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NUMERICAL MODELING OF INTERACTION BETWEEN UNDERWATER GAS BUBBLE AND SUBMERGED TORPEDOES

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Abstract: *The experiments have determined that, even close to the detonating underwater charge, the gas bubble and shock wave are sufficiently separated to produce individual effects onr structures. These results allow evaluating the shock wave parameters and the effects of these two phenomena to be studied separately. This paper focuses on the numerical modeling of the underwater gas bubble effect on submerged torpedo. A torpedo is simplified as free-free beams made from rigid perfectly plastic material. A detailed fluid structure interaction is analytically studied to obtain the equation governing the fluid force per unit length of the beam and the fluid - beam interaction equation. The time history of a bubble radius and explosion magnitude is graphically shown. The numerical simulation of interaction between underwater explosion and underwater structure will be presented.*

1. UNDERWATER EXPLOSION PHENOMENON

An underwater explosion interacts with the surrounding fluid in two different phases. The first phase is a transient shock wave, with a rapid rise in the fluid velocity, and large inertial loading. The peak pressure of this phase is very high, but extremely short duration. The second phase is a radial pulsation of the gas bubble. This phase is characterized by lower peak pressure and much longer duration.

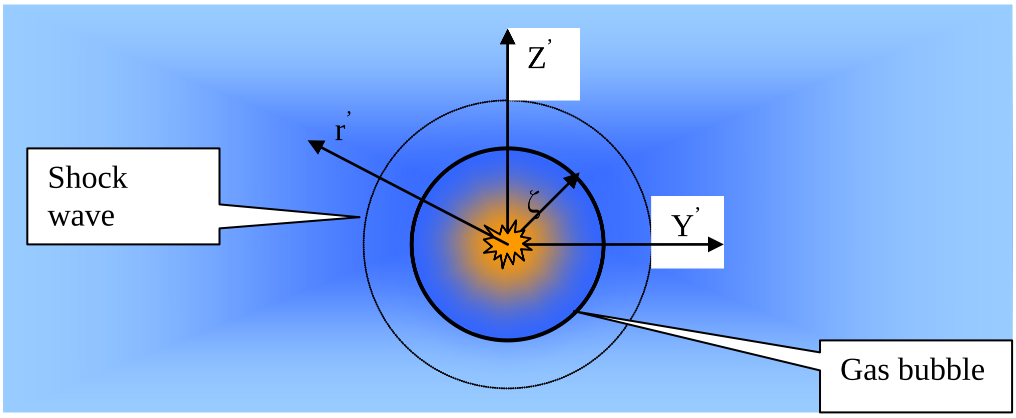


Figure 1 O'x'y'z' coordinate systems with the origin located at the bubble centre

In an underwater explosion, we must consider both types of loads: shock wave and bubble pulse, but because of their quite different time scales, they may be separately analyzed.

Basically, a shock wave induces local damages but a bubble can lead to global damages. The present paper is concerned with the damage pattern produced by the bubble pulse. The pulse duration of an underwater explosion bubble is close to the lower frequency vibration modes of a typical ship, submarine or torpedo. Thus, the induced vibration can easily be so severe that the hull girder fails and a plastic hinge is formed at the point of failure.

2. PROBLEM FORMULATION/ASSUMPTIONS

To facilitate the derivation and to simplify the problem as much as possible without losing essential features we consider:

1. The torpedo is considered a uniform free-free beam of circular section, subjected to a pulsating gas bubble only as shown in figure 3.

2. The beam is slender, $\frac{R_c}{R_0} << 1$, and because $\varepsilon = \frac{R_C}{L} << 1$ resulting that a 3-dimensional flow can be locally approximated by a 2-dimensional flow.

3. The bubble radius and pressure at any time are *ζ(t)* and *P(t)*, and the initial radius and pressure are ζ_0 and P_0.

