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Ballistic Behaviour of Thick Steel Armour Plate under Oblique Impact : Experimental Investigation-II

S.N. Dikshit

Defence Metallurgical Research Laboratory, Hyderabad-500 058.

ABSTRACT

The ballistic behaviour of thick steel armour plate at different obliquities has been investigated. Ballistic experiments were conducted in the velocity range 300-800 m/s at 0°, 15°, 30° and 45° obliquity. A steel, conical projectile of 6.1 mm diameter was impacted on a 10 mm thick steel armour plate. At 30° and 45° obliquity, the plate offers protection up to a striking velocity of 800 m/s. At zero obliquity, the plate provides protection below 600 m/s. The depth of penetration decreases with increasing obliquity. The plate resistance does not decrease at higher obliquity as observed in an earlier work.

1. INTRODUCTION

The importance of oblique impact both in the monolithic and composite armours is well-acknowledged by the armour designers. The oblique impact studies offer valuable information for reducing the overall weight penalties of the mobile systems used at the battlefield. These studies are also useful for planning the protective mechanism against the onslaught of the ricochetting projectiles or fragments. With this background, the ballistic behaviour of thick steel armour plate under oblique impact was investigated[1]. In that study, an ogive-nose shape steel projectile was impacted on rolled homogeneous armour plate at different obliquities at the subordnance velocity. The ratio of T/D was 1 (T = Plate thickness, D = Projectile diameter). The decrease in the plate resistance at 15° and 30° obliquity was an important observation in that investigation. An appropriate reason for such behaviour of steel armour plate was required to be examined.

This paper is aimed to study the ballistic behaviour of thick steel armour plate at subordnance velocity at different obliquities by a conical shape projectile and also to understand the reason of the decreased plate resistance at higher obliquity[1]. Here, the obliquity refers to the plate inclination in terms of the angle of attack. The angle of attack is the angle formed by the incoming projectile wrt the normal of the target plate. When the direction of motion of the projectile coincides with the normal of the target plate, it is termed as the zero angle of attack.

2. BALLISTIC PARAMETERS

The selection of appropriate ballistic parameters has assumed special importance as the basic aim of the present study is to find reasons associated with

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decrease in the resistance of the steel armour plate. The factors considered responsible for the above-mentioned behaviour of the steel armour plate are : (i) texture of the plate, (ii) ratio of the target thickness (T) to the projectile diameter (D), i.e., (T/D), (iii) ratio of the projectile length (L) to the projectile diameter (D), i.e. (L/D), (iv) nose shape of the projectile, (v) plate-to-projectile hardness ratio, and (vi) tendency of the projectile to turn towards the normal during the penetration process.

In order to finalise the ballistic parameters, it was felt that the target related parameters, as far as possible, be kept the same. The projectile related parameters were however, decided to be changed. It was decided to eliminate or reduce the effect of some of the above-listed factors like the tendency of the projectile to turn towards the normal, plate texture, plate-to-projectile hardness ratio, and T/D ratio by proper selection of the experimental parameters.

2.1 Final Selection of Parameters

On the basis of above discussion, the final selection of ballistic parameters was made as given below:

2.1.1 *Unchanged Parameters*

The unchanged parameters are:

(a) Range of projectile velocity

(b) Target obliquity (θ)

(c) Target material

(d) T/D ratio

(e) Plate-to-projectile hardness ratio.

2.1.2 *Changed Parameters*

The changed ballistic parameters are:

(a) Nose shape of the projectile

(b) L/D ratio of the projectile

More details about the ballistic parameters chosen in the present investigation along with the parameters used in the earlier investigation[1] are mentioned in Table 1.

Table 1. Parameter selection

Parameters	Present investigation	Reference[1]
T/D ratio	1.6	1.0
Plate-to-projectile hardness ratio	0.51	0.58
L/D ratio	5.73	2.71
Nose length (mm)	8.5	17.8
Range of velocity (m/s)	300-800	300-800
Angle of attack (obliquity) (deg)	0, 15, 30 & 45	0, 15, 30 & 45
Nose shape	Conical	Ogive
Mass of the projectile (g)	5.2	110

3. EXPERIMENTAL DETAILS

A few ballistic tests were conducted on 10 mm thick steel armour plates by impacting conical shape steel projectile at 0°, 15°, 30° and 45° obliquity (θ). The details of the projectile and the target are provided in Table 1. Conduct of the ballistic experiments and measurements of the related parameter are as described in earlier investigation[2-5]. The depth of penetration (X_p) and the crater volume (U) were measured for each striking velocity of the projectile. Cumulative specific energy (E_{SC}), i.e., average resistance offered by the plate to the penetrating projectile, was computed as described in earlier investigations[2]. E_{SC} is described as the kinetic energy per unit volume.

