Journal of Mining and Earth Sciences Vol.56 (2016) 26-30

Journal of Mining and Earth Sciences

Website: http://tapchi.humg.edu.vn

Studying the effect of fly fragments in underwater explosion

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ARTICLE INFO

Article history:
Received 05 May 2016
Accepted 10 Oct. 2016
Available online 20 Nov. 2016

Keywords:
Underwater blast
Safety charge
Fly fragment
Explosion

ABSTRACT

Fragments in a blast is one of the factors to cause the unsafety for humans, equipments, and structures around the blasting areas. Thus, all standards and norms used for blasting safety refer to the radius of safety zone around the blast calculated by the largest distance of the fly fragments. However, recent researches are only applied for the fly fragments when blasting occurs on surface. In this paper, a method is proposed for determining the flying distance of fragments created by blasts in underwater environment. The equations of motion are derived for underwater fragments and then the impact resistance between an underwater blasting and the surface blasting are analyzed and compared to show the advantages of the method.

1. Introduction

Fly fragments in mine blasting is an important factor in assessing the blasting safety for humans, buildings and surrounding environment. In the field of blasting by weapons, fly fragments are the most important elements to damage the enemy's strength. For the air explosion, fly fragments have also been studied for the safety work in blasting. However, in underwater explosion, the studies on the effects of fly fragments are not widely public and the researches are almost not mention on the effects of fly fragments by underwater explosion (Ho, 2010). In underwater weapons, besides the effects of shock waves, fly fragments of underwater weapons may kill or make the enemy out of the battle. In contrast, in building the structures on the island, or in mining using explosive energy to construct or destroy bombs, explosive materials. It is necessary to restrict the effects of a fly fragment to human and surrounding equipment, environments.

Thus, the study on the effects of fly fragments of the underwater explosion is of important work in designing the blasts and calculating the blasting safety.

2. The equation of motion of fly fragments in underwater explosion

Fly fragments in an underwater explosion moving to the environment depend on many

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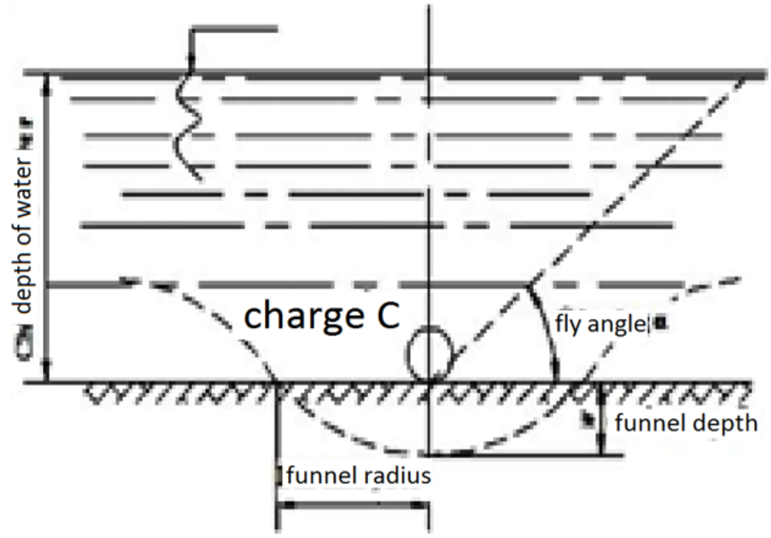

Figure 1. Diagram of the fragment of rocks in underwater explosion

factors affecting their trajectory such as: charge weight (*m)*; the shape of fragment, cross-sectional area (*S)* of the fragment, and these factors play an important role in the moving process causing the reduction of speed by the resistance of water. The reduction of moving speed is shown by a frontal resistance coefficient, (C_x); the density of water (ρ_n), which also impact the flying of the fragments.

The equations of motion by any fragment following the Newton's laws has the form (Орленко, 2002)

$$M\frac{dU}{dt} = Sp \qquad (1)$$

where *M* is the charge weight; *U* is the moving speed of fragment; *S* is the cross-sectional area of fragment; *p* is the pressure on the fragment.

Then, the equation of motion of the fly fragment in underwater explosion can be written in the form:

$$m\frac{dv}{dt} = -C_x S\frac{\rho_n v^2}{2} \qquad (2)$$

Where *m* is the charge weight, kg; C_x is frontal resistance coefficient; ρ_n is the density of water, kg/m3; *v* is the speed of the fly fragment, m/s.

By solving the Equation (2), one previously achieved as

$$\frac{dv}{dx}\frac{dx}{dt} = \frac{dv}{dx}v$$

According to Equation (2), one has a new form as

$$\frac{dv}{dx}v = -C_x S\frac{\rho_n v^2}{2m}$$
$$\frac{dv}{v} = -C_x S\frac{\rho_n v^2}{2m}dx \qquad (3)$$

Taking integral of two sides of Equation (3). Assume that the speed of fly fragment *v* changes from the initial speed v_0 to the speed v_n. It has just throw out of the water and the moving distance x changes from 0 to r (throw of the water), one get Equation (4).

$$v_n = v_0 e^{-C_x S\frac{\rho_n}{2m}r} \qquad (4)$$

where *r* is water depth, (m).

