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Numerical simulation of underwater explosive shock wave with gas layer charge

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Numerical simulation of underwater explosive shock wave with gas layer charge

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Abstract: To investigate the effect of the gas layer on the explosive's underwater explosion shock wave load, based on AUTUODYN kinetic analysis software, we establish a one-dimensional underwater explosion numerical simulation model with a gas layer charge and study underwater explosion with a gas layer charge on the impact of the peak pressure and specific impulse of the shock wave underwater explosion. The results show that the gas's low impedance and the continuous reciprocal reflection of the shock wave in the layer of the shock wave in the water led to a lower pressure Peak pressure of the shock wave in the water and its post-wave oscillatory decay waveform. With the increase of the uncoupling coefficient, the peak pressure of the shock wave in the water decreases, and the specific impulse increases and then decreases, through the range of 5~1, 000 kg of TNT spherical charge underwater explosion calculations, to verify the reliability of the conclusions. The study's conclusion shows that applying an underwater blast protection project with a gas layer charge should be reasonably designed for gas layer thickness to avoid the enhancement of the impulse but increase the harm of the shock wave.

1. Introduction

In the underwater blasting project, to prevent the damage of underwater explosion shock waves on dams, wharves, and other underwater buildings, we often use the gas layer structure to block the shock wave propagation. Related research can be traced back to the beginning of the 20th century. In 1907, Brasher [1] first proposed the use of air layers to cut wave impact methods to protect underwater buildings. Liang et al. [2] found that the air barrier structure on the shock wave attenuation effect is significant. Du et al. [3] found that a smaller number of air barriers can significantly attenuate the underwater explosion shock wave. With the increase in the number of air barriers, the attenuation effect is less and less obvious.

The early idea was to place the air layer near the protection object, and later researchers began to focus on the structure of the added air layer around the explosives. Han et al. [4] established a one-dimensional wedge model of underwater explosion based on AUTODYN software to study the output of explosion energy under the structure of air uncoupled charge. Wang et al. [5] and Zhang et al. [6] used different sizes of plexiglass − air compartment structures for underwater explosion experiments, respectively, to explore the air layer structure of the explosion pool underwater explosion foundation vibration and the impact of underwater explosion energy output. Huang et al. [7] used PVC pipe to add air to the RDX column, by changing the diameter of the PVC pipe, to explore the effect of the air layer on the explosive properties of RDX. In summary, domestic and foreign researchers have conducted a lot of studies on the protection of underwater buildings by air layer. Only the attenuation effect of the air layer on the peak pressure is considered, and the peak pressure is not the only factor of structural damage but also should be considered as a continuous effect of the pressure, i.e., the effect of the specific impulse. In this paper, we use a numerical simulation method to establish the underwater free-field explosion model with gas layer charge and have a comprehensive analysis of the relationship between the thickness of the gas layer, the peak pressure of the shock wave, and the specific impulse, to explore the impact of the charge with a gas layer on the shock wave load of the underwater explosion.

2. Numerical simulation modelling

2.1 Grid division

The numerical simulation model is shown in **Figure 1**. The water radius of 50 m is to simulate the non-reflection boundary. The grid cell size is 1 mm, the spherical center is filled with TNT explosives, the detonation point is set in the center of the spherically symmetric model, the TNT charge is 10 g, and the charge radius of 11.43 mm. Between 20 times to 100 times, the charge radius every 5 times the radius of the charge sets up an observation point, to extract the peak pressure of the shockwave at each observation point.

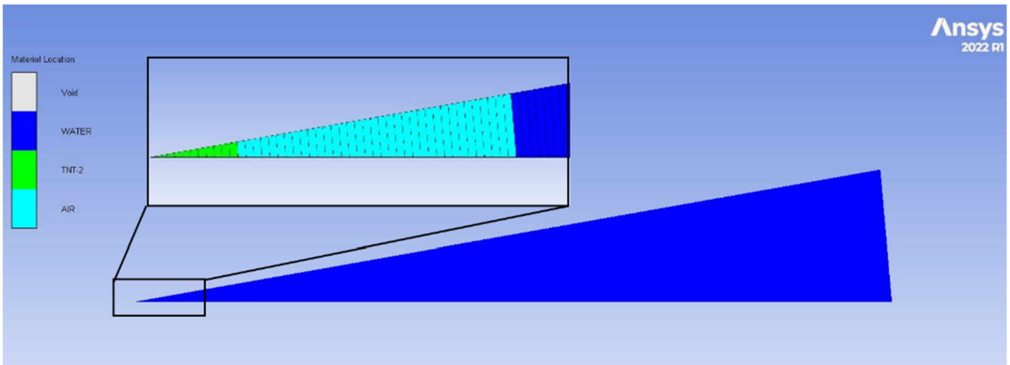

Figure 1. One-dimensional numerical simulation modeling of underwater explosions with gas layer charges.

