

## Macro order SIMU\_POINT\_MAT

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### 1 Goal

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To calculate the mechanical evolution of a material point, into quasi-static nonlinear.

All behaviors available in `STAT_NON_LINE` [U4.51.11] are it also here.

The goal of this macro-order is to simplify to the maximum the data: it is enough to provide:

- 1) The behavior and the material;
- 2) Functions defining the evolution of the components of constraints or selected deformations;
- 3) Discretization in time.

This makes it possible in particular to in the case of calculate the evolution of the tensor of the constraints imposed deformations, or the reverse (current cases in identification of parameters material)

Product a structure of data of the type `table` container, according to time, the evolution of all the components of the tensors of constraints and deformations, as well as the internal variables.

## 2 Syntax

```

tabres [table] = SIMU_POINT_MAT (
  ♦ / BEHAVIOR      =_F (see the document [U4.51.11]),
  ♦ MATER          = / chechmate, [to subdue]
                  / l_mat, [l_mater]
  ◇ SOLID MASS      = /`ANGL_REP'                                [R]
                  /`ANGL_EULER'                                [R]
  ◇ ANGLE           = angz,                                    [R]
  ♦ INCREMENT       =_F ( to see the document [U4.51.03]),
  ◇ NEWTON          =_F ( to see the document [U4.51.03]),
  ◇ CONVERGENCE     =_F (
    /RESI_GLOB_RELA  = 1.E-6,                                [DEFECT]
    /|RESI_GLOB_MAXI = resmax,                               [R]
    |RESI_GLOB_RELA  = resrel,                               [R]
    ITER_GLOB_MAXI   = /10,                                  [DEFECT]
                  /maglob,                                  [I]
  ),
  ◇ SUPPORT = /`ELEMENT'
    ◇ MODELING      = /`3D' [DEFECT]
                  /`C_PLAN'
                  /`D_PLAN'
    ◇ RECH_LINEAIRE =_F ( to see the document [U4.51.03]),
    ◇ FILING         =_F ( to see the document [U4.51.03]),
    # variable of orders function scalars of time
    ◇ SUIVI_DDL      =_F ( to see the document [U4.51.03]),
    ◇ AFFE_VARC      =_F (♦ NOM_VARC = `TEMP',
                          /`CORR',
                          /`IRRA',
                          /`HYDR',
                          /`SECH',
                          /`EPSA',
                          /`NEUT1',
                          /`NEUT2',
                          ◇ VALE_REF =vref [R]
                          ♦ VALE_FONC =foncvarc [function]
                          /`M_ACIER',
                          / ◇ V1 =foncv1 [function]
                          / ◇ V2 =foncv2 [function]
                          / ◇ V3 =foncv3 [function]
                          / ◇ V4 =foncv4 [function]
                          / ◇ V5 =foncv5 [function]
                          / ◇ V6 =foncv6 [function]
                          / ◇ V7 =foncv7 [function]
                          / ◇ V8 =foncv8 [function]

```

```

/ ◇ V 9 =foncv 9 [function]
/ 'M_ZIRC' ,
/ ◇ V1 =foncv1 [function]
/ ◇ V2 =foncv2 [function]
/ ◇ V3 =foncv3 [function]
/ ◇ V4 =foncv4 [function]
/ ◇ V5 =foncv 5 [function]
),
◇ SIGM_IMPOSE=_F ( ◇ SIXX = sigxx [function]
◇ SIYY = sigyy [function]
◇ SIZZ = sigzz [function]
◇ SIXY = sigxy [function]
◇ SIXZ = sigxz [function]
◇ SIYZ = sigyz [function]
),
◇ EPSI_IMPOSE=_F ( ◇ EPXX = epsxx [function]
◇ EPYY = epsyy [function]
◇ EPZZ = epszz [function]
◇ EPXY = epsxy [function]
◇ EPXZ = epsxz [function]
◇ EPYZ = epsyz [function]
),
◇ SUPPORT= / 'NOT' [DEFECT]
◇ NB_VARI_TABLE = nvar [I]
◇ FORMAT_TABLE = / 'CMP_COLONNE' [DEFECT]
/ 'CMP_LIGNE'
◇ OPER_TANGENT = / 'NOT' [DEFECT]
/ 'YES'
◇ FILING =_F (
◇ LIST_INST = linst (see document [U4.51.03]),
◇ PRECISION = prec ),
/ ◇ SIGM_IMPOSE=_F ( ◇ SIXX = sigxx [function]
◇ SIYY = ifgyy [function]
◇ SIZZ = sigzz [function]
◇ SIXY = sigxy [function]
◇ SIXZ = sigxz [function]
◇ SIYZ = sigyz [function]),
◇ EPSI_IMPOSE=_F ( ◇ EPXX = epsxx
[function]
◇ EPYY = epsyy [function]
◇ EPZZ = epszz [function]
◇ EPXY = epsxy [function]
◇ EPXZ = epsxz [function]
◇ EPYZ = epsyz [function]),
/ ◇ GRAD_IMPOSE=_F ( ◇ F11 = fonc [function]
◇ F12 = fonc [function]
◇ F12 = fonc [function]
◇ F13 = fonc [function]
◇ F21 = fonc [function]
◇ F22 = fonc [function]
◇ F23 = fonc [function]
◇ F31 = fonc [function]
◇ F32 = fonc [function]
◇ F33 = fonc [function]),
/ ◇ MATR_C1=_F ( ◆ VALE = cij [R]
◆ NUME_LIGNE = numlig [I]
◆ NUME_COLONNEE = numcol [I]
),

