Operator CALC_FATIGUE

1 Drank

Compute a field of damage of fatigue undergone by a structure; a critical plane in which the shears are maximum; or a maximum amplitude of acceptable vibration.

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

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

Critical plane and maximum shears : from a history of stresses calculated with Gauss points or the nodes, if the loading is periodic, we calculate a field of variables which contains inter alia: the half amplitude of maximum shears, the associated normal vector, the number of cycles to the fracture and the damage corresponding to Gauss points or to the nodes. If the loading is not periodical the field of variables contains the maximum damage and the normal vector associated with Gauss points or with 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 stresses of the eigen modes considered, calculated with Gauss points or the nodes, the amplitude of maximum vibration is calculated by means of a uniaxial criterion of fatigue.

Product a concept of the cham_elem `type` or `cham_no`.

2 Syntax

```
    CHAM [cham_elem*] = CALC_FATIGUE  (

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

# If TYPE_CALCUL = "CUMUL_DOMMAGE" - > computation of the damage

       #Choix  of the computation option

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

       #Lecture   of the history of stress or strain

    ♦HISTOIRE  = _F   (

          ♦RESULTAT=res       ,                        /[evol_elas]
                                                       /[evol_noli]
                                                       /[dyna_trans]

          ♦EQUI_GD=/             "VMIS_SG",                [DEFAULT]
                          /  "INVA_2_SG",

                     )

       #Calcul    of damage

    ♦DOMMAGE=/             "WOHLER",
                     /  "MANSON_COFFIN",
                     /  "TAHERI_MANSON",
                     /  "TAHERI_MIXTE",

    ♦   MATER=mater         ,                                [to subdue]

    ◊   TAHERI_NAPPE =nappe ,                          /   [three-
dimensions function]
                                                       /   [formula]

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

                     ),

# Finsi

# If TYPE_CALCUL = "FATIGUE_MULTI" - >Calcul   of the maximum shears or
                                        the maximum damage

    ♦TYPE_CHARGE=/            "PERIODIQUE",
                        /  "NON_PERIODIQUE",

    ♦OPTION=/              "DOMA_ELGA",
                     /  "DOMA_NOEUD",

    ♦RESULTAT=res          ,                           /   [evol_elas]
                                                       /   [evol_noli]

    ◊CHAM_MATER=cham_mater        ,                        [cham_mater]

    # If TYPE_CHARGE = "PERIODIQUE"

    ♦CRITERE=/                "MATAKE_MODI_AC",
                        /  "DANG_VAN_MODI_AC",
                        /  "FORMULE_CRITERE",
```

```
                    /  "VMIS_TRESCA",
       # If CRITERE! = "VMIS_TRESCA"
       ♦METHODE=/                "CERCLE_EXACT",
       # Finsi
       # If CRITERE = "FORMULE_CRITERE"
       ♦FORMULE_GRDEQ        =for_grd  ,                     /  [formula]
       ♦COURBE_GRD_VIE    =     "WOHLER",
                               /  "MANSON_C",
                                /  "FORM_VIE"
          # If COURBE_GRD_VIE = "FORM_VIE"
         ♦FORMULE_VIE  = for_vie,                    /  [formula]
                                                     /  [function]
         # Finsi
       # Finsi
        ◊  INST_INIT_CYCL =    / inst_ini_cyc           [R]
        ◊  INST_CRIT  =/ "RELATIF"
                    /"ABSOLU"
        # If INST_CRIT = "RELATIF"
           ◊ accuracy =/ prec                      [R]
                     /  1.E-6 ,                           [DEFAULT]
        #Finsi
        # If INST_CRIT = "ABSOLU"
           ♦ accuracy =/ prec                      [R]
        #Finsi
    # Finsi

    # If TYPE_CHARGE = "NON_PERIODIQUE"
    ♦  CRITERE=/           "MATAKE_MODI_AV",
                    /  "DANG_VAN_MODI_AV",
                    /  "FATESOCI_MODI_AV",
                    /  "FORMULE_CRITERE",
                    /  "VMIS_TRESCA",
       # If If CRITERE = "MATAKE_MODI_AC" gold CRITERE = "DANG_VAN_MODI_AC"
       ♦PROJECTION=/           "UN_AXE",
                          /  "DEUX_AXES",
       ◊DELTA_OSCI=/delta           ,                          [R]
                          /0  . ,                        [DEFAULT]
       # Finsi
       # If CRITERE = "FORMULE_CRITERE"
       ♦FORMULE_GRDEQ        =for_grd  ,                     /  [formula]
       ♦COURBE_GRD_VIE    =     "WOHLER",
                               /  "MANSON_C",
                               /  "FORM_VIE"
         # If COURBE_GRD_VIE = "FORM_VIE"
         ♦FORMULE_VIE  = for_vie,                    /  [formula]
                                                     /  [function]
         # Finsi
       # Finsi
    # Finsi
    /◊GROUP_MA=grma                  ,                          [l_gr_maille]
    /◊MAILLE=ma                      ,
[l_maille]
```

```
        /   ◊   GROUP_NO=grno       ,                            [l_gr_noeud]
        /   ◊   NOEUD=no            ,                               [l_noeud]
            ◊COEF_PREECROU=/coef_pre          ,                           [R]
                             /1.0   ,                             [DEFAULT]
```

