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A Computer Code For Evaluation of Design Parameters of Concrete Piercing Earth Shock Missile Warhead

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Abstract. A simple and reliable computer code has been devised for evaluating various design parameters, and predicting the penetration performance of concrete piercing earth shock missile-warhead and will be useful to the designers of earth penetrating weapon system.

Symbols

c	= maximum size of aggregate in concrete, cm.
CRH & CRH_i	= external and internal radii of curvature respectively of the ogive in terms of warhead calibre
D	= warhead calibre, i.e. maximum external diameter of the warhead, cm
Da	= assumed diameter (calibre) of warhead, cm
Di	= internal diameter at the shoulder of warhead, cm
Dbi	= internal diameter at the base end of warhead, cm
H & Hi	= external and internal length respectively of the ogive, cm
Lb	= length of body section of the warhead, cm
Lbp & Lbt	= length of parallel and taper portions respectively of the body section, cm
Lw	= total length of warhead, cm
Kf	= ratio of the filling plug length to warhead calibre
Kl	= ratio of the length of taper portion to the full length of the body section of warhead
Kw	= ratio of explosive charge to warhead weight
Kwa	= assumed ratio of explosive change to warhead weight
N	= nose shape factor
p	= depth of penetration into concrete, cm

Pr	=	resistive pressure of concrete, Kgf/cm^2
R & Ri	=	external and internal radius of curvature respectively of the ogive, cm
S_c	=	cube compressive strength of concrete, Kgf/cm^2
T	=	average wall thickness of the body section, cm
Ts	=	minimum permissible wall thickness at shoulder, cm
Tb	=	wall thickness at the base end, cm
vs	=	striking velocity of warhead, m/sec
vb	=	equivalent normal critical velocity for bending when warhead impacts concrete surface at an angle, m/sec
Ve & Vs	=	total volumes respectively of the explosive content and the steel material in the warhead, cm^3
Vo & Vb	=	external volumes of the ogive and the body sections respectively, cm^3
Voi	=	internal volume of the ogive, cm^3
$Vbpi$ & $Vbti$	=	internal volumes respectively of the parallel and the taper portions of the body section, cm^3
Vfp	=	volume of filling plug, cm^3
Wm	=	weight of the carrier missile only, kg
Ww	=	all up weight of the warhead, kg
$(W_w)_{cal}$	=	calculated weight of the warhead, Kg
$(W_w)_{cal}$	=	calculated weight of explosive content, kg
Y	=	dynamic compressive yield strength of warhead casing meterial, Kgf/cm^2
θ	=	angle of incidence with respect to the vertical at the time of impact of warhead, degrees
ϕ_o	=	angle between warhead axis and radius joining the point on nose to the centre of curvature of the ogive, degrees
ρ_e & ρ_s	=	density of explosive & casing steel material of warhead, gram/cm^3

1. Introduction

Concrete piercing earth shock warhead (CPESW) is expected to penetrate the concrete surface or earth, or concrete backed up by earth soil and then explode, there by causing local as well as area spread damage due to shock wave through the earth. This type of warhead is highly effective against aircraft runways, railway yards, industrial buildings/structures, and burried targets. The warhead, in order to penetrate the hard medium and to produce significant earth shock effects, should fulfil the following requirements :

(a) a strong warhead casing of sufficient wall thickness, capable of withstanding the shock and impact load on striking the hard concrete surface with high velocity, and overcoming the resistive force offered by the concrete medium for smooth penetration without any deformation of the warhead.

(b) maximum possible quantity of explosive content for producing crater of maximum possible dimension and causing maximum damage covering widest possible area due to earth shock effect.

It is obvious that the two requirements mentioned above conflict with each other. For a strong casing its wall thickness should be considerably high, but for large explosive content, the wall casing should be as thin as possible, when other conditions such as, all-up-weight, striking velocity, angle of incidence and casing meterial of warhead and the strength characteristics of concrete etc. remain unchanged. It has been found that the penetration depth of the war-head into the concrete slab is a function of the sectional density (Ww/D^2) of the warhead. Therefore, the problem of designing such a warhead reduces to the following :

(1) determination of the optimum calibre of the warhead for a given all up weight, (2) determination of minimum wall thickness of warhead casing of a specified material so that the warhead will not break up or even bulge when it impacts at the given striking velocity on concrete surface of known strength, (3) determination of maximum length of the warhead that will not bend on impacting the concrete surface under specified conditions of strike.

The aim of this paper is not to theoretically investigate or analyse the penetration dynamics as affected by the design parameters or the earth shock phenomena, but to devise a simplied procedure leading to a 'Computer Code' for quick evaluation of various design parameters alongwith an estimate of its penetration capability, based on the existing well proven formulae and available experimental data in published literature on the similar weapons.

