Operator CALC_FATIGUE

1 Goal

To calculate a field of damage of tiredness undergone by a structure; a critical plan in which shearing is maximum; or a maximum amplitude of acceptable vibration.

Calculation of a field of damage : starting from a history of equivalent constraints (forced of von Mises signed) or deformations equivalent (invariant of the second signed order) calculated to the nodes or the points of Gauss, one calculates a field of size which contains the damage undergone by the structure in each node or each point of Gauss. The elementary cycles of loading are extracted by a method of counting of cycles (method RAINFLOW); the total damage undergone by the structure is the sum of the damage associated with the elementary cycles.

Criterion of starting: to calculate the damage, it is essential to have a criterion of starting. The criteria of starting are provided by the keyword (like criterion of Dang-Van…). It is also possible for the user to build a criterion in formula of the sizes predefined.

Critical plan and maximum shearing : starting from a history of constraints calculated at the points of Gauss or the nodes, if the loading is periodic, we calculate a field of size which contains inter alia: the half amplitude of maximum shearing, the associated normal vector, the number of cycles to the rupture and the damage corresponding to the points of Gauss or the nodes. If the loading is not periodical the field of sizes contains the maximum damage and the normal vector associated with the points of Gauss or the nodes.

Maximum amplitude of acceptable vibration : this option aims at considering the amplitude maximum of vibration acceptable of a structure subjected to a static loading (known) and to a dynamic loading (unknown). From the static stress and modal constraints of the clean modes considered, calculated at the points of Gauss or the nodes, the amplitude of maximum vibration is calculated by using a uniaxial criterion of tiredness.

Product a concept of the type cham_elem or cham_no.

2 Syntax

```
    CHAM [cham_elem*] = CALC_FATIGUE (

    ♦  TYPE_CALCUL   =  /   'CUMUL_DOMMAGE',
                        /   'FATIGUE_MULTI',
                        /   'FATIGUE_VIBR',

# If TYPE_CALCUL = 'CUMUL_DOMMAGE' - > calculation of the damage

       #  Choice of the option of calculation

    ♦  OPTION     =  /   'DOMA_ELNO_SIGM',
                     /   'DOMA_ELGA_SIGM',
                     /   'DOMA_ELNO_EPSI',
                     /   'DOMA_ELGA_EPSI',
                     /   'DOMA_ELNO_EPME',
                     /   'DOMA_ELGA_EPME',

       #  Reading of the history of constraint or deformation

    ♦  HISTORY = _F (

          ♦  RESULT =   LMBO,                          / [evol_elas]
                                                          / [evol_noli]
                                                          / [dyna_trans]

          ♦  EQUI_GD   =  /   'VMIS_SG',                    [DEFECT]
                          /   'INVA_2_SG',

                     )

       #  Calculation of the damage

    ♦  TOO BAD    =  /   'WOHLER',
                     /   'MANSON_COFFIN',
                     /   'TAHERI_MANSON',
                     /   'TAHERI_MIXTE',

    ♦  MATER      =  to subdue,                                 [to
subdue]

    ◊  TAHERI_NAPPE =   tablecloth,                          /
    [tablecloth]
                                                          /   [formula]

    ◊  TAHERI_FONC  =   fonc,                             /   [function]
                                                          /   [formula]

                     ),

# Finsi

# If TYPE_CALCUL = 'FATIGUE_MULTI' - >  Calculation of the maximum shearing
or of
                                                maximum damage

    ♦  TYPE_CHARGE   =  /   'PERIODIC',
                        /   'NON_PERIODIQUE',

    ♦  OPTION     =  /   'DOMA_ELGA',
                     /   'DOMA_NOEUD',

    ♦  RESULT     =  LMBO,                             /   [evol_elas]
                                                          /   [evol_noli]

    ◊  CHAM_MATER    =   cham_mater,                          [cham_mater]

    # If TYPE_CHARGE = 'PERIODIC'

    ♦  CRITERION     =  /   'MATAKE_MODI_AC',
```

```
                      /   'DANG_VAN_MODI_AC',
                      /   'FORMULE_CRITERE',
                      /   'VMIS_TRESCA',

  # If CRITERION! = 'VMIS_TRESCA'
  ♦  METHOD    =  /   'CERCLE_EXACT',

  # Finsi
  # If CRITERION = 'FORMULE_CRITERE'
  ♦  FORMULE_GRDEQ   =   for_grd,                     /   [formula]
  ♦  COURBE_GRD_VIE  =   /   'WOHLER',
                         /   'MANSON_COFFIN',
                          /   'FORMES_VIE'
     # If COURBE_GRD_VIE = 'FORMES_VIE'
     ♦  FORMULE_VIE = for_vie,                     /   [formula]
                                                   /   [function]
     # Finsi
  ◊  FORMULE_CRITIQUE =  for_grd,                  /   [formula]

  # Finsi
   ◊  INST_INIT_CYCL =    / inst_ini_cyc            [R]
   ◊  INST_CRIT  =/ 'RELATIVE'
                  / 'ABSOLUTE'
   # If INST_CRIT = 'RELATIVE'
      ◊ PRECISION =/prec                       [R]
                   /  1.E-6 ,                      [DEFECT]
   #Finsi
   # If INST_CRIT = 'ABSOLUTE'
      ♦ PRECISION =/prec                       [R]
   #Finsi
# Finsi

# If TYPE_CHARGE = 'NON_PERIODIQUE'

♦  CRITERION    =  /   'MATAKE_MODI_AV',
                   /   'DANG_VAN_MODI_AV',
                   /   'FATESOCI_MODI_AV',
                   /   'FORMULE_CRITERE',
                   /   'VMIS_TRESCA',

  # If If CRITERION = 'MATAKE_MODI_AC' gold CRITERION =
'DANG_VAN_MODI_AC'
  ♦  PROJECTION   =  /   'UN_AXE',
                     /   'DEUX_AXES',

  ◊  DELTA_OSCI   =  /   delta,                     [R]
                     /   0. ,                           [DEFECT]

  # Finsi
  # If CRITERION = 'FORMULE_CRITERE'
  ♦  FORMULE_GRDEQ   =   for_grd,                     /   [formula]
  ♦  COURBE_GRD_VIE  =   /   'WOHLER',
                         /   'MANSON_COFFIN',
                         /   'FORMES_VIE'
     # If COURBE_GRD_VIE = 'FORMES_VIE'
     ♦  FORMULE_VIE = for_vie,                     /   [formula]
                                                   /   [function]
     # Finsi
  # Finsi
```

```
        # Finsi
        /  ◊  GROUP_MA      =  grma,                          [l_gr_maille]

        /  ◊  GROUP_NO      =  grno,                          [l_gr_noeud]

           ◊  COEF_PREECROU=  /  coef_pre,                    [R]
                              /  1.0,                         [DEFECT]
        # If ( GROUP_MA! = Nun gold GROUP_NO! = Nun)
        ♦  GRID       =  grid,                         [grid]
        # Finsi
    # Finsi

    # If TYPE_CALCUL = 'FATIGUE_VIBR' - > calculation of the acceptable maximum
    amplitude for a structure subjected to a vibratory loading
           #  Choice of the option of calculation
        ♦  OPTION     =  /  'DOMA_ELNO_SIGM',
                         /  'DOMA_ELGA_SIGM',
           #  Reading of the history of constraint
        ♦  HISTORY = _F (
              ♦  RESULT =  LMBO,                          / [evol_elas]
                                                            / [evol_noli]
              ♦  MODE_MECA =  mode,                         [mode_meca]
              ♦  NUME_MODE    =  I,                         [LISTE_I]
              ♦  FACT_PARTICI =  R,                         [LISTE_R]
                         )
           #  Calculation of the damage
        ♦  TOO BAD    =  /  'WOHLER',
        ♦  MATER      =  to subdue,                             [to
    subdue]

                         ),
    # Finsi
           #  Level of impression
        ◊  INFORMATION     =     /  1,                          [DEFECT]
                              /  2,
                                    )
```

Contents

3 Operands

3.1 Keyword TYPE_CALCUL

This keyword makes it possible to calculate

- that is to say a field of damage of tiredness undergone by a structure, if `TYPE_CALCUL = 'CUMUL_DOMMAGE'` ;
- that is to say the critical plan in which shearing is maximum, if `TYPE_CALCUL = 'FATIGUE_MULTI'` ;
- that is to say the amplitude of maximum vibration acceptable by a structure subjected to a vibratory loading, if `TYPE_CALCUL = 'FATIGUE_VIBR'` .