**# If (GROUP_MA! = Nun gold NETS! = Nun gold **
GROUP_NO! = Nun gold NOEUD! = Nun)

```
        ♦MAILLAGE=maillage          ,                                  [mesh]
```

 # Finsi

 # Finsi

 # If TYPE_CALCUL = "FATIGUE_VIBR" - > computation of the acceptable maximum amplitude for a structure subjected to a vibratory loading

```
            #Choix  of computation option
        ♦OPTION=/               "DOMA_ELNO_SIGM",
                            /   "DOMA_ELGA_SIGM",

            #Lecture   of the history of stress
        ♦HISTOIRE  = _F   (
                ♦RESULTAT=res       ,                          /[evol_elas]
                                                               /[evol_noli]
                ♦MODE_MECA=mode         ,                          [mode_meca]
                ♦   NUME_MODE    =I  ,                             [LISTE_I]
                ♦FACT_PARTICI =R ,                             [LISTE_R]
                            )

            #Calcul    of damage
        ♦DOMMAGE=/              "WOHLER",
        ♦   MATER=mater         ,                               [to subdue]

                            ),
```

 # Finsi

```
            #Niveau    of printing
        ◊INFO=/1                    ,                             [DEFAULT]
                          /2  ,
                                  )
```

Contents

3 Operands

3.1 Key word TYPE_CALCUL

This key word make it possible to calculate
- is a field of damage of fatigue undergone by a structure, if TYPE_CALCUL = "CUMUL_DOMMAGE" ;
- that is to say the critical plane in which the shears are 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 structure (temporal evolution of the stresses or the strains) and one is interested in the damage or the associated critical plane.

In the last case, one knows the static loading of structure (typically centrifugal loads for a wing of turbine) but not the dynamic loading (typically the vibration of the wing). Option "FATIGUE_VIBR" then makes it possible to consider the amplitude of maximum vibration acceptable by structure to have an unlimited endurance. The principle of computation is described in the §2022.

3.2 Operands commun runs with all the options

3.2.1 Operand MATER

◊**MATER** = to subdue

Makes it possible to specify the name of the MATER material created by DEFI_MATERIAU [U4.43.01].

The MATER material must contain the definition of the curve of Wöhler of the material for the computation of the damage by the methods "WOHLER" and "TAHERI_MIXTE" and the definition of the curve of Manson-Whetstone sheath of the material for the computation of the damage by methods "MANSON_COFFIN", "TAHERI_MANSON" and "TAHERI_MIXTE".

For computations of the type "FATIGUE_VIBR", the material must moreover contain stress the rupture (operator DEFI_MATERIAU, key word factor RCCM, opérande SU).

3.2.2 Operand INFO

◊INFO=/1Aucune printing.
/2

Printing of the parameters of the computation of the damage (number of the numbers D" order, number of the points of computation, type of the computation of the damage (forced, strains), localization of the damage (nodes or Gauss points), type of the equivalent component (VMIS_SG or INVA_2SG), method of extraction of cycles (RAINFLOW) and méthode de calcul of damage (WOHLER or MANSON_COFFIN or TAHERI_MANSON or TAHERI_MIXTE).

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

The printings are made in the message file .

3.3 Operands specific to the computation of the type CUMUL_DOMMAGE

3.3.1 Key word factor HISTOIRE

This key word factor gathers all the phase of definition of the load history.

The load history is the evolution of a value of the stress or strain in the course of time.

3.3.1.1 Operand RESULTAT

♦RESULTAT=res

Name of the result concept containing the stress fields or the strain fields defining the load history. More precisely, the result concept must contain one of the fields of symbolic name SIEQ_ELNO, SIEQ_ELGA, EPEQ_ELNO, EPEQ_ELGA, EPMQ_ELNO or EPMQ_ELGA according to the desired computation option.

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, a method of Wöhler, of Manson-Whetstone sheath or a method of Taheri, it is necessary to have a "uniaxial" load history in stresses or strains. With this intention it is necessary to transform the stress tensor or the strain tensor into a uniaxial field (scalar) "equivalent".

"VMIS_SG" to compute: damage from a load history of type signed von Mises stress,
"INVA_2_SG" to compute: damage from a load history of type invariant of a nature 2 signed of the strain.

3.3.2 Operand OPTION

This key word factor makes it possible to specify the type of damage to calculating :

- "DOMA_ELNO_SIGM" for the computation of the damage to the nodes from a stress field.
- The data structure result specified under the key word factor RESULTAT must contain the field of symbolic name SIEQ_ELNO (computable by CALC_CHAMP), which amongst other things defines the value of the equivalent stress of von Mises signed (component VMIS_SG) calculated in the nodes.
- "DOMA_ELGA_SIGM" for the computation of the damage to Gauss points from a stress field.
- The data structure result specified under the key word factor RESULTAT must contain the field of symbolic name SIEQ_ELGA (computable by CALC_CHAMP), which amongst other things defines the value of the equivalent stress of von Mises signed (component VMIS_SG) calculated in Gauss points.
- "DOMA_ELNO_EPSI" for the computation of the damage to the nodes from a strain field.
- The data structure result specified under the key word factor RESULTAT must contain the field of symbolic name EPEQ_ELNO, which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated in the nodes.
- "DOMA_ELGA_EPSI" for the computation of the damage to Gauss points from a strain field.
- The data structure result specified under the key word factor RESULTAT must contain the field of symbolic name EPEQ_ELGA, which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated in Gauss points.
- "DOMA_ELNO_EPME" for the computation of the damage to the nodes from a strain field mechanics, out-thermal: $\varepsilon = B \cdot u - \varepsilon_{th}$.
- The data structure result specified under the key word factor RESULTAT must contain the field of symbolic name EPMQ_ELNO (computable by CALC_CHAMP), which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated in the nodes.
- "DOMA_ELGA_EPME" for the computation of the damage to Gauss points from a strain field mechanics, out-thermal: $\varepsilon = B \cdot u - \varepsilon_{th}$.
- The data structure result specified under the key word factor RESULTAT must contain the field of symbolic name EPMQ_ELGA, which amongst other things defines the value of the invariant of a signed nature 2 (component INVA_2SG) calculated in Gauss points.

