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NATIONAL DEFENSE RESEARCH COMMITTEE

ARMOR AND ORDNANCE REPORT NO. A-147

DIVISION 2

OBSERVATIONS ON THE PERFORATION OF SLABS OF PLASTIC PROTECTION BY SMALL-CALIBER AP PROJECTILES

OSRD. 1342

by

R. A. Beth

and

J. T. Pittenger

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R. A. Beth

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Approved on March 22, 1943
for submission to the Division Chief

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Structural Defense and Offense

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Preface

The work described in this report is pertinent to the projects designated by the War Department Liaison Officer as CE-5 and CE-6, to the projects designated by the Navy Department Liaison Officer as NO-11 and NS-145 and to Division 2 project P2-103.

This work was carried out and reported by Princeton University as part of its performance under Contract OEMsr-260.

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OBSERVATIONS ON THE PERFORATION OF SLABS OF PLASTIC PROTECTION BY SMALL-CALIBER AP PROJECTILES

Abstract

Both caliber .303 (British) and caliber .30 (U.S.) AP projectiles have been fired at the same slabs of plastic protection.1/ The slabs were about 24 in. square and 1-7/8 in. thick over-all. They consisted of an asphaltic mix (35 percent marine mastic and 65 percent Exner gravel) on a 3/16-in. mild steel backing plate. The perforation limit was found to be about 2500 ± 100 ft/sec for both projectiles. Any difference between the projectiles which may be real for these slabs seems to favor the caliber .303 AP projectile slightly.

The work has furnished evidence that an important part of the physical action of the plastic protection is to cause yaw and breakup of the projectile before it reaches the backing plate, the latter being then better able to stop the bullet or its pieces. It is suggested that any enhancement of these actions would be accompanied by an over-all improvement of the plastic protection.

1. Introduction

The basic method of testing plastic protection1/ is to fire a number of rounds of regulation service AP ammunition at the sample and to observe the percentage of the rounds fired that achieve various degrees of perforation. Such tests are made as acceptance tests for plastic protection supplied or installed by various contractors as well as in research directed at the improvement of

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1/ Plastic protection is the term used by the Bureau of Ships in referring to layers, slabs or coatings of stone aggregate in a bituminous or asphaltic mix, usually on a backing plate of mild steel or other structural material. In British reports it is variously called "plastic armor," "P.A." and "P.A. protective plating."

plastic protection. Ideally, the testing should be done with enemy ammunition, but actually most of it is done with caliber .303 (British) and caliber .30 (U.S.) AP bullets, because of the difficulty and probable delay in getting enemy ammunition and guns in sufficient amounts for all the testing that is being done. There has been some evidence that the results may depend somewhat on the type and source of the ammunition used.

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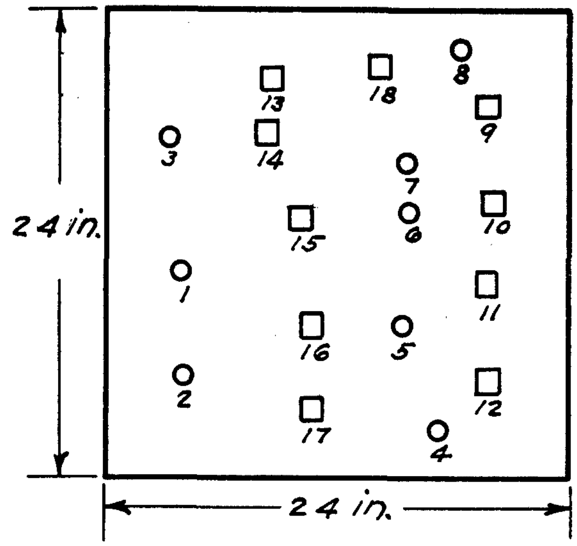
The work described in this report originated in a suggestion[2/] that caliber .303 and caliber .30 AP projectiles be compared on the same slabs of plastic protection under carefully controlled laboratory conditions. Although originally directed at a comparison of these two types of projectile, the work has furnished some interesting evidence on the mode of action of plastic protection in stopping AP bullets. These observations are described in some detail because they may lead to a better physical understanding of the phenomena involved, which in turn would furnish a basis for improvement both of plastic protection and of bullets.

