SDLL119 - Beam of beams under axial excitation fluid-rubber band

Summary

One considers a beam with square step of 3×3 aluminium tubes, placed in an enclosure rectangular and subjected to the action of an axial water flow. The tubes contain lead pastilles and are maintained between them with middle height by piano wires. This hardware configuration corresponds to the experimental device of Hotta and al. [bib1] which is used to measure the evolutions of frequency and reduced damping of the first mode of inflection of the beam, according to the mean velocity of the flow.

The goal of this CAS-test is to validate the resorption of the model `MEFISTEAU` [R4.07.04] allowing to calculate the modal characteristics of a beam of beams under confined axial flow, by taking account of an excitation of the fluid-rubber band type.

The features to be tested are the following ones:

- operator `DEFI_FLUI_STRU` [U4.80.08]: definition of the parameters for the taking into account of the coupling fluid-rubber band, in the case of a configuration of standard “the tube bundle under axial flow” (keyword factor `FAISCEAU_AXIAL`),
- operator `CALC_FLUI_STRU` [U4.80.03]: calculation of the evolutions of the frequencies and modal reduced depreciation according to the mean velocity of the flow, by the implementation of the model `MEFISTEAU`.

These features must be tested with the complete representation of the beam and a simplified representation.

The digital results of the simulation of the device of Hotta and al. are validated by comparison with the experimental results. Taking into account relatively important uncertainties on the experimental values, the results of reference for nonthe regression of *Code_Aster* are those obtained numerically during the restitution of the CAS-test.

1 Problem of reference

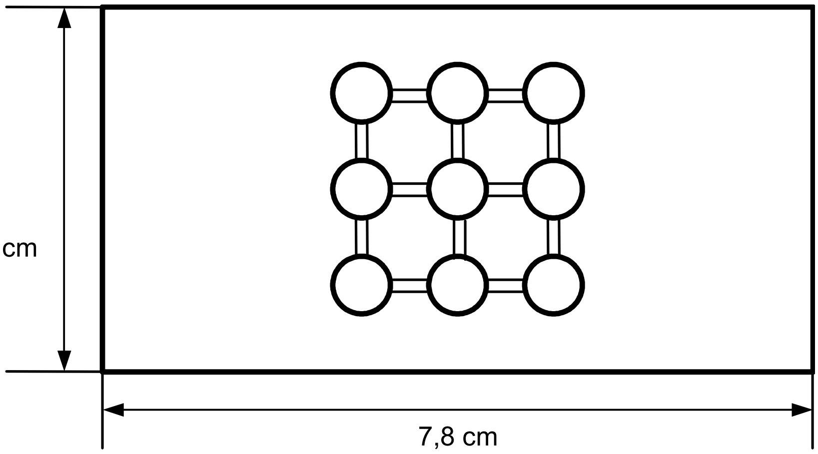
1.1 Geometry

The tubes of the beam are hollow rolls whose characteristic dimensions are the following ones:

length	$L=1{,}2\,m$
external diameter	$\phi_{\mathrm{ext}}=9{,}5\,mm$
internal diameter	$\phi_{\mathrm{int}}=8{,}5\,mm$

The piano wires maintaining the tubes between them with middle height are comparable to cylinders full with $2\ mm$ of diameter.

The beam is with square step of $12{,}6\ mm$. It is composed of 3×3 tubes and is placed in the center of a rectangular enclosure of dimensions $7{,}8\ cm\times 4{,}2\ cm$.



The surface roughness of the tubes is worth $\varepsilon=10^{-5}m$.

1.2 Properties of materials

The physical characteristics of aluminium constituting the tubes are the following ones:

Young modulus	$E_{alu}=6{,}89.10^{10}Pa$
Poisson's ratio	$\nu_{alu}=0{,}3$

The tubes containing of the lead pastilles, one must define an equivalent density brought back to their section: $\rho_{eq}=20450\,kg/m^3$

The cords maintaining the tubes between them with middle height are out of steel, whose physical characteristics are the following ones:

Young modulus	$E_{acier}=2{,}1.10^{11}Pa$
Poisson's ratio	$\nu_{acier}=0{,}3$
density	$\rho_{acier}=7800\,kg/m^3$

Surrounding water has the following properties:

density	$\rho_{eau}=1000\,kg/m^3$
kinematic viscosity	$\nu_{eau}=1{,}1.10^{-6}m^2/s$

1.3 Boundary conditions and loadings

The ends of each tube are connected to fixed supports by metal stems. The relative flexibility of inflection of these stems releases the degrees of freedom (DDL) of rotation of the ends of each tube. One can thus estimate that the tubes are kneecap-kneecaps, the metal stems introducing in each end an additional stiffness of rotation.

