SDLL118 - Beam subjected to a fluid excitation - elastic axial

Abstract:

One considers a PVC tube placed at the center of a cylindrical enclosure of section circular and subjected to the action of an axial water flow. This hardware configuration corresponds to the experimental device of Tanaka and al. [bib1] which is used to measure the evolutions of frequency and reduced damping of the first mode of the tube 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 telegraphic structure under confined axial flow, by taking account of an excitation of the fluid-elastic type.

The features particular to test are the following ones:

- operator `DEFI_FLUI_STRU` [U4.25.01]: 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` [U47.66.02]: computation of the evolutions of the frequencies and reduced dampings modal according to the mean velocity of flow, by the placement of model `MEFISTEAU`.

The numerical results of the simulation of the device of Tanaka 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 the code are those obtained numerically during the restitution of the benchmark.

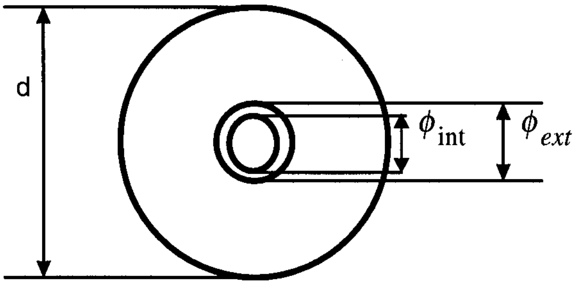
1 Problem of reference

1.1 Geometry

the tube considered is a hollow roll whose characteristic dimensions are the following ones:

length	$L=1\,m$
external diameter	$\phi_{\text{ext}}=13\,mm$
internal diameter	$\phi_{\text{int}}=8{,}8\,mm$

the tube is placed in the center of a cylindrical enclosure of circular section. The internal diameter of the enclosure is worth $d=5\,cm$.



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

1.2 Properties of the materials

the physical characteristics of material PVC constituting the tube are the following ones:

Young modulus	$E=2{,}80.10^9\,Pa$
Poisson's ratio	$\nu=0{,}3$
density	$\rho=1500\,kg/m^3$

water surrounding the tube 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 two ends of the tube are connected to fixed supports by two metal rods. The relative flexibility of bending of these rods releases the degrees of freedom of rotation of the ends of the tube. One can thus estimate that the conditions of self-supporting quality of the tube are of the standard kneecap-kneecap, the metal rods introducing of each end an additional stiffness of rotation.

Moreover, these rods make it possible to apply an axial load to the tube, which can thus be prestressed in tension or compression. In practice, two configurations are studied:

- tube nonprestressed: no force is applied. This configuration corresponds to the modelization A of the benchmark,
- tubes prestressed in compression by application of an axial load of $40\,N$ at an end.

This configuration corresponds to the modelization B of the benchmark.