4. EXPERIMENTAL RESULTS

4.1 Depth of Penetration

The variation of X_p with striking velocity of the impacting steel conical projectile on 10 mm thick steel armour plate is provided in Fig. 1. X_p has been plotted for 0°, 15°, 30° and 45° obliquity at different velocities. The variation of X_p with velocity is observed to be linear for all obliquities of the target plate. However, as expected, the slope of these curves is different in each case. X_p is the least in case of 45° obliquity, whereas X_p is maximum at zero obliquity. At 15° and 30° obliquity, the X_p shows intermediate behaviour. X_p increases with increasing velocity of the projectile at all the obliquities, whereas it decreases with increasing obliquity, i.e. X_p (45°) < X_p (30°) < X_p (15°) < X_p (0°). This kind of behaviour of the steel armour plate at different obliquity is well-understood and is in agreement with the mechanism of penetration.

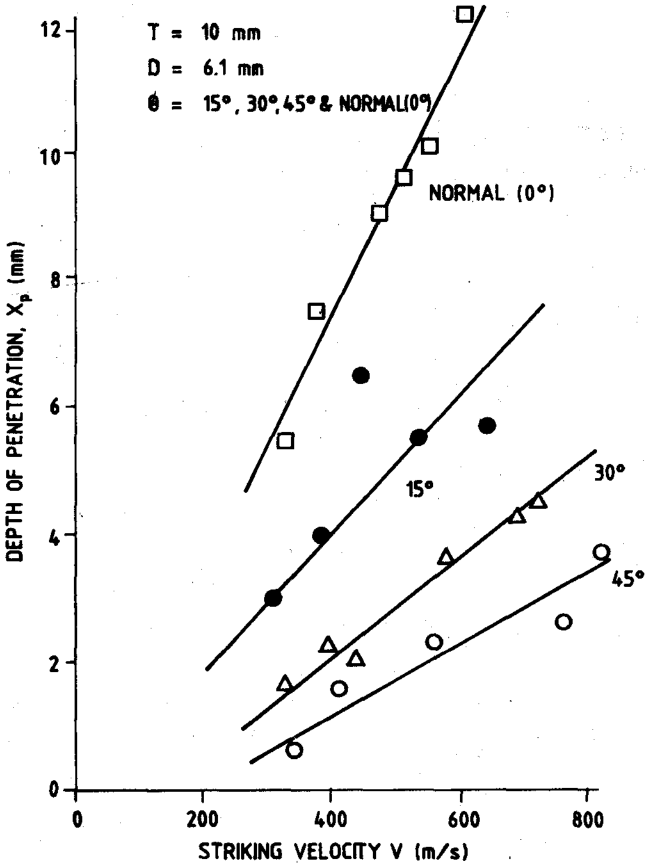

Figure 1. Variation of depth of penetration with velocity at different angles of attack (obliquity).

4.2 Crater Volume

The data in Fig. 2 provides the variation of U formed in the plate with the velocity of the penetrating projectile. The data is presented for 0°, 15°, 30° and 45° obliquity. The variation in U is observed to be linear as in the case of X_p. Slope of U at each obliquity is different. U decreases with increasing obliquity, i.e., U (0°) > U (15°) > U (30°) > U (45°). Thus, least crater volume is observed at 45° obliquity and maximum is obtained at zero obliquity. U increases with increasing striking velocity of the projectile. Such a trend is noticed at 0°, 15°, 30° and 45° obliquity. At 35° obliquity, there is an unusual trend of the scatter of data. However, U at 30° obliquity is also less than that of 15° and 0° obliquity. This kind of behaviour is quite different from that noticed in the earlier work[1], wherein U at 30° obliquity was higher than that at 15° and 0° obliquity.

