The Influence of Standoff Distance on the Shaped Charge Penetration

Khalifa Meftah Ahmed (*)

Dept. of Aeronautical Engineering, Faculty of Engineering, Zawia University, Liby

Abstract:

The main goal of this paper is to study the influence of the standoff distance on the target penetration. after the initiation of the shaped charge explosive, the liner collapse to form the penetrator jet. The standoff distance will have a great rale on the jet breakup. In this study a particular shaped charge was considered to calculate the value of penetration for different values of standoff distances. The penetration value calculation was achieved using density law. The results show the major increase in penetration value when the standoff distance is

---

(*) email: Khalifa_online381@yahoo.com

increased. But, due to jet breakup phenomena, the penetration value does not show any change even if the standoff distance still increasing.

Keywords: *shaped charge, standoff distance, jet breakup, penetration, warhead design.*

Introduction.

The distance from the base of the charge to the target is known as standoff distance or simply the standoff. The effective standoff, or virtual standoff, is the distance from the virtual origin of the warhead to the target. The virtual origin is the point from which the shaped charge jet can be assumed to originate. Recently researches recommended that, the standoff distance must be measured from virtual origin. Standoff distance is a very important design parameter; it has a great influence on the shaped charge performance. Normally, for comparison reasons, standoff distance is normalized by the CD, which referred to the charge diameter, not to be confused with the cone diameter as sometimes happens [1]. Figure (1), shows the nomenclature for a shape charge configuration**.**

2-Theory

According to intensive researches and experimental results, the penetration value depends on the jet formation and it’s physical properties. In 1948, Birkhoff et al. published the first theory of shaped charge jet formation. Their theory used the fact that, the detonation pressure was large compared with the strength of the metal liner and, therefore, the liner was treated as an in viscid fluid. They also assumed that, the detonation waves impulsively loaded the liner elements and thus instantaneously accelerated them to their final collapse velocity. Furthermore, their theory was based on steady-state, incompressible hydrodynamics and predicted the formation of a jet whose length was constant and equal to the slant height of the cone [2].

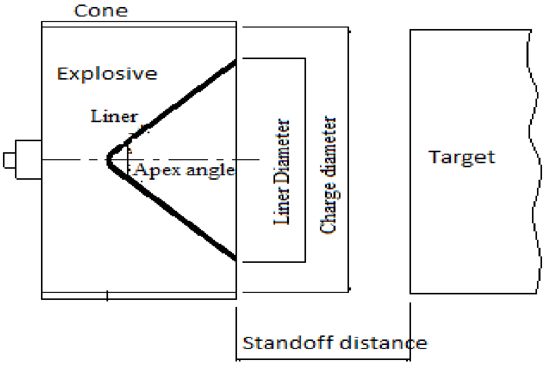

Figure (1) The nomenclature for a shape charge

It has been experimentally observed, however, that jets formed from shaped charges contain a spectrum of velocities with the front of the jet traveling much faster than the rear. This effect causes the jet to elongate and subsequently break up. To describe this velocity gradient in the jet, Pugh et al. modified the theory of Birkhoff. This modified theory, known as the non-steady theory, is based on the same hydrodynamic concepts as the original theory, except that the velocities with which various elements collapse are not the same for all elements but depend upon the original position of the element in the liner. According to this modified theory, the collapse velocity decreases continuously from the cone apex to the base. This effect produces a significant elongation of the jet. Since 1970 various fundamental improvements to the theory of shaped charge jet formation have been made in the published and unpublished literatures. They include the following: generally shaped liner; spherical or tropical detonation wave; improved explosive-metal interaction formulas for liner collapse; finite acceleration of liner elements during collapse and many other aspects

