

FDLV113 - Source of pressure in a ball full with fluid in interaction ground - fluid - structure

Summary:

This test contributes to the validation of the chaining *Code_Aster* - MISS3D by the frequential method of coupling in interaction ground-fluid-structure (ISFS).

This test makes it possible to consider all the types of interface: ground-structure, fluid-structure, ground-fluid, free ground. It also makes it possible to test the loading by source of specific pressure in the fluid.

It represents a ball, that is to say a hollow sphere of finished size, filled with water.

To have all the types of interface, the lower half of the hollow sphere is modelled by *Code_Aster* like field "structure"; the higher half representing the field "ground" of same characteristics as the structure and the "fluid" field is modelled by MISS3D. A harmonic source of pressure, of constant unit module for each frequency understood enters 1 Hz and 30 Hz , is imposed on the center of the ball in the fluid environment.

One tests the module of radial displacements obtained outside and inside the ball compared to a calculated analytical solution. The agreement is correct on condition that removing the effect of a resonance parasite corresponding to the first Eigen frequency of the sphere with water mass added to the center. That is possible by means of the introduction of a parameter `RFIC` in MISS3D.

1 Problem of reference

1.1 Geometry

Miss3D use the frequential method of coupling to take account of the interaction ground - fluid-structure. This method, based on the dynamic under-structuring, consists in cutting out the field of study in three under-fields:

- ground,
- fluid,
- the structure.

It results 4 possible types of interface from them:

- the interface ground-structure,
- the interface fluid-structure,
- the ground-free interface.

Ground, fluid, and the structure

The ground and the structure are made up by same homogeneous material.

In coupled calculation *Code_Aster*- MISS3D, to represent the case of a sphere of finished size filled of fluid digs, one models a half of the solid medium like field "structure", taken into account with *Code_Aster*, and other half like field "ground" taken into account with MISS3D.

The fluid environment, which is inside the sphere of ray $r = 5 m$, is taken into account with MISS3D. The solid medium occupies the volume ranging between the spheres of rays $r_{interne} = 5 m$ and $r_{externe} = 7 m$.

The field "structure" occupies the volume of solid delimited exceptionally by the equatorial horizontal plan passing by the origin of the sphere and the field "ground" the volume of remaining solid (see figure 1.1-a below).

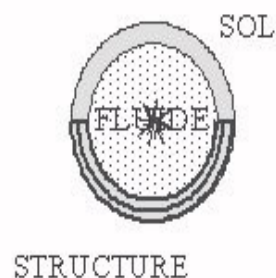


Figure 1.1-a: Field of the ball of finished size filled of fluid

The elements of the interfaces are surface elements QUAD4. The field "structure" (in yellow on figure 1-1.b) is modelled with voluminal elements HEXA8. The thickness according to the radial direction is shared in four layers for a total of 1024 elements.

The maximum size of the elements is $1.37 m$, which, with a secondary speed of the waves in the solid of $334 m/sec$, must respect the limit in frequency of $30 Hz$ according to the criteria:

$$l_{elem_max} \leq \frac{l_{onde_max}}{8} \quad f \leq f_{max} = \frac{c_s}{8 l_{elem_max}}$$

Interfaces

On the figure 1-1.b, one represents the elements of the 4 interfaces. There is here a field of free surface of ground. The interface ground - structure, in black, is discretized in 128 meshes and understands nothing any more but the crown of the horizontal plane $z=0$ understood between the rays $5m$ and $7m$. The interface ground - fluid, pink dark, and interfaces it fluid-structure, in blue, are discretized in 256 meshes. Free surface in green understands all the external envelope of the higher half-sphere is also 256 meshes.

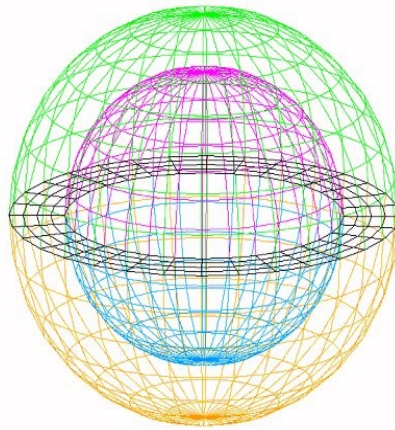


Figure 1.1-b: Models and surface grids of the interfaces

1.2 Properties of materials

Ground and the structure

The soil mechanics structure and characteristics used are those indicated in table 1.1-a.

E	700 MPa
NAKED	0.2
RHO	2500. kg/m ³
BETA	0

Table 1.2-a: characteristics of the ground and the structure

These characteristics induce a speed of the waves of shearing: $c_s = 341.56 m/s$ as well as a speed of the compression waves: $c_p = 557.77 m/s$

Fluid

Celerity	150 m/s
RHO	1000. kg/m ³

BETA 0.

