FDNV100 - Shaking of a water tank with elastic deformable wall

Summary:

This test, of the fluid-structure field, proposes the implementation of a transitory dynamic calculation (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 CAS-test of nonregression.

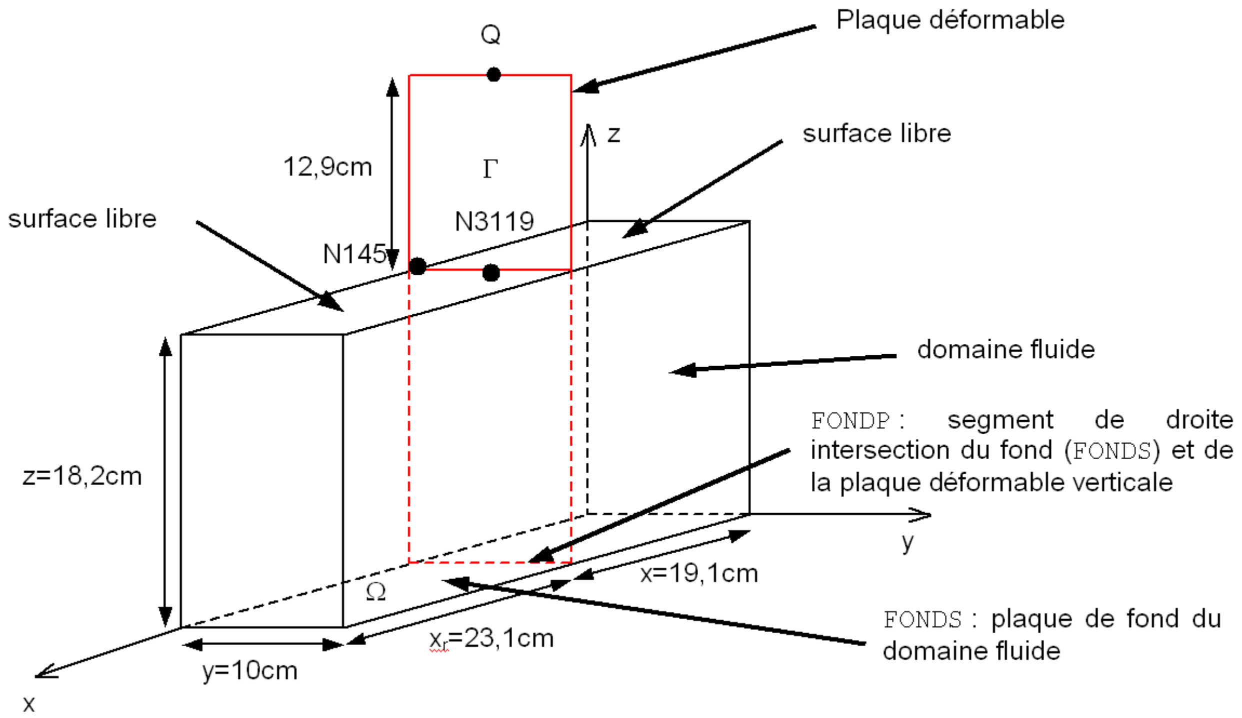
One validates also the analysis of stability (with the keyword **`CRIT_STAB`**) on this problem fluid-structure.

1 Problem of reference

This CAS-test, based on the model of the article [bib1], aims to test the correct taking into account of a free surface in a calculation fluid-structure coupled with the 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 materials

The fluid (water) contents 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 of amplitude $0{,}001\,m$.

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

1.3.2 Conditions of Neumann

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

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: Eigen frequencies and paces of certain modes.

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

In order to have a computing time about a few minutes, it is obligatory to calculate the evolution over a short time (a few seconds). This restrictive framework does not make it possible 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 type not regression of the digital solution.
As the features of calculation coupled fluid-structure in addition are already the object of a certain number of tests of validation, this limitation with nonthe regression for this particular CAS-test is not crippling.

As complementary validation, complete calculation with signal of $250\,s$ was carried out. The spectra 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 the keyword **`CRIT_STAB`** of **`DYNA_NON_LINE`**.

2.2 Results of reference

One tests values of displacements at various moments, according to the direction x , for two points of the grid: $N145$ 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 matrix of stiffness (which is inalienable for elements DKT used here), the analysis could be only of the search type for singularities of the matrix of stiffness (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 eigenvalue criticizes until for the same model but without the fluid and who is worth 2.47726. This eigenvalue will be the same one with each step of calculation because the problem remains linear.

