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Numerical-analytical evaluation about the impact in water of an elastic wedge using the SPH method

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Abstract. In a preliminary study about the structural behaviour of a body, the material can be supposed infinitely rigid. This choice is useful to simplify the problem and to obtain results that well approximate reality. In this specific case under study, it proves how the effect of the material elasticity has a fundamental role on the pressures developed when a wedge impacts water. The analysis is made using ANSYS LS-DYNA software modelling the wedge through the FEM method, characterized by the material defined by the MAT_001-ELASTIC keyword, and the water defined by the SPH (Smoothed-Particle Hydrodynamics) method. The elastic body behaviour will be evaluated through the presence of a displacement in the middle point, on the face impacting water, and the comparison between the obtained pressure and the one predicted by the analytical theories of von Karman[1] and Wagner[2], which study the impact of a rigid wedge.

Introduction

The student team "TEAM S55" of Polytechnic 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.

In a preliminary study of the phenomena [4, 5], the rigid wedge approximation can be used to predict the maximum slamming pressure.

The purpose of this paper is to evaluate the pressure trend and the displacement of the wedge's impacting surface during the penetration of a wedge into the water. The numerical analysis was done using the software ANSYS LS-DYNA, in which 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 influence the accuracy of stress prediction [6].

Starting from analytical theory developed by von Karman [7] and Wagner [8] based on a rigid wedge, subsequent studies [3, 9] have been considered that go beyond rigid wedge considerations and move towards different aspects of elasticity. The effect of the structure elasticity on the pressure peak and distribution will be considered. Furthermore, along the impacting surface, the results of displacements will be considered as the speed varies.

Von Karman and Wagner theories

Wagner [8, 10] and Von Karman [7] theories are the most indicated theories in literature to estimate the ditching of a wedge in the water.

Von Karman theory, Eq. 1, is based on the application of the momentum theorem on a body whose weight increases at the impact with the water. The increase is caused by the water contained in a cylinder of diameter equal to the wedge width. Von Karman [7] aimed to find out how the dihedral angle affected the result of the pressure on landing.

$$P_{VK}(x) = \frac{\rho V_0^2}{2} \frac{\pi}{\left(1+\frac{\gamma \pi x^2}{2W}\right)^3} \cot(\alpha) \tag{1}$$

$$P_{VK_{Max}} = \frac{\rho V_0^2}{2}\pi\, cot(\alpha) \tag{2}$$

According to his study, the maximum pressure, Eq. 2, is found at the keel of the wedge and the pressure increases as the dihedral angle decreases.

Wagner [10] studied the impact to estimate the pressure considering the superposition principle. The first studied phenomenon is the wedge penetration in the water studied like a perfectly inelastic collision. The second one is the water molecules behavior. In fact, when the wedge penetrates the water, the stationary molecules start to move, reducing the internal pressure. This decrease is function of the wedge penetration: during the phenomena both the wedge and water molecules velocity have a decreasing trend that causes a minor reduction of pressure, Eq. 3 and Eq. 4.

$$P_W(x) = \frac{1}{2}\rho V^2\left[\frac{\pi}{tan(\alpha)\sqrt{1-\frac{x^2}{L^2}}} - \frac{\frac{x^2}{L^2}}{1-\frac{x^2}{L^2}} + 2\,\frac{\ddot{y}}{V^2}\sqrt{L^2-x^2}\right] \tag{3}$$

$$P_{W_{Max}} = \frac{1}{2}\rho V^2\left[1+\frac{\pi^2}{4\,tan^2(\alpha)}\right] \tag{4}$$