```

```

    ◇ MATR_C2=_F ( ◇ VALE = cij [R]
                  ◇ NUME_LIGNE = numlig [I]
                  ◇ NUME_COLONNEE = numcol [I]
                  ),
    ◇ VECT_IMPO=_F ( ◇ VALE = cij [R]
                    ◇ NUME_LIGNE = numlig [I]
                    ),
◇ AFFE_VARC      = _F (◇ NOM_VARC = 'TEMP',
                      /'IRRA',
                      /'SECH',
                      ◇ VALE_FONC =foncvarc [function]
                      ◇ VALE_REF  =vref [R]
                      ),
◇ SIGM_INIT=_F ( ◇ SIXX = sigxx [R]
                 ◇ SIYY = sigyy [R]
                 ◇ SIZZ = sigzz [R]
                 ◇ SIXY = sigxy [R]
                 ◇ SIXZ = sigxz [R]
                 ◇ SIYZ = sigyz [R] ),
◇ EPSI_INIT=_F ( ◇ EPXX = epsxx [R]
                 ◇ EPYY = epsyy [R]
                 ◇ EPZZ = epszz [R]
                 ◇ EPXY = epsxy [R]
                 ◇ EPXZ = epsxz [R]
                 ◇ EPYZ = epsyz [R] ),
◇ VARI_INIT=_F ( ◇ VALE = vari [R] ),
◇ INFORMATION = / 1, [DEFECT]
                / 2 , );
```

## 3 Operands

### 3.1 Operand MATER

◆ **MATER** =/chechmate, [to subdue]  
/ l\_mat, [l\_mater]

This keyword makes it possible to inform the name of material (to subdue) defined by `DEFI_MATERIAU` [U4.43.01], where are provided the parameters necessary to the selected behavior. In the case of the polycrystals, one can have to give several materials (cf `ssnv194c`).

### 3.2 Word-key BEHAVIOR

The syntax of this keyword is described in the document [U4.51.11].

### 3.3 Words keys INCREMENT/FILING NEWTON

The syntax of these keywords is described in the document [U4.51.03].

The keyword `INCREMENT` defines the time intervals taken in the incremental method.

The keyword `FILING` defines the moments when the results in the table are stored `tabres`. In the case `SUPPORT=' POINT '`, these moments can be defined only by the keyword `LIST_INST` with the relative precision `PRECISION`.

Keywords `NEWTON`, optional, allows to modify the values by default of the parameters of convergence of the method of Newton.

### 3.4 Keyword CONVERGENCE

◇ `CONVERGENCE =_F ( )`

If none of the two operands following is present, then all occurs like if: `RESI_GLOB_RELA = 1.E-6`.

#### 3.4.1 Operand RESI\_GLOB\_RELA/RESI\_GLOB\_MAXI

◇ `|RESI_GLOB_RELA = resrel , [R]`

The algorithm continues the total iterations as long as:

$$\max_{i=1,\dots,nbddl} |F_i^n| > \text{resrel} \cdot \max |L|$$

where  $F^n$  is the residue of the iteration  $n$  and  $L$  the vector of the imposed loading and the reactions of supports (cf [R5.03.01] for more details).

