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

Summarized:

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

This test makes it possible to consider all the types of interface: soil-structure, fluid-structure, soil-fluid, free soil. 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 “soil” of same characteristics as structure and the “fluid” field is modelled by MISS3D. A harmonic source of pressure, of constant unit modulus 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 modulus 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 parasitic resonance corresponding to the first eigenfrequency of the sphere with mass of water added to the center. That is possible by means of the introduction of a parameter `RFIC` into MISS3D.

1 Problem of reference

1.1 Geometry

the ProMISS3D software uses the frequential method of coupling to take account of the interaction soil - fluid-structure. This method, based on the dynamic substructuring, consists in cutting out the field of study in three subdomains:

- soil,
- fluid,
- the structure.

It results 4 possible types of interface from them:

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

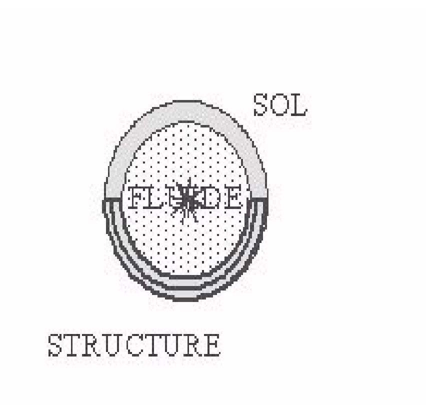
The soil, fluid, and the structure

the soil and the structure are made up by the same homogeneous material.

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

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

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



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

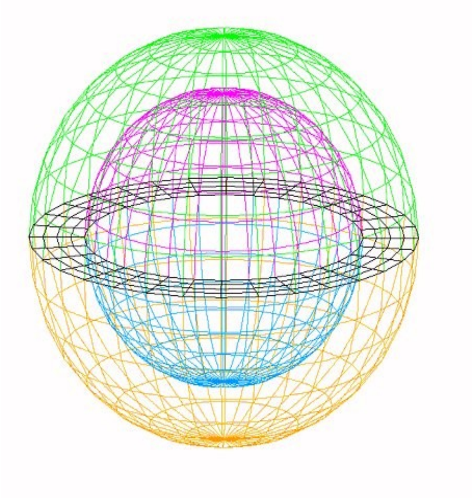
the elements of the interfaces are surface elements QUAD4. The field "structure" (in yellow on figure 1-1.b) is modelled with voluminal elements HEXA8. The thickness according to the radial direction is shared in four layers for a total of 1024 elements.

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

$$l_{\text{elem\_max}} \leq \frac{l_{\text{onde\_max}}}{8} \qquad f \leq f_{max} = \frac{c_s}{8\,l_{\text{elem\_max}}}$$

The interfaces

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



Appear 1.1-b: Models and surface meshes of the interfaces

1.2 Properties of the materials

the soil and the structure

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

E	$700\,MPa$
NU	0.2
RHO	$2500.\,kg/m^3$
BETA	0

Table 1.2-a: characteristics of the soil and structure

These characteristics induce a velocity of the waves of shears: $c_s=341.56\,m/s$ as well as a velocity of the compression waves: $c_p=557.77\,m/s$

The fluid

Celerity	$150\,m/s$
RHO	$1000.\,kg/m^3$

BETA	0.

Table 1.2-b: characteristics of the fluid

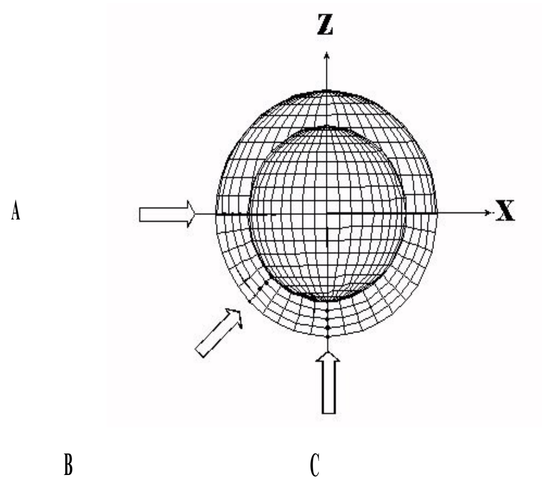
One introduces a characteristic of celerity of the fluid lower at the speeds of the waves of shears of compression into structure and the soil in order to obtain resonances in the range of the studied frequencies.

1.3 Mechanical boundary conditions and loadings

One applies a condition of specific fluid source to the center of the ball of coordinates (000) with a harmonic loading $P=P_o \sin \omega t$ whose modulus of the pressure p_o is unit with a pulsation which varies from $1\,Hz$ with $30\,Hz$ by step of $1\,Hz$. That corresponds to Dirac at initial time into temporal. That amounts in *Code_Aster* introducing into `IMPR_MISS_3D` under key word `SOURCE_FLUIDE` the coordinates of the source with a unit multiplying function in frequency.

In order not to have a problem of rigid body motion, one blocked the nodes of the mesh of 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 soil - structure, one noticed that the static modes of constrained type calculated with this limiting condition of fixed support to the interface soil - structure cannot be a complete base to represent a deformed shape with spherical symmetry.

For that, one introduced static new fashions into 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.