Moreover, these stems make it possible to apply an axial load to the tubes, which can thus be prestressed in traction or compression. The studied configuration corresponds to the tube bundle prestressed in compression by application of an axial load of $50\ N$ in each higher end of the tubes.

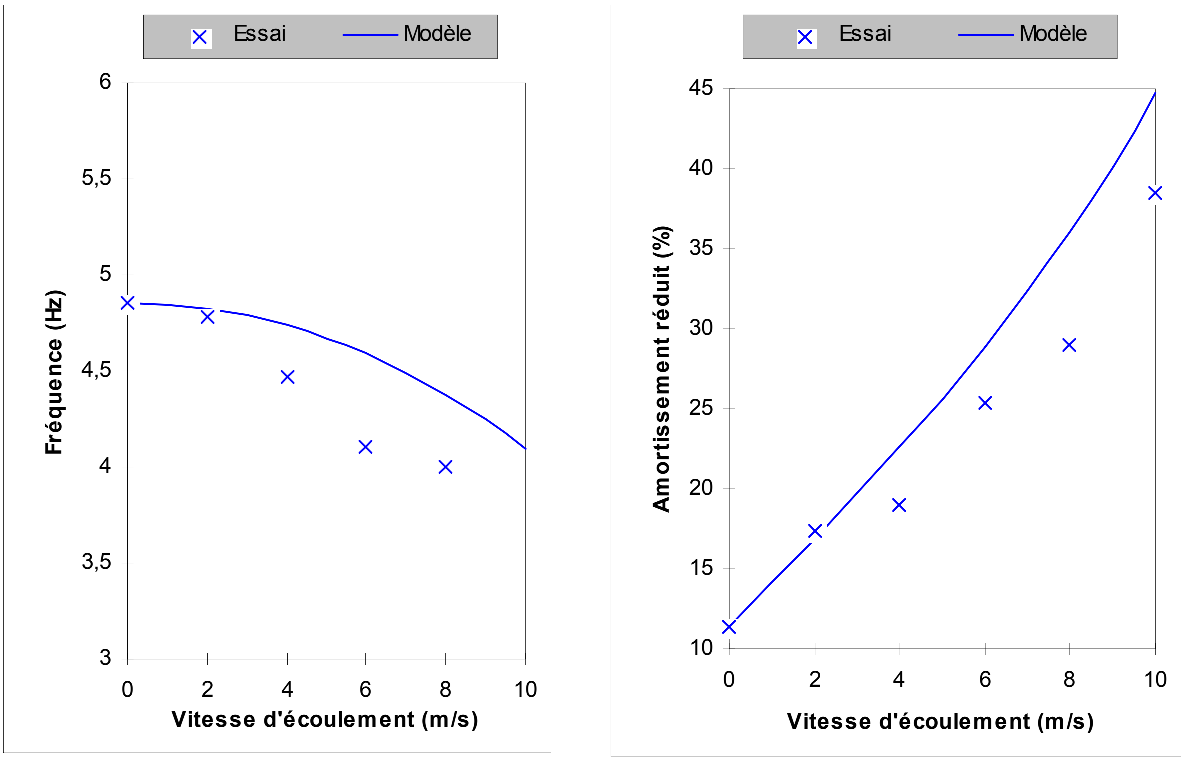
1.4 Bibliographical references

1.A. HOTTA, H. NIIBORI, Mr. TANAKA and K. FUJITA: “Parametric study one parallel flow - induced damping of PWR fuel assembly”, ASME Conference, Nashville, TN, PVP Vol.191 (1990)

2 Reference solution

The experimental mesures taken on the device of Hotta and al. constitute the values of reference for the validation of the model. The studied vibratory characteristics are those of the first vibrating mode following the largest side of the enclosure.

The two graphs below represent the evolutions of the frequency and the damping reduced according to the mean velocity of the flow, for the first mode of inflection of the beam becoming deformed according to the largest side of the enclosure. The modes of inflection of the beam are double modes in air; the dissymmetry of the coupling fluid-structure separates them under flow and directs them according to the sides of the enclosure. These graphs allow the comparison between the results of the model and experimental measurements.



Taking into account uncertainties to the measures, the tolerance of relative variation for the validation of the model is rather broad. This is why experimental measurements cannot be used as values of reference for the CAS-test, a more narrow tolerance being necessary to guarantee to it not regression of the code. The values of reference used are thus those obtained numerically during the restitution of the case - test.

