

Nonlinear behaviors

1 Goal

This document describes the nonlinear behaviors introduced via the keyword `BEHAVIOR` in the operators of nonlinear calculation: `STAT_NON_LINE`, `DYNA_NON_LINE`, `SIMU_POINT_MAT`, `CALCULATION`

For each behavior are specified the scopes of application, the keywords defining the parameters material, the contents of the internal variables and supported modelings.

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2 Syntax

```

♦ | BEHAVIOR = _F (
♦ RELATION = / 'ELAS', [DEFECT]
              / incremental relations described in this document
♦ RELATION_KIT= / relations kit described in this document
♦ DEFORMATION = / 'SMALL', [DEFECT]
                / 'PETIT_REAC',
                / 'SIMO_MIEHE',
                / 'GROT_GDEP',
                / 'GDEF_LOG'

♦ / ALL = 'YES', [DEFECT]
  / | GROUP_MA= lgrma, [l_gr_maille]
    | MESH = lma, [l_maille]

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

♦ PARM_THETA = / 1. , [DEFECT]
              / theta, [R]
♦ RIGI_GEOM = / 'DEFECT' , [DEFECT]
              / ' YES ' ,

♦ RESI_INTE_RELA = / 1.E-6, [DEFECT]
                  / resint, [R]
♦ RESI_INTE_MAXI = / 1.E-8, [DEFECT]
                  / resintmax, [R]
♦ ITER_INTE_MAXI = / 10, [DEFECT]
                  / iteint, [I]
♦ ITER_INTE_PAS = / 0, [DEFECT]
                  / itepas, [I]
♦ ALGO_INTE = / 'ANALYTICAL', [DEFECT]
              / 'SECANT',
              / 'DEKKER',
              / 'NEWTON_1D',
              / 'BRENT',
              / 'NEWTON', / 'NEWTON_RELI', / 'NEWTON_PERT',
              / 'RUNGE_KUTTA',
              / 'SPECIFIC'
              / 'SANS_OBJET'

♦ TYPE_MATR_TANG= / 'DISTURBANCE',
                  / 'CHECKING',
                  ♦ VALE_PERT_RELA = / 1.E-5, [DEFECT]
                                      / perturb, [R]
),

```

3 Conventions of notation

3.1 Nomenclature of modelings

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

Modeling 3D	= modelings 3D, 3D_SI
Modeling INCO_UPG	= modelings 3D_INCO_UPG, AXIS_INCO_UPG and D_PLAN_INCO_UPG
Modeling INCO_UP	= modelings 3D_INCO_UP, AXIS_INCO_UP D_PLAN_INCO_UP
Modeling D_PLAN	= modelings D_PLAN and D_PLAN_SI
Modeling AXIS	= modelings AXIS and AXIS_SI
Modeling 2D	= modelings D_PLAN, D_PLAN_SI, AXIS, AXIS_SI
Modeling C_PLAN	= modelings C_PLAN and C_PLAN_SI
Modeling HULL	= modelings COQUE_3D and DKT
Modeling PIPE	= modelings TUYAU_3M and TUYAU_6M
Modeling COQUE1D	= modelings COQUE_AXIS
Modeling CONT_PLAN	= modelings C_PLAN and HULL and PIPE and COQUE1D
Modeling 3D_DIS	= modelings DIS_T and DIS_TR
Modeling 2D_DIS	= modelings 2D_DIS_T and 2D_DIS_TR
Modeling DISCRETE	= modelings 3D_DIS and 2D_DIS
Modeling LOUSE	= modelings POU_D_E, POU_D_T, POU_D_TG
Modeling GRID	= modelings GRID and GRILLE_MEMBRANE
Modeling PMF	= modelings POU_D_EM and POU_D_TGM
Modeling BAR	= modelings BAR and 2D_BARRE
Modeling CONT_1D	= modelings BAR and GRID
Modeling CONT_1D (PMF)	= modelings CONT_1D for PMF (direct integration).
Modeling THM	= modelings thermo_hydro_mecanic
Modeling GRAD_VARI	= modelings 3D_GRAD_VARI, D_PLAN_GRAD_VARI, and AXIS_GRAD_VARI
Modeling JOINT	= PLAN_JOINT, AXIS_JOINT

3.2 Internal variables

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

To select the right number of variable interns (V1, V2, V3, etc) is not very practical with use and becomes very difficult when several behaviors are mixed. Therefore certain orders make it possible to use their version named using the keyword NOM_VARI : CALC_CHAMP, CREA_TABLE, IMPR_RESU, POST_CHAMP, POST_ELEM, RECU_FONCTION and TEST_RESU.

Moreover, during the impression of a result to format MED (IMPR_RESU), a named field (VARI_ELGA_NOMME) is also produced and allows to display these internal variables easily.

Notices :

- named internal variable "indicating of plasticity" indicate that there was plasticity created during the step of calculation and at the point of current Gauss and not during all the transient;
- Laws of behavior (keyword RELATION) are not the only parameters which create internal variables. The choice of the deformation (keyword DEFORMATION=' SIMO_MIEHE' for example), but also the keyword POST_ITER and the use of the algorithm of Borst use also internal variables.

- The use of external software (UMAT and MFront) to program laws of behavior does not make it possible to use the naming of the internal variables. Nevertheless, for the laws of MFront behavior officially integrated in code_aster, this naming is usable.
- Laws of behavior of the polycrystalline type do not name either their internal variables.
- Laws of behavior of the metallurgical type (`META_*`) have a specific system of naming, explained in appendix.

4 Keyword BEHAVIOR

This keyword factor makes it possible to define the relations of behavior.

Most laws of behavior (in particular in plasticity) are written in an incremental way, because the history of material influences its behavior; if it is not the case one deals with behavior rubber bands, linear or not. One can have in same calculation certain parts of the structure obeying incrémentaux behaviors, and other parts obeying with various elastic behaviors.

It is the behavior which determines (via its catalogue) the type of integration used. For example, behaviors `CABLE`, `ELAS_HYPER`, `ELAS_POUTRE_GR`, `ELAS_VMIS_LINE`, `ELAS_VMIS_TRAC`, `ELAS_VMIS_PUIS` are integrated in an elastic way (nonlinear) and not incremental. With regard to the behavior `ELAS`, the two types of integration are possible

For the precise significance of these various relations one will refer to the various reference materials like to the documentation of `DEFI_MATERIAU` [U4.43.01].

4.1 Modeling of the plane constraints by the method of Borst

Certain models of behaviors were not developed in plane constraints. In this case, the algorithm automatically is used of Borst [R5.03.03] who allows a taking into account of the assumption of the plane constraints the level of the algorithm of balance (contrary to the models of behavior developed explicitly in plane constraints, which adopt this approach on the level of the integration of the laws of behavior). One can thus also assign an unspecified nonlinear law to the elements of structure `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 state of stresses (`POU_D_EM`, `POU_D_TGM`, `GRID`, `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].

Method of Borst is available neither for the metallurgical behaviors nor with `DEFORMATION = 'SIMO_MIEHE'`.

When one uses MFront, the mode De Borst is started automatically if the law were not written in plane constraints. SI MFront is used in "prototype" mode (keyword `RELATION='MFRONT'`), it is to the user to choose the operating process (native plane constraints in MFront or by algorithm of Borst).

4.2 Local and nonlocal modeling

In the case of lenitive behaviors, the answer of a model of local behavior with damage is dependent on the grid. 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 additional material, the characteristic length. For certain models, it is defined under the keyword factor `NON_LOCAL` of the operator `DEFI_MATERIAU`.

The answer of a nonlocal modeling is more independent of the grid. There exists three types of laws in nonroom, activables in `AFFE_MODELE` by the keyword `MODELING` :

- `'3D_GRAD_VARI'`, `'D_PLAN_GRAD_VARI'` or `'AXIS_GRAD_VARI'`. They are nonlocal laws here where the gradient of the internal variables of the local model intervenes (confer [R5.04.01]).
- `'3D_GVNO'`, `'D_PLAN_GVNO'`, or `'AXIS_GVNO'`. It acts, like the preceding type, of nonlocal laws where the gradient of damage intervenes. The treatment of the damage is from now on nodal, like degree of freedom of the total system and either like variable interns local model (confer [R5.04.04]).

- 'D_PLAN_2DG', 'D_PLAN_DIL' in complement models it to regularize (confer [R5.04.03]). It is about a model regularized by a microstructural approach where either the field of deformation intervenes or the voluminal deformation.

4.3 Laws of behavior and variables of orders

For recall, the model can comprise one or more variables of order (temperature, drying, irradiation, metallurgical phase...), of which the field is affected on the meshes of the grid via the keyword `AFFE_VARC` order `AFFE_MATERIAU` (cf [U4.43.03]).

A variable of order can to impact the properties materials, which are then function.

In certain cases, they can moreover to generate a deformation. C'is the case of the variables of following orderS : the temperature 'TEMP', drying 'SECH' (one speaks then about deformation of withdrawal of desiccation), the hydration 'HYDR' (endogenous deformation of withdrawal) and unelastic deformations 'EPSAXX', 'EPSAYY', 'EPSAZZ', 'EPSAXY', 'EPSAXZ', 'EPSAXZ'. These deformations are often called "thermal deformations" by abuse language.

According to the way in which the law of behavior was developed, these deformations due to the variables of order are takings into account thanks to a generic mechanism. For other laws, they are taken into specific account of manner.

Currently, the generic mechanism of code_aster covers the following perimeter:

- calculation and taking into account of the thermal deformation with a thermal dilation coefficient `ALPHA` isotropic/anisotropic/transverse isotropic, and différenciable according to the metallurgical phase in the isotropic case;
- calculation and taking into account of the withdrawal of desiccation and the endogenous withdrawal if the parameters material controlling them, `K_DESSIC` and `B_ENDOGE`, are isotropic;
- psmall channel in account of the deformations hasnelastic.

This generic mechanism is available only for measurements of deformation of type small deformations (very except 'SIMO_MIEHE', i.e. 'SMALL', 'PETIT_REAC', 'GDEF_LOG' and in theory 'GROT_GDEP' cf. §4.6 – however it is not available for this last kinematics). That means for example that variable of order like the temperature can not to be used at the same time as a kinematics 'SIMO_MIEHE' or 'GROT_GDEP' with the generic mechanism.

It will be noted that the laws of the MFront type and UMAT follow the generic mechanism.

4.4 Operand RELATION

4.4.1 Elastic models

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

4.4.1.1 Behavior S ELAS , ELAS_ISTR , ELAS_ORTH and ELAS_GLRC

Elastic relation of behavior " Linéaire ", i.e. the relation between the strains and the stresses considered is linear. Under certain conditions this relation becomes incremental: it then makes it possible to take into account initial displacements and constraints; the behavior `ELAS`, is thus by default nonincremental, except in the following cases:

- there exists one state initial (`ETAT_INIT` , `SIGM_INIT`)
- `SIDEFORMATION=PETIT_REAC`
- if the order is `CALCULATION` .

If need be, if these exceptions are not enough one can force an incremental elastic behavior while using `VMIS_ISOT_LINE` for example, with a high elastic limit. In the same way one can force a hyperelasticity while taking `ELAS_VMIS_LINE`, with a high elastic limit.

The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under `S` keywordS following :

- `ELAS(_FO)`, with regard to isotropic elasticity,
- `ELAS_ISTR(_FO)`, with regard to transverse isotropic elasticity,
- `ELAS_ORTH(_FO)`, with regard to orthotropic elasticity.
- `ELAS_GLRC(_FO)`, with regard to the elasticity of the elements of plates `DKTG` and `Q4GG`.

The parameters material defined under `ELAS` are used for a certain number of behaviors, and also for the calculation of the elastic matrix of rigidity (`PREDICTION='ELASTIC'` or `MATRICE='ELASTIQUE'` under the keyword `NEWTON` cf [U4.51.03]).

- Supported modelings: `3D`, `2D`, `CONT_PLAN`, `DISCRETE`, `INCO_UPG`, `INCO_UP`, `POU_*`, `CONT_1D`, `CONT_1D (PMF)`, `SHB`, `CABLE`, `CABLE_POULIE`, `COQUE_3D`, `DKTG`, `Q4GG`.
- Many internal variables: 1
- Significance: V_I : vacuum thus is worth always zero

4.4.1.2 Behavior `ELAS_HYPER`

Linear relation of behavior very - elastic "not -", it is to say that the relation between the constraints is the derivative of a potential very-rubber band compared to the deformations of Green. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `ELAS_HYPER`. This relation is supported only in great displacements, rotations and deformations (`DEFORMATION='GROT_GDEP'`).

- Supported modelings: `3D`, `D_PLAN`, `C_PLAN`
- Example: to see test `SSNV187`
- Reference material: `R5.03.19`

Note: this behavior cannot take into account the deformations of thermal origin.

4.4.1.3 Behavior `ELAS_VMIS_LINE`

"Nonlinear" relation of elastic behavior (law of Hencky) of von Mises with linear isotropic work hardening. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `ECRO_LINNATE` and `ELAS` (to see [R7.02.03] for more details of its use in breaking process).

- Supported modelings: `3D`, `2D`, `C_PLAN`
- Example: to see test `SSNP110`
- Reference material: `R5.03.20`

Note: this behavior is unusable with a state of nonworthless initial stresses. It thus should not be used in recovery.

4.4.1.4 Behavior `ELAS_VMIS_TRAC`

"Nonlinear" relation of elastic behavior (law of Hencky) of von Mises with non-linear isotropic work hardening defined by a curve of taction. The data necessary of the field material are provided in the operator `OFFI_MATERIAU` [U4.43.01], under the keywords `TRACTION` and `ELAS` (to see [R7.02.03] for more details of its use in breaking process).

- Supported modelings: `3D`, `2D` and `C_PLAN`
- Example: to see test `SSNV108`
- Reference material: `R5.03.20`

Note: this behavior is unusable with a state of nonworthless initial stresses. It thus should not be used in recovery.

4.4.1.5 Behavior `ELAS_VMIS_PUIS`

Elastic relation of behavior "nonlinear" (law of Hencky) of von Mises with non-linear isotropic work hardening defined by a function power. The parameters are provided in the operator `DEFI_MATERIAU` [U4.43.01], underS keywordS `ECRO_PUIS` and `ELAS`.

- Supported modelings: 3D, 2D
- Example: to see test `COMP001I`
- Reference material: R5.03.20

Note: this behavior is unusable with a state of nonworthless initial stresses. It thus should not be used in recovery.

4.4.1.6 Behavior `ELAS_POUTRE_GR`

Elastic relation of behavior for the beams in great displacements and great rotations (`DEFORMATION='GROT_GDEP'` is obligatory). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ELAS` or `ELAS_FO` (Cf [R5.03.40] for more detail).

- Supported modelings: `POU_D_T_GD`
- Internal variables (irrelevant for the user, but necessary to operation): 3
- Example: to see test `SSNL103`

4.4.1.7 Behavior `CABLE`

Elastic relation of behavior adapted to the cables (`DEFORMATION='GROT_GDEP'` obligatory): the module of Young cable can be different in compression and traction (in particular it can be null in compression). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `CABLE` (confer [R3.08.02] for more details).

- Supported modelings: `CABLE`
- Example: to see test `HSNL100`

4.4.1.8 Behavior `ELAS_MEMBRANE_SV`

Relation of behavior hyper-rubber band of Coming Saint Kirchhoff adapted to membranes (`DEFORMATION='GROT_GDEP'` obligatory, confer [R3.08.07] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ELAS`. This relation cannot include dependence at the temperature.

- Supported modelings: `MEMBRANE`
- Example: to see test `SSNS115`

4.4.1.9 Behavior `ELAS_MEMBRANE_NH`

Relation of behavior hyper-rubber band néo-Hookéenne adapted to membranes (`DEFORMATION='GROT_GDEP'` obligatory, confer [R3.08.07] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ELAS`. This relation cannot include dependence at the temperature.

- Supported modelings: `MEMBRANE`
- Example: to see test `SSNS115`

4.4.2 Elastoplastic models

4.4.2.1 'VMIS_ISOT_TRAC'

Relation of behavior of elastoplasticity of Von Mises with nonlinear isotropic work hardening. The curve (σ, ε) in simple traction is provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `TRACTION` (Cf [R5.03.02] for more details). One can possibly define several traction diagrams according to the temperature. One must also inform the keyword `ELAS (_FO)` in the operator `DEFI_MATERIAU`. If a traction diagram is provided, the YOUNG modulus used for the relation of behavior is that calculated starting from the first point of the traction diagram, that used for the calculation of the elastic matrix (see keyword `NEWTON` [U4.51.03]) is that given in `ELAS (_FO)`.
Example: to see test `FORMA03`.

- Supported local modelings: `3D`, `2D`, `INCO_UPG`, `INCO_UP`, `CONT_PLAN`, `CONT_1D`, `CONT_1D (PMF)`, `SHB`. Great deformations of the type `SIMO_MIEHE` are available for this behavior.
 - Many internal variables: 2
 - $V1$: cumulated plastic deformation,
 - $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic).

Example: test `SSNV501`, `SSNV156`.

4.4.2.2 'VMIS_ISOT_PUIS'

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

- Supported modelings: `3D`, `2D`, `CONT_PLAN`, `CONT_1D`, `INCO`.
 - Many internal variables: 2
 - Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic).
 - Great deformations of the type `SIMO_MIEHE` are available for this behavior.

Example: to see test `COMP002`.

4.4.2.3 'VMIS_ISOT_LINE'

Relation of behavior of elastoplasticity of Von Mises with linear isotropic work hardening. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01] under the keywords `ECRO_LINE(_FO)` and `ELAS (_FO)` (Cf [R5.03.02]).

- Supported local modelings: `3D`, `2D`, `CONT_PLAN`, `CONT_1D`, `CONT_1D (PMF)`, `INCO_UPG`, `INCO_UP`.
 - Many internal variables: 2
 - Significance (except modeling `BAR`) : $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic).

Example: to see test `SSNP156`.

Great deformations of the type `SIMO_MIEHE` are available for this behavior.

- Support the method `IMPL_EX`; in this case, the variable $V2$ represent the increment of cumulated plastic deformation divided by the increment of time (either an approximation of \dot{p}

4.4.2.4 'VMIS_JOHN_COOK'

Relation of behavior of elastoplasticity of Von Mises with nonlinear isotropic work hardening defined by the law of Johnson-Cook. The parameters are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ECRO_COOK` (Cf [R5.03.02] for more details). One must also inform the keyword `ELAS (_FO)` in the operator `DEFI_MATERIAU`.

- Supported modelings: `3D`, `2D`, `CONT_PLAN`, `CONT_1D`, `INCO_UPG`, `INCO_UP`.
 - Many internal variables: 5

- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$: unelastic increment of deformation, $V4$: increment of time, $V5$: speed of dissipation mechanical.

Example: to see test COMP002.