2.1- Jet Tip Formation

In many cases, because of the finite acceleration of liner elements, the liner has a region where the elements do not reach the final collapse velocity. In this region, normally close to the charge axis, an element having a jetting velocity V_{j1} (j,1 are jet and liner element number respectively) may be followed by an element with a jetting velocity that is greater than this velocity, that is, $V_{j2}>V_{j1}$. This inverse velocity situation usually continues throughout this region. Thus, interference of the jet elements takes place and the mass piles up and usually forms the jet tip. This effect, first pointed out by Kiwan and Wisniewski, is known as the inverse velocity gradient [2]. For conventional conical charges, the first 30 to 40 % of the liner from the theoretical apex forms the tip, which has a much larger radius than the rest of the jet. In the present theory, we assume that the elements experience a perfectly plastic impact and that the element pile up to form a tip particle whose velocity may be predicted by conservation of linear momentum. We consider each element to impact until we find the first jetting element whose velocity is less than the velocity of the combined tip particle. Then conventional jetting ensues. In mathematical form, this may be calculated as:

$$\bar{V}_j(x_{tip}) = \frac{\int_0^{X_{tip}} V_j(x)\frac{dm_j}{dx}dx}{\int_0^{X_{tip}} \frac{dm_j}{dx}dx} \qquad (1)$$

Where $\bar{V}_j$ indicates the velocity of the combined tip particle, dm_j is jet mass and x is coordinate along the axis of the cone. In actuality this expression is integrated step by step until a point x_{tip} is found such that:

$V_j(x_{tip}) \leq \bar{V}_j(x_{tip})$

Then this value of x_{tip} is considered that point on the liner that distinguishes where the formation of the tip stops and where normal jetting begins.

2.2- Jet Stretching Phenomena

A typical shaped charge jet has a relatively high tip velocity and a low tail velocity. This velocity causes the jet to stretch (elongate) to great lengths at sufficiently large standoff distances. This length, which is directly proportional to the penetration capability of the jet, is limited by the eventual axial breakup of the jet into segments or particles [1]. Once the jet particulates, the penetration decreases steadily and significantly. Consequently, an understanding of the jet breakup phenomena and methods of delaying its onset are of major importance to the shaped charge designer. For certain element *i*, to calculate the jet length after stretching is over, first it is important to know the initial jet length for that element (i.e. at the moment of element arrival at the cone center line). The required length is given by:

$$l_0 = \frac{4M\sin^2\frac{\beta}{2}}{\phi_0^2\,\pi\,\rho} \qquad (2)$$

Where, M is the element mass, β collapse angle, ρ is the jet density, and ϕ_0 is initial jet diameterwhich is given by:

$$\phi_0 = 2\sqrt{2\,t\,r'}\,\sin\frac{\beta}{2} \qquad (3)$$

Where, t is the liner thickness and r' is the radial distance for the specified element at the moment of collapsing.

2.3- Jet Breakup

In the one-dimensional modeling of the jet breakup phenomenon, the approach is similar to that used in the study of stability of liquid jets. One-dimensional governing differential equations are first written in Lagrangian coordinates. The initial and boundary conditions are specified. Some small disturbance is then introduced. If the disturbance grows in amplitude, the jet is unstable and necking will occur. Familiar liquid jet instability is water flowing from a faucet; at first it has a constant diameter, then becomes wavy with necks, and finally turns into droplets. But, whereas the controlling force in the water jet is the surface tension, the governing factors for shaped charge jets are the material strength and inertia force. In a series of papers and reports, Chou and Carleone studied jet breakup using a one-dimensional model. In Chou and Carleone, they modeled the jet with linearized equations and showed that the ratio Y/ρ of jet flow stress to jet density controlled the growth of the instability. A low value of this ratio causes the jet to neck down more slowly than a material with a large value, all other conditions being equal. This early version of theory, however, could not predict the critical wavelength. Carleone et al. extended the theory to include the stress concentration at the jet necks. The resulting equations clearly showed the existence of a critical wavelength. The linearized solution of the theory showed the critical wavelength to be independent of the jet stretching rate, with a value 2.22 times the jet diameter d_0 at the time of onset of the instability. However, detailed two-dimensional hydrocode simulations, also presented by Carleone et al., clearly showed the critical wavelength to be a function of jet stretching rate. The one-dimensional solution predicted the generation of a progression of new necks from an existing neck. Also, the formation of necks near the tip of the stretching jet was accurately simulated. These results were verified by two-dimensional finite-difference calculations using the same initial conditions and constitutive equations [1]. Quite a few empirical formulas have been proposed. Hirsch presented a phenomenological formula for the jet breakup time. In this formula, the break up time is related to the smallest characteristic dimension (original liner thickness) and an empirical constant V_{pl}, the velocity that characterizes the metal and that may be related to the velocity difference between segmented jet particles as following:

$$t_b = \frac{2r_0}{V_{pl}} \qquad (4)$$

Where t_b is breakup time and r_0 is the initial jet radius or radius when the jet elongation begins.