2. Plastic protection targets

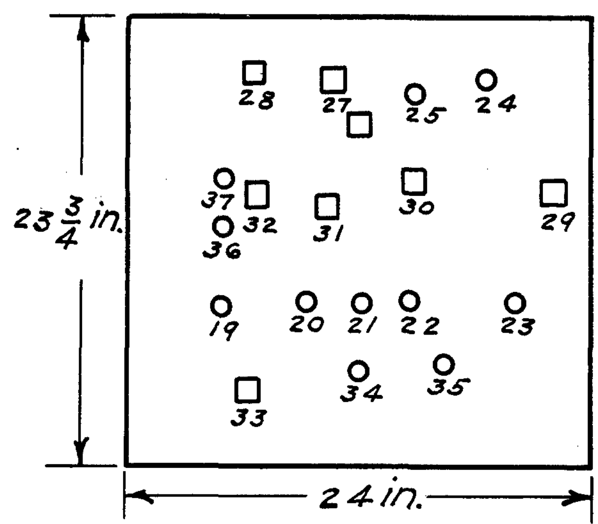
The slabs used in these tests[3/] are described in Table I. The relative positions of the shot points are shown to scale in Fig. 1.

2/ Lt. Comdr. A. H. Laurie, R.N.V.R., suggested the desirability of tests such as these when preliminary tests reported by P. R. Smith of the Flintkote Company had indicated a marked difference in the effectiveness of the two kinds of ammunition against plastic protection. For details of these results see Lt. Comdr. A. H. Laurie, R.N.V.R., British Admiralty Delegation Reports 1/3/AHL/10/42, 5/3/AHL/11/42 and 9/3/AHL/12/42, and P. R. Smith, "Tests of P.A. made with Exner gravel, October 13, 1942" and "Comparison of ratings obtained on plastic protection when tested with British and American ammunition," tests made at Hackensack, N.J., Dec. 4, 1942.

3/ The slabs were supplied through the courtesy of Mr. P. R. Smith, of the Flintkote Co.



Slab I



Slab II

Fig. 1. Shot points for slabs described in Sec. 2. Round numbers: ○, for caliber .30; □, for caliber .303.

Table I. Description of plastic protection slabs;* dimensions, 24 × 24 in.

Slab Number	I	II
Total weight (lb)	115.5	117.5
Weight of steel (lb)	31.5	30.0
Weight of plastic armor (lb)	84.0	87.5
Avg. total thickness (in.)	1.84	1.93
Avg. steel thickness (in.)	0.192	0.183
Wt. of slab per unit area (lb/ft^2)	21	21.9
Density of plastic armor (lb/ft^3)	158	165

* The composition of the plastic protection slabs used was marine mastic, 35 percent, and Exner gravel, 65 percent. The grading of the gravel was:

< 1 in. and > 3/4 in., 2.7 percent;
< 3/4 in. and > ½ in., 74.2 percent;
< ½ in. and > 3/8 in., 21.2 percent;
< 3/8 in., 1.5 percent.

Table II. Projectile data.

Projectile	Caliber .30 AP (U.S.)	Caliber .303 AP (British)	7.92 mm (German)[a]
Total mass (gm)	10.72 ± 0.06	11.32 ± 0.26	—
Core mass m (gm)	5.250 ± 0.033[b]	5.766 ± 0.067[c]	5.807
Core diameter d (in.)	0.244[b]	0.251 ±[c]	0.2408
Core sectional pressure[d] P ($lb/in.^2$)	0.248 –[b]	0.256[c]	0.281
Relative core sectional pressure (percent)	100[b]	103.3[c]	113.4
Core length (in.)	1.097	1.122	1.176
Relative core lengths (percent)	100	102.3	107.2
Core hardness, Rockwell C	54 ± 5	51 ± 10	62

[a]One core only.

[b]Average for 20 cores.

[c]Average for four cores.

[d]The core sectional pressure P is $m/356.2\,d^2$ $lb/in.^2$

The round numbers used to denote the shot points give the sequence of firing, and are the same as those given in Table III.