In the first both cases, one knows the loading of the structure (temporal evolution of the constraints or the deformations) and one is interested in the damage or with the plan criticizes associated.

In the last case, one knows the static loading of the structure (typically centrifugal loads for a wing of turbine) but not the dynamic loading (typically the vibration of the wing). The option `'FATIGUE_VIBR'` leaveT then to consider the amplitude of maximum vibration acceptable by the structure to have an unlimited endurance. The principle of calculation is described in the §22.

3.2 Operands commun runs with all the options

3.2.1 Operand MATER

◊ `MATER = to subdue`

Allows to specify the name of material `to subdue` created by `DEFI_MATERIAU` [U4.43.01].

The material `to subdue` must contain the definition of the curve of Wöhler of material for the calculation of the damage by the methods `'WOHLER'` and `'TAHERI_MIXTE'` and the definition of the curve of Manson-Whetstone sheath of material for the calculation of the damage by the methods `'MANSON_COFFIN'`, `'TAHERI_MANSON'` and `'TAHERI_MIXTE'`.

For calculations of the type `'FATIGUE_VIBR'`, the material must moreover contain stress the rupture (operator `DEFI_MATERIAU`, keyword factor `RCCM`, operand `KNOWN`).

3.2.2 Operand INFORMATION

◊ `INFORMATION = / 1` No impression.
`/ 2`

Impression of the parameters of the calculation of the damage (number of the sequence numbers, number of the points of calculation, standard of the calculation of the damage (forced, deformations), localization of the damage (nodes or points of Gauss), type of the equivalent component (`VMIS_SG` or `INVA_2SG`), method of extraction of cycles (RAINFLOW) and method of calculating of the damage (`WOHLER` or `MANSON_COFFIN` or `TAHERI_MANSON` or `TAHERI_MIXTE`).

- point by point of the history of loading, of the cycles extracted and the value of the damage.
- field of damage.

The impressions are made in the file `MESSAGE`.

3.3 Operands specific to the calculation of the type CUMUL_DOMMAGE

3.3.1 Keyword factor HISTORY

This keyword factor gathers all the phase of definition of the history of loading.

History of loading is the evolution of a value of the constraint or deformation in the course of time.

3.3.1.1 Operand RESULT

♦ RESULT = LMBO

Name of the concept result containing the stress fields or the fields of deformation defining the history of loading. More precisely, the concept result must contain one of the fields of reference symbol SIEQ_ELNO, SIEQ_ELGA, EPEQ_ELNO, EPEQ_ELGA, EPMQ_ELNO or EPMQ_ELGA according to the desired option of calculation.

3.3.1.2 Operand EQUI_GD

```
♦ EQUI_GD    =  /  'VMIS_SG',
                /  'INVA_2_SG'
```

To be able to calculate the damage undergone by a structure, by a method of Wöhler, of Manson-Whetstone sheath or a method of Taheri, it is necessary to have a "uniaxial" history of loading in constraints or deformations. With this intention it is necessary to transform the tensor of constraints or the tensor of deformations into a uniaxial field (scalar) "equivalent".

'VMIS_SG'	to calculate the damage starting from a history of loading of the type forced of von Mises signed,
'INVA_2_SG'	to calculate the damage starting from a history of loading of type invariant of a nature 2 signed of the deformation.

3.3.2 Operand OPTION

This keyword factor makes it possible to specify the type of damage to be calculated :

- 'DOMA_ELNO_SIGM' for the calculation of the damage to the nodes starting from a stress field.
- The structure of data result specified under the keyword factor RESULT must contain the field of reference symbol SIEQ_ELNO (calculable by CALC_CHAMP), which amongst other things defines the value of the equivalent constraint of von Mises signed (component VMIS_SG) calculated with the nodes.
- 'DOMA_ELGA_SIGM' for the calculation of the damage at the points of Gauss starting from a stress field.
- The structure of data result specified under the keyword factor RESULT must contain the field of reference symbol SIEQ_ELGA (calculable by CALC_CHAMP), which amongst other things defines the value of the equivalent constraint of von Mises signed (component VMIS_SG) calculated at the points of Gauss.
- 'DOMA_ELNO_EPSI' for the calculation of the damage to the nodes starting from a field of deformations.
- The structure of data result specified under the keyword factor RESULT must contain the field of reference symbol EPEQ_ELNO, which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated with the nodes.
- 'DOMA_ELGA_EPSI' for the calculation of the damage at the points of Gauss starting from a field of deformations.
- The structure of data result specified under the keyword factor RESULT must contain the field of reference symbol EPEQ_ELGA, which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated at the points of Gauss.
- 'DOMA_ELNO_EPME' for the calculation of the damage to the nodes starting from a field of mechanical deformations, out-thermics: $\varepsilon = B \cdot u - \varepsilon_{th}$.
- The structure of data result specified under the keyword factor RESULT must contain the field of reference symbol EPMQ_ELNO (calculable by CALC_CHAMP), which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated with the nodes.
- 'DOMA_ELGA_EPME' for the calculation of the damage at the points of Gauss starting from a field of mechanical deformations, out-thermics: $\varepsilon = B \cdot u - \varepsilon_{th}$.

- The structure of data result specified under the keyword factor RESULT must contain the field of reference symbol EPMQ_ELGA, which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated at the points of Gauss.

3.3.3 Operand TOO BAD

To be able to calculate the damage undergone by a structure, it is necessary beforehand to extract the elementary cycles from the history of loading.

For that of many methods are available. Method available in *Code_Aster* for the calculation of the damage by the Wöhler method or Manson-Whetstone sheath, is the method of counting of the extents in cascade or method of Rainflow [R7.04.01].

For the calculation of the damage by the methods TAHERI_MANSON and TAHERI_MIXTE, one uses the method of counting known as natural which consists in generating cycles in the order of their application.

Once the extracted elementary cycles, this operand makes it possible to specify the method of calculating of the damage for each elementary cycle.

♦ DAMAGE = / 'WOHLER'

For a history of loading of the type forced, the number of cycles to the rupture is determined by interpolation of the curve of Wöhler of material for a level of alternate constraint given (to each elementary cycle corresponds a level of amplitude of constraint $\Delta\sigma=|\sigma_{max}-\sigma_{min}|$ and an alternate constraint $S_{alt}=1/2\Delta\sigma$).
One cannot use the method WOHLER that for the options 'DOMA_ELNO_SIGM' or 'DOMA_ELGA_SIGM'. Moreover, it is necessary that the concept specified result contains respectively the field of reference symbol SIEQ_ELNO or SIEQ_ELGA (calculable by CALC_CHAMP).

The curve of Wöhler of material must be introduced into the operator DEFI_MATERIAU [U4.43.01], under one of the three possible forms [R7.04.02]:

- point by point discretized function (keyword TIREDNESS, operand WOHLER),
- analytical form of Basquin (keyword TIREDNESS, operands A_BASQUIN and BETA_BASQUIN),
- form "zones current" (keyword TIREDNESS, operands E_REFE, A0, A1, A2, A3 and SL and keyword ELAS operand E).

Notice on the curves of tiredness:

For the small amplitudes, the difficulty of the prolongation of the curve of tiredness can arise: for example, for the curves of tiredness of the RCC-M beyond 10 ^{6} cycles, the corresponding constraint 180 MPa is regarded as limit of endurance, it is - with - to say that very forced lower than 180 MPa must produce a factor of null use, or an infinite number of cycles acceptable.

In Code_Aster, the limit of endurance is fixed at 10 million cylces.
The method adopted here corresponds to this concept of limit of endurance: if the amplitude of constraint is lower than the first X-coordinate of the curve of tiredness, then one takes a factor of null use i.e. a number of infinite acceptable cycle.