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

The best result is obtained by means of 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 unknowns 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 between ProMISS3D and *Code_Aster* is described in the reference document [bib1].

One tests the modulus 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 radius and time. It is considered that the stagnation pressure in the fluid is due to the sum of two contributions:

- the pressure p_d due to the vibration of the wall to the interface with the solid medium,
- the pressure p_0 due to 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:

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

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

the solution for the pressure p_0 is given by a Green's function and the pressure in the fluid is written:

$$p=\frac{e^{ik_f r}}{4\pi r}+A(\sin\frac{(k_f r)}{4\pi r})$$

The equation of Navier of propagation waves in solid in absence of source is written in spherical coordinates after transformation of Fourier and 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:

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

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

- Continuity of normal displacements to the interface soil-fluid $\rho\omega^2 u=grad(p)$ for $r=r_1$,
- Continuity of the normal stresses to the interface soil-fluid $\sigma_{rr}+p=0$ for $r=r_1$,
- Forced radial null on external surface null $\sigma_{rr}=0$ for $r=r_2$,

2.2 bibliographical References

[1] D. CLOUTEAU: “Manual of reference of MISS3D – version 6.3 – Power station Searches G SA

[2] ”. DEVESA, M.FESTA: “study with *the Code_Aster* and its interface with MISS3D of the interaction Soil-Structure-Fluid: Application to the dynamic computation of the arch dams”, EDF/R & D HP-52/99/001/A.

3 Modelization A

3.1 Characteristic of the modelization

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

3.2 Characteristic of the mesh

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

3.3 Functionalities tested

Commands	
MODE_STATIQUE	
DEFI_BASE_MODALE	RITZ
IMPR_MACR_ELEM	FORMAT = " MISS_3D "
IMPR_MISS_3D	SOURCE_FLUIDE
MACRO_MISS_3D	TOUT=' OUI'
LIRE_MISS_3D	

3.4 Quantities tested and results

the values tested are the moduli in m responses with the points A (equatorial) and C (polar) for the external radius of 7 meters.

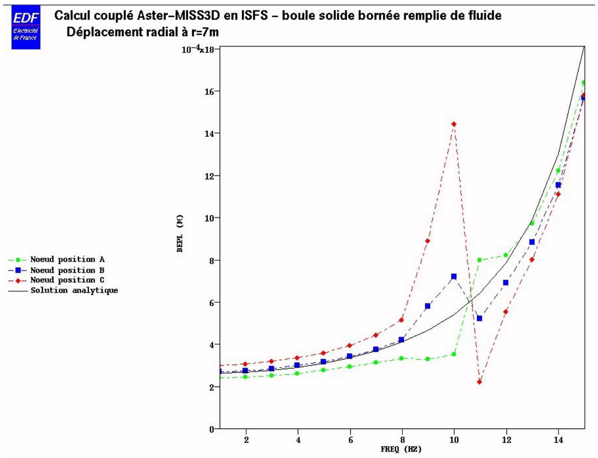
Standard	identification reference	Reference	Tolerance
$MDXA$ ($1\,Hz$)	Non regression	2.433100E-04	0.1%
$MDXA$ (5Hz)	Non regression	2.774500E-04	0.1%
$MDXA$ ($13\,Hz$)	Non regression	9.72100E-04	0.1%
$MDXA$ ($17\,Hz$)	Non regression	3.732600E-03	0.1%
$MDXA$ ($29\,Hz$)	Non regression	6.5570000E-03	0.1%
$MDZC$ ($21\,Hz$)	Non regression	0.01679100	0.1%
$MDXA$ ($1\,Hz$)	external Source	2.648E-04	9.0%
$MDXA$ ($13\,Hz$)	external Source	9.936E-04	3.0%

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 computation at the points A , B and C (positioned on the figure 1.3-a above) for a radius 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 the resonance frequencies rather well in general towards $19\,Hz$ and $25\,Hz$ in spite of a light shift and the paces of displacements except resonance at the points A and C in the planes equatorial and vertical. One however notes a significant difference on the level in the amplitudes to 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 eigenfrequency of the sphere with mass of water added to the center that one can find by a computation 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 to the resonance frequencies between the analytical results and computation.



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

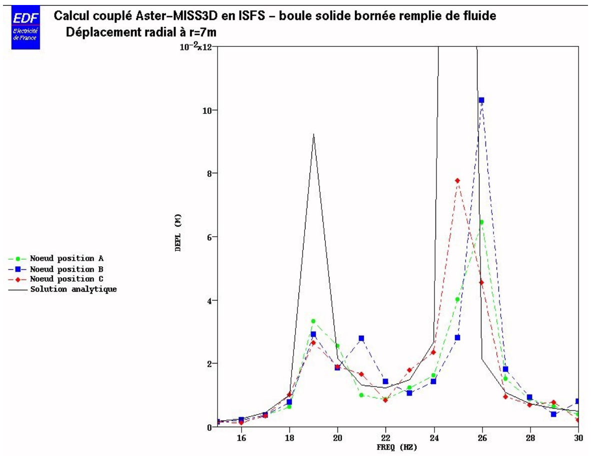


Figure 4b: analytical and calculated displacements test of the sphere of finished size (fréq > 15Hz)