When the loading and the reactions of support become worthless, i.e. when  $L$  is null (for example in the case of a total discharge), one tries to pass from the relative convergence criteria `RESI_GLOB_RELA` with the absolute convergence criteria `RESI_GLOB_MAXI`. This operation is transparent for the user (message of alarm emitted in the file `.mess`). When the vector  $L$  becomes again different from zero, one passes by again automatically with the relative convergence criteria `RESI_GLOB_RELA`.

However, this mechanism of swing cannot function with the first step of time. Indeed, to find a value of `RESI_GLOB_MAXI` reasonable in an automatic way (since the user did not inform it), one needs to have had at least a step converged on a mode `RESI_GLOB_RELA`. Consequently, if the loading is null as of the first moment, calculation stops. The user must already then check that the null loading is normal from the point of view of the modeling which it carries out, and if such is the case, to find another convergence criteria (`RESI_GLOB_MAXI` for example).

If this operand is absent, the test is carried out with the value by default, except if `RESI_GLOB_MAXI` is present.

◇ `|RESI_GLOB_MAXI = resmax , [R]`

The algorithm continues the total iterations as long as:

$$\max_{i=1,\dots,nbddl} |F_i^n| > \text{resmax}$$

where  $F^n$  is the residue of the iteration  $n$  (Cf [R5.03.01] for more details). If this operand is absent, the test is not carried out.

If `RESI_GLOB_RELA` and `RESI_GLOB_MAXI` both are present, the two tests are carried out.

### 3.4.2 Operand `ITER_GLOB_MAXI`

◇ `ITER_GLOB_MAXI = /10 [DEFECT]`  
`/maglob`

Maximum iteration count carried out to solve the total problem at every moment (10 by defaults).

## 3.5 Word key `RECH_LINEAIRE`

The syntax of these keywords is described in the document [U4.51.03].

The keyword `RECH_LINEAIRE` allows, in the case `SUPPORT=' ELEMENT '`, to activate linear research to help with the convergence of the algorithm of Newton. This functionality is not available for `SUPPORT=' POINT '`, because it does not seem necessary.

## 3.6 Word key `MODELING`

The keyword `MODELING` allows, in the case `SUPPORT=' ELEMENT '`, to carry out calculation on an element 3D or an element 2D, in plane constraints or plane deformations. It is not available in the case `SUPPORT=' POINT '`, because it is enough to impose a zero value on the components corresponding to the plane constraints or the plane deformations to get the same result.

This keyword makes it possible to define the dimension of with the dealt problem: 3D (by default) or 2D: plane strain or plane stress. In the case 2D, the components of the tensors provided under the keywords `SIGM_IMPOSE`, `EPSI_IMPOSE`, `SIGM_INIT`, `EPSI_INIT` are 4: `XX`, `YY`, `ZZ`, `XY`.

## 3.7 Operand `ANGLE`

This keyword makes it possible to specify an angle (in degrees) to carry out an overall rotation around  $Z$  applied at the same time to the loading, the grid, and the examination. This especially makes it possible to check the reliability of the integration of the behavior, as in the tests `COMP001`, `COMP002`. By default, rotation is identically worthless.

In the case of materials having an intrinsic orientation (orthotropism, behaviors crystalline), it is advisable to also use the keyword `SOLID MASS`, with a first value of angle identical to that provided under `ANGLE`.

## 3.8 Keyword `SOLID MASS`

### 3.8.1 Operands `ANGL_EULER/ANGL_REP`

These keyword make it possible to lay down an intrinsic orientation in the material (orthotropism, behaviors crystalline), and make it possible to appeal in the macro-order the keyword **SOLID MASS** of **AFFE\_CARA\_ELEM** [U4.42.01].

By default, the orientation is worthless, and one does not call on **AFFE\_CARA\_ELEM**.

## 3.9 Keywords **SIGM\_INIT/EPSI\_INIT/VARI\_INIT**

These keywords make it possible to define an initial state by the data:

- 1) components of the initial constraints (all the components are not necessary, by default one takes value 0),
- 2) components of the initial deformations (if the keyword **EPSI\_INIT** is present, it is necessary to provide all the components of the initial deformations: 4 in 2D, and 6 in 3D)
- 3) the whole of the initial internal variables for the behavior used.