4.4.2.5 'VMIS_CINE_LINE'

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

- Supported modelings: 3D, 2D, INCO_UPG, INCO_UP, CONT_PLAN (method 'BORST'), CONT_1D, CONT_1D (PMF)
- Many internal variables: 7
- Significance: $V1$ with $V6$: 6 components of the kinematic tensor of work hardening X , $V7$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic).
- Many internal variables for modelings BAR, PMF : 2
- Example: to see test SSNP14.
- For modelings BAR and PMF, the behavior is then 1D: 2 internal 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 worthless.

4.4.2.6 'VMIS_ECMI_TRAC'

Relation of behavior of elastoplasticity of Von Mises with combined, kinematic work hardening linear and isotropic nonlinear (cf [R5.03.16] for more details). Isotropic work hardening is given by a traction diagram (σ, ε) or possibly by several curves if those depend on the temperature. The characteristics of material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `PRAGER (_FO)` (for kinematic work hardening), `TRACTION` (for isotropic work hardening) and `ELAS(_FO)`.

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

4.4.2.7 'VMIS_ECMI_LINE'

Relation of behavior of elastoplasticity of Von Mises with combined, kinematic work hardening linear and isotropic linear (confer [R5.03.16] for more details). The characteristics of material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `PRAGER (_FO)` (for kinematic work hardening), `ECRO_LINE(_FO)` (for isotropic work hardening) and `ELAS (_FO)`.

- Supported modelings: 3D, 2D, INCO_UPG, INCO_UP, CONT_PLAN, CONT_1D (by BORST), CONT_1D (PMF).
- Many internal variables: 8
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic), $V3$ with $V8$: 6 components of the kinematic tensor of work hardening α .
- Example: to see test SSNP102

4.4.2.8 'VMIS_CIN1_CHAB'

Relation of behavior which gives an account of the cyclic behavior of material in elastoplasticity with a tensor of kinematic work hardening nonlinear, a nonlinear isotropic work hardening, an effect of work

hardening on the tensorial variable of recall. All the constants of material can possibly depend on the temperature. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `CIN1_CHAB (_FO)`, `ELAS (_FO)` (confer [R5.03.04] for more details).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by BORST), `CONT_1D` (by BORST).
- Many internal variables: 8
- $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the kinematic tensor of work hardening α .

4.4.2.9 ' VMIS_CIN2_CHAB '

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

- Supported modelings: 3D, 2D, `CONT_PLAN` (by BORST), `CONT_1D` (by BORST).
- Many internal variables: 14
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 .
- Example: to see test `SSNV101A`

4.4.2.10 ' VMIS_CIN2_MEMO '

Elastoplastic relation of behavior of J.L.Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall and an effect of memory of greatest work hardening. All the constants of material can possibly depend on the temperature. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `CIN2_CHAB (_FO)`, `ELAS (_FO)`, `MEMO_ECRO (_FO)` (Cf [R5.03.04] for more details).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by BORST), `CONT_1D` (by BORST).
- Many internal variables: 28
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 , $V15$: Function of work hardening $R(p)$, $V16$: relative variable in memory of work hardening q , $V17$ with $V22$: 6 components of the relative tensor in memory of work hardening ξ , $V23$ with $V28$: 6 components of the tensor plastic deformation.
- Example: to see test `SSND105`, `COMP002H`

4.4.2.11 ' VMIS_CIN2_NRAD '

Elastoplastic relation of behavior of Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall, and an effect of nonproportionality of the loading. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `CIN2_CHAB (_FO)`, `ELAS (_FO)`, `CIN2_NRAD` (confer [R5.03.04] for more details).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by BORST), `CONT_1D` (by BORST).
- Many internal variables: 14

- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 ,
- Example: to see test SSND105D

4.4.2.12 'VMIS_MEMO_NRAD'

Elastoplastic relation of behavior of Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall, and an effect of nonproportionality of the loading and an effect of memory of greatest work hardening. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `CIN2_CHAB (_FO)`, `ELAS (_FO)`, `MEMO_ECRO (_FO)`, `CIN2_NRAD` (Cf [R5.03.04] for more details).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `CONT_1D` (by `BORST`).
- Many internal variables: 28
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 , $V15$: Function of work hardening $R(p)$, $V16$: relative variable in memory of work hardening q , $V17$ with $V22$: 6 components of the relative tensor in memory of work hardening ξ , $V23$ with $V28$: 6 components of the tensor plastic deformation.
- Example: to see test SSND115

4.4.2.13 'DIS_CHOC'

Isothermal model of contact and shock with friction of Coulomb being pressed on a discrete element with 1 or 2 nodes, treated by penalization. The parameters characterizing the shock and friction are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `DIS_CONTACT` [R5.03.17].

- Supported modelings: `3D_DIS`, `2D_DIS`
- Many internal variables: 8
The internal variables describe the behavior in the tangential plan defined by the local directions y and z , which is defined compared to the normal direction of shock x .
 - $V1$: following displacement y_{local} (differential displacement of the nodes if `SEG 2`).
 - $V2$: following displacement z_{local} (differential displacement of the nodes if `SEG 2`).
 - $V3$: speed according to y_{local} (differential speed of the nodes if `SEG 2`).
 - $V4$: speed according to z_{local} (differential speed of the nodes if `SEG 2`).
 - $V5$: force according to y_{local} .
 - $V6$: force according to z_{local} .
 - $V7$: if the threshold of friction is reached =1 if not =0
 - $V8$: game enters the nodes according to x_{local} .

4.4.2.14 'DIS_CONTACT'

Isothermal model of contact and shock with friction of Coulomb being pressed on a discrete element with 1 or 2 nodes. The behavior `DIS_CONTACT` translated the contact with shock and friction between two structures, via two types of relations:

- the relation of unilateral contact which expresses to it not inter-penetrability between the solid bodies,
- the relation of friction which governs the variation of the tangential stresses in the contact. One will retain for these developments a simple relation: the law of friction of Coulomb.

The parameters characterizing the shock and friction are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `DIS_CONTACT` [R5.03.17].

- Supported modelings: `3D_DIS`.

- Many internal variables: 9
 - $V1$: COM posing tangent effort along the local axis y : F_{cy}
 - $V2$: component of the tangent effort following the local axis z : F_{cz}
 - $V3$: displacement due to the slip in the tangent plan along the local axis y .
 - $V4$: displacement due to the slip in the tangent plan along the local axis z .
 - $V5$: speed along the local axis x .
 - $V6$: speed along the local axis y .
 - $V7$: speed along the local axis z .
 - $V8$: management of the initial interpenetration of the discrete one.
 - $V9$: management of the initial contact.

4.4.2.15 'DIS_ECRO_TRAC'

The behavior `DIS_ECRO_TRAC` is a nonlinear behavior, allowing to schematize the behavior of a uniaxial device, according to local axis x or in the tangent plan yz discrete elements with two nodes (mesh `SEG2`) or of the discrete elements to a node (mesh `POI1`).

The non-linear behavior is given by a curve $F = \text{fonction}(\Delta U)$:

- for one `SEG2`, ΔU represent the relative displacement of two nodes in the local reference mark of the element;
- for one `POI1`, ΔU represent the absolute displacement of the node in the local reference mark of the element;
- for one `SEG2` or one `POI1`, F represent the effort expressed in the local reference mark of the element.

Only givenE necessary is the function describing the non-linear behavior. This function must respect the criteria according toS :

- C' is a function within the meaning of code_aster defined with the operator `DEFI_FONCTION` ;
- the interpolations on the ordinate and x-axes are linear;
- the name of the X-coordinate at the time of the definition of the function is `DX` or `DTAN` ;
- the prolongations on the left and on the right of the function are excluded;
- the function must be defined by at least three points in the case of an isotropic work hardening or of exactly three points in the case of a kinematic work hardening;
- the first point is $(0.0, 0.0)$ and must be Fourni in the definition of the function ;
- Lfunction has must be strictly increasing;
- the derivative of the function must be lower or equal to its derivative to the point $(0.0, 0.0)$.

The behavior DIS_ECRO_TRAC have 17 internal variables:

	Name of the variable	
V1	FORCEX	Force along the local axis X of the element.
V2	FORCEY	Force along the local axis there of the element.
V3	FORCEZ	Force along local axis Z of the element.
V4	DEPLX	Displacement along the local axis X of the element.
V5	DEPLY	Displacement along the local axis there of the element.
V6	DEPLZ	Displacement along local axis Z of the element.
V7	DISSTHER	Dissipation.
V8	PCUM	Plastic indicator.
V9	DEPLPX	Unelastic displacement along the local axis X of the element.
V10	DEPLPY	Unelastic displacement along the local axis there of the element.
V11	DEPLPZ	Unelastic displacement along local axis Z of the element.
V12	FORCXX	Kinematic work hardening following the local axis X of the element.
V13	FORCXY	Kinematic work hardening following the local axis there of the element.
V14	FORCXZ	Kinematic work hardening following local axis Z of the element.
V15	RAIDEX	Tangent stiffness of the discrete following the local axis X of the element.
V16	RAIDEY	Tangent stiffness of the discrete following the local axis there of the element.
V17	RAIDEZ	Tangent stiffness of the discrete following local axis Z of the element.

4.4.2.16 'WEAPON'

Relation of elastoplastic behavior isothermal for the conductor arrangements. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `WEAPON` [R5.03.17].

- Supported modelings: 3D_DIS
- Many internal variables: 1
- Significance: $V1$: maximum value attack of the quantity in absolute value $(u_y - u_{le})$ where u_y is displacement in the local direction y mesh SEG2 and u_{le} displacement limits elastic range.
- Example: to see test SSNL101.

4.4.2.17 'RELAX_ACIER'

Relation of behavior allowing to model the relieving of the cables of prestressing, available for modelings of type `BAR`.

To take account of the influence of the temperature on Lhas relieving, all coefficients of the law can be functions of the temperature.

Data necessary with material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RELAX_ACIER` [R5.03.9].

- Modelings supported: 1D
- Many internal variables: 2
 - $V1$: deformation unelastic cumulated: ϵ^{an} .
 - $V2$: memorizing of tangent stiffness with the behavior.
- ExampleS : to see testS SSNL143 [has, B, C].

4.4.2.18 'ASSE_CORN'

Relation of elastoplastic behaviour isothermal for the bolted assemblies of angles of pylons. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ASSE_CORN` [R5.03.32].

- Supported modelings: 3D_DIS
- Many internal variables: 7
- Example: to see test SSNL102.

4.4.2.19 'DIS_GOUJ2E_PLAS'

Model 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 Y . In this direction, it is about an isothermal law of elastoplasticity of VON-MISES with nonlinear isotropic work hardening (see [R5.03.17] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `TRACTION` (for the local direction Y) and `ELAS`. The curve indicated in `TRACTION` represent actually the curved effort of shearing-jump of displacement Y of a local calculation of a net and `ELAS` the rigidity assigned to discrete for the other directions (in fact defines X room)).

- Supported modelings: `2D_DIS_T`
- Many internal variables: 2
- Significance: $V1$: plastic displacement cumulated, $V2$: indicator of plasticity (cf Notices 1) (0 so elastic, 1 so plastic).
- Example: to see test `ZZZZ120`

4.4.2.20 'DIS_GOUJ2E_ELAS'

Model 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ELAS`.

- Supported modelings: `2D_DIS_T`
- Many internal variables: 1
- Significance: $V1$: vacuum (thus 0 are worth).

4.4.2.21 'VMIS_ASYM_LINE'

Relation of isothermal behavior uniaxial of elastoplasticity of VON-MISES with isotropic work hardening with different elastic limits in traction 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 ground. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `ECRO_ASYM_LINE` (Cf [R5.03.09] for more details).

- Supported modeling: `BAR`
- Many internal variables: 4
- Significance: $V1$: plastic deformation cumulated in traction, $V2$: indicator of plasticity (cf Notices 1) in traction, $V3$: plastic deformation cumulated in compression, $V4$: indicator of plasticity (cf Notices 1) in compression.
- Example: to see test `SSNL112`.

4.4.2.22 'DIS_ECRO_CINE'

Model with nonlinear kinematic work hardening being pressed on a discrete with 1 or 2 nodes, independently definite element on each degree of freedom (forces, moments), of the type $F = K_e(U - U_{an})$. Parameters characterizing the yield stress F_y , the ductile plate F_u , the kinematic constant of work hardening k_x and power n defining the curvilinear part of the traction diagram, are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `DIS_ECRO_CINE`, to also see [R5.03.17]; moreover, elastic stiffness K_e is given via the order `AFFE_CARA_ELEM` [U4.42.01].

- Supported modelings: `DIS_T`, `DIS_TR`, `2D_DIS_T`, `2D_DIS_TR`.
- Many internal variables: 3.
- Significance: $V1$: unelastic displacement U_{an} , $V2$: kinematic variable of work hardening $\tilde{\alpha}$, $V3$: dissipated energy.

- Example: to see test SSND102 [V6.08.102].

4.4.2.23 ' DIS_BILI_ELAS '

The behavior DIS_BILI_ELAS is used to model a bilinear elastic behavior in translation. The law of behavior was conceived to be used with all the discrete elements.

The behavior is characterized by 2 slopes and an effort which definite change of incline. For each degree of freedom considered, the behavior of discrete is either elastic or rubber band-bilinear. So in one of the directions the bilinear behavior is not defined, the behavior in this direction is then elastic and they are the values given in the order AFFE_CARA_ELEM who are taken. The law DIS_BILI_ELAS relate 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 the operator DEFI_MATERIAU [U4.43.01], under the keyword DIS_BILI_ELAS, to also see [R5.03.17]; they are obligatorily given in the local reference mark of the element, it is thus necessary in the order AFFE_CARA_ELEM under the key word factor DISCRETE to specify REPERE=' LOCAL '. Sizes KDEB and KFIN are functions which depend on the temperature and can be defined in the form of function, of tablecloth or formula. The local reference mark is defined in a classical way in the order AFFE_CARA_ELEM under the key word factor ORIENTATION.

There is an internal variable per degree of freedom of translation. It can take 3 values:

- $VI=0$, the discrete one was never requested in this direction.
- $VI=1$, one is if $|F| \leq FPREC$
- $VI=2$, one is if $|F| > FPREC$

4.4.2.24 ' VMIS_CINE_GC '

Relation of behavior of elastoplasticity of Von Mises with linear kinematic work hardening written in 1D, based on ECRO_LINE. The characteristics of material are provided in the operator DEFI_MATERIAU [U4.43.01], under the key word ECRO_LINE (for linear work hardening).

Supported modeling beT 1D, the number of internal variables is 6 (confer [R5.03.02] "Integration of the relations of elastoplastic behavior of Von Mises", for more details).

- $V1$: Criterion limits in constraint,
- $V2$: Criterion limits in deformation,
- $V3$: Kinematic work hardening,
- $V4$: Plastic indicator,
- $V5$: nonrecoverable dissipation,
- $V6$: thermodynamic dissipation.

4.4.2.25 Behavior DASHPOT

Relation of behavior for the discrete elements DIS_T binder, at every moment of calculation t_i , the nodal force $F(t_i)$ with the increment of displacement $\Delta_x(t_i)$ in the following way: $F(t_i) = K \Delta_x(t_i)$ where K is a parameter of stiffness provided by the user via the order AFFE_CARA_ELEM [U4.42.01] (CARA=' K_T_D_L' or 'K_T_D_N').

- Supported modelings: DIS_T.
- Many internal variables: 0.
- Reference material: R5.03.17
- Example: to see test ssnd119a [V6.08.119].

4.4.3 Élasto-viscoplastic models

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.

4.4.3.1 ' VISC_ISOT_LINE '

Visco-elastoplastic relation of behavior in great deformations (formulation `SIMO_MIEHE` only). The plastic model is `VMIS_ISOT_LINE` i.e. with linear isotropic work hardening. The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]` under the keywords `ECRO_LINE (_FO)`, `ELAS (_FO)`.

The law of viscosity is a law in hyperbolic sine (confer [R5.03.21]). The viscous parameters are to be informed under the keyword `VISC_SINH` in the operator `DEFI_MATERIAU`.

- Supported modelings: 3D, 2D, `INCO_UPG` and `INCO_UP`
- Integration: implicit
- Many internal variables: 3
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic).
- Example: to see test `SSNL129D`

4.4.3.2 ' VISC_ISOT_TRAC '

Relation of visco-elastoplastic behavior in great deformations (formulation `SIMO_MIEHE` only). The plastic model is `VMIS_ISOT_TRAC` i.e. with nonlinear isotropic work hardening. The curve (σ, ε) in simple traction is provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keyword `TRACTION` (confer [R5.03.02] for more details). One can possibly define several traction diagrams according to the temperature. One must also inform the keyword `ELAS (_FO)` in the operator `DEFI_MATERIAU`.

The law of viscosity is a law in hyperbolic sine (confer [R5.03.21]). The viscous parameters are to be informed under the keyword `VISC_SINH` in the operator `DEFI_MATERIAU`.

- Supported modelings: 3D, 2D, `CONT_1D (PMF)`, `INCO_UPG` and `INCO_UP`
- Integration: implicit
- Many internal variables: 3
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic),
- Example: to see test `SSNL129A`

4.4.3.3 ' LEMAITRE '

Relation of viscoplastic behavior nonlinear of Lemaitre (without threshold). A typical case of this relation (by cancelling the parameter `UN_SUR_M`) give a relation of NORTON. The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keywords `LEMAITRE (_FO)` and `ELAS (_FO)` (confer [R5.03.08] for more details). The correspondence of the internal variables allows the chaining with a calculation using an elastoplastic behaviour with isotropic work hardening ('`VMIS_ISOT_LINE`' or '`VMIS_ISOT_TRAC`'). L' integration of this model is carried out by an semi-implicit method (`PARM_THETA=0.5`) or implicit (`PARM_THETA=1`).

- Supported modelings: 3D, 2D, `CONT_PLAN (by BORST)`, `INCO_UPG`, `INCO_UP`, `CONT_1D (by BORST)`
- Many internal variables: 2
- Significance: $V1$: cumulated plastic deformation, $V2$: vacuum thus is worth always 0.
- Example: to see test `SSNA104`

4.4.3.4 ' NORTON '

Viscoplastic relation of behavior of Norton (without threshold). The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keywords `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 an explicit method (ALGO_INTE=RUNGE_KUTTA)

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), INCO_UPG, INCO_UP, CONT_1D (by BORST)
- Many internal variables: 7
- Significance: $V1$ with $V6$: 6 components of the plastic deformation, $V7$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic).
- Example: to see tests SSNP02E, SSNP02D

4.4.3.5 ' DIS_VISC '

The behavior DIS_VISC is a nonlinear viscoelastic rheological behavior, of type ZENER extended, allowing to schematize the behavior of a uniaxial shock absorber, applicable to local degree of freedom dx discrete elements with two nodes (mesh SEG2) or and of the discrete elements to a node (mesh POI1), in the case of a connection with a frame fixes nonwith a grid (see static and dynamic examples in the case test SSND101). The fitting of the linear elastic components allows the pre onendre counts of it a broad range of situations of environment of the damping part of the device and of its fixings.