2. Formulae Used For the Code

Various elements and design parameters of a CPES warhead is shown in Fig 1. These design parameters can be calculated using some well established formulae as outlined in subsequent paragraphs.

2.1 *Penetration Depth*

A number of empirical formulae for predicting the penetration depth[1,2] into concrete are available. From the comparative study of penetration depths obtained from various formulae, as shown in Fig. 2, it is evident that the formulae given by Kar[1] is the closest to the reality. According to this formula, penetration into infinitely thick concrete slab under specific conditions of strike can be correlated as

$$X = \frac{120328}{Sc^{0.5}} \; N \frac{Ww}{D^{2.8}} \left[\frac{vs}{1000} \right]^{1.8} \tag{1}$$

in which

$$X = (p/2D)^2 \text{ for } p/D \leqslant 2$$

$$X = (p/D) - 1 \text{ for } p/D > 2$$

$$N = 0.72 + 0.25 \text{ (CRH–0.25)}$$

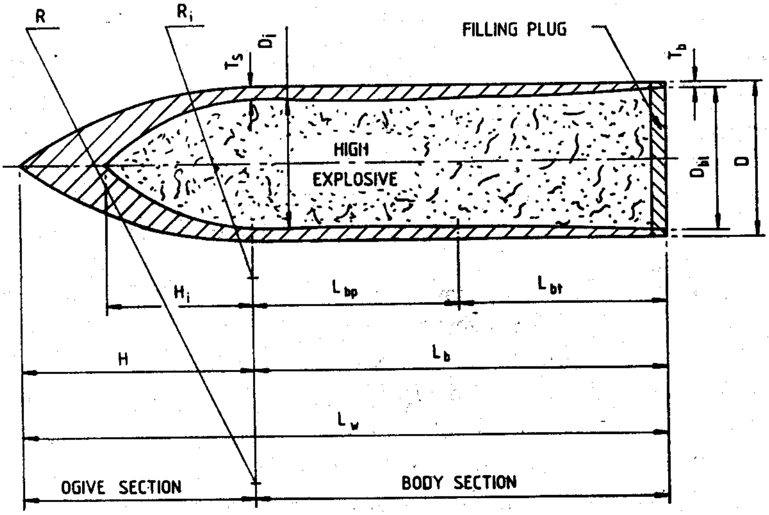

Figure 1. Design elements and parameters of CPES missile-warhead.

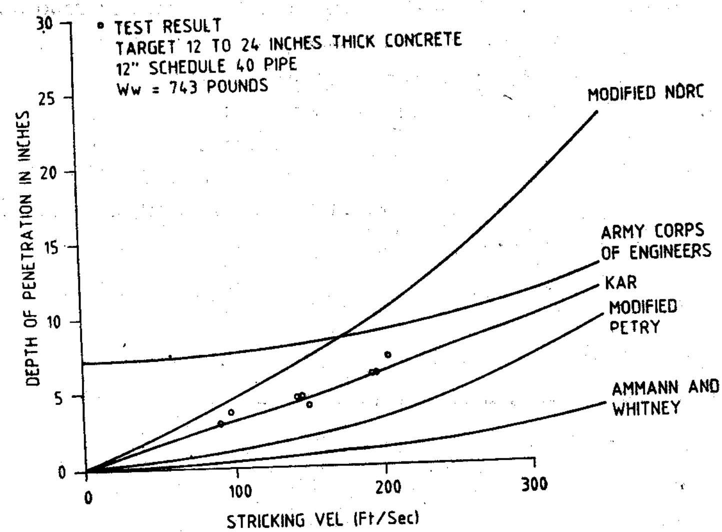

Figure 2. Comparison of penetration formulae.

2.2 *Resistive Pressure of Concrete*

Resistive force[3,4] exerted by the concrete medium on the warhead can be derived by differentiating the penetration formula with time and correlating the warhead motion as it penetrates into the concrete. When this resistive force is divided by the sectional (Projected) area of the warhead, we can obtain the resistive pressure acting on the warhead, casing. Thus, the maximum resistive pressure offered by the concrete at the instant of warhead striking the concrete surface is given by

$$P_r = \frac{150.5749\, v_s^{0.2}\, Sc^{0.5}}{D^{0.2} N} \tag{2}$$

2.3 *Wall Thickness*

For concrete penetrating warheads, the maximum stress occurs at the shoulder of the warhead and, therefore, the wall thickness at the shoulder is a critical factor. Influence of various parameters were studied from a large number of model and full scale tests to arrive at minimum wall thickness at the shoulder that would not break up or even bulge under conditions of impact on concrete surface experimentally derived formula for minimum wall thickness at the shoulder of the warhead is[4]

$$T_s = \frac{D \times 4\, vs^{0.5}\, Sc^{0.375}}{Y(D/c)^{0.1}} [2 - \sin \phi_0 (1 - K_w)] \tag{3}$$