2.4- Penetration

The primary purpose of the tactical warheads is to penetrate or damage a specific target, usually a vehicle or structure of some type. The warhead causes damage to the target by depositing a large amount of kinetic energy over a relatively small area by means of a high speed penetration, typically a jet or rod of metal. This high speed collision causes interaction pressure between the target and penetrator that result in stresses that exceed the strength of those materials. For metallic targets having density ρ_T, the material flows plastically away from the impact area causing a cavity to be formed. The penetrator is also eroded by plastic flow during this process. The target cavity continues to grow in depth until the penetrator is totally consumed or the target structure is perforated [2]. For the jet of constant velocity V, with density ρ_j and constant length L, assuming that the penetration stops when the jet length is consumed, that is, there is no after flow effect, U is the penetration velocity, the duration of the penetration is L/(V-U). The penetration is then given by [2]:

$$P = L\sqrt{\frac{\rho_j}{\rho_T}} \qquad (5)$$

This usually referred to as the *density law*. It is interesting to note that the total penetration for a constant velocity jet depends only on the length of the jet and the density ratio of the jet and target. The depth of penetration by a given jet varies inversely with the square root of the density of the target. The lack of dependence on the jet velocity holds for velocities great enough to produce pressures far above the yield strength of the target.

3- Theoretical Results

As presented above, the penetration value depends on the jet length, this is clear if we consider the equation (5). But, the elongation of the jet has a limit which ends by the jet breakup phenomena. In order to study the effect of the jet length on penetration value for different standoff distances, a shaped charge shown in figure (2) is implemented for theoretical analysis. HMX explosive was chosen. The theoretical analysis was done keeping in mind the existance of virtual origin, therefore, the standoff distance is measured from this point. The density law formula (equation 5) was used to estimate the value of penetration. The target is homogenous steel plate. The collapse velocity approach is instantaneous acceleration. A computer code SHARP is used to estimate the penetration, breakup time and jet length for different values of standoff distances. Table (1) shows results obtained for charge caliber CD =64 mm.

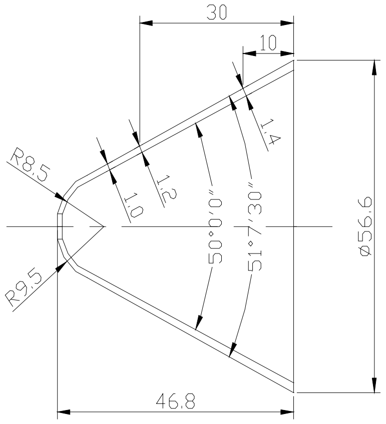

Figure (2) Conical Shaped Charge

Table (1) SHARP results for different Standoff

Standoff (CD)	P (mm)	P/d	Breakup time(µsec)	Jet length (mm)
1 CD	171	2.67	83	134
2 CD	264	4.13	83	216
3 CD	314	4.91	83	264
4 CD	338	5.28	83	286
5 CD	343	5.36	83	290
6 CD	343	5.36	83	290
7 CD	343	5.36	83	290

It is clear that by increasing standoff distance, the jet length value increases to some point, which is approximately at standoff equal 4, as standoff distance increases the jet length stay constant, this is because the jet breakup phenomena occurred. So the 290 mm as jet length for this specific charge, is the maximum jet length that can be achieved. As a result of that, the value of penetration does not change even if the value of standoff distance is increased. The jet breakup time value indicates that the jet needs only 83 µsec to particulates, so, if the distance to the target (standoff) requires more than 83 µsec to travel by the jet, then, the breakup of the penetrator jet will occur and the penetration value will decrease. But this is not the case as shown in figure (3), which shows, that, the penetration is constant as standoff distance increases. The disadvantage of using the density law is than, it does not include or show the real effect of jet breakup on the penetration value. In other words, as long as the jet is particulates, the effective jet length is decreased and therefore, the penetration value is decreased. Actually due complicity, it is quite difficult to evaluate the effective length after breakup especially if it occurs more than once.