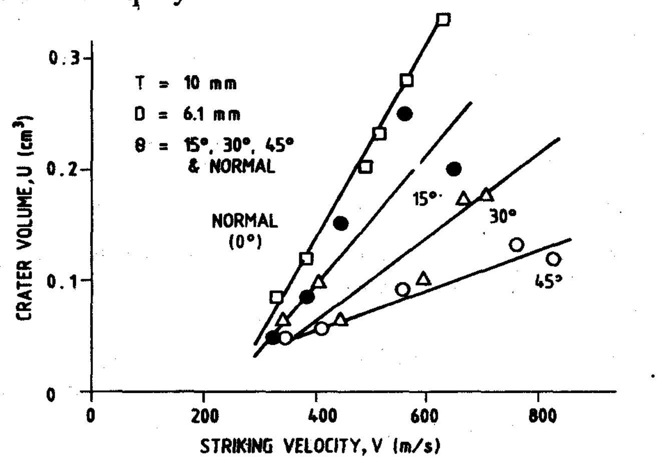

Figure 2. Variation of crater volume with projectile velocity at different angles of attack (obliquity).

4.3 Specific Energy

As described earlier[2], E_{SC} absorbed by the plate is computed and plotted with the striking velocity of the projectile as shown in Fig. 3. Careful examination of the graph reveals that at 0° and 15° obliquity, the plate offers lesser resistance to penetration at higher striking velocity. At 45° obliquity, the plate offers more resistance to penetration at higher striking velocities. This reversal in the behaviour of the target plate at 45° obliquity can be explained on the basis of either U formed by the projectile or on the projectile deflection tendency. It is clearly evident that the plate resistance increases with increasing obliquity of the target plate, i.e., E_{SC} (0°) < (E_{SC}) (15°) < E_{SC} (30°) < E_{SC} (45°). Comparing the variation of E_{SC} with the

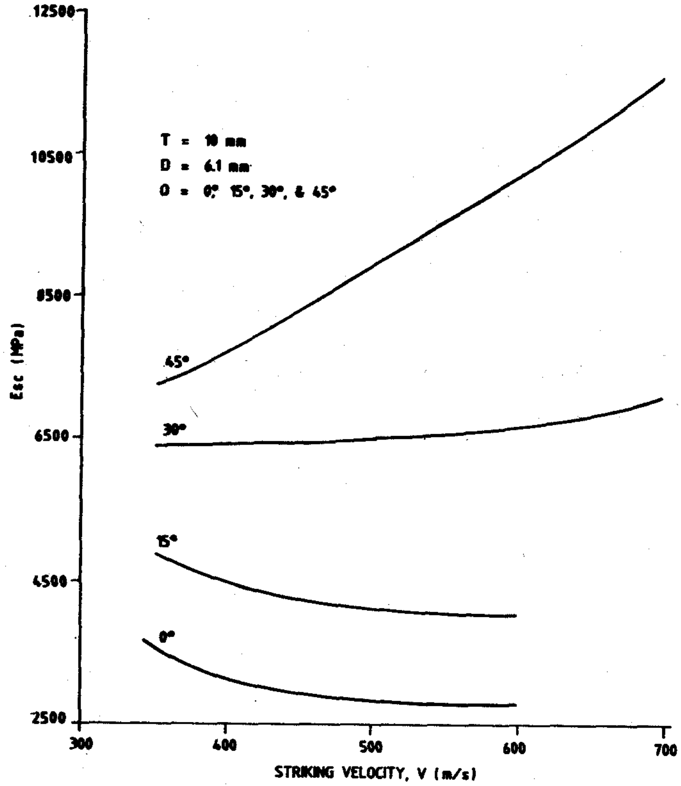

Figure 3. Variation of plate resistance with projectile velocity at different angles of attack.

one noticed in earlier work[1], it is seen that E_{SC} behaviour is quite different. Difference in the ballistic behaviour of the plate is attributed to U that is formed at 30° and 15° obliquity.

5. DISCUSSION

5.1 Depth of Penetration & Obliquity

The data of X_p has been presented with striking velocity of the projectile in Fig. 1. This data can be understood better if X_p is plotted against the obliquity. The variation of X_p is thus plotted against obliquity (θ) in Fig. 4. It is evident that X_p decreases with increasing obliquity. It is also clearly seen that X_p increases with increasing velocity of the projectile, at all the obliquity of the target plate.

