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MODELING THE EFFECT OF UNDERWATER EXPLOSION ON A SUBMERGED PLATE STRUCTURE

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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 on plane 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 plate. We consider a plane structure made from ideal rigid-plastic material. An interaction between underwater explosion and plate will be analytically studied to obtain the equation governing the fluid force per unit length of the structure and the fluid – plane structure interaction equation. The time variation of the gas bubble radius and the explosion magnitude is graphically shown. The interaction between underwater explosion and a submerged flat structure will be simulated.*

Keywords: explosion, structure, gas bubble, modeling.

1. Underwater explosion phenomenon

To study the phenomenon of underwater explosion, we must take into account two effects: shockwave and bubble gas. Because these two effects have different time scales, they can be studied separately. The peak pressure during formation and propagation of the shock wave is very high but it takes remarkably little. Compared to this phase, the formation and pulsation of gas bubble is characterized by a much less high peak pressure, but it takes much longer.

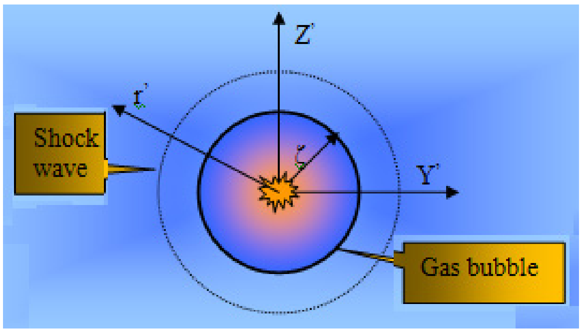

Figure 1 O'x'y'z' coordinate systems with the origin located at the bubble centre

Basically, a shock wave induces local damage, but a bubble can lead to global damage. The present paper is concerned with the damage pattern produced by the bubble pulse. The gas bubble effect resulting from underwater explosion has a very close pulse duration value to the lower frequency vibration modes of a regular ship, submarine or torpedo. In this case, the vibration caused by gas bubble pulsation leads to failure of the hull girder, making a plastic hinge point of failure.

1.1 Problem formulation / assumptions

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

a. the plane structure is considered a plate with a thickness of 1 cm, and only pulsation gas bubble acts on it;

b. $\zeta(t)$ is the radius of the gas bubble at any time, and ζ_0 represent initial value of it;

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c. *P(t)* is the pressure of the gas bubble at any time, and ζ_0 and represent initial value of it;

d. the fluid is inviscid and incompressible;

e. the domain is considered a 180 cm cube that is occupied by water. In its center is placed explosive (TNT), which is a parallelepiped with dimensions 20x20x60 cm;

f. the plate structure is totally immersed on a side face of the cube;

g. explosive detonation occurs at time t = 0 in the center of gravity of the block (coordinates 0, 0, 0);

h. there is a potential Φ which satisfy the Laplacian equation $\Phi = \varphi_b + \varphi_p$, where:

- φ_b represents the potential produced only by the bubble;
- φ_p represents all other effects as a results of the presence of the structure;

i. for modeling we use the following fundamental metrics: for lengths centimeter, for mass gram and for time microsecond.

Because the gas bubble produced the main disturbance in the fluid, we have:

- near the surface of the gas bubble, and far away from the plate (in D_b domain), $\varphi_b >> \varphi_p$;
- near the plate and far away from the gas bubble (in D_p domain), φ_b is of the same order as φ_p, i.e., $O(\varphi_b)=O(\varphi_p)$;
- if we solve the two potentials φp and φb, we get the solution to potential Φ.

1.2 Bubble dynamics

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:

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

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

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

were:

P_g denotes the pressure inside the gas bubble, d_0 denotes the depth of the center of explosive charge, g denotes the gravity acceleration, ρ_0 denotes the water density.

The solution of equations (l) - (4) is *q(t),* a point source with time-dependent strength located at the centre of the gas bubble and has the form:

$$\varphi_b = q(t)/r' \qquad (5)$$

If we consider that inside the bubble the gas is ideal and the pressure is uniform, we get:

$$\frac{P_g}{P_0} = \left(\frac{\zeta_0}{\zeta}\right)^{3\gamma} \qquad (6)$$

where γ =1,4

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

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

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

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

Giving the initial conditions, and using Runge-Kutta method the solutions of equations (7) and (8) can be numerically integrated. The solutions are two time-dependent functions ***q(t)*** and ***ζ(t)***, and an example is given in figures 2 and 3.