3.3.3 Operand DOMMAGE

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

For that of many methods are available. The method available in *Code_Aster* for computation 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 computation of the damage by 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.

♦`DOMMAGE = "WOHLER"`

For a load history of the type forced, the number of cycles to the fracture is determined by interpolation of the curve of Wöhler of the material for a level of alternate stress given (to each elementary cycle corresponds a level of amplitude of stress $\Delta\sigma=|\sigma_{max}-\sigma_{min}|$ and an alternate stress $S_{alt}=1/2\Delta\sigma$).

One can use method `WOHLER` only for options `"DOMA_ELNO_SIGM"` or `"DOMA_ELGA_SIGM"`. Moreover, it is necessary that the specified result concept contains respectively the field of symbolic name `SIEQ_ELNO` or `SIEQ_ELGA` (calculable by `CALC_CHAMP`).

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

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

Notice on the curves of fatigue:

For the small amplitudes, the difficulty of the prolongation of the curve of fatigue can arise: for example, for the curves of fatigue of the RCC-M beyond 10 ^{6} cycles, the corresponding stress 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 notion of limit of endurance: if the amplitude of stress is lower than the first X-coordinate of the curve of fatigue, then one takes a factor of null use i.e. a number of infinite acceptable cycle.

♦`DOMMAGE = "MANSON_COFFIN"`

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

One can use method `MANSON_COFFIN` only for options `"DOMA_ELNO_EPSI"` or `"DOMA_ELGA_EPSI"`, `"DOMA_ELNO_EPME"` or `"DOMA_ELGA_EPME"`. Moreover, it is necessary that the specified result concept contains respectively the field of symbolic name `EPEQ_ELNO`, `EPEQ_ELGA`, `EPMQ_ELNO` or `EPMQ_ELGA` (calculable by `CALC_CHAMP`).

The curve of Manson-Whetstone sheath must be introduced into operator `DEFI_MATERIAU` [U4.43.01] (key word `TIRES`, operand `MANSON_COFFIN`).

♦`DOMMAGE = "TAHERI_MANSON"`

This méthode de calcul of the damage applies only to loadings of type strain, i.e. for options "DOMA_ELNO_EPSI", "DOMA_ELGA_EPSI", "DOMA_ELNO_EPME" or "DOMA_ELGA_EPME". Moreover, it is necessary that the specified result concept contains respectively the field of symbolic name 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 computation elementary damage of the first cycle is determined by interpolation on the curve of Manson-Whetstone sheath of the material.
The computation 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 computation 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 three-dimensions function introduced under operand TAHERI_NAPPE.

  F_{FONC} is a function introduced under 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 the material ($Nrupt_{i+1}$ = many cycles to the fracture for the cycle $(i+1)=\text{MANSON\_COFFIN}\left(\frac{\Delta\varepsilon^*_{i+1}}{2}\right)$ and Dom_{i+1} = damage of the cycle $(i+1)={}^{1}\!\!/_{Nrupt_{i+1}}$.

The curve of Manson-Whetstone sheath must be introduced into operator DEFI_MATERIAU [U4.43.01] (key word TIRES, operand MANSON_COFFIN).

Note:

1) *The three-dimensions function or the formula introduced under operand TAHERI_NAPPE is in fact the cyclic curve of hardening with prestressed material.*
2) *The function or the formula introduced under operand TAHERI_FONC is in fact the cyclic curve of hardening of the material.*

3) *The three-dimensions function or the formula introduced under operand `TAHERI_NAPPE` , must have "`X`" and "`EPSI`" like parameters.*
4) *The function or the formula introduced under operand `TAHERI_FONC` , must have as a parameter "`SIGM`" .*

♦`DOMMAGE = "TAHERI_MIXTE"`

This méthode de calcul of the damage applies only to loadings of type strain, i.e. for options "`DOMA_ELNO_EPSI`", "`DOMA_ELGA_EPSI`", "`DOMA_ELNO_EPME`" or "`DOMA_ELGA_EPME`". Moreover, it is necessary that the specified result concept contains respectively the field of symbolic name `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 computation elementary damage of the first cycle is determined by interpolation on the curve of Manson-Whetstone sheath of the material.

The computation 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 computation 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 three-dimensions function introduced under 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 the material ($Nrupt_{i+1}$ = many cycles to the fracture 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 operator `DEFI_MATERIAU` [U4.43.01] (key word factor `TIRES`).