3 Modeling A

3.1 Characteristics of modeling

Each tube of the beam is represented by 50 elements of right beam of Timoshenko (`MECA_POU_D_T`), supported per as many meshs of the type `SEG2` (segments with 2 nodes).
An element `MECA_DIS_TR` is added in each node end; these elements make it possible to model the metal stems by discrete stiffnesses of rotation.

One assigns to the elements of the tubes the characteristics of circular section:

external ray $R_{ext}=4{,}75.10^{-3}m$

thickness $e=5.10^{-4}m$ (cf paragraph [§1.1])

One also assigns to these elements a material of behavior `ELAS` :

Young modulus $E=6{,}89.10^{10}Pa$

Poisson's ratio $\nu=0{,}3$

density $\rho=20450\,kg/m^3$ (cf paragraph [§1.2])

One assigns to the discrete elements the same stiffness of rotation around the two orthogonal axes with the directing axis of the beam:

$$K_r=6{,}29\,N.m/rad$$

This stiffness of rotation was adjusted in order to correctly find the value of frequency of the first double mode of inflection in air of the beam.

Each piano wire is represented by an element `MECA_POU_D_T`. One assigns to these elements the characteristic of a full circular section $R=10^{-3}m$ (cf paragraph [§1.1]) and a material of behavior `ELAS` :

Young modulus $E=2{,}1.10^{11}Pa$

Poisson's ratio $\nu=0{,}3$

density $\rho=7800\,kg/m^3$ (cf paragraph [§1.2])

Degrees of freedom of translation in y and z (DY and DZ) nodes at the ends of each tube are blocked. In order to prohibit a rigid movement of body (axial translatory movement), the degrees of freedom are also blocked DX nodes at the lower ends of each tube. Lastly, in each node, one blocks the degree of freedom of rotation DRX to prohibit any movement of torsion.

An axial load of compression of $26{,}7\ N$ of each node is applied at the higher ends of the tubes. The intensity of the effort was thus readjusted in order to correctly find the value of the frequency of the first double mode of inflection in air of the beam. This readjustment can be explained by modeling summary of the metal stems ensuring the self-supporting quality and the setting in compression.

One deduces from the nodal efforts the elementary vectors of effort, then an assembled vector which is built according to the classification of the degrees of freedom of the complete structure. The static deformation due to the setting in compression of the tubes is then obtained by multiplying the vector assembled by the reverse of the matrix of structural rigidity. Using this static deformation, one calculates then a stress field to the elements, whose is deduced a geometrical matrix of rigidity. This one is then added to the matrix of structural rigidity in order to obtain the matrix of rigidity after the setting in compression of the tubes, which is finally used for the calculation of the modes in air.

The beam is immersed in a rectangular enclosure of dimensions $7{,}8\ cm \times 4{,}2\ cm$ (cf paragraph [§2.1]). The profiles of density and kinematic viscosity of surrounding water are constant along the tubes:

density $\rho_{eau} = 1000\,kg/m^3$
kinematic viscosity $\nu_{eau} = 1{,}1.10^{-6}\,m^2/s$ (cf paragraph [§1.2])

The evolutions of the frequency and the reduced damping of the first two modes of inflection of the beam are calculated for mean velocities of flow varying from 0 with $10\ m/s$ by step of $1\ m/s$. One takes account of an initial reduced damping of 12.3 %.

3.2 Characteristics of the grid

The full number of nodes used for this grid is of 459.
The meshs are 470 and of type `SEG2`.
The file of grid is with the format `ASTER`.

3.3 Stages of calculation

The features which one wishes to validate are those of the operators of coupling fluid-structure, for configurations of standard “the tube bundle under axial flow”.
Initially, one defines the parameters of taking into account of the coupling fluid-rubber band, with the operator `DEFI_FLUI_STRU` keyword factor `FAISCEAU_AXIAL`.
Then, one carries out the calculation of the evolutions of the frequencies and modal reduced depreciation according to the mean velocity of the flow, with the operator `CALC_FLUI_STRU` and by the implementation of the model `MEFISTEAU`.

Modeling A makes it possible to test these features with the complete representation of the beam. Besides the operators of coupling fluid-structure, other modules of resolution and mechanical calculation are used.
In our case, one calculates the field of displacements to the nodes by inversion of the matrix of rigidity structural and multiplication of the opposite matrix obtained by a vector of effort assembled with the operators `TO FACTORIZE` and `TO SOLVE`.
Then, one calculates the geometrical matrix of rigidity using a stress field to the elements with the operator `CALC_MATR_ELEM`, option `RIGI_GEOM`.