♦ DAMAGE = / 'MANSON_COFFIN'

For a history of loading of the deformations type, the number of cycles to the rupture is determined by interpolation of the curve of Manson-Whetstone sheath of material for a level of alternate deformation given (to each elementary cycle corresponds a level of amplitude of deformation $\Delta\varepsilon=|\varepsilon_{max}-\varepsilon_{min}|$ and an alternate deformation $E_{alt}=1/2\Delta\varepsilon$).

One cannot use the method MANSON_COFFIN that for the options 'DOMA_ELNO_EPSI' or 'DOMA_ELGA_EPSI', 'DOMA_ELNO_EPME' or 'DOMA_ELGA_EPME'. Moreover, it is necessary that the concept specified result contains respectively the field of reference symbol EPEQ_ELNO, EPEQ_ELGA, EPMQ_ELNO or EPMQ_ELGA (calculable by CALC_CHAMP).

The curve of Manson-Whetstone sheath must be introduced into the operator DEFI_MATERIAU [U4.43.01] (keyword TIREDNESS, operand MANSON_COFFIN).

♦ DAMAGE = / 'TAHERI_MANSON'

This method of calculating of the damage applies only to loadings of type deformation, i.e. for the options 'DOMA_ELNO_EPSI', 'DOMA_ELGA_EPSI', 'DOMA_ELNO_EPME' or 'DOMA_ELGA_EPME'. Moreover, it is necessary that the concept specified result contains respectively the field of reference symbol EPEQ_ELNO, EPEQ_ELGA, EPMQ_ELNO or EPMQ_ELGA (calculable by CALC_CHAMP).

Are n elementary cycles of half amplitude $\frac{\Delta\varepsilon_1}{2,}\dots,\frac{\Delta\varepsilon_n}{2}$.

The calculation of the elementary damage of the first cycle is determined by interpolation on the curve of Manson-Whetstone sheath of material.
The calculation of the elementary damage of the following cycles is determined by the algorithm described Ci - below:

- If $\frac{\Delta\varepsilon_{i+1}}{2}\geq\frac{\Delta\varepsilon_i}{2}$

  the calculation of the elementary damage of the cycle $(i+1)$ is determined by interpolation on the curve of Manson-Whetstone sheath.

- If $\frac{\Delta\varepsilon_{i+1}}{2}<\frac{\Delta\varepsilon_i}{2}$

  one determines:

$$\frac{\Delta\sigma_{i+1}}{2}=F_{NAPPE}\left(\frac{\Delta\varepsilon_{i+1}}{2},\max_{j<i}\left(\frac{\Delta\varepsilon_j}{2}\right)\right)$$
$$\frac{\Delta\varepsilon^*_{i+1}}{2}=F_{FONC}\left(\frac{\Delta\sigma_{i+1}}{2}\right)$$

  where F_{NAPPE} is a tablecloth introduced under the operand TAHERI_NAPPE.

  F_{FONC} is a function introduced under the operand TAHERI_FONC.

The value of the damage of the cycle $(i+1)$ is obtained by interpolation of $\frac{\Delta\varepsilon^*_{i+1}}{2}$ on the curve of Manson-Whetstone sheath of material ($Nrupt_{i+1}$ = many cycles to the rupture for the cycle $(i+1)=\mathrm{MANSON\_COFFIN}\left(\frac{\Delta\varepsilon^*_{i+1}}{2}\right)$ and Dom_{i+1} = damage of the cycle $(i+1)={}^{1}\!/_{Nrupt_{i+1}}$.

The curve of Manson-Whetstone sheath must be introduced into the operator DEFI_MATERIAU [U4.43.01] (keyword TIREDNESS, operand MANSON_COFFIN).

Note:

1) *Tablecloth or the formula introduced under the operand `TAHERI_NAPPE` is in fact the cyclic curve of work hardening with prestressed material.*
2) *The function or the formula introduced under the operand `TAHERI_FONC` in fact the cyclic curve of work hardening of material is.*
3) *Tablecloth or the formula introduced under the operand `TAHERI_NAPPE`, must have `'X'` and `'EPSI'` like parameters.*
4) *The function or the formula introduced under the operand `TAHERI_FONC`, must have as a parameter `'SIGM'`.*

♦ `DAMAGE = / 'TAHERI_MIXTE'`

This method of calculating of the damage applies only to loadings of type deformation, i.e. for the options `'DOMA_ELNO_EPSI'`, `'DOMA_ELGA_EPSI'`, `'DOMA_ELNO_EPME'` or `'DOMA_ELGA_EPME'`. Moreover, it is necessary that the concept specified result contains respectively the field of reference symbol `EPEQ_ELNO`, `EPEQ_ELGA`, `EPMQ_ELNO` or `EPMQ_ELGA` (calculable by `CALC_CHAMP`).

Are n elementary cycles of half amplitude $\frac{\Delta \varepsilon_1}{2,} \ldots, \frac{\Delta \varepsilon_n}{2}$.

The calculation of the elementary damage of the first cycle is determined by interpolation on the curve of Manson-Whetstone sheath of material.

The calculation of the elementary damage of the following cycles is determined by the algorithm described Ci - below:

- If $\frac{\Delta \varepsilon_{i+1}}{2} \geq \frac{\Delta \varepsilon_i}{2}$

  the calculation of the elementary damage of the cycle $(i+1)$ is determined by interpolation on the curve of Manson-Whetstone sheath.

- If $\frac{\Delta \varepsilon_{i+1}}{2} < \frac{\Delta \varepsilon_i}{2}$

  one determines:

$$\frac{\Delta \sigma_{i+1}}{2} = F_{NAPPE}\left(\frac{\Delta \varepsilon_{i+1}}{2}, \max_{j<i}\left(\frac{\Delta \varepsilon_j}{2}\right)\right)$$

  where F_{NAPPE} is a tablecloth introduced under the operand `TAHERI_NAPPE`.

The value of the damage of the cycle $(i+1)$ is obtained by interpolation of $\frac{\Delta \sigma_{i+1}}{2}$ on the curve of Wöhler of material ($Nrupt_{i+1}$ = many cycles to the rupture for the cycle $(i+1) = WOHLER\left(\frac{\Delta \sigma_{i+1}}{2}\right)$ and Dom_{i+1} = damage of the cycle $(i+1) = 1/Nrupt_{i+1}$).

This method requires the data of the curves of Wöhler and Manson-Whetstone sheath of the material, which must be introduced into the operator `DEFI_MATERIAU` [U4.43.01] (keyword factor `TIREDNESS`).

Note:

1) *Tablecloth or the formula introduced under the operand `TAHERI_NAPPE` is in fact the cyclic curve of work hardening with prestressed material.*

2) *Tablecloth or the formula introduced under the operand `TAHERI_NAPPE` , must have `'X'` and `'EPSI'` like parameters.*

3.3.4 Operand TAHERI_NAPPE

This operand makes it possible to specify the name of a tablecloth $F_{NAPPE}\left(\frac{\Delta\varepsilon}{2},\varepsilon_{MAX}\right)$ necessary to the calculation of the damage by the methods `'TAHERI_MANSON'` and `'TAHERI_MIXTE'`.

The tablecloth must have `'X'` and `'EPSI'` like parameters.

Note:

This tablecloth is in fact the cyclic curve of work hardening with prestressed material.

3.3.5 Operand TAHERI_FONC

This operand makes it possible to specify the name of a function $F_{FONC}\left(\frac{\Delta\sigma}{2}\right)$ necessary to the calculation of the damage by the method `'TAHERI_MANSON'`.

The parameter of this function must be `'SIGM'`.

Note:

This function is in fact the cyclic curve of work hardening of material.

3.4 Operands specific to the calculation of the type FATIGUE_MULTI

3.4.1 Operand TYPE_CHARGE

This operand makes it possible to specify the type of loading applied to the structure:

- `PERIODIC`, the loading is periodic;
- `NON_PERIODIQUE`, the loading is not periodical.

3.4.2 Operand OPTION

This operand makes it possible to specify the place where postprocessing will be made:

- `DOMA_ELGA`, postprocessing is made at the points of Gauss of the grid;
- `DOMA_NOEUD`, postprocessing is made with the nodes of the grid or part of the grid, cf operands: `GROUP_MA` and `GROUP_NO`.