2.3 Uncertainty on the solution

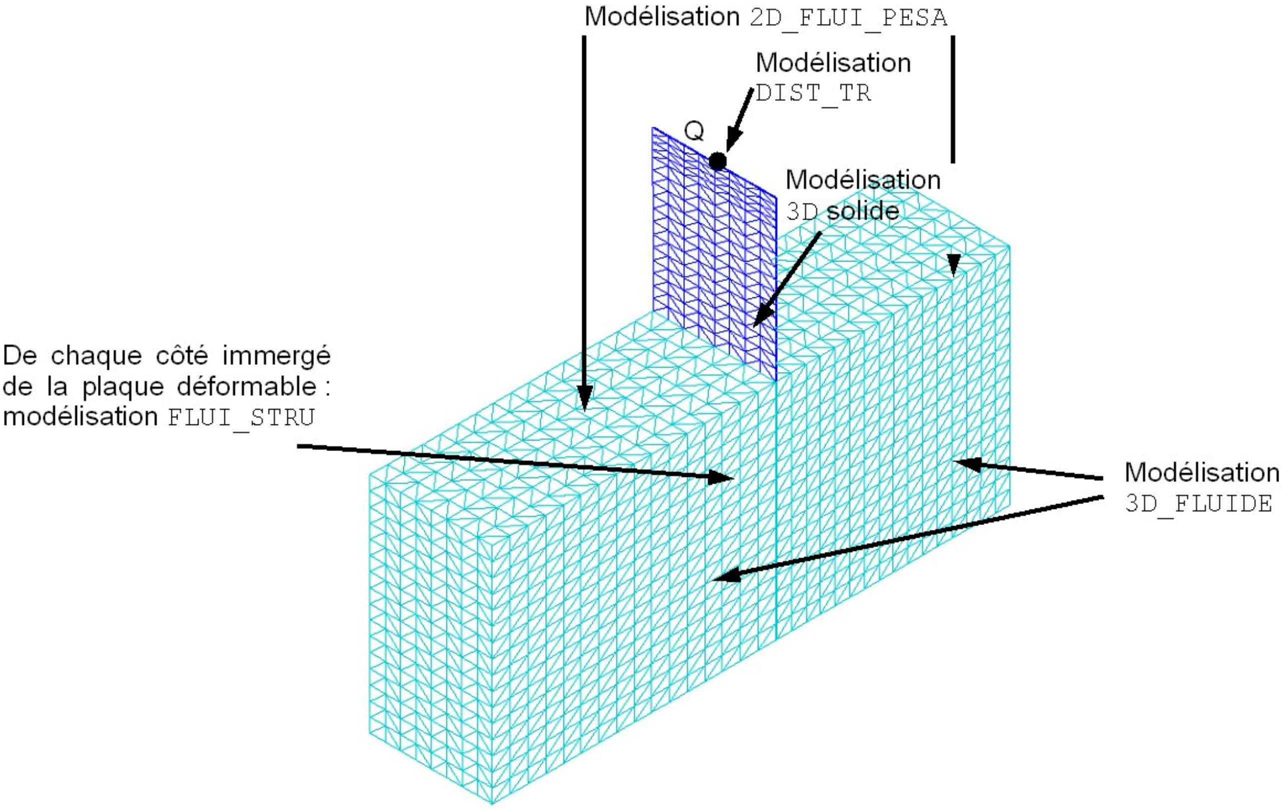
Digital solution (calculated with version 7.3.6 of the code).

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 Modeling A

3.1 Characteristics of modeling



1) The total grid comprises 8163 nodes, that is to say approximately 125000 degrees of freedom,
2) The specific element Q (modeling `DIS_TR`) allows to simply represent an accelerometer present in the model of the article [bib1],
3) The deformable plate is modelled by 5120 elements of massive solid (modeling `3D`) pentaedric with 6 nodes (10 layers in the thickness for a good approximation of the behavior in inflection in spite of the linearity of the elements),
4) free surface is modelled by 512 elements `MEFP_FACE3` (modeling `2D_FLUI_PESA`) triangles with 3 nodes,
5) fluid volume is modelled by 24576 elements of fluid (modeling `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 of 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 ( REALITY = ''' (REAL: 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 grid

The grid 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 moments 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 eigenvalue criticizes calculated with **`CRIT_STAB`**.

Identification	Reference
`CHAR_CRIT`	2.477264942149