SDLD301 - Spectral seismic answer of a system 2 masses and 3 springs multimedia (correlated or décorrélées excitations)

Summary:

The problem consists in calculating the spectral response of a system 2 masses - 3 springs subjected to a multiple seismic excitation. The excitations are considered either décorrélées and independent, or correlated between them.

One tests the discrete element in traction, the calculation of the clean modes, the static modes and the spectral response by modal superposition via the operator `COMB_SISM_MODAL`. Various office pluralities are tested during the calculation of the answers of supports. It is checked that, in the case of excitations equal to the supports, calculation in mono-support and calculation in correlated multi-support provide the same result.

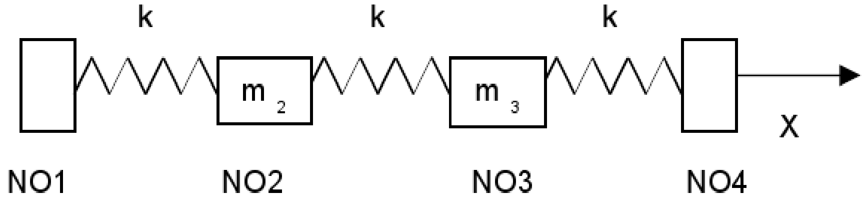
One also checks the good performance of the entry of damping in the form of matrix of damping (modeling C).

The got results are in very good agreement with the analytical results of reference.

1 Problem of reference

1.1 Geometry

The structure is modelled by a set of 3 springs and of 2 specific masses.



1.2 Properties of material

- Stiffness of connection: $k_1 = k_3 = k = 100000\ N/m$; $k_2 = 2k = 200000\, N/m$
- Specific mass: $m_2 = m_3 = m = 2533\, kg$.

1.3 Boundary conditions and loadings

- **boundary conditions**
  Only authorized displacements are the translations according to the axis x .
  Points $NO1$ and $NO4$ are embedded:
  $DX = DY = DZ = DRX = DRY = DRZ = 0$.
  The other points are free in translation according to the direction x :
  $DY = DZ = DRX = DRY = DRZ = 0$.

- **loading**
  Modeling A : the structure is subjected to a multiple spectral seismic excitation décorrélée.
  The spectra of answers of oscillator in pseudo-acceleration are defined by:
  - with the node $NO1$: $SRO_{NO1} = \dfrac{a_1 \omega^2}{|\omega_1^2 - \omega^2|}$
  - with the node $NO4$: $SRO_{NO4} = \dfrac{a_2 \omega^2}{|\omega_2^2 - \omega^2|}$

  with $\omega_1 = 2\pi f_1$ $\omega_2 = 2\pi f_2$
  $f_1 = 1.5\, Hz$, $f_2 = 2.\, Hz$, $a_1 = a_2 = 0.5\, ms^{-2}$
  They do not depend on damping.

  Modeling B : the structure is subjected to a seismic excitation identical to the two supports.
  The spectrum of answer of oscillator in pseudo-acceleration is defined by:
  - with the node $NO1$ and with the node $NO4$: $SRO = \dfrac{a_1 \omega^2}{|\omega_1^2 - \omega^2|}$

  with $\omega_1 = 2\pi f_1$
  $f_1 = 1.5\, Hz$, $a_1 = 0.5\, ms^{-2}$
  It does not depend on damping.

1.4 Initial conditions

The system is initially at rest

2 Reference solution

2.1 Method of calculating used for the reference solution

One calculates the spectral response by modal superposition of a system mass-springs subjected to two distinct excitations. One determines the displacement of the masses and the reactions of support to the nodes $NO1$ and $NO4$ along the axis x .

One calculates analytically:

- Eigen frequencies f_i ,
- associated clean vectors ϕ_{Ni} standardized compared to the modal mass,
- static modes of supports ψ_j system,
- factors of modal participation P_{ij} relating to the supports,
- Rm_{ij} the maximum of answer of each mode starting from the spectra of excitation,
- Rc_j the static term of correction.

These analytical calculations are described in the file Matlab sdld301.55.