4. The fluid is inviscid and incompressible.

5. The beam is much smaller than the distance from the bubble centre $R_c/R_0 << 1$

6. There exists a potential *Φ* satisfying the Laplacian equation $\Phi = \varphi_b + \varphi_p$ where:

- φ_b denotes the potential purely produced by the bubble;

- φ_p denotes all other effects due to the presence of the beam.

The main disturbance in the fluid is produced by the bubble: in D_b domain (near the bubble, and far away from the beam), $\varphi_b >> \varphi_p$ and in D_p domain (near the beam and far away from the bubble), φ_b is of same order as φ_p , i.e., $O(\varphi_b)=O(\varphi_p)$. The solution to potential *Φ* can then be found through solving the two potentials φ_p and φ_b.

3. BUBBLE DYNAMICS

According with [2] it is considered a *O'x'y'z'* coordinate systems with the origin located at the bubble centre as is shown in figure 1. In D_b domain, from 6th assumption $\Phi \approx \varphi_b(x',y',z';t)$, and φ_b satisfies the Laplacian equation

$$\nabla^2 \varphi_b = \frac{\partial^2 \varphi_b}{\partial^2 x'^2} + \frac{\partial^2 \varphi_b}{\partial^2 y'^2} + \frac{\partial^2 \varphi_b}{\partial^2 z'^2} = 0 \qquad (1)$$

, and the boundary conditions on the bubble surface are:

$$\frac{\partial \varphi_b}{\partial t} = -\frac{P_g}{\rho_0} - \frac{1}{2}\left|\nabla \varphi_b\right|^2 - g \cdot d_0 \quad \text{at} \quad r' = \zeta_0 \qquad (2)$$

$$\frac{d\zeta}{dt} = \frac{\partial \varphi_b}{\partial r'} \quad \text{at} \quad r' = \zeta \qquad (3)$$

$$\left|\nabla \varphi_b\right| \to 0 \quad \text{at} \quad \text{infinity} \qquad (4)$$

P_g is the pressure inside the bubble, d_0 is the charge depth, g is the gravity acceleration, ρ_0 is the water density. The solution to equations (l) - (4) is a point source with time-dependent strength *q(t)* located at the centre of the bubble of the form

$$\varphi_b = \frac{q(t)}{r'} \qquad (5)$$

Inside the bubble, the gas is assumed to be ideal and the pressure to be uniform:

$$\frac{P_g}{P_0} = \left(\frac{\zeta_0}{\zeta}\right)^{3\gamma} \text{ where } \gamma = 1{,}4 \qquad (6)$$

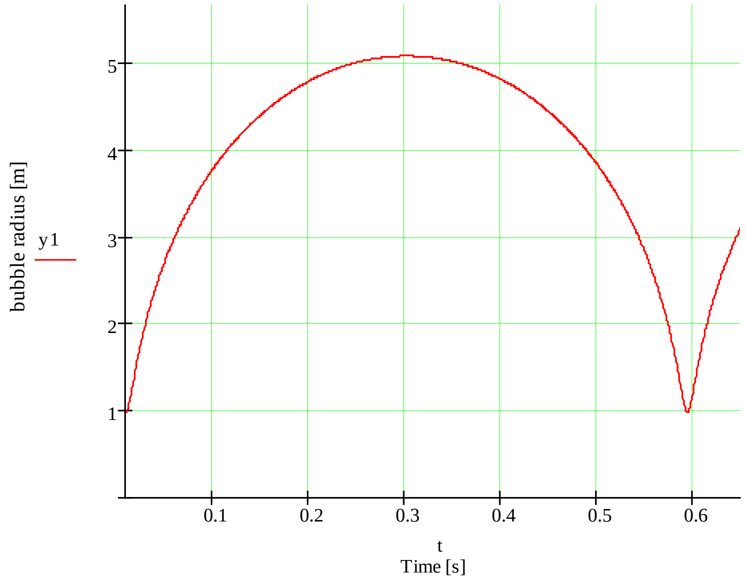
Substituting eqs (5) and (6) into eqs. (2) and (3), we obtain