This functionality is illustrated in test SSNV160E.

## 3.10 Keywords **SIGM\_IMPOSE/EPSI\_IMPOSE**

### 3.10.1 Operands **SIXX, SIYY, SIZZ, SIXY, SIXZ, SIYZ**

These keyword make it possible to define components of the tensor of constraints imposed on the material point, via functions of time. These functions can be defined using **DEFI\_FONCTION** [U4.31.02] or using **FORMULA** [U4.31.05].

By defaults, the nonaffected components are identically worthless.

### 3.10.2 Operands **EPXX, EPHY, EPZZ, EPXY, EPXZ, EPHY**

These keyword make it possible to define components of the tensor of deformation imposed on the material point, via functions of time. These functions can be defined using **DEFI\_FONCTION** [U4.31.02] or using **FORMULA** [U4.31.05].

By defaults, the nonaffected components are left without value (not imposed deformation).

It should be noted that, in the case of the model of deformation **PETIT\_REAC**, it is not possible to impose the deformation exactly using **EPSI\_IMPOSE**. Indeed, because of nature *incremental* this model, deformations obtained by this model at the end of calculation **SIMU\_POINT\_MAT** will be different from what will have been imposed, except in small deformations. For the great deformations it thus is preferable to use the model **GDEF\_LOG** who does not suffer from this disadvantage.

## 3.11 Keywords **GRAD\_IMPOSE**

### 3.11.1 Operands **F11, F12, F13, F21, F22, F23, F31, F32, F33**

These keyword make it possible to define all the components of the tensor gradient of transformation imposed, in great deformations ( **DEFORMATION=' SIMO\_MIEHE'** ) cf test ssnd113).

## 3.12 Keywords **MATR\_C1/MATR\_C2/VECT\_IMPO**

These keyword allow, in the case **SUPPORT=' POINT'**, to define the coefficients of the matrices directly **C1**, **C2** and of the vector **g** described with the §4.2 : that thus makes it possible to define linear conditions on the unknown factors (forced and deformations of the material point) more general than the components imposed by the mots key **SIGM\_IMPOSE/EPSI\_IMPOSE**. All terms of matrices **C1** and **C2** not specified are worthless. For an example of use, to see test WTNV134B [V7.31.134].

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## 3.13 Operand **AFFE\_VARC**

This keyword makes it possible to specify a variable of order (cf [U4.43.03]) whose name is defined under the keyword `NOM_VARC` ; the function defining the temporal evolution of this variable of order is provided via the keyword `VALE_FONC`. The possible value of reference `vref` is given by `VALE_REF`.

In the case `SUPPORT=' ELEMENT'`, all variables of order are authorized. Moreover, for `M_ZIRC` (resp. `M_ACIER`), it is necessary to provide the evolutions of the 4 (resp. 7) metallurgical phases according to time.

In the case `SUPPORT=' POINT'`, only variables of order 'TEMP', 'SECH' and 'IRRA' are authorized.

## 3.14 Word key **NB\_VARI\_TABLE**

The keyword `NB_VARI_TABLE` allows, in the case `SUPPORT=' POINT'`, to limit the number of internal variables written in the table. Indeed for the polycrystalline mediums, this one can reach several thousands. One then limits the number of columns of the table to `nvar`. On the other hand calculations are of course carried out with the totality of the internal variables: those are truncated only in the table as a result.

