Numerical Simulation Study of Target Response under Underwater Explosion

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Abstract. Studying the structural dynamic response characteristics under the action of underwater explosion load had great significance for improving the anti-explosion and anti-impact performance of ships. The autodyne numerical simulation software was used to calculate the dynamic response of target under the underwater explosion. A series of movable observation points are set on the target and the y-axis coordinate-time image of each observation point is extracted after the target plate is completely broken at the boundary. We find that there is a tensile wave propagating in the y-axis direction inside the target plate before the target plate is in a severely bent state. The intensity variation of the tensile wave along the thickness direction of the target plate is studied. The tensile wave has less influence on the back-explosion surface and have an obvious effect on the destruction of the detonation surface. The effect of the tensile wave on the boundary was studied. The tensile wave contributes to the fracture of the target at a fixed boundary.

1. Introduction

The load output and damage patterns generated by the underwater explosion on the target are very different from those in the air. Due to the needs of naval warfare, the effect of underwater explosions on target has gradually been valued by military scientific researchers in various countries. In 1948, Cole [1] published a book, *underwater explosion*, which summarized the main results of experimental and theoretical research on underwater explosions at that time. M.D.Olson et al[2] conducted an experimental study on the dynamic response characteristics and failure modes of solid-supported square plates under the action of explosion shock waves. The failure modes of the fixed square plates under this type of load are classified by them base on the classification of failure modes of fixed-support beams under the blast load by Menkes et al [3]. Ren Peng et al [4] carried out experimental research on the fixed circular plate under air-back condition by non-medical underwater explosion shock wave loading device. They studied the deformation and strain of the target plate under the pure shock wave of underwater explosion and found that the stretching effect at the boundary and center of the target is obvious.
2. finite element model

2.1. Model establishment
As shown in Figure 1, the simulation calculation uses a 2D axisymmetric model with a model size of 1000mm x 300mm. The water area is 2m deep. The boundary conditions of water are outflow. The target plate is 4mm thick and 250mm high. The material of target plate is Q235. There is an air field with a thickness of 100mm on the back of target. The boundary conditions of target are fixed. The explosive is a 50g cylindrical TNT with a radius of 20mm and a length of 25mm. The detonation point is at the center of the cylinder bottom and the burst distance is set to 50mm.

The equation of state for water is described by a polynomial equation of state. When compressing $\mu > 0$:

\[
p = a_1\mu + a_2\mu^2 + a_3\mu^3 + (b_0 + b_1\mu)\rho_0 e
\]

(1)

When inflated $\mu \leq 0$:

\[
p = T_1\mu + T_2\mu^2 + b_0\rho_0 e
\]

(2)

The high energy explosive unit material model uses the JWL equation of state:

\[
p = A(1 - \frac{\omega}{R_1V})e^{-r_1V} + B(1 - \frac{\omega}{R_2V})e^{-r_2V} + \frac{\omega E}{V}
\]

(3)

![Figure 1. Establishment of the finite element model](image)

2.2. Observation point setting
The observation points on the target are set as shown in Figure 2. There are five sets of observation points from left to right. Each group has 10 observation points from bottom to top and the observation points are separated by 1 mm in the x-axis direction and 25 mm apart in the y-axis direction. The first group is numbered 1-10, the second group number is 11-20, the third group number is 21-30, the fourth
group number is 31-40, and the fifth group number is 41-50. A series of observation points are arranged in the vicinity of the boundary of the target plate. The interval between the x-direction and the y-direction of the observation point is 1 mm. The setting is as shown in Figure 3.

2.3. Calculation accuracy analysis
The grid unit is the basis of numerical simulation. The number of grids will affect the accuracy of the calculation results and the size of the calculation scale. Increasing the number of meshes when the mesh is small can significantly improve the calculation accuracy and the calculation time will not increase greatly. In practical applications, the calculation results of two different number of meshes can be compared. If the two calculation results are different, the number of meshes can be increased. On the contrary, the current mesh size is recognized. It can be considered that the current calculation accuracy is reliable [5].