It is found that the stress decreases towards the base end of the warhead, and the wall thickness at the base is given by

$$T_b = D\left[\frac{Pr}{4Y} \frac{Wm}{(ww + Wm)} \right] \tag{4}$$

If W_m is equal to zero, i.e, if the missile carrying the warhead gets detached from the warhead before it strikes the concrete, the thickness at the base end may be taken as 0.05 times the warhead calibre i.e. $T_b = 0.05\ D$.

It is suggested that the warhead should have a constant wall thickness from the shoulder to about midway point and a linear taper from there to the base end of the warhead. The average wall thickness in such a case can be expressed as

$$T = D\,[(1 - 0.5\ Kl)\, T_s + 0.5\ KlT_b] \tag{5}$$

2.4 *Length of Warhead*

From the tests carried out on model projectiles fired at oblique incidence to concrete, it has been observed that the projectiles of nose-radius upto 2.5 calibres are less likely to ricochet than those with sharper noses. External CRH of 2.5 and internal CRH of 1.4 of the warhead ogive seem to be quite reasonable. Once the CRH of the ogive section of the warhead is decided, the external and internal lengths of the ogive can be geometrically calculated as

$$H = (D/2)\,(4CRH - 1)^{0.5} \tag{6}$$

$$Hi = (D_i/2)\,(4CRHi - 1)^{0.5} \tag{7}$$

in which $D_i = D - 2Ts$

Maximum length of the body section (excluding ogive) of the warhead that will not bend on impacting the concrete surface has been related to the other parameters and striking conditions based on the experimental data. The relationship is

$$L_b = D\left[\frac{9.35}{10^4} \frac{(D)^{0.422}}{C} \left(\frac{T}{D} \; \frac{Y^4}{Sc\, v_b^3} \right)^{0.64} \right] + 2.54 \tag{8}$$

in which v_b is given by

$$v_b = \frac{vs}{1 - 0.093\ \theta^{1/3}} \tag{9}$$

Therefore, the total length of the warhead will be

$$L_w = L_b + H \tag{10}$$

2.5 *Explosive Charge to Warhead Weight Ratio*

To calculate the weight of the explosive content and total weight of the warhead, it is required to find out the internal and external volumes of various sections of the warhead applying simple geometrical relationships as follows :

$$V_0 = \pi D^3 [\tfrac{1}{3}H/D \{2(CRH)^2 + (CRH - 0.5)^2\} - (CRH)^2 (CRH - 0.5) \sin^{-1}(H/R)] \tag{11}$$

$$Voi = \pi Di^3 [\tfrac{1}{3}Hi/Di\{2(CRH_i)^2 + (CRH_i - 0.5)^2\} - (CRH_i)^2 (CRH_i - 0.5) \sin^{-1}(Hi/Ri)] \tag{12}$$

$$V_b = \frac{\pi}{4} D^2 L_b \tag{13}$$

$$V_{bpi} = \frac{\pi}{4} D^2 i L_b (1 - Kl) \tag{14}$$

$$V_{bti} = \frac{\pi}{12} K_l (D^2 i + D_i D_{bi} + D^2 bi) \tag{15}$$

in which $D_b i = D - 2\,T_o$

$$V_{fp} = \frac{\pi}{4} K_f D . D^2 bi \tag{16}$$

$$V_{os} = V_0 - Voi \tag{17}$$

$$V_{bs} = V_b - V_{bpi} - V_{bti} \tag{18}$$

Now, the total volumes of the explosive content (V_e) and the steel material (V_s) in the warhead can easily be found out. These are :

$$V_s = V_{os} + V_{bs} + V_{fp} \tag{19}$$

$$V_e = V_{oi} + V_{bpi} + V_{bti} - V_{fp} \tag{20}$$

Knowing the densities of explosive and steel material, their weights can be calculated.

$$(W_e)_{\text{cal}} = V_e \times \rho_e$$

$$(W_s)_{\text{cal}} = V_s \times \rho_s$$

Therefore, the calculated weight of the warhead will be

$$(W_w)_{\text{cal}} = W_e + W_s$$

and the ratio of the explosive charges to the warhead weight will be given by

$$K_w = (W_e)_{\text{cal}}/(W_w)_{\text{cal}}$$

3. Computer Code (CPESW)

Flow chart for the computer code devised for design and prediction of penetration depth for CPES missile warhead is given in Fig. 3. The code employs the formulae outlined above. A sample computer printout from the code (CPESW) giving the list of input data the analysis of the result is shown in Table 1. It is seen that the values assigned to the assumed diameter of warhead and the ratio of explosive charge to warhead weight in the input data are most likely to be incorrect, but the code takes care of these wrong assumptions and automatically correct in the final analysis of results.