2.2 Material model

The water, explosives, and air material models all use materials from the simulation software material library, with polynomial equations of state for water, JWL equations of state for TNT, and ideal gas equations of state for air.

2.3 Numerical simulation model validation

2.3.1 Grid-independent verification. The mesh size will affect the model calculation accuracy, and it is necessary to verify the mesh independence of the model and select the appropriate mesh size so that it can ensure accuracy and calculation efficiency. The calculation results are shown in **Figure 2**, from which as the number of meshes increases, the peak pressure changes from sharp to slow. After the number of meshes increases to a certain extent, the peak pressure changes are not obvious. To ensure the calculation time and accuracy, the wedge model with a mesh size of 1 mm and a total number of meshes of 50, 000 is selected.

2.3.2 Simulation model accuracy verification. We use the above wedge model to carry out numerical simulation calculations of underwater explosions of spherical TNT with a charge of 10 g, compared with the empirical formula of Zamyshlyayev's peak pressure and the test values, respectively, from the water well test [9] and the underwater explosion test in a spherical closed container [9] with the charge of 78 g, 200 g, 540 g, and 1, 000 g respectively. The results of numerical simulation calculations were compared with the test results [8]-[9] and the empirical formula for Zamyshlyayev peak pressure.

$$P_m=\begin{cases}4.41\times10^{7}\left(\frac{W^{\frac{1}{3}}}{R}\right)^{1.5}, & 6\le\frac{R}{R_0}<12\\ 5.24\times10^{7}\left(\frac{W^{\frac{1}{3}}}{R}\right)^{1.13}, & 12\le\frac{R}{R_0}<240\end{cases} \quad (1)$$

where P_m is the peak pressure of the shock wave, and the unit is Pa. For the mass of the charge, the unit is kg; for the measurement point from the center of the blast distance, the unit is m; for the charge radius, the unit is m.

Figure 3 shows the comparison of numerical calculation results with empirical formulas and tests, from which the numerical simulation results are consistent with the empirical formula calculation results and test values. The maximum error between numerical calculation results and the empirical formula is 19.2%, which occurs at 100 times the explosion scale distance. The minimum error is 0.45%, which occurs at 25 times the scale distance, and the average error is 12.42%. 78 g of explosives test values and simulation error is 0.9%, 1.53%, 9.4%, and 16.57%; 200 g, 540 g, and 1, 000 g explosives test values and the errors of 200 g, 540 g, and 1, 000 g explosives and the simulation are 9.16%, 12.35%, 7.21%, 9.42%, 4.28%, 4.75%, respectively; the errors are less than 20%. In summary, the numerical simulation model has high calculation accuracy.

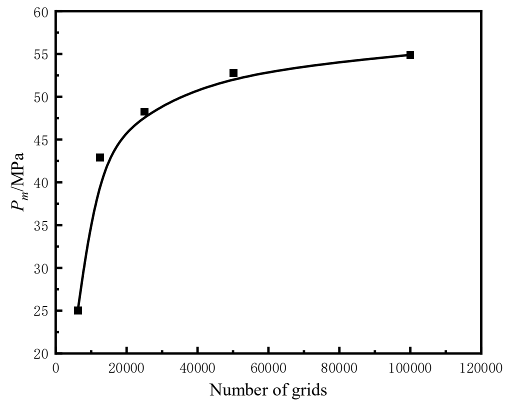

Figure 2. Variation curve of P_m with the number of grids.

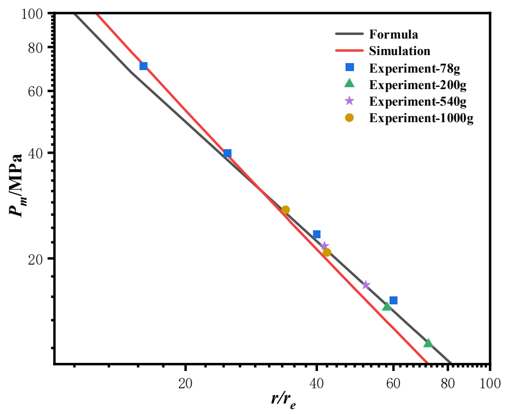

Figure 3. Comparison of numerical calculation results with empirical formulae and tests.

3. Analysis of numerical simulation results

To easily describe the relationship between the explosive and the air layer, this paper uses K to describe that:

$$K=D/d \quad (2)$$

where K is the uncoupling coefficient and an important parameter in the control of blasting, and K≥1; D is the diameter of the charge; d is the diameter of the explosives.

