Estimation of Minimum Jet Velocity for a Copper Penetrator Through a Homogenous Steel Target

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Abstract:

S*haped charge technology has an important role in the military and commercial areas, as bullets and warheads made by the shaped charge principle are especially used for penetration to target and demolition purposes [1]. The goal of this work is to estimate the value of minimum jet velocity for a copper penetrator, in order to obtain the real penetration depth record. A specified shaped charge configuration was chosen. A series of 15 tests were performed and the values of penetrations depth were recorded. SHARP computer code was used to calculate theoretical penetration values for a wide range of minimum jet* *velocity. Comparing the penetration results for both experimental and theoretical records, a value of 1938 mm/µsec as minimum jet velocity was obtained. Using the new minimum jet velocity value, a good agreement between experimental & theoretical penetration depth was observed for standoff distance not greater than 3CD (charge diameter) but for standoff distance greater than 3CD the theoretical results are higher. This because, the minimum jet velocity is not constant and it is changing by increasing the standoff distance.*

***Keywords**: shaped charge, minimum jet velocity, penetration depth, standoff distance.*

1.Introduction.

Passive

Denotations:

l -Shaped charge jet length

ρ_j -Jet density

V -Jet velocity

ρj -Target density

U -Penetration velocity

Vmin -Min. Jet velocity

T -The time at the end of penetration

tb -Time of jet breakup

t0 -Time when the tip reaches the target

P -Total penetration depth

S - Distance from the virtual origin to the target.

1-Introduction

A cylinder of explosive with a hollow cavity in one end and a detonator at the opposite end is known as a hollow charge. If the hollow cavity is lined with a thin layer of metal, glass, ceramic, or any solid, the liner may form a jet when the explosive charge is detonated if certain criteria related to the charge geometry, explosive, and liner properties are satisfied. This mechanism is known as shaped charge [2]. The shaped charge has been used in the military and civil industry for different purposes, for example: penetrating, cutting, forming, welding, etc. The process of the shaped charge jet formation and penetration into the homogenous obstacle, generally, like other phenomena of the penetration, belongs to the class of nonlinear mechanics problems, and it can be described very successfully by equations of the fluid mechanics in the field of the shock wave theory. This is possible due to the enormously high values of the velocities, pressures and temperatures that follow this process when the penetrator and obstacle materials behaviour is similar to the fluid behaviour.

2- Theory

Analytical models capable of predicting the penetration of the jets from shaped charges into a variety of target materials are extremely valuable to the terminal ballistician. Early analytical penetration models were based on the Bernoulli principle. Later, empirical factors were introduced to account for particulation of the jet.

Because of the hypervelocity associated with shaped charge jets, the pressures produced during jet-target impact far exceed the yield strength of most materials. Thus, to a first approximation, the strengths and viscosities of the jet and target materials can be neglected.

Consider a shaped charge jet of length $\boldsymbol{l}$, density $\boldsymbol{\rho_j}$, and velocity $\boldsymbol{V}$ penetrating a semi-infinite, monolithic target of density $\boldsymbol{\rho_T}$. The penetration velocity is $\boldsymbol{U}$, as shown in figure 1. The penetration is simpler when viewed from a system of coordinates moving with the penetration velocity $\boldsymbol{U}$, as shown in figure 2. In this system the hole profile is fixed, and the jet moves to the right at a velocity $\boldsymbol{V} - \boldsymbol{U}$, and the target moves left at a velocity $\boldsymbol{U}$. The pressure on the two sides of the interface between the jet and the target must be the same. Now, since the phenomenon is steady state in this system of coordinates. Bernoulli's equation may be applied along the axial streamline so that:

$$\frac{1}{2}\,\rho_j\,(V-U)^2 = \frac{1}{2}\,\rho_T\,U^2 \qquad (1)$$

The total penetration $\boldsymbol{P}$ is the penetration velocity times the penetration time or:

$$P = U\,\frac{l}{V-U} \quad or \quad P = l\,\left(\frac{\rho_j}{\rho_T}\right)^{1/2} \qquad (2)$$

