening: damage $V9$. Example: test
- SSND108 “CZM_EXP_REG

4.3.5.6 ” cohesive

Behavior model (Cohesive Exponential Zone Model Regularized) (cf [R7.02.11] for more detail) modelling the opening of a crack. This model is usable with the linear finite element of joined type (cf [R3.06.09] for more detail) or with its version THM (cf [R7.02.15]) and makes it possible to introduce a force of cohesion between the lips of crack. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_FRAG. The use of this model often requires the presence of control by PRED_ELAS (cf [U4.51 .03]). Supported

- modelization: PLAN_JOINT, AXIS_JOINT, 3D_JOINT, AXIS_JHMS, PLAN_JHMS. Many local variables
- : 9 Meaning
- : : threshold corresponding $V1$ to the greatest jump of displacement (in norm) ever reached: indicator $V2$ of dissipation (0: not, 1: yes), indicator $V3$ of damage (0: healthy, 1: damaged): indicator $V4$ of the percentage of dissipated energy: value of $V5$ dissipated energy, with: values $V7$ of $V9$ the jump, (V9=0 in 2D) Example: to see
- test SSNP118, SSNP 133, SSNV199 “CZM_LIN_REG

4.3.5.7 ” cohesive

Behavior model (Cohesive Zone Linear Model Regularized) (cf [R7.02.11] for more detail) modelling the opening of a crack. The advantage of such a model, compared with CZM_EXP_REG , is to be able to represent a true front of fracture. This last is visible thanks to the local variable (corresponds $V3$ $V3=2$ to a completely broken element). This model is usable with the linear finite element of joined type (cf [R3.06.09] for more detail) or with its version THM (cf [R7.02.15]) and makes it possible to introduce a force of cohesion between the lips of crack. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_FRAG. The use of this model often requires the presence of control by PRED_ELAS (see [U4.51 .03]). Supported

- modelization: PLAN_JOINT, AXIS_JOINT, 3D_JOINT, AXIS_JHMS, PLAN_JHMS. Many local variables
- : 9 Meaning
- : : threshold corresponding $V1$ to the greatest jump of displacement (in norm) ever reached: indicator $V2$ of dissipation (0: not, 1: yes), V3 indicator of damage (0: healthy, 1: damaged, 2: broken): indicator $V4$ of the percentage of dissipated energy: value of $V5$ dissipated energy, with: values $V7$ of $V9$ the jump, (V9=0 in 2D) Example: to see
- test SSNP118, SSNV 199 "CZM_EXP" cohesive

4.3.5.8

Behavior model (Cohesive Exponential Zone Model) (see [R7.02.12] for more detail) modelling the opening of a crack. This model is usable with the finite element with internal discontinuity (see [R7.02.12] for more detail) and makes it possible to introduce a force of cohesion between the lips of crack. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_FRAG. The use of this model requires the presence of control by PRED_ELAS (cf [U4.51 .03]) . Supported

•modelization: PLAN_ELDI, AXIS_ELDI. Many local variables
•: 7 Meaning
•: : normal jump $V1$: tangential jump $V2$: variable $V3$ threshold: indicator $V4$ of cracking (0 for linear mode, 1 for softening mode): indicator $V5$ of the percentage of dissipated energy: normal stress $V6$: shear stress $V7$. Example: to see
•test SSNP118. "CZM_OUV_MIX

4.3.5.9 " cohesive

Behavior model (Cohesive Zone Mixed Model Opening) (cf [R7.02.11]) modelling the opening and the propagation of a crack. This model is usable with the finite element of interface based on a mixed formulation Lagrangian increased (see [R3.06.13]) and makes it possible to only introduce a force of cohesion between the lips of crack in mode of opening. This model is used when one imposes conditions of symmetry on the element of interface. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_FRAG. The use of this model requires the presence of control by PRED_ELAS (cf [U4.51 .03]) . Supported

- modelization: all the modelizations of the type INTERFACES (cf U3.13.14). Many local variables
- : 9: threshold in
  $V1$ jump (greater norm reached): indicator
  $V2$ of the mode of the model = -1: Contact, 0: Initial or current dependancy, 1: Damage, 2: Fracture, 3: Return to zero with stress null. : indicator
  $V3$ of damage 0 if operational material, 1 if damaged material, 2 if broken material. : percentage
  $V4$ of dissipated energy: value of
  $V5$ dissipated energy: value
  $V6$ of current residual energy: null for this models (valid for CZM_xxx_REG). : normal jump
  $V7$: tangential jump $V8$: tangential jump $V9$ (no one in 2D). Examples:
- to see tests SSNP118 and SSNV199 . "CZM_TAC_MIX

4.3.5.10 " cohesive

Behavior model (Cohesive Zone Mixed Model Heel-Curnier) (see [R7.02.11]) modelling the opening and the propagation of a crack. This model is usable with the finite element of interface based on a mixed formulation Lagrangian increased (see [R3.06.13]) and makes it possible to introduce a force of cohesion between the lips of crack into the three modes of fracture with an irreversibility of the Heel-

Curnier type. Attention, this model cannot be used when one imposes conditions of symmetry on the element of interface. In this case it is necessary to use CZM_OUV_MIX . The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_FRAG. The use of this model requires the presence of control by PRED_ELAS (cf [U4.51 .03]) . Supported

- modelization: all the modelizations of the type INTERFACES (cf U3.13.14). Many local variables
- : 9: threshold in
  $V1$ jump (greater norm reached): indicator
  $V2$ of the mode of the model = -1: Contact (only for CZM_OUV_MIX), 0: Initial or current dependancy, 1: Damage, 2: Fracture, 3: Return to zero with stress null. : indicator
  $V3$ of damage 0 if operational material, 1 if damaged material, 2 if broken material. : percentage
  $V4$ of dissipated energy: value of
  $V5$ dissipated energy: value
  $V6$ of current residual energy: null for this models (valid for CZM_xxx_REG). : normal jump
  $V7$: tangential jump $V8$: tangential jump $V9$ (no one in 2D). Examples:
- to see tests SSNP118, SNA 115, SSNV199. "CZM_TRA_MIX

4.3.5.11 " cohesive

Behavior model (Cohesive Zone Mixed Model Trapezoid) (see [R7.02.11]) modelling the opening and the propagation of a crack in ductility fracture. This model is usable with the finite element of interface based on a mixed formulation Lagrangian increased (see [R3.06.13]) and makes it possible to introduce a force of cohesion between the lips of crack only in mode of opening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_DUCT. Supported

- modelization: all the modelizations of the type INTERFACES (cf U3.13.14). Many local variables
- : 9: threshold in
  $V1$ jump , makes it possible to take into account the irreversibility of cracking, to see its definition in the preceding ones part (specific to each model). : indicator
  $V2$ of the mode of the model: Contact $V2=-1$: initial $V2=0$ or current dependancy: dissipation $V2=1$: final fracture $V2=2$: plate. $V2=3$: indicator
  $V3$ of damage if operational $V3=0$ material, if damaged $V3=1$ material, if broken $V3=2$ material. : percentage
  $V4$ of dissipated energy. : value
  $V5=V4\times G_c$ of dissipated energy. : value of
  $V6$ current residual energy: null for this models (valid for CZM_xxx_REG). : normal jump
  $V7=\delta_n$: tangential jump $V8=\delta_t$, tangential jump $V9=\delta_\tau$ (no one in 2D). Examples :
- to see tests SSNP151, SNA 120. "CZM_FAT_MIX

4.3.5.12 " cohesive

Behavior model for fatigue (see [R7.02.11]). This model is usable with the finite element of interface based on a mixed formulation Lagrangian increased (see [R3.06.13]). The goal is to simulate the fatigue crack propagation in 2D or 3D (mode I only) with the possibility of considering nonlinear material surrounding in order to model (amongst other things) the delay effect related to an overload . The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word RUPT_FRAG. The use of this model requires the presence of control by PRED_ELAS (cf [U4.51 .03]) . Supported

- modelization: all the modelizations of the type INTERFACES (cf U3.13.14). Many local variables

- : 9 Example: to see
- tests SSNP118, SSNP 139 "CZM_LAB_MIX

4.3.5.13 " cohesive

Behavior model (Cohesive Zone Mixed Model Steel-concrete Connection) (cf [R7.02.11]) modelling the behavior of a steel-concrete interface. This model is usable with the finite elements of interface based on a mixed formulation of Lagrangian type increased (cf [R3.06.13]) and makes it possible to model the sliding of steel compared to the concrete. The data
necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word CZM_LAB_MIX . Supported

- modelizations: all the modelizations of the type INTERFACES (cf U3.13.14). Many local variables
- : 5: threshold in
  $V1$ jump (greater norm reached): indicator
  $V2$ of the mode of the model = 0: Initial or current dependancy, 1: Damage, 2: Fracture, 3: Return to zero with stress null. : normal jump
  $V3$: tangential jump $V4$: tangential jump $V5$ (no one in 2D). Example: to see
- test SSNS110. "RUPT_FRAG "

4.3.5.14 non

local Behavior model based on the formulation of J.J. Marigo and G. Frankfurt of the fracture mechanics (not of equivalent in local version). This model describes the appearance and the propagation of cracks in an elastic material (cf [R7.02.11]). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys ELAS, RUPT_FRAG and NON_LOCAL. Supported

- nonlocal modelization: GRAD_VARI. Many local variables
- : 4 Meaning
- : : value of $V1$ the damage, with: 3 components $V2$ $V4$ of the gradient of the damage. Example: to see
- test SSNA101. "JOINT_MECA_RUPT

4.3.5.15 " Behavior model

of contact, elastic with tensile strength and fracture (cf [R7.01.25]). This model is usable with the finite elements of joint into linear and quadratic. The modelization hydraulic is possible only if for the joints quadratic (cf [R3.06.09] for more detail). The normal behavior is of cohesive type, while the tangential behavior is always linear with a stiffness dependant on the normal opening of the joint. The hydrostatic pressure due to the presence of fluid in the joint is taken into account, the hydraulic coupling is also possible. The procedure of injection of the concrete under pressure (keying-up), which is specific with the construction of the stoppings, is also implemented. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word JOINT_MECA_RUPT . Modelization

- supported: PLAN_JOINT, AXIS_JOINT, 3D_JOINT, PLAN_JOINT_HYME, 3D_JOINT_HYME. Many local variables
- : 18 Example: to see
- tests SSNP162, SSNP 142, SSNP143 "JOINT_MECA_FROT

4.3.5.16 " an elastoplastic

version of the standard friction law Mohr-Coulomb (confer [R7.01 .25]). This model is usable with the finite elements of joint into linear and quadratic. The modelization hydraulic is possible only if for the joints quadratic (cf [R3.06.09] for more detail). Only the tangential part of displacements is broken up into two components - plastic and elastic. Flow is normal for this tangential part. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word JOINT_MECA_FROT . Supported

- modelization: PLAN_JOINT, AXIS_JOINT, 3D_JOINT, PLAN_JOINT_HYME, 3D_JOINT_HYME. Many local variables
- : 18 Example: to see
- tests SSNP162d/e/ f/j/k/l, SSNP142c/d/g/h "ENDO_HETEROGENE

