FDNV100 - Shaking of a water tank with deformable wall elastic

Abstract:

This test, of the fluid-structure field, proposes the implementation of a transient dynamic computation (operator DYNA_NON_LINE) with taking into account of a free surface. Being given the absence of adapted values of reference, it acts of a benchmark of non regression.

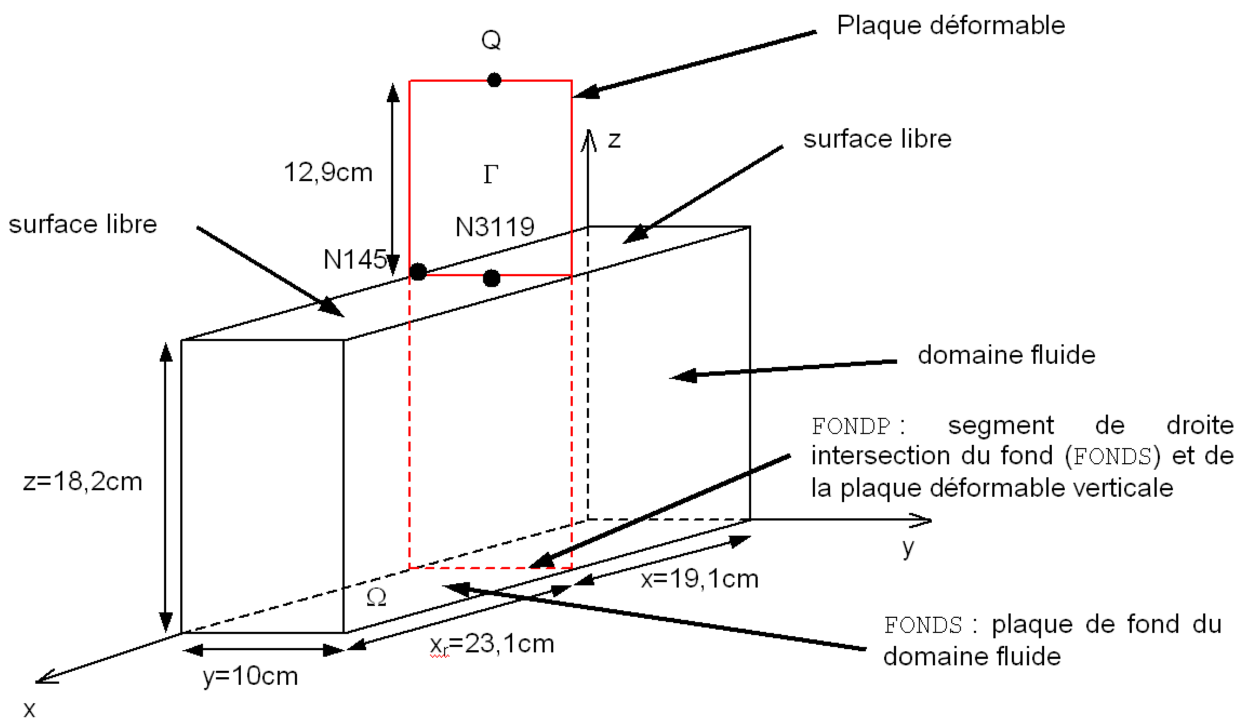
One validates also the analysis of stability (with the key word CRIT_STAB) on this problem fluid-structure.

1 Problem of reference

This benchmark, based on the model of the article [bib1], aims to test the correct taking into account of a free surface in a computation fluid-structure coupled with operator DYNA_NON_LINE.

1.1 Geometry

One considers a parallelepipedic tank, filled with water, whose external walls are indeformable. This rigid tank comprises a deformable internal plate, named Γ . It is embedded at its base at the bottom of the tank, its vertical sides being free. This flexible wall exceeds free surface a height of $12{,}9\,cm$:



1.2 Properties of the materials

the fluid (water) contained in the tank has as characteristics:

density: $\rho_f=1000\,kg/m^3$
speed of sound: $c=1500\,m/s$

The deformable wall is elastic linear (duralumin):

density: $\rho_s=2787\,kg/m^3$
Young modulus: $E=62{,}43\,GPa$
Poisson's ratio: $\nu=0{,}35$

1.3 Boundary conditions and loading

1.3.1 Conditions of Dirichlet

the loading defined here is of the standard displacement imposed on a surface. More precisely, it is considered that the bottom of the tank can move only according to the direction x .

According to this direction x , one will request the system by imposing on the bottom of the tank a sinusoidal displacement in time, of frequency $1{,}7704\,Hz$ and amplitude $0{,}001\,m$.