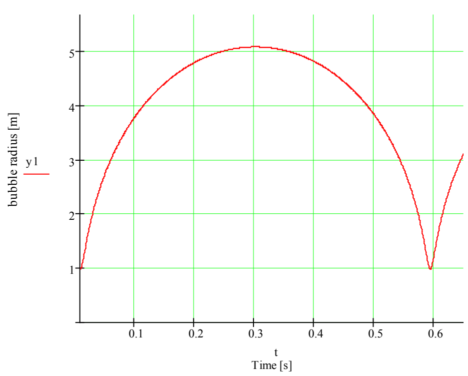

Figure 2. Time histories of bubble radius

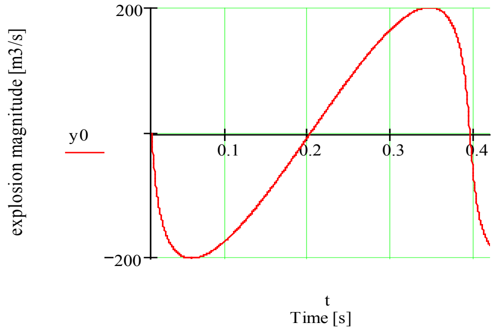

Figure 3. Time histories of explosion magnitude

Modeling the interaction between the plane structure and the shock wave produced by the explosion in water was made with LS-DYNA module that combines the capabilities of mathematical structural analysis both in linear and nonlinear, with full facilities "before" and "after" processing.

ANSYS LS DYNA software uses an explicit solver that provide solutions to the problems of rapid dynamic phenomena that involve large deformations, the quasi-static problems with multiple nonlinearities and complex problems contact / impact.

2. The finite elements model

Figure 4 shows the finite element model adopted. For the fluid and explosive mesh domain it was used the parallelipipedic volume elements and for structure plate elements.

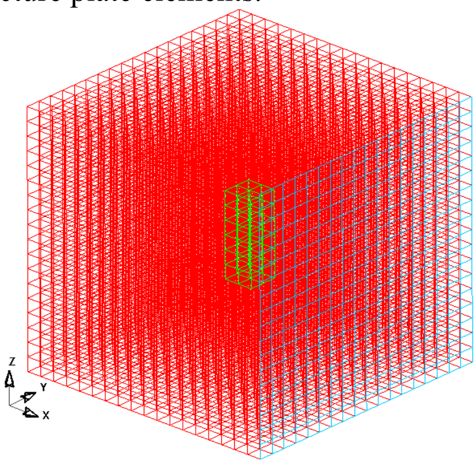

Fig. 4 The finite elements model

Domain nodes that are on the surfaces of the cube movements were restricted by the normal after those faces, except the nodes of the surface plate.

3. The deformed shape model

Figure 5 and 6 present the evolution of the model shape deformation.