4.3.5.17 " model ENDO_HETEROGENE

is an isotropic model of damage representing the training and the propagation of cracks from a distribution of microphone-defaults given by a Weibull model. The presence of crack in structure is modelled by lines of broken elements (). The fracture $d=1$ of the elements can be caused either by the starting of a new crack, or by propagation (see [R5.03.24] for more details). It is thus about a model with two thresholds. This model is adapted to the heterogeneous materials such as for example mudstone. The characteristics

of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys ENDO_HETEROGENE , ELAS and NON_LOCAL. Supported

nonlocal modelization: D_PLAN_GRAD_SIGM Many local variables
- for modelization D_PLAN_GRAD_SIGM : 12 Meaning
- : : value of
- $V1$ the damage: healthy d
- $V2$ element (0), pointed (1), broken by starting (2), broken by propagation (3): breaking stress
- $V3$ by starting: breaking stress
- $V4$ by propagation: number of
- $V5$ the element pointed number 1: number of
- $V6$ the element pointed number 2 (when starting): iteration
- $V7$ of Newton of fracture: current
- $V8$ iteration of Newton: coordinate
- $V9$ of the point X of crack after fracture by propagation: coordinate
- $V10$ of the point Y of crack after fracture by propagation: coordinate
- $V11$ of the point X of crack 2 during starting: coordinate
- $V12$ of the point Y of crack 2 during starting, Example: to see

- test ssnp147 and ssnp148 Behaviors

4.3.6 specific to the modelization of the concrete and reinforced concrete "ENDO_ISOT_BETON

4.3.6.1 " brittle

elastic Behavior model. It is about a local modelization to scalar damage and negative linear isotropic hardening which distinguishes behavior in tension and compression from the concrete (see [R7.01.04] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys BETON_ECRO_LINE and ELAS. Supported

local modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, INCO_ UP, INCO_LOG, CONT_1D (by BORST) Many local variables
- : 2 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 for elastic mode (null damage), 1 if damaged, 2 if broken (damage equal to 1)). Example: to see
- test SSNV149. Supported

nonlocal modelization: GRAD_EPSI Many local variables

- : 2 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 for elastic mode (null damage), 1 if damaged, 2 if broken (damage equal to 1)). Example: to see
- test SSNV157 "ENDO_SCALAIRE

4.3.6.2 " brittle

elastic Behavior model. It is about a nonlocal modelization to scalar damage and negative hardening which distinguishes behavior in tension and compression concerning surface from load (see [R5.03.25] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys ENDO_SCALAIRE , NON_LOCAL and ELAS. Not

supported local modelization. Supported

nonlocal modelization: GRAD_VARI Many local variables

- : 3 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 for elastic mode (null damage), 1 if damaged, 2 if broken (damage equal to 1)) : residual $V3$ stiffness Example: to see
- tests SSNL125, SSNP 146, SSNV223, SSNA119 "ENDO_CARRE

4.3.6.3 " brittle

elastic Behavior model. It is about a nonlocal modelization to quadratic regularized damage and negative isotropic hardening, which distinguishes behavior in compression from that in tension (see [R5.03.26] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys ECRO_LINE, NON_LOCAL and ELAS. Not

supported local modelization. Supported

nonlocal modelization: GVNO Many local variables

- : 2 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 for elastic mode (null damage), 1 if damaged Example: to see

tests SSNP307, SNA 119, SSNV220 "ENDO_ORTH_BETON

4.3.6.4 " anisotropic

Behavior model of the concrete with damage [R7.01.09]. It is about a local modelization of damage taking into account the reclosing of cracks. The characteristics of the materials are defined in operator DEFI_MATERIAU under key words ELAS and ENDO_ORTH_BETON . Supported

local modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, CONT _1D (by BORST) Many local variables

- : 7 Meaning
- : with: tensor $V1$ D $V6$ "damage of tension: damage
- $V7$ of compression Example: to see
- test SSNV176 supported

nonlocal Modelization: GRAD_EPSI Many local variables

- : 7 Meaning
- : with: tensor $V1$ D $V6$ " damage of tension: damage
- $V7$ of compression Example: to see
- test SSNV175 "MAZARS " brittle

4.3.6.5

elastic Behavior model. It makes it possible to give an account of the softening of the concrete and distinguishes the damage in tension and compression. Only one variable of scalar damage is used (cf [R7.01.08] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys MAZARS and ELAS (_FO). In the event of thermal loading, the coefficients materials depend on the maximum temperature reached at the Gauss point considered. Moreover, presumedly linear thermal thermal expansion does not contribute to the evolution of the damage (idem for the shrinkage of desiccation and the endogenous shrinkage). Supported

local modelizations: 3D, 2D, CONT _PLAN , INCO, CONT _1D (by BORST) Many local variables

- : 4 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 so not damaged, 1 if damaged): maximum $V3$ temperature attack at the Gauss point considered: equivalent $V4$ strain within the meaning of Mazars. Example: to see
- test SSNP113 supported

nonlocal Modelization: GRAD_EPSI Many local variables

- : 4 Meaning
- : : value of $V1$ the damage: indicator $V2$ of damage (0 for elastic mode (null damage), 1 if damaged): maximum $V3$ temperature attack at the Gauss point considered. : equivalent $V4$ strain within the meaning of Mazars. Example: to see
- test SSNV157 “MAZARS _GC”

4.3.6.6BRITTLE

elastic Behavior model. It makes it possible to give an account of the softening of the concrete and distinguishes the damage in tension and compression. Two variables of scalar damage are used (confer [R5.03.09] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys MAZARS and ELAS. Supported

modelizations: 1D, C_PLAN , LOCAL VARIABLES : 8 (confer [R5.03.09] for more details). ◦: Criterion

$V1$ in stress, ◦: Criterion
$V2$ in strain, ◦: Damage
$V3$, ◦: Equivalent
$V4$ strain of tension, ◦: Equivalent
$V5$ strain of compression, ◦: Ratio
$V6$ of sort-axialié. ◦: Maximum
$V7$ temperature attack in the material, ◦: non
$V8$ recoverable dissipation. “BETON_DOUBLE_DP

4.3.6.7 ″ three-dimensional

Behavior model used for the description of the nonlinear behavior of the concrete. It comprises a criterion of Drücker Prager in tension and a criterion of Drücker Prager in compression, decoupled. The two criteria can have a lenitive hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys BETON_DOUBLE_DP and ELAS (_FO) (confer [R7.01 .03] for more details). To facilitate the integration of this model, one can use the local automatic recutting of time step (see key word ITER_INTE_PAS). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), INCO, CONT _1D (by BORST) Many local variables
- : 4 Meaning
- : : plastic strain $V1$ cumulated in compression: plastic strain $V2$ cumulated in tension: maximum $V3$ temperature attack at the Gauss point considered: indicator $V4$ of plasticity (cf Notices 1). Example: to see

- test SSNV143. “LABORD_1D ”

4.3.6.8 unidimensional

Behavior model of unilateral damage dedicated to the concrete, adapted to the cases of monotonic loadings (static) and cyclic (static and dynamics without effect velocity). It makes it possible to describe the behavior generated by the creation of microscopic cracks (lowering of the stiffness) and bound operation, during cycles, with their reclosing (unilaterality). Two variables of damage are used (one in tension, the other in compression), the unelastic strains related to the damage are taken into account and the opening and the reclosing of cracks are managed by a function of progressive restoration of the stiffness to the reclosing (see [R7.01.07] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys LABORD_1D and ELAS. Supported

- modelization: PMF Many local variables
- : 5 Meaning
- : : value of $V1$ the damage of tension: value of $V2$ the damage of compression: value of $V3$ the threshold of tension: value of $V4$ the damage of compression: unrecoverable $V5$ deformation. Example: to see
- test SSNL119 “GRILLE_ISOT_LINE

4.3.6.9 ” isothermal

Behavior model of uniaxial elastoplasticity of Von Mises with linear isotropic hardening used for the modelization of reinforcements of the reinforced concrete. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys ELAS and ECRO_LINE (confer for more detail the document [R5.03.09]). Supported

- modelizations: GRILL Many local variables
- : 4 Meaning
- : : plastic strain $V1$ cumulated in the longitudinal meaning: indicator $V2$ of plasticity (cf Notices 1). Example: to see
- test SSNS100 “GRILLE_CINE_LINE

4.3.6.10 ” isothermal

Behavior model of uniaxial elastoplasticity of Von Mises with linear kinematic hardening used for the modelization of reinforcements of the reinforced concrete. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys ELAS and ECRO_LINE (cf for more detail the document [R5.03.09]). Supported

- modelizations: GRILL Many local variables
- : 4 Meaning
- : : kinematic hardening $V1$ in the longitudinal meaning: indicator $V2$ of plasticity (cf Notices 1): unutilised $V3$. Example: to see
- test SSNS100 “GRILLE_PINTO_MEN

4.3.6.11 ” elastoplastic

uniaxial isothermal Behavior model of Pinto-Menegotto for the modelization of reinforcements of the reinforced concrete under cyclic loading. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word PINTO_MENEGOTTO (confer for more detail the document [R5.03.09]). Supported

- modelizations: GRILL Many local variables
- : 16 Meaning
- : cf the document [R5.03.09] Example: to see
- test SSNS100 “PINTO_MENEGOTTO

4.3.6.12 ″ `elastoplastic`

uniaxial isothermal Behavior model modelling the response of steel reinforcements in the reinforced concrete under cyclic loading. The data necessary of the field material are provided in operator DEFI_MATERIAU `[U4.43.01],` under key word PINTO_MENEGOTTO `(cf for more` detail the document [R5.03.09]). Supported

- modelizations: CONT_1D Many `local variables`
- : 8 Meaning
- : cf the document [R5.03.09] Example: to see
- test SSNS10 "GLRC_DAMAGE

4.3.6.13 ″ `This constitutive law`

replaces an old version, GLRC. It `is` about a total model of reinforced concrete plate able to represent its behavior until failure. Contrary to the local modelizations where each component of the material is modelled except for, in the total models, the constitutive law is written directly in term of stresses and generalized strains. The phenomena taken into account are the elastoplasticity coupled between the effects of membrane and bending (against an elastoplasticity in bending only in GLRC) and `the damage` in bending. The damage coupled membrane/bending is treated by GLRC_DM, which `, on the other hand`, neglects elastoplasticity completely. The characteristics of the material are defined in DEFI_MATERIAU `(U4.43.01)` under key word GLRC_DAMAGE `. For the precise details` on the formulation of the model to see [R7.01.31]. Supported

- modelizations: DKTG, Q4GG `Many local variables`
- . 19 Meaning
- : with: plastic $V1$ $V3$ membrane extension, with: plastic $V4$ $V6$ curvatures, V7: plastic dissipation, with: variables $V8$ $V9$ of damage for positive and negative bending respectively: dissipation $V10$ of damage, with: angles $V11$ of $V13$ orthotropy, with: components $V14$ $V19$ of the tensor of kinematic hardening (3 for the forces of membrane, 3 for the bending moments). Example: to see
- tests SSNS104, SDNS `108` "GLRC_DM ″ `This`

4.3.6.14 `model`

total makes it possible to represent the damage of a reinforced concrete plate for moderate requests. Contrary to the local modelizations where each component of the material is modelled except for, in the total models, the constitutive law is written directly in term of stresses and generalized strains. The modelization until the fracture is not recommended, since the phenomena of plasticization are not taken into account, but are it in GLRC_DAMAGE `. On the other hand`, the modelization of the coupling of the damage between the effects of membrane and bending in GLRC_DM `is taken into` account, which is not the case in GLRC_DAMAGE `. The characteristics` of the material are defined in DEFI_MATERIAU `(U4.43.01)` under key words GLRC_DM. For `the precise details` on the formulation of the model to see [R7.01.32]. Supported