3.4.3 Operand RESULT

♦ `RESULT = LMBO`

Name of the concept result containing the deformation and stress fields defining the history of loading. More precisely, the concept result must contain the field of reference symbol

- `SIEF_ELGA, EPSI_ELGA, EPSP_ELGA` are the stress fields, total deflection and plastic deformation, respectively, for the fatigue analysis to the fields with the elements
- `SIGM_NOEU/SIEF_NOEU, EPSI_NOEU, EPSP_NOEU` are the stress fields, total deflection and plastic deformation, respectively, for the fatigue analysis to the fields with the elements

The criterion is initially analyzed. According to the parameters of the criterion, the fields above are required.

In this operator, elastic strain = total deflection - plastic deformation. For the criterion which requires the elastic strain, the request of the total deflection is obligatory. If one does not inform the plastic deformation, one will take zero value.

3.4.4 Operand CHAM_MATER

◊ `CHAM_MATER = cham_mater`

Allows to specify the name of the field of material `cham_mater` created by `AFFE_MATERIAU` [U4.43.03].

The material `to subdue` defined with the order `DEFI_MATERIAU` and which is used for the assignment of material to the grid with the order `AFFE_MATERIAU` must contain the definition of the curve of Wöhler as well as the necessary information with the implementation of the criterion, see the keywords factors `TIREDNESS` and `CISA_PLAN_CRIT` order `DEFI_MATERIAU` [U4.43.01].

3.4.5 Operand CRITERION

```
♦ CRITERION =  / 'MATAKE_MODI_AC',
              / 'DANG_VAN_MODI_AC',
              / 'MATAKE_MODI_AV',
              / 'DANG_VAN_MODI_AV',
              / 'FATESOCI_MODI_AV',
              / 'FORMULE_CRITERE',
              / 'VMIS_TRESCA',
```

Note:

For the periodic loading, the calculation of the damage is carried out only on the first complete cycle. The first part of the history of the loading corresponding to the monotonous loading is not taken into account because this one aims to impose a loading average not no one. For the elastic behavior, calculation is carried out between the maximum value and the minimal value of the cycle considered. For the elastoplastic behavior, calculation is carried out between the first discharge and the second discharge.

The following table lists criteria of starting available for two types of loadings.

TYPE_CHARGE = 'PERIODIC'	TYPE_CHARGE = 'NON_PERIODIQUE'
'MATAKE_MODI_AC' 'DANG_VAN_MODI_AC' 'FORMULE_CRITERE'	'MATAKE_MODI_AV', 'DANG_VAN_MODI_AV' 'FATESOCI_MODI_AV' 'FORMULE_CRITERE'

For the loading with constant amplitude, the operand `CRITERION` allows to specify the criterion which half amplitude will have to satisfy to it with maximum shearing. For the loading with variable amplitude, the operand `CRITERION` allows to specify the criterion which will have to satisfy the maximum damage.

The criteria of starting in Code_Aster can be called by a name for the well established criteria. It is also possible for the user to build a criterion of starting by itself like a formula of the predefined sizes.

Notation:

$\mathbf{n}^*$: normal with the plan in which the amplitude of shearing is maximum;
$\Delta\tau(\mathbf{n})$: amplitude of shearing in constraint in a plan of normal $\mathbf{n}$;
$\Delta\gamma(\mathbf{n})$: amplitude of shearing in deformation in a plan of normal $\mathbf{n}$;
$N_{max}(\mathbf{n})$: normal maximum constraint as regards normal $\mathbf{n}$;
τ_0 : limit of endurance in alternate pure shearing;
d_0 : limit of endurance in alternate pure traction and compression;
P : hydrostatic pressure;

c_p : coefficient being used to take into account possible a préécrouissage;
σ_y : elastic limit.

Criterion MATAKE_MODI_AC
The initial criterion of MATAKE is defined by the inequation [éq.3.12-1]:

$$\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,N_{max}(\mathbf{n}^*)\le b \qquad \textbf{éq 3.12-1}$$

where a and b are two constant data by the user under the keywords MATAKE_A and MATAKE_B keyword factor CISA_PLAN_CRIT of DEFI_MATERIAU, they depend on characteristic materials and are worth:

$$a=\left(\tau_0-\frac{d_0}{2}\right)/\frac{d_0}{2} \qquad b=\tau_0$$

If the user has the results of two tensile tests compression, alternated and the other not, the constant ones a and b are given by:

$$a=\frac{\Delta\sigma_2-\Delta\sigma_1}{(\Delta\sigma_1-\Delta\sigma_2)-2\sigma_m},$$
$$b=\frac{\sigma_m}{(\Delta\sigma_2-\Delta\sigma_1)+2\sigma_m}\times\frac{\Delta\sigma_1}{2},$$

with $\Delta\sigma_1$ the amplitude of loading for the alternate case $(\sigma_m=0)$ and $\Delta\sigma_2$ the amplitude of loading for the case where the average constraint is nonworthless $(\sigma_m\neq 0)$.

We modify the initial criterion of MATAKE by introducing the definition of an equivalent constraint, noted $\sigma_{eq}(\mathbf{n}^*)$:

$$\sigma_{eq}(\mathbf{n}^*)=\left(c_p\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,N_{max}(\mathbf{n}^*)\right)\frac{f}{t},$$

where f/t represent the report of the limits of endurance in inflection and alternating torsion, and must be well informed under the keyword COEF_FLEX_TORS keyword factor CISA_PLAN_CRIT of DEFI_MATERIAU.

Criterion DANG_VAN_MODI_AC
The initial criterion of DANG VAN is defined by the inequation [éq 3.12-2]:

$$\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,P\le b \qquad \textbf{éq 3.12-2}$$

where a and b are two constant data by the user under the keywords D_VAN_A and D_VAN_B keyword factor CISA_PLAN_CRIT of DEFI_MATERIAU, they depend on characteristic materials. If the user has two tensile tests compression, alternate other not constants a and b are worth:

$$a=\frac{3}{2}\times\frac{\Delta\sigma_2-\Delta\sigma_1}{(\Delta\sigma_1-\Delta\sigma_2)-2\sigma_m} \qquad b=\frac{\sigma_m}{(\Delta\sigma_2-\Delta\sigma_1)+2\sigma_m}\times\frac{\Delta\sigma_1}{2}$$

with $\Delta\sigma_1$ the amplitude of loading for the alternate case $(\sigma_m=0)$ $\Delta\sigma_2$ and for the case where the average constraint is nonworthless $(\sigma_m\neq 0)$.

Moreover, we define an equivalent constraint within the meaning of DANG VAN, noted $\sigma_{eq}(\mathbf{n}^*)$:

$$\sigma_{eq}(\mathbf{n}^*)=\left(c_p\frac{\Delta\tau}{2}(\mathbf{n}^*)+a\,P\right)\frac{c}{t}$$

where c/t represent the report of the limits of endurance in alternated shearing and traction, and must be well informed under the keyword COEF_CISA_TRAC keyword factor CISA_PLAN_CRIT of DEFI_MATERIAU.

For more information, to consult the document [R7.04.04].

Criterion MATAKE_MODI_AV

The criterion MATAKE_MODI_AV is an evolution of the criterion of MATAKE. Contrary to the two preceding criteria, this criterion selects the critical plan according to the damage calculated in each plan. It is the plan in which the damage is maximum which is retained. This criterion is adapted to the nonperiodic loadings, which induces the use of a method of counting of cycles in order to calculate the elementary damage. To count the cycles, we use method RAINFLOW.

The once known elementary damage is cumulated linearly to determine the damage.