3.4 Values tested

The tests relate to the reduced frequencies and depreciation of the first two modes of inflection of the beam, at the mean velocity of flow of $4\ m/s$.
Experimental measurements relate to only the characteristics of the first mode of inflection vibrating according to the largest side of the enclosure. This mode is the first determined by calculation. Two types of test are carried out:

- a test of comparison with experimental measurements on the first mode,
- a bearing test on the first two modes in order to guarantee to it not regression of the code.

3.4.1 Frequencies of the first two modes of inflection of the beam

- Test of comparison with the experiment on the first mode:

The tolerance of relative variation compared to the experimental value is worth 10 %.

Number of the mode	Experimental value	Computed value	Relative variation
1	4.47 Hz	4.735 Hz	5,90%

3.4.2 Reduced depreciation of the first two modes of inflection of the beam

- Test of comparison with the experiment on the first mode:

The tolerance of relative variation compared to the experimental value is worth 20 %.

Number of the mode	Experimental value	Computed value	Relative variation
1	19%	22,6474%	+ 19,20%

3.5 Remarks

The values of reference are those obtained by *Code_Aster* during the restitution of the CAS-test, which will thus make it possible to check to it not later regression of the code during its evolution.

4 Modeling B

4.1 Characteristics of modeling

Modeling B is identical to modeling A (cf paragraph [§3.1]), but one uses this time a simplified representation of the beam.

One indicates a group of meshs corresponding to the one of the tubes, which defines the only class of equivalence for all the tubes of the beam. The geometry of the beam is defined by giving the coordinates of the centers of the tubes in the orthogonal plan to the beam. It is then supposed, in the resolution of the coupling fluid-structure, that all the tubes have the same modal deformation, which is that of the tube defining the class of equivalence. Indeed, the studied mode corresponds to an overall movement of the tubes of the beam.

The evolutions of the frequency and the reduced damping of the first two modes of inflection of the beam are calculated for mean velocities of flow varying from 0 with $10\,m/s$ by step of $1\,m/s$. One takes account of an initial reduced damping of 12.3 %.

Taking into account the nature of the studied mode (overall mode of the beam), modeling B must lead to results very close to those of modeling A.

4.2 Characteristics of the grid

The characteristics of the grid of this second modeling are the same ones as that of modeling A, is: 459 nodes used and 470 meshs of the type `SEG2`.

The file of grid is with the format `ASTER`.

4.3 Stages of calculation

The features which one wishes to validate are the same ones as those enumerated for modeling A (cf paragraph [§3.3]), but by using this time a simplified representation of the beam.

The definition of the parameters taking of account the coupling fluid-rubber band of a simplified representation of the beam is carried out with the operator `DEFI_FLUI_STRU`, keyword factor `FAISCEAU_AXIAL`.
C alcul of the evolutions of the frequencies and modal reduced depreciation according to the mean velocity of the flow, by the implementation of the model `MEFISTEAU` being based on a simplified representation of the beam is carried out by the operator `CALC_FLUI_STRU`.

4.4 Values tested

The tests relate to the reduced frequencies and depreciation of the first two modes of inflection of the beam, at the mean velocity of flow of $4\,m/s$. Experimental measurements relate to only the characteristics of the first mode of inflection vibrating according to the largest side of the enclosure. This mode is the first determined by calculation. Two types of test are carried out:

- a test of comparison with the experimental values on the first mode,
- a bearing test on the first two modes in order to guarantee to it not regression of the code.

4.4.1 Frequencies of the first two modes of inflection of the beam

- Test of comparison with the experiment on the first mode:

The tolerance of relative variation compared to the experimental value is worth 10 %.

Number of the mode	Experimental value	Computed value	Relative variation
1	4.47 Hz	4.735 Hz	5,90%

4.4.2 Reduced depreciation of the first two modes of inflection of the beam

- Test of comparison with the experiment on the first mode:

The tolerance of relative variation compared to the experimental value is worth 20 %.

Number of the mode	Experimental value	Computed value	Relative variation
1	19%	22,6474%	19,20%

5 Remarks

The values of reference are those obtained by *Code_Aster* during the restitution of the CAS-test, which will thus make it possible to check later on to it not regression of the code during its evolution.

The results got for reduced depreciation are very slightly different between modelings A and B. This is explained by the fact why the modeling B, which uses a simplified representation of the beam, supposes that all the tubes have a rigorously identical modal deformation: the common deformation is that of a tube chosen arbitrarily in the beam. The modeling A, which uses the complete representation of the beam, takes account of the infinitesimal variations of the deformation of a tube with the other. It is thus normal that appear very light differences on the results.

Moreover, the weak variations observed on the results highlight the interest to use a simplified representation of the beam when one has overall modes. The saving of time of calculation is rather consequent.