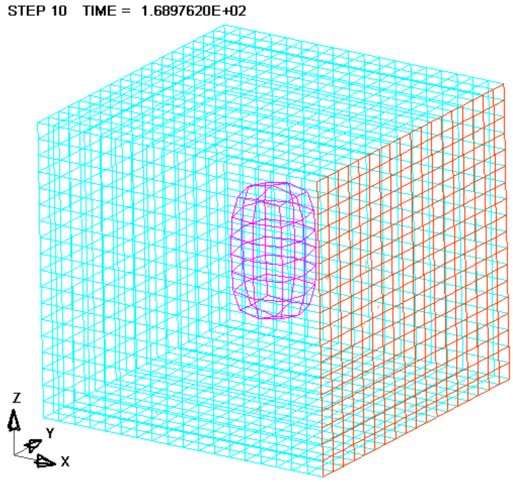

Fig. 5 The model shape deformation - Step 10

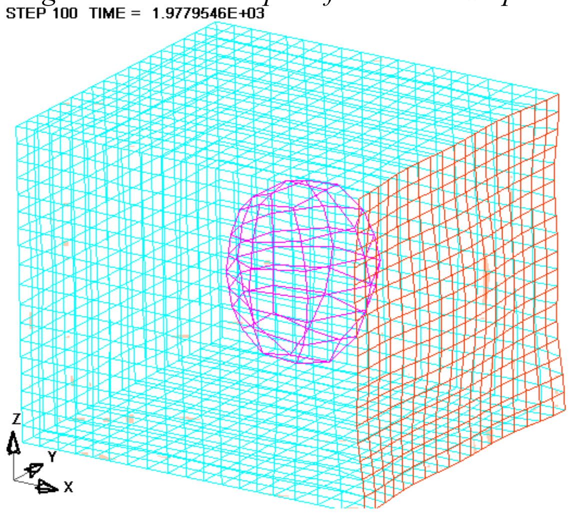

Fig. 6 The model shape deformation - Step 100

4. Velocity field

In figures 7 and 8 velocity fields are presented.

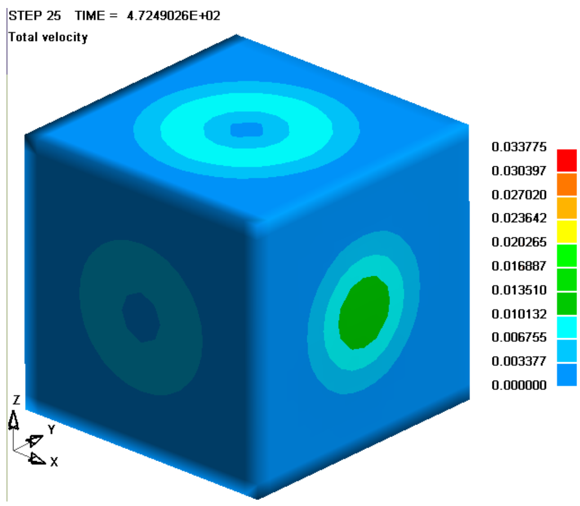

Fig. 7 The velocity fields - Step 10

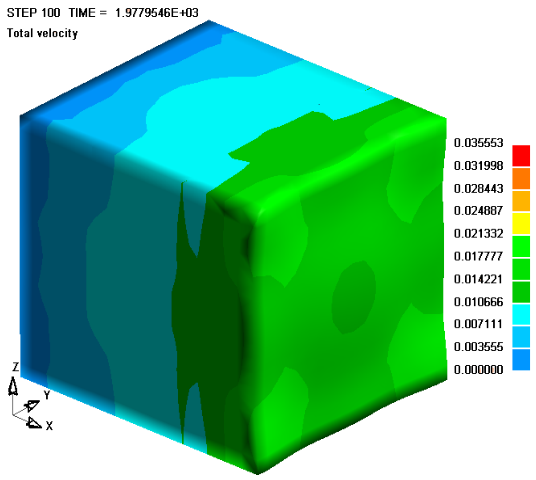

Fig. 8 The velocity fields - Step 100

5. The field of stress

In Figures 9-10 is shown the time variation of equivalent stress Von Misses on the surface of the plate.