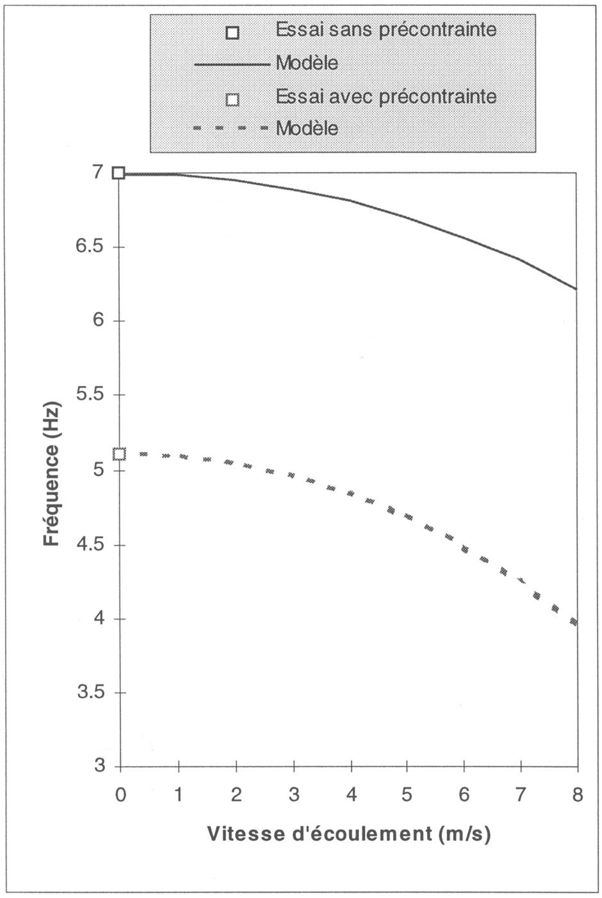
1.4 Bibliographical reference

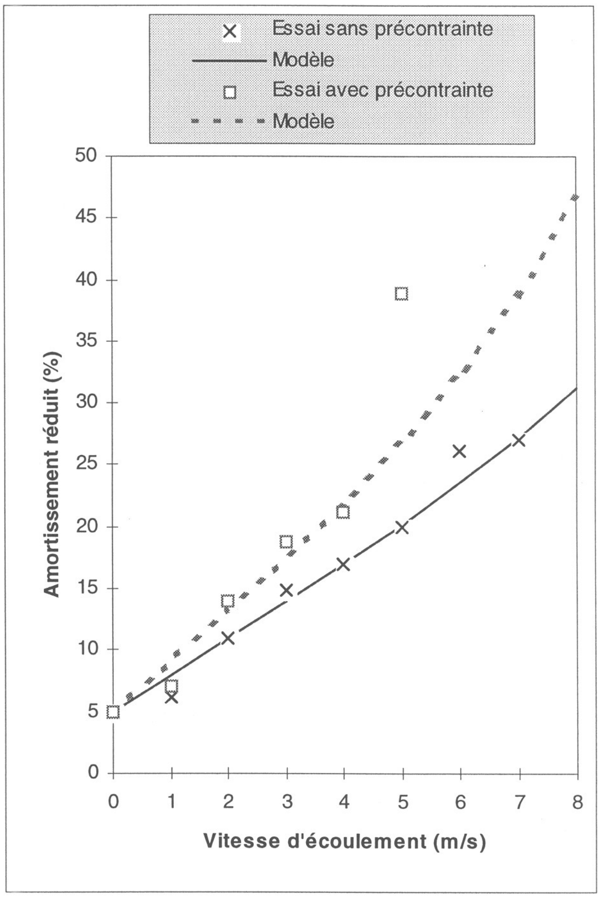
1.Mr. TANAKA, K. FUJITA, A. HOTTA and N. KONO: “Parallel flow-induced damping of PWR fuel assembly”, ASME Conference, Pittsburgh, PA, PVP vol. 133 (1988)

2 Reference solution

the experimental mesures taken on the device of Tanaka and al. provide the values of reference for the validation of the model.

The two graphs below, representing the evolutions of the frequencies and the reduced damping of the first double mode of bending according to the mean velocity of flow, make it possible to compare the results of the model with the experimental results.





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 benchmark.

3 Modelization A

3.1 Characteristic of the modelization

the tube is represented by 100 beam elements rights of Timoshenko (`MECA_POU_D_T`), supported per as many meshes segments with 2 nodes (`SEG2`). Two elements `MECA_DIS_TR` are added to the nodes ends of the tube, making it possible to model the metal rods by discrete stiffness of rotation.

One carries out with the beam elements the characteristics of circular section:

external radius	$R_{ext}=6{,}5.10^{-3}\,m$	
thickness	$E=2{,}1\,.10^{-3}\,m$	(cf paragraph [§1.1])

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

Young modulus	$E=2{,}80\,.\,10^{9}\,Pa$	
Poisson's ratio	$\nu=0{,}3$	
density	$\rho=1500\,kg/m^{3}$	(cf paragraph [§1.2])

One assigns to the discrete elements the same stiffness of rotation around the two orthogonal axes with neutral fiber of the tube:

$$K_r=6{,}29\,Nm/rad$$

This stiffness of rotation was adjusted in order to find the eigenfrequency of the first double mode in air.

The degrees of freedom in translation DX and DZ of the nodes ends $N1$ and $N101$ are blocked in order to prohibit a rigid body motion of the tube (axial translatory movement). DY Node is also blocked $N1$. Moreover, in each node, one blocks the degree of freedom of rotation DRY , in order to prohibit any motion of torsion.

The tube is immersed in a cylindrical enclosure of $2{,}5\,cm$ interior radius (cf paragraph [§1.1]). The profiles of density and kinematical viscosity of surrounding water are supposed to be constant along the tube:

density	$\rho_{eau}=1000\,kg/m^{3}$	
kinematical viscosity	$\nu_{eau}=1{,}1\,.10^{-6}\,m^{2}/s$	(cf paragraph [§1.2])

No axial load is applied to the tube which is thus not prestressed.

The evolutions of the frequency and the reduced damping of the first double mode of bending are calculated for a beach mean velocities of flow of 0 with $8\,m/s$, by step of $1\,m/s$.
One takes account of an initial reduced damping of the tube of the 4,8%.