$$\frac{dq}{dt} = -\frac{P_0 \cdot \zeta}{\rho_0}\left(\frac{\zeta_0}{\zeta}\right)^{3\gamma} - \frac{q^2}{2\zeta^3} + g \cdot \zeta \cdot d_0 \qquad (7)$$

$$\frac{d\varsigma}{dt} = -\frac{q}{\zeta^2} \qquad (8)$$

$$q(t) = -\zeta^2 \cdot \dot{\zeta} \qquad (9)$$

The solutions of eqs. (7) and (8) can be numerically integrated using Runge-Kutta method once the initial conditions are given. Its solutions are two functions ***q(t)*** and ***ζ(t)***, and an example is given in figure 2, [5].



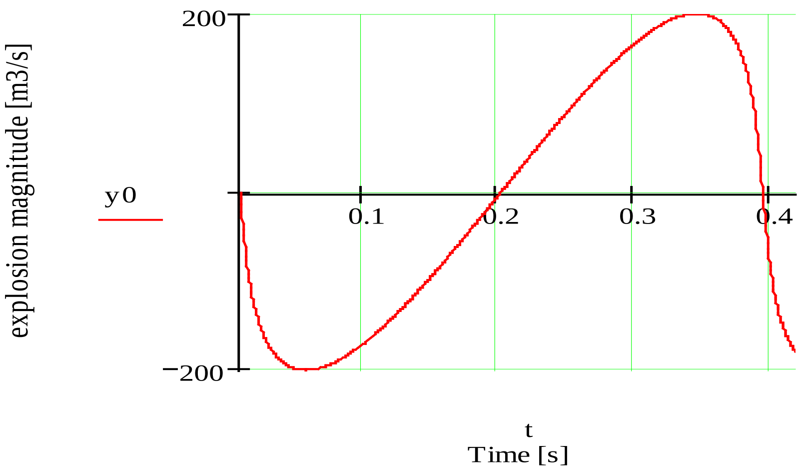


Figure 2 Time histories of bubble radius and explosion magnitude

4. A SUBMERGED FREE-FREE BEAM OF CIRCULAR SECTION SUBJECTED TO A PULSATING GAS BUBBLE

A submerged torpedo is an example of a submerged free-free beam as its buoyancy and gravity cancel each other.

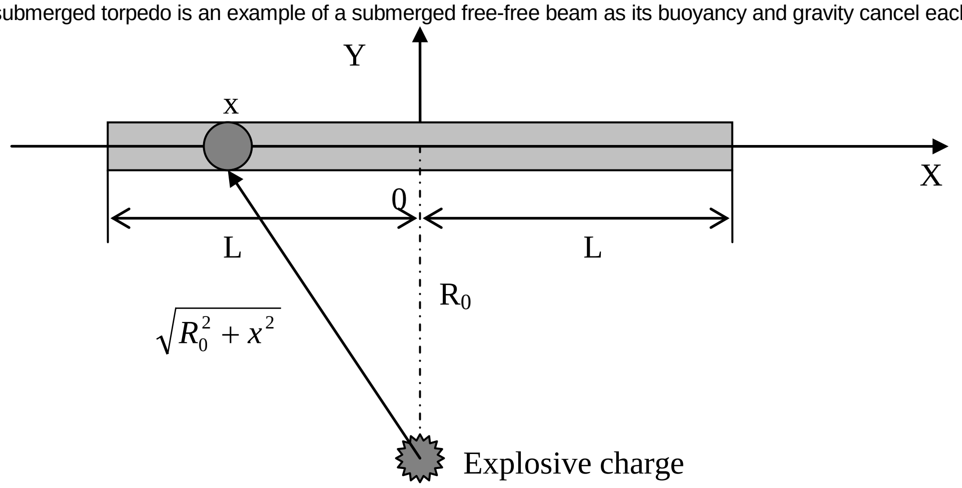


Figure 3 A free- free beam subjected to the bubble

In figure 3, R_C is the radius of the beam, $2L$ is the beam length with free-free supports at both ends, and R_0 is the stand-off distance.