3.1 Influence of the air layer on the peak pressure of the shock wave

Figure 4 shows different uncoupling coefficients under the spherical charge shock wave pressure-time curve. As can be seen from **Figure 4**, K=1, and the pressure rises sharply to reach the peak pressure, followed by a sharp decline, K>1. After the peak pressure, the shock wave attenuation rate slows down, and the waveform is an oscillating decay. The main reason for K=2 with the gas layer of charge free-field explosion shock wave evolution as an example of the process is illustrated.

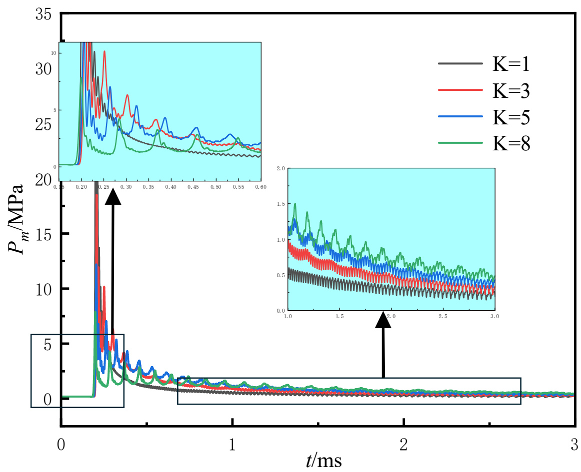

Figure 4. Pressure-time curve.

Figure 5 shows t=4.3 μs, high temperature and high pressure of the explosive products of the charge around the air to produce a strong compression, and the formation of a strong shock wave in the air. When t=5 μs, the shock wave arrived at the air-water interface. Due to the wave impedance of the water being much larger than the airwave impedance, the shock wave at the interface of the reflection occurs at the same time in the water generated by the transmission of the shock wave so that the water pressure instantly increases. In Figure 5, the process continues to repeat, resulting in the lower pressure peaks of the shock wave in the water with the air layer charge and its waveform after the oscillatory decay.

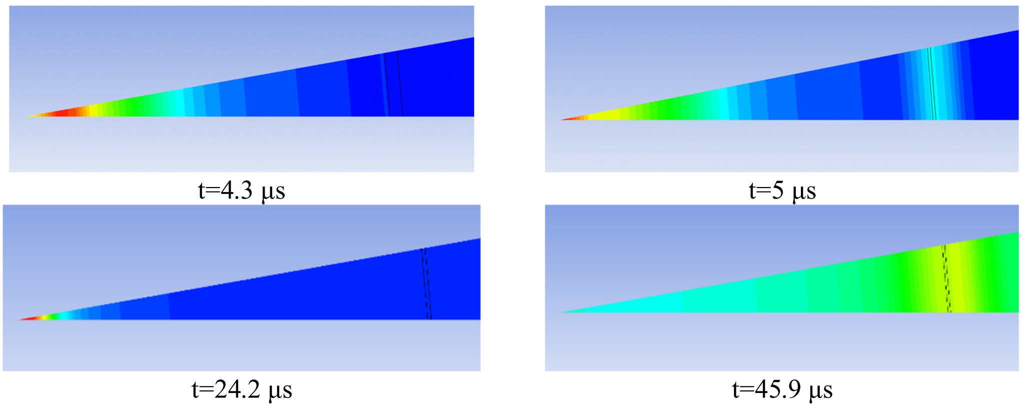

Figure 5. Evolution of free-field explosive shock wave for K=2 belt gas layer charge over.

P_m with K at different proportional burst distance curves is shown in **Figure 6**. The peak shock wave pressure increases with the proportional burst distance, in the form of exponential decay, and the uncoupling coefficient of 1. The peak shock wave pressure is generated by the underwater explosion of explosives in the near-field range of rapid attenuation in the far-field range, and the attenuation rate is slow. **Figure 7** shows the different values of K P_m with the explosion distance change curve. Under the same conditions of the explosion distance, with the increase in K, the peak shock wave pressure gradually decreased, and P_m / MPa and K between the slope gradually decreased.

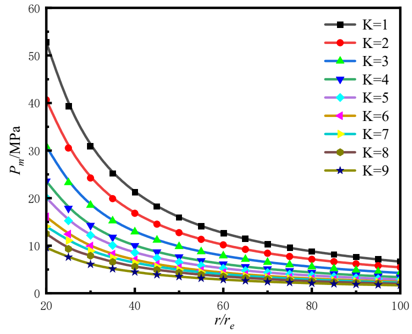

Figure 6. Variation of P_m with K at different proportional burst distances.

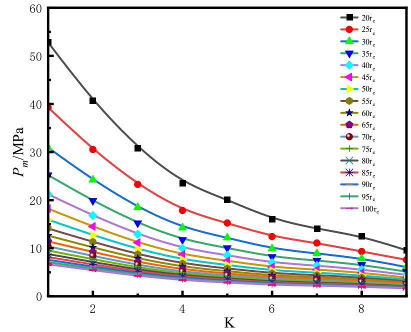

Figure 7. Variation curve of P_m with blast distance for different values of K.