This imposed displacement can be comparable to a request of type mono-bearing applied by the base of the tank (seismic application).

1.3.2 Conditions of Neumann

In superposition to the surface condition of Dirichlet previously definite, one subjects also the model to the gravity field (imposed voluminal force).

Lastly, the upper surface of the fluid field is seen characterized by conditions of type free surface.

2 Reference solution

2.1 Method of calculating used for the reference solution

the only results of the literature [bib1] are modal types: eigenfrequencies and paces of certain modes.

Being given the need for testing operator DYNA_NON_LINE, and being given the relative complexity of the model which is 3D, it is not possible to find the eigenfrequencies by transient analysis in a reasonable TEMPS CPU. One uses also the linear search.
For information, this kind of analysis carried out with a random loading corresponding to a white vibration requires, for reasons of probabilistic convergence, a computation for a physical time of loading of $250\,s$, which corresponds to a TEMPS CPU of a few hours.

In order to have a computing time about a few minutes, it is compulsory to calculate the evolution over a short time (a few seconds). This restrictive frame does not allow to find precisely and in a way compatible with a postprocessing automated the results of modal analysis.
The validation brought by this test can thus be only of the non regression type of the numerical solution.
As the features of computation coupled fluid-structure in addition are already the object of a certain number of tests of validation, this limitation with non regression for this particular benchmark is not crippling.

As complementary validation, complete computation with signal of $250\,s$ was carried out. The spectrums at the points of observations indeed showed a good agreement with the results of modal analysis of [bib1].

To validate the analysis of stability on this problem fluid-structure, one will use key word CRIT_STAB of DYNA_NON_LINE.

2.2 Results of reference

One tests values of displacements at various times, according to the direction x , for two points of mesh: $N145$ and $N3119$. These points are on free surface, on both sides of the deformable wall, as one can see it on the diagram of the paragraph [§1.1].

As for stability, as one will not use the geometrical stiffness matrix (which is unavailable for elements DKT used here), the analysis could be only of the search type for singularities of the stiffness matrix (thus an eigenvalue which tends towards 0).
The elastic problem being linear, one does not wait, on the one hand, instability and on the other hand, one should find the critical eigenvalue until for the same model but without the fluid and who is worth 2,47726. This eigenvalue will be the same one with each computation step because the problem remains linear.

2.3 Uncertainty on the numerical

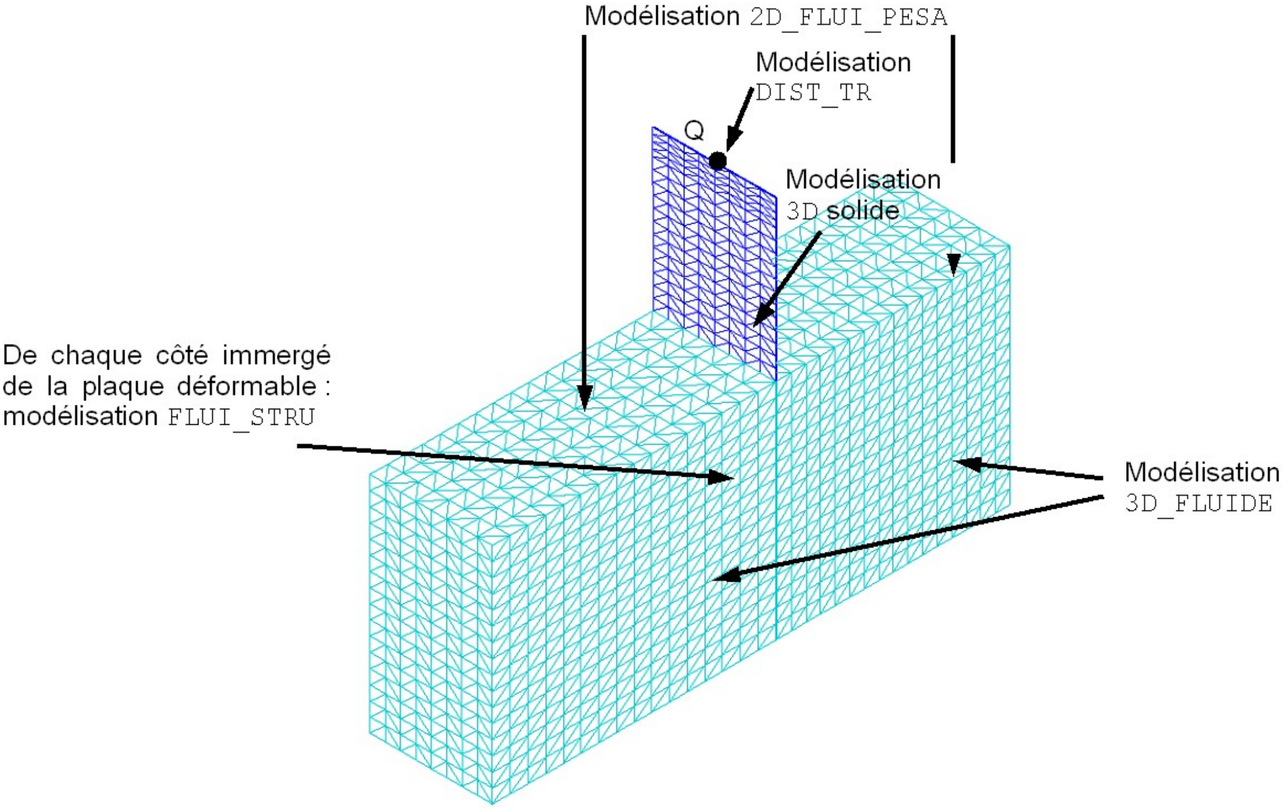
solution Solution (calculated with version 7.3.6 of the code).