Note:

1) *The three-dimensions function or the formula introduced under operand `TAHERI_NAPPE` is in fact the cyclic curve of hardening with prestressed material.*
2) *The three-dimensions function or the formula introduced under 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 three-dimensions function $F_{NAPPE}\left(\frac{\Delta\varepsilon}{2},\varepsilon_{MAX}\right)$ necessary to the computation of the damage by methods "TAHERI_MANSON" and "TAHERI_MIXTE".

The three-dimensions function must have "X" and "EPSI" like parameters.

Note:

This three-dimensions function is in fact the cyclic curve of 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 computation of the damage by method "TAHERI_MANSON".

The parameter of this function must be "SIGM".

Note:

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

3.4 Operands specific to the computation of the type FATIGUE_MULTI

3.4.1 Operand TYPE_CHARGE

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

- PERIODIQUE, the loading are periodic;
- NON_PERIODIQUE, the loading are not periodical.

3.4.2 Operand OPTION

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

- DOMA_ELGA, postprocessing are made with Gauss points mesh;
- DOMA_NOEUD, postprocessing are made with the nodes of the mesh or part of the mesh, cf operands: GROUP_MA, MESH, GROUP_NO and NO

3.4.3 Operand RESULTAT

♦RESULTAT=res

Name of the result concept containing the stress fields and strain defining the load history. More precisely, the result concept must contain the field of symbolic name

•SIEF_ELGA, EPSI_ELGA, EPSP_ELGA are the stress fields, of total deflection and plastic strain, respectively, for the fatigue analysis at the fields with elements

•SIGM_NOEU/SIEF_NOEU, EPSI_NOEU, EPSP_NOEU are the stress fields, of total deflection and plastic strain, respectively, for the fatigue analysis at 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 strain. For the criterion which requires the elastic strain, the request of the total deflection is compulsory . If the plastic strain is not informed, one will take zero value.

3.4.4 Operand CHAM_MATER

◊**CHAM_MATER** = cham_mater

Makes it possible to specify the name of the field of the material cham_mater created by AFFE_MATERIAU [U4.43.03].

The MATER material defined with the command DEFI_MATERIAU and which is used for the assignment of the material to the mesh with command AFFE_MATERIAU must contain the definition of the curve of Wöhler as well as information necessary to the implementation of the criterion, to see the key keys factors TIRES and CISA_PLAN_CRIT of the command DEFI_MATERIAU [U4.43.01].