To calculate the elementary damage we project the history of shear stresses on one or two axes in order to reduce this one to a unidimensional function of $\tau_p=f(t)$ time. After having extracted the elementary under-cycles from τ_p with method RAINFLOW we define an elementary equivalent constraint for any elementary under-cycle i :

$$\sigma^i_{eq}(\mathbf{n})=\alpha\left(c_p\frac{Max\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)-Min\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)}{2}+a\,Max\left(N^i_1(\mathbf{n}),N^i_2(\mathbf{n}),0\right)\right)$$ **éq 3.12-3**

with $\mathbf{n}$ the normal of the plan running, $\tau^i_{p1}(\mathbf{n})$ and $\tau^i_{p2}(\mathbf{n})$ S values of projected shear stresses of the under-cycle i and $N^i_1(\mathbf{n})$ and $N^i_2(\mathbf{n})$ S constraint normal of the under-cycle i. From $\sigma^i_{eq}(\mathbf{n})$ and of a curve of tiredness we determine the number of cycles to the elementary rupture $N^i(\mathbf{n})$ and corresponding damage $D^i(\mathbf{n})=1/N^i(\mathbf{n})$. In [éq 3.12 - 3] α is a corrective term which makes it possible to use a curve of tiredness in traction - compression. Constants a and α must be well informed under the keywords MATAKE_A and COEF_FLEX_TORS keyword factor CISA_PLAN_CRIT of DEFI_MATERIAU.

We use a linear office plurality of damage. That is to say k the number of elementary under-cycles, for a normal $\mathbf{n}$ fixed, the cumulated damage is equal to:

$$D(\mathbf{n})=\sum_{i=1}^{k}D^i(\mathbf{n})$$ **éq 3.12-4**

To determine the normal vector $\mathbf{n}^*$ corresponding to the maximum cumulated damage we vary $\mathbf{n}$, the normal vector $\mathbf{n}^*$ corresponding to the maximum cumulated damage is then given by:

$$D(\mathbf{n}^*)=\underset{\mathbf{n}}{Max}\left(D(\mathbf{n})\right)$$

Criterion DANG_VAN_MODI_AV

The approach and the techniques put in work to calculate this criterion are identical to those used for the criterion MATAKE_MODI_AV. The only difference lies in the definition of the elementary equivalent constraint where hydrostatic pressure P replace the maximum normal constraint N_{max} :

$$\sigma^i_{eq}(\mathbf{n})=\alpha\left(c_p\frac{Max\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)-Min\left(\tau^i_{p1}(\mathbf{n}),\tau^i_{p2}(\mathbf{n})\right)}{2}+a\,Max\left(P^i_1(\mathbf{n}),P^i_2(\mathbf{n}),0\right)\right)$$

Constants a and α are to be informed by the user under the keywords `D_VAN_A` and `COEF_CISA_TRAC` keyword factor `CISA_PLAN_CRIT` of `DEFI_MATERIAU`.

For more information to consult the document [R7.04.04].

Criterion `FATESOCI_MODI_AV`
The criterion of FATEMI and SOCIE is defined by the relation:

$$\varepsilon_{eq}(n)=\frac{\Delta\gamma(n)}{2}\left(1+k\frac{N_{max}(n)}{\sigma_y}\right)$$

where k is a constant which depends on characteristic materials. Contrary to the other criteria, it uses shearing in deformation instead of shearing in constraint. Moreover, the various quantities which contribute to the criterion are multiplied and not added. The criterion of FATEMI and SOCIE is usable after an elastic design or elastoplastic. This criterion selects the critical plan according to the damage calculated in each plan. It is the plan in which the damage is maximum which is retained.

This criterion is adapted to the nonperiodic loadings, which leads us to use the method of counting of cycles RAINFLOW to calculate the elementary damage. The elementary damage is then cumulated linearly to determine the damage.

In order to calculate the elementary damage we project the history of shearing in deformation on one or two axes in order to reduce this one to a unidimensional function of time $\gamma_p=f(t)$. After having extracted the elementary under-cycles with method RAINFLOW we define an elementary equivalent deformation for any elementary under-cycle i :

$$\varepsilon_{eq}^{i}(\mathbf{n})=\alpha\, c_p\left(\frac{Max\left(\gamma'^{i}_{p1}(\mathbf{n}),\gamma'^{i}_{p2}(\mathbf{n})\right)-Min\left(\gamma'^{i}_{p1}(\mathbf{n}),\gamma'^{i}_{p2}(\mathbf{n})\right)}{2}\right)\left(1+a\,Max\left(N_1^i(\mathbf{n}),N_2^i(\mathbf{n}),0\right)\right)$$

éq 3.12-5

with $a=\frac{k}{\sigma_y}$, $\mathbf{n}$ the normal with the plan running, $\gamma'^{i}_{p1}(\mathbf{n})$ and $\gamma'^{i}_{p2}(\mathbf{n})$ values of shearings in deformation projected of the under-cycle i, $N_1^i(\mathbf{n})$ and $N_2^i(\mathbf{n})$ being two values of the normal constraint of the under-cycle i. From $\varepsilon_{eq}^{i}(\mathbf{n})$ and of a curve of Manson-Whetstone sheath we determine the number of cycles to the elementary rupture and $N^i(\mathbf{n})$ corresponding damage $D^i(\mathbf{n})=1/N^i(\mathbf{n})$.

It will be noted that the shearing strains used in the criterion of FATEMI and SOCIE are distortions γ_{ij} ($i\neq j$). If one uses the shearing strains of the tensorial type ϵ_{ij} ($i\neq j$), they should be multiplied by a factor 2 because $\gamma_{ij}=2\epsilon_{ij}$.

In the equation [éq 3.12-5] α is a corrective term which to use a curve of Manson-Whetstone sheath obtained in traction and compression. c_p is a coefficient which makes it possible to take into account a possible pre-work hardening.

Constants a and α must be well informed under the keywords `FATSOC_A` and `COEF_CISA_TRAC` keyword factor `CISA_PLAN_CRIT` order `DEFI_MATERIAU`.

It is noted that a rigorous approach is to use the curve of Manson-Whetstone sheath obtained directly in torsion (which is not always available). The use of the curve of Manson-Whetstone sheath obtained in traction and compression with the corrective term α (which is the relationship between two limits of endurance), as programmed in Code_Aster, is thus an approximation.

As we use a linear office plurality of damage, if m is the number of elementary under-cycles, then for a normal $\mathbf{n}$ fixed, the cumulated damage is equal to:

$$D(\mathbf{n})=\sum_{i=1}^{m} D^i(\mathbf{n})$$

To find the vector normal $\mathbf{n}^*$ corresponding to the maximum cumulated damage we vary $\mathbf{n}$. The normal vector $\mathbf{n}^*$ associated with the maximum cumulated damage is then given by:

$$D(\mathbf{n}^*)=\underset{\mathbf{n}}{Max}(D(\mathbf{n}))$$

Criterion `FORMULE_CRITERE`
This kind of criterion makes it possible to the user to build a criterion like a formula of the predefined sizes. This criterion is based on a general relation:

"Equivalent size" = "Curve of life"

where the "equivalent Size" is a formula provided under the operand `FORMULE_GRDEQ` (to see 3.4.6) and the "Curve of life" is provided under the operand `COURBE_GRD_VIE` (see 3.4.7) that is to say by a function (counted or formulates, under the operand of `'FORMULE_VIE'`, to see 3.4.8), that is to say by a name of curve `'WOHLER'` or `'MANSON_COFFIN'` defined beforehand in `DEFI_MATERIAU`.

Criterion `VMIS_TRESCA`
The criterion `VMIS_TRESCA` is not strictly speaking a criterion of tiredness since it does not make it possible to calculate a damage. It determines the variation of maximum amplitude of the tensor of the constraints in the course of time. Concretely, we apply the criteria of Von Mises and Tresca to the tensors which result from the difference of the tensor of the constraints taken at two distinct moments. While varying these moments we can calculate the maximum values of the criteria of Von Mises and Tresca [R7.04.04].