2.2 Reference variable

- **matrix of rigidity** K

$$K=\begin{bmatrix} k & -k & 0 & 0 \\ -k & 3\mathrm{k} & -2\mathrm{k} & 0 \\ 0 & -2\mathrm{k} & 3\mathrm{k} & -k \\ 0 & 0 & -k & k \end{bmatrix}$$

$$K^p=\begin{bmatrix} 3\mathrm{k} & -2\mathrm{k} & -k & 0 \\ -2\mathrm{k} & 3\mathrm{k} & 0 & -k \\ -k & 0 & k & 0 \\ 0 & -k & 0 & k \end{bmatrix}$$

partitionnée matrix degrees of freedom of structure $2,3$, degrees of freedom of support $1,4$

$$K^p=\begin{bmatrix} k_{xx} & k_{xs} \\ k_{sx} & k_{ss} \end{bmatrix} \quad K_{xx}=\begin{bmatrix} 3\mathrm{k} & -2\mathrm{k} \\ -2\mathrm{k} & 3\mathrm{k} \end{bmatrix} \qquad K_{xs}=\begin{bmatrix} -k & 0 \\ 0 & -k \end{bmatrix}$$

- **matrix of mass** M

$$M=\begin{bmatrix}0&0&0&0\\0&m&0&0\\0&0&m&0\\0&0&0&0\end{bmatrix}$$

$$M^p=\begin{bmatrix}m&0&0&0\\0&m&0&0\\0&0&0&0\\0&0&0&0\end{bmatrix}$$

partitionnée matrix degrees of freedom of structure $2,3$, degrees of freedom of support $1,4$

- **modal calculation in embedded base**

$$K_{xx}=\begin{bmatrix}3\mathrm{k}&-2\mathrm{k}\\-2\mathrm{k}&3\mathrm{k}\end{bmatrix} \qquad m_{xx}=\begin{bmatrix}m&0\\0&m\end{bmatrix}$$

$$(k_{xx}-\lambda_i m_{xx})\phi_i=0 \qquad \lambda_i=\omega_{pi}^2$$

$$\lambda_1=\frac{k}{m} \quad \lambda_2=\frac{5\mathrm{k}}{m}$$

- Eigen frequencies:

$$\Rightarrow \quad freq_1=\frac{\omega_{p1}}{2\pi}\,;\,freq_2=\frac{\omega_{p2}}{2\pi}$$

- not normalized clean modes:

- $$\phi_1=\begin{pmatrix}0\\1\\1\\0\end{pmatrix} \quad \phi_2=\begin{pmatrix}0\\1\\-1\\0\end{pmatrix}$$

- generalized modal masses : $\mu_i={}^T\phi_i M \phi_i$

- $\mu_1=2\mathrm{m} \quad \mu_2=2\mathrm{m}$

- own standards modes with the unit generalized modal mass ϕ_{Ni} :

$$\Rightarrow \quad \phi_{N1}=\frac{\phi_1}{\sqrt{\mu_1}} \quad \phi_{N2}=\frac{\phi_2}{\sqrt{\mu_2}}$$

- modal reactions Fm_i :

$$\Rightarrow \quad Fm_1 = K\,\phi_{N1} = \frac{k}{\sqrt{2m}}\begin{pmatrix}1\\5\\-5\\1\end{pmatrix} \quad Fm_2 = K\,\phi_{N2} = \frac{k}{\sqrt{2m}}\begin{pmatrix}1\\1\\1\\-1\end{pmatrix}$$

- **static modes of supports** Ψ_j

  Matrix of the static modes reduced to the degrees of freedom of structure $\varphi_s = -k_{xx}^{-1}\,k_{xs}$

  $$\varphi_s = -\frac{1}{5k}\begin{bmatrix}3 & 2\\2 & 3\end{bmatrix}\begin{bmatrix}-k & 0\\0 & -k\end{bmatrix} = \frac{1}{5}\begin{bmatrix}3 & 2\\2 & 3\end{bmatrix}$$

- static solution with a unit displacement of the node $NO1$:

  displacements: $\psi_1 = \frac{1}{5}\begin{pmatrix}5\\3\\2\\0\end{pmatrix}$ nodal reactions: $Fs_1 = K\,\psi_1 = \frac{k}{5}\begin{pmatrix}-8\\0\\0\\-2\end{pmatrix}$

- static solution with a unit displacement of the node $NO4$:

  displacements: $\psi_2 = \frac{1}{5}\begin{pmatrix}0\\2\\3\\5\end{pmatrix}$ nodal reactions: $Fs_2 = K\,\psi_2 = \frac{k}{5}\begin{pmatrix}-2\\0\\0\\-3\end{pmatrix}$

