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## Operator CALC\_MODES

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### 1 Goal

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To calculate the clean modes of vibrations or the modes of buckling of Euler, a mechanical structure.

The operator `CALC_MODES` solves for that a modal problem which can be either generalized (GEP) [R5.01.01], or quadratic (QEP) [R5.01.02].

The user specifies the search criterion of the modes (for example: on a tape; near values given; etc) thanks to the keyword `OPTION`. According to the value of this keyword, the general method of calculation (simultaneous iterations or powers opposite) is then automatically given.

Within each one of these two general methods, alternatives exist:

- case of the simultaneous iterations: method of type subspace (Bathe & Wilson, Lanczos or Sorensen), global method of the type QR (QZ for the small problems);
- case of the powers opposite: method direct or accelerated by the quotient of Rayleigh.

These alternatives are accessible with a keyword factor `SOLVEUR_MODAL`.

In the case of a calculation of clean modes of vibrations, postprocessings can also be realized: standardisation of the modes according to a criterion given, filtering of the modes according to a given criterion,...

This operator produces one concept `mode_meca_*` (dynamic case) or `mode_flamb` (case buckling of Euler, only in GEP) or `mode_gene` according to the value indicated in the keyword `TYPE_RESU` and the type of the matrices of entry of the modal problem.

In a first approach one can be satisfied to inform the following parameters: `OPTION` to define the search criterion of the modes, `TYPE_RESU`, matrices of entry of the modal problem `MATR_*`, `CALC_FREQ` (or `CALC_CHAR_CRIT`).

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## 2 Syntax

mode\_ [\*] =CALC\_MODES (

### # Standard of problem

◇ 'DYNAMIC' TYPE\_RESU= / [DEFECT]  
/ 'MODE\_FLAMB'  
/ 'GENERAL'

### # Search criterion of the modes

◇ OPTION= 'CENTER'  
/ 'BAND'  
/ 'PLUS\_PETITE' [DEFECT]  
/ 'PLUS\_GRANDE'  
/ 'ALL'  
/ 'NEAR' (if pas de multiple mode)  
/ 'SEPARATE' (only in GEP)  
/ 'ADJUSTS' (only in GEP)

<p># If TYPE_RESU= 'DYNAMIQUE'</p>
--

### # Characteristic of calculation

(

- ◆ MATR\_RIGI=A / [matr\_asse\_DEPL\_R]  
/ [matr\_asse\_DEPL\_C]  
/ [matr\_asse\_PRES\_R]  
/ [matr\_asse\_GENE\_R]  
/ [matr\_asse\_GENE\_C]
- ◆ MATR\_MASS=B / [matr\_asse\_DEPL\_R]  
/ [matr\_asse\_PRES\_R]  
/ [matr\_asse\_GENE\_R]
- ◇ MATR\_AMOR=C / [matr\_asse\_DEPL\_R]  
/ [matr\_asse\_GENE\_R]

◇ CALC\_FREQ= F (

- # If OPTION= 'PLUS\_PETITE'  
◇ NMAX\_FREQ= /10 [DEFECT]  
/nf [I]
- # If OPTION= 'PLUS\_GRANDE'  
◇ NMAX\_FREQ= /1 [DEFECT]  
/nf [I]
- # If OPTION= 'CENTRE'  
◆ FREQ= l\_f [l\_R]  
◇ AMOR\_REDUIT= l\_a [l\_R]  
◇ NMAX\_FREQ= /10 [DEFECT]  
/nf [I]
- # If OPTION= 'BANDE'  
◆ FREQ= l\_f [l\_R]  
◇ TABLE\_FREQ= table\_f [table\_sdaster]
- # If OPTION= 'PROCHE'  
or 'SEPARATE'  
or 'ADJUSTS'  
◆ FREQ= l\_f [l\_R]  
◇ NMAX\_FREQ= nf [I]

◇ AMOR\_REDUIT=l\_amor

[l\_R]

## # For pre and postprocessings

```
◇ PREC_SHIFT=/0.05 [DEFECT]
    /p_shift [R]
◇ NMAX_ITER_SHIFT=/3 [DEFECT]
    /n_shift [I]
◇ SEUIL_FREQ=/1.E-2 [DEFECT]
    /f_seuil [R]
)
```

```
# If TYPE_RESU= 'MODE_FLAMB'
```

## # Characteristic of calculation

```
(
    ♦ MATR_RIGI=A
    /[matr_asse_DEPL_R]
    /[matr_asse_PRES_R]
    /[matr_asse_GENE_R]
    ♦ MATR_RIGI_GEOM=B
    /[matr_asse_DEPL_R]
    /[matr_asse_PRES_R]

    ◇ CALC_CHAR_CRIT =_F (
# If OPTION= 'PLUS_PETITE'
        ◇ NMAX_CHAR_CRIT= /10 [DEFECT]
        /nf [I]
# If OPTION= 'CENTRE'
        ♦ CHAR_CRIT= l_c [1_R]
        ◇ NMAX_CHAR_CRIT= /10 [DEFECT]
        /nf [I]

# If OPTION= 'BANDE'
        ♦ CHAR_CRIT=l_c [1_R]
        ◇ TABLE_CHAR_CRIT=table_c [table_sdaster]

# If OPTION= 'PROCHE'
    or 'SEPARATE'
    or 'ADJUSTS'
        ♦ CHAR_CRIT=l_f [1_R]
        ◇ NMAX_CHAR_CRIT=nf [I]

# For pre and postprocessings
        ◇ PREC_SHIFT=/0.05 [DEFECT]
        /p_shift [R]
        ◇ NMAX_ITER_SHIFT=/3 [DEFECT]
        /n_shift [I]
        ◇ SEUIL_CHAR_CRIT=/1.E-2 [DEFECT]
        /c_seuil [R]
    )
```

```
# If TYPE_RESU= 'GENERAL'
```

## # Characteristic of calculation

```
(
  ♦ MATR_A=A /[matr_asse_DEPL_R]
  /[matr_asse_PRES_R]
  /[matr_asse_GENE_R]
  ♦ MATR_B=B /[matr_asse_DEPL_R]
  /[matr_asse_PRES_R]
  /[matr_asse_GENE_R]

  ♦ CALC_CHAR_CRIT =_F (
# If OPTION= 'PLUS_PETITE'
  ♦ NMAX_CHAR_CRIT= /10 [DEFECT]
  /nf [I]
# If OPTION= 'CENTRE'
  ♦ CHAR_CRIT=l_c [l_R]
  ♦ NMAX_CHAR_CRIT= /10 [DEFECT]
  /nf [I]
# If OPTION= 'BANDE' (only GEP with real symmetrical matrices)
  ♦ CHAR_CRIT=l_c [l_R]
  ♦ TABLE_CHAR_CRIT=table_c [table_sdaster]
# If OPTION= 'PROCHE'
or 'SEPARATE'
or 'ADJUSTS'
  ♦ CHAR_CRIT=l_f [l_R]
  ♦ NMAX_CHAR_CRIT=nf [I]
# For pre and postprocessings
  ♦ PREC_SHIFT=/0.05 [DEFECT]
  /p_shift [R]
  ♦ NMAX_ITER_SHIFT=/3 [DEFECT]
  /n_shift [I]
  ♦ SEUIL_CHAR_CRIT=/1.E-2 [DEFECT]
  /c_seuil [R]
)
```

## # modal Solveur

◇ SOLVEUR\_MODAL = \_F (

### # If OPTION = 'PLUS\_PETITE', 'PLUS\_GRADE', 'CENTER', 'BAND', 'ALL' : choice of the method of the simultaneous iterations

◇ METHODE= / 'SORENSEN' [DEFECT]  
/ 'TRI\_DIAG' (only real symmetrical GEP/QEP)  
/ 'JACOBI' (except in QEP)  
/ 'QZ' (problem of smalls  $< 10^3$  degrees of freedom)

### # Parameter setting interns methods

#### # If METHODE= 'SORENSEN'

◇ PREC\_SOREN=/0 [DEFECT]  
/pso [R]  
◇ NMAX\_ITER\_SOREN= /20 [DEFECT]  
/nso [I]  
◇ PARA\_ORTHO\_SOREN=/0.717 [DEFECT]  
/porso [R]

#### # If METHODE= 'TRI\_DIAG'

◇ PREC\_ORTHO=/1.E-12 [DEFECT]  
/po [R]  
◇ NMAX\_ITER\_ORTHO=/5 [DEFECT]  
/nio [I]  
◇ PREC\_LANCZOS=/1.E-8 [DEFECT]  
/pl [R]  
◇ NMAX\_ITER\_QR=/30 [DEFECT]  
/nim [I]  
◇ MODE\_RIGIDE='NOT' [DEFECT]  
/ 'YES'

#### # If METHODE= 'JACOBI'

◇ PREC\_BATHE=/1.E-10 [DEFECT]  
/pbat [R]  
◇ NMAX\_ITER\_BATHE=/40 [DEFECT]  
/nbat [I]  
◇ PREC\_JACOBI=/1.E-2 [DEFECT]  
/pjaco [R]  
◇ NMAX\_ITER\_JACOBI=/12 [DEFECT]  
/njaco [I]

#### # If METHODE= 'QZ'

◇ TYPE\_QZ='QZ\_SIMPLE' [DEFECT]  
/ 'QZ\_EQUI'  
/ 'QZ\_QR' (if GEP with matrices SPD)

### # If OPTION = 'NEAR', 'SEPARATED', 'ADJUSTS' : choice of the parameters of the method powers opposite

#### # If OPTION= 'SEPRE' or 'ADJUSTS' (only in GEP)

◇ NMAX\_ITER\_SEPRE= /30 [DEFECT]  
/nis [I]  
◇ PREC\_SEPRE= /1.E-4 [DEFECT]  
/ps [R]

#### # If OPTION= 'AJUSTE'



```

◇ NMAX_ITER_AJUSTE= /15 [DEFECT]
                        /nia [I]
◇ PREC_AJUSTE= /1.E-4 [DEFECT]
                        /pa [R]

# Parameters of the second phase of calculation of the powers opposite
◇ OPTION_INV=/'DIRECT' [DEFECT]
                /'RAYLEIGH' (only in GEP)
◇ NMAX_ITER_INV= /30 [DEFECT]
                /nim [I]
◇ PREC_INV= /1.E-5 [DEFECT]
            /pm [R]
)

# For final checks
◇ VERI_MODE=_F (
                ◇ STOP_ERREUR=/'YES' [DEFECT]
                /'NOT'
                ◇ SEUIL= /1.E-6 [DEFECT for
the method of the simultaneous iterations]
                /1.E-2 [DEFECT for
the method of the powers opposite]
                /r [R]
                # Only if methods of the simultaneous iterations
                ◇ PREC_SHIFT=/0.05 [DEFECT]
                /prs [R]
                ◇ STURM=/'YES' [DEFECT]
                /'NOT'
                # if TYPE_RESU=' DYNAMIQUE' and OPTION='
BANDE' :
                /'TOTAL'
                /'LOCAL'
)

# Postprocessings: only in the case of dynamic and physical modes (matrices of entries of the
type matr_asse_DEPL_R):
◇ NORM_MODE = _F (
                ◇ / NORMALIZES = / 'EUCL_TRAN'
                / 'MASS_GENE'
                / 'RIGI_GENE'
                / 'TRAN'
                / 'TRAN_ROTA' [DEFECT]
                / 'EUCL'
                ◇ INFORMATION = / 1
[DEFECT]
                / 2
)

◇ FILTRE_MODE = _F (
                ◇ CRIT_EXTR = / 'MASS_EFFE_UN' [DEFECT]
                / 'MASS_GENE'
                ◇ THRESHOLD = / 0,001 [DEFECT]
                / rseuil [R]
)

◇ IMPRESSION = _F (
                ◇ OFFICE PLURALITY = / 'YES'
[DEFECT]

```

```

/ 'NOT'
◇ CRIT_EXTR = / 'MASS_EFFE_UN' [DEFECT]
/ 'MASS_GENE'
◇ TOUT_PARA = / 'YES' [DEFECT]
/ 'NOT'
)
```

## # Solveur linear and parallelism

◇ SOLVEUR=\_F (For more details to see the document [U4.50.01]).

# In parallel, one advises the parameter setting particularly METHODE=' MUMPS '  
and RENUM=' QAMD '.

# Only if TYPE\_RESU=' DYNAMIQUE ' and OPTION=' BANDE ' and FREQ is a list of at least 3  
values:

```
◇ NIVEAU_PARALLELISME = / 'COMPLETE' [DEFECT]
/ 'PARTIAL'
```

# Activated only in parallel mode (many processors nb\_proc>1).

# Rq: the option 'COMPLETE' functions some is the direct linear solver if nb\_proc=nombre of  
sub-bands. With the option 'PARTIAL', only SOLVEUR=\_F (METHODE=' MUMPS ') is licit.