Speed is estimated via the increment of displacement (and not by the diagram). The parameters characterizing the model are provided in the operator DEFI_MATERIAU [U4.43.01], under the keyword DIS_VISC, to also see [R5.03.17]. Elastic stiffnesses K_e , which is used for the phase of prediction of the nonlinear algorithm, are given via the order AFFE_CARA_ELEM [U4.42.01].

- Supported modelings: DIS_T, DIS_TR, 2D_DIS_T, 2D_DIS_TR.
- Many internal variables: 4.
 - $V1$: FORCE : the effort contains σ at every moment in rheological model.
 - $V2$: UVISQ : viscous displacement of the shock absorber ε_v
 - $V3$: UVISQ : contains at every moment reactualized dissipated energy: $V2 = - \sum F \cdot \Delta U$
 - $V4$: STIFFNESS : tangent stiffness with the behavior dF/dU
- Example: to see test SSND101 [V6.08.101].

4.4.3.6 ' VISC_CIN1_CHAB '

Relation of behavior of Chaboche (account of the cyclic behavior of material returns) in élasto-viscoplasticity with a tensor of kinematic work hardening nonlinear, a nonlinear isotropic work hardening, an effect of work hardening on the tensorial variable of recall and taking into account of viscosity. All the constants of material can possibly depend on the temperature. The data necessary of the field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords CIN1_CHAB (_F0), ELAS (_FO) (see [R5.03.04] for more details) and LEMAITRE for viscosity. Integration is completely implicit.

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), INCO_UPG, INCO_UP, CONT_1D (by BORST)
- Many internal variables: 8
- Significance: $V1$: cumulated viscoplastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the kinematic tensor of work hardening α .
- Example: to see test HSNV124

4.4.3.7 ' VISC_CIN2_CHAB '

Relation of behavior of Chaboche (account of the cyclic behavior of material returns) in élasto-viscoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the tensorial variable of recall and taking into account of viscosity. All the constants of material can possibly depend on the temperature. The data necessary of the field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords

CIN2_CHAB (_FO), ELAS (_FO) (see [R5.03.04] for more details) and LEMAITRE for viscosity. Integration is completely implicit.

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), INCO_UPG, INCO_UP, CONT_1D (by BORST)
- Many internal variables: 14
- Significance: $V1$: cumulated viscoplastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 .
- Example: to see test HSNV124

4.4.3.8 ' VISC_CIN2_MEMO '

Relation of behavior elastoviscoplastic of Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in élasto-viscoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall and an effect of memory of greatest work hardening. All the constants of material can possibly depend on the temperature. The data necessary of the field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords CIN2_CHAB (_FO), ELAS (_FO), MEMO_ECRO (_FO), LEMAITRE for viscosity. Integration is completely implicit. (see [R5.03.04] for more details).

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), CONT_1D (by BORST).
- Many internal variables: 28
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 , $V15$: Function of work hardening $R(p)$, $V16$: relative variable in memory of work hardening q , $V17$ with $V22$: 6 components of the relative tensor in memory of work hardening ξ , $V23$ with $V28$: 6 components of the tensor plastic deformation.
- Example: to see test SSND105, COMP002H, SSNV118

4.4.3.9 ' VISC_CIN2_NRAD '

Relation of behavior elastoviscoplastic of Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in élasto-viscoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall, and an effect of nonproportionality of the loading. The data necessary of the field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords CIN2_CHAB (_FO), ELAS (_FO), CIN2_NRAD (confer [R5.03.04] for more details).

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), CONT_1D (by BORST).
- Many internal variables: 14
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 ,
- Example: to see test SSND105D

4.4.3.10 ' VISC_MEMO_NRAD '

Relation of behavior elastoplastic of Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in élasto-viscoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall, and an effect of nonproportionality of the loading and an effect of memory of greatest work hardening. The data necessary of the field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords CIN2_CHAB (_FO), ELAS (_FO), MEMO_ECRO (_FO), CIN2_NRAD (confer [R5.03.04] for more details).

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), CONT_1D (by BORST).
- Many internal variables: 28
- Significance: $V1$: cumulated plastic deformation, $V2$: indicator of plasticity (cf Notices 1) (0 for rubber band, iteration count internal for plastic), $V3$ with $V8$: 6 components of the 1^{er} tensor of the kinematic variable α_1 , $V9$ with $V14$: 6 components of the 2^{ème} tensor of the kinematic variable α_2 , $V15$: Function of work hardening $R(p)$, $V16$: relative variable in memory of work hardening q , $V17$ with $V22$: 6 components of the relative tensor in memory of work hardening ξ , $V23$ with $V28$: 6 components of the tensor plastic deformation.
- Example: to see test SSND115

4.4.3.11 'VISCOCHAB'

Relation of behavior elastoviscoplastic of Chaboche with 2 variable kinematics which gives an account of the cyclic behavior in elastoplasticity with 2 tensors of nonlinear kinematic work hardening, a nonlinear isotropic work hardening, an effect of work hardening on the variables tensorial of recall, an effect of memory of greatest work hardening, and effects of restoration. All the constants of material can possibly depend on the temperature. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `VISCOCHAB (_FO)`, `ELAS (_FO)`. Integration is either implicit, or clarifies (`RUNGE_KUTTA`) (Cf [R5.03.12] for more details).

- Supported modelings: 3D, 2D, CONT_1D (by BORST).
- Many internal variables: 28
- Significance: $V1$ with $V12$: 12 components of the 2 tensors kinematics X_1 , X_2 , $V13$: cumulated plastic deformation, $V14$: Function of work hardening $R(p)$, $V15$: relative variable in memory of work hardening q , relative variable in memory of work hardening q , $V16$ with $V21$: 6 components of the relative tensor in memory of work hardening ξ , $V22$: indicator of plasticity (cf Notices 1) (0 for rubber band, 1 for plastic), $V23$ with $V28$: 6 components of the tensor plastic deformation (only in the explicit case).
- Example: to see test HSNV125D, COMP002I, SSNV118

4.4.3.12 'NORTON_HOFF'

Relation of behavior of viscosity independent of the temperature, to use for the calculation of limiting loads of structures, with threshold of Von Mises. The only parameter material is the elastic limit to be informed in the operator `DEFI_MATERIAU` [U4.43.01] under the keyword `ECRO_LINE` (confer [R7.07.01] and [R5.03.12] for more details). For the calculation of the limiting load, there exists a specific keyword under `PILOTING` for this model (see keyword `PILOTING: 'ANA_LIM'` of `STAT_NON_LINE` [U4.51.03]). It is strongly advised to employ linear research (see keyword `RECH_LINEAIRE` of `STAT_NON_LINE` [U4.51.03]). Indeed, the calculation of the limiting load requires many iterations of linear research (about 50) and of iterations of Newton (about 50).

- Supported modeling: `INCO_UPG`, `INCO_UP`
- Many internal variables: 1
- Significance: $V1$: vacuum thus is worth 0.
- Example: to see test SSNV124

4.4.3.13 'VISC_TAHERI'

Relation of behavior (visco) - plastic modelling the material answer under cyclic plastic loading, and in particular allowing to represent the effects of ratchet. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `TAHERI(_FO)` for the description of work hardening, `LEMAITRE(_FO)` for viscosity and `ELAS (_FO)` (confer [R5.03.05] for more details). In the absence of `LEMAITRE`, the law is purely elastoplastic.

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), `INCO_UPG`, `INCO_UP`, CONT_1D (by BORST).
- Many internal variables: 9

- Significance: $V1$: cumulated plastic deformation, $V2$: constraint of peak, $V3$ with $V8$: 6 components of the tensor of plastic deformations due to the last discharge, $V9$: discharge/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).

4.4.4 Crystalline behaviors

◆ COMPOR = comp [compor]

The detail of the crystalline behaviors is provided via the concept `compor`, resulting from `DEFI_COMPOR`.

4.4.4.1 'MONOCRYSTAL'

This model makes it possible to describe the behavior of a monocrystal whose relations of behavior are provided via the concept `compor`.

The number of internal variables is function of the choices carried out in `DEFI_COMPOR` :

The six first are the 6 components of the viscoplastic deformation: E_{ij}^{vp} :

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

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

V_7, V_8, V_9 are the values of $\alpha_1 \gamma_1 p_1$ for the system of slip $s=1$

V_{10}, V_{11}, V_{12} correspond to the system $s=2$, and so on, where:

- α_s represent the kinematic variable of the system s in the case of phenomenologic models, and density of dislocations in a model resulting from the DD;
- γ_s represent the plastic slip of the system s
- p_1 represent the cumulated plastic slip of the system s

Taking into account of the irradiation:

- in the case `DD_CC_IRRA`, it is necessary to add $n_{irra}=12$ internal variables: V_{6+3n_s+1} with V_{6+3n_s+12} contain for each system of slip density of dislocations related to the irradiation ρ_s^{irr}
- in the case `DD_CFC_IRRA`, it is necessary to add $n_{irra}=24$ internal variables: V_{6+3n_s+1} with V_{6+3n_s+12} contain for each system of slip ρ_s^{loops}
 V_{6+3n_s+13} with V_{6+3n_s+24} contain for each system of slip ϕ_s^{voids}

One stores then cissions them for each system of slip: $\tau_1, \dots, \tau_{n_s}$

If one takes into account the rotation of the crystal lattice, it is necessary to add $n_{rota}=16$ internal variables:

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

The variable antepenultimate interns is the constraint of cleavage: $\max_s (\Sigma . n) : n$

Before last internal variable contains the total cumulated plastic deformation, defined by:

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

The last internal variable, V_p , ($p=6+3n_s+n_{rota}+3$, n_s being the full number of systems of slip) is an indicator of plasticity (cf Notices 1) (threshold exceeded in at least a system of slip to the step of current time). If it is null, there no was increase in internal variables at the current moment. If not, it contains the iteration count of local Newton (for an implicit resolution) which was necessary to obtain convergence.

For more precise details to consult [R5.03.11].

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST).
- Example: to see test SSNV194

4.4.4.2 'POLYCRYSTAL'

This model makes it possible to describe the behavior of a polycrystal whose relations of behavior are provided via the concept `compor`, resulting from `DEFI_COMPOR`.

The number of internal variables is $p=7+6m+\sum_{g=1,m}(3n_s(g))+6m+1$, m being the number of phases and $n_s(g)$ being the number of systems of slip of the phase g)

- The first six internal variables are the components of the macroscopic viscoplastic deformation E^{vp} :

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

- the seventh is the cumulated equivalent viscoplastic deformation macroscopic P :

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

- then, for each phase, one finds the 6 components of the viscoplastic deformations or the tensor β

$$\text{phase: } \left\{ \varepsilon_{xx}^{vp}(g), \varepsilon_{yy}^{vp}(g), \varepsilon_{zz}^{vp}(g), \sqrt{(2)}\varepsilon_{xy}^{vp}(g), \sqrt{(2)}\varepsilon_{xz}^{vp}(g), \sqrt{(2)}\varepsilon_{yz}^{vp}(g) \right\}_{g=1,m};$$

- then, for each phase:

- for each system of slip of the phase, one finds the values of $\alpha_s \gamma_s P_s$;
- if the behavior currently takes into account the irradiation (`MONO_DD_CC_IRRA`), it is then necessary to add 12 internal variables: densities of dislocations due to the irradiation.

- then, for each phase, one finds the 6 components of the constraints of the phase:

$$\left\{ \sigma_{xx}(g), \sigma_{yy}(g), \sigma_{zz}(g), \sqrt{(2)}\sigma_{xy}(g), \sqrt{(2)}\sigma_{xz}(g), \sqrt{(2)}\sigma_{yz}(g) \right\}_{g=1,m};$$

- the last internal variable is an indicator of plasticity (cf Notices 1) (threshold exceeded in at least a system of slip to the step of current time).

For more precise details to consult [R5.03.11].

- Supported modelings: 3D
- Example: to see test SSNV171

4.4.5 Behaviors specific to the fuel pins and metals under irradiation

4.4.5.1 `VISC_IRRA_LOG`

Law of axial creep 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `VISC_IRRA_LOG`. The field of fluence is defined by the keyword `AFFE_VARC` order `AFFE_MATERIAU`.

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `CONT_1D`, `CONT_1D` (PMF).
- Many internal variables: 2. $V1$: cumulated equivalent viscoplastic deformation, $V2$: memorizing of the history of irradiation (fluence).
- Example: to see test `SSNV113`

4.4.5.2 `GRAN_IRRA_LOG`

Relation of behavior of creep and growth under irradiation for the fuel assemblies, similar to the law `VISC_IRRA_LOG` for the viscoplastic, and integral deformation in more one deformation of growth under irradiation (cf [R5.03.09]). The field of fluence is defined by the keyword `AFFE_VARC` order `AFFE_MATERIAU`. The characteristics of the behavior are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `GRAN_IRRA_LOG`. The growth being done only according to one direction, it is necessary in the cases 3D and 2D to give the direction of the growth by the operand `ANGL_REP` keyword `SOLID MASS` of the operator `AFFE_CARA_ELEM`.

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `CONT_1D`, `CONT_1D` (PMF).
- Many internal variables: 3. $V1$: cumulated equivalent viscoplastic deformation, $V2$: memorizing of the history of irradiation (fluence), $V3$: deformation of growth.
- Example: to see test `SSNL128`

4.4.5.3 `LEMAITRE_IRRA`

Relation of behavior of creep and growth under irradiation for the fuel assemblies. The field of fluence is defined by the keyword `AFFE_VARC` order `AFFE_MATERIAU`. The characteristics of the behavior are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `LEMAITRE_IRRA`. The growth being done only according to one direction, it is necessary in the cases 3D and 2D to give the direction of the growth by the operand `ANGL_REP` keyword `SOLID MASS` of the operator `AFFE_CARA_ELEM`. 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 modelings: 3D, 2D, `CONT_PLAN` (by `BORST`).
- Many internal variables: 3. $V1$: cumulated plastic deformation, $V2$: worthless, $V3$: deformation of growth.
- Example: to see test `SSNL121`.

4.4.5.4 `LEMA_SEUIL`

Viscoplastic relation between behavior and threshold under irradiation for the fuel assemblies (cf [R5.03.08]). The field of fluence is defined by the keyword `AFFE_VARC` order `AFFE_MATERIAU`. The characteristics of the growth are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `LEMA_SEUIL`. The integration of the model is carried out by a method semi - implicit or implicit.

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `CONT_1D` (by `BORST`).
- Many internal variables: 2
- $V1$: cumulated plastic deformation,
- $V2$: represent the current threshold
- Example: to see test `SSNA104`

4.4.5.5 'IRRAD3M'

Elastoplastic relation of behaviour under irradiation of the stainless steels 304 and 316, materials of which are made up the internal structures of tank of the nuclear reactors. The field of fluence is defined by the keyword `AFPE_VARC` order `AFPE_MATERIAU`. The model takes into account plasticity, creep under irradiation, swelling under neutron flux. The characteristics are provided in the operator `DEFI_MATERIAU` [U4.43.01], under keyword `IRRAD3M`. The integration of the model is carried out by an implicit scheme in time (cf [R5.03.13]).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`)
- Many internal variables: 5
 - $V1$: cumulated equivalent plastic deformation,
 - $V2$: threshold for the creep of irradiation
 - $V3$: equivalent plastic deformation of irradiation
 - $V4$: swelling
 - $V5$: indicator of plasticity (cf Notices 1)
- Example: to see test `SSNA118`

4.4.5.6 'DIS_GRICRA'

The behavior `DIS_GRICRA` allows to model the connections between grids and pencils of the fuel assemblies. It is pressed on discrete elements with 2 nodes, with 6 ddl by node (translation+rotation). The law of behavior on each subsystem (slip - axial friction, rotation in the plan, and rotation except plan) is of standard plasticity with positive work hardening in the tangential directions with discrete to model the slip, and of the unilateral elastic type in the direction of discrete to model the contact. Parameters of `DIS_GRICRA`, characterizing the contact and friction, are directly rigidities in rotation and thresholds in rotation (standard critical angles). These parameters are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `DIS_GRICRA`. Contrary to the other discrete ones, one does not take into account the characteristics of rigidity of `AFPE_CARA_ELEM`. The matrix of rigidity of discrete must thus be taken worthless in `AFPE_CARA_ELEM`. Rigidity is only resulting from the parameters in `DEFI_MATERIAU`.

The unilateral contact takes place in the direction X data by the mesh `SEG2` discrete element, and the slip takes place in the direction Y data by the keyword `ORIENTATION` of `AFPE_CARA_ELEM` (confer [R5.03.17] for more details). The tangent matrix is symmetrical.

- Supported modelings: `DIS_TR`
- Many internal variables: 6
 - $V1$: plastic displacement cumulated
 - $V2$: indicator of contact/friction (1 if slip, 0 so not slip)
 - $V3$: indicator of separation in rotation
 - $V4$: plastic angle (slip)
 - $V5$: cumulated plastic angle
 - $V6$: memorizing of the history of irradiation (fluence)
- Example: to see test `SSNL131`

4.4.6 Mechanical models with effects of the metallurgical transformations

The following relations of behavior apply to a material which undergoes metallurgical phase shifts (confer [R4.04.02] for more detail). Mechanical calculations taking of account the metallurgy are based on a calculation of evolution of the metallurgical phases (see the order `CALC_META` [U4.85.01]).

4.4.6.1 Laws in kit of the type `META_*` except `META_LEMA_ANI`

One can activate by the keyword `RELATION_KIT` two types of material, is `STEEL` who comprises at the maximum five different metallurgical phases, is `ZIRC` who comprises at the maximum three different metallurgical phases.

Moreover, the name of the relation of behavior is form `META_x_yy_zzz`, with the following possibilities

X	=	P	or	V		
YY	=	IT	or	INL	or	CL
zzz	=	Pt	or	RE	or	PT_RE

The significance of the letters defined above is the following one:

P	=	plastic behavior
V	=	viscoplastic behavior
IT	=	linear isotropic work hardening
IN	=	nonlinear isotropic work hardening
L	=	
CL	=	linear kinematic work hardening
Pt	=	plasticity of transformation
RE	=	restoration of work hardening of metallurgical origin

Examples:

```
BEHAVIOR = (RELATION = 'META_P_INL'  
            RELATION_KIT = 'ZIRC' )  
  
BEHAVIOR = ( RELATION = 'META_V_CL_PT_RE'  
            RELATION_KIT = 'STEEL' )
```

See also the tests: `HSNV101`, `HSNV1202`, `HSNV103`, `HSNV104`, `HSNV105`, `HTNA100`.

Note: pour all the metallurgical laws, the plane constraints are impossible even with the method `BORST`.