## 3.15 Word key **FORMAT\_TABLE**

```
◇ FORMAT_TABLE = /'CMP_COLONNE' [DEFECT]
                  /'CMP_LIGNE'
```

The keyword `FORMAT_TABLE` allows, in the case `SUPPORT=' POINT'`, to define the mode of storage of the sizes in the table result (the test `SSNV194C` illustrate these two formats). If the number of internal variables exceeds the maximum of columns authorized for a table (9999, cf D4,02,05), the format rocks automatically in: `FORMAT_TABLE = /'CMP_LIGNE'`.

```
FORMAT_TABLE = /'CMP_LIGNE' :
... V845          V846          V847          V848          NB_ITER
... 1.16186E-17  1.32359E-17  1.11751E-17  1.00000E+00  1.00000E+00
... 1.29473E-16  1.47341E-16  1.24474E-16  1.00000E+00  1.00000E+00
... 8.90739E-16  1.00875E-15  8.55093E-16  1.00000E+00  1.00000E+00
... 4.40109E-15  4.92817E-15  4.21938E-15  1.00000E+00  1.00000E+00
... 1.70332E-14  1.87022E-14  1.63484E-14  1.00000E+00  1.00000E+00
... 5.44940E-14  5.80870E-14  5.25904E-14  1.00000E+00  1.00000E+00
```

```
FORMAT_TABLE = /'CMP_COLONNE' :
... INST          SIZE CMP          VALUE
...
... 4.97867E-03 VARI          V845          -1.43828E+01
... 4.97867E-03 VARI          V846          -2.63548E+01
... 4.97867E-03 VARI          V847          2.80907E+01
... 4.97867E-03 VARI          V848          1.00000E+00
... 5.00000E-03 EPSI          EPXX          -2.20535E-03
... 5.00000E-03 EPSI          EPYY          -1.96506E-03
... 5.00000E-03 EPSI          EPZZ          5.00000E-03
... 5.00000E-03 EPSI          EPXY          -1.98892E-04
... 5.00000E-03 EPSI          EPXZ          -2.11427E-04
... 5.00000E-03 EPSI          EPYZ          -3.00870E-04
... 5.00000E-03 V7.32.119SIGM SIXX          1.67146E-04
... 5.00000E-03 SIGM          SIYY          2.78713E-05
```



5.00000E-03	SIGM	SIZZ	3.01140E+02
5.00000E-03	SIGM	SIXY	9.15194E-05
5.00000E-03	SIGM	SIXZ	1.62000E-04
5.00000E-03	SIGM	SIYZ	6.86376E-05
5.00000E-03	SIEQ	VMIS	3.01140E+02
5.00000E-03	SIEQ	TRACE	3.01140E+02
5.00000E-03	VARI	V1	-1.58316E-03
5.00000E-03	VARI	V2	-1.34287E-03
5.00000E-03	VARI	V3	2.92604E-03
5.00000E-03	VARI	V4	-2.81276E-04

...

## 3.16 Word key OPER\_TANGENT

◇ OPER\_TANGENT = / 'NOT' [DEFECT]  
/ 'YES'

The keyword OPER\_TANGENT allows, in the case SUPPORT=' POINT', to add to the table result the 36 values of the tangent operator resulting from the behavior.

## 3.17 Operand INFORMATION

◇ INFORMATION = inf

Allows to carry out in the file message various intermediate impressions.

## 4 Operation of the macro\_commande

The purpose of this macro\_commande is to restrict with bare essential the relative data for a simulation on a material point for a model of incremental behavior.

The inner working thus reduces the command file of the user, by carrying out repetitive operations for this kind of situations.

### 4.1 Case SUPPORT=' ELEMENT '

Operation is:

1. creation of a grid of only one element at only one point of Gauss (a tetrahedron with four nodes in 3D, a triangle with three nodes in 2D) (see for example [V6.04.176]).
2. assignment of a model 3D or C\_PLAN or D\_PLAN
3. assignment of material on this grid;
4. assignment of the loadings:
5. with regard to the imposed deformations, for each component affected via one of the keywords of EPSI\_IMPOSE , creation of a unit loading in deformation which will be multiplied by the function of time provided for this component by the user;
6. with regard to the imposed constraints, for each component affected via one of the keywords of SIGM\_IMPOSE , creation of a unit loading in constraints which will be multiplied by the function of time provided for this component by the user;
7. Call to STAT\_NON\_LINE . All the keywords having values by default are used, except if they are overloaded by the utilisor ( NEWTON, CONVERGENCE, SUIVI\_DDL, FILING, RECH\_LINEAIRE ) and of the initial state.

The whole of the results (six or four components of constraints and deformations, internal variables) are stored in a table (tabres). For each component (column of the table) the evolution according to time appears.

## 4.2 Case SUPPORT= ' POINT '

In this case, plutôt to use a finite element (even single) to carry out calculation, SIMU\_POIN\_MAT fact call to a dedicated order, CALC\_POINT\_MAT, which includes in FORTRAN the direct call with the routine 3D of integration of the behaviors, NMCOMP. This is available only Dyears the case of the small deformations.

