SDLS103 - Coaxial shells under annular flow : inertial coupling between modes

Summarized

One considers a hardware configuration made up of two coaxial cylindrical shells, in interaction with a fluid running out in annular space separating the shells.

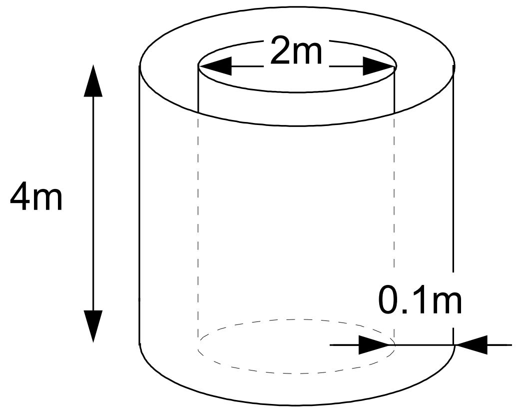
The goal of the benchmark is to validate the model fluid-structure coupling developed in operator `CALC_FLUI_STRU` for this kind of configuration.

One is interested here more particularly in the taking into account of the inertial coupling between modes, obtained out of water at rest (mean velocity of flow null). The reference solution is provided by a computation carried out with *Code_Aster* implementing operator `CALC_MATR_AJOU`.

1 Problem of reference

1.1 Geometry

the studied configuration consists of two 4 meters height coaxial cylindrical shells:



The inner shell has an average radius of $1\,m$ and a thickness of $1\,cm$.

The outer shell has an average radius of $1{,}10\,m$ and a thickness of $1\,cm$.

1.2 Properties of the material

the material constituting the two shells is steel. Its physical characteristics are:

$\rho=7800\,kg/m^3$ $E=2.10^{11}\,Pa$ $\nu=0{,}3$

1.3 Boundary conditions and loadings

the conditions of self-supporting quality are the same ones for the two shells: embedded ends partly lower ($z=0$) and free partly higher ($z=4\,m$).

2 Reference solution

2.1 Method of calculating used for the reference solution

the reference solution is provided by a computation carried out by means of *Code_Aster* implementing operator CALC_MATR_AJOU.

With this intention, one uses a mesh on which the elements of the structure (shells internal and external) are defined, voluminal fluid elements (annular space) and the elements of fluid interface - structure. This method is described completely in [bib1].
On the elements of interface, the speed limit condition normal null is imposed, translating the condition of nonpenetration of the fluid in the shells.
On the sections of entry and output of annular space, the limiting condition of null potential is imposed, translating the condition of pressure disturbed null at the ends.

One carries out the first modal computation of structure in air. Operator CALC_MATR_AJOU then allows to calculate the mass matrix added by the fluid, projected on the basis of the structure modal base in air. One can then recombine this mass matrix added with the generalized mass matrix of structure in air, then to solve a new modal problem which leads to the characteristics of the water system at rest. **The results got for the eigenfrequencies of the water system at rest constitute the reference solution.**

Characteristics of mesh:
17 nodes on a vertical generator
60 nodes on a contour

960 meshes QUAD4 on each shell
=> 1920 meshes for the interface fluid-structure

2880 meshes HEXA8 for the fluid field
180 meshes QUAD4 for the section of entry of annular space
180 meshes QUAD4 for the section of output of annular space

2.2 Results of N°

reference of mode	1	2	3	4	5	6	7	8	9	10	11	12
Fréq. (Hz)	5,65	5,65	6,48	6,48	9,34	9,34	20,82	20,82	28,22	28,22	31,48	31,48

2.3 Uncertainty on the solution

In the studied case, the half-thicknesses of shell represent 10 % of the dimension of annular clearance. In the computation of reference carried out by the operator CALC_MATR_AJOU, the half-thicknesses are neglected for the definition of the fluid field. One thus expects a systematic error of about 5 % on the frequencies, because of this approximation.
Moreover, the differences of modelization and resolution between the numerical method put in work in operator CALC_MATR_AJOU and the model analytical developed in operator CALC_FLUI_STRU induce an additional variation.

2.4 Bibliographical references

1.G. ROUSSEAU: “Specifications and principle of realization of the computation of stiffness and damping added in *Code_Aster*”, HP-51/96/005/B.

2.L. PEROTIN, “Note of principle of model MOCCA_COQUE”, HT-32/95/021/A.