3.4.5 Operand CRITERE

```
♦CRITERE   =   "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 computation of the damage is carried out only on the first complete cycle. The first part of the history of the loading corresponding to the monotonic loading is not taken into account because this one aims to impose a non-zero average loading. For the elastic behavior, computation is carried out between the maximum value and the minimal value of the cycle considered. For the elastoplastic behavior, computation 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 = "PERIODIQUE"	**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, operand CRITERE makes it possible to specify the criterion which half amplitude will have to satisfy to it with maximum shears. For the loading with variable amplitude, operand CRITERE makes it possible 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 quantities.

Notation:

- $\mathbf{n}^*$: norm with the plane in which the amplitude of shears is maximum;
- $\Delta\tau(\mathbf{n})$: amplitude of shears in stress in a plane of norm $\mathbf{n}$;
- $\Delta\gamma(\mathbf{n})$: amplitude of shears in strain in a plane of norm $\mathbf{n}$;
- $N_{max}(\mathbf{n})$: normal maximum stress as regards norm $\mathbf{n}$;
- τ_0 : limit of endurance in alternate pure shears;
- 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]:

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

where a and b are two constant data by the user under key keys MATAKE_A and MATAKE_B of the key word factor CISA_PLAN_CRIT of DEFI_MATERIAU, they depend on the 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 traction 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 non-zero $(\sigma_m\neq 0)$.

We modify the initial criterion of MATAKE by introducing the definition of an equivalent stress, 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 the ratio of the limits of endurance in bending and alternating torsion represents, and must be well informed under key word COEF_FLEX_TORS of the key word 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]:

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

where a and b is two constant data by the user under key keys D_VAN_A and D_VAN_B of the key word factor CISA_PLAN_CRIT of DEFI_MATERIAU, they depend on the characteristic materials. If the user has two traction tests compression, alternate other not the 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 the case where the average constraint is non-zero $(\sigma_m\neq 0)$.

Moreover, we define an equivalent stress 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 the ratio of the limits of endurance in alternated shears and tension represents, and must be indicated under key word `COEF_CISA_TRAC` of the key word factor `CISA_PLAN_CRIT` of `DEFI_MATERIAU`.

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

Criterion `MATAKE_MODI_AV`

criterion `MATAKE_MODI_AV` is an evolution of the criterion of MATAKE. Contrary to the two preceding criteria, this criterion selects the critical plane according to the damage calculated in each plane. It is the plane 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 damages. To count the cycles, we use method RAINFLOW.

The once known elementary damages are cumulated linearly to determine the damage.

To compute: the elementary damages we project the history of the shearing 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 stress 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 norm of the plane running, $\tau^i_{p1}(\mathbf{n})$ and the $\tau^i_{p2}(\mathbf{n})$ values of the projected shearing stresses of the under-cycle i and $N^i_1(\mathbf{n})$ the $N^i_2(\mathbf{n})$ normal stresses of the under-cycle i. From $\sigma^i_{eq}(\mathbf{n})$ and of a curve of fatigue we determine the number of cycles to the elementary fracture $N^i(\mathbf{n})$ and the damage corresponding. $D^i(\mathbf{n}) = 1/N^i(\mathbf{n})$ In [éq 3.12 - 3] α is a corrective term which makes it possible to use a curve of fatigue in tension - compression. The constants a and α must be indicated under key keys `MATAKE_A` and `COEF_FLEX_TORS` of the key word 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 fixed $\mathbf{n}$ norm, 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 vector normalcorrespondant $\mathbf{n}^*$ with 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 technical implementations to compute: this criterion are identical to those used for criterion `MATAKE_MODI_AV`. The only difference lies in the definition of the elementary equivalent stress where the hydrostatic pressure P replaces the maximum normal stress N_{max} :

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

The constants a and α are with being informed by the user under key keys `D_VAN_A` and `COEF_CISA_TRAC` of the key word 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 the characteristic materials. Contrary to the other criteria, it uses the shears in strain instead of the shears in stress. 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 plane according to the damage calculated in each plane. It is the plane in which the damage is maximum which is retained.

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

In order to calculate the elementary damages we project the history of the shears in strain 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 strain for any elementary under-cycle i :

$$\varepsilon^i_{eq}(\mathbf{n})=\alpha\,c_p\left(\frac{Max\left(\gamma^i_{p1}(\mathbf{n}),\gamma^i_{p2}(\mathbf{n})\right)-Min\left(\gamma^i_{p1}(\mathbf{n}),\gamma^i_{p2}(\mathbf{n})\right)}{2}\right)\left(1+a\,Max\left(N^i_1(\mathbf{n}),N^i_2(\mathbf{n}),0\right)\right)$$

éq 3.12-5

with $a=\frac{k}{\sigma_y}$, $\mathbf{n}$ the norm with the plane running, $\gamma^i_{p1}(\mathbf{n})$ and the $\gamma^i_{p2}(\mathbf{n})$ values of the shears in strain projected of the under-cycle i , $N^i_1(\mathbf{n})$ and $N^i_2(\mathbf{n})$ being two values of the normal stress of the under-cycle i . From $\varepsilon^i_{eq}(\mathbf{n})$ and of a curve of Manson-Whetstone sheath we corresponding. determine the number of cycles to the elementary fracture $N^i(\mathbf{n})$ etle damage $D^i(\mathbf{n})=1/N^i(\mathbf{n})$