Let us recall that NMCOMP is the general routine of integration of the laws of behavior, called by all the finite elements 3D and 2D. It allows calculation in a point (this point being the point of integration for a finite element) of the constraints and internal variables the current moment, knowing the internal constraints and variables at the previous moment; and the current increase in deformation. (cf [D5.04.01] and [R5.03.14]). More precisely, at the moment  $t_i$ , and with the iteration  $n$  the tensor of the constraints  $\sigma_i^n$ , in a point is calculated from  $(\sigma_{i-1}, \alpha_{i-1})$  and of the increment of deformation  $\Delta \varepsilon_i^n$ .

When all the components of the tensor of the deformations are provided, the algorithm is immediate: it is about a simple loop in time, containing for each temporal increment the data of the mechanical state of the preceding increment and the tensor (symmetrical) corrépondant with the known increase in deformation.

But in the contrary case, that is to say which one only provides  $n$  components of the history of the deformations,  $n < 6$ , that is to say that one provides  $n$  components of the history of the constraints, the algorithm is the following:

- by default, any component not specified corresponds to a component of subjugated constraint to remain worthless (condition of Neumann)
- the equations to be solved are (by using the notation in vectorial form of the symmetrical tensors of order 2):
- $\sigma_i = F(\Delta \varepsilon_i; \sigma_{i-1}, \alpha_{i-1})$  where  $F$  represent the result of the integration of the behavior by NMCOMP
- for J varying from 1 to 6:
  - that is to say  $(\sigma_i)_j = g_j(t_i)$
  - that is to say  $(\varepsilon_i)_j = g_j(t_i)$ 
    - where  $\bar{\sigma}_j(t)$  and  $\bar{\varepsilon}_j(t)$  are given by SIGM\_IMPOSE/EPSI\_IMPOSE.

This can be still written:

for each moment  $t_i$ , to solve:

$$R(Y_i) = 0 \text{ with } Y_i = Y(t_i) = \begin{Bmatrix} \sigma_i \\ \varepsilon_i \end{Bmatrix} \text{ and } R(Y_i) = \begin{Bmatrix} \sigma_i - F(\Delta \varepsilon_i; \sigma_{i-1}, \alpha_{i-1}) \\ [C_1] \sigma_i + [C_2] \varepsilon_i - g(t_i) \end{Bmatrix}$$

who is a nonlinear system of order 12.

The last relation translates the conditions of constraints or imposed deformations: matrices  $C_1$  and  $C_2$  only terms contain on the diagonal, being worth 1 if the corresponding component is imposed, knowing that one cannot have at the same time forced and imposed deformation.

For example, if deformation  $\varepsilon_{yy}$  is imposed, the last relation is written:

$$[C_1]\boldsymbol{\sigma}_i + [C_2]\boldsymbol{\varepsilon}_i - \mathbf{g}(t_i) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \sigma_{xy} \\ \sigma_{xz} \\ \sigma_{yz} \end{pmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{pmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xy} \\ \varepsilon_{xz} \\ \varepsilon_{yz} \end{pmatrix} = \begin{pmatrix} 0 \\ \varepsilon_{yy}(t_i) \\ 0 \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

If the user specified (via the keywords MATR\_C1, MATR\_C2 and VECT\_IMPO) additional relations, those are taken into account directly in the matrices  $C_1$  and  $C_2$ .

The resolution of this system of nonlinear equations is carried out by a method of Newton:

$$\text{-initialization: } Y_i^0 = Y_{i-1} + [K_i^0]^{-1} \begin{bmatrix} 0 \\ -[C_1]\boldsymbol{\sigma}_{i-1} - [C_2]\boldsymbol{\varepsilon}_{i-1} + \mathbf{g}(t_i) \end{bmatrix}$$