3.4.6 Opéranof `FORMULE_GRDEQ`

♦ `FORMULE_GRDEQ = for_grd,` / [formula]

Allows to provide the formula of the criterion like a function of the sizes available. The lists of sizes available for each type of loading are in the following table:

`TYPE_CHARGE = 'PERIODIC', CRITERION = 'FORMULE_CRITERE'`
The sizes available are:
`'DTAUMA'`: half-amplitude of maximum constraint shearing($\Delta\tau(\mathbf{n}^*)/2$)
`'PHYDRM'`: hydrostatic pressure (P)
`'NORMAX'`: maximum normal constraint on the critical level ($N_{max}(\mathbf{n}^*)$)
`'NORMOY'`: average normal constraint on the critical level ($N_{moy}(\mathbf{n}^*)$)
`'EPNMAX'`: maximum normal deformation on the critical level ($\varepsilon_{Nmax}(\mathbf{n}^*)$)
`'EPNMOY'`: average normal deformation on the critical level ($\varepsilon_{Nmoy}(\mathbf{n}^*)$)
`'DEPSPE'`: half-amplitude of the equivalent plastic deformation ($\Delta\varepsilon_{eq}^{p}/2$)
`'EPSPR1'`: half-amplitude of the first principal deformation (with the taking into account of the sign)
`'SIGNM1'`: maximum normal constraint on the level associated with ε_1
`'DENDIS'`: density of dissipated energy (W_{cy})
`'DENDIE'`: density of energy of the elastic distortions (W_e)
`'APHYDR'`: half-amplitude of the hydrostatic pressure (P_a)

`'MPHYDR'`: average hydrostatic pressure (P_m)
`'DSIGEQ'`: half-amplitude of the equivalent constraint ($\Delta\sigma_{eq}/2$)
`'SIGPR1'`: half-amplitude of the first principal constraint (with the taking into account of the sign)
`'EPSNM1'`: maximum normal deformation on the level associated with σ_1
`'INVA2S'`: half-amplitude of the second invariant of the deformation $J_2(\epsilon)$
`'DSITRE'`: half-amplitude of the Tresca half-constraint ($(\sigma_{max}^{Tresca}-\sigma_{min}^{Tresca})/4$)
`'DEPTRE'`: half-amplitude of the Tresca half-deformation ($(\epsilon_{max}^{Tresca}-\epsilon_{min}^{Tresca})/4$)
`'EPSPAC'`: plastic deformation accumulated p
`'RAYSPH'`: the ray of the smallest sphere circumscribed with the way of loading within the space of diverters of the constraints R
`'AMPCIS'`: amplitude of cission τ_a
`'DEPSEE'`: half-amplitude of the equivalent elastic strain ($\Delta\varepsilon_e^p/2$)

There exist sizes depending on the orientation of the plan which pass through a point of material. For these sizes, one defines criteria of the standard critical plan. The critical plan is the plan which makes maximum a formula criticizes (see Opéranof FORMULE_CRITIQUE).

`'DTAUCR'`: half-amplitude of constraint shearing as regards normal **N** ($\Delta\tau(\mathbf{n})/2$)
`'DGAMCR'`: half-amplitude of deformation (of engineering) shearing as regards normal **N** ($\Delta\gamma(\mathbf{n})/2$)
`'DSINCR'`: half-amplitude of normal constraint as regards normal **N** ($\Delta N(\mathbf{n})/2$)
`'DEPNCR'`: half-amplitude of normal deformation as regards normal **N** ($\Delta\epsilon_n(\mathbf{n})/2$)

`'MTAUCR'`: maximum constraint shearing as regards normal **N** ($\tau_{max}(\mathbf{n})$)
`'MGAMCR'`: deformation (of engineering) maximum shearing as regards normal **N** ($\gamma_{max}(\mathbf{n})$)
`'MSINCR'`: maximum normal constraint as regards normal **N** ($N_{max}(\mathbf{n})$)
`'MEPNCR'`: maximum normal deformation as regards normal **N** $\varepsilon_{nmax}(\mathbf{n})$

`'DGAMPC'` : half-amplitude of plastic deformation (of engineering) shearing as regards normal **N** ($\Delta\gamma^p/2$)
`'DEPNPC'` :half-amplitude of normal plastic deformation as regards normal **N** ($\Delta\varepsilon_e^p/2$)
`'MGAMPC'`: plastic deformation (of engineering) maximum shearing as regards normal **N** ($\gamma_{max}^p(\mathbf{n})$)
`'MEPNPC'`: maximum normal plastic deformation as regards normal **N** $\varepsilon_{nmax}^p(\mathbf{n})$

It will be noted that there exist two types of shearing strain measurement: distortions of shearing γ_{ij} ($i\neq j$) and shearing strains ϵ_{ij} ($i\neq j$). Let us note that $\gamma_{ij}=2\epsilon_{ij}$. For `'DGAMCR'`, `'MGAMCR'`, `'MGAMPC'`, the distortions of shearing were used γ_{ij} .

TYPE_CHARGE = 'NON-PERIODIQUE', CRITERION = 'FORMULE_CRITERE'
Sizes available: `'TAUPR_1'`: projected shear stresses of the first top of the under-cycle ($\tau_{p1}(\mathbf{n})$) `'TAUPR_2'`: projected shear stresses of the second top of the under-cycle ($\tau_{p2}(\mathbf{n})$) `'SIGN_1'`: normal constraint of the first top of the under-cycle ($N_1(\mathbf{n})$) `'SIGN_2'`: normal constraint of the second top of the under-cycle ($N_2(\mathbf{n})$) `'PHYDR_1'`: hydrostatic pressure of the first top of the under-cycle `'PHYDR_2'`: hydrostatic pressure of the second top of the under-cycle

`EPSPR_1' : shearing in deformation projected of the first top of the under-cycle ($\gamma_{p1}(\mathbf{n})$)
`EPSPR_2' : shearing in deformation projected of the second top of the under-cycle($\gamma^{i}_{p2}(\mathbf{n})$)
`SIPR1_1' : first principal constraint of the first top of the under-cycle ($\sigma_1(1)$)
`SIPR1_2' : first principal constraint of the second top of the under-cycle ($\sigma_1(2)$)
`EPSN1_1' : normal deformation on the level associated with $\sigma_1(1)$ first top of the under-cycle
`EPSN1_2' : normal deformation on the level associated with $\sigma_1(2)$ second top of the under-cycle
`ETPR1_1' : first principal total deflection of the first top of the under-cycle ($\epsilon_1^{tot}(1)$)
`ETPR1_2' : first principal total deflection of the second top of the under-cycle ($\epsilon_1^{tot}(2)$)
`SITN1_1' : normal constraint on the level associated with $\epsilon_1^{tot}(1)$ first top of the under-cycle
`SITN1_2' : normal constraint on the level associated with $\epsilon_1^{tot}(2)$ second top of the under-cycle
`EPPR1_1' : first principal plastic deformation of the first top of the under-cycle ($\epsilon_1^{p}(1)$)
`EPPR1_2' : first principal plastic deformation of the second top of the under-cycle ($\epsilon_1^{p}(2)$)
`SIPN1_1' : normal constraint on the level associated with $\epsilon_1^{p}(1)$ first top of the under-cycle
`SIPN1_2' : normal constraint on the level associated with $\epsilon_1^{p}(2)$ second top of the under-cycle
`SIGEQ_1' : equivalent constraint of the first top of the under-cycle ($\sigma_{eq}(1)$)
`SIGEQ_2' : equivalent constraint of the second top of the under-cycle ($\sigma_{eq}(2)$)
`ETEQ_1' : equivalent total deflection of the first top of the under-cycle ($\epsilon_{eq}^{tot}(1)$)
`ETEQ_2' : equivalent total deflection of the second top of the under-cycle ($\epsilon_{eq}^{tot}(2)$)

Note:

1) For the periodic loading, the formula of criterion is used to determine the plan of maximum shearing if the parameter 'DTAUMA' is introduced into the formula.
2) For the loading not-periodical, after having extracted the elementary under-cycles with method RAINFLOW, we calculate an elementary equivalent size by the formula of criterion for any elementary under-cycle. It is noted that the under-cycle is represented by two states of stress or deformation, noted by the first and the second tops of the under-cycle.
3) Parameters of entries of the order FORMULA must be among those listed in the table above.
4) Expressions of certain sizes are in the document [R7.04.04].
5) One stresses that the thermal deformation was not taken into account, i.e., $\epsilon^{tot}=\epsilon^{e}+\epsilon^{p}$.
6) The operators used in the formula must be in conformity with the syntax of Python as indicated in the note [U4.31.05].
7) For the periodic loading, the evaluation of the equivalent size left under the name 'SIGEQ1'.