It will be noted that the shear strains used in the criterion of FATEMI and SOCIE are distortions γ_{ij} ($i\neq j$). If one uses the shear 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-hardening.

The constants a and α must be indicated under key keys FATSOC_A and COEF_CISA_TRAC of the key word factor CISA_PLAN_CRIT of the command 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 an office plurality of linear damage, if m is the number of elementary under-cycles, then for a fixed $\mathbf{n}$ norm, the cumulated damage is equal to:

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

To find the normal vector $\mathbf{n}^*$ 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 quantities. This criterion is based on a general relation:

"Equivalent Quantity" = "Curve of life"

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

Criterion `VMIS_TRESCA`
criterion `VMIS_TRESCA` is not to be strictly accurate a criterion of fatigue since it does not make it possible to calculate a damage. It determines the variation of maximum amplitude of the tensor of the stresses 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 stresses taken at two distinct times. While varying these times we can calculate the maximum values of the criteria of Von Mises and Tresca [R7.04.04].

3.4.6 Operand `FORMULE_GRDEQ`

♦ `FORMULE_GRDEQ =for_grd , /[formula]`

Makes it possible to provide the formula of the criterion like a function of the quantities available. The lists of quantities available for each type of loading are in the following table:

TYPE_CHARGE = "PERIODIQUE", CRITERE = "FORMULE_CRITERE"
quantities available:
"DTAUMA": half-amplitude of shears in maximum stress ($\Delta\tau(\mathbf{n}^*)/2$)
"PHYDRM": hydrostatic pressure (P)
"NORMAX": maximum normal stress on the critical plane ($N_{max}(\mathbf{n}^*)$)
"NORMOY": average normal stress on the critical plane ($N_{moy}(\mathbf{n}^*)$)
"EPNMAX": maximum normal strain on the critical plane ($\varepsilon_{Nmax}(\mathbf{n}^*)$)
"EPNMOY": average normal strain on the critical plane ($\varepsilon_{Nmoy}(\mathbf{n}^*)$)
"DEPSPE": half-amplitude of equivalent plastic strain ($\Delta\varepsilon_{eq}^{p}/2$)
"EPSPR1": half-amplitude of first principal strain (with the taking into account of the sign)
"SIGNM1": maximum normal stress on the level associated with ε_1
"DENDIS": density of dissipated energy (W_{cy})
"DENDIE": density of energy of 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 stress ($\Delta\sigma_{eq}/2$)
"SIGPR1": half-amplitude of first principal stress (with the taking into account of the sign)

"EPSNM1": maximum normal strain on the level associated with σ_1
"INVA2S": half-amplitude of the second invariant of the strain $J_2(\epsilon)$
"DSITRE": half-amplitude of half-forced Tresca ($(\sigma_{max}^{Tresca}-\sigma_{min}^{Tresca})/4$)
"DEPTRE": half-amplitude of the half-strain Tresca ($(\epsilon_{max}^{Tresca}-\epsilon_{min}^{Tresca})/4$)
"EPSPAC": plastic strain accumulated p
"RAYSPH": the radius of the smallest sphere circumscribed with the way of loading within the space of deviators of the stresses R
"AMPCIS": amplitude of cission τ_a

TYPE_CHARGE = "NON-PERIODIQUE", CRITERE = "FORMULE_CRITERE"

the quantities available:
"TAUPR_1": projected shearing stresses of the first top of the under-cycle ($\tau_{p1}(\mathbf{n})$)
"TAUPR_2": projected shearing stresses of the second top of the under-cycle ($\tau_{p2}(\mathbf{n})$)
"SIGN_1": normal stress of the first top of the under-cycle ($N_1(\mathbf{n})$)
"SIGN_2": normal stress of the second top of the under-cycle ($N_2(\mathbf{n})$)
"PHYDR_1": hydrostatic pressure of the first top of under-cycle
"PHYDR_2": hydrostatic pressure of the second top of under-cycle
"EPSPR_1": shears in strain projected of the first top of the under-cycle ($\gamma_{p1}(\mathbf{n})$)
"EPSPR_2": shears in strain projected of the second top of the under-cycle ($\gamma_{p2}^{i}(\mathbf{n})$)
"SIPR1_1": first principal stress of the first top of the under-cycle ($\sigma_1(1)$)
"SIPR1_2": first principal stress of the second top of the under-cycle ($\sigma_1(2)$)
"EPSN1_1": normal strain on the level associated with $\sigma_1(1)$ with the first top with under-cycle
"EPSN1_2": normal strain on the level associated with $\sigma_1(2)$ with the second top with 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 stress on the level associated with $\epsilon_1^{tot}(1)$ with the first top with under-cycle
"SITN1_2": normal stress on the level associated with $\epsilon_1^{tot}(2)$ with the second top with under-cycle
"EPPR1_1": first principal plastic strain of the first top of the under-cycle ($\epsilon_1^{p}(1)$)
"EPPR1_2": first principal plastic strain of the second top of the under-cycle ($\epsilon_1^{p}(2)$)
"SIPN1_1": normal stress on the level associated with $\epsilon_1^{p}(1)$ with the first top with under-cycle
"SIPN1_2": normal stress on the level associated with $\epsilon_1^{p}(2)$ with the second top with under-cycle
"SIGEQ_1": equivalent stress of the first top of the under-cycle ($\sigma_{eq}(1)$)
"SIGEQ_2": equivalent stress 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 plane of maximum shears if parameter "DTAUMA" is introduced into the formula.
2) For the loading NON-periodical, after having extracted the elementary under-cycles with method RAINFLOW, we calculate an elementary equivalent quantity by the formula of

criterion for any elementary under-cycle. It is noted that the under-cycle is represented by two stress states or strain, noted by the first and the second tops of the under-cycle.
3) The parameters of entries of the command `FORMULA` must be among those listed in the table above.
4) Statements of certain quantities are in the document [R7.04.04].
5) One stresses that the thermal strain was not taken into account, i.e., formula $\epsilon^{tot}=\epsilon^{e}+\epsilon^{p}$)
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 evaluating of the equivalent quantity left under name "SIGEQ 1". Operand

3.4.7 COURBE_GRD_VIE ♦