## # Others

```
◇ STOP_BANDE_VIDE=/ 'NOT' [DEFECT if
```

TYPE\_RESU=' DYNAMIQUE' and OPTION=' BANDE' and FREQ comprises n>2 frequencies]

```
/ 'YES' [DEFECT in the
```

other cases]

```
◇ INFO=/1 [DEFECT]
/2 [I]
```

```
◇ TITRE=ti
```

```
);
```

## # Results of the modal problem

```
If TYPE_RESU= 'MODE_FLAMB' then [*] - >mode_flamb
If TYPE_RESU= 'GENERAL' then [*] - >mode_flamb
If MATR_AMOR then [*] - >mode_meca_c
If MATR_RIGI or MATR_A= [matr_asse_DEPL_C] then [*] - >mode_meca_c
If MATR_RIGI or MATR_A= [matr_asse_DEPL_R] then [*] - >mode_meca
If MATR_RIGI or MATR_A= [matr_asse_PRES_R] then [*] - >mode_acou
If MATR_RIGI or MATR_A= [matr_asse_GENE_R] then [*] - >mode_gene
If MATR_RIGI or MATR_A= [matr_asse_GENE_C] then [*] - >mode_gene
```

## 3 Operands

### 3.1 Principles

This operator solves it **generalized problem (GEP)** with the eigenvalues according to [R5.01.01]:

To find  $(\lambda, \mathbf{x})$  such as  $\mathbf{A}\mathbf{x} = \lambda\mathbf{B}\mathbf{x}$ ,  $\mathbf{x} \neq \mathbf{0}$ , where  $\mathbf{A}$  and  $\mathbf{B}$  are real, symmetrical matrices or not.

To model a damping hysteretic in the study of the free vibrations of a structure, the matrix  $\mathbf{A}$  can be complex symmetrical [U2.06.03] [R5.05.04].

This kind of problem corresponds, in mechanics, in particular with:

- **The study of the free vibrations of a structure** not deadened and nonrevolving. For this structure, one searches the smallest eigenvalues or those which are in an interval given to know if an exiting force can create a resonance. In this case, the matrix  $\mathbf{A}$  is the matrix of material rigidity, noted  $\mathbf{K}$ , symmetrical real (possibly increased geometrical matrix of noted rigidity  $\mathbf{K}_g$ , if the structure is prestressed), and  $\mathbf{B}$  is the matrix of mass or noted inertia  $\mathbf{M}$  (symmetrical real). The eigenvalues obtained are the squares of the pulsations associated with the sought frequencies. The system to be solved can be written

$$\underbrace{(\mathbf{K} + \mathbf{K}_g)}_{\mathbf{A}} \mathbf{x} = \lambda \underbrace{\mathbf{M}}_{\mathbf{B}} \mathbf{x}$$

where  $\lambda = (2\pi f)^2$  is the square of the pulsation  $\omega$ ,  $f$  the Eigen frequency and  $\mathbf{x}$  the vector of associated clean displacement. Handled clean modes  $(\lambda, \mathbf{x})$  are with actual values. This kind of problems are activated by the keyword `TYPE_RESU=' DYNAMIQUE'` and a structure of data generates *Aster* of type `mode_meca`, `mode_acou` or `mode_gene` (according to the type of the data input).

- **The search for linear mode of buckling.** Within the framework of the linearized theory, while supposing *a priori* that the phenomena of stability are suitably described by the system of equations obtained by supposing the linear dependence of displacement compared to the level of critical load, the research of the mode of buckling  $\mathbf{X}$  associated with this level of critical load  $\mu = -\lambda$ , brings back itself to a problem generalized to the eigenvalues of the form

$$(\mathbf{K} + \mu \mathbf{K}_g) \mathbf{x} = 0 \Leftrightarrow \underbrace{\mathbf{K}}_{\mathbf{A}} \mathbf{x} = \lambda \underbrace{\mathbf{K}_g}_{\mathbf{B}} \mathbf{x}$$

with  $\mathbf{K}$  matrix of material rigidity and  $\mathbf{K}_g$  geometrical matrix of rigidity. Handled clean modes  $(\lambda, \mathbf{x})$  are with actual values. This kind of problems are activated by the keyword `TYPE_RESU=' MODE_FLAMB'` and a structure of data generates *Aster* of type `mode_flamb`.

#### Caution:

- In the code, one treats only the eigenvalues of the generalized problem, the variables  $\lambda$ . To obtain the true critical loads, the variables  $\mu$ , they should be multiplied by  $-1$ .
- In GEP, to deal with problems with complex modes (nonsymmetrical matrices and/or with complex values), it is necessary to use the method of the simultaneous iterations and method of resolution `METHODE=' SORENSEN'` or `'QZ'`.

This operator allows also the study of **dynamic stability of a structure in the presence of depreciation and/or gyroscopic effects**. That led to the resolution of a modal problem of a nature higher, known as quadratic (QEP) [R5.01.02]. Complex values and clean vectors then are searched  $(\lambda, \mathbf{x})$ .

- The problem consists in finding  $(\lambda, \mathbf{x}) \in (\mathbb{C}, \mathbb{C}^N)$  such as

$$(\lambda^2 \mathbf{B} + \lambda \mathbf{C} + \mathbf{A}) \mathbf{x} = \mathbf{0}$$

where typically, in linear mechanics, **A** will be the matrix of rigidity, **B** the matrix of mass and **C** the matrix of damping. Matrices **A**, **B** and **C** are symmetrical and real matrices. complex eigenvalue  $\lambda$  is connected to the Eigen frequency  $f$  and with reduced damping  $\xi$  by  $\lambda = \xi(2\pi f) \pm i(2\pi f)\sqrt{1-\xi^2}$ . This kind of problems are activated by the keyword `TYPE_RESU='DYNAMIQUE'` and a structure of data generates Aster of type `mode_meca_c`.

## Caution:

- In QEP, to deal with problems with nonsymmetrical matrices and/or complex values, it is necessary to use the method of the simultaneous iterations and method of resolution `METHODE='SORENSEN'` or `'QZ'`.
- Buckling (`TYPE_RESU='MODE_FLAMB'`) is not licit in QEP.
- The test of Sturm is operative only in GEP with real symmetrical matrices. Apart from this framework (QEP, GEP with nonsymmetrical real matrices or matrix **A** complex symmetrical), the option `'BAND'` is proscribed and the post-checking based on Sturm `N'` is not activated (parameter `VERI_MODE/STURM` inoperative).

To solve these generalized or quadratic modal problems, Code\_Aster propose various approaches. Beyond their digital specificities and functional calculuses which are taken again in the documents [R5.01.01] [R5.01.02], one can synthesize them in the shape of the table below ( **the values by default are materialized in fat** ).

Operator Perimeter of application	Algorithm	Keyword	Advantages	Disadvantages
<b>Method of the powers opposite</b> <i>OPTION=</i> <i>'SEPARATED'</i> , <i>'ADJUST'</i> or <i>'NEAR'</i> <i>1<sup>ère</sup> phase</i> <i>(heuristics)</i>		OPTION=		Only symmetrical reality (GEP and QEP).
Calculation of some modes	Bisection (without object in QEP).	'SEPARATED'		
Calculation of some modes	Secant Bisection+ (GEP) or Müller-Traub (QEP).	'ADJUST'	Better precision	Cost calculation
Improvement of some estimates	Initialization by the user	'NEAR'	Resumption of eigenvalues estimated by another process. Cost calculation of this phase quasi-no one	Pas de captures multiplicity of the modes
<i>2<sup>ème</sup> phase</i> <i>(method of the powers opposite)</i>				Only symmetrical reality (GEP and QEP)
Basic method	Powers opposite	'DIRECT'	Very good construction of clean vectors	Not very robust
Option of acceleration	Quotient of Rayleigh (without object in QEP)	'RAYLEIGH'	Improve convergence	Cost calculation
<b>Method of the simultaneous iterations</b> <i>OPTION= 'PLUS_*'</i> , <i>'CENTER'</i> , <i>'BAND'</i> or <i>'ALL'</i>		SOLVEUR_MO DAL=_F (METHODE=		
Calculation of part of the spectrum	Bathe & Wilson	'JACOBI'		Not very robust Only symmetrical reality (GEP)
	Lanczos (Newman-Pipano in GEP and Jennings in QEP)	'TRI_DIAG'	Specific detection of the rigid modes.	Only symmetrical reality (GEP and QEP)
	IRAM (Sorensen)	'SORENSEN'	Increased robustness. Better complexities calculation and memory.	Method by default. Range in nonsymmetri cal and with

Operator Perimeter of application	Algorithm	Keyword	Advantages	Disadvantages
Calculation of all the spectrum then filtering of a part.	QZ	'QZ'	Quality control of the modes. Method of reference in term of robustness.	<i>A complex symmetrical.</i> Very expensive in CPU and memory. To reserve for the small cases (<10 <sup>3</sup> degrees of freedom). <i>Range in nonsymmetrical and with A complex symmetrical.</i>

Table 3.1-1 - Summary of the modal methods of Code\_Aster

To capture a significant part of the spectrum, it is preferable to use the values 'PLUS\_PETITE' , 'PLUS\_GRADE' , 'CENTER' or 'BAND' keyword OPTION , who use one method of the type "simultaneous iterations" : methods of subspace (Lanczos, IRAM, Jacobi) or global method QZ (very robust but expensive method; to reserve for the small problems).

On the other hand, when it is a question of determining some simple eigenvalues discriminated well or of refining some estimates, values 'SEPARATE' , 'ADJUSTS' or 'NEAR' keyword OPTION (which uses a method of the type "powers opposite ") are often clearly shown.

It is completely recommended besides to benefit from the strong points of the two classes of method by refining the clean vectors obtained beforehand by a method of simultaneous iterations, via method of the powers opposite. That will make it possible to reduce the standard of the final residue. It is what postprocessing makes it possible to do 'IMPROVEMENT'.

Thus, even if options of the methods of simultaneous iterations ( 'PLUS\_PETITE/GRANDE' , 'CENTER' and 'BAND' ) are often preferable, one to calculate until about ten modes with the options of the methods of type power: 'SEPARATE' , 'ADJUSTS' or 'NEAR' . To even calculate tens of the hundreds of modes, it is necessary to privilege, when it is possible, the option 'BANDE' . That improves the robustness, the quality and the performances of calculation.

In the standard case of a real symmetrical GEP, ideally it would be necessary to organize its calculation in several sub-bands comprising each one between 20 and 60 modes. With, if possible a homogeneous cutting of many modes (a déséquilibre lower than X3<sup>1</sup> ).

With this intention, one can to proceed in several stages:

- To gauge zones of interest by an initial call to INFO\_MODE on a list of frequencies<sup>2</sup> (resp. critical loads) given,
- To look at numbers of clean modes displayed in the file message (or in sd\_table generated),
- To start again one or more calculations CALC\_MODES with OPTION=' BANDE ' while testing to balance bands.

If one calculates finally only one bandages, to save time, one can even pool part of the cost calculation of INFO\_MODE initial while notifying with CALC\_MODES the name of sd\_table generated

1 If the sub-band the least filled contains only 20 modes, the most provided should not contain ideally more than 60 modes. That makes it possible to optimize the costs of calculation, the robustness as well as the quality of the modes obtained.

2 For reasons of costs calculation, it is to better limit the list to a dozen values. Since it is necessary to starting again several CALC\_MODES successive to sweep all the required sub-bands.

Warning : The translation process used on this website is a "Machine Translation". It may be imprecise and inaccurate in whole or in part and is provided as a convenience.

(cf keywords TABLE\_\*). This chaining can thus return the overcost of INFO\_MODE negligible and to guide modal calculation effectively.

On the other hand, as soon as one treats a QEP or an atypical GEP (complex and/or nonsymmetrical matrix), the spectrum becomes complex. The chaining INFO\_MODE + CALC\_MODES is not then possible any more. Certain keywords or values become without object (OPTION='BANDE', VERI\_MODE/STURM...).

**Note:**

- One strongly advises a preliminary reading of the reference materials [R5.01.01] [R5.01.02] and [R5.01.04]. It gives to the user the properties and the limitations, theoretical and practical, of the modal methods approached while connecting these considerations to a precise parameter setting of the options.