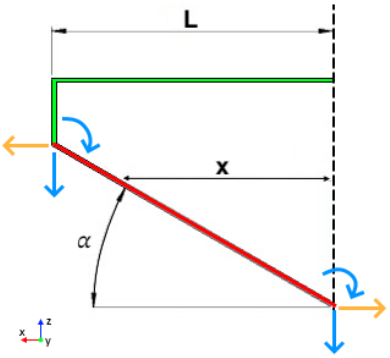

Figure 1: Model constraints

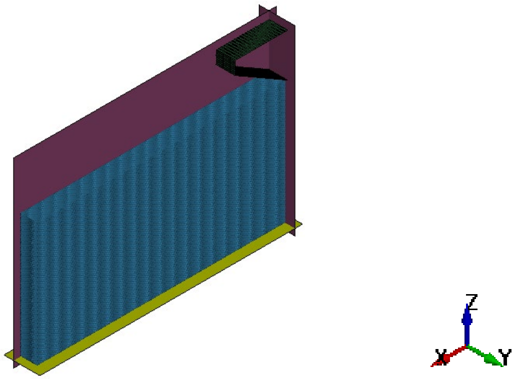

Figure 2: Half wedge model in ANSYS LS-DYNA

Model

The elastic model shown in Fig. 1 is a wedge modelled in ANSYS LS-DYNA PrePost. The wedge has a width of 127.4 mm, a height of 105 mm, a thickness of 2 mm and a dihedral angle α of 30°. It is 0.43 kg heavy, and the material is considered as isotropic. The surface impacting water, the oblique one, and the others are modelled respectively through 001 MAT_ELASTIC and 020 MAT_RIGID, both considering a steel with a Young's modulus of 190GPa. The decision to use MAT_RIGID in non-impact water surfaces is in according to reduce the computational cost and to model the boundary as desired.

The boundary conditions, shown in Fig. 1 and Fig. 2 are:

- displacements allow in x and z directions, and rotation allow along y direction for elastic surface;
- displacements constrain in x and y directions at the edge of elastic surface;
- displacements allowed just in z directions and all rotations blocked for the rigid surfaces;
- control volume is composed of a **RIGIDWALL_PLANAR,* in the bottom (yellow plane), a **BOUNDARY_SPH_NON_REFLECTING*, perpendicular to x-direction and on the side

opposite the wedge, and three **BOUNDARY_SPH_SYMMETRY-PLANE* (purple planes), two perpendicular to the y-direction and one perpendicular to the x direction and close to the wedge.

The material used for the water is 009 MAT_NULL and the Equation Of State is **EOS_GRUNEISEN*.

The total number of elements is 901200, which 1200 are shell elements and 900000 are SPH (Smoothed Particle Hydrodynamics). The computational cost for each simulation is about 15 h using 48 CPUs simultaneously.

Pressure and displacement results

The study results plotted in Fig. 3 and Fig. 4 show the pressure trend as function of the wedge surface and velocity respectively. The Fig. 3 represents the Von Karman and Wagner theories applied to our wedge and the results of the numerical analysis, when the impact velocity is 5.8 m/s. The Fig. 4 considers the pressure detection sensor, in all analyses, is positioned at 13.93 mm along the x direction. The maximum pressure expected is reached at the wedge's keel for Von Karman and Wagner theory both. It is interesting to notice that Von Karman predicts higher pressure value than Wagner along the surface. This Wagner trend is due to fluid dynamic effect that becomes increasingly negligible along the surface.

The numerical model results are included between the two theories values until they reach the middle of the impact surface. Over that position the numerical results estimate higher pressure values than the two theories.