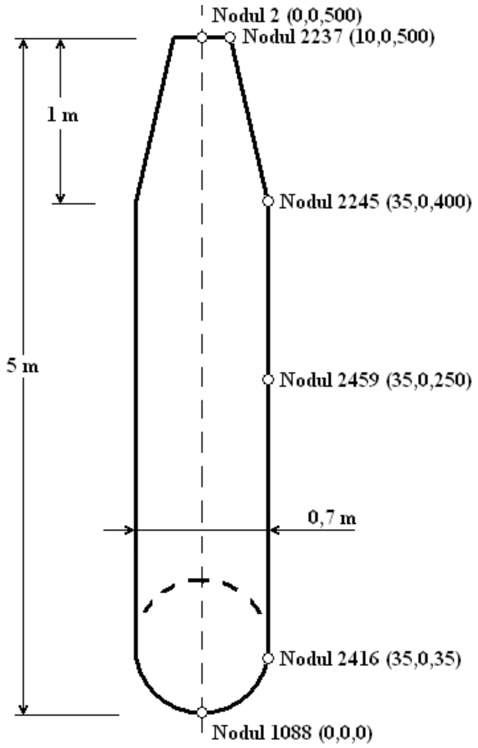
The fluid force per unit length is [5]:

$$f(x,t) = \pi\rho_0 R_C^2 \dot{v} + \pi\rho_0 R_C^2 \dot{v} - \pi\rho_0 R_C^2 \frac{\partial^2 w}{\partial t^2} = 2m_a \dot{v} - m_a \frac{\partial^2 w}{\partial t^2} \quad (10)$$

The first term is the bubble-induced force without diffraction effect considered. The second term is caused by the diffraction effect. The third term is the radiation force caused by the beam motion, and the added mass of a circular section in water is $m_a = \pi\rho_0 R_C^2$.

5. LS-DYNA NUMERICAL MODELING OF A INTERACTION BETWEEN UNDERWATER GAS BUBBLE AND SUBMERGED TORPEDOES

We consider a torpedo with geometrical characteristics: length $L_{tor} = 5\ [m]$, diameter $D_{tor} = 70\ [cm]$, s = 1 cm, stand-off distance $d = 5\ [m]$. The explosive $(\rho = 1.2\ g/cm^3)$ is cylindrical shaped, r = 5 cm, length l = 40 cm and s = 10 mm.



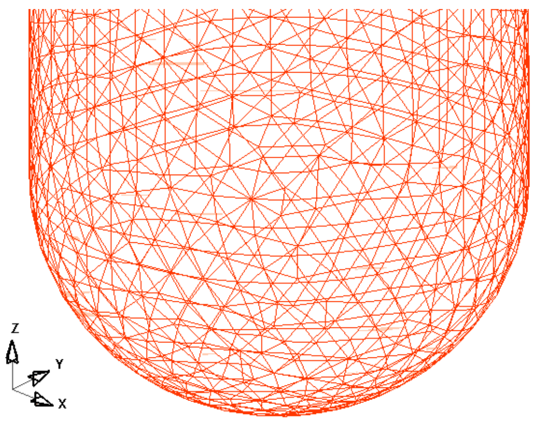


Figure 4 The geometry of the torpedo and a torpedo mesh

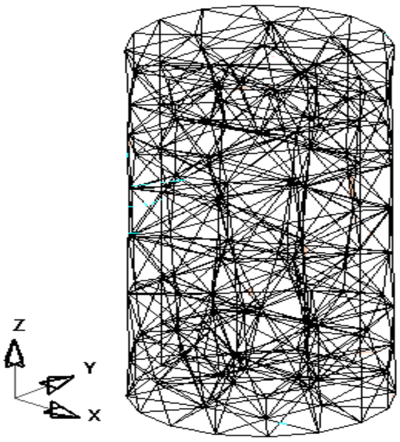


Figure 5 The mesh of the explosive charge

To facilitate the derivation and to simplify the problem as much as possible without losing essential features we consider:

1. There is no cavitations effect;
2. There is no transfer of heat between fluid and metallic submerged torpedo.

6. VON MISES FORCES ON THE TORPEDO

Modeling a interaction between underwater gas bubble and submerged torpedoes, using LS-Dyna we got:

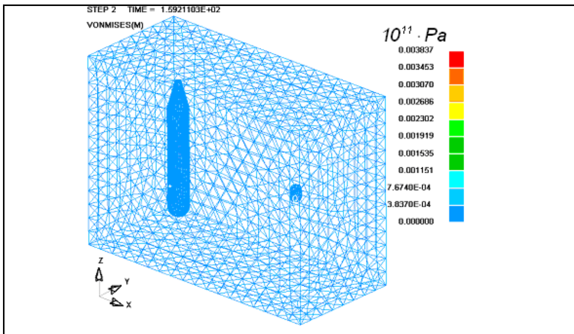
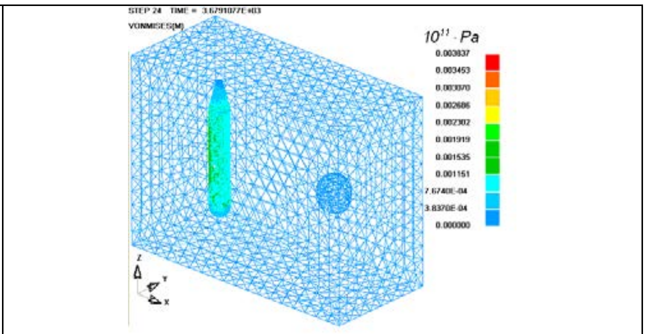
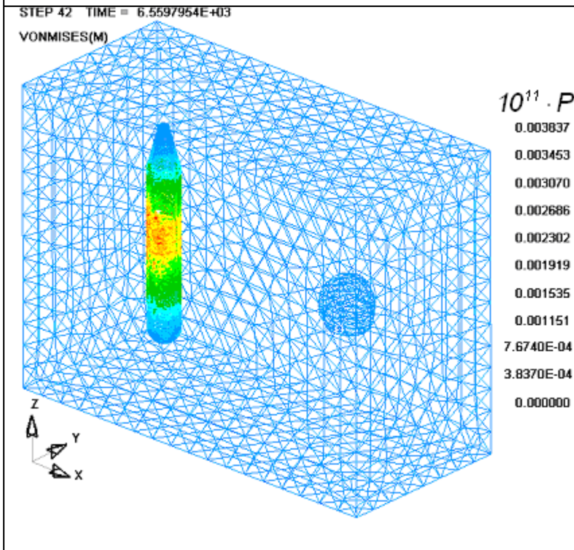
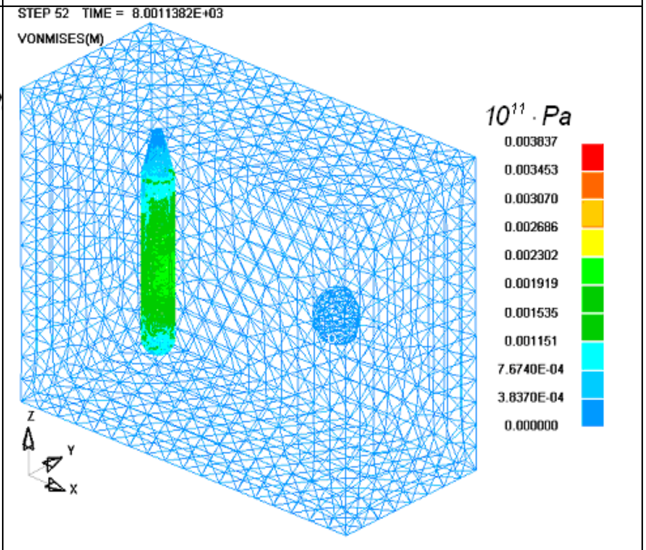
	