```
COURBE_GRD_VIE =  /   "WOHLER",/
        "MANSON_C",/
        "FORM_VIE" Makes it possible
```

to provide a curve of connecting the quantity equivalent to the number of cycles to the fracture. If COURBE_GRD_VIE = `"WOHLER", one` will take the curve of Wohler () defined $N_f=f(SIGM)$ in AFFE_MATERIAU . `If`
COURBE_GRD_VIE = `"MANSON_C", one` will take the curve of Manson_Coffin () defined $N_f=f(EPSN)$ in AFFE_MATERIAU . `If`
COURBE_GRD_VIE = `"FORM_VIE", one` will provide a function defining the curve of life, to see 3.4.8. Operand

3.4.8 FORMULE_VIE ♦

```
FORMULE_VIE   = for_vie,/[formula          ]/[
                                function  ] Makes it possible
```

to specify the curve connecting the equivalent quantity and the life duration. If for `_vie` is provided by a tabulated 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 command FORMULA `must` be "NBRUPT " (i.e.,). Operand N_f

3.4.9 METHODE ♦METHODE

```
= "CERCLE_EXACT" Makes it possible
```

to specify the name of the method which will be used to compute: to it half amplitude of maximum shears. The method

of the "CERCLE_EXACT " `is used` to determine the circle circumscribed at the points which are in planes of shears. This method rests on the process which consists in obtaining the circle which passes by three points, cf document [R7.04.04]. Operand

3.4.10 INST_ INIT_CYCL ◊ INST

```
_ INIT_CYCL =/inst    _ini_cyc Makes it possible
```

to specify time intial part of the cyclic loading. If this operand is not indicated or inst _ `ini_cyc is not` part of calculated times, one takes the initial value stored as a result like the initial time of the cycle. This operand also makes it possible to the users to apply a loading average NON-no one. Operand

3.4.11 INST_ CRIT ◊ INST