The data material necessary to mechanical calculation are to be defined for each metallurgical phase in presence in material. They are provided in the operator `DEFI_MATERIAU` [U4.43.01]:

Type of behavior	Keyword of <code>DEFI_MATERIAU</code>
P = elastoplastic behavior	<code>ELAS_META</code> (<code>_FO</code>) follow-up of a work hardening...
V = viscoplastic behavior	<code>META_VISC_FO</code> and elastoplastic data
IT = linear isotropic work hardening	<code>ELAS_META</code> (<code>_FO</code>) and <code>META_ECRO_LINE</code>
INL = nonlinear isotropic work hardening	<code>ELAS_META</code> (<code>_FO</code>) and <code>META_TRACTION</code> (*)
CL = linear kinematic work hardening	<code>ELAS_META</code> (<code>_FO</code>) and <code>META_ECRO_LINE</code>
Pt = plasticity of transformation	<code>META_PT</code>
RE = restoration of metallurgical work hardening of origin	<code>META_RE</code>

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

Many internal variables and significances

One gathers here the information on the internal variables because their number varies according to the type of work hardening (isotropic or kinematic), of the type of material (STEEL or ZIRC) and of the type of deformations (SMALL, PETIT_REAC, GROT_GDEP or SIMO_MIEHE).

Phases steel are the following ones:

Phase	Type	Name
Ferrite	Cold	FERRITE
Pearlite	Cold	PEARLITE
Bainite	Cold	BAINITE
Martensite	Cold	MARTENSITE
Austenite	Heat	AUSTENITE

Phases zircaloy are the following ones:

Phase	Type	Name
Alpha	Cold	ZIRCALPH
Alpha+Bêta	Cold	ZIRCALBE
Beta	Heat	ZIRCBETA

The internal variables depend on the type of deformation and the type of work hardening:

Deformation	Isotropic work hardening		Kinematic work hardening	
	STEEL	ZIRC	STEEL	ZIRC
SMALL, PETIT_REAC and GROT_GDEP	<i>V1</i> with <i>V5</i> : variables related to isotropic work hardening for the 5 phases	<i>V1</i> with <i>V3</i> : variables related to isotropic work hardening for the 3 phases	<i>V1</i> with <i>V30</i> : variables related to kinematic work hardening α for the 5 phases	<i>V1</i> with <i>V18</i> : variables related to kinematic work hardening α for the 3 phases
	<i>V6</i> : average isotropic work hardening	<i>V4</i> : average isotropic work hardening	<i>V31</i> with <i>V36</i> : average kinematic work hardening <i>X</i>	<i>V19</i> with <i>V24</i> : average kinematic work hardening <i>X</i>
	<i>V7</i> : indicator of plasticity (0 so elastic, 1 so plastic)	<i>V5</i> : indicator of plasticity (0 so elastic, 1 so plastic)	<i>V37</i> : indicator of plasticity (cf Notices 1) (0 so elastic, 1 so plastic)	<i>V25</i> : indicator of plasticity (cf Notices 1) (0 so elastic, 1 so plastic)
SIMO_MIEHE	<i>V8</i> : trace of the elastic strain divided by 3 used into great deformations	<i>V6</i> : trace of the elastic strain divided by 3 used into great deformations	Do not exist	Do not exist

The first line of the table gives the classical internal variables of plasticity (see §4.4.2), by phase. They are thus named also by phase. For example, for an isotropic work hardening of a steel alloy, one a: FERRITE#EPSPEQ, PERLITE#EPSPEQ, BAINITE#EPSPEQ, MARTENSITE#EPSPEQ and AUSTENITE#EPSPEQ.

The following lines are quantities *total*. For example, one applies the law of the mixtures to the internal variables by phase.

4.4.6.2 Law META_LEMA_ANI

META_LEMA_ANI is a law of fascinating anisotropic viscoplastic behavior of account the metallurgy, for Zirconium only [R4.04.04] and [R4.04.05] (and tests HSNV134 and HSNV135).

The characteristics are:

- taking into account of three metallurgical phases of Zircaloy.
- viscosity of the Lemaitre type, without threshold
- anisotropy with criterion of Hill

Supported modelings are: 3D, 2D, INCO.

Lbe coefficients material are defined in the operator `DEFI_MATERIAU` under ' META_LEMA_ANI '.

Internal variables of the model META_LEMA_ANI are:

$V1 \rightarrow VN$: NR components of the tensor symmetrical elastic strain

$VN+1$: p: cumulated viscous deformation

$VN+2$: Zb: proportion of beta phase

$VN+3$: epsther: thermal deformation

$VN+4$: seq: equivalent constraint of Hill

$VN+5, +6, +7$: sv1, sv2, sv3: viscous constraint respectively of the phases α pure, $\alpha\beta$ and β

$VN+8$: pch: indicator of phase shift (0 or 1)

$VN+9$: tdeq urgent to which the temperature is worth TDEQ (see [R4.04.04]) (initialized to 0 at the beginning of calculation)

$VN+10$: tfeq urgent to which the temperature is worth TFEQ (see [R4.04.04]) (initialized to 0 at the beginning of calculation)

4.4.6.3 Law MetaAcierEPIL_PT

The law `MetaAcierEPIL_PT` is a law specific to the alloys of the type STEEL (five metallurgical phases) which undergo metallurgical phase shifts. This law is characterized by a linear isotropic work hardening and makes it possible to take into account the plasticity of transformation.

The whole of the parameters materials are indicated in the keyword factor `MetaAcierEPIL_PT` (`_FO`) order `DEFI_MATERIAU` .

The internal variables depend on the type of modeling, 2D or 3D:

Type of modeling	
2D	3D
$V1$ with $V4$: components of the tensor of the elastic strain	$V1$ with $V6$: components of the tensor of the elastic strain
$V5$ with $V9$: variables related to isotropic work hardening for the 5 phases	$V7$ with $V11$: variables related to isotropic work hardening for the 5 phases
$V10$: average isotropic work hardening	$V12$: average isotropic work hardening
$V11$: indicator of plasticity (0 so elastic, 1 so plastic)	$V13$: indicator of plasticity (0 so elastic, 1 so plastic)

Supported modelings are 3D, AXIS and D_PLAN. These modelings can be employed with the keywords `DEFORMATION = 'SMALL', 'PETIT_REAC' or 'GROT_GDEP'` .

The implementation of the law `MetaAcierEPIL_PT` is illustrated in the case test `mfron06`.

4.4.7 Local and nonlocal models of damage

4.4.7.1 'ROUSSELIER', 'ROUSS_PR', 'ROUSS_VISC'

Note:

Three following models 'ROUSSELIER' (elastoplastic model), 'ROUSS_PR' (elastoplastic model) and 'ROUSS_VISC' (model elastoviscoplastic) are three versions different from the model of Rousselier. This model is a relation of behavior élasto (visco) plastic which makes it possible to give an account of the growth of the cavities and to describe the ductile rupture in steels. Apart from with dimensions viscous plastic/, the essential difference lies in the way in which the great 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' need for much more iterations of Newton has to converge compared to the model 'ROUSSELIER' .

It should be also noted that these three models treat in a different way broken material. In the models 'ROUSS_PR' and 'ROUSS_VISC' , when porosity reaches a limiting porosity, broken material is considered. The behavior is then replaced by an imposed fall of the constraints. To activate this modeling of broken material, it is then necessary to inform in the operator *DEFI_MATERIAU* [U4.43.01], under the keyword *ROUSSELIER* (*_FO*) , two coefficients 'PORO_LIMI' and 'D_SIGM_EPSI_NORM' . For 'ROUSSELIER' , nothing in particular is done because the constraint 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 relation of behavior. It makes it possible to give an account of the growth of the cavities and to describe the ductile rupture. This model gets busy exclusively with the keyword *DEFORMATION* = 'SIMO_MIEHE'). The data necessary of the field material are provided in the operator *DEFI_MATERIAU* [U4.43.01], under the keywords *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 the step of time (see *STAT_NON_LINE* [U4.51.03], keyword *INCREMENT*). This model is not developed in plane constraint. Moreover, with the keyword *SIMO_MIEHE*, one cannot use the plane constraints by the method *BORST*.

Supported local modelings: 3D, 2D, *INCO_UPG* (if *DEFORMATION*=' PETIT' or 'SIMO_MIEHE')

- Many internal variables: 9
- Significance: *V1* : cumulated plastic deformation, *V2* : value of porosity, *V3* : indicator of plasticity (cf Notices 1) (0 so elastic, 1 so plastic with regular solution, 2 so plastic with singular solution). *V4* with *V9* : 6 components of a tensor eulérien in great deformations of elastic strain,
- Example: to see test *SSNV147*.

Supported nonlocal modeling: to use modelings *INCO* with internal length

- Many internal variables: 12
- Significance:
 - *V1* : cumulated plastic deformation,
 - *V2* with *V4* : gradient of the plastic deformation cumulated along the axes *x, y, z* , respectively,
 - *V5*: porosity,
 - *V6* with *V11* : elastic strain used for *SIMO_MIEHE*,
 - *V12* : indicator 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 relation of behavior. It makes it possible to give an account of the growth of the cavities and to describe the ductile rupture. This model gets busy exclusively with the keywords `DEFORMATION`: 'PETIT_REAC' or 'PETIT', (to use modeling preferably 'PETIT_REAC' because it is a model great deformations). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `ROUSSELIER (_FO)` and `ELAS (_FO)` (Cf [R5.03.06] for more details). One can also take into account the nucleation of the cavities. The parameter should then be informed `YEAR` (keyword 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 the step of time (keyword `ITER_INTE_PAS`).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `INCO_UPG`, `INCO_UP`.
- Many internal variables: 5
- Significance: $V1$: cumulated plastic deformation, $V2$: value of porosity, $V3$: indicator of dissipation, $V4$ = stored energy, $V5$ = indicating of plasticity (cf Notices 1)
- Example: test SSNV103

'ROUSS_VISC'

Relation of behavior élasto-visco-plastic. It makes it possible to give an account of the growth of the cavities and to describe the ductile rupture. This model gets busy exclusively with the keywords `DEFORMATION` = 'PETIT_REAC' or 'PETIT', (to take modeling 'PETIT_REAC' because it is a model great deformations). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `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 the step of time, keyword `ITER_INTE_PAS`). For the integration of this law, one θ - method is available and one advises to use an integration semi - implicit i.e.: `PARAM_THETA` = 0.5

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `INCO`.
- Many internal variables: 5
- Significance: $V1$: cumulated plastic deformation, $V2$: value of porosity, $V3$: indicator of dissipation, $V4$ = stored energy, $V5$ = indicating of plasticity (cf Notices 1)
- Example: test SSNP117.

4.4.7.2 'GTN'

The law of behavior entitled 'GTN', name of its authors Gurson, Tvergaard and Needleman, is a model élasto-visco-plastic which gives an account of the ductile damage of metals by describing the phases of germination, growth and coalescence of cavities.

By nature, this model is based on a kinematics of great deformations, restricted with 'GDEF_LOG' .

In addition to the local version of the model, a formulation with gradient of cumulated plastic deformation (modeling '*_GRAD_VARI') is also available to control the localization of the deformations, inherent in the models of damage. Lastly, isochoric plastic deformations are generally observed on a great beach of the loading; the problems of incompressibility which result from it can require the use of finite elements mixed displacements – pressure – swelling (modelings '*_INCO_UPG' locally or '*_GRAD_INCO' in nonroom).

Data who characterize it material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `ELAS`, `ECRO_NL`, `GTN`, `VISC_SINH_REG` and `NON_LOCAL`. This model is not developed in `constraintS` `planeS`, these last not being compatible on the theoretical level with the marked gradients which result from the localization of the deformations.

The internal variables are 9, to which are added the filing of the constraints **T** clean with 'GDEF_LOG' . Their significance is the following one:

- $V1$: cumulated plastic deformation
- $V2$: porosity
- $V3$: indicator of plasticity (0 = rubber band, 1 = plastic regular, 2 = mode of point)
- $V4$ with $V9$: components plastic deformation

One will be able to refer to the CAS-tests SN V250 with SSNV257 for examples of use.

4.4.7.3 'HAYHURST'

Élasto-viscoplastic model of Hayhurst, to describe the behavior of the austenitic steels, with a scalar damage in hyperbolic sine, function of the maximum principal constraint or trace of the constraints, an isotropic work hardening and a viscous law in hyperbolic sine.

This model gets busy with the keywords DEFORMATION = SMALL or PETIT_REAC. or GDEF_LOG. The data necessary are defined in DEFI_MATERIAU under the keywords HAYHURST and ELAS.

- Supported modelings: 3D, 2D, INCO_UPG, INCO_UP.
- Many internal variables: 12
- Significance: $V1$ with $V6$: 6 components of the viscoplastic deformation, $V7$: cumulated plastic deformation, $V8$ and $V9$: variables of work hardening H_1 and H_2 , $V10$: variable ϕ , $V11$: damage, $V12$: indicator.
- Example: test SSNV222

4.4.7.4 'VENDOCHAB'

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

- Supported modelings: 3D, 2D, INCO_UPG, INCO_UP.
- Many internal variables: 9
- Significance: $V1$ with $V6$: viscoplastic deformation, $V7$: cumulated plastic deformation, $V8$: isotropic work hardening, $V9$: damage.
- Example: test SSNV183

4.4.7.5 'VISC_ENDO_LEMA'

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

- Supported modelings: 3D, 2D, INCO_UPG, INCO_UP.
- Many internal variables: 9
- Significance: $V1$ with $V6$: viscoplastic deformation, $V7$: cumulated plastic deformation, $V8$: isotropic work hardening, $V9$: damage.
- Example: test SSND108

4.4.7.6 `CZM_EXP_REG`

Cohesive relation of behavior (Cohesive Exponential Model Zone Regularized) (cf [R7.02.11] for more detail) modelling the opening of a crack. This law is usable with the linear finite element of joint 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 the crack. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model often requires the presence of piloting by `PRED_ELAS` (cf [U4.51.03]).

- Supported modeling: `PLAN_JOINT`, `AXIS_JOINT`, `3D_JOINT`, `AXIS_JHMS`, `PLAN_JHMS`.
- Many internal variables: 9
- Significance: $V1$: threshold corresponding to the greatest jump of displacement (in standard) ever reached, $V2$: indicator of dissipation (0: not, 1: yes), $V3$ indicator of damage (0: healthy, 1: damaged), $V4$: indicator of the percentage of dissipated energy, $V5$: value of dissipated energy, $V7$ with $V9$: values of the jump, ($V9=0$ in 2D)
- Example: to see test `SSNP118`, `SSNP133`, `SSNV199`

4.4.7.7 `CZM_LIN_REG`

Cohesive relation of behavior (Cohesive Linear Model Zone Regularized) (cf [R7.02.11] for more detail) modelling the opening of a crack. Interest of such a law, compared with `CZM_EXP_REG`, is to be able to represent a true face of rupture. This last is visible thanks to the internal variable $V3$ ($V3=2$ corresponds to a completely broken element). This law is usable with the linear finite element of joint 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 the crack. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model often requires the presence of piloting by `PRED_ELAS` (see [U4.51.03]).

- Supported modeling: `PLAN_JOINT`, `AXIS_JOINT`, `3D_JOINT`, `AXIS_JHMS`, `PLAN_JHMS`.
- Many internal variables: 9
- Significance: $V1$: threshold corresponding to the greatest jump of displacement (in standard) ever reached, $V2$: indicator of dissipation (0: not, 1: yes), indicating $V3$ of damage (0: healthy, 1: damaged, 2: broken), $V4$: indicator of the percentage of dissipated energy, $V5$: value of dissipated energy, $V7$ with $V9$: values of the jump, ($V9=0$ in 2D)
- Example: to see test `SSNP118`, `SSNV199`

4.4.7.8 `CZM_EXP`

Cohesive relation of behavior (Cohesive Exponential Model Zone) (see [R7.02.12] for more detail) modelling the opening of a crack. This law 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 the crack. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model requires the presence of piloting by `PRED_ELAS` (cf. [U4.51.03]).

- Supported modeling: `PLAN_ELDI`, `AXIS_ELDI`.
- Many internal variables: 7
- Significance: $V1$: normal jump, $V2$: tangential jump, $V3$: variable threshold, $V4$: indicator of cracking (0 for linear mode, 1 for softening mode), $V5$: indicator of the percentage of dissipated energy, $V6$: normal constraint, $V7$: tangential constraint.
- Example: to see test `SSNP118`.

4.4.7.9 `CZM_OUV_MIX`

- - Cohesive relation of behavior (Cohesive Zone Mixed Model Opening) (cf [R7.02.11]) modelling the opening and the propagation of a crack. This law 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 the crack in mode of opening. This law is used when one imposes conditions of symmetry on the element of interface. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model requires the presence of piloting by `PRED_ELAS` (cf. [U4.51.03]).
 -
 - Supported modeling: all modelings of the type `INTERFACE` (cf U3.13.14).
 - Many internal variables: 9
 - `V1` : threshold in jump (greater standard reached),
 - `V2` : indicator of the mode of the law = -1: Contact, 0: Initial or current adherence, 1: Damage, 2: Rupture, 3: Return to zero with worthless constraint.
 - `V3` : indicator of damage 0 if healthy material, 1 if damaged material, 2 if broken material.
 - `V4` : percentage of dissipated energy,
 - `V5` : value of dissipated energy,
 - `V6` : value of current residual energy: Nulle for this laws (valid for `CZM_XXX_REG`).
 - `V7` : normal jump, `V8` : tangential jump, `V9` : tangential jump (no one in 2D).
- Examples: to see tests `SSNP118` and `SSNV199`.

4.4.7.10 `CZM_EXP_MIX`

Cohesive relation of behavior (Cohesive Mixed Model Zone Exponential) (cf [R7.02.11]) modelling the opening and the propagation of a crack. This law 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 the crack in mode of opening according to an exponential form. It is appropriate at the time of the quasi-fragile modeling of material like the concrete. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model can sometimes require to use the techniques of piloting by `PRED_ELAS` to facilitate convergence (cf. [U4.51.03]).

- Supported modeling: all modelings of the type `INTERFACE` (cf U3.13.14).
- Many internal variables: 9
 - `V1` : threshold in jump (greater standard reached),
 - `V2` : indicator of the mode of the law = -1: Contact, 0: Initial or current adherence, 1: Damage, 2: Rupture, 3: Return to zero with worthless constraint.
 - `V3` : indicator of damage 0 if healthy material, 1 if damaged material, 2 if broken material.
 - `V4` : percentage of dissipated energy,
 - `V5` : value of dissipated energy,
 - `V6` : value of current residual energy: Nulle for this laws (valid for `CZM_XXX_REG`).
 - `V7` : normal jump, `V8` : tangential jump, `V9` : tangential jump (no one in 2D).
- Examples: to see tests `SSNP118` and `SSNP166`.