Pas 2, time $T = 1.5921103 \cdot 10^{2}$ μs	*Pas 24, time* $T = 3.6791077 \cdot 10^{3}$ μs
	
Pas 42, time $T = 6.5597954 \cdot 10^{3}$ μs	*Pas 52, time, timpul* $T = 8.0011382 \cdot 10^{3}$ μs

Figure 6

In figures 7 is shown the time history of forces for 1915 element which is on the half point of the submerged torpedo opposite to the explosive and 6015 element which is on the half point of the submerged torpedo on the explosive side

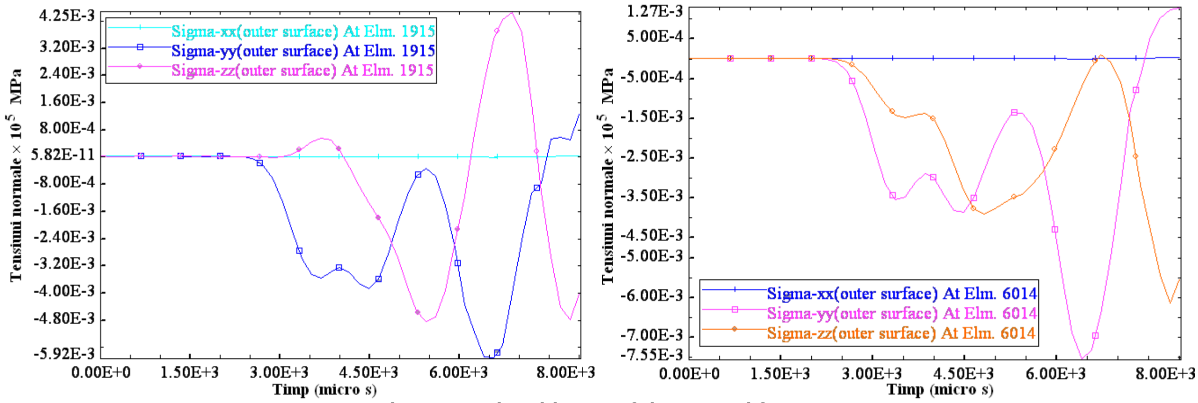


Figure 7.1 Time history of the normal forces

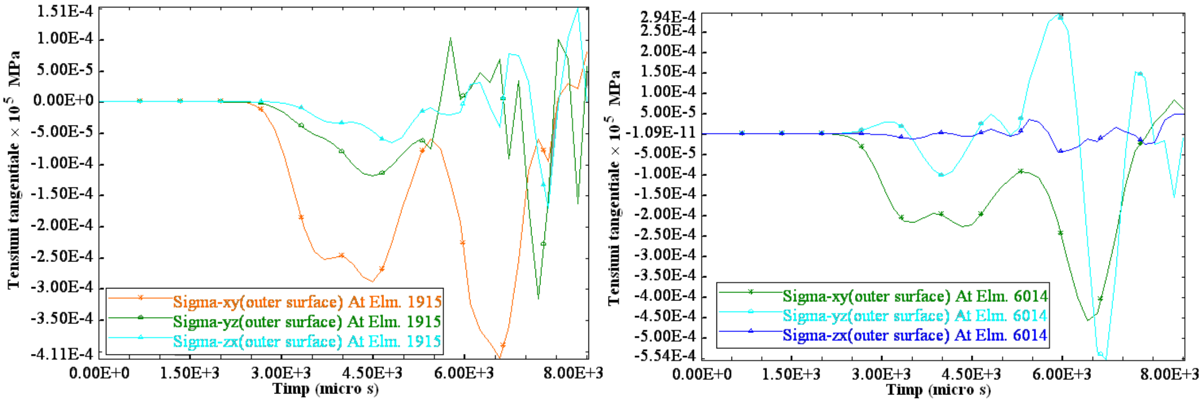
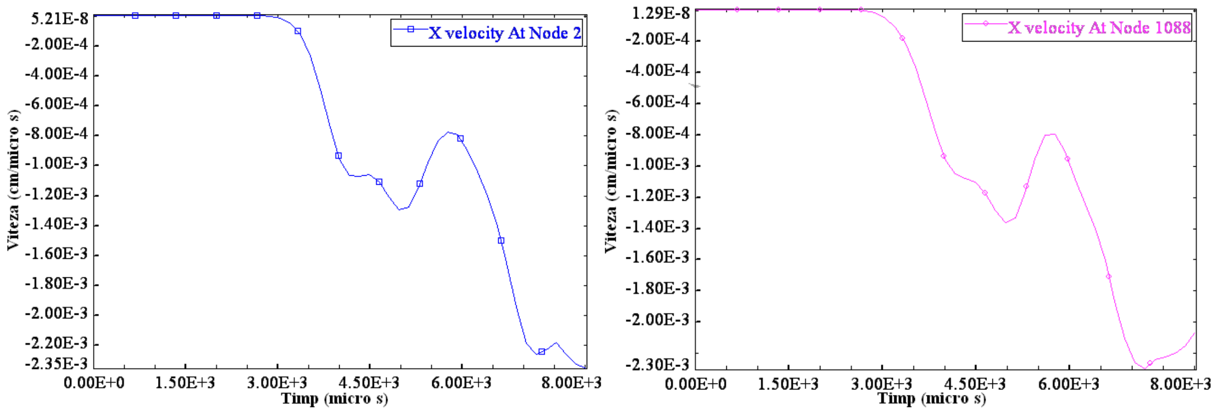


Figure 7.2 Time history of the tangential forces

It can be seen a time delay for the node 1915. The forces are big enough to produce plastic deformation of the submerged torpedo but not strong enough to destroy it.

To destroy the submerged torpedo we should choose a bigger weight of explosive or a less distance between explosive and submerged torpedo.



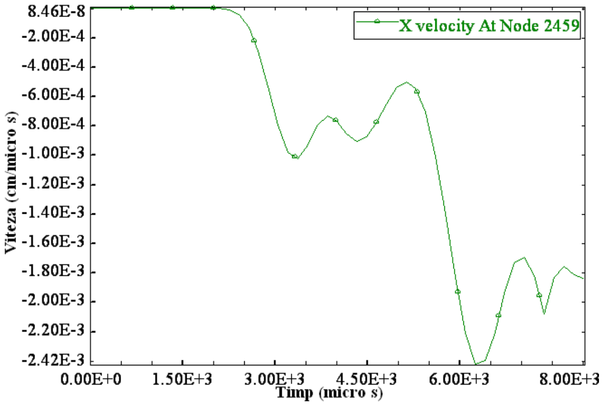


Figure 8 The velocity of nodes

Figure 8 shows the time history of the velocity for 3 nodes located on the torpedo surface, node 2, node 1088 and node 2459. The negative values show to us a back movement of the torpedo related to the OX axe as a result of shock pressure waves.

7. CONCLUSIONS

The bubble radius decreases from its maximum value at the beginning to its minimum. This is the process referred to as bubble collapse. During the process, the bubble radius decreases, but the pressure inside the bubble increases quickly. Thus the force acting on the mid-span of the beam increases as the bubble radius decreases. Note that most part of the force during the bubble collapsing is negative because the bubble contracts and surrounding water flows towards the bubble. After reaching its minimum radius, the pressure inside the bubble is so large that the bubble rebounds. The radius then increases with time. During the rebounding process, the force acting on the beam decreases quickly to values below zero. Thus the force acting on the beam is characterized by a narrow pulse of high amplitude superposed on a slowly-varying load of low amplitude.

8. REFERENCES

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