SPHERIC benchmark test case

test case title	Tuned Liquid Damping problem
SPHERIC test case number	
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Introduction

This test case deals with the coupling of the motion of a sloshing tank and a single degree of freedom structural system (SDOF), which is generally denoted as a tuned liquid damper (TLD). The tank is free to roll and its motion is excited by an external angular moment created by a periodically moving mass.

The aim of this test case is to show the extent to which the breaking waves and sloshing dynamics affect the damping characteristics of a sloshing damper.

Flow phenomena

In the wave impact problem, overturning and breaking waves are present influenced by a resonance phenomenon, because the first sloshing frequency referred to the filling level matches the natural frequency of the moving mass.

The breaking waves and sloshing dynamics affect the damping characteristics of a sloshing damper.

Geometry

The Plexiglas tank along with its dimensions used in the experiments is shown in figure 1 (its perpendicular dimension is 62 mm). The rotation center is 470 mm above the baseline of the tank. The tank, initially in equilibrium, is free to rotate and its movement is induced by a weight of mass m=4.978 kg that moves along an initially horizontal rail attached to the rotation center of the tank which periodically displaces the centre of gravity. A basin experiment analogy would be a vessel with free roll motion subjected to regular transverse waves.

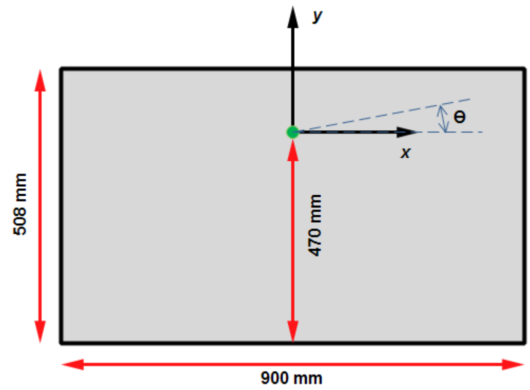

Figure 1 Tank Geometry

Boundary conditions

An analytical model (Fig. 2) of the SDOF structural system used in the experiments is needed in order to have it incorporated into the structure part of the SPH code. It was obtained by measuring system masses and inertias and by analyzing its dynamics, in order to characterize its damping term, which is composed of a dry friction and a linear damping term.

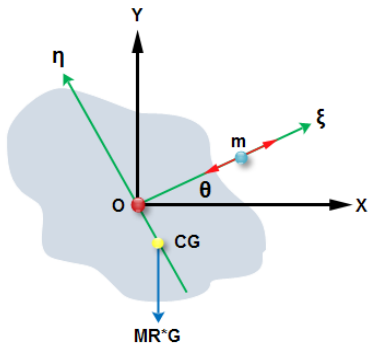

Figure 2. Analytical Model

The analytical model used to describe the behavior of the system is described in the following equations:

$$\left[\mathrm{I}_0 + m\xi_m^{\ 2}(t)\right]\ddot{\phi} + 2m\xi_m(t)\dot{\xi}_m(t)\dot{\phi} - gS_G\sin(\phi) + mg\xi_m(t)\cos(\phi) = Qdamp(t) + Qfluid(t)$$

$$Qdamp(t) = -K_{df}\,sign(\dot{\phi}) - B_\phi\dot{\phi}$$

In these equations Φ is the roll angle, g is the gravity constant, I_0 and S_G are the polar moment of inertia and static moment of the rigid system with respect to the center of rotation, $\xi m(t)$ and $\xi m(t)'$ are the moving mass position and velocity (included in results file), K_{df} is the dry friction damping coefficient and B_Φ is the linear damping coefficient. Finally, *Qfluid(t)* is the fluid moment to be simulated with SPH. The values of these coefficients are shown in the Table 1.

Quantity	Units	Value
S_G	$kg \cdot m$	−29.2
I_0	$kg \cdot m^2$	26.9
K_{df}	$N \cdot m$	0.540
B_ϕ	$N \cdot m/(rad/s)$	0.326
ω_0	rad/s	3.26

Table 1. Mechanical parameters of the rigid system

Initial conditions

At time zero the moving mass is located at the center of rotation, thus the tank is initially in horizontal position.

The free surface is located at 92 mm filling for the three different fluids used which are at 19 ºC and can be considered Newtonian with the S.I units values as shown in Table 2.