4.4.7.11 `CZM_EXP_MIX`

Cohesive relation of behavior (Cohesive Mixed Model Zone Exponential) (cf [R7.02.11]) modelling the opening and the propagation of a crack. This law 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 the crack in mode of opening according to an exponential form. It is appropriate at the time of the quasi-fragile modeling of material like the concrete. The data necessary

of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model can sometimes require to use the techniques of piloting by `PRED_ELAS` to facilitate convergence (cf. [U4.51.03]).

- Supported modeling: all modelings of the type `INTERFACE` (cf U3.13.14).
- Many internal variables: 9
 - $V1$: threshold in jump (greater standard reached),
 - $V2$: indicator of the mode of the law = -1: Contact, 0: Initial or current adherence, 1: Damage, 2: Rupture, 3: Return to zero with worthless constraint.
 - $V3$: indicator of damage 0 if healthy material, 1 if damaged material, 2 if broken material.
 - $V4$: percentage of dissipated energy,
 - $V5$: value of dissipated energy,
 - $V6$: value of current residual energy: Nulle for this laws (valid for `CZM_xxx_REG`).
 - $V7$: normal jump, $V8$: tangential jump, $V9$: tangential jump (no one in 2D).
- Examples: to see tests `SSNP118` and `SSNP166`.

4.4.7.12 '`CZM_TAC_MIX`'

Cohesive relation of behavior (Cohesive Zone Mixed Model Heel-Curnier) (see [R7.02.11]) modelling the opening and the propagation of a crack. This law 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 the crack into the three modes of rupture with an irreversibility of the Heel-Curnier type. Attention, this law 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model requires the presence of piloting by `PRED_ELAS` (cf. [U4.51.03]).

- Supported modeling: all modelings of the type `INTERFACE` (cf U3.13.14).
- Many internal variables: 9
 - $V1$: threshold in jump (greater standard reached),
 - $V2$: indicator of the mode of the law = -1: Contact (only for `CZM_OUV_MIX`), 0: Initial or current adherence, 1: Damage, 2: Rupture, 3: Return to zero with worthless constraint.
 - $V3$: indicator of damage 0 if healthy material, 1 if damaged material, 2 if broken material.
 - $V4$: percentage of dissipated energy,
 - $V5$: value of dissipated energy,
 - $V6$: value of current residual energy: Nulle for this laws (valid for `CZM_xxx_REG`).
 - $V7$: normal jump, $V8$: tangential jump, $V9$: tangential jump (no one in 2D).
- Examples: to see tests `SSNP118`, `SSNA115`, `SSNV199`.

4.4.7.13 '`CZM_TRA_MIX`'

Cohesive relation of behavior (Cohesive Zone Mixed Model Trapezoid) (see [R7.02.11]) modelling the opening and the propagation of a crack in ductile rupture. This law 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 the crack only in mode of opening. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_DUCT`.

- Supported modeling: all modelings of the type `INTERFACE` (cf U3.13.14).
- Many internal variables: 9
 - $V1$: threshold in jump, allows to take into account the irreversibility of cracking, to see its definition in the preceding ones part (specific to each law).
 - $V2$: indicator of the mode of the law $V2=-1$: Contact, $V2=0$: initial or current adherence, $V2=1$: dissipation, $V2=2$: final rupture, $V2=3$: plate.

$V3$: indicator of damage $V3=0$ if healthy material, $V3=1$ if damaged material, $V3=2$ if broken material.

$V4$: percentage of dissipated energy.

$V5 = V4 \times G_c$: value of dissipated energy.

$V6$: value of current residual energy: Nulle for this laws (valid for `CZM_xxx_REG`).

$V7 = \delta_n$: jump normal, $V8 = \delta_t$: tangential jump, $V9 = \delta_r$ tangential jump (no one in 2D).

- Examples : to see tests SSNP151, SSNA120.

4.4.7.14 'CZM_FAT_MIX'

Cohesive relation of behavior for tiredness (see [R7.02.11]). This law 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 propagation of fatigue crack 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `RUPT_FRAG`. The use of this model requires the presence of piloting by `PRED_ELAS` (cf. [U4.51.03]).

- Supported modeling: all modelings of the type `INTERFACE` (cf U3.13.14).
- Many internal variables: 9
- Example: to see tests SSNP118, SSNP139

4.4.7.15 'CZM_LAB_MIX'

Cohesive relation of behavior (Cohesive Zone Mixed Model Steel-concrete Connection) (cf [R7.02.11]) modelling the behavior of a steel-concrete interface. This law 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 slip of steel compared to the concrete.

The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `CZM_LAB_MIX`.

- Supported modelings: all modelings of the type `INTERFACE` (cf U3.13.14).
- Many internal variables: 5
 - $V1$: threshold in jump (greater standard reached),
 - $V2$: indicator of the mode of the law = 0: Initial or current adherence, 1: Damage, 2: Rupture, 3: Return to zero with worthless constraint.
 - $V3$: normal jump, $V4$: tangential jump, $V5$: tangential jump (no one in 2D).
- Example: to see test SSNS110.

4.4.7.16 'RUPT_FRAG'

Nonlocal relation of behavior based on the formulation of J.J. Marigo and G. Frankfurt of the breaking process (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 material are defined in the operator `DEFI_MATERIAU` [U4.43.01] under the keywords `ELAS`, `RUPT_FRAG` and `NON_LOCAL`.

- Supported nonlocal modeling: `GRAD_VARI`.
- Many internal variables: 4
- Significance: $V1$: value of the damage, $V2$ with $V4$: 3 components of the gradient of the damage.
- Example: to see test SSNA101.

4.4.7.17 'RANKINE'

Relation of behavior used for modeling simplified joints of the stoppings out of concrete [R7.01.39]. It is about a criterion of perfect plasticity in traction relating to the components of the principal constraints: $\sigma_{i=1,2,3} \leq \sigma_t$. When a principal constraint reaches the value threshold σ_t , the joint opens in this direction. It should be noted that the plastic deformation thus created is not reversible, the model thus does not make it possible to represent the Re-closing of the joint and is valid only on one way of monotonous loading. The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keyword `RANKINE`.

- Modeling supported: `D_PLAN`, `C_PLAN`, `AXIS`, `3D`.
- Many internal variables: 9
- Example: to see tests `SNV515`, `SNV516`

4.4.7.18 `\JOINT_MECA_RUPT'`

Relation of behavior of contact, rubber band with tensile strength and rupture (cf [R7.01.25]). This law is usable with the finite elements of joint into linear and quadratic. Hydraulic modeling is not possible that 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 rigidity dependent on the normal opening of the joint. The hydrostatic pressure due to the presence of liquid 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 to the construction of the stoppings, is also implemented. The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keyword `JOINT_MECA_RUPT`.

- Modeling supported: `PLAN_JOINT`, `AXIS_JOINT`, `3D_JOINT`, `PLAN_JOINT_HYME`, `3D_JOINT_HYME`.
- Many internal variables: 18
- Example: to see tests `SSNP162`, `SSNP142`, `SSNP143`

4.4.7.19 `\JOINT_MECA_FROT'`

An elastoplastic version of the standard law of friction Mohr-Coulomb (confer [R7.01.25]). This law is usable with the finite elements of joint into linear and quadratic. Hydraulic modeling is not possible that 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 rubber band. The flow is normal for this tangential part. The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keyword `JOINT_MECA_FROT`.

- Supported modeling: `PLAN_JOINT`, `AXIS_JOINT`, `3D_JOINT`, `PLAN_JOINT_HYME`, `3D_JOINT_HYME`.
- Many internal variables: 18
- Example: to see tests `SSNP162d/e/f/j/k/l`, `SSNP142c/d/g/h`

4.4.7.20 `\ENDO_HETEROGENE'`

The law `ENDO_HETEROGENE` is an isotropic model of damage representing the formation and the propagation of the cracks starting from a distribution of microphone-defects given by a model of Weibull. The presence of crack in the structure is modelled by lines of broken elements ($d=1$). The rupture of the elements can be caused either by the starting of a new crack, or by propagation (see [R7.01.29] for more details). It is thus about a model with two thresholds. This law is adapted to heterogeneous materials such as for example mudstone.

The characteristics of material are defined in the operator `DEFI_MATERIAU [U4.43.01]` under the keywords `ENDO_HETEROGENE`, `ELAS` and `NON_LOCAL`.

Supported nonlocal modeling: D_PLAN_GRAD_SIGM

- Many internal variables for modeling D_PLAN_GRAD_SIGM : 12
- Significance:
- $V1$: value of the damage d ,
- $V2$: healthy element (0), pointed (1), broken by starting (2), broken by propagation (3)
- $V3$: breaking stress by starting,
- $V4$: breaking stress by propagation,
- $V5$: number of the element pointed number 1,
- $V6$: number of the element pointed number 2 (when starting),
- $V7$: iteration of Newton of rupture,
- $V8$: current iteration of Newton,
- $V9$: coordinate X point of crack after rupture by propagation,
- $V10$: coordinate Y point of crack after rupture by propagation,
- $V11$: coordinate X point of crack 2 during starting,
- $V12$: coordinate Y point of crack 2 during starting,
- Example: to see test ssnp147 and ssnp148

4.4.8 Behaviors specific to the modeling of the concrete and the reinforced concrete

4.4.8.1 'ENDO_ISOT_BETON'

Relation of elastic behavior fragile. It is about a local modeling with scalar damage and negative linear isotropic work hardening which distinguishes behaviour in traction and compression from the concrete (see [R7.01.04] for more details). The characteristics of material are defined in the operator `DEFI_MATERIAU` [U4.43.01] under the keywords `BETON_ECRO_LINE` and `ELAS`.

Supported local modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `INCO_UPG`, `INCO_UP`, `CONT_1D` (by `BORST`)

- Many internal variables: 2
- Significance: $V1$: value of the damage, $V2$: indicator of damage (0 for elastic mode (null damage), 1 if damaged, 2 if broken (damage equal to 1)).
- Example: to see test `SSNV149`.

4.4.8.2 'ENDO_FISS_EXP'

Relation of quasi-fragile behavior nonlocal intended for the modeling of the cracking of the concrete at the level of the individual crack. The model introduces a threshold of damage characteristic of the concrete, restores part of rigidity in the directions of requests in compression and tends towards a cohesive law when the internal length (the nonlocal scale) tends towards zero (see [R5.03.28] for more details). The characteristics of the concrete are ideally defined in the operator `DEFI_MATER_GC` [U4.42.07] in terms of sizes of the engineer or, if not, in the operator `DEFI_MATERIAU` [U4.43.01] (keywords factors `ENDO_FISS_EXP`, `ELAS` and `NON_LOCAL`) to inform the values of the internal parameters of the law.

Not supported local modeling.

Supported nonlocal modeling: `GRAD_VARI`

- Many internal variables: 9
- Significance: $V1$ = value of the damage, $V2$ = indicating of damage (0 for elastic mode (null damage), 1 if damaged, 2 if broken (damage equal to 1)) $V3$ = residual rigidity, $V4$ with $V9$ = mechanical deformation at the end of the step of time (used in the event of recovery with adaptation of grid)
- Example: to see tests `SSNL125`, `SSNP168`, `SSNV234`, `SSNA119`

4.4.8.3 'ENDO_SCALEIRE'

Relation of fragile elastic behavior. It is about a nonlocal modeling with scalar damage and negative work hardening which distinguishes behaviour in traction and compression concerning surface from load (see [R5.03.25] for more details). The characteristics of material are defined in the operator `DEFI_MATERIAU` [U4.43.01] under the keywords `ENDO_SCALEIRE`, `NON_LOCAL` and `ELAS`.

Not supported local modeling.

Supported nonlocal modeling: `GRAD_VARI`

- Many internal variables: 3
- Significance: $V1$: value of the damage, $V2$: indicator of damage (0 for elastic mode (null damage), 1 if damaged, 2 if broken (damage equal to 1)) $V3$: residual rigidity
- Example: to see tests `SSNL125`, `SSNP146`, `SSNV223`, `SSNA119`

4.4.8.4 'ENDO_CARRE'

Relation of elastic behavior fragile. It is about a nonlocal modeling with quadratic regularized damage and negative isotropic work hardening, which distinguishes behaviour in compression from that in traction (see [R5.03.26] for more details). The characteristics of material are defined in the operator `DEFI_MATERIAU [U4.43.01]` under the keywords `ECRO_LINE`, `NON_LOCAL` and `ELAS`.

Not supported local modeling.

Supported nonlocal modeling: `GVNO`

- Many internal variables: 2
- Significance: $V1$: value of the damage, $V2$: indicator of damage (0 for elastic mode (null damage), 1 if damaged)

Example: to see tests `SSNP307`, `SSNA119`, `SSNV220`

4.4.8.5 'ENDO_ORTH_BETON'

Anisotropic relation of behavior of the concrete with damage [R7.01.09]. It is about a local modeling of fascinating damage of account the refermeture of the cracks. The characteristics of materials are defined in the operator `DEFI_MATERIAU` under the keywords `ELAS` and `ENDO_ORTH_BETON`.

Supported local modelings: `3D`, `2D`, `CONT_PLAN` (by `BORST`), `INCO`, `CONT_1D` (by `BORST`)

- Many internal variables: 7
- Significance: $V1$ with $V6$: tensor of damage of traction
- $V7$: damage of compression
- Example: to see test `SSNV176`

4.4.8.6 'MAZARS'

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

Supported local modelings: `3D`, `2D`, `CONT_PLAN`, `INCO`, `CONT_1D` (by `BORST`)

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

4.4.8.7 'MAZARS_GC'

Relation of elastic behavior fragile. It makes it possible to give an account of the softening of the concrete and distinguishes the damage in traction and compression. Two variables of scalar damage are used (confer [R5.03.09] for more details). The characteristics of material are defined in the operator `DEFI_MATERIAU [U4.43.01]` under the keywords `MAZARS` and `ELAS`.

Supported modelings : `1D`, `C_PLAN`, goesriables internal: 8 (confer [R5.03.09] for more details).

- $V1$: Criterion in constraint,
- $V2$: Criterion in deformation,
- $V3$: Damage,
- $V4$: Equivalent deformation of traction,
- $V5$: Equivalent deformation of compression,
- $V6$: Report of tri-axialité.
- $V7$: Maximum temperature attack in material,

- $V8$: nonrecoverable dissipation.

4.4.8.8 'ENDO_PORO_BETON'

ENDO_PORO_BETON is the model of damage of the concrete developed within the LMDC (Laboratory Materials and Durability Of Constructions) in collaboration with the Hydraulic Center of Engineering of EDF. This module of damage takes into account the dissymmetry of the behavior of the concrete (will traCtion-compression), residual deformations and refermeture of crack. In traction, the damage is described by an orthotropic tensor and in compression, the damage is described by an isotropic tensor. This module can also be coupled with module FLUA_PORO_BETON through use FLUA_ENDO_PORO to take into account the phenomena of creep and also with model RGI_BETON. Let us specify that RGI_BETON is a set of three modules making it possible to take into account the deformations differed from the concrete with FLUA_PORO_BETON, the damage of the concrete with ENDO_PORO_BETON and the reactions of internal swelling (alkali-reaction and sulfatic intern) with RGI_BETON. To use it, it is necessary to inform the parameters materials in DEFI_MATERIAU: ENDO_PORO_BETON. [U4.43.01]

- Supported modelings: 3D, 2D
- Many internal variables: 108
- Significance: to see [R7.01.30]
- Example: to see test SSNV238 and SSNV239

4.4.8.9 'BETON_DOUBLE_DP'

Three-dimensional relation of behavior used for the description of the nonlinear behavior of the concrete. It comprises a criterion of Drucker Prager in traction and a criterion of Drucker Prager in compression, uncoupled. The two criteria can have a lenitive work hardening. The data necessary of the field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords 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 the step of time (see keyword ITER_INTE_PAS).

- Supported modelings: 3D, D_PLAN and AXIS
- Many internal variables: 4
- Significance: $V1$: plastic deformation cumulated in compression, $V2$: plastic deformation cumulated in traction, $V3$: maximum temperature attack at the point of Gauss considered, $V4$: indicator of plasticity (cf Notices 1).
- Example: to see test SSNV143.

4.4.8.10 'GRILLE_ISOT_LINE'

Isothermal relation of behavior of elastoplasticity of uniaxial Von Mises with linear isotropic work hardening used for the modeling of the reinforcements of the reinforced concrete. Data necessary of field material are provided in the operator DEFI_MATERIAU [U4.43.01], under the keywords ELAS and ECRO_LINE (confer for more detail the document [R5.03.09]).

- Supported modelings: GRID
- Many internal variables: 4
- Significance: $V1$: plastic deformation cumulated in the longitudinal direction, $V2$: indicator of plasticity (cf Notices 1).
- Example: to see test SSNS100

4.4.8.11 `GRILLE_CINE_LINE`

Isothermal relation of behavior of elastoplasticity of uniaxial Von Mises with linear kinematic work hardening used for the modeling of the reinforcements of the reinforced concrete. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `ELAS` and `ECRO_LINE` (Cf for more detail the document [R5.03.09]).

- Supported modelings: `GRID`
- Many internal variables: 4
- Significance: $V1$: kinematic work hardening in the longitudinal direction, $V2$: indicator of plasticity (cf Notices 1), $V3$: unutilised.
- Example: to see test `SSNS100`

4.4.8.12 `GRILLE_PINTO_MEN`

Elastoplastic relation of isothermal behavior uniaxial of Pinto-Menegotto for the modeling of the reinforcements of the reinforced concrete under cyclic loading. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `PINTO_MENEGOTTO` (confer for more detail the document [R5.03.09]).

- Supported modelings: `GRID`
- Many internal variables: 16
- Significance: cf the document [R5.03.09]
- Example: to see test `SSNS100`

4.4.8.13 `PINTO_MENEGOTTO`

Elastoplastic relation of isothermal behavior uniaxial modelling the answer of the steel reinforcements in the reinforced concrete under cyclic loading. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `PINTO_MENEGOTTO` (Cf for more detail the document [R5.03.09]).

- Supported modelings: `CONT_1D`
- Many internal variables: 8
- Significance: cf the document [R5.03.09]
- Example: to see test `SSNS10`

4.4.8.14 `GLRC_DAMAGE`

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

- Supported modelings: `DKTG`, `Q4GG`
- Many internal variables: 19
- Significance: $V1$ with $V3$: plastic membrane extension, $V4$ with $V6$: plastic curves, $V7$: plastic dissipation, $V8$ with $V9$: variables of damage for the positive and negative inflection respectively, $V10$: dissipation of damage, $V11$ with $V13$: angles of orthotropism, $V14$ with $V19$: components of the kinematic tensor of work hardening (3 for the efforts of membrane, 3 for the moment bending).
- Example: to see tests `SSNS104`, `SDNS108`

4.4.8.15 'GLRC_DM'

This total model makes it possible to represent the damage of a reinforced concrete plate for moderate requests. Contrary to local modelings where each component of material is modelled except for, in the total models, the law of behavior is written directly in term of constraints and generalized deformations. Modeling until the rupture is not recommended, since the phenomena of plasticization are not taken into account, but are it in `GLRC_DAMAGE`. On the other hand, the modeling of the coupling of the damage between the effects of membrane and inflection in `GLRC_DM` is taken into account, which is not the case in `GLRC_DAMAGE`. The characteristics of material are defined in `DEFI_MATERIAU` [U4.43.01] under the keywords `GLRC_DM`. For the precise details on the formulation of the model to see [R7.01.32].

