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Zener/mmg

5 July 1944

Laboratory (CZ)

Subject: Watertown Arsenal Laboratory Experimental Report No. 710/607-3

To: Chief of Ordnance
Army Service Forces
Pentagon Building
Washington 25, D. C.

Attn: SPOTB - Technical Reports

1. Inclosed are six (6) copies of subject report entitled "Principles of Armor Protection, Fourth Partial Report".

2. The following distribution is suggested:

1 - Ordnance Technical Library. Index cards are inclosed for its use.
1 - SPOTB - Technical Reports
1 - SPOTM
1 - SPOIM - Attn: Col. I. A. Luke
1 - U. S. Naval Proving Ground
1 - U. S. Naval Research Laboratory

Since it is believed that the British Army Staff would find this report of interest, three (3) copies are being retained in accordance with directive letter O.O. 400.112/7404 - Wtn. 350.05/607, 23 May 1944, pending further instructions from his office.

3. In addition, a copy of the subject report will be sent to each of the following: Springfield Armory, Watervliet Arsenal, Picatinny Arsenal and three (3) copies to the Ordnance Research Center. Two copies also will be sent to Office, Chief of Ordnance-Detroit.

4. In this report a study is made of the advantages to be gained by the addition of a thin (1/12th caliber) decapping plate

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Wtn. 470.5/F283(6)

5 July 1944

Subject: Watertown Arsenal Laboratory Experimental Report No. 710/607-3

To: Chief of Ordnance, ASF, Washington 25, D.C.
Attn: SPOTE - Technical Reports

in front of the main armor. It is found that the increase in protection thereby afforded is about five times that which would result merely from an equivalent increase in the thickness of the main armor.

For the Commanding Officer:

H. H. Zornig,
Colonel, Ord. Dept.,
Assistant.

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Watertown Arsenal Laboratory
Report Number WAL 710/607-3
Problem Number J-1.2

28 June 1944

PRINCIPLES OF ARMOR PROTECTION

Fourth Partial Report

OBJECT

To investigate the increase in protection which is afforded by a thin decapping plate.

SUMMARY

One-twelfth caliber plates remove the caps of APC projectiles at service velocities, irrespective of hardness of cap, closeness of fitting, or, within wide limits, of cap design.

The use of such a decapping plate would result in a marked lowering of the shatter velocity of the enemy's projectiles, and therefore in their effectiveness, particularly in the important obliquity range $30^\circ - 45^\circ$. As an example, the lowering of the shatter velocity would be enough to exclude the possibility that 75 mm. APC projectiles could penetrate, without shattering, 320 BHN plate of 2.5" thickness at obliquities of 35° and over.

C. Zener
C. Zener
Senior Physicist

J. F. Sullivan
J. F. Sullivan
Assistant Engineer

UNCLASSIFIED

APPROVED:

H. H. Zornig
H. H. ZORNIG
Colonel, Ordnance Dept.,
Director of Laboratory

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INTRODUCTION

In armor design primary consideration is given to a high resistance to penetration consistent with satisfactory shock properties. The concept of resistance to penetration is not, however, without considerable ambiguity.

Firstly there is an ambiguity as to the conditions of attack. These conditions may be roughly represented by a velocity - e/d diagram, as in Figure 1. In armor design two conditions need not be considered, high velocity impacts against considerably undermatching plate, a condition under which there is no hope for protection, and low velocity impacts against overmatching plate, a condition under which protection is certain. In design one need consider only the regions in the velocity - e/d diagram corresponding to low velocity impacts against undermatching plate, and to high velocity impacts against plates which either overmatch, or only slightly undermatch, the projectile. Those properties of armor which give best protection in one region do not necessarily give the best protection in the other region. Under the combat conditions prevalent in the present war, impacts are much more likely to occur in the high velocity (above 2000 f/s) region than in the low velocity region.