Similarly, the equation can be achieved by determining the coordinates of the fragment rock when it landed on:

$$\frac{e^{2CX} - 2CX - 1}{2CX} = \frac{Cv_n^2 sin2\alpha}{g} \qquad (5)$$

$$C = \frac{C_x S\rho_{kk}}{2V\rho_{dd}} \qquad (6)$$

where:

g is the gravitational acceleration, m/s^2;

V is the volume of a fly fragment, m^3;

ρ_n is the density of water, kg/m^3;

ρ_{kk} is the density of air, kg/m^3;
α is throwing angle, degree;
ρ_{dd} is the density of rock, kg/m^3;
X is the coordinate of fragment when it dropped, m.

Thus, from the Equations (4), (5) and (6) with other known parameters of the underwater explosion, the speed, and distance of fly rock, flying velocity of fragments can be calculated.

Since then, we may determine the safety distance for humans, buildings affected by the underwater explosion.

3. Application on specific case

Based on this theory, we examine a practical problem as follows:

The explosive charge is at the depth of 1.5 m as show Figure 1 and after blasting it created a spherical fragment, the parameters of the problem as follows:

+ Diameter of the rock (a spherical fragment): Φ = 0,2 m;

+ The density of rock ρ_{dd} = 2200 kg/m^3;

+ Throwing angle when the rock flying out of the water α = 45^0;

+ The density of water, ρ_n = 1000 kg/m^3;

+ The density of air, ρ_{kk} = 1,25 kg/m^3;

+ The frontal resistance coefficient (Ho, S. G., 2010), C_x = 1;

+ Initial speed, v_0 = 1500 m/s.

Solving the problem to find the speed of the fragment flying out of the water and the coordinate of fragment when it dropped.

Based on the Equations (4), (5) and (6) to solve the above-mentioned problem:

+ Calculating the mass of the rock:

$$m = V\rho_{dd} = \frac{4}{3}\pi(\frac{\Phi}{2})^3\rho_{dd} \qquad (7)$$

Putting the parameters in Equation (7) we get:

$$m = (4/3).0,0001.2200 = 9,21\ (kg)$$

By calculating the exponent of e with

$$n = C_x S\frac{\rho_n}{2m}r \qquad (8)$$

Putting the known data into Equation (8), we obtain:

$$n = 1.\pi.(\frac{0,2}{2})^2\frac{1000}{2.9,21}1,5 = 2,56$$

From Equation (4), we have the speed of the fragment flying out of water:

$$v_n = 1500e^{-2,56} = 116(m/s)$$

+ Calculating the coefficient C of Equation (6), we have:

$$C = \frac{1.\pi.(\frac{0,2}{2})^2 1,25}{2.9,21} = 0,00213$$

+ Determining the coordinate of fragment when it dropped:

From Equation (5), we have:

$$\frac{e^{2CX} - 2CX - 1}{2CX} = \frac{0,00213.116^2\sin(2.45^o)}{9,81} = 3,15$$

$$\frac{e^{0,00426X} - 0,00426X - 1}{0,00426X} = 3,15$$

Solve this equation, we obtain:

X = 561 (m). This shows that after flying out of the water, the distance of the rock from the explosive charge is 561m.

In case of air explosion, the resistance of the water is zero, it can be seen that the formulas do not change, but only the initial speed of the rock was replaced for v_n in the Equation (5):

$$\frac{e^{2CX} - 2CX - 1}{2CX} = \frac{0,00213.1500^2\sin(2.45^o)}{9,81} = 488,5$$

The veriable is calculated: X = 1948 (m).

This shows that the rock could fly to 1948 meters if the explosion is carried out in the air.

If using the same charge buried in the same rock, the air explosion, and underwater explosions are at a different flying distance. This happens because the water has the effect of hindering very effective the fragment from flying. To evaluating the influence of water in decreasing the flying radius of fragment in underwater explosion and in air with the charges of the same charge weight, the coefficient of water depth lying above the rocks on the declination of the flying radius of fragments in air explosion has the form:

$$K = X_2/X_1$$

Figure 2. The underwater explosion to open a stream in Spratly Islands 1991 (Le, 1991)

Figure 3. The underwater explosion in Son Ca island in 2013 (600g TNT charge) (Vu, 2014)

In the case of the above-mentioned problem: $K = X_2/X_1$ = 1948/561 = 3.47 (times), this means the flying radius of the fragment in an underwater an explosion with the same charge weight in air explosion will be reduced by 3.47 times. By using this feature, many underwater explosions carried out at the high tide and this even eliminated the unsafety zone of fly fragments. Some underwater explosions like this have been carried out in Vietnam such as: openning stream in Spratly Islands 1991 in Figure 2 (Le, 1991). building Hai Ha sea port in Quang Ninh province in 2007 by (Dam, 2014) and the underwater explosion in Son Ca island in 2013 by (Vu, 2014), as shown in Figures 3.

Some results of the underwater explosion were implemented on Hai Ha sea port in Quang Ninh province in 2007. There were 3 types of TNT charges: 10 kg, 11 kg and 12 kg, located at depths d = 1,5 m, 3 m respectively. The furthest distances of fragments of explosions which are measured experimentally are shown in Table 1. Those results are verified to prove the proposed analytical model in the paper.

4. Conclusion

Based on the research results, the establishment of the motion equation of fly fragment throwing out water has been determined. Especially, the paper shows the influence of water thickness lying above rock surface in declining the motion of fly fragment in underwater explosion. Research results confirmed that water has hindered the movement of a fly fragment in an underwater explosion. These results are also entirely consistent with the theory of underwater rock blasting is mentioned in theory (Dam, 2014).

Table 1. The experimental furthest distance (m) of the fragments from the charges in the underwater explosion

Furthest distance	10 kg	11 kg	12 kg
Case 1: (d=1,5 m)	430	500	550
Case 2: (d= 3m)	350	400	500

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