- factors of modal participation in multi-support : $P_{ij} = {}^T\phi_i\,M\,\psi_j$

  - contribution of the dynamic mode 1 with the movement imposed on the node $NO1$:

    $$P_{11} = {}^T\phi_{N1}\,M\,\psi_1 = \frac{1}{5}\sqrt{\frac{m}{2}}$$

  - contribution of the dynamic mode 1 with the movement imposed on the node $NO4$:

    $$P_{12} = {}^T\phi_{N1}\,M\,\psi_2 = \frac{-1}{5}\sqrt{\frac{m}{2}}$$

  - contribution of the dynamic mode 2 with the movement imposed on the node $NO1$:

    $$P_{21} = {}^T\phi_{N2}\,M\,\psi_1 = \sqrt{\frac{m}{2}}$$

  - contribution of the dynamic mode 2 with the movement imposed on the node $NO4$:

    $$P_{22} = {}^T\phi_{N2}\,M\,\psi_2 = \sqrt{\frac{m}{2}}$$

  - factor of participation of the dynamic mode 1 in the direction X:

    $$P_{1X} = P_{11} + P_{12}$$

  - factor of participation of the dynamic mode 2 in the direction X:

    $$P_{2X} = P_{21} + P_{22}$$

- factors of modal participation in mono-support $P_i=\frac{\phi_{\mathrm{Ni}} M \psi_{R1}}{\mu_i}$
- contribution of the dynamic mode 1 :

$$P_1={}^T\phi_{N1} M \psi_{R1}=\phi_{N1} M(\psi_{s1}+\psi_{s2})=P_{11}+P_{12}$$

- contribution of the dynamic mode 2 :

$$P_2={}^T\phi_{N2} M \psi_{R1}=\phi_{N2} M(\psi_{s1}+\psi_{s2})=P_{21}+P_{22}$$

- factor of participation of the dynamic mode 1 in the direction X :

$$P_{1X}=P_1+P_2$$

- **answer of the mode i with the movement of the support j in multi-support**

$$Rm_{ij}=r_i P_{ij}\frac{A_{ij}}{\omega_i^2} \text{ with } r_i=\phi_{\mathrm{Ni}}\, ou\, Fm_i$$

Modeling A :

$$A_{11}=\frac{a_1\, freq_1^2}{|f_1^2-freq_1^2|} \text{ : mode } 1 \text{, Nœud } 1$$

$$A_{12}=\frac{a_2\, freq_1^2}{|f_2^2-freq_1^2|} \text{ : mode } 1 \text{, Nœud } 2$$

$$A_{21}=\frac{a_1\, freq_2^2}{|f_1^2-freq_2^2|} \text{ : mode } 2 \text{, Nœud } 1$$

$$A_{22}=\frac{a_2\, freq_2^2}{|f_2^2-freq_2^2|} \text{ : mode } 2 \text{, Nœud } 2$$

Modeling B :

$$A_{11}=A_{12}=\frac{a_1\, freq_1^2}{|f_1^2-freq_1^2|} \text{ : mode } 1 \qquad A_{21}=A_{22}=\frac{a_1\, freq_2^2}{|f_1^2-freq_2^2|} \text{ : mode } 2$$

- **answer of the mode i in mono-support**

$$Rm_i=r_i P_i\frac{A_i}{\omega_i^2} \text{ with } r_i=\phi_{\mathrm{Ni}}\, ou\, Fm_i$$

Combined answers of the modal oscillators

Answer of the mode 1 : $Rm_1=\phi_{N1} P_1\frac{A_1}{\omega_1^2}=Rm_{11}+Rm_{12}$

Answer of the mode 2 : $Rm_2=\phi_{N2} P_2\frac{A_2}{\omega_2^2}=Rm_{21}+Rm_{22}$

- **static correction**
- static modes u_j solution of $k_{xs} u_{sj}=m_{xs}\phi_{sj}$:

modes ψ reduced to the degrees of freedom of structure: $\Psi_{S1}=\frac{1}{5}\begin{pmatrix}3\\2\end{pmatrix}$ $\Psi_{S2}=\frac{1}{5}\begin{pmatrix}2\\3\end{pmatrix}$

displacements: $u_1=\frac{m}{25k}\begin{pmatrix}0\\13\\12\\0\end{pmatrix}$ nodal reactions: $Fu_1=\frac{m}{25}\begin{pmatrix}-13\\3\\10\\-1\end{pmatrix}$

displacements: $u_2=\frac{m}{25k}\begin{pmatrix}0\\12\\13\\0\end{pmatrix}$ nodal reactions: $Fu_2=\frac{m}{25}\begin{pmatrix}-13\\3\\10\\-12\end{pmatrix}$

2.3 Uncertainty on the solution

No (exact analytical solution).