Secondly there is ambiguity as to the quality of the attacking projectile. If the enemy's projectiles could not be deformed, then design would have to be concerned exclusively either with absorbing the kinetic energy of the projectile, or with deflecting the projectile. Actually all projectiles may be deformed, and consequently their kinetic energy dissipated, if the conditions of attack are sufficiently severe. Changes in plate design which increase the ability of a plate to deform and fracture projectiles frequently lower the plate's resistance to penetration by projectiles which are not so deformed or fractured. Thus face hardened armor is better able to break up projectiles than is homogeneous armor, but if the projectiles are not broken up, the face hardened armor offers less resistance to penetration than does the homogeneous armor. Armor design must therefore involve a compromise between the attempt to defeat the enemy's projectiles by absorbing or deflecting their kinetic energy, and the attempt to defeat the projectiles by breaking them up. To maintain an optimum compromise requires constant vigilance in observing and in anticipating any improvements in the enemy's projectiles which might render its defeat by the second method more unlikely.

One design feature which favors the defeat of a projectile by shatter is the apportionment of part of the armor in a front thin plate, the purpose of which is to remove the cap of the attacking projectiles. Unless the cap is removed, however, such a design feature would lower the resistance of the armor to penetration. This may be seen from the fact that the surface layers of armor offer less resistance to penetration[1] per unit depth than does the interior. Since any spaced armor must necessarily have a greater portion of the armor in surface layers, it will be less resistant to penetration unless the first layer alters the projectile in some manner other than in the loss of some kinetic energy. The present report presents an investigation of the advantages which may accrue from the introduction of a thin plate in front of the main armor, the purpose of which is to decap the attacking projectiles.

RESULTS AND DISCUSSION

1. Removal of cap.

It has recently been found[2] that a 1/4" plate, either face hardened or homogeneous, will remove the cap from 75 mm. APC M61 projectiles fired through it at velocities over 1400 f/s. Confirmatory experiments have been reported[3] on the removal of the cap from 37 mm. APC M51 projectiles by plates of the same e/d ratio of 1/12, namely by 1/8" plate.

It was suspected that the cap removal was associated with the brittleness of the hard caps. This suspicion was

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1. C. Zener: "Principles of Armor Protection, Third Partial Report", Report No. WAL 710/607-2.
2. Aberdeen Proving Ground Projectile Test Report No. AD-P27.
3. C. Zener and J. Sullivan, "Principles of Projectile Design for Penetration, Second Partial Report", Report No. WAL 762/231-2.

removed by the firing of M51 projectiles whose caps had been previously softened. These were also removed by the 1/8" plate.

It was then suspected that the removal of the cap might be due to a failure which starts at the threads whereby the ballistic windshield is attached to the cap. Accordingly 37 mm. APC M59 projectiles, in which these threads are absent, were fired through 1/8" plate. The caps of these projectiles were likewise removed.

It was further suspected that the cap removal might be attributable to a relatively weak bond between cap and core due to an imperfect fitting. Accordingly the caps of several M59's were removed, a lap fitting was made, and they were then resoldered on. These caps were likewise removed by the 1/8" plate.

The lack of success in the above attempts to make caps resist the penetration of 1/8" plate, together with the reports that thin plates also decap German projectiles[1], make it seem likely that if our armored vehicles are equipped with 1/12th caliber decapping plate, the enemy will not, in the near future, perfect his projectiles so as to defeat the purpose of such plates.

2. Effects of removal of cap.

Previous experiments[2] have shown that the decapping

1. Aberdeen Proving Ground, loc. cit.
2. C. Zener and J. Sullivan, loc. cit.

plate need be placed only one projectile length in front of the main plate in order for the projectile to behave as if the cap were entirely absent. Hence in the present experiments the effect of cap removal was investigated by comparing the behavior of projectiles with and without caps. The projectiles used in this study were cal. .30 artillery type projectiles modelled after the German 75 mm. APC Pak 40 projectiles. A description of these projectiles is given in a current report.[1]

The primary difference between the performance of a capped and an uncapped projectile against homogeneous armor lies in their respective shatter velocities. The shatter velocity for the capped projectiles, in attack against plate of 321 BHN, lies above 2700 f/s under all circumstances.[2] The capped projectiles are therefore not subject to shatter under the usual conditions of combat. In order to find the conditions under which the uncapped projectiles shattered, they were fired against matching plate (0.30") of the same hardness (321 BHN), at various obliquities. The observations are presented as Figure 2. From this figure it is seen that the shatter velocity falls from above combat velocity at 15° obliquity, to a minimum below 2200 f/s in the

1. D. Van Winkle: "Principles of Projectile Design for Penetration, Third Partial Report," Report No. WAL 762/231-3.
2. B. C. Ward: "Principles of Armor Protection, Second Partial Report," Report No. WAL 710/607-1.

range $35^{\circ} - 40^{\circ}$ obliquity, and rises again with a further increase in obliquity.