-iteration N has:

$$\delta Y_i^{n+1} = -[K_i^n]^{-1} R(Y_i^n) = [K_i^n]^{-1} \begin{bmatrix} F(\Delta \boldsymbol{\varepsilon}_i^n; \boldsymbol{\sigma}_{i-1}, \alpha_{i-1}) - \boldsymbol{\sigma}_i^n \\ -[C_1]\boldsymbol{\sigma}_i^n - [C_2]\boldsymbol{\varepsilon}_i^n + \mathbf{g}(t_i) \end{bmatrix};$$

$$\Delta Y_i^n = \delta Y_i^n + \Delta Y_i^{n-1}; Y_i^n = \Delta Y_i^n + Y_{i-1}$$

with

$$[K_i^n] = \begin{bmatrix} \frac{\partial R}{\partial Y} \end{bmatrix} = \begin{bmatrix} \mathbf{1} & -\left(\frac{\partial \boldsymbol{\sigma}}{\partial \boldsymbol{\varepsilon}}\right)_i^n \\ [C_1] & [C_2] \end{bmatrix} \text{ and } [K_i^0] = \begin{bmatrix} \mathbf{1} & -\left(\frac{\partial \boldsymbol{\sigma}}{\partial \boldsymbol{\varepsilon}}\right)_i^0 \\ [C_1] & [C_2] \end{bmatrix}$$

where  $\left(\frac{\partial \boldsymbol{\sigma}}{\partial \boldsymbol{\varepsilon}}\right)_i^0$  represent the tangent operator of prediction (option RIGI\_MECA\_TANG, cf [R5.03.01, R5.03.02]) and  $\left(\frac{\partial \boldsymbol{\sigma}}{\partial \boldsymbol{\varepsilon}}\right)_i^n$  represent the coherent tangent operator (option FULL\_MECA), cf [R5.03.01, R5.03.02]). These operators can be replaced by the operator of elasticity according to the keywords PREDICTION, REAC\_ITER.

The only non linearity of the problem comes from the behavior:  $F(\Delta \boldsymbol{\varepsilon}_i^n; \boldsymbol{\sigma}_{i-1}, \alpha_{i-1})$ .

In the case of a linear behavior, one checks that the solution of the problem is obtained at the conclusion of phase of prediction.

The convergence of the iterations is vérifiée:

- maybe in relative value, (keyword RESI\_GLOB\_RELA) :

$$\max \left( \frac{\max_{j=1,6} |(R_i^n)_j|}{\max_{j=1,6} |(\sigma_i^0)_j|}; \frac{\max_{j=7,12} |(R_i^n)_j|}{\max_{j=7,12} |(R_i^0)_j|} \right) < \text{RESI\_GLOB\_RELA}$$

DaNS this case, the terms in constraints and deformations are separate for the examination of the convergence criteria to avoid the problems due to the differences in orders of magnitude.

- maybe in absolute value (keyword RESI\_GLOB\_MAXI) or value of the denominator close to zero in the relative criterion above:

$$\max_{j=1,12} |(R_i^n)_j| < \text{RESI\_GLOB\_MAXI}$$

The options of calculation of tangent rigidity by disturbance and the automatic management of the step of time are also activated, as in [U4.51.03].

In the preceding resolution, the terms in constraints are adimensionnalisés, to avoid a bad conditioning of the matrix jacobienne. One thus divides for the resolution all the terms into constraints by the max of the diagonal terms of the operator of elasticity; it is thus necessary to provide in DEFI\_MATERIAU the keyword ELAS or ELAS\_ORTH or ELAS\_ISTR.

In the case SUPPORT=' POINT', certain keywords do not have utility:

- in the case of linear research, this one is not programmed in the current version
- in the case of filing, only the keyword LIST\_INST is taken into account
- in the case CONVERGENCE/RESI\_REFE\_RELA, this keyword without object: the residue by value of reference does not have a direction for a material point.
- If the value of the keyword DEFORMATION is not SMALL, one alarms the user by specifying that the type of DEFORMATION chosen is incompatible with SUPPORT=POINT, and that one thus uses SUPPORT=ELEMENT, except if one provides all the components of the gradient of transformation (keyword GRAD\_IMPOSE).