- modelization: DKTG Many `local variables`
- : 7 with: variables
  - $V1$ $V2$ of damage for positive and negative bending respectively: indicator
  - $V3$ of damage corresponding to (0 for elastic $V1$ mode and 1 if non-zero velocity of the damage): indicator
  - $V4$ of damage corresponding to (0 for elastic $V2$ mode and 1 if non-zero velocity of the damage): relative
  - $V5$ weakening of stiffness out of membrane in tension: relative
  - $V6$ weakening of stiffness out of membrane in compression: relative
  - $V7$ weakening of stiffness in bending Example: to see
- test SSNS106 "CORR_ACIER

4.3.6.15 " Models elastoplastic

endommageable for which the plastic strain with fracture depends on the rate of corrosion (cf [R7.01.20]). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key key ELAS and CORR_ACIER . Modelizations

- : 3D, 2D, CONT _1D 3 local variables
- : cumulated
  - $V1$ plastic strain: coefficient
  - $V2$ of damage: indicator
  - $V3$ of plasticity (cf Notices 1) Example: to see
- test SSNL127 "BETON_REGLE_PR

4.3.6.16 " concrete

Behavior model (developed by company NECS) known as "right-angled parabola". The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key word BETON_REGLE_PR and ELAS. Model BETON_REGLE_PR

is a concrete model approaching the lawful concrete models (from where its name) which has the following summary characteristics: it is a model
- 2D and more exactly 2 times 1D: in the clean reference of strain, one writes a model 1D stress-strain; the model 1D on
- each direction of clean strain is the following one: in tension
  - , linear until a peak, linear softening up to 0; in compression
  - , a model power to a plate (from where PR: parabola – rectangle). Modelizations

- : CONT_PLAN, D_PLAN 1 local variable
- : cumulated $V1$ plastic strain Example: to see
- test SSNP129 the equations

of the model are described in [U4.43.01]. "JOINT_BA"

4.3.6.17 local

Behavior model in 2D describing the phenomenon of steel-concrete connection for reinforced concrete structures. It makes it possible to give an account of the influence of connection in the redistribution of the stresses in the body of the concrete as well as the prediction of cracks and their spacing. Available for loadings into monotonous and in cyclic, she takes into account the effects of the friction of cracks, and containment. Only one variable of scalar damage is used (cf [R7.01.21] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys JOINT_BA and ELAS. Supported

- modelizations: PLAN_JOINT and AXIS_JOINT. Many local variables
- : 6 Meaning
- : : value of $V1$ the damage in the normal direction: value of $V2$ the damage in the tangential direction: scalar $V3$ variable of isotropic hardening for the damage in mode 1: scalar $V4$ variable of isotropic hardening for the damage in mode 2: strain $V5$ of sliding cumulated by friction of cracks: value of $V6$ kinematic hardening by friction of cracks. Example: to see
- test SSNP126 "GRANGER_FP

4.3.6.18 " Behavior model

for the modelization of the clean creep of the concrete. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word GRANGER_FP (see [R7.01 .01] for more details). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST) Many local variables

- : 55 Meaning
- : to see [R7.01.01] Example: to see
- test SSNP116 “GRANGER_FP_V

4.3.6.19 ″ Behavior model

for the modelization of the clean creep of the concrete with taking into account of the phenomenon of aging. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word V_GRANGER_FP (confer [R7.01 .01] for more details). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST) Many local variables
- : 55 Meaning
- : to see [R7.01.01] Example: to see
- test YYYY1 17 “GRANGER_FP_INDT

4.3.6.20 ″ Identical to

GRANGER_FP_V but treating only one isothermal behavior. Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST) Many local variables
- : 55 Meaning
- : to see [R7.01.01] Example: to see
- test SSNV142 “BETON_UMLV_FP

4.3.6.21 ″ Behavior model

for the modelization of the clean creep of the concrete with taking into account of the distinction between voluminal creep and creep deviatoric in order to give an account of the phenomena in the cases of multiaxial creeps. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word BETON_UMLV_FP (confer [R7.01 .06] for more details). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST) Many local variables
- : 21 Meaning
- : to see [R7.01.06] Example: to see
- test SSNV163 “BETON_RAG ″

4.3.6.22 Behavior model

for the modelization of structures affected by the reaction alkali-aggregate. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word BETON_RAG (confer [R7.01 .26] for more details). Supported

- modelizations: 3D, 2D AXI , 2D D_PLAN Many local variables
- : 65 Meaning
- : to see [R7.01.26] Example: to see
- test SSNV212 “BETON _BURGER

4.3.6.23 _FP″ Behavior model

for the modelization of the clean creep of the concrete with taking into account of the distinction between voluminal creep and creep deviatoric in order to give an account of the phenomena in the cases of multiaxial creeps. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word BETON_BURGER _FP (confer [R7.01 .06] for more details). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST) Many local variables
- : 21 Meaning

- : to see [R7.01.35] Example: to see
- test SSNV163 Structural mechanics behaviors

4.3.7 for the géo-materials the mechanical

models for the géo-materials (soils, rocks) only can for the majority being used in the mechanical modelizations or modelizations THM, via key word KIT_HM, KIT_HHM , KIT_THM, KIT_THHM. "ELAS_GONF"

4.3.7.1 Behavior model

being used to describe the behavior of "the inflating" clay materials type (bentonite) . It is about a nonlinear elastic model connecting the clear stress () to the pressure $contrainte-Pgaz$ of swelling which it even depends on suction (or capillary pressure). This model is developed for the modelizations unsaturated with type *HH*. Supported

- modelizations: HHM, THHM. Many local variables
- : 0 Example: to see
- the tests reproducing the swelling of a clay cell which one saturates gradually: plane (wtnp119 has, B, C, d), axi (wtna110a, B, C, d) and 3D (wtnv136a, B, C, d) "CJS" Behavior model

4.3.7.2

elastoplastic for computations in soil mechanics. This model is a multicriterion model which comprise a nonlinear elastic mechanism, an isotropic plastic mechanism and a plastic mechanism déviatoire (see [R7.01.13] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CJS and ELAS . To facilitate the integration of this model, one can use the local automatic recutting of time step (see key word ITER_INTE_PAS). Supported

- modelizations: 3D, 2D, CONT _PLAN (by BORST), CONT_1D (by BORST), THM. Many local variables
- : 16 in 3D and 14 in 2D Meaning
- : : isotropic threshold $V1$: angle of $V2$ the threshold déviatoire, with (V3 with $V3$ V6 in $V8$ 2D): 6 (4 in 2D) component of the tensor of kinematic hardening, (in 2D): $V9$ outdistance $V7$ standardized with the threshold déviatoire, (in 2D): $V10$ relationship $V8$ between the threshold déviatoire and the threshold deviatoric criticism, (in 2D): $V11$ outdistance $V9$ standardized with the isotropic threshold, (in 2D): $V12$ nombre of iterations $V10$ interns, (in 2D): $V13$ value $V11$ of the local test of stop of the iterative process, (in 2D): $V14$ many $V12$ local recuttings of time step, (in 2D): $V15$ sign $V13$ contracted product of the deviatoric stress by the deviatoric plastic strain, (in 2D): $V16$ indicator $V14$ (0 so elastic, 1 so elastoplastic with isotropic plastic mechanism, 2 so elastoplastic with plastic mechanism déviatoire, 3 so elastoplastic with plastic mechanisms isotropic and déviatoire). Example: to see
- tests SSNV135, SSNV 136, SSNV154, following WTNV100 "LAIGLE"

4.3.7.3

Behavior model for the modelization of the rocks the model of Laigle. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word LAIGLE (cf the document [R7.01.15] for more details). To facilitate the integration of this model, one can use the local automatic recutting of time step (key word ITER_INTE_PAS). Supported

- modelizations: 3D, 2D, THM Many local variables
- : 4 Meaning
- : : plastic $V1$ strain déviatoire cumulated: cumulated $V2$ plastic voluminal strain, fields of $V3$ behavior of the rock: indicator $V4$ of state. Example: to see

- test SSNV158, following WTNV 101 "LETK"

4.3.7.4

Behavior model for the elastoviscoplastic modelization of the rocks the model of Laigle and Kleine. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word LETK (cf the document [R7.01.24] for more details). The tangent operator not being validated, it is possible to use the matrix of disturbance under key word TYPE_MATR_TANG . The operator relating to the elastic prediction is that of nonlinear elasticity specific to the model. Supported

- modelizations: 3D, 2D, THM Many local variables
- : 7 Meaning
- : : elastoplastic $V1$ variable of hardening: plastic $V2$ deviatoric strain: viscoplastic $V3$ variable of hardening: viscoplastic $V4$ strain déviatoire: indicator $V5$ of contractance (0) or dilatancy (1): indicator $V6$ of viscplasticity: indicator $V7$ of plasticity (cf Notices 1) Example: to see
- the tests SSNV206A, WTNV 135A "HOEK_BROWN

4.3.7.5 " Behavior model

of Hoek and Brown modified for the modelization of the behavior of the rocks [R7.01.18] for the pure mechanics. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word HOEK_BROWN to facilitate the integration of this model, one can use the local automatic recutting of time step (see key word ITER_INTE_PAS). Supported

- modelizations: 3D, 2D, C_PLAN Many local variables
- : 3 Meaning
- : to see [R7.01.18] Example: to see
- test SSNV184 "HOEK_BROWN_EFF

4.3.7.6 " Behavior model

of Hoek and Brown modified for the modelization of the behavior of the rocks [R7.01.18] in THM. The coupling is formulated in effective stresses. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word HOEK_BROWN to facilitate the integration of this model, one can use the local automatic recutting of time step (see key word ITER_INTE_PAS). Supported

- modelizations: THM Many local variables
- : 3 Meaning
- : to see [R7.01.18] Example: to see
- test WTNV128 " HOEK_BROWN_TOT

4.3.7.7" Behavior model

of Hoek and Brown modified for the modelization of the behavior of the rocks [R7.01.18] in THM. The coupling is formulated in total stresses. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word HOEK_BROWN to facilitate the integration of this model, one can use the local automatic recutting of time step (see key word ITER_INTE_PAS). Supported

- modelizations: THM Many local variables
- : 3 Meaning
- : to see [R7.01.18] Example: to see
- test WTNV129 "CAM_CLAY "

4.3.7.8 elastoplastic

Behavior model for computations in soil mechanics normally consolidated (cf [R7.01.14] for more details). The elastic part is nonlinear. The plastic part can be hardening or lenitive. The data necessary to the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys CAM_CLAY and ELAS. So the model
CAM_CLAY is used with the modelization THM, key word PORO indicated under CAM_CLAY and under THM_INIT must be the same one. Modelization

- supported: 3D, 2D and THM Many local variables
- : 2 Meaning
- : : voluminal $V1$ plastic strain: indicator $V2$ of plasticity (cf Notices 1). Example: to see
- tests SSNV160, WTNV 122 "BARCELONE"