## 3.2 Keyword TYPE\_RESU

```
◇ TYPE_RESU=/ 'DYNAMIC' [DEFECT]
           / 'MODE_FLAMB'
           / 'GENERAL'
```

This keyword makes it possible to define the nature of the modal problem to treat: search for frequencies of vibration (classical case of dynamics with or without gyroscopic damping and effects) or search for critical loads (case of the theory of linear buckling, only in GEP). According to this class of membership, the results are displayed and stored differently in the structure of data:

- **In dynamics** (TYPE\_RESU=' DYNAMIQUE '), the frequencies are ordered by order ascending of the module of their variation to the shift (cf [R 5.01.01/02], §3.8/2.5). It is the value of the variable of access NUME\_ORDRE structure of data. The other variable of access, NUME\_MODE, is equal to the true modal position in the spectrum of the eigenvalue (determined by the test of Sturm cf [R5.01.04]). This test of Sturm is licit only in GEP with real modes (real symmetrical matrices), in other cases (GEP with complex modes and QEP), one poses NUME\_MODE=NUMÉRIQUE\_ORDRE.
- **In buckling** (TYPE\_RESU=' MODE\_FLAMB '), the eigenvalues are stored by order ascending algebraic. Variables NUME\_ORDRE and NUME\_MODE take the same value equal to this order.
- **Case general** (TYPE\_RESU=' GENERAL '): idem that for the case of buckling.

Note: TYPE\_RESU=' GENERAL ' a problem of eigenvalues in the case of one makes it possible to solve **matrix system general**. For the moment its perimeter is limited to GEPs standards (symmetrical real matrices). Its only difference with MODE\_FLAMB is thus only in the denomination of the matrices: MATR\_A/MATR\_B rather than MATR\_RIGI/MATR\_RIGI\_GEOM.

## 3.3 Operands MATR\_RIGI/MATR\_A/MATR\_MASS/MATR\_RIGI\_GEOM /MATR\_B/MATR\_AMOR

The table below represents the operands to be used according standard to the keyword TYPE\_RESU.

TYPE_RESU		
'DYNAMIC'	'MODE_FLAMB'	'GENERAL'
◆ MATR_RIGI = With	◆ MATR_RIGI = WITH	◆ MATR_A = WITH
◆ MATR_MASS = B	◆ MATR_RIGI_GEOM = B	◆ MATR_B = B
◇ MATR_AMOR = C	Without object	Except current perimeter

**Table 3.3-1 - Name of the matrices of entry according to TYPE\_RESU**

- ◆ MATR\_RIGI/MATR\_A = WITH  
Assembled, real matrix (symmetrical or not) or complex symmetrical, of type [matr\_asse\*\_R/C] GEP/QEP to be solved.
- ◆ MATR\_MASS/MATR\_RIGI\_GEOM/MATR\_B = B  
Assembled, real matrix (symmetrical or not), of type [matr\_asse\*\_R] GEP/QEP to be solved.
- ◇ MATR\_AMOR = C  
Assembled, real matrix (symmetrical or not), of type [matr\_asse\*\_R] QEP to be solved.

**Note:**

*If the matrix With is complex symmetrical or if one of the matrices WITH, B or C is nonsymmetrical real, only certain sets of parameters are licit. In particular:*

- options 'BAND', 'NEAR', 'SEPRE', 'ADJUSTS' are not usable
- if A is complex: 'PLUS\_PETITE' is not usable, nor 'CENTER' if the target frequency is 0
- methods of resolution 'JACOBI' and 'TRI\_DIAG' (in SOLVEUR\_MODAL/METHOD) are not usable.

## 3.4 Operand OPTION

- ◇ OPTION=



`BAND`	<p>One searches all the eigenvalues in a given band. This band is defined by the argument of <math>FREQ=(f_{min}, f_{max})</math> or by that of <math>CHAR\_CRIT=(\lambda_{min}, \lambda_{max})</math>. Option only available in GEP to symmetrical real matrices.</p> <p>In the case <math>TYPE\_RESU='DYNAMIQUE'</math>, the keyword <math>FREQ</math> can be a list of <math>n&gt;2</math> values: <math>FREQ=(f_1=f_{min}, \dots, f_i, \dots, f_n=f_{max})</math>. Dyears this case, the band of total research is cut out in sub-bands <math>[f_i, f_{i+1}]</math> almost independent (cf §3.6.1).</p>
`CENTER`	<p>They are searched <math>NMAX\_FREQ</math> the eigenvalues closest to the frequency <math>f</math> (argument of the keyword <math>FREQ=f</math>) or them <math>NMAX\_CHAR\_CRIT</math> the critical loads closest to the load <math>\lambda</math> (argument of the keyword <math>CHAR\_CRIT=\lambda</math>).</p>
`PLUS_PETITE` [DEFECT]	<p>They are searched <math>NMAX\_FREQ</math> smaller Eigen frequencies (case <math>TYPE\_RESU='DYNAMIQUE'</math>) or them <math>NMAX\_CHAR\_CRIT</math> smaller critical loads (<math>TYPE\_RESU='MODE\_FLAMB'</math> or <math>'GENERAL'</math>).</p>
`PLUS_GRADE`	<p>They are searched <math>NMAX\_FREQ</math> greater eigenvalues.</p> <p>Option usable only in the case <math>TYPE\_RESU='DYNAMIQUE'</math>, for a generalized problem, with symmetrical real matrices.</p> <p>The roles of the matrices of rigidity and mass are inverted in a transparent way for the user.</p> <p>Rq: it can be useful to disconnect the test of STURM in the operand <math>VERI\_MODE</math>. Indeed, in the middle of the algorithm, before being converted into physical Eigen frequencies, the eigenvalues can be very small and very close.</p>
`ALL`	<p>One seeks all the modes associated with physical degrees of freedom.</p> <p>Option usable only with the method of resolution QZ (cf §3.5.1.1).</p>
`NEAR`	<p>One research the modes to which the eigenvalues are closest to values given. These values are indicated by:</p> <ul style="list-style-type: none"> <li>• the argument <math>lfreq</math> keyword <math>FREQ</math> for GEP of a dynamic type (<math>TYPE\_RESU='DYNAMIQUE'</math>).</li> <li>• the argument <math>lcharc</math> keyword <math>CHAR\_CRIT</math> for a GEP of type linear buckling (<math>TYPE\_RESU='MODE\_FLAMB'</math>).</li> <li>• arguments <math>lfreq</math> and <math>lamor</math> keyword <math>FREQ</math> and <math>AMOR\_REDUIT</math> for QEP of a dynamic type (<math>TYPE\_RESU='DYNAMIQUE'</math>).</li> </ul> <p>There are as many searches for modes than of terms in this list (or these lists).</p> <p>Rq: If one wishes to calculate a multiple mode, this option should not be used because one will find one mode for each value given of the list.</p>
`SEPARATE`	<p>One separates the eigenvalues by a method of bisection based on the criterion of Sturm. The terminals of the interval of research are:</p> <ul style="list-style-type: none"> <li>• values of the list <math>lfreq</math> keyword <math>FREQ</math> for a generalized or quadratic problem of dynamic type (<math>TYPE\_RESU='DYNAMIQUE'</math>).</li> <li>• values of the list <math>lcharc</math> keyword <math>CHAR\_CRIT</math> for a generalized problem of standard linear buckling (<math>TYPE\_RESU='MODE\_FLAMB'</math>).</li> </ul>
`ADJUSTS`	<p>Operation similar to the option <math>'SEPARATE'</math> the preceding one.</p> <p>After having separated the Eigen frequencies via the option <math>'SEPARATE'</math> (in GEP only), one carries out additional iterations either by the method of secant (GEP) or by the method of Müller-Traub (QEP) to obtain a better precision on the eigenvalues.</p>

**Table 3.4-1 - Possible values of the keyword OPTION**

It is important to remember that the choice of one of these options involves the use of a special method:

- `OPTION= 'BAND' , 'CENTER' , 'PLUS_PETITE' , 'PLUS_GRANDE' or 'ALL'` imply the use of a method of the simultaneous iterations
- `OPTION= ' PROCHE' , 'SEPARATE' , 'ADJUSTS'` imply the use of the method of the powers opposite.

This choice has consequences on the rest of the keyword accessible in the order, in particular on the parameter setting of `SOLVEUR_MODAL` (cf § according to).

See [R 5.01.01/02] §2.5/3.8.

## 3.5 Keyword factor `SOLVEUR_MODAL`

Keyword allowing to regulate the algorithms and the parameters of the modal solver.

### 3.5.1 Keywords associated with the method of the simultaneous iterations

These keywords are not usable which if the value of the keyword `OPTION` is among `'PLUS_PETITE'`, `'PLUS_GRANDE'`, `'BAND'`, `'CENTER'`, `'ALL'`.

#### 3.5.1.1 Keyword `METHOD`

Four methods of resolution are then available to solve the problem with the eigenvalues (cf too Table 3.1-1):

◇ `METHODE= 'SORENSEN' [DEFECT]`

One uses the method of Sorensen (external package ARPACK) to calculate the clean modes of the GEP or the QEP (cf [R 5.01.01/02] §7/4). Its perimeter includes the real, symmetrical matrices or not, even a matrix  $A$  complex symmetrical.

`/ 'TRI_DIAG'`

One uses the method of Lanczos (alternative of Newmann-pipano in GEP, Parlett & Saad in QEP) to calculate the clean modes of the GEP or the QEP (cf [R 5.01.01/02] §6/4). Its perimeter is limited to the real symmetrical matrices.

`/ 'JACOBI'`

One uses the method of Bathe & Wilson (then method of Jacobi on the system project) to calculate the clean modes of the GEP (cf [R5.01.01] §8). Its perimeter is limited to the real symmetrical matrices.

`/ 'QZ'`

One uses method QZ of external library LAPACK to calculate the clean modes of the GEP or the QEP (cf [R 5.01.01/02] §9/5). Its perimeter includes the real, symmetrical matrices or not, even a matrix  $A$  complex symmetrical. This method of very expensive reference is to be held for the problems smalls ( $<10^3$  degrees of freedom).

#### 3.5.1.2 Parameters related to the method of resolution

Each one of these methods of resolution has various adjustments:

- if `METHODE= 'SORENSEN' :`

◇ `PREC_SOREN=ps0 (0.) [DEFECT]`

**Note:**

- *The method considers whereas it must work with the smallest possible precision, the "zero machine". To have an order of magnitude of it, in double precision on the machines standards, this value is close to  $2.22 \cdot 10^{-16}$ .*

◇ NMAX\_ITER\_SOREN=nso (20) [DEFECT]  
◇ PARA\_ORTHO\_SOREN=porso (0,717) [DEFECT]

They are parameters of adjustment of the necessary precision on the modes (by default, the precision machine is selected), amongst restartings authorized of the method of Sorensen (cf. [R5.01.01] §7) and of the coefficient of orthogonalisation of the IGSM of Kahan-Parlett (cf [R5.01.01] appendix 2).

If the coefficient `porso` is negative, the reorthogonalisation is carried out on all the modes calculated instead of targeting only the modes belonging to the same clean space. Calculation can then be two or three times more expensive.

For more information on the mode of selection of clean spaces one will be able to consult the parameters `SEUIL_FREQ/CHAR_CRIT`.

**Note:**

- *At the time of the first passages, it is strongly advised not to modify these advanced parameters of the algorithm and which are initialized empirically with values standards.*

- if METHODE= 'TRI\_DIAG' :

◇ PREC\_ORTHO =po (1.10<sup>-12</sup>) [DEFECT]  
◇ NMAX\_ITER\_ORTHO=nio (5) [DEFECT]  
◇ PREC\_LANCZOS=pl (1.10<sup>-8</sup>) [DEFECT]  
◇ NMAX\_ITER\_QR=nim (30) [DEFECT]  
◇ MODE\_RIGIDE=/ 'YES'  
/ 'NOT' [DEFECT]

The first two parameters make it possible, respectively, to adjust the precision of orthogonalisation and the number of réorthogonalisations in the method of Lanczos to obtain independent vectors generating the subspace (cf [R5.01.01] §6).

The third is a parameter of adjustment to determine the nullity of a term on the surdiagonale of the matrix tridiagonale characterizing the reduced problem obtained by the method of Lanczos. It is right a criterion of deflation and not, as opposed to what could let believe its name, a quality standard of the modes.

The fourth fixes the maximum iteration count for the resolution of the system reduced for method QR ([R5.01.01] appendix 1).

