SDLL119 - Beam bundle under axial excitation fluid-elastic

Abstract

One considers a beam with square step of 3×3 aluminum tubes, placed in a rectangular enclosure 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 bending of the beam, according to the mean velocity of flow.

The goal of this benchmark is to validate the resorption of model `MEFISTEAU` [R4.07.04] making it possible to calculate the modal characteristics of a beam bundle under confined axial flow, by taking account of an excitation of the fluid-elastic 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-elastic, in the case of a configuration of standard “the tube bundle under axial flow” (factor key word `FAISCEAU_AXIAL`),
- operator `CALC_FLUI_STRU` [U4.80.03]: computation of the evolutions of the frequencies and reduced dampings modal according to the mean velocity of flow, by the placement of model `MEFISTEAU`.

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

The numerical 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 the non regression one of *Code_Aster* are those obtained numerically during the restitution of the benchmark.

1 Problem of reference

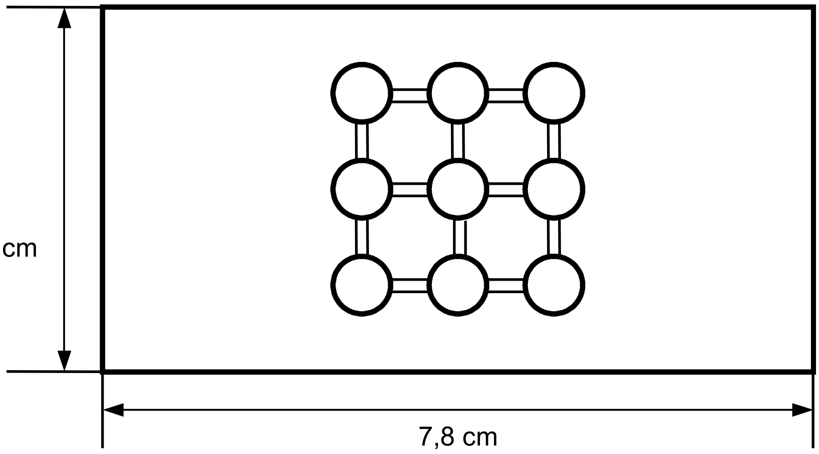
1.1 Geometry

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

length	$L=1,2\,m$
diameter external	$\phi_{\mathrm{ext}}=9,5\,mm$
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 $2\ mm$ 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 $7,8\ cm\times4,2\ cm$.



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

1.2 Properties of the materials

the physical characteristics of aluminum 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 ropes 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	$\rho_{eau}=1000\,kg/m^3$
kinematical 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 rods. The relative flexibility of bending of these rods releases the (DDL) degrees of freedom of rotation of the ends of each tube. One can thus estimate that the tubes are kneecap-kneecaps, the metal rods introducing in each end an additional stiffness of rotation.

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

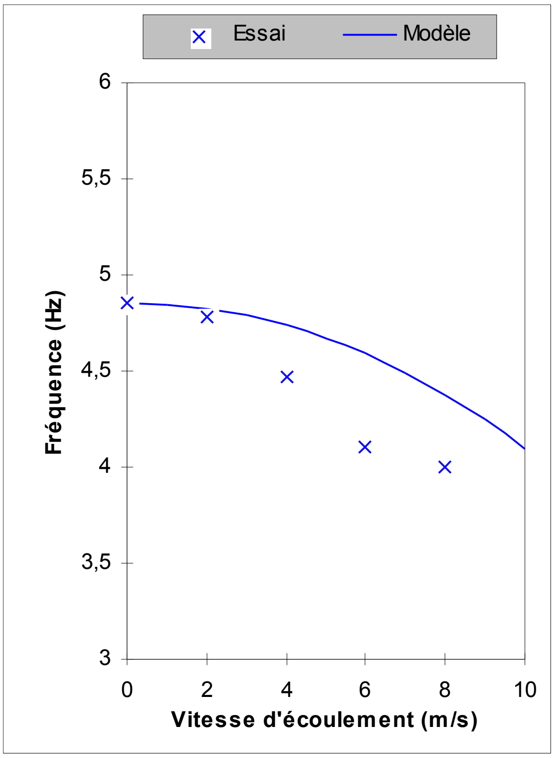
1.4 Bibliographical references

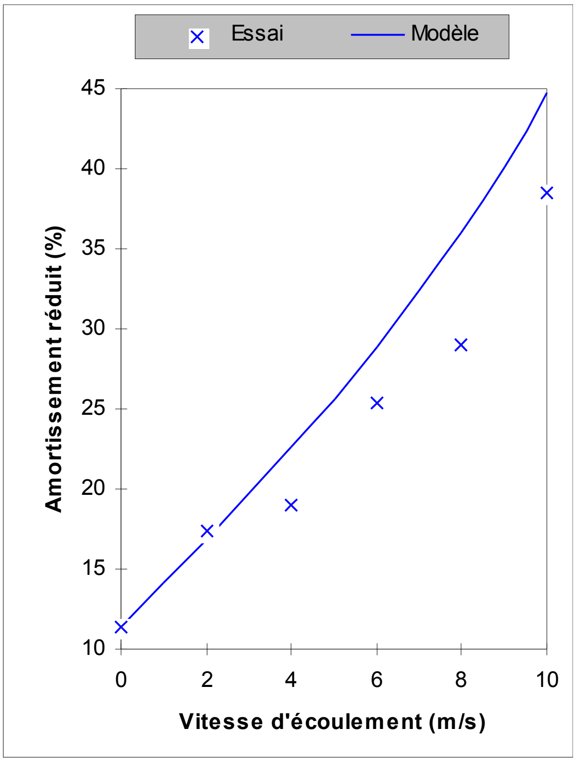
1.A. HOTTA, H. NIIBORI, Mr. TANAKA and K. FUJITA: “Parametric study one parallel flow - induced damping of PWR fuel assembly”, ASME Conference, Nashville, TN, PVP Vol.191 (1990)

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 reduced damping according to the mean velocity of flow, for the first mode of bending of the beam becoming deformed according to the largest side of the enclosure. The modes of bending of the beam are double modes in air; the dissymmetry of fluid-structure coupling and the separates them under flow directs 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 benchmark, a more narrow tolerance being necessary to guarantee non regression code. The values of reference used are thus those obtained numerically during the restitution of the case - test.