4.3.7.9 Relation describing

the elastoplastic structural mechanics behavior of the unsaturated soils coupled with the hydraulic behavior (cf [R7.01.14] 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). This model must be used in relations KIT_HHM or KIT_THHM. The data necessary to the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys BARCELONE, CAM_CLAY and ELAS. Modelization

- supported: THM Many local variables
- : 5 Meaning
- : : critical $V1$ (1 p /2 pressure of consolidation): indicator $V2$ of plasticity (cf Notices 1) mechanical: hydrous threshold $V3$: hydrous $V4$ indicator of irreversibility: (cohesion $V5$) Ps . Example: to see
- test WTNV123 "DRUCK_PRAGER

4.3.7.10 " associated

Behavior model of the Drucker-Prager type for the soil mechanics (cf [R7.01.16] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys DRUCK_PRAGER and ELAS (_FO). It is supposed however that the thermal coefficient of thermal expansion is constant. Hardening can be linear or parabolic. Modelization

- supported: THM, 3D, 2D Many local variables
- : 3: plastic
- $V1$ strain déviatoire cumulated: cumulated $V2$ plastic voluminal strain, V3 indicator of state. Example: to see
- tests SSNV168, WTNA 101 "DRUCK_PRAG_N_A

4.3.7.11 " non

associated Behavior model of the Drucker-Prager type for the soil mechanics (cf [R7.01.16] for more details). The characteristics of the material are defined in operator DEFI_MATERIAU [U4.43.01] under key keys DRUCK_PRAGER and ELAS (_FO). It is supposed however that the thermal coefficient of thermal expansion is constant. Hardening can be linear or parabolic. Modelization

- supported: THM, 3D, 2D Many local variables
- : 3: plastic
- $V1$ strain déviatoire cumulated: cumulated $V2$ plastic voluminal strain, indicator $V3$ of state. Example: to see
- test SSND104. "VISC_DRUC_PRAG

4.3.7.12 Behavior model

for the plastic modelization élasto visco of the rocks. Elastoplasticity is of type Drucker Prager and creep is a model power of the Perzyna type. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word VISC_DRUC_PRAG (cf the document [R7.01.22] for more details). Modelization

- supported: 3D and THM supported
- Modelizations: 3D, 2D, THM Many local variables
- : 4 Meaning
- : : viscoplastic $V1$ variable of hardening: indicator $V2$ of plasticity (cf Notices 1): level of $V3$ hardening: nombre of iterations $V4$ local Example: to see
- tests SSNV211A, WTNV 137A, WTNV138A "HUJEUX" cyclic

4.3.7.13

elastoplastic Behavior model for the soil mechanics (géomatériaux granular: sandy, normally consolidated or on-consolidated, serious clays…). This model is a multi-criteria model which comprise a nonlinear elastic mechanism, three plastic mechanisms déviatoires and an isotropic plastic mechanism (cf [R7.01.23] for more details). The data necessary to the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys HUJEUX and ELAS. To facilitate the integration of this model, one can use the local automatic recutting of time step (key word ITER_INTE_PAS). Modelization

- supported: 3D and THM open Diagrams
- of integration: "NEWTON", "NEWTON_PERT", "NEWTON_RELI", "SPECIFIQUE" Many local variables
- : 50 Meaning
- : with: hardening factors $V1$ $V3$ of the monotonous mechanisms déviatoires: factor D $V4$ "hardening of the monotonous isotropic mechanism, with: factors $V5$ $V7$ D" hardening of the cyclic mechanisms déviatoires: factor D $V8$ "hardening of the cyclic isotropic mechanism, with: variables $V9$ $V22$ D" history related to the cyclic mechanisms: cumulated $V23$ plastic voluminal strain, with: indicators $V24$ $V31$ of state of the monotonous and cyclic mechanisms: criterion $V32$ of Hill. "INDETAC3", "HIS34", "HIS35", "XHYZ1", "XHYZ2", "THYZ1", "THYZ2", "RHYZ", "XHXZ1", "XHXZ2", "THXZ1", "THXZ2", "RHXZ", "XHXY1", "XHXY2", "THXY1", "THXY2", "RHYZ" Example: to see
- tests SSNV197, SSNV 204, SSNV205, WTNV132, WTNV133, WTNV134. "JOINT_BANDIS

4.3.7.14" nonlinear

elastic Behavior model for the water seals in rock mechanics. In the normal direction with the joint, one has a hyperbolic relation between the effective stress and the opening of the joint. In the tangential direction, there is a linear elastic behavior. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word JOINT_BANDIS (confer the document [R7.02.15] for more details). Modelization

- supported: PLAN_JHMS, AXIS_JHMS Many local variables
- : 1 Meaning
- : : longitudinal $V1$ permeability of the crack Example: to see
- tests WTNP125, WTNP126. Behaviors

4.3.8 integrated by an external software "ZMAT" ♦

4.3.8.1 NB_VARI

= **nbvar ♦ UNITE =**
links **ZMAT is**

the modulus of resolution of the constitutive laws of the code Zebulon (Center of the Materials, École Nationale Supérieure of the Mines of Paris) the Zmat coupling – Code_Aster *is translated* for the user of Code_Aster *in the following way* : on the level of

- COMP_INCR, key word RELATION=' ZMAT ", to go to read the file containing the data Zmat (which allows at the same time the choice of the behavior and the definition of the coefficients material). This file can call on a behavior already available in Zmat, or well defined by the user in a relatively simple language (Zebfront). always under

- COMP_INCR, a key word UNITE makes it possible to define the logical unit on which comes to read to card-index it zmat and one have mot_clé NB_VARI making it possible to specify the number of local variables of the behavior, and of course usual key keys: GROUP_MA, DEFORMATION . L" assumption
- of the plane stresses is taken into account by the method OF BORST To take into account
- the large deformations, it is necessary to use DEFORMATION = ' GDEF_HYPO_ELAS', and in the data file Zmat, the key keys lagrange_rotate or lagrange _polar . The key word
- relating to local integration: RESI_INTE_RELA , ITER_INTE_MAXI, ITER_INTE_PAS, ALGO_INTE, PARM_THETA, are not used, since well informed in the file zmat. In ASTK,
- compared to a classical study, it is enough to add the Zmat file corresponding to the unit defined above. The use

of Zmat for Code_Aster *is envisaged* at EDF, in the frame of the partnership School of the Mines - EDF, for computations of R & D only, which excludes in particular studies IPS. Out of this frame, the license of Zmat can be acquired near the Center of the Materials of the ENSMP. For more

details, to see the document [U2.10.01] (note of use of the coupling Zmat-Aster). The documentation of use of ZMat is available on the machine of development in the /aster/public/Z8.4/HANDBOOK directory . "UMAT" ♦

4.3.8.2 NB_VARI

= **nbvar UMAT is**

a format of routine FORTRAN familiar to the users of the Abaqus code, being used to integrate their own constitutive laws. The dynamic
library containing routine UMAT must be prepared before the execution of computation. For that, the user has a simple way compile this library by means of the utility "as_run --make_shared" (cf [U1.04 .00]). The Umat
coupling – Code_Aster *is translated* in the command file in the following way: on the level of

- COMP_INCR, key word RELATION=' UMAT ", always under
- COMP_INCR, mot_clé the NB_VARI allowing to specify the number of local variables of the behavior, and of course usual key keys: GROUP_MA, DEFORMATION , One shows
- the way towards the library under the key word LIBRARY and the name of the symbol (name of the routine contained in the library) under key word NOM_ROUTINE . L" assumption
- of the plane stresses is taken into account by the method OF BORST. The key word
- relating to local integration: RESI_INTE_RELA , ITER_INTE_MAXI, ALGO_INTE, PARM_THETA, are not used. The data

necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word UMAT/UMAT_FO . Supported

- modelizations: 3D AXIS D_PLAN Example: to see
- tests UMAT001, UMAT the 002 current

limitations of the interface Aster-Umat are: output of

- energies: for the moment, it are not recovered by Code_Aster In the same way not
- thermomechanical coupling for the moment. MFRONT ♦

4.3.8.3 NB_VARI

= **nbvar MFRONT is**

a software making it possible to integrate constitutive laws, developed by CEA/Cadarache in the frame of PLEIADS (cf.CR-AMA-13.049.pdf). Its use is thus currently restricted at EDF/R & D and it is accessible only in-house EDF for tests because the use of a constitutive law by this mechanism (for a study of R & D or other) is currently out of perimeter quality assurance. The dynamic

library containing routine MFRONT must be prepared before the execution of computation. For that, the user has a simple way compile this library by means of the utility "as_run --make_shared" (cf [U1.04 .00]). The Umat
coupling – Code_Aster *is translated* in the command file in the following way: on the level of

- COMP_INCR, key word RELATION=' MFRONT ", always under
- COMP_INCR, mot_clé the NB_VARI allowing to specify the number of local variables of the behavior, and of course usual key keys: GROUP_MA, DEFORMATION , (one can use large deformations GDEF_LOG in particular). One shows
- the way towards the library under the key word LIBRARY and the name of the symbol (name of the routine contained in the library) under key word NOM_ROUTINE . L" assumption
- of the plane stresses is taken into account by the method OF BORST. Keywords
- relating to local integration: RESI_INTE_RELA , ITER_INTE_MAXI, ALGO_INTE, PARM_THETA, are not used. The data

necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word UMAT/UMAT_FO . Supported

- modelizations: 3D AXIS D_PLAN Example:
- to see tests MFRON01, MFRON 02 Behavior

4.3.9 for multifibre beams "MULTIFIBRE

4.3.9.1 " When

the modelization comprises multifibre beam elements, it is necessary to indicate meshes and the mesh groups concerned with this modelization, way of pointing on the good behavior: key key RELATION=' MULTIFIBRE' under COMP_INCR.The definition
of the material is done using the commands: DEFI_COMPOR and AFFE_MATERIAU . COMPF =DEFI

```
    _COMPOR (GEOM_FIBRE=
       GF, MATER_SECT= BETON, MULTIFIBRE=
       (_F (GROUP_FIBRE
              = ' SACI', MATER=ACIER , RELATION=' VMIS _CINE_GC'), _F
   (GROUP_FIBRE
          = ' SBET', MATER=BETON , RELATION=' MAZARS "),),) CHMAT
       =AFFE


    _MATERIAU (MAILLAGE=MA
       , AFFE=_F (GROUP_MA
       = "POUTRE", MATER = (ACIER , BETON ,),), AFFE_COMPOR
       =_F (GROUP_MA = "POUTRE", COMPOR=COMPF )) Operand
```

4.4 RELATION_KIT under COMP_INCR For the behaviors

specific to the concrete and the porous environments, RELATION_KIT makes it possible to couple several behaviors. For the structural mechanics behaviors with effects of the metallurgical transformations, RELATION_KIT makes it possible to choose the type of treated material (ACIER or ZIRCALOY). KIT associated

4.4.1 with the metallurgical behavior/“ACIER”/”

ZIRC' Makes it possible to choose

for all the metallurgical constitutive laws (META_xxx) to treat a material of type steel or Zircaloy type. Standard material ACIER comprises with more the 5 different metallurgical phases, material ZIRC comprises with more the 3 different metallurgical phases. Examples:

COMP_INCR =

```
(RELATION =   '  META_P_      INL'    RELATION_KIT
                = ' ZIRC'     )    COMP_INCR    =

(RELATION =   '  META_V_         CL_PT_RE' RELATION_KIT
                = ' ACIER'    )    KIT associated
```