The keyword `MODE_RIGIDE` allows to detect and calculate as a preliminary, by an algebraic method, the modes of body of rigid. They are used thereafter to calculate the other modes with the algorithm of Lanczos. They are provided to the user only if they belong to the modes requested. If the modes of rigid body are calculated without using this option, the eigenvalues calculated by the algorithm of Lanczos are not worthless but very close to zero.

**Note:**

- *At the time of the first passages, it is strongly advised not to modify these parameters which rather relate to the mysteries of the algorithm and which are initialized empirically with values standards.*

- if METHODE= 'JACOBI' :

◇ PREC\_BATHE =pbat (1.10<sup>-10</sup>) [DEFECT]  
◇ NMAX\_ITER\_BATHE=nbat (40) [DEFECT]  
◇ PREC\_JACOBI=pjaco (1.10<sup>-2</sup>) [DEFECT]

◇ NMAX\_ITER\_JACOBI=njaco (12) [DEFECT]

The first two parameters make it possible, respectively, to adjust the precision of convergence and the maximum number of allowed iterations of the method of Bathe & Wilson (cf [R5.01.01] §8).

The two others adjust the precision of convergence and the maximum number of iterations of the method of JACOBI (cf [R5.01.01] appendix 3). This total modal solver is used to calculate the clean modes of the matrix projected by Bathe & Wilson.

**Note:**

- *At the time of the first passages, it is strongly advised not to modify these parameters which rather relate to the mysteries of the algorithm and which are initialized empirically with values standards.*

- if METHODE= 'QZ' :

```
◇ TYPE_QZ = / 'QZ_SIMPLE' [DEFECT]
            / 'QZ_EQUI'
            / 'QZ_QR'
```

This parameter makes it possible to choose one of the alternatives of algorithm QZ proposed by LAPACK. The first choice ('QZ\_SIMPLE') indicate the basic method, the second ('QZ\_EQUI') he add a preprocessing of balancing of the terms of the matrix. That often improves quality of the modes but, *a contrario*, if the matrix presents very small terms due to rounding errors, this phase generates parasitic modes then.

As for the third choice ('QZ\_QR'), it is reserved for the positive definite symmetrical case (matrix of real stiffness, condition of Dirichlet without Lagrange, not of buckling or damping). It is much faster than the preceding options.

### 3.5.1.3 Keyword APPROACH

```
◇ APPROCHE= / 'REEL' [DEFECT]
            / 'IMAG'
            / 'COMPLEX' (only with Sorensen)
```

This keyword defines the type of approach (real, imaginary or complex) for the choice of the scalar pseudo-product of the QEP used with the method of Lanczos or that of Sorensen (cf [R5.01.02]).

This operand does not have a direction that for the analysis of the vibrations (TYPE\_RESU= 'DYNAMIQUE') free of a deadened or revolving structure (complex clean modes; the keyword MATR\_AMOR must be well informed). In buckling, (TYPE\_RESU= 'MODE\_FLAMB') that does not have any interest.

**Note:**

- *Into quadratic, with the method of Lanczos only approach 'IMAG' is compatible with a worthless frequential terminal ('OPTION=PLUS\_PETITE' or 'CENTER' with  $f=0$ ).*
- *With Sorensen, none is compatible.*

### 3.5.1.4 Keywords DIM\_SOUS\_ESPACE and COEF\_SOUS\_ESPACE

```
◇ DIM_SOUS_ESPACE=des
◇ COEF_DIM_ESPACE=mse
  EXCLUDED ('DIM_SOUS_ESPACE', 'COEF_DIM_ESPACE')
```

If the keyword DIM\_SOUS\_ESPACE is not informed or is initialized with a value strictly lower than the number of frequencies requested `nf`, the operator automatically calculates an acceptable dimension for the subspace of projection to the assistance COEF\_DIM\_ESPACE (cf §5 this document and [R5.01.01] §5.3).

Thanks to the data of this multiplicative factor,  $m_{se}$ , one can project on a space whose size is proportional to the number of frequencies contained in the interval of study.

If one searches clean modes on a tape cut out in several sub-bands (`OPTION='BANDE'` and `FREQ` is a list of at least 3 values), one can thus optimize the size subspaces which remains proportional to the number of frequencies searched on each sub-band: the subspaces rich in eigenvalues thus do not penalize poorest (in term of CPU).

One can however arbitrarily fix the size of this subspace, via the value `catch` by the keyword `DIM_SOUS_ESPACE` (which must be higher than `nf` to be taken into account).

In both cases, if size of the subspace of projection `ndim` is strictly higher than the number of "active degrees of freedom", `nactif` (cf [R5.01.01] §3.2), then one forces it to take this value ceiling.

**Note:**

- If one uses the method of Sorensen (IRAM) and that  $ndim - nf < 2$ , data-processing requirements *numérico* - force to impose  $ndim = nf + 2$ .  
Into quadratic, one works on a real problem of double size:  $2 * nf$ ,  $2 * ndim$ .
- These parameters are useless for method 'QZ'.

## 3.5.2 Parameters associated with the method of the powers opposite

These parameters are thus available only if the value of the keyword `OPTION` is among 'NEAR', 'SEPARATE', 'ADJUSTS'.

### 3.5.2.1 Operands of the bisection (if `OPTION= 'SEPARATE'` or 'ADJUSTS')

◇	<code>NMAX_ITER_SEPARE=</code> <code>nis</code>	<b>(30)</b>	<b>[DEFECT]</b>
◇	<code>PREC_SEPARE =</code> <code>ps</code>	<b>(1.10<sup>-4</sup>)</b>	<b>[DEFECT]</b>

Parameters of adjustment amongst iterations and the precision of separation for the dichotomizing search. These operands are ignored for the option 'NEAR' (Cf [R5.01.01] §4.2).

### 3.5.2.2 Operands of the secant (if `OPTION= 'AJUSTE'`)

◇	<code>NMAX_ITER_AJUSTE =</code> <code>denied</code>	<b>(15)</b>	<b>[DEFECT]</b>
◇	<code>PREC_AJUSTE =</code> <code>Pa</code>	<b>(1.10<sup>-4</sup>)</b>	<b>[DEFECT]</b>

Parameters of adjustment amongst iterations and the precision of separation for the method of the secant. These operands are used only for the option 'ADJUSTS' (Cf [R5.01.01] §4.2).

**Note:**

At the time of the first passages, it is strongly advised not to modify these parameters which rather relate to the mysteries of the algorithm and which are initialized empirically with values standards.

### 3.5.2.3 Parameters of calculation of the second phase of calculation of the method of the powers opposite

◇	<code>OPTION_INV=</code> / <code>'DIRECT'</code>	<b>[DEFECT]</b>
	/ <code>'RAYLEIGH'</code>	

Definition of the method of the powers opposite (confer [R 5.01.01/02] §4.3/3.3):

'DIRECT' standard method in GEP or alternative of Jennings in QEP.  
[DEFECT]  
'RAYLEIGH' Acceleration via the quotient of Rayleigh (only in GEP)

**Table 3.5.2.3-1 - Operation of OPTION\_INV according to its value**

◇ NMAX\_ITER\_INV=nim (30) [DEFECT]  
Maximum number of iterations of the method of the powers opposite for the research of the clean modes.

◇ PREC\_INV=pm (1.10<sup>-5</sup>) [DEFECT]  
Test of stop of the method of the powers opposite.

## 3.6 Keyword CALC\_FREQ (if TYPE\_RESU= ' DYNAMIQUE ')

◇ CALC\_FREQ=\_F (...)

Keyword factor which specifies the parameters of calculation of the clean modes and their number, according to OPTION chosen.

### 3.6.1 Operand FREQ (only if OPTION=' BANDE ' or ' CENTER ' or ' NEAR ' or ' SEPARATE ' or ' ADJUSTS ')

◆ FREQ=l\_f  
◇ TABLE\_FREQ=table\_f

List of the frequencies: its use depends on OPTION chosen.

OPTION='BAND'	A list of N is expected $\geq 2$ values ( $f_{min}=f_1, \dots, f_i, \dots, f_{max}=f_n$ ) who define the band of research. If $N > 2$ , the band of total research $[f_{min}, f_{max}]$ is cut out in sub-bands $[f_i, f_{i+1}]$ .
OPTION='CENTER'	Only one value of frequency is expected.
OPTION='NEAR'	A list of N is expected $\geq 1$ values ( $f_1, \dots, f_i, \dots, f_n$ ) who define the frequencies around which one seeks the Eigen frequency nearest.
OPTION='SEPARATE' or 'ADJUSTS'	A list of N is expected $\geq 2$ values ( $f_1, \dots, f_i, \dots, f_n$ ) who define the terminals of the intervals of research $[f_i, f_{i+1}]$ .

**Table 3.6.1-1 - Use of the keyword FREQ according to OPTION chosen**

- With the option ' BAND ': the values stipulated under this keyword must be positive strictly increasing.

- If  $N = 2$ :

one starts by operating expensive<sup>3</sup> test of Sturm in order to determine the number of modes contained in the band (cf [R5.01.04]). If one has, as a preliminary, carried out a calibration of the zone of interest by one INFO\_MODE, one can save part of this cost of calculation. With this intention, one re-uses the table generated by INFO\_MODE. Terminals ( $f_{min}, f_{max}$ ) defined above allow to select one or more lines of the aforesaid table.

For example, if the table were generated by one

$$\text{INFO\_MODE+FREQ} = (f_{im0}, f_{im1}, f_{im2}, f_{im3}, f_{im4}, f_{im5}),$$

<sup>3</sup> On average 20/30% of the cost total calculation of the operator.

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one can pool part of the cost calculation of it while posing in `CALC_MODES+' BANDE'`,  $FREQ=(f_{min}=f_{im1}, f_{max}=f_{im4})$ . The stage of pretreatment of `CALC_MODES` then will carry out the test of Sturm but, in the place, will not detect in the table the sub-bands included in the interval. Maybe, here:

$$[f_{im1}, f_{im2}] \cup [f_{im2}, f_{im3}] \cup [f_{im3}, f_{im4}] .$$

One then just will summon the numbers of modes corresponding to each subinterval to deduct the total number of modes from it to search.

This chaining really makes it possible to reduce the overcost of the initial calibration by `INFO_MODE` and is thus to use each time it is possible.

## Remarks concerning chaining `INFO_MODE+CALC_MODES+' BANDE'`:

- Terminals of selection  $(f_{min}, f_{max})$  must correspond exactly to those having been used to generate it `INFO_MODE` initial (with `VERI_MODE/PREC_SHIFT % near4`).
- The selection of the lines of the table is carried out compared to the initial values of the frequencies. But if they underwent shifts (because they were too close to clean modes), the table traces also these values after shifts (values `FREQ_MIN/MAX` versus `BORNE_MIN/MAX_EFFECT`). These are of course the last shifted values which are transmitted to the algorithm of `CALC_MODES`. This strategy preserves thus, at the same time, the ergonomics of the option and the consistency of the behaviors software: one `CALC_MODES+' BANDE'` provides the same result, whether it starts its phase of pretreatment with or without precalculated table.
- If one of the terminals of selection had to be shifted (in `INFO_MODE` precondition), the phase of preprocessing emits one `ALARM` to reproduce the same behavior as for a standard calculation.
- The table should comprise neither hole, nor covering, if not it is rejected. But this case cannot normally occur with a map resulting from `INFO_MODE`. This rule makes it possible to preserve the robustness of the algorithmic diagram: one wants to miss no frequency.

- If  $N > 2$ :

the calibration of each sub-band by the operator `INFO_MODE` is made automatically within the operator `CALC_MODES`. Moreover, research on each sub-band can be paralleled in order to reduce the computing times (cf §3.12).

### Note:

- Each frequency is treated only once: as a lower limit of the first sub-band for the first of the list, as an upper limit of the sub-bands which follow for the other frequencies. In particular, if this frequency is judged too near to an eigenvalue, it is shifted ( cf `[U4.52.01]` and `[R5.01.04]`).
  - The possible shift of a terminal of frequency does not take place any more but only once in `INFO_MODE` initial. There is not thus more risk of overlapping of intervals shifted as until in version v10. One is not thus likely any more to twice calculate by error the same mode.
- With the option 'NEAR': the values stipulated under this keyword must be positive strictly increasing. C is the list of the frequencies whose one seeks the mode nearest.
  - With the option 'SEPARATED' or 'AJUSTE' : the values are the terminals of the intervals of research. One will seek to separate the frequencies in the intervals  
 $[F_1, F_2], [F_2, F_3] \dots [F_{N-2}, F_{N-1}], [F_{N-1}, F_N]$   
The list has at least two elements. The frequencies must be positive and in the ascending order.