3 Modeling A

3.1 Characteristics of modeling

The system is modelled by:

- 3 discrete elements K_T_D_L,
- 2 discrete elements M_T_D_N.

3.2 Characteristics of the grid

The grid consists of 3 meshs SEG2.

3.3 Sizes tested and results

3.3.1 Eigen frequencies

MODE	Reference	Tolerance (%)
1	1.000E+00	0.1
2	2.236E+00	0.1

3.3.2 Static modes for the training

Mode 1 : absolute displacements *DEPL*

NODE	Reference	Tolerance (%)
NO2	0.4E+00	0.1
NO3	0.6E+00	0.1

Mode 2 : absolute displacements *DEPL*

NODE	Reference	Tolerance (%)
NO2	0.4E+00	0.1
NO3	0.6E+00	0.1

3.3.3 Static modes for the static correction

Mode 1 : absolute displacements *DEPL*

NODE	Reference	Tolerance (%)
NO2	1.317E−02	0.1
NO3	1.216E−02	0.1

Mode 2 : absolute displacements *DEPL*

NODE	Reference	Tolerance (%)
NO2	1.216E−02	0.1
NO3	1.317E−02	0.1

3.3.4 Total answer on modal basis supplements (calculation décorrélé multi-support)

Modes 1 and 2 are taken into account.

- **calculation** $n°1$

```
COMB_MODE=' SRSS'
```

For each active degree of freedom 2 and 3 :

- answer of the support $j=1$ (node $NO1$) : $R_1=\sqrt{Rm_{11}^2+Rm_{21}^2}$ (office plurality on the modes 1 and 2)
- answer support $j=2$ (node $NO4$) : $R_2=\sqrt{Rm_{12}^2+Rm_{22}^2}$ (office plurality on the modes 1 and 2)
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the supports)

absolute displacements: $DEPL$

NODE	**Reference**	**Tolerance** $(\%)$
$NO2$	$5.65E-03$	0.1
$NO3$	$5.65E-03$	0.1

- **calculation** $n°2$

```
COMB_MODE=' ABS'
```

- answer of the support $j=1$ (node $NO1$) : $R_1=|Rm_{11}|+|Rm_{21}|$ (office plurality on the modes 1 and 2)
- answer of the support $j=2$ (node $NO4$) : $R_2=|Rm_{12}|+|Rm_{22}|$ (office plurality on the modes 1 and 2)
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the supports)

absolute displacements: $DEPL$

NODE	**Reference**	**Tolerance** $(\%)$
$NO2$	$6.476E-03$	0.1
$NO3$	$6.476E-03$	0.1

- **calculation** $n°3$

```
COMB_MODE=' DPC'
```

- answer of the support $j=1$ (node $NO1$) : $R_1=\sqrt{Rm_{11}^2+Rm_{21}^2}$ (office plurality on the modes 1 and 2)
- answer of the support $j=2$ (node $NO4$) : $R_2=\sqrt{Rm_{12}^2+Rm_{22}^2}$ (office plurality on the modes 1 and 2)
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the supports)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
$NO2$	$5.65\text{E}-03$	0.1
$NO3$	$5.65\text{E}-03$	0.1

- **calculation** $n°4$

  `COMB_MODE=' CQC'`

  modal depreciation = 0.05

- answer of the support $j=1$ (node $NO1$) : $R_1=\sqrt{\rho_{12} Rm_{11} Rm_{21}}$ (office plurality on the modes 1 and 2)
- answer of the support $j=2$ (node $NO4$) : $R_2=\sqrt{\rho_{12} Rm_{12} Rm_{22}}$ (office plurality on the modes 1 and 2)
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the supports)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
$NO2$	$5.65\text{E}-03$	0.1
$NO3$	$5.65157\text{E}-03$	0.1