	ρ	μ	ν	σ
Water	998	8.94e-4	8.96e-7	0.0728
Oil	990	0.045	5e-5	0.033
Glycerin	1261	0.934	7.4e-4	0.064

Table 2. Liquids properties

Discretisation

Does not apply.

Results specification

Motion signal moving mass and structure response

Two motion signals are registered: the first one is the motion signal of the moving mass, which is directly registered through the electrical motor control card. The second one is the motion signal of the structural response which is measured using a linear encoder.

The experimental data of the moving mass is fitted using least squares in order to obtain a smoothed angles curve, which is necessary to obtain an estimation of the curve derivative and second derivatives, necessary for SPH codes.

Digital video

General 30 FPS videos of the motion of a sloshing tank and a single degree of freedom structural system were taken. The resolution is 640X480. Files are converted to AVI format, using the XVID compressor (please install it for a correct decoding).

Visit http://canal.etsin.upm.es/ftp/SPHERIC_BENCHMARKS/ for a full description of all these data.

Results format

The file ***T_1-94_A100mm.txt*** is located in the subfolder ***\data_files*** which is a ASCII file with 8 columns as follows:

Column 1:***Weight_X_Position_smooth_splines [deg]***
Column 2:***dx\dt Weight_X_Position_smooth_splines [deg\s]***
Column 3:***dx\dt^2 Weight_X_Position_smooth_splines [deg\s^2]***
Column 4:***Weight_X_Position_original [deg]***
Column 5:***Roll_angle_response_empty [deg]***
Column 6:***Roll_angle_response_water [deg]***
Column 7:***Roll_angle_response_oil [deg]***
Column 8:***Roll_angle_response_glycerin [deg]***

Video files
The files are located in the subfolder **\ *Video Files,*** where there is a video file for each fluid as follows:
a100_h93_ww0_glicerin.avi
a100_h93_ww0_oil.avi
a100_h93_ww0_water.avi
a100_ww0_empty.avi

Benchmark results

The liquid depth (92mm) was chosen in order to match the first resonance period T0 of the structural system. The most relevant case with moving mass amplitude A=100mm and excitation period equal to the structure's natural period is presented. The indicator devised to characterize the damping effect of the liquid inside the tank is defined as 1 minus the ratio of the maximum amplitude of the roll angle in the partially filled and empty tank condition. The ratio ranges from a 76% reduction for water to 57% for glycerin, with oil in between. This can be appreciated from the time history of the tank motion from figure 3.

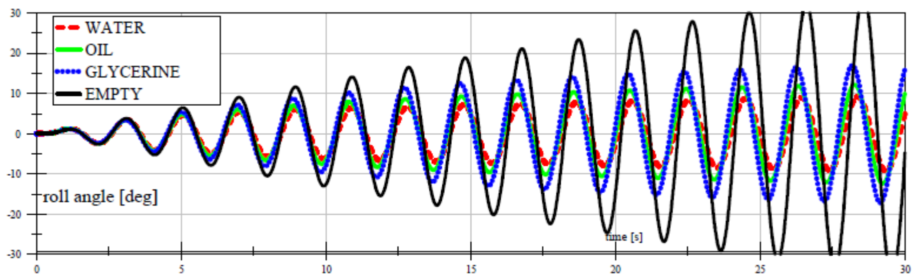

Figure 3. Coupling problem: Roll angle time-history at resonance for A = 100mm

Future work

There are no plans at the moment to continue with this test case. It is not easy to obtain the same properties for the structure. Nonetheless it is necessary to mention that the uncertainty of the data is low. The motion of the tank is the result of the integration of the liquid action on the tank walls. This integration mitigates the fluctuations that occur in the fluid flow and therefore, the repeatability of the motion is high. This was confirmed during the experimental campaign though no specific uncertainty assessment was conducted.

References

When using this test case, please cite these references.

[1] G. Bulian, A. Souto-Iglesias, L. Delorme, and E. Botia-Vera, “SPH simulation of a tuned liquid damper with angular motion,” Journal of Hydraulic Research, vol. 48, no. Extra Issue, pp. 28–39, 2010.

[2] Botia-Vera, E., A. Souto-Iglesias, G. Bulian, and L. Lobovský (2010). Three SPH Novel Benchmark Test Cases for free surface flows. In *5th ERCOFTAC SPHERIC workshop on SPH applications*.