5.2 Cumulative Specific Energy & Obliquity

The variation of cumulative specific energy (E_{SC}) with striking velocity at different obliquities is presented in Fig. 3. The data if plotted against

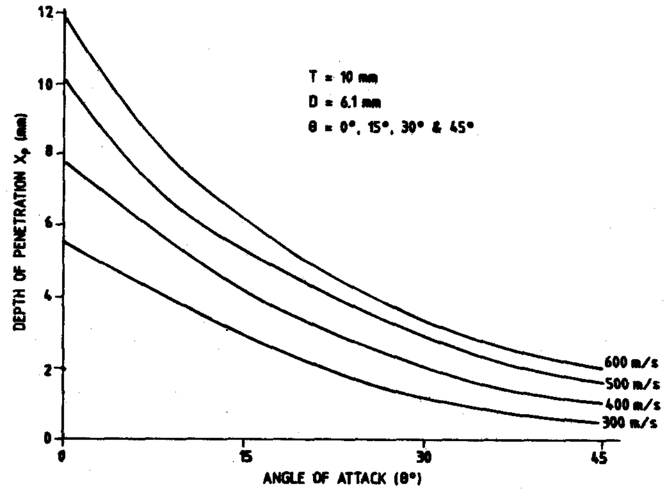

Figure 4. Variation of depth of penetration with the obliquity

obliquity at different velocities, can also be understood in a better way. Figure 5 provides the variation of E_{SC} with obliquity (θ) at different velocities. At zero obliquity, plate offers maximum resistance to the penetrating projectile at low velocity and minimum resistance at higher velocities. This is quite natural and also noticed in Figs 1 and 2, wherein X_p and U are observed to increase with increasing velocity of the projectile. This kind of plate behaviour is observed to be valid only up to 23° obliquity. Beyond 23° obliquity, plate is observed to offer more resistance to penetrating projectile with increasing velocity. This reversal in the behaviour of plate resistance at higher obliquity is related to lesser U that is being formed at higher velocity and not to the ricochet angle of the projectile. The ricochet angle of 6.1 mm diameter steel conical projectile is higher than the obliquity of the plate used in the present investigation.

The specific energy absorption capacity of the plate, i.e., the average resistance offered by the steel armour plate is directly proportional to the square of the projectile velocity and inversely proportional to U. As evident from Fig. 3, slope of the volume curve at 45° obliquity is very small, thereby meaning that the increase in U at higher velocities is smaller. At higher velocity, therefore, value of E_{SC} comes out to be much higher due to the smaller U.