Table 1.2-b: characteristics of the fluid

One introduces a characteristic of celerity of the fluid lower at the speeds of the waves of shearing of compression into the structure and the ground in order to obtain resonances in the range of the studied frequencies.

1.3 Boundary conditions and loadings mechanical

One applies a condition of specific fluid source to the center of the ball of coordinates (000) with a harmonic loading $P = P_o \sin \omega t$ of which the module of the pressure p_o is unit with a pulsation which varies 1 Hz with 30 Hz by step of 1 Hz. That corresponds to Dirac at the initial moment into temporal. That returns in Code_Aster to introduce into CALC_MISS under the keyword SOURCE_FLUIDE coordinates of the source.

In order not to have a problem of rigid movement of body, one blocked the nodes of the grid of the structure, which are on the axes X, Y and Z respectively according to (Y and Z), (X and Z), (X and Y). Thus, one prevents displacements of rigid body, while allowing radial displacement.

With regard to the modes of interface ground - structure, one noticed that the static modes of constrained type calculated with this limiting condition of embedding to the interface ground - structure cannot be a complete base to represent a deformation with spherical symmetry.

For that, one introduced static new fashions into the modal base. The introduced modes are of the modes of the type constrained on the external envelope of the lower half-sphere (in yellow on the figure 1,1-b). They correspond to a new limiting condition of blocking according to the 3 degrees of freedom of all the nodes of this surface, except for its nodes of intersection with the axes. For these nodes, there is not the unit mode corresponding to the degree of freedom which is tangential on the surface, because the displacement which one searches does not have of component according to this direction.

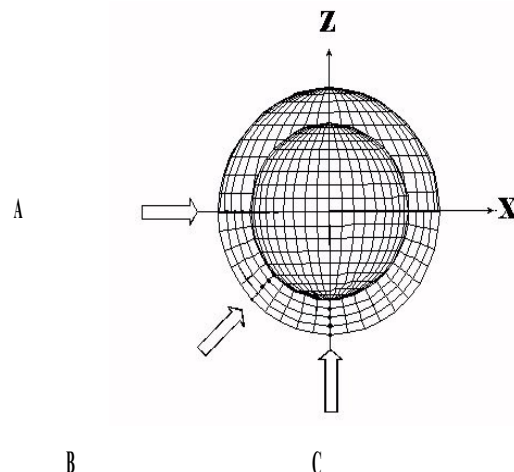


Figure 1.3-a: Points of measurement of radial displacement.

The best result is got by using a modal base of Ritz without dynamic modes, and with the static modes supplemented as previously indicated. Indeed, there is thus exactly the number of unknown factors of displacement to determine to represent a displacement with spherical symmetry, in particular on the interface structure – fluid.

2 Reference solution

2.1 Results of reference

The frequential method of coupling enters Miss3D and *Code_Aster* is described in the reference document [bib1].

One tests the module of radial displacements obtained outside and inside the ball compared to an analytical solution calculated and detailed in an application study [bib2]. The solutions under development pressure and depend only on the ray and time. It is considered that the total pressure in the fluid is due to the sum of two contributions:

- pressure p_d had with the vibration of the wall to the interface with the solid medium,
- pressure p_0 had with the action of the mass of Dirac in the center of the sphere, in an infinite fluid

$$p = p_d + p_0$$

The equation of Helmholtz of propagation waves in the fluid in absence of source is written in spherical coordinates after transformation of Fourier:

$$\frac{1}{r^2} \frac{\delta}{\delta r} \left(r^2 \frac{\delta p_d}{\delta r} \right) (r, \omega) + \frac{\omega}{c_f^2} p_d (r, \omega) = 0$$

While posing: $k_f(\omega) = \frac{\omega}{c_f}$, a solution of the form is obtained $p_d = A \left(\sin \frac{(k_f r)}{4\pi r} \right)$,

The solution for the pressure p_0 is given by a function of Green and the pressure in the fluid is

$$\text{written: } p = \frac{e^{ik_f r}}{4\pi r} + A \left(\sin \frac{(k_f r)}{4\pi r} \right)$$

The equation of Navier of propagation waves in the solid in absence of source is written in spherical coordinates after transformation of Fourier and by carrying out the change of variables $u = \frac{\delta \phi}{\delta r}$:

$$\frac{\delta^2}{\delta r^2} (r \phi)(r, \omega) + k_p^2 (r \phi)(r, \omega) = 0$$

While posing $k_p(\omega) = \frac{\omega}{c_p}$, a solution of the form is obtained:

$$u = B \frac{e^{ik_p r}}{4\pi r} \left(\frac{ik_p r - 1}{r} \right) + C \frac{e^{-ik_p r}}{4\pi r} \left(\frac{-ik_p r - 1}{r} \right).$$

3 unknown coefficients A , B and C are then given starting from 3 limiting conditions:

- Continuity of normal displacements to the interface ground-fluid $\rho \omega^2 u = \text{grad}(p)$ for $r = r_1$,
- Continuity of the normal constraints to the interface ground-fluid $\sigma_{rr} + p = 0$ for $r = r_1$,
- Worthless radial constraint on worthless external surface $\sigma_{rr} = 0$ for $r = r_2$,

2.2 Bibliographical references

- [1] D. CLOUTEAU: "Manual of reference of MISS3D – version 6.3 – Power station Searches SA"
- [2] G. DEVESA, M.FESTA: "étude with *Code_Aster* and its interface with MISS3D of the interaction Ground-Structure-Fluid: Application to the dynamic calculation of the arch dams", EDF/R & D HP-52/99/001/A.