## 3.6.2 Operand `AMOR_REDUIT` (only if `OPTION=' CENTRE'` or 'NEAR')

◇ `AMOR_REDUIT=1_a`

4 The sort criterion is into relative, except when the required terminal is close to zero. It becomes an absolute criterion then.

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Value of the reduced damping which makes it possible to define the eigenvalue complexes (the “shift”) around which one seeks the eigenvalues closest (cf [R5.01.01] §5.4). This option cannot be used that within the framework of a modal problem to complex modes: QEP or GEP with nonsymmetrical real matrices or with  $A$  complex symmetrical.

OPTION='CENTER'	One expects only one value of reduced damping
OPTION='NEAR'	One expects a list of values of reduced damping, of the same size than the list given under the keyword <code>FREQ</code> .

**Table 3.6.2-1 - operation of the keyword `AMOR_REDUIT` according to `OPTION` chosen**

The value stipulated under this keyword must be positive and be ranging between 0 and 1.

### 3.6.3 Operand `NMAX_FREQ` (only if `OPTION=' PLUS_PETITE'` or `'PLUS_GRANDE'` or `'CENTER'` or `'SEPARATE'` or `'ADJUSTS'`)

◇ `NMAX_FREQ=nf` (10 if `OPTION=' PLUS_PETITE'`, 1 if `OPTION=' PLUS_GRANDE'`, 0 if `OPTION=' SEPARATE'` or `'ADJUSTS'`) [DEFECT]

Maximum number of eigenvalues to calculate.

- If `OPTION=' PLUS_PETITE'` or `'PLUS_GRANDE'` or `'CENTER'` :  
If `nf` is strictly higher than the number of “degrees of freedom-credits”, `nactif` (cf. [R5.01.01] §3.2), then one forces it to take this value ceiling.

- If `OPTION=' PROCHE'` :  
The value is ignored.

- If `OPTION=' SEPARATE'` or `'ADJUSTS'` :  
If the user does not inform this keyword, all the eigenvalues contained in the intervals specified by the user are calculated. If not, then `NMAX_FREQ` first eigenvalues, therefore lowest, are calculated.

### 3.7 Keyword `CALC_CHAR_CRIT` (if `TYPE_RESU=' MODE_FLAMB'` or `'GENERAL'`)

◇ `CALC_CHAR_CRIT=_F` (...)

Keyword factor which specifies the parameters of calculation of the clean modes and their number, according to `OPTION` chosen.

#### 3.7.1 Operand `CHAR_CRIT` (only if `OPTION=' BANDE'` or `'CENTER'` or `'NEAR'` or `'SEPARATE'` or `'ADJUSTS'`)

◆ `CHAR_CRIT=l_c`  
◇ `TABLE_CHAR_CRIT=table_c`

List of the critical loads: its use depends on the option chosen.



OPTION= 'BAND'	Two values are expected ( $\lambda_{min}, \lambda_{max}$ ) who define the band of research
OPTION= 'CENTER'	One expects only one value of critical load
OPTION= 'NEAR'	A list of N is expected $\geq 1$ values who define them ( $\lambda_1, \lambda_2, \dots, \lambda_{n-1}, \lambda_n$ ) loads around which one seeks the critical load nearest.
OPTION= 'SEPARATE' or 'ADJUSTS'	A list of N is expected $\geq 2$ values who define them ( $\lambda_1, \lambda_2, \dots, \lambda_{n-1}, \lambda_n$ ) terminals of the intervals of research $[\lambda_i, \lambda_{i+1}]$ .

**Table 3.7.1-1 - Use of the keyword CHAR\_CRIT according to OPTION chosen**

The values stipulated under this keyword are positive or negative. In QEP that does not have any interest.

- With the option 'BAND', one starts by operating expensive <sup>5</sup> test of Sturm in order to determine the number of modes contained in the band (cf [R5.01.04]). If one has, as a preliminary, carried out a calibration of the zone of interest by one INFO\_MODE, one can save part of this cost of calculation. With this intention, one re-uses the table generated by INFO\_MODE. Terminals ( $\lambda_{min}, \lambda_{max}$ ) defined above allow to select one or more lines of the aforesaid table.

For example, if the table were generated by one

$$\text{INFO\_MODE+CHAR\_CRIT} = (\lambda_{im0}, \lambda_{im1}, \lambda_{im2}, \lambda_{im3}, \lambda_{im4}, \lambda_{im5}),$$

one can pool part of the cost calculation of it while posing in CALC\_MODES+'BANDE', CHAR\_CRIT=( $\lambda_{min} = \lambda_{im1}, \lambda_{max} = \lambda_{im4}$ ). The stage of preprocessing of CALC\_MODES then will carry out the test of Sturm but, in the place, will not detect in the table the sub-bands included in the interval. Maybe, here:

$$[\lambda_{im1}, \lambda_{im2}] \cup [\lambda_{im2}, \lambda_{im3}] \cup [\lambda_{im3}, \lambda_{im4}].$$

One then just will summon the numbers of modes corresponding to each subintervals to deduct the number of modes from it total to search.

This chaining really makes it possible to reduce the overcost of the initial calibration by INFO\_MODE and is thus to use each time it is possible.

#### Remarks concerning chaining INFO\_MODE+CALC\_MODES+'BANDE':

- Terminals of selection ( $\lambda_{min}, \lambda_{max}$ ) must correspond exactly to those having been used to generate it INFO\_MODE initial (with VERI\_MODE/PREC\_SHIFT % near <sup>6</sup>).
- The selection of the lines of the table is carried out compared to the initial values of the frequencies. But if they underwent shifts (because they were too close to clean modes), the table traces also these values after shifts (values CHAR\_CRIT\_MIN/MAX versus BORNE\_MIN/MAX\_EFFECT). These are of course the last shifted values which are transmitted to the algorithm of CALC\_MODES. This strategy preserves thus, at the same time the ergonomics of the option and the consistency of the behaviors software: one CALC\_MODES+'BANDE' provides the same result, whether it starts its phase of preprocessing with or without precalculated table.
- If one of the terminals of selection had to be shifted (in INFO\_MODE precondition), the phase of preprocessing emits one ALARM to reproduce the same behavior as for a standard calculation.
- The table should comprise neither hole, nor covering, if not it is rejected. But this case cannot normally occur with a map resulting from INFO\_MODE. This rule makes it possible to preserve the robustness of the algorithmic diagram: one wants to miss no frequency.

<sup>5</sup> On average 20/30% of the cost total calculation of the operator.

<sup>6</sup> The sort criterion is into relative, except when the required terminal is close to zero. It becomes an absolute criterion then.

- With the option 'NEAR': the values stipulated under this keyword must be positive strictly increasing. C is the list of the loads whose one seeks the mode nearest.
- With the option 'SEPARATED' or 'AJUSTE' : the values are the terminals of the intervals of research. One will seek to separate the critical loads in the intervals  

$$[\lambda_1, \lambda_2], [\lambda_2, \lambda_3] \dots [\lambda_{n-2}, \lambda_{n-1}], [\lambda_{n-1}, \lambda_n]$$
The list has at least two elements. The frequencies must be positive and in the ascending order.

### 3.7.2 Operand NMAX\_CHAR\_CRIT (only if OPTION=' PLUS\_PETITE' or 'CENTER' or 'SEPARATE' or 'ADJUSTS')

◇ NMAX\_CHAR\_CRIT=nf (10) [DEFECT]

Maximum number of critical loads to calculate.

- If OPTION=' PLUS\_PETITE' or 'CENTER' :  
If nf is strictly higher than the number of "active degrees of freedom", nactif (cf. [R5.01.01] §3.2), then one forces it to take this value ceiling.

- If OPTION=' PROCHE' :  
The value is ignored.

- If OPTION=' SEPARATE' or 'ADJUSTS' :  
If the user does not inform this keyword, all the eigenvalues contained in the intervals specified by the user are calculated. If not, them NMAX\_CHAR\_CRIT first eigenvalues, therefore lowest, are calculated.

### 3.8 Operands common to CALC\_FREQ and CALC\_CHAR\_CRIT : SEUIL\_FREQ/SEUIL\_CHAR\_CRIT, PREC\_SHIFT, NMAX\_ITER\_SHIFT

These operands are located inside the keyword CALC\_FREQ (case TYPE\_RESU=' DYNAMIQUE') or CALC\_CHAR\_CRIT (case TYPE\_RESU=' MODE\_FLAMB' or 'GENERAL').

```
# IF TYPE_RESU=' DYNAMIQUE'
  ◇ PREC_SHIFT      = p_shift      (0.05) [DEFECT]
  ◇ SEUIL_FREQ      = f_seuil      (0.01) [DEFECT]
  ◇ NMAX_ITER_SHIFT = n_shift      (3)     [DEFECT]

# IF TYPE_RESU=' MODE_FLAMB' or 'GENERAL'
  ◇ PREC_SHIFT      = p_shift      (0.05) [DEFECT]
  ◇ SEUIL_CHAR_CRIT = c_seuil      (0.01) [DEFECT]
  ◇ NMAX_ITER_SHIFT = n_shift      (3)     [DEFECT]
```

The course of a modal calculation in this operator requires factorization  $LDL^T$  dynamic matrices  $Q(\lambda)$  type (cf [R 5.01.01/02] §2.5/3.8)

$$Q(\lambda) := A - \lambda B \quad (\text{in GEP})$$

$$Q(\lambda) := \lambda^2 B + \lambda C + A \quad (\text{in QEP})$$

These factorizations are dependent on digital instabilities when the shift  $\lambda$  is close to an eigenvalue of the problem. This detection takes place by comparing the loss of decimals of the diagonal terms of this factorized compared to their initial values (in absolute value). If it maximum

of this loss is higher than  $ndeci^7$ , the matrix is supposed to be singular and one seeks a shifted value of the shift getting an invertible matrix.

For GEPs, the parameters  $SEUIL_*$  allow to define “the zero modal one”, i.e. the value in on this side which it is considered that an eigenvalue is worthless. In corollary, in certain operator salaries, if the difference between two eigenvalues is lower than this figure, one considers that they are confused. It is thus necessary to adjust this value according to the average amplitude of the required modes.

If one is in dynamics one transforms this value into pulsation

$$omecor = (2\pi f\_seuil)^2$$

while in buckling one keeps it such as it is

$$omecor = c\_seuil.$$

For QEPs, this value of “the zero modal one” is used at the time of the sorting carried out at the conclusion of modal calculation. At the time of this sorting, one seeks to determine if a mode is real (it is not retained), complex combined (one keeps that of positive imaginary part) or complex odd (it is not retained). Two modes  $\lambda_1, \lambda_2$  are regarded as combined if

$$|\lambda_1 - \bar{\lambda}_2| < omecor$$

## Note:

- A mode is regarded as reality if its imaginary part is lower than  $SEUILR=1E-7$  (value into hard initialized in the routines of sorting).
- When modes were sorted like purely real or spoiled complexes, an informational message or an alarm appears (*ALGELINE4\_87/88*) according to the cases.
- With the methods of Sorensen and QZ, in standard GEP (symmetrical reality), the parameters  $*\_threshold$  are used to determine if two modes must be orthogonalized or not (when the selective orthogonalisation is activated as it is the case by default, cf. *PARA\_ORTHO\_SOREN*). Two modes are regarded as “multiples”, therefore with réorthogonaliser, if their modules are all the two lower than  $100*omecor$  or, in the contrary case, if their relative variation is lower than  $omecor$ . This reorthogonalisation is expensive but essential for later projections on modal basis, from where the need for values balanced for this criterion. Normally the fixed values by default are sufficient and they do not have to be often modified.

Other parameters,  $PREC\_SHIFT$  and  $NMAX\_ITER\_SHIFT$ , are related to the algorithm of shift of the terminals of the interval  $[f_{min}, f_{max}]$  (cf [R5.01.04] §3.2), when one realizes that those are very close to an eigenvalue. Coarsely these terminals  $f_{min}$  (or  $\lambda_{min}$  in buckling) or  $f_{max}$  (resp.  $\lambda_{max}$ ) are then shifted towards the outside of the segment of  $p\_shift\%$ . If the dynamic matrix thus rebuilt is always considered to be “numerically singular”, one again shifts after having emitted one *ALARM*. This shift is tried  $n\_shift$  time.

$$\lambda_{min}^- = \lambda_{min} - \max(omecor, 2^{(i-1)} \times p\_shift \times |(\lambda_{min})|) \quad (\text{lème attempt})$$

$$\lambda_{max}^- = \lambda_{max} + \max(omecor, 2^{(i-1)} \times p\_shift \times |(\lambda_{max})|) \quad (\text{lème attempt})$$

In fact, in dynamics as in buckling, the shift takes place same manner. *Stricto sensu*, in dynamics these are thus not the frequencies that one shifts, but pulsations.