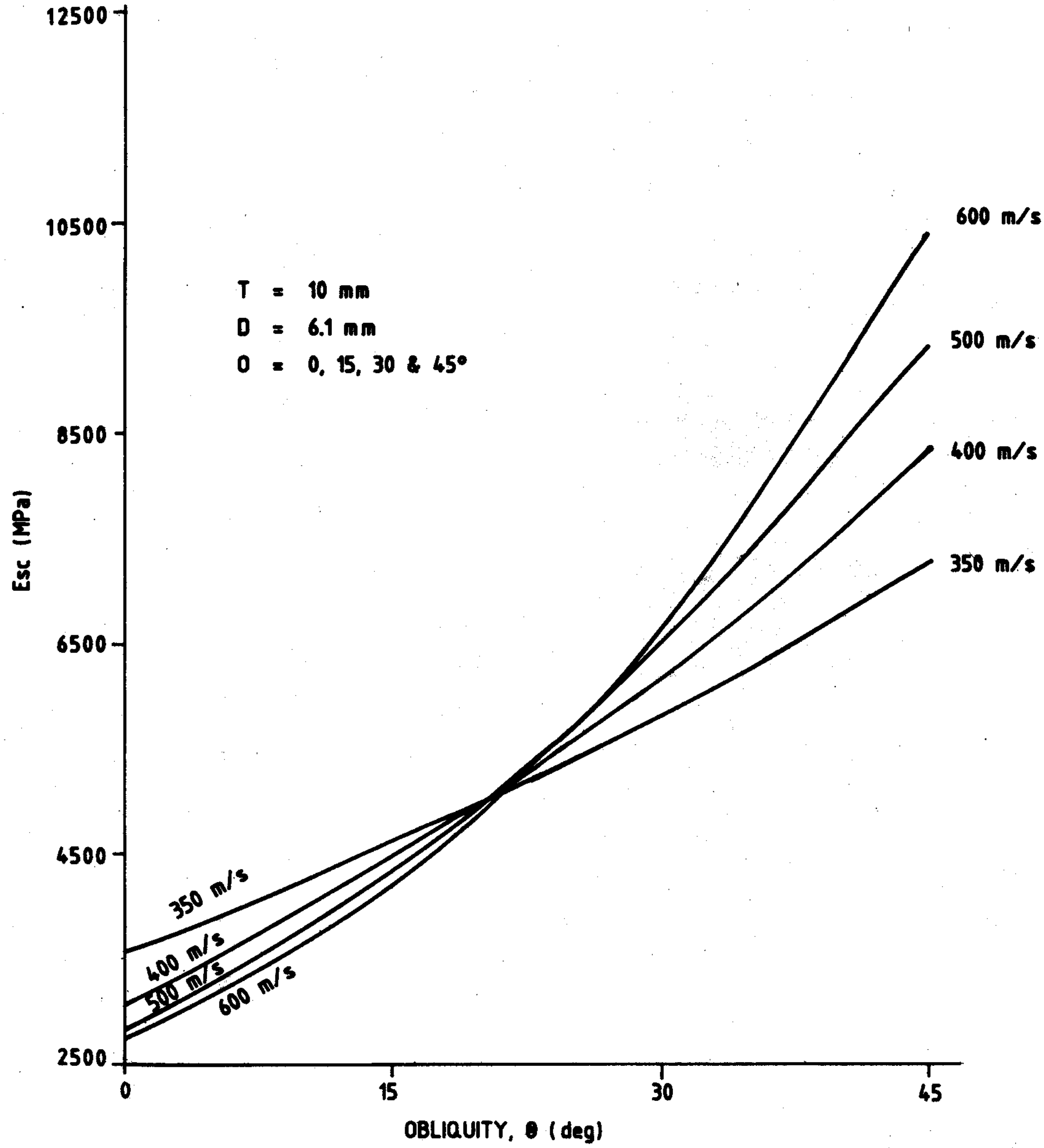

Figure 5. Variation of plate resistance with the obliquity.

6. CONCLUSION

From the present investigation, it can thus be concluded that the most probable reason of decreased E_{SC} due to the increase in U observed in the earlier work[1] is related to the shape of the projectile. This conclusion seems to be valid as only the shape and the size of the projectile in this investigation is different from that used in the earlier work[1] Other parameters like obliquity, range of velocity, plate-to-projectile thickness ratio and the plate-projectile hardness ratio are identical as seen from Table 1. Comparison of the data, presented in the earlier work[1], and the findings of the present investigation reveal important phenomenon related to the shape of the projectile. In ogive-shaped projectile[1], the plate resistance is decreased due to more U formed at the higher angle of attack (obliquity). Such an observation is contrary to the present findings, and relates to the nose shape of the projectile. This study is thus important to understand that at higher angle of attack (obliquity), an ogive-shaped projectile causes more plate damage than the conical-shaped projectile.

On the basis of above results, the following observations are made:

- At higher angle of attack an ogive-shaped steel projectile causes more plate damage than the conical-shaped steel projectile.
- Depth of penetration decreases with increasing obliquity.
- X_p increases with increasing velocity at each obliquity.
- 10 mm diameter steel armour plate offers protection at 30° and 45° obliquity up to a striking velocity of 800 m/s. At zero obliquity, the plate offers protection below 600 m/s.
- Specific energy absorption capacity of the plate increases with increasing obliquity.

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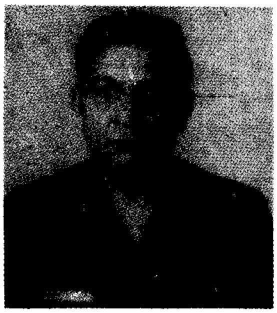

Col (Dr) SN Dikshit, *VSM*, obtained his ME (Mechanical) from Indian Institute of Science, Bangalore, in 1982 and PhD from Banaras Hindu University, in 1994. His area of research includes : ballistic performance of thick steel armour plates. At the Defence Metallurgical Research Laboratory, Hyderabad, he is actively engaged in the design and development of light-weight *Kanchan* composite armour and explosive reactive armour for the protection of *Arjun*, *Vijayanta* and *Ajeya* tanks. He has published papers in international/national journals. He is a life member of the Indian Institute of Metals. For his distinguished services in the field of armour development for the battle tanks, he has been awarded *Vishist Seva Medal* by the President of India during 1997.