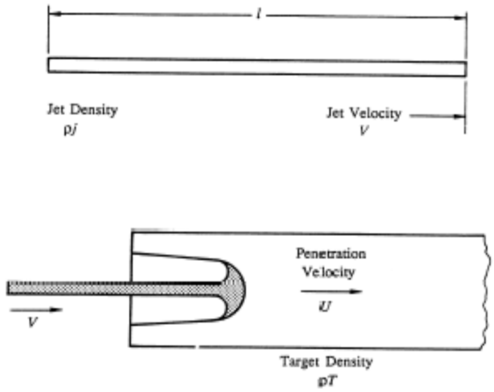

Figure 1. Jet penetration

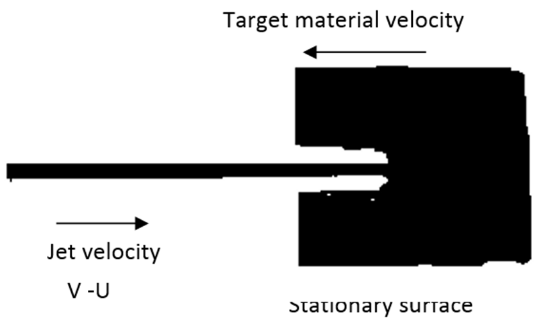

Figure 2. jet penetration with a coordinate system moving at the penetration velocity U

There are several limitations to this simple theory [2]. First, after the jet (penetrator) is consumed, the residual inertia of the penetrator may cause the hole to continue to grow in depth and width. Second, it was observed that, a penetration into mild steel is greater than in armour steel, even though both have the same density. This because that, material strength, strain rate and other material properties are not included in the simple penetration theory. Third, for real jets, the average penetration into a given target increases, reaches a peak value, and then decreases as the distance between the base of the charge and the target increases.

Later on many ideas were implemented to understand the behaviour of shaped charge, and a new parameter was defined that is V_{min}, the minimum jet velocity for penetration or the cut off velocity. If the jet velocity is below V_{min}, the jet will cease to penetrate. It was found that V_{min} is not constant for a given jet or target, but increases with standoff distance. DiPersio and Simon presented explicit formulas for three cases (a) penetration before jet breakup ($T < t_b$). (b) jet breaks during penetration ($t_0 < t_b \leq T$), and (c) jet breaks before the target ($t_b < t_0 \leq T$). For case (a) the total penetration is:

$$P = S\left[\left(\frac{V_0}{V_{min}}\right)^{1/\gamma} - 1\right] \quad (3)$$

In this case S is bounded by:

$$0 \leq S < V_{min} t_b \left(\frac{V_{min}}{V_0}\right)^{1/\gamma}$$

For case (b), the penetration is:

$$P = \frac{(1+\gamma)(V_0+t_b)^{1/(1+\gamma)}\, S^{\gamma/(1+\gamma)} - V_{min}\, t_b}{\gamma} - S \quad (4)$$

Where S is bounded by:

$$V_{min} t_b \left(\frac{V_{min}}{V_0}\right)^{1/\gamma} < S < V_0 t_b$$

Finally, for case (c), the penetration is:

$$P = \frac{(V_0 - V_{min})\, t_b}{\gamma} \quad (5)$$

Where S is bounded by:

$$V_0 t_b < S < \infty$$

And: $\gamma = \sqrt{\rho_T / \rho_j}$

These formulas are the result of the so-called DSM (DiPersio, Simon, and Merendino) theory. DSM theory shows the importance of the parameter V_{min}. The penetration process at low velocity must depend on the strengths of the jet and target. Table 1 shows a data review for V_{min} values.