3.4.7 Opéranof COURBE_GRD_VIE

♦ COURBE_GRD_VIE = / 'WOHLER',
/ 'MANSON_COFFIN',
/ 'FORMES_VIE'

Allows to provide a curve of connecting the size equivalent to the number of cycles to the rupture.
If COURBE_GRD_VIE = 'WOHLER', one will take the curve of Wohler ($N_f=f(SIGM)$) defined in AFFE_MATERIAU.
If COURBE_GRD_VIE = 'MANSON_COFFIN', one will take the curve of Manson_Coffin ($N_f=f(EPSN)$) defined in AFFE_MATERIAU.
If COURBE_GRD_VIE = 'FORMES_VIE', one will provide a function defining the curve of life, to see 3.4.8.

3.4.8 Opéranof FORMULE_VIE

♦ FORMULE_VIE = for_vie, / [formula]
/ [function]

Allows to specify the curve connecting the equivalent size and the lifetime.
If for_vie is provided by a tabulée function, it must be in the form:

$N_f = f \quad (grandeur_{équivalente})$.

If for_vie is provided by a formula, it must be in the form:

$grandeur_{équivalente} = f(N_f)$.

In this case, the parameter of entry for the order FORMULA must be ' NBRUPT '(i.e., N_f).

3.4.9 Opéranof FORMULE_CRITIQUE

◊ FORMULE_CRITIQUE = for_grd, [formula]

It keyword makes it possible to define a critical size that the critical plan makes maximum. It is necessary that this formula contains at least a parameter depend on the orientation of the plan.

3.4.10 Operand METHOD

♦ METHOD = 'CERCLE_EXACT'

Allows to specify the name of the method which will be used to calculate to it half amplitude of maximum shearing.

Method of 'CERCLE_EXACT' is used to determine the circle circumscribed at the points which are in plans of shearing. This method rests on the process which consists in obtaining the circle which passes by three points, cf document [R7.04.04].

3.4.11 Operand INST_INIT_CYCL

◊ INST_INIT_CYCL = / inst_ini_cyc

Allows to specify the moment intial part of the cyclic loading. If this operand is not indicated or inst_ini_cyc is not part of the calculated moments , one takes the initial value stored in the result like the initial moment of the cycle. This operand also makes it possible to the users to apply a loading average not-no one.

3.4.12 Operand INST_CRIT

◊ INST_CRIT =/ 'RELATIVE'
/ 'ABSOLUTE'

Allows to specify the criterion to seek the initial moment INST_INIT_CYCL

3.4.13 Operand PRECISION

◊ PRECISION =/prec [R]
/ 1.E-6 ,

Allows to specify the precision of the initial moment INST_INIT_CYCL

3.4.14 Operand PROJECTION

♦ PROJECTION = / 'UN_AXE',
/ 'DEUX_AXES',

If the loading is not periodical, it is necessary to project the history of shearing on one or two axes, cf document [R7.04.04].

- UN_AXE, the history of shearing is projected on an axis;
- DEUX_AXES, the history of shearing is projected on two axes.

3.4.15 Operand DELTA_OSCI

◊ DELTA_OSCI = / delta,

`/ 0.0,`

Filtering of the history of the loading. In all the cases, if the function remains constant or decreasing on more than two consecutive points one removes the intermediate points to keep only the two extreme points. Then, one removes history of loading the points for which the variation of the value of the constraint is lower than the value `delta`. By default `delta` is equal to zero, which amounts keeping all the oscillations of the loading, even those of low amplitude. For more information to see the documentation of the order `POST_FATIGUE`, [U4.83.01], even operand.

3.4.16 Operands GROUP_MA GROUP_NO

◊ `GROUP_MA = lgma,`

The options are calculated on the groups of meshs contained in the list `lgma` .

◊ `GROUP_NO = lgno,`

The options are calculated on the groups of nodes contained in the list `lgno` .

3.4.17 Operand COEF_PREECROU

```
◊ COEF_PREECROU = /  coef_pre,
                  /  1.0,
```

This coefficient is used to take into account the effect of possible a préécrouissage.

3.4.18 Operand GRID

♦ `GRID = grid,`

Allows to specify the name of the grid given by the user.

3.5 Operands specific to the calculation of the type FATIGUE_VIBR

3.5.1 Principle of calculation

This option does not aim at calculating the damage associated with a known loading, but contrary considering the loading vibratory maximum associated with an unlimited endurance with the studied structure. The structures concerned are typically the wings, solicited by a known static loading (centrifugal load related to the rotation of the machine) and by an unknown or badly known dynamic loading (vibrations induced by the flow of the fluid).

A fundamental assumption of this option is to consider a uniaxial criterion of tiredness (method of Wöhler). In other words, it is supposed that the principal directions of the static loading and the dynamic loading are the same ones. This assumption seems licit for the usual structures concerned (wings, lines of piping,…) ; it induces a conservatism undoubtedly excessive in the case general.

The approach of a study with this option is the following one:

- Calculation of the constraint related to the static loading σ_{stat} with `MECA_STATIQUE` or `STAT_NON_LINE` ;
- Calculation of the constraints associated with N clean modes considered σ_{mod}^{i} with `CALC_MODES` ;
- Fatigue analysis with `CALC_FATIGUE/TYPE_CALCUL = 'FATIGUE_VIBR'`
  - Introduction of an assumption on the relative weight of the various clean modes considered $(\beta_i)_{1\leq i\leq N}$ (corresponds to the operand `FACT_PARTICI`) :

$$\sigma_{total}(t)=\sigma_{stat}+\alpha\sum_{i=1}^{N}\beta_i\sigma_{mod}^i\cos(\omega_i t+\phi_i) ,$$

where ω_i and ϕ_i are respectively the pulsation (known) and the dephasing (unknown) of mode I. The coefficient α is the parameter which one seeks to calculate;

- Recovery of the parameters materials and choices of the criterion of calculation of the damage (operands CORR_SIGM_MOYE and MATER , cf § 24). One notes f the criterion which the maximum amplitude of variation of the constraint must check S_{alt}^{max} . f depends on the limit of endurance S_l and of the limit to the rupture S_u material:

$$S_{alt}^{\max}=f(\sigma_{stat},S_l,S_u)$$

- On all the nodes or points of Gauss of the grid (according to the choice in OPTION) :
  - Calculation of the amplitude of variation of the constraints: $S_{alt}=\alpha\sum_{i=1}^{N}\beta_i\sigma_{mod}^i$ (to be noted that, not knowing dephasings between the modes, the amplitude is defined in a conservative way as the sum of the amplitude of each mode);
  - Calculation of the coefficient α correspondent with an unlimited endurance:

$$\alpha=\frac{f(\sigma_{stat},S_l,S_u)}{\sum_{i=1}^{N}\beta_i\sigma_{mod}^i}$$

- Interpretation and use of the result of CALC_FATIGUE : the operator provides the field (with the nodes or the point of Gauss) of the acceptable values of α : the minimal value of α on the grid allows to calculate the acceptable maximum amplitude of vibration of the structure (the minimal value is displayed in the file message; it can also be found by post-treating or visualizing the field result); the field makes it possible to locate the zones which limit the lifetime of the structure.

To pass from the coefficient α with the acceptable amplitude of vibration in a given point $\partial\tilde{u}$ (corresponding for example to the position of a sensor), an additional operation is to be realized. One notes $\tilde{u}_{mod}^i$ displacement at the point of interest associated with the mode i ; the acceptable amplitude of vibration in this point is then:

$$\partial\tilde{u}=min(\alpha)\sum_{i=1}^{N}\beta_i\tilde{u}_{mod}^i$$

Note:

> *If the static stress exceeds in a node stress the rupture of material, the acceptable amplitude of vibration is worthless. In this case, a message of alarm is transmitted and calculation continues on the other nodes.*

3.5.2 Keyword factor HISTORY

This keyword factor gathers the phase of definition of the loading: static stress (operand RESULT) ; modal constraints (MODE_MECA) ; number of the modes to be considered (NUME_MODE) ; relative weight of each one of its modes (FACT_PARTICI).

