A computer modeling to estimate the design characteristics of a shaped charge warhead

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Abstract:

The main objective of this work is to develop a computer code that can be used as a major tool for shaped charge warhead design. The code "SHARP" was established using FORTRAN 95. The SHARP program starts by: estimation of explosive properties used in warhead, evaluating detonation wave properties and profile, driven liner velocity calculation, estimation liner collapse velocity & angles, jet breakup & length determination and finally, evaluating the target penetration. For the purpose of verifying SHARP results, a set of 20 shaped charges were tested. The tests were directed to investigate the influence of cone apex angle and standoff distance on the performance of shaped charge. The *experimental results were compared with SHARP results. The comparison shows a remarkable agreement between the theoretical and experimental results.*

Keywords: *shaped charge warhead, liner collapse, penetration, warhead design.*

1.Introduction:

The term shaped charge has been applied to explosive charges with lined or unlined cavities, although in current usage the term applies primarily to charge with lined cavities. The cavity is formed in the end of the explosive charge opposite the point of detonation [1]. It was one of the aims of this work to develop a computer code which can be used as a design tool for preliminary design and study shaped charge for different liner configurations. This task includes the following phases:

1- Estimation of explosive properties.
2- Detonation wave properties and profile.
3- Calculation of driven liner velocity.
4- Calculation of liner collapse velocity and angle.
5- Jet length determination.
6- Evaluation of the target penetration. The previous phases can be performed after fixing up the liner shape and preliminary shaped charge dimensions. Shaped charge design program "SHARP", was built to perform the mentioned phases. SHARP used all the available and approved approaches for phases 3,4,5 and 6. For example, on phase 3, the velocity of the driven liner is calculated using four different formulas. Performing the shaped design phases by utilizing the mostly known approaches, makes SHARP a very powerful design

tool. Also, it gives a great chance to the designer to have a wide range of calculated results which indicate the expected performance for the designed shaped charge.

2- Computer Code SHARP Structure:

FORTRAN 95 was implemented for creating the SHARP code, however, the input data subroutine was created using Visual Basic. SHARP consists of 18 subroutines having a source file with more than 3200 lines. Figure (1) shows the main outlines of the SHARP code. A simple finite element approach was used for building up the code. This approach is relying on the fact, that, the liner is divided into 350 elements, and a complete analysis is done for each element.

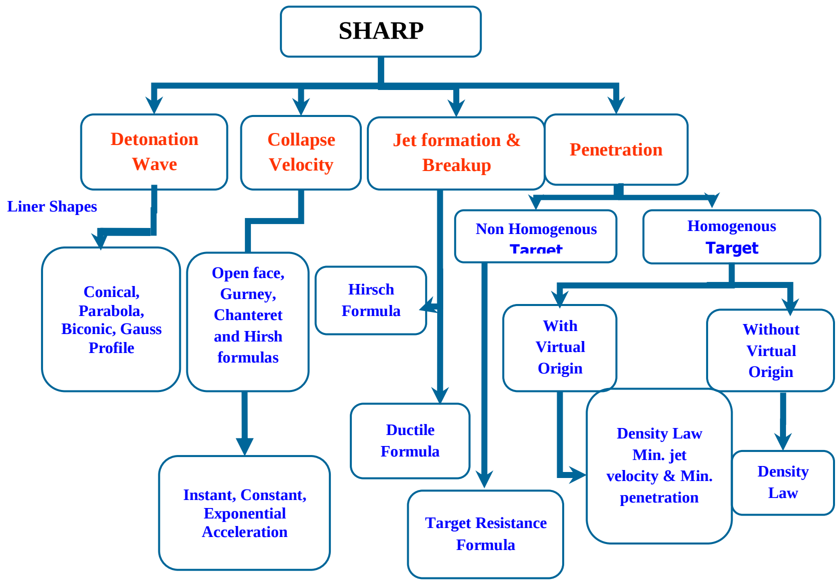

Fig. 1. SHARP main outlines

3- Input Data Subroutine:

This subroutine was designed to read in all the input data needed for running SHARP. Input data can be classified as follows: explosive input data, shape & dimensions for the shaped charge liner and options for approaches to be used for calculations. For easy input excess, the input subroutine was written in Visual Basic, which can provide a very simple, easy and understandable excess to create the input data file and also running SHARP.