3 Modeling A

3.1 Characteristics of modeling

The characteristics used and the grid are those deduced from the data of the paragraph [1].
One assigns a modeling 3D to the elements of the structure

3.2 Characteristics of the grid

Grid provided to Code_Aster contains meshes of the type HEXA8 to model the structure and meshes of the types QUAD4 to model the interfaces with a discretization detailed in the paragraph [1.1]. It is important to have directed the elements of surface of the interfaces according to the conventions described in the document [U2.06.08].

3.3 Sizes tested and results

The values tested are the modules in m answers to the points A (equatorial) and C (polar) for the external ray of 7 meters.

Identification	Standard reference	Reference	Tolerance
<i>MDXA</i> (1 Hz)	Not regression	2.433100E-04	0.1%
<i>MDZC</i> (21 Hz)	Not regression	0.01679100	0.1%
<i>MDXA</i> (1 Hz)	External source	2.648E-04	9.0%

4 Summary of the results

One represents on the figures 4a and 4b analytical radial displacement according to the frequency compared to those obtained by calculation at the points *A*, *B* and *C* (positioned on the figure 1.3-a above) for a ray of *7 m* outside the structure field while post-treating with *Code_Aster*.

One notes a correct agreement of the results as a whole. In particular, one finds rather well the frequencies of resonance in general towards *19 Hz* and *25 Hz* in spite of a light shift and paces of displacements except resonance to points *A* and *C* in the plans equatorial and vertical. One however notes a significant difference on the level as of amplitudes with resonance related at least to the light preceding shift. In addition, one notes at least another disturbance with a resonance parasitizes towards *10 Hz*. This frequency is the first Eigen frequency of the sphere with water mass added to the center that one can find by a calculation of modal analysis. The mode corresponding is a mode of incompressible fluid different from the modes of swelling searched here. One can attenuate this disturbance by the introduction of parameter RFIC (here being worth 0.5) like data of MISS3D.

The use of static modes constrained on the external envelope of the sphere is thus exhaustive to represent modes of swelling to spherical symmetry but it is thus also likely to represent modes of another nature being able to disturb the solution, in particular at the point *B* where one did not force limiting conditions explicitly to find this spherical symmetry of displacements. The introduction of a structural damping would be also likely to decrease the differences in amplitude at the frequencies of resonance between the analytical results and calculation.

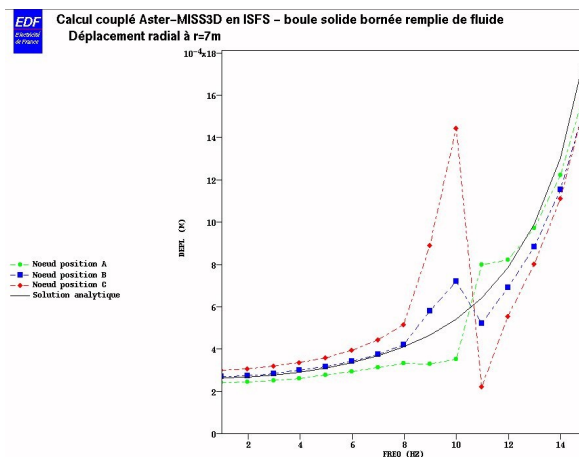


Figure 4a: analytical and calculated displacements test of the sphere of finished size (fréq < 15Hz)

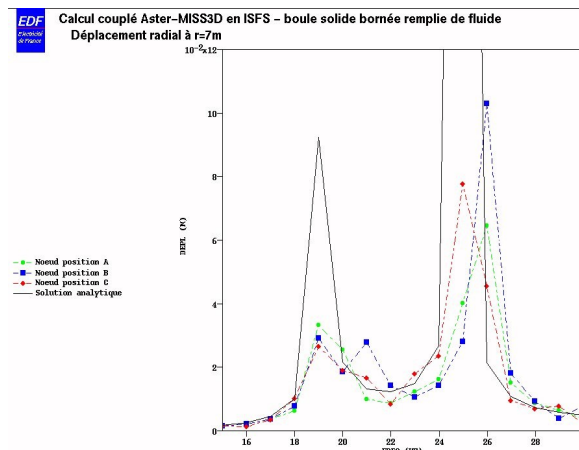


Figure 4b: analytical and calculated displacements test of the sphere of finished size (fréq > 15Hz)