## 5 Example of use

This example is resulting from the test SSNV160E :

```
# TITRATES CA HYDROSTATIC TEST CAM_CLAY IN 3D WITH SIMU_POINT_MAT

# CHARACTERISTICS OF MATERIAL
MATER=DEFI_MATERIAU (ELAS=_F (E=7.74E6, NU=0.285),
                    CAM_CLAY=_F (DRIVEN = 6.E6,
                                PORO=0.66,
                                LAMBDA=0.25,
                                KAPA=0.05,
                                M=0.9,
                                PRES_CRIT=3.E5),);

# LOADING
PRESS2=DEFI_FONCTION (NOM_PARA=' INST', NOM_RESU=' PRESSION',
                    VALE= (0.0, 0.0,
                            100.0, - 100000.0,
                            600.0, - 320000.0,
                            1000.0, - 350000.0,
                            5000.0, - 500000.0,
                            8000.0, - 800000.0),
                    PROL_DROITE=' CONSTANT');

# LIST OF THE MOMENTS OF CALCULATION
LI1=DEFI_LISTE_REEL (DEBUT=0.0,
                   INTERVALLE= (_F (JUSQU_A=1000.0, NOMBRE=10),
                                _F (JUSQU_A=1.E4, NOMBRE=60),),);
```

SXXINI= -7.99000E+05  
EXXINI= -1.82689E-02

```
RESU3=SIMU_POINT_MAT (  
BEHAVIOR =_F (RELATION=' CAM_CLAY', ITER_INTE_MAXI=100, ITER_INTE_PAS=-10,),  
NEWTON=_F (MATRICE=' TANGENTE', REAC_ITER=1,),  
CONVERGENCE=_F (ITER_GLOB_MAXI=20,),  
MATER = MATER,  
INCREMENT=_F (LIST_INST=LI1, INST_INIT= 7990. , INST_FIN = 8000.),  
SIGM_INIT=_F (SIXX=SXXINI, SIYY=SXXINI, SIZZ=SXXINI,),  
EPSI_INIT=_F ( EPXX=EXXINI, EPYY=EXXINI, EPZZ=EXXINI,  
EPXY=0., EPYZ=0., EPXZ=0.),  
VARI_INIT=_F ( VALE= ( 3.99500E+05,1.0, 7.99000E+05,4.63066E-  
10,  
1.94773E-02,2.99086E-17,1.79821E+00),),  
SIGM_IMPOSE=_F ( SIXX=PRESS2, SIYY=PRESS2, SIZZ=PRESS2,),  
);  
IMPR_TABLE (TABLE=RESU3)
```

The table result contains:

```
#-----  
#  
#CALC_POINT_MAT  
INST      EPXX      EPYY      ... SIXX      SIYY      ... TRACE      ... V1      V2      .  
0.00000E+00 0.00000E+00 0.00000E+00 -1.00000E+05 -1.00000E+05 0.00000E+00 0.00000E+00 0.00000E+00  
2.00000E+02 -2.06631E-03 -2.06631E-03 -1.44000E+05 -1.44000E+05 -4.32000E+05 3.00000E+05 0.00000E+00  
3.00000E+02 -3.57721E-03 -3.57721E-03 -1.88000E+05 -1.88000E+05 -5.64000E+05 3.00000E+05 0.00000E+00  
4.00000E+02 -4.76888E-03 -4.76888E-03 -2.32000E+05 -2.32000E+05 -6.96000E+05 3.00000E+05 0.00000E+00  
5.00000E+02 -5.75297E-03 -5.75297E-03 -2.76000E+05 -2.76000E+05 -8.28000E+05 3.00000E+05 0.00000E+00  
6.00000E+02 -6.59119E-03 -6.59119E-03 -3.20000E+05 -3.20000E+05 -9.60000E+05 3.00000E+05 0.00000E+00  
7.00000E+02 -6.72247E-03 -6.72247E-03 -3.27500E+05 -3.27500E+05 -9.82500E+05 3.00000E+05 0.00000E+00  
8.00000E+02 -6.85078E-03 -6.85078E-03 -3.35000E+05 -3.35000E+05 -1.00500E+06 3.00000E+05 0.00000E+00  
9.00000E+02 -6.97624E-03 -6.97624E-03 -3.42500E+05 -3.42500E+05 -1.02750E+06 3.00000E+05 0.00000E+00  
1.00000E+03 -7.09899E-03 -7.09899E-03 -3.50000E+05 -3.50000E+05 -1.05000E+06 3.00000E+05 0.00000E+00  
1.40000E+03 -7.33679E-03 -7.33679E-03 -3.65000E+05 -3.65000E+05 -1.09500E+06 3.00000E+05 0.00000E+00  
1.80000E+03 -7.56501E-03 -7.56501E-03 -3.80000E+05 -3.80000E+05 -1.14000E+06 3.00000E+05 0.00000E+00  
.....
```