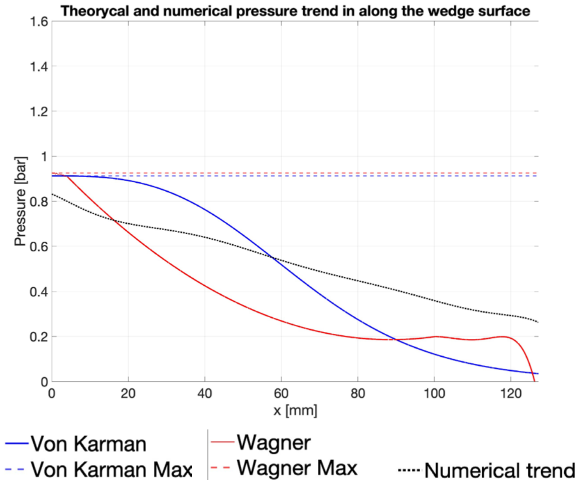

Figure 3: Pressure as function of the surface

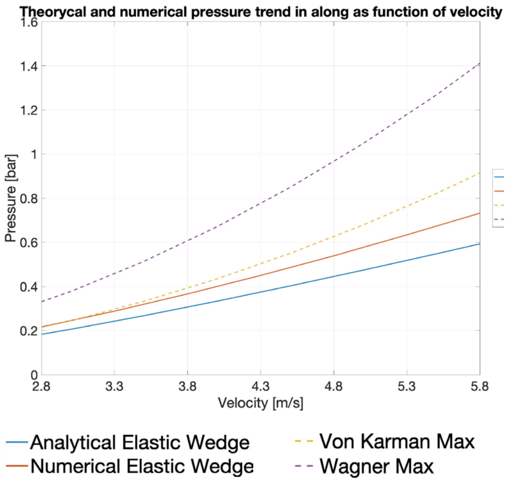

Figure 4: Pressure as function of the velocity

The phenomena studied correspond to a perfectly inelastic collision, so it is important to observe how the pressure changes as function of velocity. Fig. 4 compares the wedge behaviour assuming a rigid, as descripted by Von Karman and Wagner theories, and an elastic material, as reported in [3]. At the impact, the rigid material undergoes a higher-pressure magnitude than elastic material, because part of the impact energy is the source of the deformation of the impact surface and the remaining part is absorbed by the body. Moreover, the analytical and numerical results are different due to the boundary conditions considered; in [3] the panel is considered simply supported and greater freedom to deform have consequently a reduction of pressure.

In Fig. 5 is showed the maximum displacement for each node that makes up the mesh, not to be confused with the maximum deformation. As expected, the numerical results of maximum displacement depend on the vertical speed; as higher as speed, the higher the maximum displacement will be.

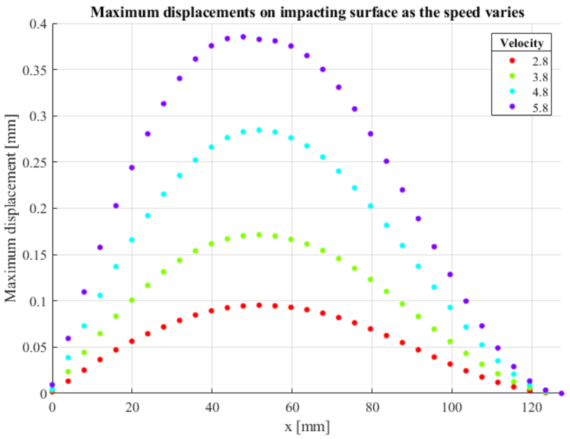

Figure 5: Displacement as function of the velocity

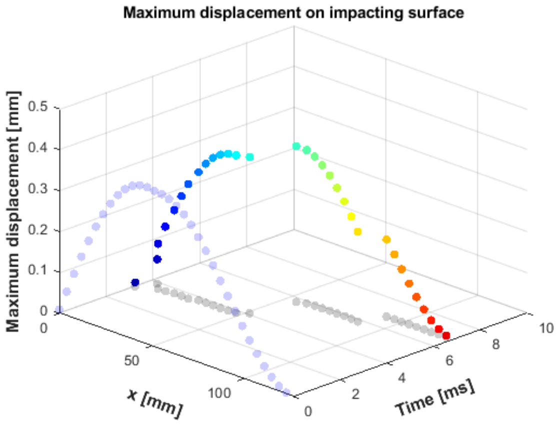

Figure 6: Displacement as function of the velocity

In Fig. 6 the vertical velocity considered is 5.8 m/s; being the maximum displacement in function of surface position, the blue shadow is the same curve plotted in Fig. 5. In Fig. 6, the added value is given by the providing of how the maximum displacement evolves over time. Being the keel to impact the water first, the maximum displacement moves with the increase of the wetted part.

Conclusions

A preliminary study on a rigid wedge impacting water be made neglecting the elasticity behaviour to predict the maximum slamming pressure. On the other hand, results of real impacting model can be conflicting and for pressure can be lower than expecting. An elastic model may be introduced trying to predict a better behaviour of the real nature of things.
The elastic model introduces the possibility of wedge deformation, this allows a local increase of dihedral angle with a decrease of pressure. In conclusion, the effect of flexibility on pressure distribution is more important as speed increases due to the higher displacement measured.

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