Another precision, the shift is in fact, by preoccupations with an effectiveness, dichotomic:  $p\_shift\%$  the first time,  $2 \times p\_shift\%$  second time etc This process must make it possible quickly to move away from the “zone of singularity” to lower costs. *A contrario*, one should not too much increase the values of these parameters, because through shifts, the resulting terminals can prove to be very different from the initial terminals.

Moreover, to remain coherent with “the zero modal one” (noted here  $omecor$ ):

- one does not shift a value lower than this minimum (from where the max in the formulas above);

7 Fixed value via the parameter *NPREC* keyword *SOLVEUR* (by default  $ndeci=8$ ).

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- so from the beginning, the measured terminal is lower than this “zero”  $|\lambda_i| < \text{omecor}$  (in absolute value) one fixes it at more or less this value (according to whether this terminal is positive or negative). One then allows any more no shift.

**Note:**

- A terminal of the interval  $\sigma$  is close to an eigenvalue, when factorization LDLT of the dynamic matrix associated on this terminal (for example that of a GEP is written  $\mathbf{Q}(\sigma) := \mathbf{A} - \sigma \mathbf{B}$ ), led to a loss of decimal of more than *NPREC* digits (value parameterized under the keyword *SOLVEUR*). While exploiting the value of this parameter (*NPREC*=7, 8 or 9), one can then avoid the expensive refactorisations which these shifts imply when this digital singularity is not very marked.
- In the same way, while exploiting the digital parameters of the linear solveurs (for example: *METHOD*, *RENUM*, *PRETREATMENTS*...), one can also influence this criterion of singularity.
- One implements this technique of shift in two cases: calculation of a test of Sturm (pre and/or postprocessing) and construction of the dynamic matrix of work. In the event of failure of the algorithm of shift: in the first case, one is emitted *ALARM*, in the second, one stops in *ERREUR\_FATALE*.

## 3.9 Keyword factor SOLVEUR

◇ SOLVEUR=\_F(),

One has access to all the parameters of the direct linear solveurs (*METHODE*= 'LDLT' / 'MULT\_FRONT' / 'MUMPS').

In parallel mode, one advises the parameter setting particularly <sup>8</sup> *METHODE*= 'MUMPS' and *RENUM*= 'QAMD'.

For more details on the solveurs, one will be able to consult the document [U4.50.01]. Concerning parallelism, one returns to the document [U2.08.06] and the dedicated paragraph of the document [U2.06. 01 ].

## 3.10 Keyword VERI\_MODE

◇ VERI\_MODE=\_F (...

Keyword factor for the definition of postprocessings of checking of the clean modes. These postprocessings relate to the standard of the residue of the modes and possibly the counting of the eigenvalues (cf [R5.01.01] §3.7.4 and [R5.01.02] §2.5.4).

**Note:**

At the time as of first passages, it is strongly advised not to modify these parameters which rather relate to the mysteries of the algorithm and which are initialized empirically with values standards.

### 3.10.1 Operand STOP\_ERREUR

◇ STOP\_ERREUR=/ 'YES' [DEFECT]  
/ 'NOT'

<sup>8</sup> In order to at least reduce the cost in time of the phase of analysis (sequential) of MUMPS. This parameter setting is done however to the detriment of consumption memory. But this overcost quickly proves compensated by the distribution of the data on the processors which parallelism implies.

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Allows to indicate to the operator if it must stop ('YES') or to continue ('NOT') if one of the criteria THRESHOLD (whatever the method used: simultaneous iterations or powers opposite) or STURM (only with the method of the simultaneous iterations) is not checked.

By default the concept of exit is not produced.

## 3.10.2 Operand THRESHOLD

◇ SEUIL=r (1.10<sup>-6</sup>) [DEFECT] for the method of the simultaneous iterations  
(1.10<sup>-2</sup>) [DEFECT] for the method of the powers opposite

Tolerance level for the standard of error relative of the mode to the top of which he is regarded as forgery or too approximated (cf [R 5.01.01/02] algorithm  $n^2/n^1$ ). See also parameter STOP\_ERREUR.

## 3.10.3 Operand STURM (only for the method of the simultaneous iterations)

- if TYPE\_RESU=' DYNAMIQUE' and OPTION=' BANDE' :

◇ STURM= / 'TOTAL' [DEFECT]  
/ 'LOCAL'  
/ 'YES'  
/ 'NOT'

Rq: 'TOTAL' and 'LOCAL' a direction has if there are at least two sub-bands of calculation. If there is only one bandages calculation, these two values are equivalent to 'YES'.

Checking known as of STURM allowing to make sure that the algorithm used in the operator determined the exact number of eigenvalues, sub-band by sub-band ('LOCAL') or only in the total band<sup>9</sup> ('TOTAL') (cf [U4.52.01] [R5.01.04]). The second alternative is most of the time amply sufficient and much less expensive than the first.

However, when the terminals provided to the test of Sturm are close to an eigenvalue, they should be shifted (to preserve the robustness of the process). Sometimes this shift is pronounced too much and it will thus lead the test of Sturm to include a too large interval comprising not calculated frequencies (and not wished).

The test then will alert the user sometimes unnecessarily. After being itself assured that they were not multiple frequencies disastrous close to the terminals of the band, one can then disconnect it ('NOT') or to reduce the parameters of shift (to pass from PREC\_SHIFT=5% to 2% for example).

For example, the interval is tested [100,500] and 499.5 and 520 are eigenvalues of the problem. Because of proximity of the eigenvalue 499.5 with the maximum terminal 500, the test of Sturm will have to shift the latter. By default it will take value 525. This new band of test [100,525] is now too important because it includes value 520: the test will conclude, wrongfully, that it there is a problem including a frequency in excess.

*A contrario*, if 500.1 had been an eigenvalue, the test of Sturm would undoubtedly have made well alert the user.

### Note:

- In standard parallel mode (NIVEAU\_PARALLELISME=' COMPLET'), there is no possibility of test of local Sturm. STURM=' GLOBAL' or ' LOCAL' carry out the same treatment: they check the validity of the test of Sturm on the whole of the sub-bands of calculation.
- This test of post-checking is carried out besides other tests (non-disengageable and essential):  
Internal tests of convergence<sup>10</sup> with the modal solver ('SORENSEN', 'TRI\_DIAG' and 'JACOBI') flexible via keywords PREC\_\*.

<sup>9</sup> Cf Example of §10.

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Checking of the residues (cf [R 5.01.01/02] algorithm  $n^2/n^1$ ) of each mode calculated (cf keyword `SEUIL_FREQ` and `THRESHOLD`).  
One makes sure finally that the frequencies exhumed for each sub-band belong well to the selected interval (at `VERI_MODE/PREC_SHIFT %` near).

- in the other cases:

◇ `STURM= / 'YES' [DEFECT]`  
`/ 'NOT'`

Checking known as of `STURM` allowing to make sure that the algorithm used in the operator determined the exact number of eigenvalues in the interval of research (§3.5/6/8 [R5.01.01]). This option thus has interest only in GEP with real modes (not with **K** complex and with nonsymmetrical matrices).

See also parameter `STOP_ERREUR`.

### 3.10.4 Operand `PREC_SHIFT` (only for the method of the simultaneous iterations)

◇ `PREC_SHIFT=prs (0.05) [DEFECT]`

This parameter (which is a percentage) makes it possible to define an interval containing the calculated eigenvalues, for which the checking of Sturm will be carried out ([R5.01.01] algorithm  $n^2$ ). It is also used to select the lines of the table provided in the event of chaining `INFO_MODE+CALC_MODES+' BANDE'` (cf keywords `TABLE_FREQ/TABLE_CHAR_CRIT`). This option has interest only in GEP with real modes.

### 3.11 Operand `STOP_BANDE_VIDE` (only for the method of the simultaneous iterations)

◇ `STOP_BANDE_VIDE== 'NOT' [DEFECT if`  
`TYPE_RESU=' DYNAMIQUE' and OPTION=' BANDE' and FREQ comprises n>2 frequencies ]`  
`/ 'YES' [DEFECT in the`  
`other cases ]`

'YES' stop calculation if no eigenvalue is detected in the band stipulated by the user (or the sub-bands if the keyword `FREQ` is a list of  $n>2$  values): an exception (named `BandeFrequenceVide`) is emitted. It can be treated to continue the course of the study. One can find an example in the case test `SDLL11a`:

```
try:
    MODE1=CALC_MODES (MATR_RIGI=K_ASSE,
                     MATR_MASS=M_ASSE,
                     OPTION=' BANDE',
                     CALC_FREQ=_F (FREQ= (100. , 200.)))
except aster.BandeFrequenceVideError:
    MODE1=CALC_MODES (MATR_RIGI=K_ASSE,
                     MATR_MASS=M_ASSE,
                     OPTION=' BANDE',
                     CALC_FREQ=_F (FREQ= (200. , 3500. ,)))
```

10 These tests are expressed in the context of the “problem of work” provides for each sub-band the modal solver. Often this transformed problem is different from the initial problem. The good convergence of this stage thus does not ensure 100% that of the initial problem.

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'NOT' do not stop calculation (emission only of one ALARM) if no eigenvalue is detected in the band stipulated by the user.

This option does not have interest with method QZ.

### 3.12 Operand NIVEAU\_PARALLELISME

This keyword is available only in the case of clean modes of vibrations (TYPE\_RESU='DYNAMIQUE') and if calculation is carried out on a frequential tape (OPTION='BANDE') cut out in at least 2 sub-bands (FREQ is a list of nb\_freq > 2 values).

◇ NIVEAU\_PARALLELISME=/ 'COMPLETE' [DEFECT]  
/ 'PARTIAL'

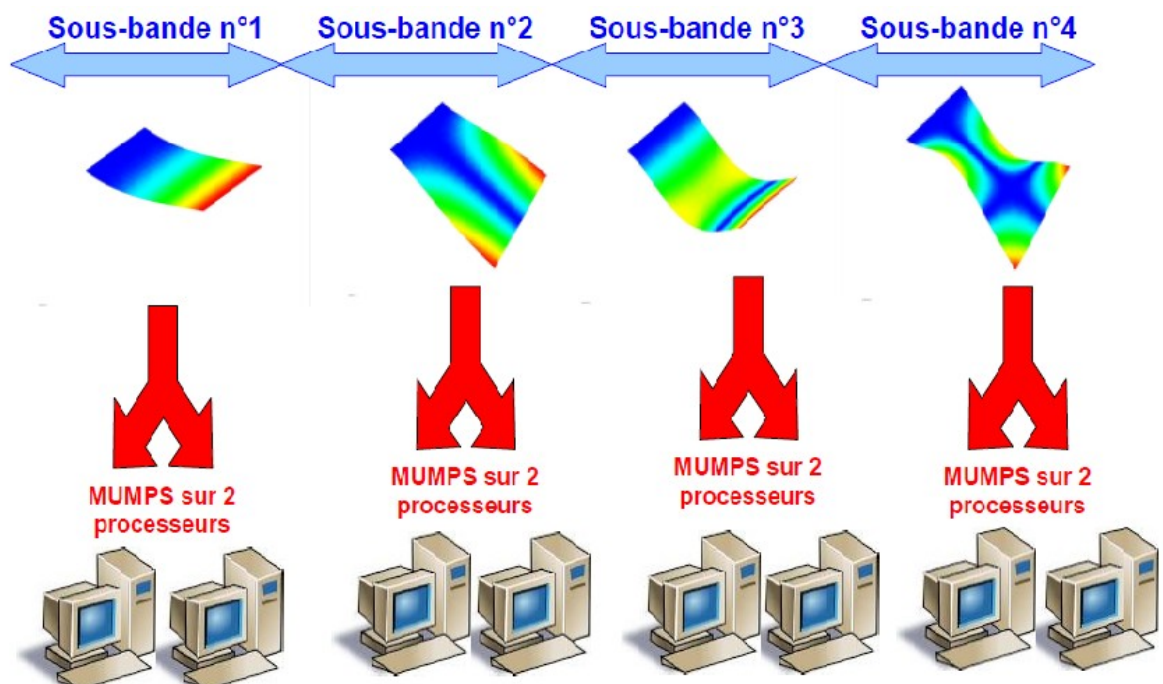
Cutting in several sub-bands is to be privileged when with problems are dealt **mean sizes or large** (> 0.5M ddls) and/or that one seeks one **good part of their spectra** (> 50 modes).