Table 1. V_{min} values for different jet & obstacle combination

	Type	V_{min} (m/s)	Comment
Jet	Cu	2225 Experimental	Reference (3)
Obstacle	Steel		
Jet	Steel	2200	Reference (4)
Obstacle	Steel		
Jet	Cu	2200-2300	Reference (2)
Obstacle	Steel		

3- Experimental work

The work plane was to conduct a series of shaped charge tests for a specified configuration. A conical shaped charge was chosen. It is fabricated with liner made of copper had thickness of 1.0 mm. The cone angle is 50°. The shaped charge calibre is 64 mm. The standoff distance was 2.5 CD,3 CD and 4 CD . The target was a steel plate of a thickness of 400 mm. A series of 15 tests (5 specimens for each specified standoff distance) were performed. Table 2 summarizing the experimental results.

Table 2 Penetration (in mm) for different standoff distances.

Test No.	Standoff Distance		
	2.5 CD	3 CD	4 CD
1	250	310	>335
2	310	310	260
3	310	312	312
4	>300	283	312
5	290	315	312

A theoretical calculation of penetration depth was done using SHARP computer code. The calculation was performed by assuming a range of V_{min} possible values. The values start from 1.6 mm/µsec to 3.0 mm/µsec. The next step is to compare the theoretical results for penetration depth with the record obtained from experimental work. The results for 3 CD was picked for comparison, and the value for penetration of 312 mm was considered for comparison. Figure 3 shows the theoretical and the experiment result. It can be seen very obviously, that the two curves intersect at a value of V_{min} = 1938 mm/µsec.

Now, after the value of V_{min} was established, the same value will be used to calculate the theoretical penetration depth (again by using SHARP computer code). Standoff distance is 2.5CD. The result obtained from SHARP for penetration is P = 306 mm which is very closed to the penetration values gained from tests shown in table 2 for standoff distance 2.5 CD.

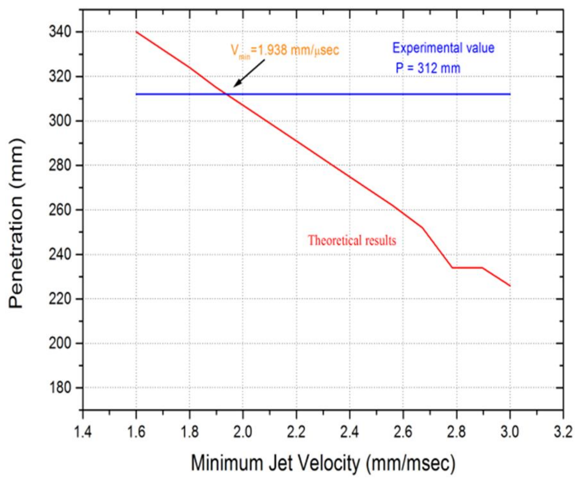

Figure 3. Theoretical and experimental penetration result for S = 3 CD

If the same procedure is repeated (with V_{min}=1938 mm/µsec) keeping standoff distance equal to 4 CD, the penetration value obtained using SHARP code is P = 366 mm. Obviously it is not matching with the experimental result given in Table 2 when the standoff distance is 4 CD. The theoretical value for penetration is greater than, the experimental one.

4- Conclusion

The determination of shaped charge penetration depth through specified target is very crucial and complicated as well. This is due to the fact that, they are many parameters had a great influence on the final penetration depth. The minimum jet velocity V_{min}, is considered one of those parameters. Table 1, shows many values for different combination of liner and target materials. In this work a combination of copper liner and steel target was considered. The theoretical value for minimum jet velocity was estimated. This value is 12% lower than, the reference values given above. The new minimum jet velocity value (V_{min}=1938 mm/µsec) obtained, give a closed penetration depth results compared to the penetration values achieved from experimental work especially for standoff distance equal or less than 3CD. If standoff distance increased to 4CD, then, the penetration depth value obtained using the new minimum jet velocity is higher than the values gained from experimental effort. This is because the minimum jet velocity is not constant. It is changing by increasing the standoff distance.

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