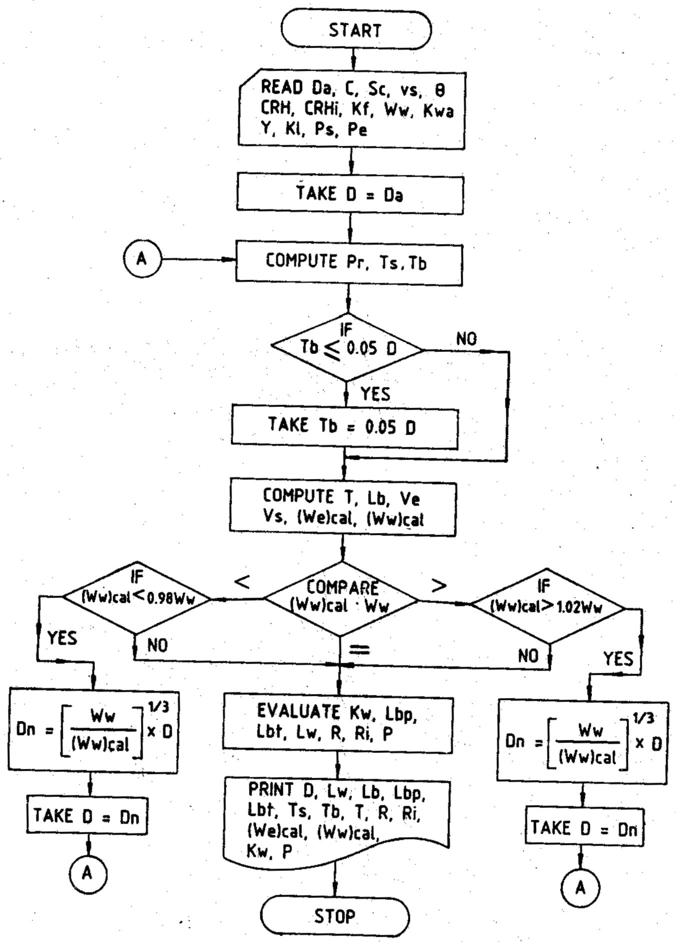

Figure 3. Flow chart for computer code (CPESW).

4. Conclusions

To meet the conflicting requirement for concrete piercing earth shock (CPES) type of missile warhead, there exists only one optimum design, once the values of the input

Table 1. Typical output of computer code (CPESW)

Input Parameters	
Assumed Diameter of Bomb (CM)	30.00
Max size of Aggregate in Concrete (CM)	2.00
Strength of Concrete (KG/CM**2)	450.00
Striking Velocity of Missile (M/SEC)	500.00
Angle of Incidence with Vertical (DEG)	20.00
External CRH	2.50
Ratio Filling Plug Thick to WH Cal	0.10
Assumed WT of WH (KG)	800.00
WT of Missile Minus WH (KG)	700.00
Ratio of Expl WT to WH WT	0.40
Dyn Comp Yld STR Case Mat (KG/SQCM)	12000.00
Ratio of Tamper Length to Boby Length	0.50
Internal CRH	1.40
Density of Body Material (G/CC)	7.80
Density of Explosive Filling (G/CC)	1.60

Results of Analysis	
Final Calculated DIa of WH (CM)	40.69
Total Length of Warhead (CM)	196.22
Length of Body (CM)	135.19
Length Parallel Portion of Body (CM)	67.59
Length Taper Portion of Body (CM)	67.59
Thick at Base end (CM)	2.03
Thick at Shoulder (CM)	3.06
Average Thick of Body (CM)	2.80
Ext Rad of Ogive Portion (CM)	101.73
Int Rad of Ogive Portion (CM)	48.41
Cal WT of Explosive (KG)	233.99
Cal WT of Warhead (KG)	805.67
Ratio Charge to Metal Mass	0.41
Ratio of Expl WT to WH WT	0.29
Penetration (M)	2.08
Perforation (M)	2.78
Optimum Depth of Burst (M)	4.15
Max Crater Dia (M)	14.67
Crater Depth at Optm Depth of Brst (M)	4.38
Max Richochet Angle of Incidence With Vertical (DEG)	44.33

data and the conditions of strike are specified. No change in output design parameters can be accomplished without making changes in one or more input data.

The computer code (CPESW) devised by the authors will be useful to the practical designers of the similar types of warheads.

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