3.2 Characteristics of the mesh

the nombre total of nodes used for the mesh is of 101.
Meshes (of type `SEG2`) are 100.
Mesh file is with the Aster format .

3.3 Stages of computation

the validation of the operators of fluid-structure coupling, for configurations of standard “the tube bundle under axial flow” is made in two principal stages.

The first consists in defining the parameters of taking into account of fluid-structure coupling with followed `operator` DEFI_FLUI_STRU by key word `FAISCEAU_AXIAL`.
The second is the computation of the evolutions of modal frequency and reduced damping according to the mean velocity of flow, with operator `CALC_FLUI_STRU` and by the placement of model `MEFISTEAU`.

3.4 Values tested

the tests relate to the frequency and the reduced damping of the first double mode of bending of the tube, with the mean velocity of flow of $0\,m/s$ and $4\,m/s$. 2 types of test are carried out:

1) a test of comparison with experimental measurements,
2) a test to guarantee non regression code.

3.4.1 Frequency of the first mode doubles bending

1) Test of comparison with the experiment, with the rate of flow of $0\,m/s$:

The tolerance of relative variation compared to the experimental value is worth 0,1%.

Number of experimental	the Value mode	Computed value	relative Variation
1	7 Hz	7.000871 Hz	1.2E-02%
2	7 Hz	7.000871 Hz	1.2E-02%

3.4.2 Reduced damping of the first double mode of bending

1) Test of comparison with the experiment, with the rate of flow of 4 m/s:

The tolerance of relative variation compared to the reference is worth 1%.

Number of experimental	the Value mode	Computed value	relative Variation
1	17%	17%	0,2%
2	17%	17%	0,2%

3.5 Remarks

the values of reference those are obtained by *Code_Aster* during the restitution of the benchmark, which thus makes it possible to check non regression 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 this time the tube is prestressed in compression.

An axial load of compression of $23{,}7\,N$ is applied to ending node $N101$. The intensity of the force was thus readjusted compared to the experimental value provided of $40\,N$, in order to correctly find the value of frequency of the first double mode in air (cf paragraphs [§1.2], [§1.3]). This readjustment can apply by the summary modelization of the metal rods ensuring the self-supporting quality and the setting in compression.

One deduces from the nodal force the vector of elementary forces, then an assembled vector which is built according to the classification of the degrees of freedom of the tube. The static deformed shape due to the setting in compression 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 of the tube in compression, which is finally used for the computation of the modes in air.

The evolutions of the frequency and the reduced damping of the first double mode of bending are calculated for a beach mean velocities of flow of 0 with $8\,m/s$, by step of $1\,m/s$. One takes account of an initial reduced damping of the tube of 4,3%.

4.2 Characteristics of the mesh

the characteristics of the mesh of this second modelization are the same ones as those of the modelization A, is:
101 nodes used and 100 meshes of type `SEG2`.

Mesh file is with the Aster format .

4.3 Stages of computation

Just as for the modelization A, the functionalities to be validated are those of the operators of fluid-structure coupling for configurations of standard “the tube bundle under axial flow” (cf paragraph [§3.3]).

Moreover, the modelization B makes it possible to test other functionalities.
The first makes it possible to carry out the computation of a field of displacements to the nodes by inversion of the stiffness matrix structural and produced reverse by a vector of assembled force, with the operators `TO FACTORIZE` and `SOLVE`.
The second allows the computation of a geometrical stiffness matrix using a stress field the elements, with the operator `CALC_MATR_ELEM`, option `RIGI_GEOM`.

4.4 Values tested

the tests relate to the frequency and the reduced damping of the first double mode of bending of the tube, with the mean velocity of flow of $0\,m/s$ and $4\,m/s$. 2 types of test are carried out:

1) a test of comparison with experimental measurements,
2) a test to guarantee non regression code.

4.4.1 Frequency of the first mode doubles bending

1) Test of comparison with the experiment, with the rate of flow of $0\,m/s$:

The tolerance of relative variation compared to the reference is worth 0,1%.

Number of experimental	the Value mode	Computed value	relative Variation
1.5,1	Hz	5.10426 Hz	8.4E-02%
2.5,1	Hz	5.10426 Hz	8.4E-02%

4.4.2 Reduced damping of the first double mode of bending

1) Test of comparison with the experiment, with the rate of flow of $4\,m/s$:

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

Number of experimental	the Value mode	Computed value	relative Variation
1	21.10%	21.94%	4.00%
2	21.10%	21.94%	4.00%

4.5 Remarks

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