Impact of a wedge in water: assessment of the modeling keyword, presence of cavitation and choice of the filter most suitable for the case study

D. Guagliardo[1,a], E. Cestino[1,b*], G. Nicolosi[1,a], E. Guarino[1,a], A. Virdis[1,a], A. Alfero[1,a], D. Pittalis[1,a] and M.L. Sabella[1,a]

[1]Politecnico di Torino (DIMEAS), Corso Duca degli Abruzzi, 24 10129 Torino, Italy

[a] teams55.polito@gmail.com, [b] enrico.cestino@polito.it

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Abstract. The purpose of this paper is to compare the results obtained from a rigid wedge impacting water that is modelled using different techniques based on the SPH (Smoothed Particle Hydrodynamics) method. The study aims to evaluate the quality of the results, optimizing the computational time, which is obtained when the wedge is discretized as a section or as a half of it. The comparison of the results obtained considers the different materials that the ANSYS LS-DYNA software allows to assign to water through different keywords. The effect of cavitation on the pressures reached during the vertical impact was evaluated as a function of ambient temperature. Finally, given the high noise recorded in the pressure files, the study uses a filter created in MATLAB. The latter involves a double pass through the Kalman filter first and the Gauss filter later. All results obtained through the numerical method are compared with Von Karman and Wagner analytical theories.

Introductio

The student team ”TEAM S55” of Politecnico of Turin was born in 2017 to rebuild the SIAI-Marchetti S55 seaplane on a 1:8 scale [1-3]. The following paper is created by the FSI section which studies the interaction between the aircraft and the water at ditching. The purpose of this paper is to describe through ANSYS LS-DYNA the water impact of a wedge, at a vertical speed of 5.8 m/s, to evaluate the effect of various parameters in wedge and water modelling. Due to the high computational requirements inherent in the SPH method, the influence of air is neglected to reduce the computational time, since it doesn't have an influence on the accuracy of stress prediction [4]. The analysis results are purified from numerical noise through a filter implemented in MathWorks MATLAB.

Model description

Full model. The model under study is composed of two parts, here under described. The first one is the wedge, it has a width of 254.8 mm, a height of 105 mm, a thickness of 2 mm and a dihedral angle of 30°, as shown in *Fig. 1*. The item is discretized in 1320 shell elements, mainly concentrated in the impacting wall. The material used is an infinitely rigid steel, modelled through the keyword *020 MAT_RIGID*. The boundary conditions forced the wedge to translate only along the z-direction and lock any rotation.

The second one is the water. The water box has dimensions x = 1200 mm, y = 40 mm, z = 300 mm, and it got an SPH number of 56000. It has got **BOUNDARY_SPH_NON_REFLECTING* plans in the bottom and perpendicular to the x-direction, and **BOUNDARY_SPH_SYMMETRY-PLANE* perpendicular to the y-direction. It's possible to use three different materials to model the water [5]: *009 MAT_NULL*, *001 MAT_FLUID-ELASTIC_FLUID* and *010 MAT_ELASTIC_PLASTIC_HYDRO*. For each material, it's possible to define the cavitation pressure. The phenomenon of cavitation is a function of the ambient temperature through vapor pressure, and it is defined differently for each material. For materials 009 and 010 cavitation is indicated by the pressure cut-off, while for materials 001 it is defined by the cavitation pressure parameter.

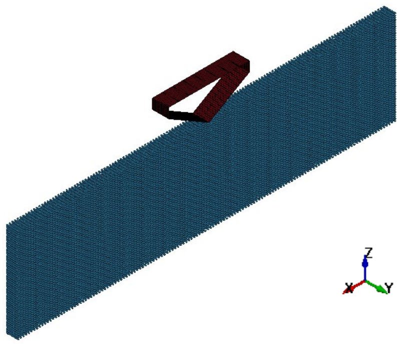

Figure 1. Wedge and water

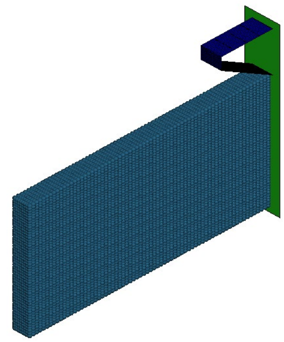

Figure 2. Half wedge with symmetry plane

Model description

Half model. The geometry in this case turns out to be the exact half as shown in *Fig. 2*; both the wedge and the water box were halved along the x direction and a symmetry wall was then added via the keyword **BOUNDARY_SPH_SYMMETRY_PLANE*, green in *Fig. 2*, as used by [4].