4- Explosive Properties Determination:

Explosive.F95 subroutine calculates the explosive properties such as Chapman-Jouguet pressure, Detonation velocity and Gurney constant. After it reads from *Sharp.inp* the explosive name or names if it is a mixture, densities and percentage, it will make use of another data base file (*Epro.dat*) which contains a list of 28 explosive names, also it contains atomic number for each item, number of moles of gaseous products of detonation per gram of explosive, and average molecular weight of the gaseous products in grams of gas per mole of gas.

5- Estimation of Detonation Wave Profile & Mass Calculations:

Actually, determination of wave profile and mass calculations is fully depended on the liner shape used. In other words, the equations used for calculating the liner and explosive masses in the case of conical liner are differ from the one used for Gauss liner shape. Although, detonation profile technique used is the same (i.e. Model of logarithmic spiral), but the application of this method differ froms one liner shape to another. Due to variety of liner shapes, a separated subroutines were created, so, every liner shape has it is own subroutine. There are four subroutines involved for four different liner shapes " Conical, Parabola, Biconic, and Gauss shapes". Each subroutine performs the following: 1- Detonation wave profile estimation, starting from the initiation of the explosive until all the explosive is consumed. 2- Masses and mass ratios calculation. 3- Velocity determination.

6- Initial Driven Liner Velocity Evaluation.

when detonation wave arrive at the liner, the liner element will accelerate to a velocity V_o. In the seek of considering all the approved ideas for this phase, SHARP provides four approaches for V_o calculations: Open face sandwich, Gurney formula, Chanteret formula and Hirsch formula. Using these approaches give the user the opportunity to compare the results obtained by all the approved ideas for this phase.

7-Evaluation of Collapse Velocity:

When the liner element collapses, the driven velocity history from that moment till the moment where the elements arrive at the charge center line, is assumed to follow one of the following profiles: 1) Instantaneous Acceleration 2) Constant Accele- ration 3) Exponential Acceleration. The three profiles were involved in SHARP. For further explanation, reader can reefer to App.[7]

8-Evaluation of jet forming and stretching:

The phase of jet forming and stretching is very important and complex stage of shaped charge design procedure. This is due to the fact, that there are many different parameters to be calculated, and leak of informations which can mathematically describe this part of design. During this phase, the first step is to consider the jet forming case, that is, at the moment when the collapsed liner elements arrive to the center line of shaped charge. This consideration does not include stretching and particulation of the jet. At the moment of jet formation, the initial jet length, mass, diameter, arrival time and arrival velocity are calculated. on the other hand, the same procedure is applied to calculate the slug properties as well, but, because the slug part does not contribute in penetration phenomena, it is coming out of the picture of interest. The second step is to consider jet stretching and particulation phenomena.

9-Penetration:

A penetration value is considered as the indicating sign for the shaped charge performance. Most of the shaped charge users and designers as will having the interest to know how much penetration can be achieved by a certain shaped charge. So, due to this, it was taken into consideration that, the design of this phase is to be made using all the recently discovered and approved approaches for the estimation of the value of penetration. The type of the target was considered as a classification issue **A)** Homogenous Target: when the target consists of one material, it is called a homogenous target. In this case there are two possible ways of calculations:

1- Applying virtual origin approach: Virtual origin is an important issue for deciding the standoff distance [9]. By finding the location of virtual origin, the standoff distance can be easily achieved by simple addition operation. Then the penetration value can be calculated by the following techniques (this can be decided by the user): Density law formula (DL), Minimum velocity (Vmin), and Minimum penetration velocity (Umin).