```
_ CRIT =/"  RELATIF "/"ABSOLU
              " Makes it possible
```

to specify the criterion to seek initial time INST_ `INIT_CYCL Operand`

3.4.12 accuracy ◊

`accuracy =/prec [R]/ 1.E`
`- 6 , Makes it possible`

to specify the accuracy of initial time INST_ `INIT_CYCL Operand`

3.4.13 PROJECTION ♦ PROJECTION

`= "UN_AXE ",/"DEUX_AXES`
`", If`

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

- , the history of the shears are projected on an axis; DEUX_AXES
- , the history of the shears are projected on two axes. Operand

3.4.14 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 load history the points for which the variation of the value of the stress 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 documentation of the command POST_ `TIRES, [U4.83.01]`, even operand. Operands

3.4.15 GROUP_MA /MESH/GROUP_NO/NOEUD ◊GROUP

`_MA = lgma, the options`

are calculated on the mesh groups contained in the list lgma . ◊ MESH

`= lma, the options`

is calculated on meshes contained in the list lgma . ◊ GROUP_NO

`= lgno, the options`

is calculated on the nodes groups contained in the list lgno . ◊ NOEUD

`= lno, the options`

is calculated on the nodes contained in the list lno. `Operand`

3.4.16 COEF_PREECROU ◊COEF

`_PREECROU =/coef_pre , /1.0,`
`This coefficient`

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

3.4.17 MAILLAGE ♦MAILLAGE

`= mesh, Makes it possible`

to specify the name of the mesh given by the user. Operands

3.5 specific to the computation of the type FATIGUE_VIBR Principle

3.5.1 of computation 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 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 fatigue (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 usual structures concerned (wings, lines of pipework,…) ; it induces a conservatism undoubtedly excessive in the general case. The approach

of a study with this option is the following one: Computation

•of the stress related to the static loading with σ_{stat} MECA_STATIQUE `or STAT_NON_LINE ;` `Computation`

•of the stresses associated with the eigen modes N considered with σ^i_{mod} MODE_ITER_SIMULT `;` `Fatigue analysis`

•with CALC_ `TIRES/TYPE_CALCUL = "FATIGUE_VIBR" Introduction`

- •of an assumption on the relative weight of the various eigen modes considered (corresponds $(\beta_i)_{1\leq i\leq N}$ to operand FACT_ `PARTICI) : ,` where

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

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

- •of materials parameters and choice of the criterion of computation of the damage (operands CORR_SIGM_MOYE `and MATER , cf` § 22). 24 notes the criterion f which the maximum amplitude of variation of the stress must check. depends S^{max}_{alt} f on the limit on endurance and S_l limit when the material breaks S_u : On all the

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

- •nodes or Gauss points of the mesh (according to the choice in OPTION `) : Computation`
  - •of the amplitude of variation of the stresses: (to be noted $S_{alt}=\alpha\sum_{i=1}^{N}\beta_i\sigma^i_{mod}$ that, not knowing the phase shifts between the modes, the amplitude is defined in a conservative way as the sum of the amplitude of each mode); Computation
  - • of the coefficient corresponding α to an unlimited endurance: Interpretation

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

•and use of result of CALC_ `TIRE: the operator` provides the field (with the nodes or the Gauss point) of the acceptable values of: α the minimal value of on α the mesh makes it possible to calculate the acceptable maximum amplitude of vibration of the structure (the minimal value is displayed in the message file; 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 life duration of structure.

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

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

If

the static stress exceeds in a node the stress when the material breaks, the acceptable amplitude of vibration is null. In this case, an alarm message is transmitted and computation continues on the other nodes. Key word

3.5.2 factor HISTOIRE This key word

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

3.5.2.1 RESULTAT ♦RESULTAT

=res Name of

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

3.5.2.2 MODE_MECA ♦MODE

_MECA=mode Name of

the concept of the type mode_ meca, containing the stress fields for the eigen modes of structure.

More precisely, the result concept must contain one of the fields of symbolic name SIEQ_ELNO or SIEQ_ELGA according to the desired computation option. These fields are calculated with operator CALC_CHAMP , in postprocessing of computation of eigen modes with MACRO_MODE_MECA or MODE_ITER_SIMULT . Operand

3.5.2.3 NUME_MODE ♦NUMÉRIQUE

_MODE=liste_I Number

of the modes to be considered for the computation of the damage. Operand

3.5.2.4 FACT_ PARTICI ♦FACT

_PARTICI=liste_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 operand NUME_MODE . Only

the relationship between the various provided factors is important. If one wants to pass from the parameter calculated by CALC_ TIRES with a maximum amplitude of displacement in a given node, it is however advisable to take well into account the same coefficients (cf § 20). 22

3.5.3 OPTION This key word

factor makes it possible to specify the place of computation of the damage: “DOMA_ELNO_SIGM

- ″ for the computation of the damage to the nodes from a stress field. The static and modal results (operands RESULTAT and MODE_MECA) must contain the field of symbolic name SIEQ_ELNO (computable by CALC_CHAMP), which amongst other things defines the value of the equivalent stress of von Mises signed (component VMIS_ SG) calculated in the nodes. “DOMA_ELGA_SIGM
- ″ for the computation of the damage to Gauss points from a stress field. The static

and modal results (operands RESULTAT and MODE_MECA) must contain the field of symbolic name SIEQ_ELGA (computable by CALC_CHAMP), which amongst other things defines the value of the equivalent stress of von Mises signed (component VMIS_ SG) calculated in Gauss points. Operand

3.5.4 CORR_ SIGM_MOYENNE ♦ CORR_SIGM_MOYE

= "GOODMAN ",/"GERBER
", the structure

is subjected to a loading with non-zero average constraint, the average constraint corresponding to the static stress. The taking

into account of the average constraint in σ_m the curve of fatigue of Wöhler can be done using the diagram of Haigh [R7.04.01]. Two corrections are available to compute: the acceptable alternate stress according to $S_{alt}^{\max}$ the limit of endurance and S_l the limit when the material breaks S_u : right

of Goodman: parabola

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

To stack: The value

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

of the limit when the material breaks must S_u be introduced into operator DEFI_ MATERIAU [U4.43 .01] (key word factor RCCM, operand Known). The limit of endurance corresponds S_l to the first point of the curve of Wöhler (operator DEFI_ MATERIAU, key word TIRES , operand WOHLER). Operand

3.5.5 DOMMAGE ♦DOMMAGE

= "WOHLER " For the moment

, only the method of Wöhler is available for the vibratory fatigue analyzes. This method rests on the computation of the amplitude of variation of the stresses and the comparison with the curve of fatigue of Wöhler of the material. The curve

of Wöhler of the material must be introduced into operator DEFI_ MATERIAU (key word TIRES , operand WOHLER). Only the limit of endurance (i.e S_l the first point of the curve) is really used in computation. Quantity

4 and components introduced into Code_Aster *the computed values*

are stored with Gauss points or the nodes according to the option selected. Quantity FACY_R (Cyclic Fatigue) was introduced into the catalog of quantities. For

the periodic loading and the criteria of the type of maximum critical plane shears DTAUM1 first

	value of the half amplitude max of the shears in component critical plane VNM1X
	formulates x with the critical plane related to DTAUM1 VNM 1Y component
	formula y to the critical plane related on DTAUM1 VNM 1Z component
	formula z to the critical plane related on DTAUM1 SINMAX 1
normal	constraint to the critical plane corresponding to DTAUM1 SINMOY 1
normal	average constraint with the critical plane corresponding to DTAUM1 EPNMAX 1
normal	maximum strain with the critical plane corresponding to DTAUM1 EPNMOY 1
average	maximum strain with the critical plane corresponding to DTAUM1 SIGEQ 1 Equivalent stress
	within the meaning of the criterion selected corresponding with DTAUM1 NBRUP 1 many
	cycles before fracture (function of SIGEQ1 and a curve of Wöhler) ENDO1 damage associated with NBRUP1 (ENDO1=1 /NBRUP1) DTAUM2 second
	value with the half amplitude max with the shears in component critical plane VNM2X
	formulates x with the critical plane related to DTAUM2 VNM 2Y component
	formula y to the critical plane related on DTAUM2 VNM 2Z component
	formula z to the critical plane related on DTAUM2 SINMAX 2
normal	constraint to the critical plane corresponding to DTAUM2 SINMOY 2
normal	average constraint with the critical plane corresponding to DTAUM2 EPNMAX 2
normal	maximum strain with the critical plane corresponding to DTAUM2 EPNMOY 2
average	maximum strain with the critical plane corresponding to DTAUM2 SIGEQ 2 Equivalent stress
	within the meaning of the criterion selected corresponding with DTAUM2 NBRUP 2 many
	cycles before fracture (function of SIGEQ2 and a curve of Wöhler) ENDO2 damage associate with NBRUP2 (ENDO2=1 /NBRUP2) Table

5.5-1: Components specific to multiaxial cyclic fatigue for the periodic loading For

the loading NON-periodical and the criteria of the type of critical plane of maximum damage VNM1X component

	formulates x with the critical plane related to the damage component max VNM1Y
	formulates y with the critical plane related to the damage component max VNM1Z
	formulates z with the critical plane related to the damage max ENDO1 damage associated with the block with component loading VNM2X
	formulates x with the critical plane related to the damage component max VNM2Y
	formulates y with the critical plane related to the damage component max VNM2Z
	formulates z with the critical plane related to the damage max Table

5.5-2: Components specific to multiaxial cyclic fatigue for the loading NON-periodical For

the loading NON-periodical, if there exist only one critical plane of the maximum damage, VNM2X, VNM2Y, VNM 2Z are identical to the VNM1X, VNM 1Y, VNM1Z. If several planes exist, one emits an alarm and leaves the two foregrounds. Examples

5 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 . Computation of

5.1 the half amplitude of maximum shears by the method: "CERCLE_EXACT " See

the case SSLV135a test. Here the loading is periodic and the damage is calculated with Gauss points. Computation of

5.2 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 group of mesh: "FACE1", "FACE3" and "FACE 5". Computation of

5.3 the damage with 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 group of mesh: "FACE1", "FACE2" and "FACE 3". Computation of

5.4 the damage with the criteria in formula criterion

of "MAKATE_ MODI_AC": See the case test SSLV 135a. criterion
of "DANG_VAN_MODI_AC ": See the case test SSLV 135a. criterion
of "MATAKE_MODI_AV": See the case test SSLV 135b. criterion
of "DANG_VAN_MODI_AV": See the case test SSLV 135b. criterion
of "FATESOCI_MODI_AV ".: See the case test SSLV 135b.