- **calculation** $n°5$

  `COMB_MODE=' DSC'`

  modal depreciation = 0.05
  duration: 15 S

- answer of the support $j=1$ (node $NO1$) : $R_1=\sqrt{\rho_{12} Rm_{11} Rm_{21}}$ (office plurality on the modes 1 and 2)
- answer of the support $j=2$ (node $NO4$) : $R_2=\sqrt{\rho_{12} Rm_{12} Rm_{22}}$ (office plurality on the modes 1 and 2)
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the supports)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
$NO2$	$5.649\text{E}-03$	0.1
$NO3$	$5.6521\text{E}-03$	0.1

4 Modeling B

4.1 Characteristics of modeling B

The system is modelled by:

- 3 discrete elements `K_T_D_L`,
- 2 discrete elements `M_T_D_N`.

4.2 Characteristics of the grid

The grid consists of 3 meshs `SEG2`.

4.3 Sizes tested and results

4.3.1 Eigen frequencies

MODE	Reference	*Tolerance* (%)
1	1.000E+00	0.1
2	2.236E+00	0.1

4.3.2 Static modes for the training

Mode 1 : absolute displacements $DEPL$

NODE	Reference	*Tolerance* (%)
NO2	0.6E+00	0.1
NO3	0.4E+00	0.1

Mode 2 : absolute displacements $DEPL$

NODE	Reference	*Tolerance* (%)
NO2	0.6E+00	0.1
NO3	0.4E+00	0.1

4.3.3 Static modes for the static correction

Mode 1 : absolute displacements $DEPL$

NODE	Reference	*Tolerance* (%)
NO2	1.317E−02	0.1
NO3	1.216E−02	0.1

Mode 2 : absolute displacements $DEPL$

NODE	Reference	*Tolerance* (%)
NO2	1.216E−02	0.1
NO3	1.317E−02	0.1

4.3.4 Total answer on complete modal basis

4.3.4.1 Calculation mono-support

Modes 1 and 2 are taken into account.

- **calculation** $n°1$

`COMB_MODE=' SRSS'`

For each ddl credit 2 and 3 :

- answer of the mode 1 : $R_1=Rm_{11}+Rm_{12}$
- answer of the mode 2 : $R_2=Rm_{21}+Rm_{22}$
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the modes)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
NO2	1.01321E−02	0.1
NO3	1.01321E−02	0.1

- **calculation** $n°2$

`COMB_MODE=' ABS'`

- answer of the mode 1 : $R_1=Rm_{11}+Rm_{12}$
- answer of the mode 2 : $R_2=Rm_{21}+Rm_{22}$ R
- total answer: $R=|R_1|+|R_2|$ (office plurality on the modes)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
NO2	0.01013	0.1
NO3	0.01013	0.1

- **calculation** $n°3$

`COMB_MODE=' DPC'`

- answer of the mode 1 : $R_1=Rm_{11}+Rm_{12}$
- answer of the mode 2 : $R_2=Rm_{21}+Rm_{22}$
- total answer: $R=\sqrt{R_1^2+R_2^2}$ (office plurality on the modes)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
NO2	0.01013	0.1
NO3	0.01013	0.1

- **calculation** $n°4$

`COMB_MODE=' CQC'`

modal depreciation = 0.05

- answer of the mode 1 : $R_1 = Rm_{11} + Rm_{12}$
- answer of the mode 2 : $R_2 = Rm_{21} + Rm_{22}$
- total answer: $R = \sqrt{\rho_{12} R_1 R_2}$ (office plurality on the modes)

absolute displacements: $DEPL$

NODE	Reference	Tolerance $(\%)$
$NO2$	0.01013	0.1
$NO3$	0.01013	0.1

- **calculation** $n°5$

`COMB_MODE=' DSC'`

modal depreciation = 0.05
duration: 15 seconds

- answer of the mode 1 : $R_1 = Rm_{11} + Rm_{12}$
- answer of the mode 2 : $R_2 = Rm_{21} + Rm_{22}$
- total answer: $R = \sqrt{\rho_{12} R_1 R_2}$ (office plurality on the modes)

absolute displacements: $DEPL$

NODE	Reference	Tolerance $(\%)$
$NO2$	0.01013	0.1
$NO3$	0.01013	0.1

4.3.4.2 Calculation correlated multi-support

- **calculation** $n°6$

`COMB_MODE=' SRSS'`

For each active degree of freedom 2 and 3 :

- answer of the mode 1 : $R_1 = Rm_{11} + Rm_{12}$ (office plurality on the supports)
- answer of the mode 2 : $R_2 = Rm_{21} + Rm_{22}$ (office plurality on the supports)
- total answer: $R = \sqrt{R_1^2 + R_2^2}$ (office plurality on the modes)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
$NO2$	$1.01321\text{E}-02$	0.1
$NO3$	$1.01321\text{E}-02$	0.1

4.3.5 Total answer on incomplete modal basis (calculation mono-support with static correction)

Only base modal made up of mode 2.