Supported modeling: `DKTG`.

- Many internal variables: 18
 - `V1` (`ENDOFLL+`) with `V2` (`ENDOFLL-`): variables of damage for the positive and negative inflection respectively
 - `V3` : `INDIEND1` : indicator of damage corresponding to `V1` (0 for elastic mode and 1 if the nonworthless speed of the damage)
 - `V4` : `INDIEND2` : indicator of damage corresponding to `V2` (0 for elastic mode and 1 if the nonworthless speed of the damage)
 - `V5` : `ADOUTRAC` : relative weakening of stiffness out of membrane in traction
 - `V6` : `ADOUCOMP` : relative weakening of stiffness out of membrane in compression
 - `V7` : `ADOUFLEX` : relative weakening of stiffness in inflection
 - `V8` : `ACIXELS` : ruffleport enters the deformation of steel direction X (maximum between the tablecloth lower and higher) and the deformation `EPSI_ELS`
 - `V9` : `ACIXELU` : ruffleport enters the deformation of steel direction X (maximum between the tablecloth lower and higher) and the deformation `EPSI_ELU`
 - `V10` : `ACIYELS` : ruffleport enters the deformation of steel the direction Y (maximum enters the lower and higher tablecloth) and deformation `EPSI_ELS`
 - `V11` : `ACIYELU` : ruffleport enters the deformation of steel the direction Y (maximum enters the lower and higher tablecloth) and deformation `EPSI_ELU`
 - `V12` : `BETSUP` : ruffleport enters the principal deformation weakest (in compression) of the concrete opposite higher and the limiting deformation the concrete in compression `EPSI_C`.
 - `V13` : `Study BureauINF` : ruffleport enters the principal deformation weakest (in compression) of the concrete opposite inférieure and the deformation limits concrete in compression `EPSI_C`.
 - `V14` : `TRAMAX` : Dmaximum eformation temporal in traction
 - `V15` : `COMAX` : Dmaximum eformation temporal in compression
 - `V16` : `FLEMAX` : Dmaximum eformation temporal in inflection
 - `V17` : `ERRCOM` : Error expressed as a percentage between the surfaces of the curve in theoretical compression (defined by `EPSI_C` and `FCJ`) and the approximated curve (`NYC`, `GAMMA_C`) between 0 and `COMAX`
 - `V18` : `ERRFLE` : Error expressed as a percentage between the surfaces of the curve in theoretical inflection (calculation of reinforced concrete section) and the approximated curve (`MFY`, `GAMMA_F`) between 0 and `FLEMAX`

Example: to see test `SSNS106`.

4.4.8.16 'DHRC'

This total model, formulated in deformations and generalized efforts, makes it possible to represent the damage of a plate out of reinforced concrete as well as the slip steel/consecutive concrete with the damage, for moderate cyclic requests. Contrary to local modelings where each component of material is modelled except for, in the total models, the law of behavior is written directly in terms of constraints and generalized deformations. Modeling until the rupture is not recommended, since the phenomena of plasticization are not taken into account, but are it in `GLRC_DAMAGE`. On the other hand, the modeling of the coupling of the damage between the effects of membrane and inflection in `DHRC` is taken into account, which is not the case in `GLRC_DAMAGE`. Compared to the model `GLRC_DM`, the model `DHRC` allows to represent moreover: the slip steel/concrete and the dissipation of associated energy, the anisotropic elastic coupling out of inflection-membrane coming from an unspecified dissymmetry enters the steel tablecloths lower and higher. The characteristics of material are to be provided in `DEFI_MATERIAU` [U4.43.01] under the keywords `DHRC`, starting from preliminary calculations of homogenisation. For the precise details on the formulation of the model to see [R7.01.36].

Modeling supported: `DKTG`.

- Many internal variables: 9
- $V1$ with $V2$: variables of damage for the positive and negative inflection respectively,
- $V3$ with $V6$: variables of slip steel/concrete: directions x and y (in local reference mark) of steels of the higher tablecloth then idem for steels of the lower tablecloth,
- $V7$ with $V9$: dissipation of internal energy due to the damage, dissipation of internal energy due to the slips, and total dissipation (nap of the two preceding ones).

Example: to see test `SSNS106`.

4.4.8.17 'CORR_ACIER'

Elastoplastic model endommageable for which the plastic deformation with rupture depends on the rate of corrosion (cf [R7.01.20]). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `ELAS` and `CORR_ACIER`.

- Modelings:: 3D, 2D, `CONT_1D`, `CONT_1D` (PMF)
- 3 internal variables:
 - $V1$: cumulated plastic deformation
 - $V2$: coefficient of damage
 - $V3$: indicator of plasticity (cf Notices 1)
- Example: to see test `SSNL127`.

4.4.8.18 'BETON_REGLE_PR'

Relation of concrete behavior nonlinear rubber band (developed by company NECS) known as 'right-angled parabola'. The characteristics of material are defined in the operator `DEFI_MATERIAU` [U4.43.01] under the keyword `BETON_REGLE_PR` and `ELAS`.

The law `BETON_REGLE_PR` is a concrete law approaching the lawful concrete laws (from where its name) which has the characteristic summaries following:

- it is a law 2D and more exactly 2 times 1D: in the clean reference mark of deformation, one writes a law 1D stress-strain;
- the law 1D on each direction of clean deformation is the following one:
 - in traction, linear until a peak, linear softening up to 0;
 - in compression, a law power to a plate (from where `PR` : parabola-rectangle).
- Modelings: `C_PLAN`, `D_PLAN`
- Example: to see test `SSNP129` or `SSNS114`

The equations of the model are described in [R7.01.27].

4.4.8.19 'JOINT_BA'

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

- Supported modelings: `PLAN_JOINT` and `AXIS_JOINT`.
- Many internal variables: 6
- Significance: $V1$: value of the damage in the normal direction, $V2$: value of the damage in the tangential direction, $V3$: scalar variable of isotropic work hardening for the damage in mode 1, $V4$: scalar variable of isotropic work hardening for the damage in mode 2, $V5$: deformation of slip cumulated by friction of the cracks, $V6$: value of kinematic work hardening by friction of the cracks.
- Example: to see test `SSNP126`

4.4.8.20 'BETON_GRANGER'

Relation of behavior for the modeling of the creep of the concrete. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `BETON_GTO` `ARRANGE` (see [R7.01.01] for more details).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`), `CONT_1D` (by `BORST`), `CONT_1D` (PMF)
- Many internal variables: 55
- Significance: to see [R7.01.01]
- Example: to see test `SSNP116`

4.4.8.21 'BETON_GRANGER_V'

Relation of behavior for the modeling of the creep of the concrete with taking into account of the phenomenon of ageing. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `V_BETON_GRANGER` (confer [R7.01.01] for more details).

- Modelings knownranges: 3D, 2D, `CONT_PLAN` (by `BORST`), `CONT_1D` (by `BORST`)
- Many internal variables: 55
- Significance: to see [R7.01.01]
- Example: to see test `YYYY1 17`

4.4.8.22 'BETON_UMLV'

Relation of behavior for the modeling of the 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 cases of multiaxial creeps. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `BETON_UMLV` (confer [R7.01.06] for more details).

- Supported modelings: 3D, 2D, `CONT_PLAN` (by `BORST`),
- Many internal variables: 21
- Significance: to see [R7.01.06]
- Example: to see test `SSNV163`

4.4.8.23 'BETON_RAG'

Relation of behavior for the modeling of the structures affected by the reaction alkali-aggregate. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `BETON_RAG` (confer [R7.01.26] for more details).

- Supported modelings: 3D, 2D AXI, 2D D_PLAN
- Many internal variables: 33
- Significance: to see [R7.01.26]

4.4.8.24 'BETON_BURGER'

Relation of behavior for the modeling of the 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. Taking into account of the thermo-activation of the deformations of creep via a law of the Arrhenius type. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `BETON_BURGER` (confer [R7.01.35] for more details).

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST),
- Many internal variables: 33
- Significance: to see [R7.01.35]
- Example: to see test S `SSNV163`, `SSNV174`, `SSNV180`, `SSNV181` and `SSNV235`

4.4.8.25 Behavior `FLUA_PORO_BETON`

`FLUA_PORO_BETON` is the model of creep of the concrete developed within the LMDC (Laboratory Materials and Durability Of Constructions) in collaboration with the Hydraulic Center of Engineering of EDF. This module of creep takes into account all the deformations differed (withdrawal, creep of desiccation and clean creep) using a poromechanic modeling and from a diagram of BURGER. This module belongs to the model `RGI_BETON`. Let us specify that `RGI_BETON` is a set of three modules allowing to take into account the deformations differed from the concrete with `FLUA_PORO_BETON`, the damage of the concrete with `ENDO_PORO_BETON` and the reactions of swelling interns (alkali-reaction and sulfatic intern) with `RGI_BETON`. To use it, it is necessary to inform the parameters materials `FLUA_PORO_BETON` in `DEFI_MATERIAU`.

- Supported modelings: 3D, 2D
- Many internal variables: 108
- Reference material: R7.01.30
- Example: to see test S `SSNV235` and `SSNV236`

4.4.8.26 Behavior `RGI_BETON`

`RGI_BETON` is the model of reaction of expansion of concrete (alkali-reaction and sulfatic intern) developed within the LMDC (Laboratory Materials and Durability Of Constructions) in collaboration with the Hydraulic Center of Engineering of EDF. This module belongs to the model `RGI_BETON`. Let us specify that `RGI_BETON` is a set of three modules allowing to take into account the deformations differed from the concrete with `FLUA_PORO_BETON`, the damage of the concrete with `ENDO_PORO_BETON` and the reactions of swellings interns with `RGI_BETON`. Pour to use it, it is necessary to inform the parameters materials `RGI_BETON` in `DEFI_MATERIAU`.

- Supported modelings: 3D, 2D
- Many internal variables: 108
- Reference material: R7.01.30

4.4.9 Mechanical behaviors for géo-materials

The mechanical models for the géo-materials (grounds, rocks) only can for the majority being used in mechanical modelings or modelings THM, via the keyword KIT_HM, KIT_HHM, KIT_THM, KIT_THHM.

4.4.9.1 'GONF_ELAS'

Relation of behavior being used to describe the behavior of "inflating" clay materials type (bentonite). It is about a nonlinear elastic model connecting the clear constraint (*contrainte* – *Pgaz*) with the pressure of swelling which it even depends on suction (or capillary pressure). This model is developed for modelings not saturated with type *HH*.

- Supported modelings: HHM, THHM.
- Many internal variables: 0
- Example: to see the tests reproducing the swelling of a clay cell which one saturates gradually: plan (wtnp119a, B, C, D), axi (wtna110a, B, C, D) and 3D (wtnv136a, B, C, D)

4.4.9.2 'MOHR_COULOMB'

Elastoplastic relation of behavior for calculations in soil mechanics. It is the simplest model used to represent at first approximation the behavior with the rupture of a ground under monotonous loading. This model is a multicriterion model characterized by the intersection of 6 plans within the space of diverters of the principal constraints (see [R7.01.28] for more details). The data necessary of the field material are provided in the operator DEF_MATERIAU [U4.43.01], under the keywords MOHR_COULOMB and ELAS.

- Supported modelings: 3D, 2D, THM.
- Many internal variables: 3
- Significance: *V1* : voluminal plastic deformation, *V2* : normalizes deviatoric deformations, *V3* : indicator of activation of plasticity (1) or not (0).
- Example: to see tests SSVN232, SSVN233, SSVN104, WTNV142

4.4.9.3 'CJS'

Elastoplastic relation of behavior for calculations 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 the operator DEF_MATERIAU [U4.43.01], under the keywords CJS and ELAS. To facilitate the integration of this model, one can use the local automatic recutting of the step of time (see keyword ITER_INTE_PAS).

- Supported modelings: 3D, 2D, CONT_PLAN (by BORST), CONT_1D (by BORST), THM.
- Many internal variables: 16 in 3D and 14 in 2D
- Significance: *V1* : isotropic threshold, *V2* : angle of the threshold déviatoire, *V3* with *V8* (*V3* with *V6* in 2D): 6 (4 in 2D) component of the kinematic tensor of work hardening, *V9* (*V7* in 2D): distance standardized with the threshold déviatoire, *V10* (*V8* in 2D): relationship between the threshold déviatoire and the threshold deviatoric criticism, *V11* (*V9* in 2D): distance standardized with the isotropic threshold, *V12* (*V10* in 2D): iteration count internal, *V13* (*V11* in 2D): value of the local test of stop of the iterative process, *V14* (*V12* in 2D): many local recuttings of the step of time, *V15* (*V13* in 2D): sign of the contracted product of the deviatoric constraint by the deviatoric plastic deformation, *V16* (*V14* in 2D): indicator (0 so elastic, 1 so

elastoplastic with mechanism isotropic plastic, 2 so elastoplastic with plastic mechanism déviatoire, 3 so elastoplastic with plastic mechanisms isotropic and déviatoire).

- Example: to see tests SSNV135, SSNV136, SSNV154, WTNV100

4.4.9.4 'LAIGLE'

Relation of behavior for the modeling of the rocks according to the model of Laigle. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `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 the step of time (keyword `ITER_INTE_PAS`).

- Supported modelings: 3D, 2D, THM
- Many internal variables: 4
- Significance: $V1$: plastic deformation déviatoire cumulated, $V2$: cumulated plastic voluminal deformation, $V3$ fields of behavior of the rock, $V4$: indicator of state.
- Example: to see test SSNV158, WTNV101

4.4.9.5 'LETK'

Relation of behavior for the elastoviscoplastic modeling of the rocks according to the model of Laigle and Kleine. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `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 the keyword `TYPE_MATR_TANG`. The operator relating to the elastic prediction is that of nonlinear elasticity specific to the law.

- Supported modelings: 3D, 2D, THM
- Many internal variables: 7
- Significance: $V1$: elastoplastic variable of work hardening, $V2$: plastic deviatoric deformation, $V3$: viscoplastic variable of work hardening, $V4$: viscoplastic deformation déviatoire, $V5$: indicator of contractance (0) or dilatancy (1), $V6$: indicator of viscoplasticity, $V7$: indicator of plasticity (cf Notices 1)
- Example: to see the tests SSNV206A, WTNV135A

4.4.9.6 'HOEK_BROWN'

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

- Supported modelings: 3D, 2D, C_PLAN
- Many internal variables: 3
- Significance: to see [R7.01.18]
- Example: to see test SSNV184

4.4.9.7 'HOEK_BROWN_EFF'

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

- Supported modelings: THM
- Many internal variables: 3
- Significance: to see [R7.01.18]
- Example: to see test WTNV128

4.4.9.8 'HOEK_BROWN_TOT'

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

- Supported modelings: THM
- Many internal variables: 3
- Significance: to see [R7.01.18]
- Example: to see test WTNV129

4.4.9.9 'CAM_CLAY'

Elastoplastic relation of behavior for calculations in soil mechanics normally consolidated (cf [R7.01.14] for more details). The elastic part is non-linear. The plastic part can be hardening or lenitive. The data necessary to the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `CAM_CLAY` and `ELAS`.

If the model `CAM_CLAY` is used with modeling THM, the keyword `PORO` informed under `CAM_CLAY` and under `THM_INIT` must be the same one.

- Modeling supported: 3D, 2D and THM
- Many internal variables: 2
- Significance: $V1$: voluminal plastic deformation, $V2$: indicator of plasticity (cf Notices 1).
- Example: to see tests `SSNV160`, `WTNV122`

4.4.9.10 'BARCELONA'

Relation describing the elastoplastic mechanical behavior of the unsaturated grounds 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 criterion of plasticity mechanical (that of Camwood-Clay) and one 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `BARCELONA`, `CAM_CLAY` and `ELAS`.

- Modeling supported: THM
- Many internal variables: 5
- Significance: $V1$: p critical (1/2 pressure of consolidation), $V2$: indicator of plasticity (cf Notices 1) mechanical, $V3$: hydrous threshold, $V4$: hydrous indicator of irreversibility, $V5$: P_s (cohesion).
- Example: to see test WTNV123

4.4.9.11 'DRUCK_PRAGER'

Associated relation of behavior of the Drucker-Prager type for the soil mechanics (cf [R7.01.16] for more details). The characteristics of material are defined in the operator `DEFI_MATERIAU` [U4.43.01] under the keywords `DRUCK_PRAGER` and `ELAS(_FO)`. It is supposed however that the thermal dilation coefficient is constant. Work hardening can be linear or parabolic.

- Modeling supported: THM, 3D, 2D
- Many internal variables: 3
- $V1$: plastic deformation déviatoire cumulée, $V2$: cumulée plastic voluminal deformation, indicating $V3$ of state.
- Example: to see tests SSNV168, WTNA101

4.4.9.12 'DRUCK_PRAG_N_A'

Nonassociated relation of behavior of the Drucker-Prager type for the soil mechanics (cf [R7.01.16] for more details). The characteristics of material are defined in the operator `DEFI_MATERIAU` [U4.43.01] under the keywords `DRUCK_PRAGER` and `ELAS(_FO)`. It is supposed however that the thermal dilation coefficient is constant. Work hardening can be linear or parabolic.

- Modeling supported: THM, 3D, 2D
- Many internal variables: 3
- $V1$: plastic deformation déviatoire cumulée, $V2$: cumulée plastic voluminal deformation, $V3$ indicator of state.
- Example: to see test SSND104.

4.4.9.13 'VISC_DRUC_PRAG'

Relation of behavior for plastic modeling élasto visco of the rocks. Elastoplasticity is of type Drucker Prager and creep is a law power of the Perzyna type. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `VISC_DRUC_PRAG` (Cf the document [R7.01.22] for more details).

- Modeling supported: 3D and THM
- Supported modelings: 3D, 2D, THM
- Many internal variables: 4
- Significance: $V1$: viscoplastic variable of work hardening, $V2$: indicator of plasticity (cf Notices 1), $V3$: level of work hardening, $V4$: iteration count local
- Example: to see tests SSNV211A, WTNV137A, WTNV138A

4.4.9.14 'HUJEUX'

Relation of elastoplastic behavior cyclic 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `HUJEUX` and `ELAS`. To facilitate the integration of this model, one can use the local automatic recutting of the step of time (keyword `ITER_INTE_PAS`).