4.4.2 with the behavior with the concrete: “KIT_DDI” Makes it possible

to add two terms with unelastic strains defined by certain already existing constitutive laws in COMP_INCR (cf [R5.03 .60] for more details). One can assemble a model of creep of the concrete with a behavior elastoplastic or damaging. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under the key keys ELAS (_FO) (the two models **must have the same modulus of YOUNG) and those corresponding** to the two selected models. Under the assumption

that creep is a phenomenon which evolves more slowly than plasticity, one compares the tangent matrix of the complete model to that of plasticity. This choice will thus require to adapt the increments of computation to times characteristic of the phenomena modelled in order not to handicap computation in term of nombre of iterations. In this case, the local parameters of convergence (RESI_INTE_RELA and ITER_INTE_MAXI under key word CONVERGENCE) are the same ones for the integration of the two models. With the models

of creep: “GRANGER_FP
- ” “GRANGER_FP_V
- ” “GRANGER_FP_INDT
- ” can be

associated the following models of behavior: “BETON_DOUBLE_DP
- ” “VMIS_ISOT_TRAC
- ” “VMIS_ISOT_PUIS
- ” “VMIS_ISOT_LINE
- ” “ROUSS_PR”
- “BETON_DOUBLE_DP
- ” With the model

of creep “BETON_UMLV_FP
- ” can be

associated the following models of behavior: “ENDO_ISOT_BETON
- ”, “MAZARS”
- supported

Modelizations: 3D, 2D, CONT _PLAN (by BORST or ANALYTIQUE according to each model, CONT_1D (by BORST). The local variables

- of each model are cumulated in the table of the local variables, and are restored model by model. Example:

COMP_INCR =

```
    _F (RELATION =    “KIT_DDI         ” RELATION_KIT
                      = (“BETON_UMLV_FP   ”, “MAZARS”)) See also
```

- test SSNV169 formalism

KIT_DDI also makes it possible the model to associate total with plate, GLRC_DM, which implements the damage coupled membrane-bending, with models of plasticity of Von Mises, to take into account elastoplasticity (out of membrane only): "GLRC_DM"
•can be

associated the following models of behavior: "VMIS_ISOT_TRAC
- ", "VMIS_ISOT_LINE
- ", "VMIS_CINE_LINE
- ", supported

Modelization: DKTG. Example: tests SSNS106F, SSNS 106G KIT associated

4.4.3 with the behavior with the porous environments (modelizations thermo-hydro-mechanics) For more

details on the modelizations thermo-hydro-mechanics and the model of behavior, one will be able to consult the documents [R7.01.10] and [R7.01.11], as well as the note of use [U2.04.05]. Key word RELATION

4.4.3.1relations

make it possible to solve simultaneously from two to four balance equations. The equations considered depend on suffix with the following rule: M indicates

- the mechanical balance equation, T indicates
- the thermal balance equation, H indicates
- a hydraulic balance equation. V
- the presence of a phase in form vapor indicates (besides the fluid) the associated

problems thermo-hydro-mechanics are treated in a completely coupled way. Only one letter

H means that the porous environment is saturated (only one variable of pressure), for example p either of gas, or of fluid, or of a liquid mixture/gas (of which the pressure of gas is constant). Two letters

H mean that the porous environment is not saturated (two variables of pressure), for example p a liquid mixture/vapor/gas. The presence

of two letters HV means that the porous environment is saturated by a component (in practice of water), but that this component can be in liquid form or vapor. There is not whereas a conservation equation of this component, therefore only one pressure degree of freedom, but there are a liquid flux and a flux vapor. The table

below summarizes to which kit each modelization corresponds: KIT_HM D_PLAN_HM

,	D_PLAN_HMS, D_PLAN_HMD, AXIS_HM, AXIS_HMS, AXIS_HMD, 3D_HM, 3D_HMS, 3D_HMD KIT_THM D_PLAN_THM
,	D_PLAN_THMS, D_PLAN_THMD, AXIS_THM, AXIS_THMS, AXIS_THMD, 3D_THM, 3D_THMS, 3D_THMD KIT_HHM D_PLAN_HHM
,	D_PLAN_HHMS, D_PLAN_HHMD, AXIS_HHM, AXIS_HHMS, AXIS_HHMD, 3D_HHM, 3D_HHMS, 3D_HHMD, D_PLAN_HH2MD D_PLAN_HH2MS, AXIS_HH2MD, AXIS_HH2MS, 3D_HH2MD, 3D_HH2MS KIT_THH D_PLAN_THHD
	, D_PLAN_THHS, AXIS_THHD, AXIS_THHS, 3D_THHD, 3D_THHS, D_PLAN_THH2D, AXIS_THH2D, 3D_THH2D, D_PLAN_THH2S, AXIS_THH2S, 3D_THH2S KIT_HH D_PLAN_HHS
,	D_PLAN_HHD, AXIS_HHS, AXIS_HHD, 3D_HHS, 3D_HHD, D_PLAN_HH2D, AXIS_HH2D, 3D_HH2D, D_PLAN_HH2S, AXIS_HH2S, 3D_HH2S, D_PLAN_HH2SUC, D_PLAN_HH2SUDM, D_PLAN_HH2SUDA, _3D_HH2SUC, 3D_HH2SUDM, 3D_HH2SUDA, KIT_THV D_PLAN_THVD

	, AXIS_THVD, 3D_THVD KIT_THHM D_PLAN_THHMS
	, D_PLAN_THHMD, AXIS_THHMS, AXIS_THHMD, 3D_THHM, 3D_THHMS, 3D_THHMD, D_PLAN_THH2MD, AXIS_THH2MD, 3D_THH2MD D_PLAN_THH2MS, AXIS_THH2MS, 3D_THH2MS Key word RELATION_KIT

4.4.3.2For each

modelled phenomenon, one must specify in RELATION_KIT : the model

- of structural mechanics behavior of the squelette, the gas
- /liquid reaction of, the hydraulic model
- . HYDR_UTIL (
  - if the structural mechanics behavior is without damage): Mean that no material characteristic returned "into tough". Concretely in the saturated case, it will be necessary to define point by point the 6 curves (by DEFI_FONCTION) following: saturation
    - according to the capillary pressure, derivative
    - of this curve, the permeability
    - relating to the fluid according to saturation, its derivative
    - . the permeability
    - relating to gas according to saturation, its derivative
    - . HYDR_VGM (if
  - the structural mechanics behavior is without damage). Here and only for the coupling laws liquid/gas "LIQU_GAZ ", "LIQU_AD_GAZ", "LIQU_AD_GAZ" and "LIQU_VAPE _GAZ_VAPE", the curves of saturation, permeabilities relating to water and with gas and their derivatives are defined by the model of Mualem Van-Genuchten. The user must then inform the parameters of this model. The model (n, Pr, Sr) Mualem Van-Genuchten is the following: , and where

    $k_r^w = \sqrt{S_{we}}\left(1-\left(1-S_{we}^{1/m}\right)^m\right)^2$ and $k_r^{gz} = \sqrt{1-S_{we}}\left(1-S_{we}^{1/m}\right)^{2m}$

    HYDR

    $S_{we} = \frac{1}{\left(1+\left(\frac{P_c}{P_r}\right)^n\right)^m}$ _VGC $S_{we} = \frac{S_w - S_{wr}}{1 - S_{wr} - S_{gr}}$ (if $m = 1 - \frac{1}{n}$

  - the structural mechanics behavior is without damage). Exactly same thing as HYDR_VGM safe for the model of permeability relating to the gas which is a cubic model: HYDR_ENDO (

    $k_r^{gz} = \left(1 - S_w\right)^3$

  - if one uses "MAZARS" or "ENDO_ISOT_BETON ") under RELATION_KIT (this key word makes it possible to inform the curve of saturation and its derivative according to the capillary pressure as well as the relative permeability and its derivative according to saturation. Structural mechanics behaviors

4.4.3.3 of squelette (if there is mechanical modelization M) "ELAS"

- "ELAS_GONF"
- "CJS" "CAM_CLAY
- "
- "BARCELONE"
- "LAIGLE" "DRUCK_PRAGER
-
- " "DRUCK_PRAG_N_A
- " "HOEK_BROWN_EFF
- " "HOEK_BROWN_TOT

- •" "MAZARS" "ENDO
- •_ISO_BETON
- •" "HUJEUX"
- •"JOINT_BANDIS
- •" gas

4.4.3.4 /liquid Reactions of "LIQU_SATU"

Constitutive law

for porous environments saturated by only one fluid (confer [R7.01.11] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word THM_LIQ. "LIQU_GAZ "

Constitutive law

for a porous environment unsaturated liquidates/gas without phase change (confer [R7.01.11] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys THM_LIQ and THM_GAZ . "GAZ " Constitutive law

of a perfect gas i.e. checking the relation where is $P/\rho=RT/Mv$ the pressure P , the density ρ , the molar mass Mv , the Boltzmann constant R and the temperature T (confer [R7.01.11] for more details). For only saturated medium. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word THM_GAZ. "LIQU_GAZ_ATM

" **Constitutive law**

for a porous environment unsaturated with a fluid and gas with atmospheric pressure (confer [R7.01.11] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys THM_LIQU. " LIQU_VAPE_GAZ

" **Constitutive law**

for a porous environment unsaturated water/vapor/dry air with phase change (confer [R7.01.11] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys THM_LIQ, THM _VAPE and THM_GAZ . "LIQU_AD_GAZ_VAPE

" **Constitutive law**

for a porous environment unsaturated water/vapor/dry air/air dissolved with phase change (confer [R7.01.11] for more details). The data

necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys THM_LIQ, THM _VAPE, THM_GAZ and THM_AIR_DISS . "LIQU_AD_GAZE

" **Constitutive law**

for a porous environment unsaturated water/dry air/air dissolved with phase change (confer [R7.01.11] for more details). It is thus about a version without vapeu of the model supplements below the data

necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys THM_LIQ, THM_GAZ and THM_AIR_DISS . "LIQU_VAPE"

Constitutive law

for porous environments saturated by a component present in liquid form or vapor. with phase change (confer [R7.01.11] for more details). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys THM_LIQ and THM_VAPE hydraulic model

4.4.3.5 "HYDR_UTIL

" (if the structural mechanics behavior is without damage): Mean that no material characteristic returned "into tough". Concretely in the saturated case, it will be necessary to define point by point the 6 curves (by DEFI_FONCTION) following: saturation

- according to the capillary pressure, derivative
- of this curve, the permeability
- relating to the fluid according to saturation, its derivative
- . the permeability
- relating to gas according to saturation, its derivative
- . "HYDR_VGM