This paper calculates two mesh size models of 1mm × 1mm and 0.5mm × 0.5mm. We found that the difference is not large by comparing the y-axis coordinate-time images of the corresponding observation points of the two groups of models, Arbitrarily take the 5th point for display, the schematic is as follows. The left side is the calculation result of 1mm grid and the right side is the calculation result of 0.5mm grid. From the results, we can consider that the image calculated in this paper has certain reliability.

3. Phenomenon analysis
The target response process is shown in Figure 5. At t=0ms, explosive begin to detonate. At t=0.04ms, the target plate is bent and deformed toward the back of the target. At t=0.08ms, a clearly visible bulge has been formed at the center of the target. At the same time, central area where the target plate contacts the water forms a cavitation zone because there is a difference in the speed of the x-direction between the target particle point and the fluid particle point in the area. Target particle velocity is greater than
fluid particle velocity. At $t=0.16\text{ms}$, the cavitation zone disappears. So, the water flow contacts the target plate again. The target plate is subjected to secondary impact loading. At $t=0.6\text{ms}$, cracks began to appear at the boundary and the target broke at the fixed boundary as the explosion continues.

![Figure 5. Target response](image)

**Figure 5.** Target response

4. Analysis of calculation results

4.1. Analysis of y-axis coordinate value-time relationship diagram of detonation surface

![Figure 6.](image)

**Figure 6.** The first set observation points y-axis coordinates - time chart

The y-axis coordinates - time chart of the first set observation points (except number 1) shown in the figure 6. We can see that the position curve of each observation point has a small upward displacement in the early stages of deformation from the image. For structural damage, this can be ignored.
Subsequently, the position curve of each observation point has a downward displacement with a large amplitude and a long duration. The influence of the downward displacement of the target particle on the damage for the target is not negligible. The downward shift of the position curve at each point of the target's detonation surface can be regarded as the action of the stretching wave [6]. Then the curve rises again. Both the ascending speed and the rising amplitude are greater than the previous displacement. In conjunction with Figure 5, this is due to the dramatic overall stretching caused by the large deflection of the target. Finally, the position curves of No. 9 and No. 10 drop rapidly because the target boundary is broken.

4.2. Change of tensile wave intensity along the thickness of the target

We select five observation points with the same y-axis coordinate values for analysis. From the detonation surface to the back explosion surface, the displacement amplitude of each position curve gradually decreases. The effect of the stretching wave is no longer visible on the back side. This shows that the intensity of the stretching wave causing the downward of each point gradually decreases in the thickness direction of the target plate. The tensile wave studied in this paper has a certain influence on the detonation surface of the target plate and has little effect on the back explosion surface.

4.3. The effect of stretching waves on the boundary of the target

The observation points near the boundary of the target plate were selected for analysis to study the effect of the stretching wave on the boundary of the target plate. As can be seen from Fig. 8, the position curve of each point on the boundary falls slowly before 0.5 ms and begins to decrease rapidly at some point from 0.5 ms to 0.6 ms. It can be considered that the slow downward movement at the beginning is the action of the stretching wave. The effect is not negligible from the extent of the downward movement of the point at the boundary. Under the cumulative action of the tensile wave, the target plate is broken at the boundary.
5. Conclusion
(1) A tensile wave propagating along the y-axis direction is generated on the target detonation surface at the initial stage of the deformation of the target plate.

(2) The tensile wave gradually weakens along the thickness of the target plate. The tensile wave has a great influence on the detonation surface of the Q235 target but has little effect on the back surface of the Q235 target.

(3) The tensile phenomenon due to the bending of the target plate occurs after the tensile wave is transmitted on the detonation surface. The stretching wave is not the cause of the severe stretching and thinning of the target plate. The stretching wave only moves the target particle down in the initial stage of deformation of the target plate. Moreover, this effect is not negligible for target damage.

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