2.4 Bibliographical reference

1) BERMUDEZ A., RODRIGUEZ R., SANTAMARINA D.: “Finite element computation of sloshing modes in containers with elastic baffle punts”, Int. J. Numer. Meth. In Engrg., vol. 56,447-467, 2003

3 Modelization A

3.1 Characteristic of the modelization



1) the total mesh comprise 8163 nodes, that is to say approximately 125000 degrees of freedom,
2) the point element Q (modelization DIS_TR) makes it possible to simply represent an accelerometer present in the model of the article [bib1],
3) the deformable plate is modelled by 5120 massive solid elements (modelization 3D) pentaedric with 6 nodes (10 layers in the thickness for a good approximation of the behavior in bending in spite of the linearity of the elements),
4) the free face is modelled by 512 elements MEFP_FACE3 (modelization 2D_FLUI_PESA) triangles with 3 nodes,
5) fluid volume is modelled by 24576 fluid elements (modelization 3D_FLUIDE) tetrahedral with 4 nodes.

3.2 Writing of the boundary conditions

the bottom of the tank can move only according to the direction x :

```
CONDLIM=AFFE_CHAR_MECA ( MODELE=MODELE,
                         DDL_IMPO= (_F (
                         GROUP_NO= ("FUNDS", "FONDP",),
                         DY=0.0, DZ=0.0,),),),);
```

According to this direction x, one imposes on the bottom of the tank a sinusoidal displacement in time, of frequency $1{,}7704\,Hz$ and amplitude $0{,}001\,m$:

```
FREQ = 1.7704;
LFONC=DEFI_LISTE_REEL (DEBUT=0.0, INTERVALLE=_F (JUSQU_A=10.0,
                                                PAS=0.01,),);
FONC = FORMULA ( REEL = ''' (REEL: INST) =
                  (0.001) *SIN (2*PI*FREQ*INST) ''');
DEPLX=CALC_FONC_INTERP (      FONCTION=FONC,
                             NOM_PARA=' INST',
                             LIST_PARA=LFONC,);
CHARG_SE=AFFE_CHAR_MECA_F (   MODELE=MODELE,
                      DDL_IMPO=_F (
                      GROUP_NO= ("FUNDS", "FONDP",), DX=DEPLX,),);
```

The voluminal loading of gravity is defined as follows:

```
PESA=AFFE_CHAR_MECA (  MODELE=MODELE,
                        PESANTEUR=_F (   GRAVITE=9.81,
                                     DIRECTION= (0. , 0. , -
1. ,),),);
```

3.3 Characteristics of the mesh

The mesh contains:	24575 `TETRA4`
	5120 `PENTA6`
	4096 `TRIA3`

3.4 Values tested

the tests are done on the value of following displacement x (noted DX) for various times and the nodes $N145$ and $N3119$.

Identification	Reference
$DX(N145, t=0{,}8\,s)$	5.1624169321991e-04
$DX(N145, t=1{,}4\,s)$	1.4970110314375e-04
$DX(N145, t=2{,}0\,s)$	- 2.3927413131721e-04
$DX(N3119, t=1{,}0\,s)$	-9.9736272860105e-04
$DX(N3119, t=1{,}6\,s)$	- 8.7855056121762e-04
$DX(N3119, t=2{,}0\,s)$	- 2.3929161952584e-04

One tests also the critical eigenvalue calculated with `CRIT_STAB`.

Identification	Reference
`CHAR_CRIT`	2.477264942149