3.5.2.1 Operand RESULT

♦ RESULT = LMBO

Name of the concept result containing the stress field associated with the static loading with the structure (only one step of time). More precisely, the concept result must contain one of the fields of reference symbol SIEQ_ELNO or SIEQ_ELGA according to the desired option of calculation.

3.5.2.2 Operand MODE_MECA

♦ MODE_MECA = mode

Name of the concept of the type mode_meca, containing the stress fields for the clean modes of the structure.

More precisely, the concept result must contain one of the fields of reference symbol SIEQ_ELNO or SIEQ_ELGA according to the desired option of calculation. These fields are calculated with the operator CALC_CHAMP, in postprocessing of a calculation of clean modes with CALC_MODES.

3.5.2.3 Operand NUME_MODE

♦ NUME_MODE = list_I

Number of the modes to be considered for the calculation of the damage.

3.5.2.4 Operand FACT_PARTICI

♦ FACT_PARTICI = list_R

Relative weight of each mode to be considered. The length of the list must be identical to the length of that well informed under the operand NUME_MODE.

Only the relationship between the various provided factors is important. If one wants to pass from the parameter calculated by CALC_FATIGUE for a maximum amplitude of displacement in a given node, it is however advisable to take well into account the same coefficients (cf § 22).

3.5.3 Operand OPTION

This keyword factor makes it possible to specify the place of calculation of the damage:

- 'DOMA_ELNO_SIGM' for the calculation of the damage to the nodes starting from a stress field.
  Static and modal results (operands RESULT and MODE_MECA) must contain the field of reference symbol SIEQ_ELNO (calculable by CALC_CHAMP), which amongst other things defines the value of the equivalent constraint of von Mises signed (component VMIS_SG) calculated with the nodes.
- 'DOMA_ELGA_SIGM' for the calculation of the damage at the points of Gauss starting from a stress field.
  Static and modal results (operands RESULT and MODE_MECA) must contain the field of reference symbol SIEQ_ELGA (calculable by CALC_CHAMP), which amongst other things defines the value of the equivalent constraint of von Mises signed (component VMIS_SG) calculated at the points of Gauss.

3.5.4 Operand CORR_SIGM_MOYENNE

♦ CORR_SIGM_MOYE = / 'GOODMAN',
/ 'TO STACK' ,

The structure is subjected to a loading with nonworthless average constraint, the average constraint corresponding to the static stress.

The taking into account of the average constraint σ_m in the curve of tiredness of Wöhler can be done with the aidE of the diagram of Haigh [R7.04.01]. Two corrections are available to calculate the acceptable alternate constraint S_{alt}^{max} according to the limit of endurance S_l and of the limit to the rupture S_u material:

right-hand side of Goodman:

$$S_{alt}^{max}=S_l\left(1-\frac{\sigma_m}{S_u}\right)$$

parabola To stack:

$$S_{alt}^{max}=S_l\left(1-\frac{\sigma_m}{S_u}\right)^2$$

The value of the limit to the rupture of material S_u must be introduced into the operator DEFI_MATERIAU [U4.43.01] (keyword factor RCCM, operand Known). Limit of endurance S_l corresponds to the first point of the curve of Wöhler (operator DEFI_MATERIAU, keyword TIREDNESS, operand WOHLER).

3.5.5 Operand **TOO BAD**

♦ DAMAGE = / 'WOHLER'

For the moment, only the method of Wöhler is available for the vibratory fatigue analyses. This method rests on the calculation of the amplitude of variation of the constraints and the comparison with the curve of tiredness of Wöhler of material.

The curve of Wöhler of material must be introduced into the operator DEFI_MATERIAU (keyword TIREDNESS, operand WOHLER). Only limit of endurance S_l (i.e the first point of the curve) is really used in calculation.

4 Size and components introduced into *Code_Aster*

The computed values are stored at the points of Gauss or the nodes according to the option selected. Size FACY_R (Cyclic Tiredness) was introduced into the catalogue of the sizes.

For the periodic loading and the criteria of the type of plan criticizes maximum shearing

DTAUM1	**first** value of the half amplitude max of shearing in the critical plan
VNM1X	component x normal vector with the plan criticizes related to DTAUM1
VNM1Y	component y normal vector with the plan criticizes related to DTAUM1
VNM1Z	component z normal vector with the plan criticizes related to DTAUM1
SINMAX1	normal maximum constraint with the plan criticizes correspondent with DTAUM1
SINMOY1	normal average constraint with the plan criticizes correspondent with DTAUM1
EPNMAX1	normal maximum deformation with the plan criticizes correspondent with DTAUM1
EPNMOY1	average maximum deformation with the plan criticizes correspondent with DTAUM1
SIGEQ1	Constraint equivalent within the meaning of the criterion selected correspondent to DTAUM1
NBRUP1	many cycles before rupture (function of SIGEQ1 and of a curve of Wöhler)
ENDO1	damage associated with NBRUP1 (ENDO1=1/NBRUP1)
DTAUM2	**second** value of the half amplitude max of shearing in the critical plan
VNM2X	component x normal vector with the plan criticizes related to DTAUM2
VNM2Y	component y normal vector with the plan criticizes related to DTAUM2
VNM2Z	component z normal vector with the plan criticizes related to DTAUM2
SINMAX2	normal maximum constraint with the plan criticizes correspondent with DTAUM2
SINMOY2	normal average constraint with the plan criticizes correspondent with DTAUM2
EPNMAX2	normal maximum deformation with the plan criticizes correspondent with DTAUM2
EPNMOY2	average maximum deformation with the plan criticizes correspondent with DTAUM2
SIGEQ2	Constraint equivalent within the meaning of the criterion selected correspondent to DTAUM2
NBRUP2	many cycles before rupture (function of SIGEQ2 and of a curve of Wöhler)
ENDO2	damage associates with NBRUP2 (ENDO2=1/NBRUP2)

Table 5.5-1: Components specific to multiaxial cyclic tiredness for the periodic loading

For the loading not-periodical and the criteria of the type of plan criticizes maximum damage

VNM1X	component x normal vector with the plan criticizes dependent with the damage max
VNM1Y	component y normal vector with the plan criticizes dependent with the damage max
VNM1Z	component z normal vector with the plan criticizes dependent with the damage max
ENDO1	damage associated with the block with loading
VNM2X	component x normal vector with the plan criticizes dependent with the damage max
VNM2Y	component y normal vector with the plan criticizes dependent with the damage max
VNM2Z	component z normal vector with the plan criticizes dependent with the damage max

Table 5.5-2: Components specific to multiaxial cyclic tiredness for the loading not-periodical

For the loading not-periodical, if there exists only one critical plan of the maximum damage, VNM2X, VNM2Y, VNM2Z are identical to VNM1X, VNM1Y, VNM1Z. If several plans exist, one an alarm emits and leaves the two foregrounds.

5 Examples

One will be able to refer to test SZLZ105 concerning the damage and the office plurality of damage, with the SSLV135a tests as regards relating to the periodic loadings as with the SSLV135c tests for the case where the loading is not periodical.

For the use of TYPE_CALCUL = 'FATIGUE_VIBR', one will be able to refer to the case test sdlv129a.

5.1 Calculation of the half amplitude of maximum shearing by the method: 'CERCLE_EXACT'

See the case SSLV135a test. Here the loading is periodic and the damage is calculated at the points of Gauss.

5.2 Calculation of the damage when the loading is not periodical

See the case SSLV135b test. Here the loading is not periodic, the damage is calculated at the points nodes on part of the whole of the grid: 'FACE1', 'FACE3' and 'FACE5'.

5.3 Calculation of the damage with the criterion FATESOCI_MODI_AV

See the case SSLV135b test. Here the loading is not periodic, the damage is calculated with the nodes on part of the whole of the grid: 'FACE1', 'FACE2' and 'FACE3'.

5.4 Calculation of the damage with the criteria in formula

criterion of 'MAKATE_MODI_AC': See the case SSLV135a test.
criterion of 'DANG_VAN_MODI_AC': See the case SSLV135a test.
criterion of 'MATAKE_MODI_AV': See the case SSLV135b test.
criterion of 'DANG_VAN_MODI_AV': See the case SSLV135b test.
criterion of 'FATESOCI_MODI_AV'.: See the case SSLV135b test.