3.2 Influence of the air layer on the specific impulse of the shock wave

The impulse I of an underwater blast shockwave is the integral of pressure over time.

$$I = \int_{t_a}^{6\theta} P(t)dt \tag{3}$$

where the arrival moment of the shock wave is often referred to as the time decay constant; the decline to the time is the base of the natural logarithm.

Figure 8 shows the variation curve of specific impulses with proportional burst distance for different K values. As can be seen from **Figure 8**, the same value is K, and with the increase in the burst distance, the specific impulse was an exponential form of decay. **Figure 9** shows the different proportions of the burst distance of the impulse with the K curve. The shock wave changes with the increase in K, showing the trend of increasing and then decreasing. When K=5, the impulse reaches its maximum, and the main reason for this phenomenon is that the existence of the air layer prolongs the time of action of the shockwave. The thickness of the air layer is too large to make the peak pressure in the water extremely low, and excessive consumption of energy is generated by the explosion.

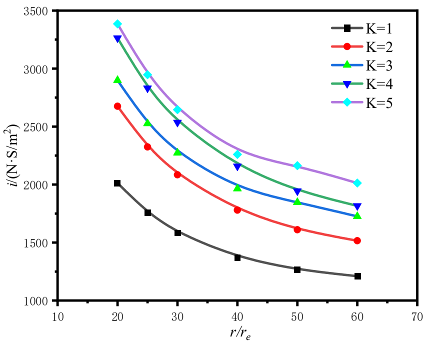

Figure 8. Variation curve of specific impulse with blast distance at different values of K.

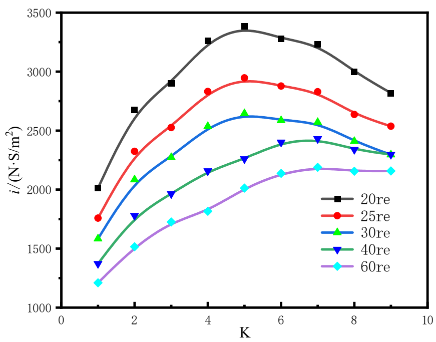

Figure 9. Variation curves of specific impulse with K at different proportional burst distances.

3.3 Law applicability verification

To verify the reliability of the simulation results, respectively, 5, 100, and 1, 000 kg TNT spherical charge underwater explosion simulation calculations, and different amounts of peak pressure and specific impulse with the uncoupling coefficient of change were shown in **Figure 10** and **Figure 11**. You can see different amounts of different drugs with the law of change of the uncoupling coefficient of change, with the previous article consistent with the above rules for different amounts of different loads with a high degree of applicability.

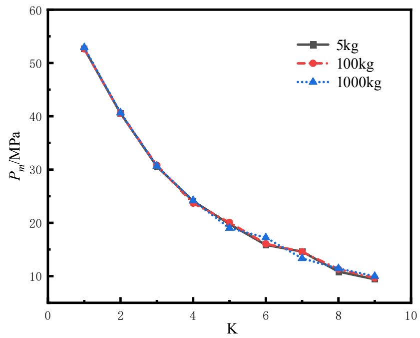

Figure 10. Variation of P_m with K at different dosage rates.

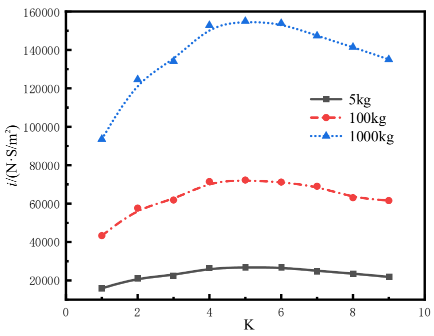

Figure 11. Variation of specific impulse with K at different dosages.

4. Conclusion

This paper uses AUTODYN software to carry out a numerical simulation of the structure of the charge with a gas layer, analyses the effect of the charge with a gas layer on the underwater explosion shock wave load, and obtains the following conclusions:

(1) For a charge with a gas layer, the low impedance of the gas and the continuous reciprocal reflection of the shock wave in the gas layer result in a lower peak pressure of the shock wave in the water and an oscillatory decay of the wave after it;

(2) With the increase of the uncoupling coefficient, the peak pressure of the shock wave in the water decreases and the rate of decrease is gradually slowed down; the specific impulse increases and then decreases, through the TNT spherical charge in the range of 5~1, 000 kg of underwater explosion calculations, to verify the reliability of the conclusions;

(3) In the application of charging with a gas layer in the actual project, it is necessary to consider the impact of the gas layer on the peak pressure and specific impulse, to avoid the enhancement of the impulse instead of increasing the hazards of the shockwave, for the reasonable design of underwater blasting protection project in the thickness of the gas layer to provide a theoretical basis.

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