- **calculation** $n°7$

```
COMB_MODE=' ABS'
```

For each active degree of freedom 2 and 3 :

- answer of the mode $i=2$ (node $NO4$) : $R_2=Rm_{21}+Rm_{22}$ (office plurality on the supports 1 and 2)
- total answer: $R=\sqrt{R_2^2+U^2}$ (office plurality modal answer and static correction)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance*
$NO2$	0.02302302705	0.001
$NO3$	0.02302302705	0.001

- **calculation** $n°8$

```
COMB_MODE=' SRSS'
```

For each active degree of freedom 2 and 3 :

- answer of the mode $i=2$ (node $NO4$) : $R_2=Rm_{21}+Rm_{22}$ (office plurality on the supports 1 and 2)
- total answer: $R=\sqrt{R_2^2+U^2}$ (office plurality modal answer and static correction)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance*
$NO2$	0.02302302705	0.001
$NO3$	0.02302302705	0.001

- **calculation** $n°9$

```
COMB_MODE=' DPC'
```

For each active degree of freedom 2 and 3 :

- answer of the mode $i=2$ (node $NO4$) : $R_2=Rm_{21}+Rm_{22}$ (office plurality on the supports 1 and 2)
- total answer: $R=\sqrt{R_2^2+U^2}$ (office plurality modal answer and static correction)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance*
$NO2$	0.02302302705	0.001
$NO3$	0.02302302705	0.001

- **calculation** $n°10$

```
COMB_MODE=' CQC'
```

modal depreciation = 0.05

For each active degree of freedom 2 and 3 :

- answer of the mode $i=2$ (node $NO4$) : $R_2=Rm_{21}+Rm_{22}$ (office plurality on the supports 1 and 2)
- answer total: $R=\sqrt{R_2^2+U^2}$ (office plurality modal answer and static correction)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance*
$NO2$	0.02302302705	0.001
$NO3$	0.02302302705	0.001

- **calculation** $n°11$

```
COMB_MODE=' DSC'
```

For each active degree of freedom 2 and 3 :

- answer of the mode $i=2$ (node $NO4$) : $R_2=Rm_{21}+Rm_{22}$ (office plurality on the supports 1 and 2)
- total answer: $R=\sqrt{R_2^2+U^2}$ (office plurality modal answer and static correction)

absolute displacements: $DEPL$

NODE	Reference	*Tolerance*
$NO2$	0.02302302705	0.001
$NO3$	0.02302302705	0.001

5 Modeling C

Modeling C is purely functional: it is used to validate the entry of damping in the form of a diagonal matrix of damping.
It is taken again calculation $n°4$ modeling A (calculation multi-support décorrélé by the method 'CQC').
The values of reference are obviously the same ones:

absolute displacements: $DEPL$

NODE	Reference	*Tolerance* $(\%)$
$NO2$	5.65E−03	0.0001
$NO3$	5.65157E−0	0.0001

Note:
This test was selected because it has clear values of reference and that the system is characterized by two clean modes. One can thus perfectly determine the matrix of damping of Rayleigh starting from reduced damping ξ of the two clean modes and their own pulsations (ω_1 and ω_2):

$$C=\alpha K+\beta M \text{ with } \alpha=\frac{2\xi}{\omega_1+\omega_2} \text{ and } \beta=\frac{2\xi\omega_1\omega_2}{\omega_1+\omega_2}$$

Before the projection of the structural matrices (and damping stamps it in particular) one took care to specify (in generalized classification) that the matrices were diagonal. It is necessary to remain within the framework of the classical damping to which COMB_SISM_MODAL is restricted.

6 Summary of the results

Results got with *Code_Aster* are in conformity with the analytical results of reference.