3 Modelization A

3.1 Characteristic of the modelization

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

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

external radius	$R_{ext}=4{,}75.10^{-3}\,m$	
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 bending 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 circular section full $R=10^{-3}\,m$ (cf paragraph [§1.1]) and a material with 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])

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

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

One deduces from the nodal forces the elementary vectors of force, then an assembled vector which is built according to the classification of the degrees of freedom of complete structure. The static deformed shape due to the setting in compression of the tubes is then obtained by multiplying the vector assembled by the reverse of the structural stiffness matrix. Using this static deformed shape, one calculates then a stress field with the elements, from which is deduced a geometrical stiffness matrix. This one is then added to the structural stiffness matrix in order to obtain the stiffness matrix after the setting in compression of the tubes, which is finally used for the computation 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 kinematical viscosity of surrounding water are constant along the tubes:

density $\rho_{eau} = 1000\, kg/m^3$
kinematical 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 bending 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 mesh

the nombre total of nodes used for this mesh is of 459.
Meshes are 470 and of type `SEG2`.
Mesh file is with the Aster format .

3.3 Stages of computation

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

The modelization A allows to test these functionalities with the complete representation of the beam. Besides the operators of fluid-structure coupling, other moduli of resolution and mechanical computation are used.
In our case, one calculates the field of displacements to the nodes by inversion of the stiffness matrix structural and multiplication of the opposite matrix obtained by a vector of force assembled with the operators `TO FACTORIZE` and `SOLVE`.
Then, one calculates the geometrical stiffness matrix using a stress field with the elements with the operator `CALC_MATR_ELEM`, option `RIGI_GEOM`.

3.4 Values tested

the tests carry on the frequencies and reduced dampings of the first two modes of bending of the beam, with the mean velocity of flow of $4\ m/s$.
Experimental measurements relate to only the characteristics of the first mode of bending vibrating according to the largest side of the enclosure. This mode is the first determined by computation. 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 non regression code.

3.4.1 Frequencies of the first two modes of bending 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 experimental	the Value mode	Computed value	relative Variation
1	4,47 Hz	4,735 Hz	5.90%

3.4.2 Reduced dampings of the first two modes of bending 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 experimental	the Value mode	Computed value	relative Variation
1	19%	22.6474%	+ 19,20%

3.5 Remarks

the values of reference those are obtained by *Code_Aster* during the restitution of the benchmark, which will thus make it possible to check non regression later code during its evolution.

4 Modelization B

4.1 Characteristic of the modelization

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

One indicates a mesh group 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 plane to the beam. It is then supposed, in the resolution of fluid-structure coupling, that all the tubes have the same modal deformed shape, which is that of the tube defining the class of equivalence. Indeed, the studied mode corresponds to an overall motion of the tubes of the beam.

The evolutions of the frequency and the reduced damping of the first two modes of bending 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), the modelization B must lead to results very close to those of modelization A.

4.2 Caractéristiques of the mesh

the characteristics of the mesh of this second modelization are the same ones as that of the modelization A, is:
459 nodes used and 470 meshes of type `SEG2`.

Mesh file is with the Aster format .

4.3 Stages of computation

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

The definition of the parameters taking into account the coupling fluid-elastic of a simplified representation of the beam is carried out with operator `DEFI_FLUI_STRU`, factor key word `FAISCEAU_AXIAL`.
The computation evolutions of the frequencies and reduced dampings modal according to the mean velocity of flow, by the placement of model `MEFISTEAU` leaning on a simplified representation of the beam is carried out by the operator `CALC_FLUI_STRU`.

4.4 Values tested

the tests carry on the frequencies and reduced dampings of the first two modes of bending of the beam, with the mean velocity of flow of $4\,m/s$. Experimental measurements relate to only the characteristics of the first mode of bending vibrating according to the largest side of the enclosure. This mode is the first determined by computation. 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 non regression code.

4.4.1 Frequencies of the first two modes of bending 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 experimental	the Value mode	Computed value	relative Variation
1	4,47 Hz	4,735 Hz	5.90%

4.4.2 Reduced dampings of the first two modes of bending 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 experimental	the Value mode	Computed value	relative Variation
1	19%	22.6474%	19.20%

5 Remarks

the values of reference those are obtained by *Code_Aster* during the restitution of the benchmark, which will thus make it possible to check later on non regression code during its evolution.

The results got for reduced dampings are very slightly different between the modelizations A and B. This is explained by the fact why the modelization B, which uses a simplified representation of the beam, supposes that all the tubes have a rigorously identical modal deformed shape: the common deformed shape is that of a tube chosen arbitrarily in the beam. The modelization A, which uses the complete representation of the beam, account of the infinitesimal variations of the deformed shape of a tube takes 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 computation is rather consequent.