The initial drop in shatter velocity with obliquity can be readily understood from the mechanism of shatter. This mechanism has previously been discussed,[1] and will be briefly reviewed. A projectile experiences two distinct types of forces when it strikes a plate. One force arises from the resistance of the plate material to plastic deformation. The second force arises from the resistance of the plate material to acceleration, which acceleration it must have in order to get out of the way of the projectile. This second force is called the "inertia force". It is the force which is responsible for the shatter of projectiles. The primary function of a cap is to distribute the acceleration of the plate material over a longer time, and hence to reduce its peak value, and consequently the peak value of the inertia force. In the absence of a cap, the acceleration, and hence the inertia force, will be greater both the higher the velocity of the projectile and, at normal incidence, the blunter the ogive, or, more generally, the blunter the apex the ogive presents to the plate. In the particular projectile used in the present experiments, the

1. C. Zener: "Mechanism of Armor Penetration, Third Partial Report," Report No. WAL 710/492-1.

ogive tip presents a tangent surface to the plate at an obliquity angle of 30°. The apex of the ogive therefore presents an increasingly blunter apex to the plate as the obliquity angle increases from 0° to 30°. The velocity needed for shatter therefore decreases in this obliquity range.

The final rise in the velocity needed for shatter with obliquity is due to the fact that when the ogive presents a tangent surface to the plate, essentially only the normal component of the projectile's velocity is responsible for the acceleration of the plate material, and therefore for the inertia force. In order for this normal component of velocity to remain constant, the critical velocity for shatter, V, must vary with obliquity θ as

$$V \sim 1/\cos\theta \qquad (1)$$

This theoretical relation is consistent with the observations in Figure 2 beyond 40°.

Equation (1) also gives[1] the relation in the case of capped projectiles between ballistic limit and obliquity for obliquities over 30°. From the manner in which the critical shatter velocity and the ballistic limit for no shatter vary with obliquity, it may be deduced that if a projectile shatters at one obliquity below the ballistic

1. B. C. Ward: loc. cit.

limit for no shatter, the same will be true for all higher obliquities.

The above conclusion may be used to make a rough survey of the consequences of decapping. It was found that against plates with an e/d of 0.83 (2.5" plate for 3" projectiles) or over uncapped projectiles shattered before penetration at 35°. Therefore decapped projectiles cannot penetrate, without shattering, plates thicker than 0.83 d unless the obliquity is less than 35°. On the other hand, it was found that at 30° obliquity these projectiles could penetrate, without shattering, plates as thick as 1.2 d (3.5" plate for 3" projectiles). Such penetration is possible, however, only for a restricted velocity range, shatter again occurring at the upper limit of the range.

The influence of a 1/12th caliber decapping plate may be most vividly presented by comparing the obliquity range over which penetration without shatter is excluded by the decapping plate, with the decrease in critical angle for penetration which would be introduced if the thickness of the main armor were increased by 1/12th caliber. Suppose that a projectile will just penetrate a plate of thickness e at an obliquity θ and velocity V. If the thickness is now increased to e + Δe and the velocity maintained constant, the projectile will then just penetrate at some reduced obliquity θ − Δθ. From the formula[1]

$$V \sim (e/d)^{0.63} / \cos\theta$$

1. B. C. Ward: loc. cit.

for the ballistic limit with respect to the projectiles used in the present study, it may be seen that

$$\frac{\cos(\theta - \Delta\theta)}{\cos\theta} = \left(\frac{e-\Delta e}{e}\right)^{0.63}$$

When $\Delta e/e \ll 1$, this equation reduces to

$$\Delta\theta = 0.63\left(\frac{\Delta e}{e}\right)\cot\theta \text{ radians} \qquad (2)$$

Upon taking $\Delta e/e \simeq \Delta e/d = 1/12$, one finds

$$\Delta\theta \simeq 3^{\circ} \quad , \left\{ \begin{array}{l} 30^{\circ} < \theta < 50^{\circ} \\ \Delta e/d \simeq 1/12 \end{array} \right. \qquad (3)$$