- Modeling supported: 3D and THM
- Diagrams of open integration: 'NEWTON', 'NEWTON_PERT', 'NEWTON_RELI', 'SEMI_EXPLICITE', 'BASCULE_EXPLICIT', 'SPECIFIC'
- Many internal variables: 50
- Significance: $V1$ with $V3$: factors of work hardening of the monotonous mechanisms déviatoires, $V4$: factor of work hardening of the monotonous isotropic mechanism, $V5$ with $V7$: factors of work hardening of the cyclic mechanisms déviatoires, $V8$: factor of work hardening of the cyclic isotropic mechanism, $V9$ with $V22$: variables of history related to the cyclic mechanisms, $V23$: cumulée plastic voluminal deformation, $V24$ with $V31$: indicators of

state of the monotonous and cyclic mechanisms, $V32$: criterion of Hill. 'INDETAC3', 'HIS34', 'HIS35', 'XHYZ1', 'XHYZ2', 'THYZ1', 'THYZ2', 'RHYZ', 'XHXZ1', 'XHXZ2', 'THXZ1', 'THXZ2', 'RHXX', 'XHXY1', 'XHXY2', 'THXY1', 'THXY2', 'RHYZ'

- Example: to see tests SSNV197, SSNV204, SSNV205, WTNV132, WTNV133, WTNV134.

4.4.9.15 'JOINT_BANDIS'

Relation of nonlinear elastic behavior for the water seals in rock mechanics. In the normal direction with the joint, one has a hyperbolic relation between the effective constraint 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 the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `JOINT_BANDIS` (confer the document [R7.02.15] for more details).

- Supported modeling: `PLAN_JHMS`, `AXIS_JHMS`
- Many internal variables: 1
- Significance: $V1$: longitudinal permeability of the crack
- Example: to see tests WTNP125, WTNP126.

4.4.9.16 'LKR'

Relation of behavior for modeling thermoélasto(visco)plastic of the rocks. The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `LKR` (Cf. the document [R7.01.40] for more details). The tangent operator not being complete, it is possible to use the matrix of disturbance under the keyword `TYPE_MATR_TANG`. The operator relating to the elastic prediction is that of nonlinear elasticity specific to the law.

- Supported modelings: 3D, 2D, THM
- Many internal variables: 12
- Significance: $V1$: variable of work hardening plastic mechanism, $V2$: plastic deformation equivalent, $V3$: variable of work hardening mechanism viscoplastic, $V4$: deformation viscoplastic equivalent, $V5$: indicator of contractance (0) or dilatancy (1), $V6$: indicator of viscoplasticity, $V7$: indicator of plasticity, $V8$: voluminal mechanical elastic strain, $V9$: voluminal thermal elastic strain, $V10$: voluminal plastic deformation, $V11$: voluminal viscoplastic deformation, $V12$: field
- Example: to see the tests SSNV206, WTNV135.

4.4.9.17 'Iwan'

Elastoplastic law of behavior multicriterion in soil mechanics adapted for the cyclic behavior deviatoric, written under MFront. The law of behavior of Iwan [R7.01.38] makes it possible to reproduce the curves of degradation of the modulus of rigidity.. The data necessary to the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `Iwan`.

- Modeling supported: 3D
- Open diagrams of integration: 'NEWTON', 'NEWTON_PERT',
- Many internal variables: 103
- Significance: $V1$ with $V6$: terms of the tensor of elastic strain, $V7$ with $V18$: scalar plastic multipliers of surfaces of load, $V19$ with $V91$: terms of the tensors of kinematic work hardening, $V92$ with $V103$: values of the surface of load
- Example: to see tests MFRON02, COMP012, SSNV205, SSNV207.

4.4.10 Behaviors integrated by an external software

use of these laws of behavior “made-to-order” implies a specific validation for the study considered, because one places oneself out of field described as *Code_hasster*.

4.4.10.1 'UMAT'

◆ **NB_VARI = nbvar**

UMAT is a format of routine FORTRAN familiar of the users of the Abaqus code, being used to integrate their own laws of behavior.

The dynamic library containing the routine UMAT must be prepared before the execution of calculation. For that, the user has a simple way compile this library by using 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 BEHAVIOR, the keyword RELATION=' UMAT',
- always under BEHAVIOR, mot_clé NB_VARI allowing to specify the number of internal variables of the behavior, and of course the keywords usual: GROUP_MA, DEFORMATION,
- One shows the way towards the library under the keyword BOOKSTORE and the name of the symbol (name of the routine contained in the library) under the keyword NOM_ROUTINE ;
- the assumption of the plane constraints is taken into account by the method of Borst [R5.03.03] ;
- 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 the operator DEFI_MATERIAU [U4.43.01], under the keyword UMAT/UMAT_FO.

The current limitations of the interface Aster-Umat are:

- exit of energies: for the moment, they are not recovered by Code_Aster,
- of the same step of thermomechanical coupling for the moment.

For more details on the use of UMAT in Code_Aster, cf. [U2.10.01].

- Supported modelings: 3D, AXIS, D_PLAN
- Example: to see the tests UMAT001, UMAT002

4.4.10.2 'MFRONT'

MFRONT is a generator of code allowing to write and to integrate laws of behavior easily, it is developed by CEA Cadarache within the framework of the platform PLEIADS (cf. <http://tfel.sourceforge.net/>).

The dynamic library containing the routine MFRONT must be prepared before the execution of calculation. For that, the user will call on the order CREA_LIB_MFRONT (cf. [U7.03.04]).

The MFront coupling – **code_aster** is translated in the command file in the following way:

- on the level of BEHAVIOR, the keyword RELATION=' MFRONT',
- always under BEHAVIOR, usual keywords GROUP_MA, DEFORMATION (one can use great deformations in particular 'GDEF_LOG') ;
- one shows the way the library under the keyword UNITE_BOOKSTORE (if one used CREA_LIB_MFRONT) or BOOKSTORE (if one compiled the library with the hand) and the name of the symbol (name of the routine contained in the library) under the keyword NOM_ROUTINE ;
- the assumption of the plane constraints is taken into account by the method of Borst [R5.03.03] ;
- keywords RESI_INTE_MAXI, ITER_INTE_MAXI are transmitted to law MFront (cf. §4.11);

- keywords `ALGO_INTE`, `PARM_THETA` are not used.

The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `MFRONT/MFRONT_FO`.

If the file `MFront` allows it, of the checks can be made on the values of the parameters materials. The behavior in the event of going beyond the terminals is controlled by the keyword `VERI_BORNE` who is worth `'STOP'` by default. The other possible choices (for a behaviour in prototype mode) are `'MESSAGE'` (impression of the message without interruption of calculation) and `'WITHOUT'` (the error overlooked).

- Supported modelings: `3D` `AXIS` `D_PLAN`
- Example: to see the tests `MFRON01`, `MFRON02`, `MFRON03`, `MFRON04`, `MFRON05`.

More information on the use of `MFront` in `code_aster` in the dedicated note (cf. [U2.10.02]).

4.4.11 Behavior for the multifibre beams

4.4.11.1 'MULTIFIBRE'

When modeling comprises multifibre elements of beams, it is necessary to indicate the meshes and groups of meshes concerned with this modeling, way of pointing on the good behavior: key word `RELATION='MULTIFIBRE'` under `BEHAVIOR`.

The definition of material is done using the orders: `DEFI_COMPOR` and `AFFE_MATERIAU`.

```
COMPOR =DEFI_COMPOR (
  GEOM_FIBRE=GF, MATER_SECT=CONCRETE,
  MULTIFIBRE= (
    _F (GROUP_FIBRE='SACI', MATER=STEEL, RELATION='VMIS_CINE_GC'),
    _F (GROUP_FIBRE='SBET', MATER=CONCRETE, RELATION='MAZARS'),
  ),
)

CHMAT =AFFE_MATERIAU (
  MAILLAGE=MY,
  AFFE=_F ( GROUP_MA = 'BEAM', MATER = (STEEL,CONCRETE,) ),
  AFFE_COMPOR=_F (GROUP_MA = 'BEAM', COMPOR=COMPOR)
)
```

4.5 Operand RELATION_KIT under BEHAVIOR

For the behaviors specific to the concrete and the porous environments, RELATION_KIT allows to couple several behaviors. For the mechanical behaviors with effects of the metallurgical transformations, RELATION_KIT allows to choose the type of treated material (STEEL or ZIRCALOY). Finally to model cables rubbing in their sheath (elements CABLE_GAINE), RELATION_KIT allows to define the law of behavior of the cable and the law of friction of the cable in its sheath.

4.5.1 KIT associated with the metallurgical behavior

```
/ 'STEEL'  
/ 'ZIRC'
```

Allows to choose for all the metallurgical laws of behavior (META_XXX) to treat a material of type steel or Zircaloy type. The standard material STEEL comprise with more the 5 different metallurgical phases, the material ZIRC comprise with more the 3 different metallurgical phases.

Examples:

```
BEHAVIOR = ( RELATION = 'META_P_INL'  
             RELATION_KIT = 'ZIRC' )  
  
BEHAVIOR = ( RELATION = 'META_V_CL_PT_RE'  
             RELATION_KIT = 'STEEL' )
```

4.5.2 KIT associated with the behavior with the concrete: 'KIT_DDI'

Allows to add two terms with unelastic deformations defined by certain already existing laws of behavior in BEHAVIOR (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 the operator DEFI_MATERIAU [U4.43.01], under the keywords ELAS (_FO) (**the two laws must have the same YOUNG modulus**) 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 calculation to times characteristic of the phenomena modelled in order not to handicap calculation in term of iteration count. In this case, local parameters of convergence (RESI_INTE_RELA and ITER_INTE_MAXI under the keyword CONVERGENCE) are the same ones for the integration of the two models.

With the models of creep:

- 'BETON_GRANGER'
- 'BETON_GRANGER_V'

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'

can be associated the following models of behavior:

- 'ENDO_ISOT_BETON',
- 'MAZARS'

Supported modelings: 3D, 2D, CONT_PLAN (by BORST or ANALYTICAL according to each model.

- The internal variables of each law are cumulated in the table of the internal, and restored variables law by law.

Example:

```
BEHAVIOR = _F ( RELATION = 'KIT_DDI'  
RELATION_KIT = ('BETON_UMLV_FP', 'MAZARS'))
```

- See also yourT SSNV169

With the model of creep

- 'FLUA_PORO_BETON'

can be associated the following models of behavior:

- 'ENDO_PORO_BETON',

Supported modelings: 3D

The internal variables of each law are cumulated in the table of the internal, and restored variables law by law.

- Example:

```
BEHAVIOR = _F ( RELATION = 'KIT_DDI'  
RELATION_KIT = ('FLUA_PORO_BETON',  
'ENDO_PORO_BETON'))
```

See also your T SSNV237

Formalism `KIT_DDI` also allows to associate the total model of plate, `GLRC_DM`, which implements the damage coupled membrane-inflection, with models of plasticity of Von Mises, to take into account elastoplasticity (out of membrane only):

- 'GLRC_DM'

can be associated the models with following behavior:

- 'VMIS_ISOT_TRAC',
- 'VMIS_ISOT_LINE',
- 'VMIS_CINE_LINE',

Supported modeling: DKTG. Example: tests SSNS106F, SSNS106G

4.5.3 KIT associated with the behavior with the porous environments (modelings thermo-hydro-mechanics)

For more details on modelings thermo-hydro-mechanics and the models 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].

4.5.3.1 Keyword `RELATION`

Relations `KIT_XXXX` allow to solve simultaneously from two to four equilibrium equations. The equations considered depend on the suffix `XXXX` with the following rule:

- `M` indicate the mechanical equilibrium equation,
- `T` indicate the thermal equilibrium equation,
- `H` indicate a hydraulic equilibrium equation.
- `V` indicate the presence of a phase in form vapor (besides the liquid)

With the associated problems thermo-hydro-mechanics are dealt in a completely coupled way.

Only one letter `H` mean that the porous environment is saturated (only one variable with pressure p), for example either of gas, or of liquid, 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 with pressure p), for example a liquid mixture/vapor/gas.

The presence of the two letters HV mean 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 degree of freedom pressure, but there are a liquid flow and a flow vapor.

The table below summarizes to which kit each modeling 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
KIT_THH	D_PLAN_THHD, D_PLAN_THHS, AXIS_THHD, AXIS_THHS, 3D_THHD, 3D_THHS,
KIT_HH	D_PLAN_HHS, D_PLAN_HHD, AXIS_HHS, AXIS_HHD, 3D_HHS, 3D_HHD,
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
KIT_HH2	3D_HH2S 3D_HH2D 3D_HH2SUDA AXIS_HH2D AXIS_HH2S D_PLAN_HH2D D_PLAN_HH2S D_PLAN_HH2SUDA
KIT_THH2	D_PLAN_THH2D, AXIS_THH2D, 3D_THH2D, D_PLAN_THH2S, AXIS_THH2S, 3D_THH2S
KIT_HH2M	D_PLAN_HH2M, D_PLAN_HH2MS, D_PLAN_HH2MANDELEVIVUM, AXIS_HH2M, AXIS_HH2MS, AXIS_HH2MANDELEVIVUM, 3D_HH2M, 3D_HH2MS, 3D_HH2MANDELEVIVUM
KIT_THH2M	D_PLAN_THH2MD, AXIS_THH2MD, 3D_THH2MD D_PLAN_THH2MS, AXIS_THH2MS, 3D_THH2MS, D_PLAN_HH2M_SI

4.5.3.2 Keyword `RELATION_KIT`

For each modelled phenomenon, one must specify in `RELATION_KIT` :

- the mechanical model of behavior of the skeleton,
- the gas/liquid reaction of,
- the hydraulic law.
 - `HYDR_UTIL` (if the mechanical behavior is without damage): Mean that no data material returned "into hard". Concretely in the saturated case, it will be necessary point by point to define the 6 curves (by `DEFI_FONCTION`) following:
 - saturation according to the capillary pressure,
 - the derivative of this curve,
 - the permeability relating to the liquid according to saturation,
 - its derivative.
 - the permeability relating to gas according to saturation,
 - its derivative.
 - `HYDR_VGM` (if the mechanical behavior is without damage). Here and only for the rates mixing 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 derivative are defined by the model of Mualem Van-Genuchten. The user must then inform the parameters of this law (n, Pr, Sr). The model Mualem Van-Genuchten is the following:

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

and

$$S_{we} = \frac{1}{\left(1 + \left(\frac{P_c}{P_r}\right)^n\right)^m} \quad \text{where } S_{we} = \frac{S_w - S_{wr}}{1 - S_{wr} - S_{gr}} \quad \text{and } m = 1 - \frac{1}{n}$$

- HYDR_VGC (if the mechanical behavior is without damage). Exactly the same thing as HYDR_VGM except for the law of permeability relating to the gas which is a cubic law:
$$k_r^{gz} = (1 - S_w)^3$$
- HYDR_ENDO (if one uses 'MAZARS' or 'ENDO_ISOT_BETON') under RELATION_KIT (this keyword 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).

4.5.3.3 Mechanical behaviors of the skeleton (if there is mechanical modeling \mathfrak{M})

- 'ELAS'
- 'GONF_ELAS'
- 'MOHR_COULOMB'
- 'CJS'
- 'CAM_CLAY'
- 'BARCELONA'
- 'LAIGLE'
- 'DRUCK_PRAGER'
- 'DRUCK_PRAG_N_A'
- 'HOEK_BROWN_EFF'
- 'HOEK_BROWN_TOT'
- 'MAZARS'
- 'ENDO_ISO_BETON'
- 'HUJEUX'
- 'JOINT_BANDIS'

4.5.3.4 Gas/liquid reactions of

'LIQU_SATU'

Law of behavior for porous environments saturated by only one liquid (confer [R7.01.11] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keyword `THM_LIQ`.

'LIQU_GAZ'

Law of behavior for a porous environment unsaturated liquid/gas without phase shift (confer [R7.01.11] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `THM_LIQ` and `THM_GAZ`.

'GAS'

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

'LIQU_GAZ_ATM'

Law of behavior for a porous environment unsaturated with a liquid and gas with atmospheric pressure (confer [R7.01.11] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU` [U4.43.01], under the keywords `THM_LIQ`.

'LIQU_VAPE_GAZ'

Law of behavior for a porous environment unsaturated water/vapor/dry air with phase shift (confer [R7.01.11] for more details). The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keywords `THM_LIQ`, `THM_VAPE` and `THM_GAZ`.

'LIQU_AD_GAZ_VAPE'

Law of behavior for a porous environment unsaturated water/vapor/dry air/air dissolved with phase shift (confer [R7.01.11] for more details).

The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keywords `THM_LIQ`, `THM_VAPE`, `THM_GAZ` and `THM_AIR DISS`.

'LIQU_AD_GAZE'

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

The data necessary of the field material are provided in the operator `DEFI_MATERIAU [U4.43.01]`, under the keywords `THM_LIQ`, `THM_GAZ` and `THM_AIR DISS`.

'LIQU_VAPE'

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

4.5.3.5 The hydraulic law

'HYDR_UTIL' (if the mechanical behavior is without damage): Mean that no data material returned "into hard". Concretely in the saturated case, it will be necessary point by point to define the 6 curves (by `DEFI_FONCTION`) following:

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

'HYDR_VGMe (if the mechanical behavior is without damage). Here and only for the rates mixing 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 derivative are defined by the model of Mualem Van-Genuchten. The user must then inform the parameters of this law (n, Pr, Sr). The model Mualem Van-Genuchten is the following:

$$k_r^{gz} = \sqrt{1 - S_{we}} (1 - S_{we}^{1/m})^{2m} \quad \text{and} \quad S_{we} = \frac{1}{\left(1 + \left(\frac{P_c}{P_r}\right)^n\right)^m}$$

where

$$S_{we} = \frac{S_w - S_{wr}}{1 - S_{wr} - S_{gr}} \quad \text{and} \quad m = 1 - \frac{1}{n}.$$

'HYDR_VGC' (if the mechanical behavior is without damage). Here and only for the rates mixing 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 derivative are defined by the model of Mualem Van-Genuchten (see above). The permeability relating to gas is defined by a cubic law:

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

The user must then inform the parameters of this law (n, Pr, Sr).

'HYDR_ENDO' (if one uses 'MAZARS' or 'ENDO_ISOT_BETON') under RELATION_KIT (this keyword 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).