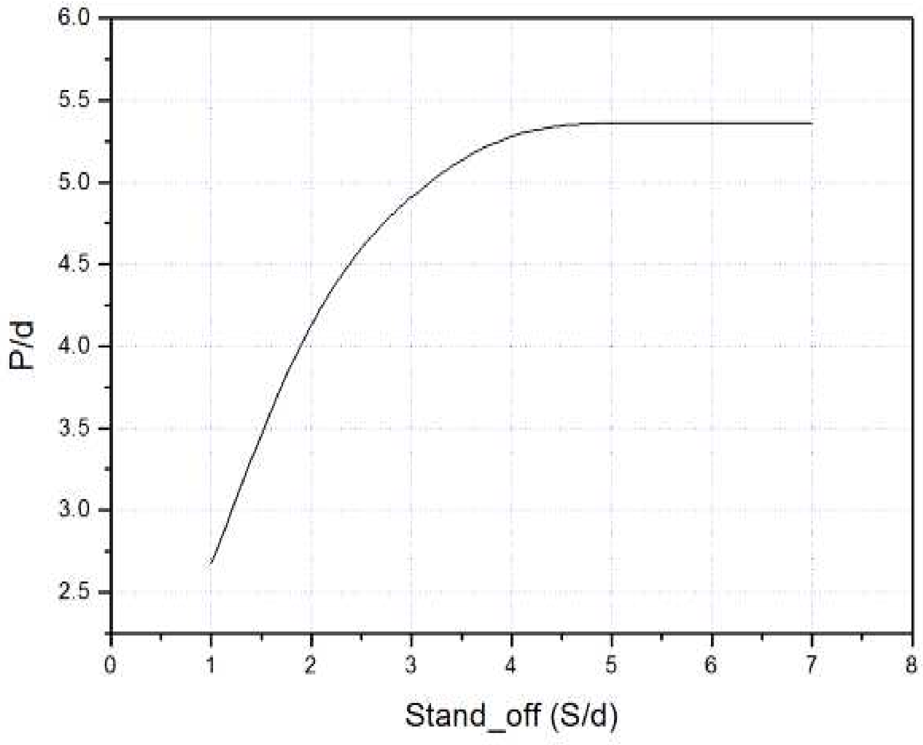

Figure (3) Variation of P/d vs. standoff distance

4- Conclusion

The performance of shaped charge depends on many design parameters. The standoff distance has a great role on the resulting target penetration. The jet formulation is very important to build a strong jet, so a high penetration value can be obtained. As long as the designer keeps the standoff distance within appropriate values, the jet breakup phenomena will not have a negative impact on the penetration value. For a good design, the value of standoff distance is designed so it can give enough time to the jet to build and obtain the maximum length but not to give the jet any chance to start particulating, because if the breakup occurs, then, the penetration value is seriously affected.

5- References :

1-W. P. Walter & J. A. Zukas “Fundamentals of Shaped Charges”, John Wiley & Sons, Inc. 1989.

2- David Chi. " Target Interaction: Fundamentals of Penetration Mechanics-Jets and Rods", Aero jet General Corporation, Azusa, California 91702, Part A.

3- W.J. Flis." The Effects of Finite Liner Acceleration On Shaped-Charge Jet Formation".19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

4- ESER GÜREL.” Modeling and simulation of shaped charges”. submitted in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering Department, Middle East Technical University, July 2009

5-- William P. Walters and Daniel R. Scheffler. “A method to increase the tip velocity of a shaped charge jet”. 23RD International Symposium on Ballistics, TARRAGONA, SPAIN 16-20 APRIL 2007.

6- Chris Poole. “Penetration of shaped charge”. Corpus Christi College, University of Oxford, A thesis submitted for the degree of Doctor of Philosophy

Trinity 2005

7- Tamer Abd Elazim Elshenawy.” CRITERIA OF DESIGN IMPROVEMENT OF SHAPED CHARGES

8- USED AS OIL WELL PERFORATORS”. University of Manchester, A thesis submitted for the degree of Doctor of Philosophy 2012.