2- No virtual origin is applied: In this case the standoff distance is taken as it is provided by the user and the penetration calculation is performed using density law only, this is, because the minimum jet velocity and minimum penetration velocity approaches are considered standoff distance which is measured from virtual origin location. **B)**

Non-Homogenous Target: Non-homogenous target is defined as the target which consists of many layers of different material. Due to target non-homogeneity, a target resistance factor was defined. By using this factor the expected penetration value can be calculated using the formula[2]:

$$P = \frac{L_j\left[1-\sqrt{\frac{\rho_\tau}{\rho_j}+\frac{2R}{\rho_j V_{jtip}^2}\left(1-\frac{\rho_\tau}{\rho_j}\right)}\right]}{\sqrt{\frac{\rho_\tau}{\rho_j}+\frac{2R}{\rho_j V_{jtip}^2}\left(1-\frac{\rho_\tau}{\rho_j}\right)}-\frac{\rho_\tau}{\rho_j}}$$

where ρ_τ is target density given by ρ_H/ρ_j, ρ_H hydrodynamic density, and R is target resistance factor. For example, each initial driven liner velocity (i.e. openface sandwich, Gurney, Chanteret or Hirsch), the three categories are applied to cover all the assumed possibilities that. describe the way of movement, traveling path and the position of arrival at center line, which the liner element had followed. In the case of exponential velocity profile, the formula used for calculating projection angle is dependent on the averaged values for collapse velocity V and time constant τ divided by the liner element length.

10- Experimental Work and Results:

The main aim from the present experimental work is to measure the penetration caused by specified shaped charge. This includes the study of changing apex angle and stand off distance on the resulting penetration. Two models of shaped charge with conical liner were implemented in experimental work. First model with apex angle 2α=50°, second model has an apex angle 2α=60°. The defined shaped charge having a 64 mm diameter and HMX explosive material was chosen.

Three steel plates with 300 mm, 10 mm and 25 mm thickness were used as a target. The experiments were performed in special military field under supervision of qualified experts. On the other hand, a complete theoretical analysis for the two models was carried out using SHARP program. Three different acceleration histories were implemented, Penetration results were calculated using density law, minimum jet velocity Vmin, and minimum penetration velocity Umin approaches. Four approaches for calculating liner collapse velocity were used. Finally, a comparison between the theoretical and experimental results were performed. Figure (1) shows, comparison between cone angle versus P/d (penetration / charge diameter) using the three approaches (used to estimate penetration value), density law (*chart a*), minimum jet velocity (*chart b*) and minimum penetration velocity (*chart c*). The solid lines represent the theoretical results (i.e cone angle vs. P/d) for each approach used to calculate the driven liner velocity. The experimental results are shown in marks. From figure (1), the results obtained using Vmin, show more compatibility with experimental results (*chart b*) more than density law and Umin approaches. Figure (2) shows, standoff distance versus P/d (penetration / charge diameter) using the three approaches, density law (*chart a*), minimum jet velocity (*chart b*) and minimum penetration velocity (*chart c*). The cone angle is fixed 50°. Again, The solid lines represent the theoretical results (i.e standoff distance vs. P/d) for each approach are used to calculate the driven liner velocity. The experimental results are shown in marks.

From figure (2), density law formula shows remarkable agreement with the experimental results (*chart a*) Also, the minimum jet velocity technique gives good agreement with experimental results (*chart b*).