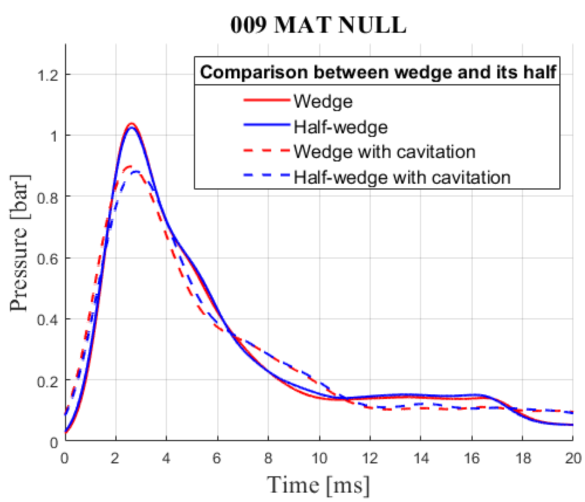

Figure 3. Comparison using MAT_NULL

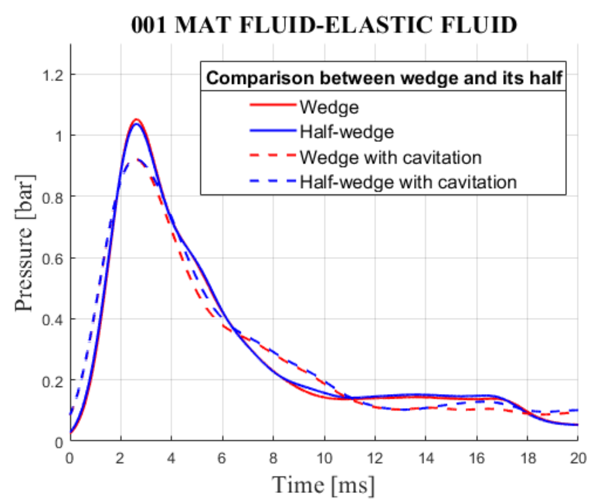

Figure 4. Comparison using MAT_ELASTIC

Between a complete model and a halved one there is a time saving of 48% with a discrepancy in the results, as regards the peak pressure in *001 MAT_FLUID-ELASTIC_FLUID*, of 1% for the results in which cavitation is neglected and almost nothing as regards the case in which cavitation is considered. The pressure peaks for *009 MAT_NULL* differ by 1.34% when cavitation is ignored and by 1.84% when cavitation is considered. The pressure detection sensor, in all analyses, is positioned at 13.93 mm along the x direction; this position will be the same one considered for the analytic theories of von Karman [6] and Wagner [7].

The pressure results for the cases just mentioned are shown in *Fig. 3* and *Fig. 4* and are related respectively to the materials *009 MAT_NULL* and *001 MAT_FLUID-ELASTIC_FLUID*. Furthermore, the vertical impact velocity of the wedge is 5.8 m/s and the vapor pressure considered for cavitation is referred to standard conditions (25 °C).

Water keyword comparison

As studied by Q.W. Ma and D.J. Andrews [7] the water can be defined in three different ways. *009 MAT_NULL* and 0*10 MAT_ELASTIC_PLASTIC_HYDRO* need an EOS (Equation Of State), it was chosen the **EOS_GRUNEISEN* for both materials. In modelling a fluid, it can be observed that some keywords can be advantageous due to computational cost, the *001 MAT_FLUID-ELASTIC_FLUID* appears to be the fastest in computation, because it's the only one without an EOS. The *009 MAT_NULL* is 6% slower, and the 0*10 MAT_ELASTIC_PLASTIC_HYDRO* is even 26% slower. *Fig. 5* shows the results obtained for the three different keywords, in the absence of cavitation, compared with the maximum values predicted by the analytical theories of von Karman [6] and Wagner [7]. It's noteworthy that in the peak pressure zone, which is the most important in terms of structural strength, the values are consistent among the various materials, with an error lower than 2%.