One then cuts out calculation in several frequential sub-bands (cf operand FREQ). On each one of these sub-bands, a modal solvor carries out the associated search for modes. With this intention, this modal solvor uses a linear solvor intensively.

These two bricks of calculation (modal solvor and linear solvor) are them **dimensioning stages** calculation in term of consumption memory and time. It is on them which it should be put the accent if one wants significantly to reduce the costs of calculation of this operator.

However the organization of modal calculation on distinct sub-bands offers here an ideal framework of parallelism: **distribution of large almost independent calculations**<sup>11</sup>. Its parallelism makes it possible to gain much in time but at the cost of a overcost in memory<sup>12</sup>.

If one has a sufficient number of processors (higher than the number of nonempty sub-bands), one can then engage one **second level of parallelism via the linear solvor** (if one has chooses METHODE='MUMPS'). This one will make it possible to continue to gain in time but especially, it will make it possible to compensate for the overcost report of the first level to even decrease the peak sequential report notably.



11 With t

12 Because **Image 3.12-1 - Example of distribution of calculations of CALC\_MODES on 8 processors with a cutting in 4 frequential sub-bands**

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This double level of parallelism (activated by default via the keyword `NIVEAU_PARALLELISME='COMPLET'`) then allows to benefit, at best, of the two aspects.

When one truly wishes to gain in peak report because calculation does not pass on the machine and that one test, without success, all the other arms of lever<sup>13</sup>, one can knowingly choose to limit parallelism only to the level of the linear solver<sup>14</sup>: `NIVEAU_PARALLELISME='PARTIEL'`. That functions only with linear solver parallel MUMPS.

**Functional rules** are the following ones, while noting `nbproc` the number of processors parameterized (mitre `option/mpi_nbcpu` of Astk) and `nb_sbande` the number of nonempty sub-bands (`=nb_freq-1`):

- With `NIVEAU_PARALLELISME='COMPLET'` (**defect**): very large saving of time/improvement or average deterioration of the peak RAM report.

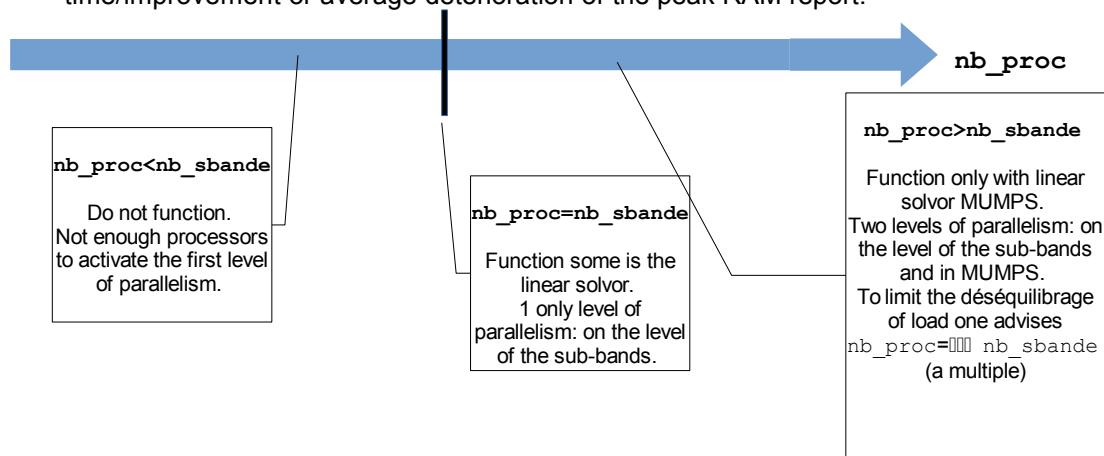


Image 3.12-2 - Perimeter of use with `NIVEAU_PARALLELISME='COMPLET'`.

- With `NIVEAU_PARALLELISME='PARTIEL'`: profit moderated in time/important profit on the peak RAM report.

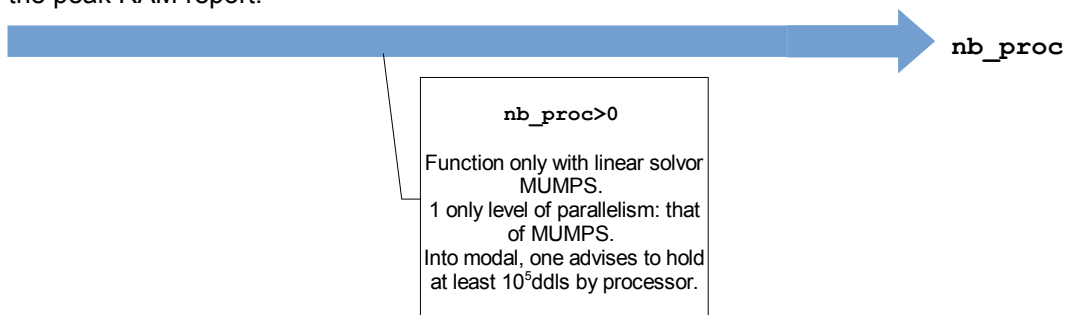


Image 3.12-3 - Perimeter of use with `NIVEAU_PARALLELISME='PARTIEL'`.

For one **optimal use** parallelism, it is thus advised of:

- To build relatively balanced sub-bands of calculation. With this intention, one can thus, as a preliminary, gauge the studied spectrum via one or more call to `INFO_MODE [U4.52.01]`. If possible in parallel mode. Then to launch calculation `CALC_MODES parallel` according to the number of selected sub-bands and amongst processors available.
- To take sub-bands finer than into sequential, between 10 and 20 modes instead of 40 to 80 modes into sequential. The quality of the modes and the robustness of calculation will be

<sup>13</sup> To cut out besides sub-bands, to use the modal solver `SORENSEN`, to reduce the size of the space of projection via `COEF_DIM_ESPACE`, to use the linear solver `MUMPS` in `OUT_OF_CORE` and/or with `MONGREL...`

<sup>14</sup> It is this kind of parallelism which is deployed in the rest of the code.

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some increased. The peak report will be decreased by it. It is however necessary to have sufficient processors available (and with enough memory).

- To select a number of processors which is a multiple amongst sub-bands (not vacuums). Thus, one reduces the déséquilibrages of loads which harm the performances.

To reduce the peak report of a calculation, one has several arms of lever: to reduce the size of the sub-bands, to use linear solver MUMPS if required (in OUT\_OF\_CORE[U4.50.01]) and/or to parallel only this brick of calculation (NIVEAU\_PARALLELISME=' PARTIEL').

To use effectively CALC\_MODES in parallel , one thus proposes to proceed in **three stages**:

- **modal Pre-calibrations** preconditions via INFO\_MODE. If possible, in parallel mode (potential Profits in time x70 on hundreds of processors. Profit in peak RAM report until x2).
- To examine the produced results and to break up calculation into sub-bands of sizes modest (e.g. 20 modes) and balanced, according to the number of processors available.
- To launch in mode CONTINUATION, calculation CALC\_MODES parallel itself.

CAS-test perf016a (N=4.0M, 50 modes) cutting in 8 sub-bands	Time elapsed	Peak RAM report
1 processor	5524s	16.9Go
8 processors	1002s	19.5Go
32 processors	643s	13.4Go
cutting in 4 sub-bands		
1 processor	3569s	17.2Go
4 processors	1121s	19.5Go
16 processors	663s	12.9Go

**Table 3.12-1 - Résultats of CALC\_MODES parallel with the parameters by default (+ SOLVEUR=MUMPS in IN\_CORE and RENUM=' QAMD') on the CAS-test PERF016A. Obtained with Code\_Aster v11.3.11 on machine IVANOE (1 or 2 processes MPI by node).**

Seismic study (N=0.7M, 450 modes) cutting in 20 sub-bands	Time elapsed	Peak RAM report
1 processor	5200s	10.5Go
20 processors	407s	12.1Go
80 processors	270s	9.4Go
cutting in 5 sub-bands		
1 processor	4660s	8.2Go
5 processors	1097s	11.8Go
20 processors	925s	9.5Go

**Table 3.12-2 - Résultats of CALC\_MODES parallel with the parameters by default (+ SOLVEUR=MUMPS in IN\_CORE and RENUM=' QAMD') on a seismic study. Obtained with Code\_Aster v11.3.11 on machine IVANOE (1 or 2 processes MPI by node).**

**Note:**

- In mode `NIVEAU_PARALLELISME=' COMPLET'`, if the number of processors is not a multiple amongst sub-bands (not vacuums), one distributes the remainder of processors by privileging the first sub-bands. A message informs the user of the potential déséquilibre of load and the sub-optimal character of calculation.
- In mode `NIVEAU_PARALLELISME=' COMPLET'`, one disabled the parallelism of elementary calculations and the assemblies which can take place in `NORM_MODE`. Their cost is marginal in any case. This desactivation temporary and is just limited to `CALC_MODES`.
- In mode `NIVEAU_PARALLELISME=' COMPLET'`, one communicates all the clean vectors exhumed in the end of `CALC_MODES`. Thus distinction<sup>15</sup> between the values `STURM=' LOCAL'` or `' GLOBAL'` any more place does not have to be functionally. It is not serious because the by default mode to be privileged is the mode `' GLOBAL'`.

For implementation the practical of parallelism, one will refer to the documents credits [U2.08.06] on parallelism, and in the paragraph dedicated of [U2.06.01] on modal calculation.

## 3.13 Keyword IMPROVEMENT

◇ `AMELIORATION=/ 'NOT' [DEFECT]`  
`/ 'YES'`

Keyword allowing to improve in an automatic way quality of the calculated modes: mainly modal deformations (what results in a reduction in the standard of error) and eigenvalues. This improvement is carried out by a chaining of two modal calculations: a first, preferably carried out by a method of the simultaneous iterations (keyword `OPTION=' BANDE'` or `' PLUS_PETITE'` or `' CENTER'` or `' TOUT'`); second is realized in a transparent way for the user, with the method of the iterations opposite (`OPTION=' PROCHE'`) with like entry eigenvalues estimated thanks to the first calculation.

Rq: the quality of the modes is generally already sufficient at the conclusion of the first calculation. This option is interesting for complicated models and/or of big size.

## 3.14 Keywords for postprocessing: `NORM_MODE`, `FILTRE_MODE`, `IMPRESSION`

These keyword are available only in the case of clean modes of vibrations (`TYPE_RESU=' DYNAMIQUE'`) and physical realities (matrices of entry of the type `matr_asse_depl_r`).

### 3.14.1 Keyword factor `NORM_MODE`

Is used to define the arguments for the standardisation of the modes. All the modes are normalized in the same way. The arguments are the same ones as for the order `NORM_MODE` [U4.52.11].

### 3.14.2 Keyword factor `FILTRE_MODE`

If it is present, this keyword is used to introduce the arguments of filtering of the modes according to a given criterion. The arguments are the same ones as for the order `EXTR_MODE` [U4.52.12].

---

15 The distinction between the two modes is just here of a data-processing nature: in the case `' TOTAL'`, the test of Sturm is brought in work to the level of the file `PYTHON` the macro one, whereas in the case `' ROOM'`, it is operated in sources `FORTTRAN` of the operator (invisible for the user) carrying out modal calculation by the method of the simultaneous iterations.

## 3.14.3 Keyword IMPRESSION

Allows to possibly display the office plurality of values of a selected modal parameter. The internal keywords have the same meaning as in the order EXTR\_MODE [U4.52.12].

The selected modal parameter can not be the same one as that which was possibly used to filter the calculated modes.

The keyword TOUT\_PARA allows to display, after possible standardisation, the value of all the modal parameters contained in the structure of data produced (frequency, masses effective,...). This posting is activated in the case of generalized modes.

## 3.15 Operand INFORMATION

◇ INFO=/1 [DEFECT]  
/2

Indicate the level of impression in the file MESSAGE.

- 1: Impression on the file 'MESSAGE' eigenvalues, of their modal position, reduced damping, standard of error *a posteriori* and certain useful parameters to follow the course of calculation.
- 2: Impression rather reserved for the developers.

**Table 3.15-1 - Operation of the keyword INFORMATION according to its value.**

## 3.16 Operand TITLE

◇ TITRE=ti  
Title attached to the concept produced by this operator [U4.03.01].

## 4 Phase of checking

---

Matrices **A**, **B** and **C**, arguments of the keyword (MATR\_A/MATR\_RIGI), (MATR\_MASS/MATR\_RIGI\_GEOM/MATR\_B) and (MATR\_AMOR), must be coherent between them (i.e. to be based on the same classification and the same mode of storage).