" (if the structural mechanics behavior is without damage). Here and only for the coupling laws liquid/gas "LIQU_GAZ ", "LIQU_AD_GAZ_VAPE", "LIQU_AD_GAZ" and "LIQU_VAPE_GAZ ", the curves of saturation, permeabilities relating to water and with gas and their derivatives are defined by the model of Mualem Van-Genuchten. The user must then inform the parameters of this model. The model (n, Pr, Sr) Mualem Van-Genuchten is the following: and where and

$$k_r^{gz}=\sqrt{1-S_{we}}\left(1-S_{we}^{1/m}\right)^{2m}$$. "

$$S_{we}=\frac{1}{\left(1+\left(\frac{P_c}{P_r}\right)^n\right)^m}$$

HYDR

$$S_{we}=\frac{S_w-S_{wr}}{1-S_{wr}-S_{gr}}$$ _VGC $m=1-\frac{1}{n}$

" (if the structural mechanics behavior is without damage). Here and only for the coupling laws liquid/gas "LIQU_GAZ ", "LIQU_AD_GAZ_VAPE", "LIQU_AD_GAZ" and "LIQU_VAPE_GAZ ", the curves of saturation, permeabilities relating to water and their derivatives are defined by the model of Mualem Van-Genuchten (see above). The permeability relating to gas is defined by a cubic model: The user

$$k_r^{gz}=\left(1-S_w\right)^3$$

must then inform the parameters of this model. "HYDR_ENDO (n, Pr, Sr)

" (if one uses "MAZARS" or "ENDO_ISOT_BETON ") under RELATION_KIT (this key word makes it possible to inform the curve of saturation and its derivative according to the capillary pressure as well as the relative permeability and its derivative according to saturation. The possible

4.4.3.6 combinations According to the value

of key word RELATION=' chosen, all the behaviors are not licit in RELATION_KIT (for example if one selected porous environments unsaturated, one cannot affect a perfect gas reaction of standard). All the possible combinations here are summarized. For relation

KIT_HM and KIT_THM : ("ELAS"

```
"GAZ" "             HYDR_UTIL             ") ("CJS" "
GAZ" "              HYDR_UTIL             ") ("HUJEUX"
```

```
"GAZ" "             HYDR_UTIL              ") ("LAIGLE"
"GAZ" "             HYDR_UTIL              ") ("CAM_CLAY
" "GAZ" "       HYDR_UTIL              ") ("JOINT_BANDIS
" "GAZ" "    HYDR_UTIL              ") ("MAZARS"
"GAZ" "             HYDR_ENDO              ") ("ENDO_ISOT_BETON
" "GAZ" " HYDR_ENDO              ") ("ELAS"

"LIQU_SATU              " "HYDR_UTIL        ") ("CJS" "
LIQU_SATU               " "HYDR_UTIL        ") ("HUJEUX"
"LIQU_SATU              " "HYDR_UTIL        ") ("LAIGLE"
"LIQU_SATU           " "HYDR_UTIL        ") ("CAM_CLAY
" "LIQU_SATU         " "HYDR_UTIL        ") ("JOINT_BANDIS
" "LIQU_SATU     " "HYDR_UTIL        ") ("MAZARS"
"LIQU_SATU              " "HYDR_ENDO        ") ("ENDO_ISOT_BETON
" "LIQU_SATU " "HYDR_ENDO        ") ("ELAS"

"LIQU_GAZ_ATM           " "HYDR_UTIL    ") ("CJS" "
LIQU_GAZ_ATM               " "HYDR_UTIL    ") ("HUJEUX"
"LIQU_GAZ_ATM           " "HYDR_UTIL    ") ("LAIGLE"
"LIQU_GAZ_ATM           " "HYDR_UTIL    ") ("CAM_CLAY
" "LIQU_GAZ_ATM         " "HYDR_UTIL    ") ("MAZARS"
"LIQU_GAZ_ATM           ""HYDR_ENDO     ") ("ENDO_ISOT_BETON
" "LIQU_GAZ_ATM  " "HYDR_ENDO     ") For relation
```

KIT_HHM and `KIT_THHM` : `("ELAS"`

```
"LIQU_GAZ"              "HYDR_UTIL                          ") ("ELAS_GONF
" "LIQU_GAZ"         "HYDR_UTIL                          ") ("CJS" "
LIQU_GAZ"               "HYDR_UTIL                          ") ("HUJEUX"
"LIQU_GAZ"              "HYDR_UTIL                          ") ("LAIGLE"
"LIQU_GAZ"              "HYDR_UTIL                          ") ("CAM_CLAY
" "LIQU_GAZ"         "HYDR_UTIL                          ") ("BARCELONE
" "LIQU_GAZ"         "HYDR_UTIL                          ") ("ELAS"
"LIQU_GAZ"              "HYDR_VGM                           ") ("ELAS_GONF
" "LIQU_GAZ"         "HYDR_VGM                       ") ("CJS" "
LIQU_GAZ"               "HYDR_VGM                           ") ("LAIGLE"
"LIQU_GAZ"              "HYDR_VGM                           ") ("CAM_CLAY
" "LIQU_GAZ"         "HYDR_VGM                       " ") (" BARCELONE
"" LIQU_GAZ'         "HYDR_VGM                       ") ("MAZARS"
"LIQU_GAZ           " "HYDR_ENDO                        ") ("ENDO_ISOT_BETON
" "LIQU_GAZ"  "HYDR_ENDO                       ") ("ELAS"

"            LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("ELAS_GONF
" "       LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("CJS" "
               LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("HUJEUX"
"            LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("LAIGLE"
"            LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("CAM_CLAY
" "       LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("BARCELONE
" "       LIQU_VAPE_GAZ" "HYDR_UTIL              ") ("ELAS"
"            LIQU_VAPE_GAZ" "HYDR_VGM"              ) ("ELAS_GONF
" "       LIQU_VAPE_GAZ" "HYDR_VGM"              ) ("CJS" "
               LIQU_VAPE_GAZ" "HYDR_VGM"              ) ("LAIGLE"
"            LIQU_VAPE_GAZ" "HYDR_VGM"              ) ("CAM_CLAY
" "       LIQU_VAPE_GAZ" "HYDR_VGM"              ) ("BARCELONE
" "       LIQU_VAPE_GAZ" "HYDR_VGM"              ) ("MAZARS"
"LIQU_VAPE_GAZ           " "HYDR_ENDO              ") ("ENDO_ISOT_BETON
" " LIQU_VAPE_GAZ" "HYDR_ENDO            ") ("ELAS"

"            LIQU_AD_GAZ_VAPE" "HYDR_UTIL           ") ("ELAS_GONF
" "       LIQU_AD_GAZ_VAPE" "HYDR_UTIL           ") ("CJS" "
```

```
            LIQU_AD_GAZ_VAPE" "HYDR_UTIL             ") ("HUJEUX"
"        LIQU_AD_GAZ_VAPE" "HYDR_UTIL             ") ("LAIGLE"
"        LIQU_AD_GAZ_VAPE" "HYDR_UTIL             ") ("CAM_CLAY
" "     LIQU_AD_GAZ_VAPE" "HYDR_UTIL             ") ("BARCELONE
" "     LIQU_AD_GAZ_VAPE" "HYDR_UTIL             ") ("ELAS"
"        LIQU_AD_GAZ_VAPE" "HYDR_VGM"              ) ("ELAS_GONF
" "     LIQU_AD_GAZ_VAPE" "HYDR_VGM"              ) ("CJS" "
            LIQU_AD_GAZ_VAPE" "HYDR_VGM"              ) ("LAIGLE"
"        LIQU_AD_GAZ_VAPE" "HYDR_VGM"              ) ("CAM_CLAY
" "     LIQU_AD_GAZ_VAPE" "HYDR_VGM"              ) ("BARCELONE
" "     LIQU_AD_GAZ_VAPE" "HYDR_VGM"              ) ("MAZARS"
"LIQU_AD_GAZ_VAPE            " "HYDR_ENDO            ") ("ENDO_ISOT_BETON
" " LIQU_AD_GAZ_VAPE" "HYDR_ENDO            ") ("ELAS"


"LIQU_AD_GAZ           " "HYDR_UTIL            ") ("ELAS_GONF
" "LIQU_AD_GAZ         " "HYDR_UTIL            ") ("CJS" "
LIQU_AD_GAZ              " "HYDR_UTIL            ") ("HUJEUX"
"LIQU_AD_GAZ           " "HYDR_UTIL            ") ("LAIGLE"
"LIQU_AD_GAZ           " "HYDR_UTIL            ") ("CAM_CLAY
" "LIQU_AD_GAZ         " "HYDR_UTIL            ") ("BARCELONE
" "LIQU_AD_GAZ         " "HYDR_UTIL            ") ("ELAS"
"LIQU_AD_GAZ           " "HYDR_VGM"             ) ("ELAS_GONF
" "LIQU_AD_GAZ         " "HYDR_VGM"             ) ("CJS" "
LIQU_AD_GAZ              " "HYDR_VGM"             ) ("LAIGLE"
"LIQU_AD_GAZ           " "HYDR_VGM"             ) ("CAM_CLAY
" "LIQU_AD_GAZ         " "HYDR_VGM"             ) ("BARCELONE
" "LIQU_AD_GAZ         " "HYDR_VGM"             ) ("MAZARS"
"LIQU_AD_GAZ           " "HYDR_ENDO            ") ("ENDO_ISOT_BETON
" "LIQU_AD_GAZ   " "HYDR_ENDO           ") For relation
```

KIT_THH and the KIT_HH: ("LIQU_GAZ

```
" "HYDR_UTIL        ") ("LIQU_VAPE_GAZ
" "HYDR_UTIL    ") ("LIQU_AD_GAZ_VAPE
" "HYDR_UTIL ") ("LIQU_AD_GAZ
" "HYDR_UTIL    ") ("LIQU_GAZ
" "HYDR_VGM"        ) ("LIQU_VAPE_GAZ
" "HYDR_VGM"    ) ("LIQU_AD_GAZ_VAPE
" "HYDR_VGM" ) For relation
```

KIT_THV: ("LIQU_VAPE

```
" "HYDR_UTIL        ") Note:
```

In the event of problem

of convergence it can be very useful to activate the linear search as indicated in the example set at the top of this section. The linear search does not improve however systematically convergence, it is thus to handle with precaution. Example: COMP_INCR

```
=_F (RELATION    =
   "KIT_THM      ", RELATION_KIT
   = ("LIQU_SATU    ", "CJS", "HYDR_UTIL")) In this example
```

, one deals in a coupled way with a problem thermo-hydro-mechanics for a saturated porous environment, LIQU_SATU as behavior of the fluid, CJS like structural mechanics behavior . Other

examples are available, either in the document [U2.04.05], or in all the tests WTNAxxx, WTNLxxx , WTNPxxx, WTNVxxx. Operand

4.5 DEFORMATION under COMP_INCR ◊ DEFORMATION

: **This key word**

makes it possible to define the assumptions of used for the computation of the strains: by default, one considers small displacements and small strains. DEFORMATION

4.5.1 : "PETIT" the strains

used in the behavior model are the linearized strains: That means

$$\varepsilon_{ij}=\frac{1}{2}(u_{i,j}+u_{j,i})$$

that one remains in Assumption of the Small Disturbances: small displacements, small rotations, small strains (lower than approximately 5%) DEFORMATION

4.5.2 : "GROT_GDEP" Makes it possible to treat

large rotations and the large displacements, but while remaining in small strains, in a specific way according to the modelizations: for all

- the constitutive laws under COMP_INCR provided with the modelizations 3D, D_PLAN , AXIS and C_PLAN , the strains used in the behavior model are the strains of GREEN-LAGRANGE : [R5.03.22] $E_{ij}=\frac{1}{2}(u_{i,j}+u_{j,i}+u_{k,i}.u_{k,j})$ to treat
- large rotations and the small strains for all the incremental constitutive laws under COMP_INCR provided with modelizations COQUE_3D (GREEN_GR in the past). It is a total Lagrangian formulation, making it possible to calculate the exact configuration for large rotations [R3,07,05]. Caution:

It

> *is strongly disadvised using the linear search for the COQUE_3D with option GROT_GDEP (sometimes convergence is impossible and if one converges, computation needs more than iterations of Newton). to treat*

- large displacements and large rotations and the small strains for the shell elements and shells: modelizations DKT (only in linear elasticity), DKTG (only with behaviors GLRC_*) and SHB. to treat
- large displacements and large rotations and the small strains for modelizations POU_D_TGM and POU_D_EM (multifibre beams) (in the past REAC_GEOM). One makes the assumption of a reactualization of the geometry has each iteration and one adds the geometrical stiffness has the material stiffness to form the tangent stiffness. With regard to large rotations, instead of passing by an "exact" approach complexes as for the POU_D_T_GD and COQUE_3D , one authorizes moderate rotations (of the second order). This kind of computation of the strains makes it possible to treat with effectiveness of the multifibre problems of beams nonlinear behavior, in moderate rotations [R3.08.09]. Note:

for the behaviors

- hyper elastics (such ELAS_HYPER) , this option also allows computation in large deformations. DEFORMATION

4.5.3 : "PETIT_REAC" the increments

of strains used for the behavior model incremental are the linearized strains of the displacement increment in the reactualized geometry. I.e. if $X, u, \Delta u$ the position, the displacement and the displacement increment indicate respectively calculated with a given iteration of a material point [R5.03.24]. The equilibrium

$$\Delta \epsilon_{ij}=\frac{1}{2}\left(\frac{\partial \Delta u_i}{\partial (X+u)_j}+\frac{\partial \Delta u_j}{\partial (X+u)_i}\right)$$

is thus solved on the current geometry but the behavior remains writes under the assumption of the small strains. Consequently, the use of PETIT_REAC is thus not appropriate to large rotations but it is it with the large deformations, under certain conditions [10]: very small

- increments, very small
- rotations (what implies a quasi-radial loading) elastic strain
- small in front of plastic strains, isotropic
- behavior. Apart from

these assumptions, this approximation can give very bad results. It is thus advisable to check the convergence of the results compared to the discretization. Caution:

It is disadvised

using this option with the structural elements COQUE, COQUE _1D and LOUSE (an alarm message appears in the file .mess). DEFORMATION

4.5.4 : "SIMO_MIEHE" It is a formulation

incrémentalement objective in large deformations of the constitutive laws leaning on a criterion of Von Mises with isotropic hardening. The relation stress-strains elastic is hyper elastic. All information on the gradient of the transformation is taken into F account, as well rotation as the strains: That makes it possible

$$F_{ij}=\delta_{ij}+\frac{\partial u_i}{\partial x_j}$$

to carry out computations in plastic large deformations, with behavior models "VMIS_ISOT_LINE", "VMIS_ISOT_TRAC", "ROUSSELIER " and all the behaviors, with isotropic hardening only, associated with an undergoing material of the metallurgical phase changes (relations META_X_IL_XXX _XXX and META_X_ INL_ XXX_XXX,). This formulation

automatically adds to the selected behavior 6 local variables, storing the 6 components of the tensor (cf [R5.03 $\frac{1}{2}\left(\boldsymbol{I}_d-\boldsymbol{b}^e\right)$ .21]). Caution:

This option

is valid only for the modelizations 3D, 2D, INCO _ GD (not of plane stress with the method OF BORST). For further information on the formulation of the plastic large deformations according to SIMO and MIEHE, one will be able to refer to [R5.03.21]. In large deformations

of the type "SIMO_MIEHE", the tangent matrixes are not symmetric except for case (hyper) - elastic. To version 7.4, one proceeded to a systematic symmetrization of the matrix. Henceforth, it is the asymmetric matrix which is provided. If it wishes it, the user can nevertheless ask to symmetrize it under the key word solver = _F (SYME = "OUI'). Caution: SYME = "OUI' is not the default. The resolutions will thus take a priori more time with this new version if have it does not do anything with regard to the command file. On the other hand the asymmetric tangent matrix will allow a better convergence. DEFORMATION

4.5.5 : "GDEF_HYPO_ELAS" It is a hypoelastic

formulation incrémentalement objective in large deformations exit of an approach due to Simo and Hughes. It is based on the notion of a turned configuration objectifies in which the derivatives are carried out. This generic approach makes it possible to treat the constitutive laws with hardenings isotropic and kinematical, with or without viscosity, with formulation of a hypoelastic type: hardenings

- isotropic: VMIS_ISOT_LINE , VMIS_ISOT_TRAC, VMIS_ISOT_PUIS, kinematic hardening

- : VMIS_CINE_LINE , VMIS_CIN2_MEMO, VMIS_ECMI_LINE, VMIS_ECMI_TRAC, VMIS_CIN1_CHAB, VMIS_CIN2_CHAB, viscoplasticity
- : LEMAITRE, VENDOCHAB , VISC_CIN1_CHAB, VISC_CIN2_CHAB VISC_CIN2_MEMO. This formulation

is valid only for the modelizations 3D, 2D. It allows an integration incrémentalement objectifies constitutive laws like SIMO_MIEHE the model. However, like all the hypoelastic models, these constitutive laws in any rigor are limited to the weak elastic strain; moreover, the model suffers at present from some difficulties of robustness (related to the tangent operator) and asks a rather important computing time (compared to formalism SIMO-MIEHE). DEFORMATION

4.5.6 : "GDEF_LOG" It is a formulation

in large deformations using a logarithmic curve strain measurement, resulting from an approach due to Miehe, Call, Lambrecht. It makes it possible to use following incremental elastoplastic constitutive laws (cf [R5.03.24]): hardenings

- isotropic: VMIS_ISOT_LINE , VMIS_ISOT_TRAC, VMIS_ISOT_PUIS, VMIS_JOHN_COOK , kinematic hardening
- : VMIS_CINE_LINE , VMIS_CIN2_MEMO, VMIS_ECMI_LINE, VMIS_ECMI_TRAC, VMIS_CIN1_CHAB, VMIS_CIN2_CHAB This formulation

is valid only for the modelizations 3D, 2D. It allows an integration incrémentalement objectifies constitutive laws like models SIMO_MIEHE and GEDF_HYPO _ELAS . However, like all the hypoelastic models, these constitutive laws in any rigor are limited to the weak elastic strain. To save computing time, a specific tensor is stored in 6 additional local variables. Operands

4.6 TOUT/GROUP_ MA/MAILLE under COMP_INCR ◊ /TOUT = '

OUI' / | GROUP_MA=
lgrma |MAILLE=lma
Specify

meshes on which the incremental behavior model is used. Operands

4.7 RESI_CPLAN_ RELA, RESI_CPLAN_MAXI, ITER_CPLAN_MAXI the method

of BORST makes it possible to add the plane constraint to all the models of COMP_INCR (for more detail to see documentation [R5.03.03]). The assumption of the plane stresses is checked with convergence. One recommends to rather often reactualize the tangent matrix in the method of Newton (MATRICE = "TANGENT" REAC_ITER = 1 to 3). ◊ /RESI_

CPLAN _RELA =/1.E-6, [DEFAULT]// RESI_CPLAN
ε_{rela}
_MAXI = In certain ε_{abso}

cases, convergence is reached for the algorithm of Newton, but not for the checking of the stress state plane, which leads to additional iterations, even an excessive recutting of time step. These keywords make it possible to dissociate the accuracy relating to the integration of the constitutive law of that used to check the assumption of the plane stresses. For this checking, two criteria are possible: that is to say a relative

- criterion: that is to say an absolute $|\sigma_{zz}|<\|\sigma\|\times\varepsilon_{rela}$
- criterion: ◊ ITER_CPLAN $|\sigma_{zz}|<\varepsilon_{abso}$

_ MAXI =/1 [DEFAULT] /iter_cplan
_maxi This key word

makes it possible to improve the accuracy of the algorithm of BORST: It activates an additional loop on the level of the behavior of each point of integration, in order to better satisfy the plane stresses in the course of the total iterations with Newton. The value by default ITER_CPLAN_ MAXI=1 corresponds exactly to the initial version of the method. On certain tests (SSNV102B, SSNS106F, SSNS108A), ITER_CPLAN_MAXI > 1 makes it possible systematically to decrease the nombre of iterations necessary for the total process of Newton. In the studies realized, with damage, the robustness of computation was clearly improved. The method

of BORST described above was generalized with the case of the behaviors 1D (used by the modelizations BARS, GRILL , GRILLE_MEMBRANE, POU_D_EM, POU_D_TGM). This makes it possible to add the uniaxial constraint to all the models of COMP_INCR (for more detail to see documentation [R5.03.09]). The assumption of the uniaxial stresses is checked with convergence. One recommends to rather often use and reactualize the tangent matrix in the method of Newton (MATRICE = "TANGENT" REAC_ITER = 1 to 3). Operand

4.8 PARM_THETA ◊PARM_THETA

```
=/1. [DEFAULT    ]    /theta                       For
                     the modelizations
```

THM, the argument theta is the parameter of the theta-method used to solve the evolutionary equations of thermal and hydraulics (see [R5.03.60] for more details). Its value must be ranging between 0 (explicit method) and 1 (completely implicit method). For constitutive laws

LEMAITRE, ROUSS_VISC, the argument theta is used for integration of the constitutive law. It can 0.5 take the values (semi-implicit) or 1 (implicit). Operands

4.9 RESI_INTE_RELA /ITER_INTE_MAXI ◊RESI_INTE

```
_RELA   =/1.E-6 [DEFAULT      ] /resint     ◊
                    ITER_INTE_MAXI
   =/20 [DEFAULT]       /iteint          In
                       certain
```

behavior models, a nonlinear equation or a nonlinear system must be solved locally (in each Gauss point). These operands (residue and maximum number of iterations known as internal) are used to test the convergence of this iterative algorithm of resolution. They are useless if ALGO_INTE=' ANALYTIQUE', "SPECIFIQUE " or "SANS_OBJET ". FOR MORE details, to refer to the documentation of reference of each behavior. Operand

4.10 RESI_RADI_RELA ◊ RESI_RADI

```
_RELA  = tolrad Measurement    of
```

the error due to the discretization η in time, directly connected to the rotation of the norm on the surface of load. One calculates the angle enters, the norm $\boldsymbol{n}^-$ with the plasticity criterion at the beginning of time step (urgent T), and, the norm $\boldsymbol{n}^+$ with the plasticity criterion calculated at the end of time step in the following way: . That provides $\eta=\frac{1}{2}\|\Delta\boldsymbol{n}\|=\frac{1}{2}\|\boldsymbol{n}^+-\boldsymbol{n}^-\|=\left|\sin\left(\frac{\alpha}{2}\right)\right|$ a measurement of the error (also used for the computation of component ERR_RADI of option DERA_ELGA of CALC_CHAMP) . Time step is cut out (via DEFI_LIST_INST) if. This criterion $\eta>\text{tolrad}$ is operational for the behaviors élastoplastiqus of Von Mises with hardening isotropic, kinematical linear and mixed: VMIS_ISOT_LINE , VMIS_ISOT_TRAC, VMIS_ISOT_PUIS, VMIS_CINE_LINE, VMIS_ECMI_LINE, VMIS_ECMI_TRAC, and for the behaviors élasto-visco-plastics of Chaboche: VMIS_CIN1_CHAB , VMIS_CIN2_CHAB, VMIS_CIN2_MEMO, VISC_CIN1_CHAB, VISC_CIN2_CHAB, VISC_CIN2_MEMO. Operand