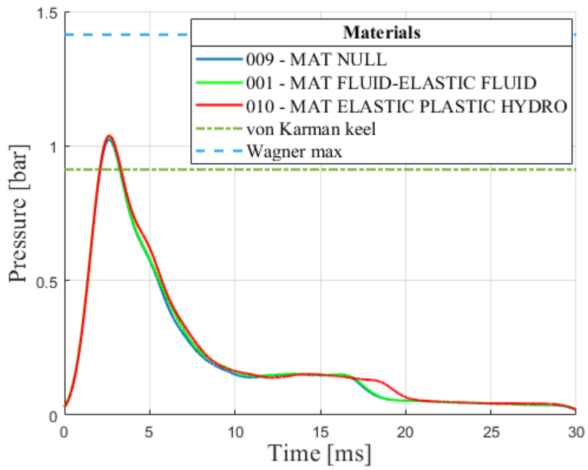

Figure 5. Water keyword comparison

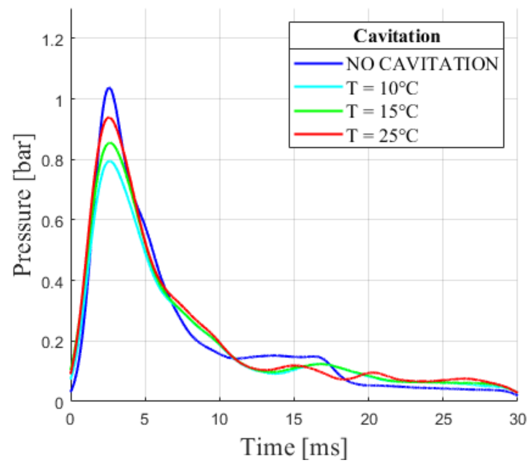

Figure 6. Pressure as function of temperature

Effect of cavitation

Cavitation is a phenomenon that can occur when an object impacts a liquid, causing its phase change to gas due to the variation in fluid pressure, as predicted by Wagner [8]. That condition is verified in the study, but it was found a similar phenomenon even with velocities that don't verify the relation. This phenomenon is defined by Korobkin [9] as interface cavitation. The study shows that in a zone close to the first impacting object part, the hydrodynamic pressure is smaller than the atmospheric pressure. This leads to the formation of a cavity that, however, does not extend to the peripheral zones. The formation of this cavity, whose shape and size are described analytically in [9], changes the liquid flow and the pressure distribution. On the LS-DYNA software [10], pressure cut-off (PC) is defined to allow for a material to "numerically" cavitate. In other words, when a material undergoes dilatation above a certain magnitude, it should no longer be able to resist this dilatation. Since dilatation stress or pressure is negative, setting PC as the vapor pressure value, for the desired temperature, would allow for the material to cavitate once the pressure in the material goes below this negative value. Cavitation pressure (CP) is also defined in *001 MAT_FLUID-ELASTIC_FLUID*, but in this case the chosen value is positive. Analysis have been carried out by comparing the pressure trend in the case where the cavitation is not considered and if the cavitation is considered at the temperatures of 10°C, 15°C and 25°C. For the comparison the material 001 MAT_FLUID-ELASTIC_FLUID is used. As can be seen in *Fig. 6* the pressure peak without cavitation is greater with respect to the cases where cavitation is considered, but after the peak, signal noise is lower. Considering that the vapor pressure decreases as the temperature decreases, it was found that the peak pressure decreases with decreasing water temperature and the effect of cavitation becomes more significant.