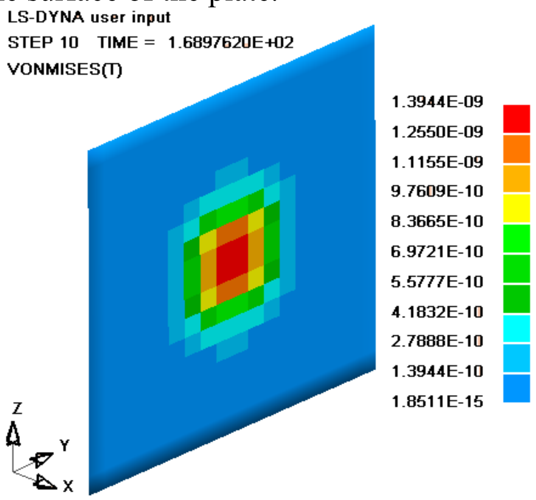

Fig. 9 The equivalent stress Von Misses-Step 10

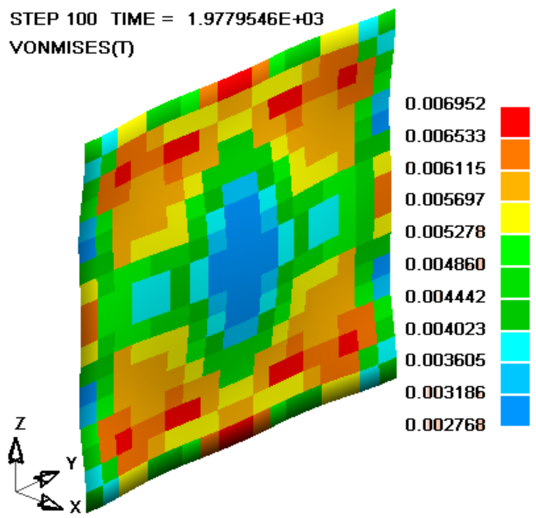

Fig. 10 The equivalent stress Von Misses - Step 100

6. Plotting the diagrams of movement and velocity

For plotting the movement and velocity three nodes consider - node 6149 located in the center of the plate, node 6483 located at the half side of the plate and 6511 node located in the corner of plate.

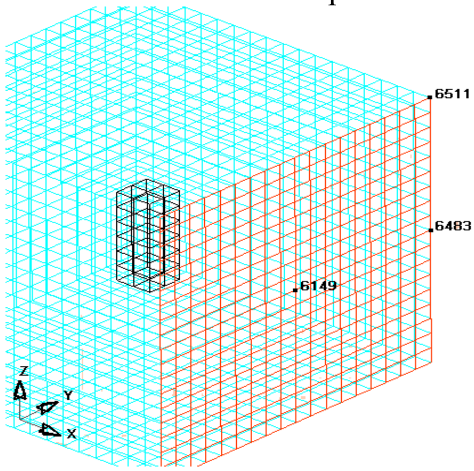

Fig. 11 The position of nodes of interest

6.1 Time history of the nodes displacement

Figure 12 shows the time history of the displacement for 3 nodes located on the plate surface, node 6149, node 6483 and node 6511.

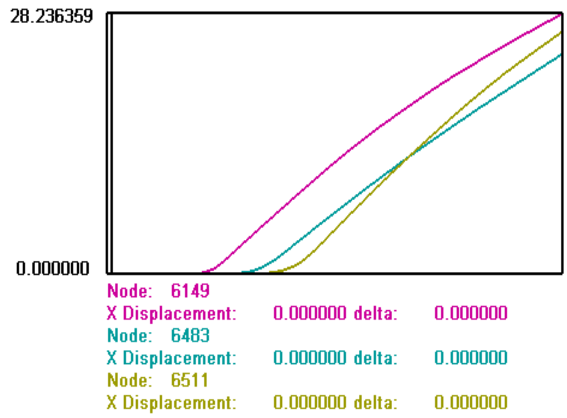

Fig. 12 Time history of the nodes displacement

6.2 Time history of the nodes velocity

Figure 13 shows the time history of the velocity for 3 nodes located on the plate surface, node 6149, node 6483 and node 6511.

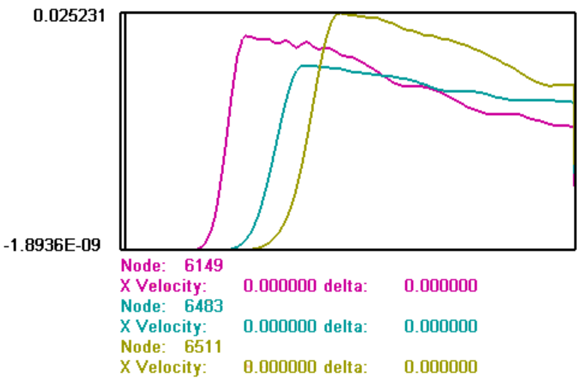

Fig. 13 Time history of the velocity

7. Conclusions

As seen from the chart analysis, the movement begins in the center of the plate (the first area touched by the pressure wave), extending it as circular (the equivalent stress field developments like Von Misses) to the edge. Such displacement of half edge of the plate (node 6483) starts before to the node from corner plate (node 6511).

The simulations are useful for both qualitative and quantitative assessments for complex dynamic phenomena including shock waves in different environments and at high speeds plastic deformation of metal components found in many applications. The effects of multiple reflections and interaction of shock waves with complex geometry parts are difficult to calculate theoretical and cannot be easily observed experimentally. From this point of view, numerical simulation is an appropriate tool for designing experimental configuration and mechanical systems. Results depend on the accuracy of the geometric model, the quality of the mesh, the material properties of parts, the material used in the simulation model.

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