4.11 ITER_INTE_PAS , ALGO_INTE ◊ITER_INTE

_PAS =/0 [DEFAULT] /itepas Allows redécouper

locally time step to facilitate the integration of the local behavior model (in each point of integration). If itepas is worth , or there 0 1 is no -1 recutting. If itepas is positive , one redécoupe systematically time step locally in the itepas small ones time step before carrying out the integration of the behavior model. If itepas is negative , recutting in |itepas| small time step is carried out only in the event of nonlocal convergence. ◊ ALGO_INTE

```
=   /"ANALYTIQUE " # methods
       of solution of scalar equations/" SECANTE
           "/ " DEKKER "
           /" NEWTON _1
           Of /" BRENT "
           # methods
       of resolution of systems of equations/" NEWTON "
           /" NEWTON_RELI
           "/" NEWTON_PERT
           "/" RUNGE_KUTTA
           "# SPECIFIC
       methods of resolution (not of parameter)/" SPECIFIQUE
           "/" SANS_OBJET
           "MAKES IT POSSIBLE to specify
```

the type of diagram of integration to solve the nonlinear equation or the system of equations formed by the constitutive equations of the models of behavior to local variables: A method of by default resolution is planned for each behavior. However, it is possible to modify the method of by default resolution for a certain number of behaviors. For example: the model

- VISC_ENDO_LEMA can be integrated either with SECANTE, or with BRENT, the model
- VENDOCHAB can be integrated or with NEWTON, or WITH RUNGE_KUTTA . the model
- MONOCRISTAL can be integrated either with NEWTON, or WITH NEWTON_RELI , OR WITH NEWTON_PERT , OR WITH RUNGE_KUTTA . Operand

4.12 TYPE_MATR_TANG ◊ TYPE_MATR_TANG

```
=/"PERTURBATION ",/"VERIFICATION
                 ", ◊ VALE_PERT_RELA
                          = 1.E-5, [DEFAULT  ]/perturb , [
                                          R] This key word
```

allows the checking of the tangent matrix for a given behavior. He addresses mainly to the developers constitutive laws, and its use must be held with models comprising very few elements. In the absence of this key word, the tangent matrix is calculated in a classical way. (These key words are used jointly with REAC_ITER=1). TYPE_MATR_TANG

- = " PERTURBATION" makes it possible to use the tangent matrix calculated by disturbance instead of the tangent matrix calculated by the behavior. The value of the disturbance is given by perturb. So that can function independently of the units, the disturbance is calculated in a way relating to the norm max of the increase in displacement on the element: . This is possible only if $\delta U = perturb \times max|U_i|$ for the modelizations of continuums 2D and 3D, in pure mechanics, comprising only degrees of freedom of displacement. TYPE_MATR_TANG
- = " VERIFICATION" relates to the developers which want problem: to check an elementary tangent matrix (on small an element is enough: only the last matrixes are preserved). The matrix by disturbance is stored, as well as the coherent matrix tangent, which makes it possible to compare them . Moreover the modulus python veri_matr_tang allows

this comparison in an easy way, as well as the test of symmetry of the matrix. See tests COMP001, COMP 002. ◊ TYPE_MATR_TANG

= "T ANGENTE_ SECANTE " ◊ SEUIL =
/3 , [DEFAULT] / threshold , [R]
◊ AMPLITUDE
= /1.5 [DEFAULT] /amplitude
, [R] ◊ TAUX_RETOUR
= 0.05 [DEFAULT]/taux_retour
[R] Makes it possible to modify

the tangent matrix in an evolutionary way while being based on the linear combination between the tangent operator and the secant operator. [R5.03.01]. SEUIL; threshold

- of activation in term of alternation observed during iterations of Newton between an elastic state and a state damages. Recommendation: . AMPLITUDE ≥ 3 :
- amplitude of modification. Recommendation: enter and. TAUX_RETOUR 1.3 1.5
- : rate of return towards the tangent matrix if one remains damaged. Recommendation: enter and (default 0.05 =) 0.1 One increases 0.05

by 1 (one) the number of local variables to be able to follow the evolution of the elastic states/damage. In version 9, the only constitutive law taking into account method "TANGENTE_SECANTE " is ENDO_ISOT_BETON . Operand

4.13 POST_ITER ◊ POST_ITER

= /"CRIT_RUPT ", Definition

of an action to be carried out in postprocessing of the iterations of Newton, with each time step. In case

CRIT_RUPT, it is about a rupture criterion in critical stress . If the greatest average principal stress in an element exceeds a threshold given sigc, the Young modulus is divided with time step according to by the coefficient coeff. These two coefficients are defined under key word CRIT_RUPT of operator DEFI_MATERIAU [U4.43.01]. This criterion

available for constitutive laws VISCOCHAB, VMIS_ISOT_TRAC (_LINE), VISC_ISOT_TRAC (_LINE), and is validated by tests SSNV226A, B, C. Key word COMP_ELAS

5 This key word

factor gathers elastic behavior models the "linear and nonlinear ", C" is to be said connecting the strains (compared to the reference configuration) and the forced (elastic behavior). One can incremental behaviors have in same computation certain parts of structure obeying various (COMP_INCR) and other parts obeying with various elastic behaviors (COMP_ELAS). Operand

5.1 RELATION under COMP_ELAS " ELAS" elastic

5.1.1

Behavior model "linear", i.e. the relation between the strains and the forced considered is linear. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys ELAS or ELAS_FO , ELAS_ORTH or ELAS_ORTH_FO and ELAS_ISTR or ELAS_ISTR_FO (confer [R4.01 .02]). It is the behavior model by default for the elastic behaviors. Supported

- modelizations: 3D, 2D, CONT _PLAN , POU_D_T_GD, CABLE, CABLE_POULIE COQUE_3D (with DEFORMATION = "GROT_GDEP"). Example: to see
- test SSLS120. "ELAS_HYPER

5.1.2 " linear

Behavior model hyper - elastic "not -", i.e. that the relation between the stresses is the derivative of a potential very-elastic compared to the strains of Green. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01] , under key keys ELAS_HYPER. This relation is supported only in large displacements, rotations and strains (DEFORMATION=' GROT_GDEP'). Supported

- modelizations: 3D, D_PLAN, C_PLAN Example: to see
- test SSNV187 "ELAS_VMIS_LINE

5.1.3 " elastic

Behavior model "nonlinear" (model of HENCKY) of Von Mises with linear isotropic hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys VMIS_ISOT_LINE and ELAS (confer [R7.02 .03] for more details). Supported

- modelizations: 3D, 2D, C_PLAN . Example: to see
- test SSNP110. "ELAS_VMIS_TRAC

5.1.4 " elastic

Behavior model "nonlinear" (model of HENCKY), of Von Mises with nonlinear isotropic hardening. The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key keys VMIS_ISOT_TRAC and ELAS (confer [R7.02 .03] for more details). Supported

- modelizations: 3D, 2D and C_PLAN . Example: to see
- test SSNV108. "ELAS_VMIS_PUIS

5.1.5 " elastic

Behavior model "nonlinear" (model of HENCKY), of Von Mises with nonlinear isotropic hardening defined by a function power. The parameters are provided in operator DEFI_MATERIAU

[U4.43.01], under key word ECRO_PUIS (confer [R5.03 .02] for more details). One must also inform key word ELAS (_FO) in operator DEFI_MATERIAU . Supported

- modelizations: 3D, 2D. Example: to see
- COMP001i test. "ELAS_POUTRE_GR

5.1.6 " elastic

Behavior model for the beams in large displacements and large rotations (DEFORMATION=' GROT_GDEP' is compulsory). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word ELAS or ELAS_FO (cf [R5.03 .40] for more detail). Supported

- modelizations: POU_D_T_GD Local variables
- (without interest for the user, but necessary to operation): 3 Example: to see
- test SSNL103 "CABLE " elastic

5.1.7

Behavior model adapted to cables (DEFORMATION: Compulsory "GREEN"): the modulus of YOUNG of the cable can be different in compression and tension (in particular it can be null in compression). The data necessary of the field material are provided in operator DEFI_MATERIAU [U4.43.01], under key word CABLE (confer [R3.08 .02] for more details). Supported

- modelizations: CABLE Example : to see
- test HSNL100 Operand

5.2 DEFORMATION ◊ DEFORMATION

This key word
makes it possible to define the assumptions of used for the computation of the strains: by default, one considers small displacements and small strains. DEFORMATION

5.2.1 = ' PETIT' the strains

used in the behavior model are the linearized strains: DEFORMATION

$$\varepsilon_{ij}=\frac{1}{2}(u_{i,j}+u_{j,i})$$

5.2.2 = ' GROT_GDEP' Makes it possible to treat

large rotations and the large rotations, but while remaining in small strains, in a specific way according to the modelizations: allows to treat

- large rotations and the small strains for all the constitutive laws under COMP_INCR provided with the modelizations 3D, D_PLAN , AXIS and C_PLAN . The strains used in the behavior model are the strains of GREEN-LAGRANGE: allows to treat

$$E_{ij}=\frac{1}{2}(u_{i,j}+u_{j,i}+u_{k,i}.u_{k,j})$$

- large rotations and the small strains for all the constitutive laws under COMP_INCR provided with modelizations COQUE_3D, POU_D_T_GD . Caution:

For the shells

(modelization COQUE_3D), it is strongly disadvised using the linear search with option GROT_GDEP (convergence can be difficult). Note:

This key word
•replaces GREEN and GREEN_GR from version 10.1.1 for the behaviors
•hyper elastics (such ELAS_HYPER) , this option also allows computation in large deformations. Operands

5.3 TOUT/GROUP_MA /MESH under COMP_ELAS ◊ /TOUT = '

OUI' /| GROUP_MA=
lgrma |MAILLE=lma
Specify

meshes on which the elastic behavior model is used. Operands

5.4 RESI_INTE_RELA /ITER_INTE_MAXI under COMP_ELAS ◊ RESI_INTE_RELA

=/1.E-6 [DEFAULT] /resint ◊
ITER_INTE_MAXI
=/10 [DEFAULT] /iteint In
the nonlinear

elastic behavior models (ELAS_VMIS_LINE, ELAS_VMIS_TRAC in plane stresses , and ELAS_HYPER), an iterative algorithm is used. These operands (residue and maximum number of iterations known as internal) are used to test the convergence of this iterative algorithm of resolution. For more details, to refer to documentation of reference. These operands are useless with **behavior** ELAS, and ELAS_VMIS_LINE , ELAS_VMIS_TRAC except plane stresses . Operands

5.5 PARM_ALPHA ◊ PARM_ALPHA

=/1. [DEFAULT] Useful only

for the modelizations finished volumes (of type D_PLAN_HH2SUC , D_PLAN_HH2SUDA, D_PLAN_HH2SUDM, 3D_HH2SUC, 3D_HH2SUDA and 3D_HH2SUDM). Numerical parameter of finished volumes allowing to control the coercity of the diagram (1: value recommended).