3 Modelization A

3.1 Characteristic of the modelization

the geometry of structures and the characteristic of the material constituting the shells were presented before.

Concerning the absolute roughness of wall of structures, one takes a value of 10-5 meter.

The surrounding fluid is water. The values taken for the density and kinematical viscosity are respectively

$$\rho_f = 1000\,kg/m^3 \qquad \nu_f = 10^{-6}\,m^2/s$$

One considers the flow not confined upstream and downstream from structures.

The problem of fluid-structure coupling is solved by the model analytical MOCCA_COQUE [bib2] integrated in *Code_Aster* (operator `CALC_FLUI_STRU`), for a mean velocity of flow null: one thus obtains the modal characteristics of the water system at rest, by taking into account of the effects of added mass.

3.2 Characteristics of the mesh

Compared to the computation of reference, the characteristics of the mesh are similar, with the difference close the fluid field is not represented any more. In order to make the two shells interdependent one of the other, one adds a mesh group connecting the nodes to the level of the fixed support.

One a: 17 nodes on a vertical generator,

60 nodes on a contour,

960 meshes QUAD4 on each shell,
60 meshes QUAD4 to solidarize the two shells (bases clamped).

3.3 Stages of computation

the definition of the characteristics of a hardware configuration made up by two coaxial cylindrical shells for a computation of fluid-structure coupling is given via operator `DEFI_FLUI_STRU` factor key word `COQUE_COAX`.

The resolution of fluid-structure coupling for a configuration of the type “shells coaxial” and the computation of the modal parameters (frequencies and reduced dampings) and deformed modal out of water at rest are carried out with operator `CALC_FLUI_STRU`.

4 Results of the modelization A

4.1 Values tested

the comparisons relate to the frequencies out of water at rest of the first 12 modes of the system.

Numbers of modes	CALC_FLUI_STRU ($H=9\text{cm}$)	CALC_MATR_AJOU ($H=10\text{cm}$)	variation
1 and 2	5,30 Hz	5,65 Hz	6,2%
3 and 4	6,12 Hz	6,48 Hz	5,5%
5 and 6	8,69 Hz	9,34 Hz	6,9%
7 and 8	21,96 Hz	20,82 Hz	– 5,5%
9 and 10	29,34 Hz	28,22 Hz	– 3,9%
11 and 12	33,75 Hz	31,48 Hz	– 7,2%

One give, for information, the values of the frequencies of these modes in air:

Numbers of the Shell	modes moving	Order of shell	Order of external	beam
Frequency 1 and	2	3	1	25,15 Hz
3 and 4	intern	3	1	26,12 external
Hz 5 and	6	4	1	31,91 Hz
7 and 8	intern	2	1	36,85 Hz
9 and 10	intern	4	1	37,42 external
Hz 11 and	12	2	1	39,49 Hz

4.2 Remarks

the results are in conformity so that one could wait. One observes indeed:

a systematic error of about 5 %, because not taken into account of the thickness of shell for the definition of the fluid field in the computation of reference;
a residual variation due to the differences of modelization and resolution between two operators CALC_MATR_AJOU and CALC_FLUI_STRU.

Modes 1 to 6 are modes for which the structure is strongly coupled with the fluid. In practice, these modes correspond to motions of the shells internal and external overall in opposition of phase. For these modes, the terms of added mass are theoretically proportional to $\frac{\rho_f \pi R^3}{H}$, where R indicates the average radius and H the thickness of annular space.

For these the first six modes, the results provided by CALC_FLUI_STRU lead to eigenfrequencies lower than those calculated by CALC_MATR_AJOU. Indeed, H being weaker, the terms of added mass are larger.

Modes 7 to 12 are modes for which the structure is slightly coupled with the fluid. In practice, these modes correspond to motions of the shells internal and external almost in phase. Thus, the terms of added mass are theoretically proportional to the mass of trained water, i.e. with $\rho_f \pi R H$.

In this case, it is normal that the results provided by CALC_FLUI_STRU lead to eigenfrequencies higher than those calculated by CALC_MATR_AJOU. Indeed, H being weaker, the terms of added mass are smaller.

5 Summary of the results

the comparison of the frequencies out of water at rest calculated with operators CALC_FLUI_STRU and CALC_MATR_AJOU is satisfactory. The variations met between these two operators are explained by the fact why they use a different modelization.