A comparison is given in Table I of the effects of adding 1/12th caliber to the armor, as decapping plate and as additional thickness to the main armor. The upper limit of the obliquity range in the third column gives approximately the maximum angle which the capped projectiles will completely penetrate the plate at the velocity of 2700 f/s, the maximum striking velocity which is likely to be encountered in service. Thus a 3" capped projectile may be expected to completely penetrate a 2.5" plate at maximum service velocities (~2700 f/s) for all angles of attack up to 53°. In such penetration the projectile remains whole. If the thickness of the plate were increased by 1/4", the projectile could still completely penetrate, and remain undeformed, for all angles of attack up to 50°. On the other hand, if a 1/4"

TABLE I

EFFECT OF ADDITION OF ONE TWELFTH CALIBER PLATE THICKNESS (EXAMPLES OF ATTACK BY 3" PROJECTILE).

BASIC PLATE THICKNESS	ADDED AS INCREASED THICKNESS OF MAIN PLATE	ADDED AS DECAPPING PLATE
	Decreases critical angle for penetration (without shatter) ($\theta > 30^\circ$) by	Decreases critical angle for penetration without shatter from
2.5"	$\sim 3^\circ$	53° to 35°
3.0"	$\sim 3^\circ$	50° to 35°
3.5"	$\sim 3^\circ$	45° to 35°

decapping plate were added, the same projectile could not penetrate in an unshattered condition for angles of attack of 35° or greater.

FIGURE I

SCHEMATIC REPRESENTATION OF CONDITIONS OF ATTACK

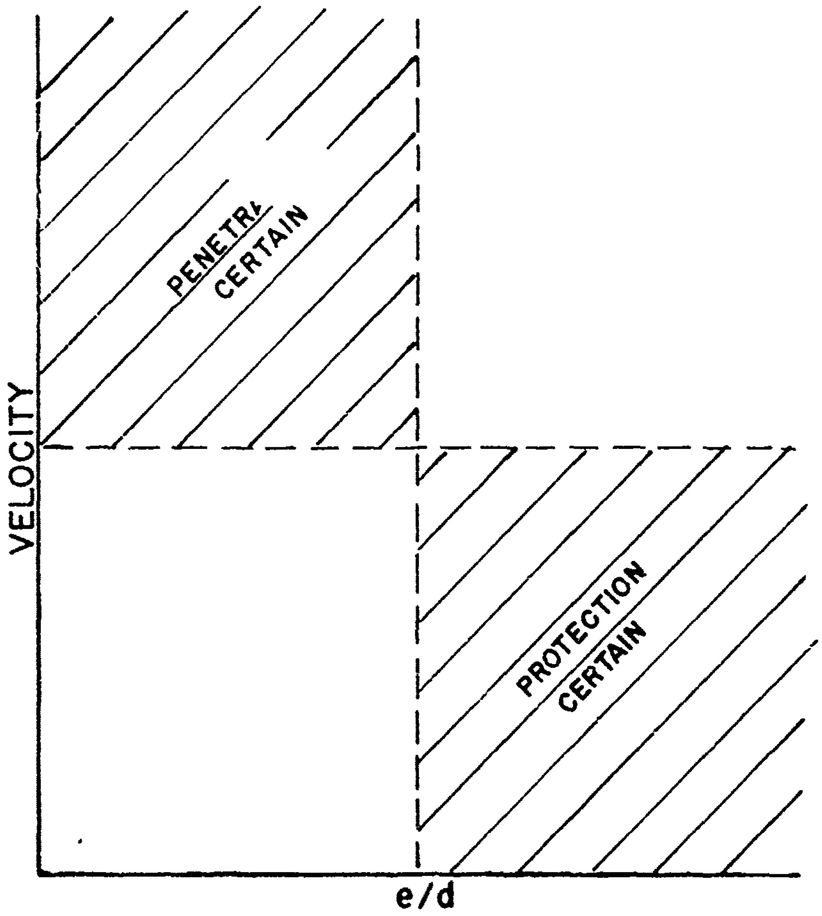

FIGURE 2

SHATTER DATA

(CAL. 30 MODEL ARTILLERY TYPE UNCAPPED PROJECTILE CORE VS 0.30" 321 BHN PLATE