4.5.3.6 Possible combinations

According to the value of the keyword RELATION='KIT_XXXX' 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'	'GAS'	'HYDR_UTIL')
('MOHR_COULOMB'	'GAS'	'HYDR_UTIL')
('CJS'	'GAS'	'HYDR_UTIL')
('HUJEUX'	'GAS'	'HYDR_UTIL')
('LAIGLE'	'GAS'	'HYDR_UTIL')
('CAM_CLAY'	'GAS'	'HYDR_UTIL')
('JOINT_BANDIS'	'GAS'	'HYDR_UTIL')
('MAZARS'	'GAS'	'HYDR_ENDO')
('ENDO_ISOT_BETON'	'GAS'	'HYDR_ENDO')

('ELAS'	'LIQU_SATU'	'HYDR_UTIL')
('MOHR_COULOMB'	'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')
('MOHR_COULOMB'	'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')
('GONF_ELAS'	'LIQU_GAZ'	'HYDR_UTIL')
('MOHR_COULOMB'	'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')
('BARCELONA'	'LIQU_GAZ'	'HYDR_UTIL')

```
( `ELAS'                `LIQU_GAZ'                `HYDR_VGM' )
( `GONF_ELAS'          `LIQU_GAZ'                `HYDR_VGM' )
( `CJS'                `LIQU_GAZ'                `HYDR_VGM' )
( `LAIGLE'             `LIQU_GAZ'                `HYDR_VGM' )
( `CAM_CLAY'           `LIQU_GAZ'                `HYDR_VGM' ` ` )
( `BARCELONA'         `LIQU_GAZ'                `HYDR_VGM' )
( `MAZARS'             `LIQU_GAZ'                `HYDR_ENDO' )
( `ENDO_ISOT_BETON'   `LIQU_GAZ'                `HYDR_ENDO' )

( `ELAS'                `LIQU_VAPE_GAZ'           `HYDR_UTIL' )
( `GONF_ELAS'          `LIQU_VAPE_GAZ'           `HYDR_UTIL' )
( `MOHR_COULOMB'      `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' )
( `BARCELONA'         `LIQU_VAPE_GAZ'           `HYDR_UTIL' )
( `ELAS'                `LIQU_VAPE_GAZ'           `HYDR_VGM' )
( `GONF_ELAS'          `LIQU_VAPE_GAZ'           `HYDR_VGM' )
( `CJS'                `LIQU_VAPE_GAZ'           `HYDR_VGM' )
( `LAIGLE'             `LIQU_VAPE_GAZ'           `HYDR_VGM' )
( `CAM_CLAY'           `LIQU_VAPE_GAZ'           `HYDR_VGM' )
( `BARCELONA'         `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' )
( `GONF_ELAS'          `LIQU_AD_GAZ_VAPE'         `HYDR_UTIL' )
( `MOHR_COULOMB'      `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' )
( `BARCELONA'         `LIQU_AD_GAZ_VAPE'         `HYDR_UTIL' )
( `ELAS'                `LIQU_AD_GAZ_VAPE'         `HYDR_VGM' )
( `GONF_ELAS'          `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' )
( `BARCELONA'         `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' )
( `GONF_ELAS'          `LIQU_AD_GAZ'             `HYDR_UTIL' )
( `MOHR_COULOMB'      `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' )
( `BARCELONA'         `LIQU_AD_GAZ'             `HYDR_UTIL' )
( `ELAS'                `LIQU_AD_GAZ'             `HYDR_VGM' )
( `GONF_ELAS'          `LIQU_AD_GAZ'             `HYDR_VGM' )
( `CJS'                `LIQU_AD_GAZ'             `HYDR_VGM' )
( `LAIGLE'             `LIQU_AD_GAZ'             `HYDR_VGM' )
( `CAM_CLAY'           `LIQU_AD_GAZ'             `HYDR_VGM' )
( `BARCELONA'         `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 linear research as indicated in the example set at the top of this section. Linear research does not improve however systematically convergence, it is thus to handle with precaution.

Example:

```
BEHAVIOR = _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 like behavior of the liquid, CJS like mechanical behavior.

Other examples are available, either in the document [U2.04.05], or in the whole of the tests WTNAXXX, WTNLXXX, WTNPXXX, WTNVXXX.

4.5.4 KIT associated with modeling with the rubbing cables: KIT_CG

To model rubbing or slipping cables, it is necessary to be able to inform at the same time the behavior to be assigned to the cable and the law of behavior of friction of the cable in its sheath. One gives for that to the keyword RELATION the value 'KIT_CG'. In the keyword RELATION_KIT, it is necessary to inform the law of behavior of the cable (all those accepted by modeling BAR) then the law of behavior of friction which is always CABLE_GAINE_FROT.

For more details on the law of friction, one will be able to consult the reference material of the elements CABLE_GAINE [R3.08.10].

Example:

```
BEHAVIOR = _F ( RELATION      = 'KIT_CG',  
                RELATION_KIT = ('ELAS', 'CABLE_GAINE_FROT'))
```

4.6 Operand DEFORMATION

◇ DEFORMATIONR

This keyword makes it possible to define the assumptions of used for the calculation of the deformations: by default, one considers small displacements and small deformations.

4.6.1 DEFORMATION = ' SMALL '

The deformations used in the relation of behavior are the linearized deformations:

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

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

4.6.2 DEFORMATION = ' GROT_GDEP '

Allows to treat great rotations and great displacements, but while remaining in small deformations, in a specific way according to modelings:

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

Caution:

It is strongly disadvised using linear research for COQUE_3D with the option GROT_GDEP (sometimes convergence is impossible and if one converges, calculation needs more than iterations of Newton).

- to treat GRands displacements and great rotations and small deformations for the elements of plates and hulls: modelings DKT (only in linear elasticity), DKTG (only with the behaviors GLRC_*) and SHB.
- to treat great displacements and great rotations and small deformations for modelings 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 geometrical rigidity has material rigidity to form tangent rigidity. With regard to great rotations, instead of passing by an "exact" approach complexes as for POU_D_T_GD and COQUE_3D, moderate rotations are authorized (of the second order). This kind of calculation of the deformations 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 hyperelastic (such ELAS_HYPER), this option also allows calculation in great deformations.

4.6.3 DEFORMATION = ' PETIT_REALT '

The increments of deformations used for the relation of incremental behavior are the linearized deformations of the increment of displacement in the reactualized geometry. I.e. if $X, u, \Delta u$ indicate

respectively the position, the displacement and the increment of displacement calculated with a given iteration of a material point [R5.03.24].

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

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

- very small increments,
- very small rotations (what implies a quasi-radial loading)
- elastic strain small in front of the plastic deformations,
- 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 elements of structure `HULL`, `COQUE_1D` and `LOUSE` (a message of alarm appears in the file `.mess`).

4.6.4 DEFORMATION = ' SIMO_MIEHE '

It is a formulation incrémentalement objective in great deformations of the laws of behaviors being based on a criterion of Von Mises with isotropic work hardening. The relation stress-strains rubber band is hyperelastic. All information on the gradient of the transformation F is taken into account, as well rotation as the deformations:

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

That makes it possible to carry out calculations in great plastic deformations, with the relations of behavior '`VMIS_ISOT_LINE`', '`VMIS_ISOT_TRAC`', '`ROUSSELIER`' and all behaviors, with isotropic work hardening only, associated with an undergoing material of the metallurgical phase shifts (relations `META_X_IL_XXX_XXX` and `META_X_INL_XXX_XXX`).

This formulation automatically adds to the selected behavior 6 internal variables, storing at the end the 6 components of the tensor $\frac{1}{2}(\mathbf{I}_d - \mathbf{b}^e)$ (cf [R5.03.21]).

Caution:

This option is valid only for modelings `3D`, `2D`, `INCO_UPG` (not of constraint planes with the method `BORST`). For further information on the formulation of the great plastic deformations according to `SIMO` and `MIEHE`, one will be able to refer to [R5.03.21].

In great deformations of the type '`SIMO_MIEHE`', tangent matrices are not symmetrical except for the case (very) - elastic. To version 7.4, one proceeded to a systematic symmetrization of the matrix. Henceforth, it is the nonsymmetrical matrix which is provided. If it wishes it, the user can nevertheless ask to symmetrize it under keyword `SOLVEUR = _F` (`SYME = 'YES'`). Caution: `SYME = 'YES'` is not the defect. 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 nonsymmetrical tangent matrix will allow a better convergence.

4.6.5 DEFORMATION = ' GDEF_LOG '

It is a formulation in great deformations using a measurement of deformation logarithmic curve, resulting from an approach due to Miehe, Call, Lambrecht. It makes it possible to use elastoplastic or viscoplastic laws of behavior incremental following (cf [R5.03.24]) :

VMIS_ISOT_*, VMIS_JOHN_COOK, VMIS_CINE_LINE, VMIS_ECMI_*, VMIS_CIN*_CHAB,
VMIS_CIN2_MEMO, VISC_CIN*_CHAB, VISC_CIN2_MEMO, LEMAITRE.

This formulation is valid only for modelings 3D , 2D. It allows an integration incrémentalement objectifies laws of behavior like the models SIMO_MIEHE and GEDF_HYPO_ELAS. However, like all the hypoelastic laws, these laws of behavior in any rigour are limited to the weak elastic strain. To save computing time, a specific tensor is stored in 6 additional internal variables. The tensor in question, T is the tensor of the constraints expressed in space logarithmic curve. Owing to the fact that it is stored in the internal variables, that implies with the user wishing to use formalism GDEF_LOG with an initial stress field (ETAT_INIT) to refer to the docs U4.51.03 and V6.03.159 (case test ssnp159b).

4.6.6 Models of deformation for MFront

All the models of great deformations existing in code_aster are usable with MFront behaviors (RELATION=' MFRONT'), in particular 'PETIT_REAC', 'GBELCH_GDEP', 'SIMO_MIEHE' and 'GDEF_LOG'.

Models PETIT_REAC and GDEF_LOG of code_aster rest necessarily on a written law in small deformations.

For SIMO_MIEHE and GROT_GDEP , the law MFront used must explicitly be programmed to support these models (cf. [U2.10.02]).

4.7 Operands TOUT/GROUP_MA/MAILLE

```
/ ALL = 'YES'  
/ | GROUP_MA = lgrma  
| MESH = lma
```

The meshes specify on which the incremental relation of behavior is used.

Note:

S you explicitly do not specify the behavior on certain elements of the model, Code_hasster selectedruffle RELATION=' ELAS' and DEFORMATION=' PETIT' by default on these elements. A message of information is printed in the file of message. You will have an explicit alarm if you do not affect any element of the model in an occurrence of BEHAVIOR.

4.8 Operands RESI_CPLAN_RELA, RESI_CPLAN_MAXI, ITER_CPLAN_MAXI

The method of BORST makes it possible to add the condition of plane constraint to all the models of BEHAVIOR (for more detail to see documentation [R5.03.03]). The assumption of the plane constraints is checked with convergence. One recommends to rather often reactualize the tangent matrix in the method of Newton (MATRIX = 'TANGENT' REAC_ITER = 1 to 3).

```
◇ / RESI_CPLAN_RELA = / 1.E-6, [DEFECT]  
/ εrela  
/ RESI_CPLAN_MAXI = / εabso
```

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

- that is to say a relative criterion: $|\sigma_{zz}| < \|\sigma\| \times \epsilon_{rela}$
- that is to say a criterion absolute: $|\sigma_{zz}| < \epsilon_{abso}$

```
◇ ITER_CPLAN_MAXI = / 1 [DEFECT]  
/ iter_cplan_maxi
```

This keyword makes it possible to improve the precision 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 constraints 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 allows to decrease systematically the iteration count necessary for the total process of Newton. In the studies realized, with damage, the robustness of calculation was clearly improved.

The method of BORST described above was generalized with the case of the behaviors 1D (used by modelings BAR, GRID, GRILLE_MEMBRANE, POU_D_EM, POU_D_TGM). This makes it possible to add the condition of uniaxial constraint to all the models of BEHAVIOR (for more detail to see documentation [R5.03.09]). The assumption of the uniaxial constraints is checked with convergence. One recommends to rather often use and reactualize the tangent matrix in the method of Newton (MATRIX = 'TANGENT' REAC_ITER = 1 with 3).

4.9 Operand RIGI_GEOM

```
◇ RIGI_GEOM = / 'DEFECT' [DEFECT]  
/ 'YES'
```

L' argument RIGI_GEOM is used for to activate the calculation of balance on the deformed configuration of the structure, only for the multifibre beams POU_D_TGM.

4.10 Operand PARM_THETA

◇ PARM_THETA = / 1. [DEFECT]
/ theta [R]

For the laws of behavior LEMAITRE, ROUSS_VISC, the argument theta is used with integration of the law as behavior. It can take values 0.5 (semi-implicit) or 1 (implicit).

4.11 Operands RESI_INTE_RELA/RESI_INTE_MAXI, ITER_INTE_MAXI

◇ RESI_INTE_RELA = / 1.E-6 [DEFECT]
/ resint

◇ RESI_INTE_MAXI = / 1.E-8, [DEFECT]
/ resintmax,

◇ ITER_INTE_MAXI = / 20 [DEFECT]
/ iteint

In certain relations of behavior, a nonlinear equation or a nonlinear system must be solved locally (in each point of GAUSS). 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', 'SPECIFIC' or 'SANS_OBJET'. For more details, to refer to the reference material of each behavior.

The keyword RESI_INTE_MAXI is used only by the coupling MFront – Code_Aster (cf. §4.4.10.2). In MFront, the integrators implicit and explicit use variables which are of the deformations (or of the same order of magnitude as the deformations). The value of RESI_INTE_MAXI is transmitted to the parameter of convergence used by MFront (@Epsilon), it is thus an “absolute” parameter, its value by default is the same one as that used by MFront, is 10^{-8} .

4.12 Operand RESI_RADI_RELA

◇ RESI_RADI_RELA = tolrad

Measurement of the error η had with the discretization in time, directly connected to the rotation of the normal on the surface of load. One calculates the angle enters n^- , the normal with the criterion of plasticity at the beginning of the step of time (urgent T), and n^+ , the normal with the criterion of plasticity calculated at the end of the step of time in the following way:

$$\eta = \frac{1}{2} \|\Delta n\| = \frac{1}{2} \|n^+ - n^-\| = \left| \sin\left(\frac{\alpha}{2}\right) \right|$$
. That provides a measurement of the error (also used for the

calculation of the component ERR_RADI option DERA_ELGA of CALC_CHAMP). The step of time is cut out (via DEFI_LIST_INST) if $\eta > \text{tolrad}$. This criterion is operational for the behaviors élastoplastiques of Von Mises with work hardening isotropic, kinematic linear and mixed: VMIS_ISOT_LINE, VMIS_ISOT_TRAC, VMIS_ISOT_PUIS, VMIS_CINE_LINE, VMIS_ECFI_LINE, VMIS_ECFI_TRAC, and for behaviors élasto-visco-plastics of Chaboche: VMIS_CIN1_CHAB, VMIS_CIN2_CHAB, VMIS_CIN2_MEMO, VISC_CIN1_CHAB, VISC_CIN2_CHAB, VISC_CIN2_MEMO.

4.13 Operand ITER_INTE_PAS

◇ ITER_INTE_PAS = / 0 [DEFECT]
/ itepas

Redécouper localement le pas de temps permet de faciliter l'intégration de la relation locale de comportement (en chaque point d'intégration). Si itepas est égal à 0, 1 ou -1 il n'y a pas de recoupage.

`itepas` is positive, one redécoupe systematically the step of time locally in `itepas` small steps of time before carrying out the integration of the relation of behavior. If `itepas` is negative, recutting in `|itepas|` small steps of time are carried out only in the event of nonlocal convergence.

Caution: CE keyword is not possible that with `DEFORMATION=' PETIT'`, `DEFORMATION=' PETIT_REAC'` and `DEFORMATION=' GROT_GDEP'`. It is not usable in great deformations.

4.14 Operand ALGO_INTE

```
◇ ALGO_INTE = /'ANALYTICAL'  
  # methods of solution of scalar equations  
    /' SECANT '  
    /' DEKKER '  
    /' NEWTON_1D '  
    /' BRENT '  
  # methods of resolution of systems of equations  
    /' NEWTON '  
    /' NEWTON_RELI '  
    /' NEWTON_PERT '  
    /' RUNGE_KUTTA '  
  # specific methods of resolution (not of parameter)  
    /' SPECIFIC '  
    /' SANS_OBJET '
```

Allows to specify the type of diagram of integration to solve the equation or the system of nonlinear equations formed by the equations constitutive of the models of behavior to internal 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 `SECANT`, that is to say with `BRENT`,
- the model `VENDOCHAB` can be integrated either with `NEWTON`, maybe with `RUNGE_KUTTA`.
- the model `MONOCRYSTAL` can be integrated either with `NEWTON`, maybe with `NEWTON_RELI`, maybe with `NEWTON_PERT`, maybe with `RUNGE_KUTTA`.

4.15 Operand TYPE_MATR_TANG

```
◇ TYPE_MATR_TANG= /'DISTURBANCE',  
                  /'CHECKING',  
                  ◇ VALE_PERT_RELA = / 1.E-5, [DEFECT]  
                                      / perturb, [R]
```

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

- `TYPE_MATR_TANG= " DISTURBANCE"` allows 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 standard max of the increase in displacement on the element: $\delta U = perturb \times \max |U_i|$. This is not possible that for modelings of continuous mediums 2D and 3D, in pure mechanics, only comprising degrees of freedom of displacement.
- `TYPE_MATR_TANG= " CHECKING"` relate to the developers which want to check an elementary tangent matrix (on small problems: an element is enough: only the last matrices are preserved). The matrix by disturbance is stored, as well as the coherent matrix tangent, which allows to compare. Moreover the module python `veri_matr_tang` this comparison

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allows in an easy way, as well as the test of symmetry of the matrix. See the tests COMP001 , COMP002 .

4.16 Operand POST_ITER

◇ POST_ITER = / 'CRIT_RUPT' ,

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

In the case CRIT_RUPT, it is about one criterion DE rupture in critical stress. If the greatest average principal constraint in a élément exceeds a given threshold sigc, the Young modulus is divided with the step of time following by the coefficient coeff. These two Coefficients is defined under the keyword CRIT_RUPT of the operator DEFI_MATERIAU [U4.43.01].

This criterion is available for the laws of behavior VISCOCHAB, VMIS_ISOT_TRAC (_LINE) , VISC_ISOT_TRAC (_LINE) , and validated by the tests SSNV226A, B, C.

4.17 Operand POST_INCR

◇ POST_INCR = / 'REST_ECRO' ,

Definition of an action to be carried out in postprocessing of each step of time of a thermomechanical calculation.

In the case REST_ECRO , postprocessing consists in modifying the internal variables in order to take into account the phenomenon of restoration of work hardening. The cumulated plastic deformation and/or the components of the tensor describing the center of the surface of load are multiplied by the function fonc_mult , with actual values in [0.1] , and which depends on the temperature and possibly on time. This function is indicated under the keyword REST_ECRO of the operator DEFI_MATERIAU [U4.43.01].

This criterion is available for the laws of behavior VMIS_ISOT_TRAC (_LINE), VMIS_CINE_LINE and VMIS_ECMI_LINE, and for modelings 3D, AXIS, D_PLAN and C_PLAN.
The validation of this criterion is carried out in the tests HSNV140A, B, C, D, E and ZZZZ367A.