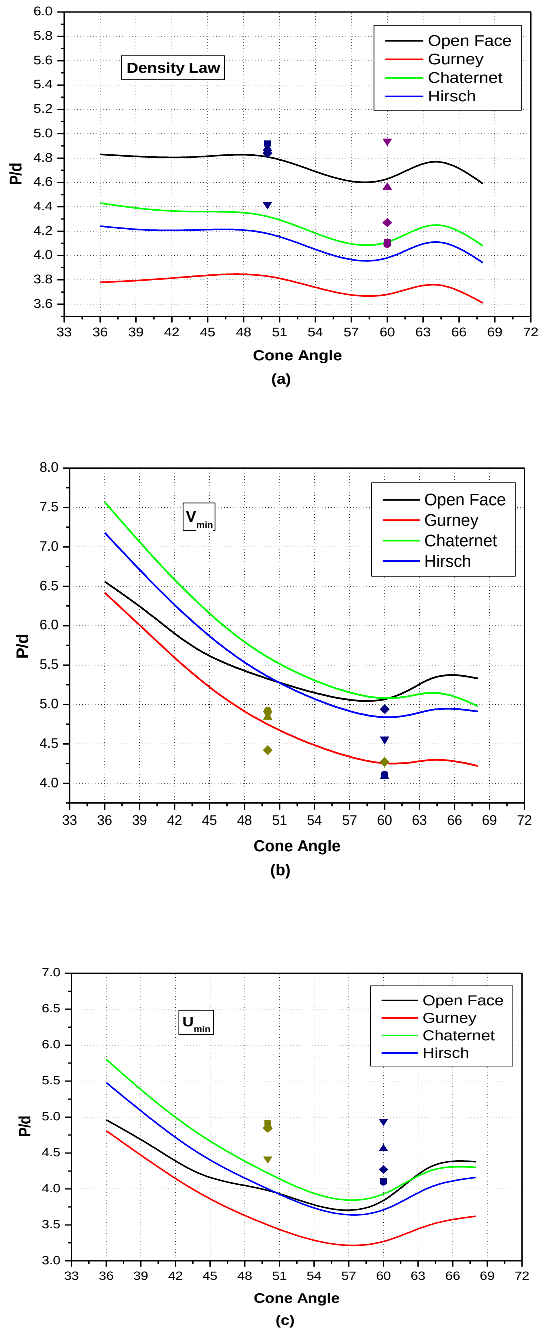

Figure (1) P/d vs. Cone Angle

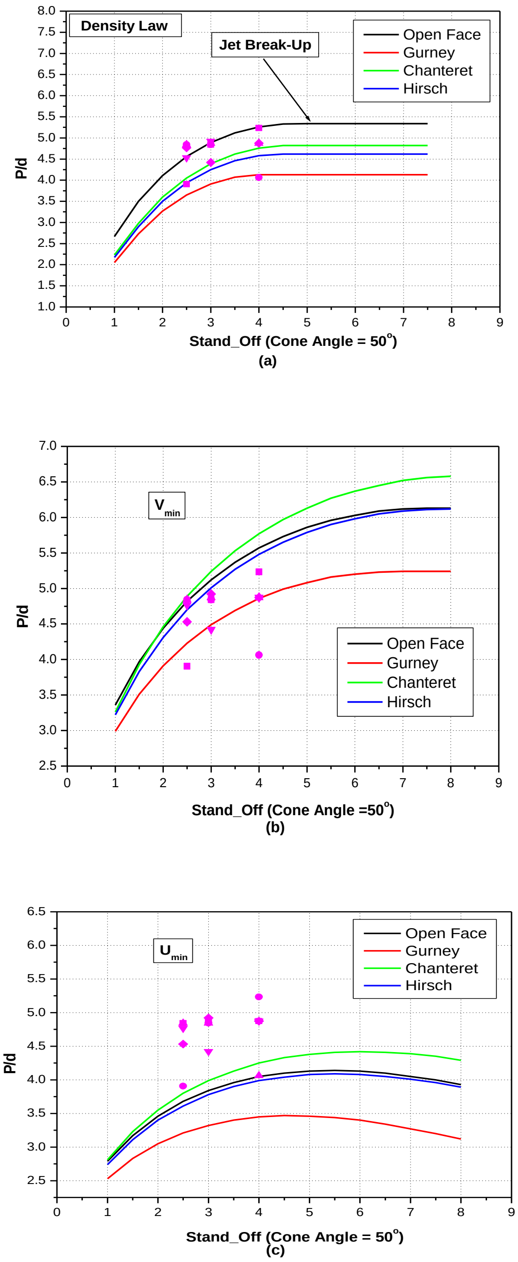

Figure (2) P/d vs. Standoff distance

11-Conclusions :

SHARP code provides a wide range of different approaches and techniques used for preliminary shaped charge design. This is quite clear during the calculation collapse liner velocity (four approaches), jet formation & breakup (two approaches) and the type of target homogenous & non-homogenous was considered for estimating penetration value. A set of 20 specimen of shaped charge were tested in favor of verifying the theoretical results gained by SHARP. Two different apex angles (50° & 60°) were implemented and the different values of standoff distances (1d,2d and 3d) were considered (d is charge diameter). A complete comparison of theoretical and experimental results was done. Density law and Vmin approaches show a good agreement during studying the influence of changing cone angle. Also, the two approaches again show a remarkable agreement with experimental results when the standoff distance influence on the performance of shaped charge was considered. A further work (experimental and theoretical) is needed in order to improve the computer code SHARP.

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