Filter choice and effects

The pressure results contained in the outputs provided by LS-DYNA are very noisy due to the unstable nature of the SPH. From previous studies [11], the importance of data filtering in this type of experiment was understood; so, the new goal was to search for the best filter that approximated data accurately with a lower error correlation. The choice was the Kalman filter following the indications given by [12] as it also reconstructs the trend without adding delays. From experimental results, Kalman filter is superior in terms of filtering accuracy, it's implemented in two iterative repeated phases: prediction and update. The *prediction* part consists in predicting the estimated state variable and the predicted state variance variable; the update part includes the Kalman gain and inside it the filtered data corresponds to the *updated* estimated state variable and is shown as the output of the algorithm. However, filtering performance depend on the parameters R, measurement constant, and Q, process variance constant. As reported by [13], the parameters R = 1 and Q = 0.01 experimentally provide the best filter results because noise is reduced but the original characteristics of the data are preserved. In general, the ratio of R to Q should not exceed 100 to avoid excessively filtered results. After the application of the Kalman filter, the graph is still partially affected by noise, for this reason a Gaussian filter is also applied to further smooth the curves (*Fig. 7*).

A Gaussian filter attenuates the high-frequency components in the signal and passes the low-frequency components. It is based on input signal convolution with a Gaussian function. The input signal is convoluted with the Gaussian filter kernel. This involves point-by-point multiplication

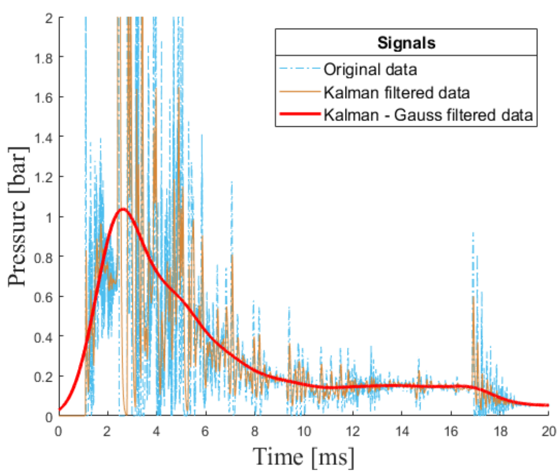

Figure 7. Kalman – Gauss filter

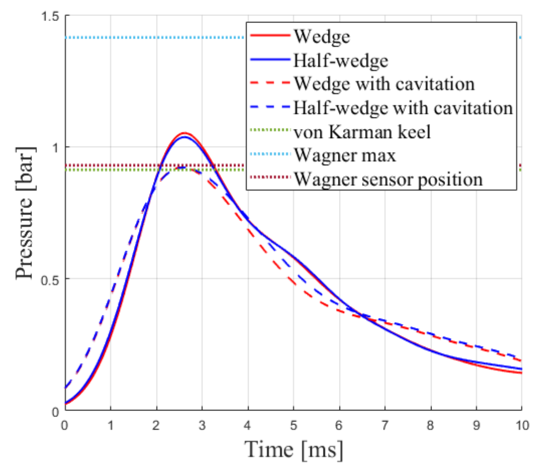

Figure 8. Numerical-analytical comparison

between kernel samples and input signal samples, followed by the sum of the results. The smoothing effect produced by a Gaussian filter will depend on the width of the kernel, which is controlled by the sigma parameter, standard deviation, automatically calculated by MATLAB.

Conclusions

Using a half geometry, it's worth choice to maintain the precision in the results and to reduce the computational cost. The cavitation effect or the cavity formed under the wedge reduce the pressure peak, but it can produce undesired vibrations. It's highlighted the importance of the cavitation as function of temperature variation in the range from 25 °C to 10 °C. A lower water temperature can produce a lower pressure due to the reduction of vapor pressure and bulk modulus. The reduction of these two values prevails over the increase of density and viscosity coefficient. Furthermore, the peak pressure, obtained in the analyses considering cavitation with the water temperature at 25 °C, well fit with the pressure values predicted by the analytical theories of Wagner and von Karman for the sensor position (*Fig. 8*), that were based, especially the von Karman theory, on practical experiments in which is naturally included the cavitation effect.

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