One checks, according to the option of selected research:

OPTION=' BANDE '

The argument of the keyword `FREQ` (case `TYPE_RESU=' DYNAMIQUE'`) must provide at least **two** values.

The argument of the keyword `CHAR_CRIT` (case `TYPE_RESU=' MODE_FLAMB'` or `'GENERAL'`) must provide exactly **two** values.

OPTION=' CENTRE '

The argument of the keyword `FREQ` or of the keyword `CHAR_CRIT` must provide exactly **one** only value.

OPTION=' SEPRE' or 'ADJUSTS'

The argument of the keyword `FREQ` or of the keyword `CHAR_CRIT` must provide at least **two** values.

If the maximum precise details and numbers of iterations are unrealistic (for example precise details lower than the precision machine or negative iteration counts), calculation is not carried out.

## 5 Production run

---

- If it is the method of the simultaneous iterations which is used (i.e if `OPTION='BANDE'` or `'CENTER'` or `'PLUS_PETITE'` or `'PLUS_GRANDE'` or `'ALL'`):  
if the keyword `DIM_SOUS_ESPACE` (under the keyword factor `SOLVEUR_MODAL`) is not informed or is initialized with a value strictly lower than the number of modes requested `nf` (operand `NMAX_FREQ` or `NMAX_CHAR_CRIT`), the operator automatically calculates an acceptable dimension for the subspace of projection *via* empirical formulas (cf §3.5.1.4):

```
METHODE='SORENSEN'  
ndim=MIN (MAX (2+nf, mse*nf), nactif) with mse=2 by default.
```

```
METHODE='TRI_DIAG'  
ndim=MIN (MAX (7+nf, mse*nf), nactif) with mse=4 by default.
```

```
METHODE='JACOBI'  
ndim=MIN (MAX (7+nf, mse*nf), nactif) with mse=2 by default.  
where nactif is the number of active degrees of freedom (i.e. the full number of degrees of freedom minus the number of degrees of freedom of LAGRANGE and less the number of linear relations which bind degrees of freedom between them, [R5.01.01] §3.2) and mse is the factor of proportionality fixed by COEF_DIM_ESPACE.
```

If a GEP is solved, the dimension of the subspace is doubled. The values of these various parameters are printed in the file `MESSAGE`.

- For the option `'SEPARATE'` : having obtained an interval determining an eigenvalue, one takes for the calculation of the mode the medium of the interval. During the calculation of the mode, the value of the eigenvalue is still refined. It is the result of the opposite iteration itself.
- For the option `'ADJUSTS'` : if the separation is not possible and that in a given interval there is more than one value of eigenvalue, one does not apply the method of adjustment with this interval. On the other hand, one will carry out during the calculation of the modes of the réorthogonalisations compared to the preceding modes contained in the interval (this makes it possible to calculate modes associated with a multiple eigenvalue).

## 6 Modal parameters Normalizes modal Position modes

---

At exit of this operator, the real or complex clean modes are standardized with largest components which is not a multiplier of `LAGRANGE`. To choose another standard, the keyword `factor` should be used `NORM_MODE` inside `CALC_MODES`, or orders it `NORM_MODE` [U4.52.11] following `CALC_MODES` (one has in this access to more features).

In the case of a dynamic calculation, the structure of data `mode_meca_*`, contains, besides the frequencies of vibration and of the associated modal deformations, of the modal parameters (generalized mass, generalized stiffness, factor of participation, effective mass). One will find the definition of these parameters in [R5.01.03].

In the case of a linear calculation of buckling, the structure of data `mode_flamb`, contains only the critical loads and the associated deformations.

In the case of a generalized dynamic calculation with symmetrical real matrices, the modal position corresponds to the position of the mode in the whole of the spectrum defined by the initial matrices. In all the other cases, the modal positions are allotted of 1 to `nf` (`nf` being the number of modes retained) by classifying them by order ascending algebraic. All the modal positions are thus positive.

## 7 Optimization of performances CPU

---

### 7.1 Parallelism of the linear solvor

Modal calculation calls upon a linear solvor. If one chooses linear solvor MUMPS with the keyword `SOLVEUR`, operand `METHODE=' MUMPS '`, one can activate his parallel operation. It is necessary for that to use a parallel version of *Code\_Aster*, and to inform the number of processors to be used in interface ASTK (mitre 'Options'). Empirically, the use of a processor per slice of  $10^5$  to  $10^6$  degrees of freedom which the model comprises, gives of good performances. In parallel, one recommends also the parameter setting `RENUM=' QAMD '`.

### 7.2 Calculation of the modes by sub-bands

If the problem to be treated is a GEP and that one searches many modes on a given tape or that the number of degrees of freedom of the model is high ( $> 10^5$ ), it is advised to cut out the band of total research in several sub-bands, from 40 to 80 modes, the most balanced possible. Calculation will be thus more robust and faster, even by calling séquentiellement one `CALC_MODES` for each sub-band.

For a better ergonomics, calculations on each sub-band can be realized in an automatic and transparent way for the user, while giving to the keyword `FREQ` a list of  $n > 2$  values. That makes it possible moreover to parallel the treatment of the various sub-bands, generating considerable profits on performances CPU (factor which can reach 10 to 20 on the computing time, and several tens of for hundred on the peak report).

For more details, one will refer to generic documentations [U2.08.06] on parallelism, and [U2.06.01] on the calculation of clean modes.

## 8 Impression of the results

---

To display the modal parameters associated with each mode and the coordinates with the modes, the operator should be used `IMPR_RESU[U4.91.01]` in the following way:

- Posting of the modal parameters only in the form of table:

```
IMPR_RESU (RESU=_F (RESULTAT=mode,  
                   TOUT_PARA= 'OUI',  
                   TOUT_CHAM= 'NON')) ;
```

- Posting of the modal parameters and the clean vectors:

```
IMPR_RESU (RESU=_F (RESULTAT=mode,  
                   TOUT_PARA= 'OUI',  
                   TOUT_CHAM= 'OUI')) ;
```

## 9 Sorting of modes/Characterization of mode\_meca\_\*

---

For example, at the time of seismic requests in modal analysis, the modal base used must contain the modes which have an important unit effective mass in the direction of the earthquake.

The keyword factor `WIRETRE_MODE` allows to extract in the structure of data of the type `mode_meca_*` modes which check a certain criterion. One can also use the order has order `EXTR_MODE[U4.52.12]` afterwards `CALC_MODES`, so for example of concaténer several structures of data of the type `mode_meca_*`.



## 10 Examples

### 10.1 Calculation of the 5 clean modes closest to a given frequency

```
mode=CALC_MODES (MATR_RIGI=rigid,  
                 MATR_MASS=masse,  
                 OPTION= 'CENTER',  
                 CALC_FREQ=_F (FREQ=100.,  
                               NMAX_FREQ=5)  
                 );
```

### 10.2 Calculation of the critical loads contained in a band

```
mode=CALC_MODES (TYPE_RESU= 'MODE_FLAMB',  
                 MATR_RIGI=rigid,  
                 MATR_RIGI_GEO=riggeo,  
                 OPTION= 'BANDE',  
                 CALC_FREQ=_F (  
                               CHAR_CRIT= (-  
1.E8,1.5E8)  
                               )  
                 );
```

### 10.3 Chaining INFO\_MODE+CALC\_MODES (extracted from SDL504a)

```
nbmod1 = INFO_MODE (TYPE_MODE=' MODE_FLAMB',  
                   ...  
                   CHAR_CRIT= (- 1.E+6, - 5.E+5,0.0, 1.E+5,1.1E+6),)  
RESULT0=CALC_MODES (TYPE_RESU=' MODE_FLAMB',  
                   ...  
                   OPTION=' BANDE',  
                   CALC_CHAR_CRIT=_F ( TABLE_CHAR_CRIT=nbmod1,  
                                       CHAR_CRIT= (- 1.E+06,1.E+05)),  
                   )
```

### 10.4 Calculation of the Eigen frequencies contained in the band [50; 150] Hz

with the method of the powers opposite

```
mode=CALC_MODES ( MATR_RIGI=rigidite,  
                 MATR_MASS=masse,  
                 OPTION=' AJUSTE',  
                 CALC_FREQ=_F ( FREQ= (50. , 150.))  
                 )
```

### 10.5 Calculation of the Eigen frequencies closest to 20 and 50 Hz

with the method of the powers opposite, acceleration of convergence by the coefficient of Rayleigh

```
mode= CALC_MODES ( MATR_RIGI=rigidite,  
                 MATR_MASS=masse,  
                 OPTION=' PROCHE',  
                 CALC_FREQ=_F (FREQ= (50. , 150.)),  
                 SOLVEUR_MODAL=_F (OPTION_INV=' RAYLEIGH')
```

)

## 10.6 Cutting in several sub-bands

That is to say the following sequence :

```
mode=CALC_MODES (
  MATR_RIGI=rigi,
  MATR_MASS=masse,
  OPTION=' BANDE',
  CALC_FREQ=_F ( FREQ= (1. , 3. , 5.),)
  VERI_MODE=_F (),

  NORM_MODE=_F (NORME=' TRAN_ROTA',),

  FILTRE_MODE=_F (CRIT_EXTR='
MASS_EFFE_UN'),

  IMPRESSION=_F (CUMUL=' OUI',
                 CRIT_EXTR=' MASS_EFFE_UN')
);
```

One wants to thus seek all the modes understood in the total band  $[1., 5.]$  Hz by cutting out it in two frequential sub-bands:  $[1., 3.]$  and  $[3., 5.]$ .

Once interpreted, the macro-order consists of the sequence of usual orders describes below.

- Stage 1: Determination amongst frequencies in each sub-bands

```
table1=INFO_MODE ( MATR_RIGI=rigi,
                  MATR_MASS=masse,
                  FREQ= (1. , 3. , 5.)
```

# Calculation amongst theoretical frequencies of the total band<sup>16</sup>: nbmodeth

# If the total band is empty: ALARM or ERREUR\_FATALE according to the value of CALC\_FREQ/STOP\_BANDE\_VIDE.

- Stage 2: Calculation and standardisation of the modes in each sub-band

# to save the costs calculation, one re-uses the table generated previously<sup>17</sup> and, by default, one locally does not make with each sub-band the test of Sturm of post-checking.

# If the local sub-band is empty: ALARM or ERREUR\_FATALE according to the value of CALC\_FREQ/STOP\_BANDE\_VIDE.

```
mode_1=CALC_MODES ( MATR_RIGI=rigi,
                   MATR_MASS=masse,
                   OPTION=' BANDE',
                   CALC_FREQ=_F ( FREQ= (1. , 3.),
                                  TABLE_FREQ=table1),)
  VERI_MODE (STURM=' NON'));

mode_1=NORM_MODE (MODE=mode_1,
                 reuse=model,
                 NORME=' TRAN_ROTA',);

mode_2=CALC_MODES ( MATR_RIGI=rigi,
                   MATR_MASS=masse,
                   OPTION=' BANDE',
                   CALC_FREQ=_F ( FREQ= (3. , 5.),
                                  TABLE_FREQ=table1),),
```

<sup>16</sup> One summons just the numbers of frequencies calculated previously and stored in table1.

<sup>17</sup> Not to remake the test of specific Sturm of pretreatment to each sub-band.

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```
VERI_MODE (STURM=' NON' ));  
mode_2=NORM_MODE (MODE=mode_2,  
reuse=mode2,  
NORME=' TRAN_ROTA', );
```

# Checking by a test of total Sturm of a good amount of calculated frequencies  
# Determination of smallest (resp. great) frequency of the first (resp. last) nonempty sub-band:  
freq\_ini (resp. freq\_fin ).  
# Calculation amongst frequencies understood in the interval: [freq\_ini, freq\_fin] : nbmodeef.

```
table2=INFO_MODE ( MATR_RIGI=rigi,  
MATR_MASS=masse,  
FREQ= (freq_ini, freq_fin))
```

# If this number of modes different amongst modes is envisaged initially: ERREUR\_FATALE .

- Stage 3: Filtering, concatenation and impression of the calculated modes.

```
mode=EXTR_MODE (FILTRE_MODE=_F (MODE=mode_1,  
CRIT_EXTR='  
MASS_EFFE_UN'),  
FILTRE_MODE=_F (MODE=mode_2,  
CRIT_EXTR='  
MASS_EFFE_UN'),  
IMPRESSION=_F (CUMUL=' OUI',  
CRIT_EXTR=' MASS_EFFE_UN'),  
);
```