3. <u>Projectiles</u>

When small-caliber jacketed AP projectiles penetrate into steel, concrete or plastic protection the soft metal jacket is usually stripped off very quickly. The maximum penetration or perforation is achieved only by the armor-piercing core, and experience indicates that this maximum is mainly dependent on the mass and diameter of the core rather than on the mass and diameter of the whole bullet consisting of core and jacket. The core data for the two types of projectile used on these slabs are given in Table II, and the corresponding data for a German 7.92-mm AP core are given for comparison. Only four caliber .303 AP cores were measured; a large supply of caliber .30 AP cores was available, so that the averages for this projectile are more reliable.

Although no specific experimental data are available, it is plausible to assume for a given normal striking velocity and a given kind of target that the proof thicknesses for various bullets will be roughly proportional to the sectional pressures of the cores. However, this assumption may have to be modified, in the sense of penalizing a relatively longer core, if yaw and core breakup action are important factors in plastic protection, as is suggested in Secs. 5 and 6.

4. <u>Test procedure</u>

The tests were made in the ballistic laboratory of the Princeton Research Station, Division 2, NDRC. The velocity of each shot was measured over a 1-ft interval between light screens placed about 7 ft in front of the target, the time interval being determined by means of the spiral cathode-ray chronograph developed in this laboratory.[4] The spirals were read visually and also recorded photographically. It is estimated that the measured velocities are correct to ± ¼ percent.

The slab under test was placed in a vertical position. The horizontal line of fire measured about 25 to 28 ft from the gun muzzle to the target. Normal incidence was used throughout, and no obliquity tests were made at this time.

The relative positions of the shot points are shown to scale in Fig. 1, the shots being numbered consecutively in the order of firing. Although the slabs were found to be uniform in thickness to ± 1/16 in., it was thought that any possible effect of systematic variations in thickness from side to side would be minimized by thus interspersing alternate rows of the two projectiles.

Certain previous work[5] at the respective service velocities (about 2440 and 2720 ft/sec) for the British and American AP bullets had indicated a distinctly greater effectiveness against plastic protection for the American bullet. In the present test the velocities were adjusted by varying the powder load in order to obtain a

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4/ R. J. Emrich and L. A. Delsasso, Short base line projectile velocity measurements, NDRC Report A-89 (OSRD No. 927).

5/ See the reports cited in reference 2.

better comparison of the projectiles on a limit velocity basis. The results indicate that the difference vanishes when the striking velocities are made the same.

For both slabs the caliber .30 AP projectiles were fired from a Mann-type barrel. For Slab I the caliber .303 AP projectiles were fired from the same caliber .30 barrel, using U.S. service caliber .30 cases and powder, because some difficulty was experienced at first in reducing the powder load in the British fixed rounds. For Slab II a British Enfield rifle was used for firing the caliber .303 AP projectiles.[6/] It is felt that the slight additional squeezing of the caliber .303 bullets by the caliber .30 barrel had no significant effect on the results with Slab I.

Of possibly greater significance was the fact that some shots pushed the steel backing plate away slightly from the plastic armor. This was usually restricted to the immediate vicinity of the bulge and with the spacings as shown in Fig. 1, probably did not affect other shots.

5. Observations

Figures 2 to 6 are photographs of Slab I before and after shooting. Similar photographs of Slab II were made, but are not reproduced here because they do not differ essentially from those for Slab I.

6/ Both the British rifle and its ammunition were furnished for this test through the courtesy of Lt. Comdr. A. H. Laurie, R.N.V.R.

The front and back craters (Figs. 3 and 5) generally are similar in shape and size. The crater surfaces sometimes pass through a piece of aggregate, but more often, in these samples, the cleavage of the asphalt is interrupted to follow the surfaces of the stones; that is, intact aggregate pieces are either left exposed in the craters or pulled away in the spall. The asphaltic matrix served to resist the repeated impacts very well, and, on the whole, there were surprisingly few mass cracks extending beyond the individual shot craters. This is a very favorable aspect of the slabs tested.

Table III gives the firing data for both slabs, the shots for each projectile and target being listed in the order of increasing velocity. The actual sequence of firing is given by the "Shot Number" in this table and in Fig. 1.

The table gives a semiquantitative estimate of the observed degree of perforation, which increases, in order, from a bulging of the back plate, then a crack or small portion of the core nose through the back plate, and, finally to the case where the core or a large piece thereof passes through the back plate. These estimates, which are based on observations made at the time of firing, indicate that the likelihood of complete core perforations exceeds 50 percent for these slabs at about 2500 ft/sec for both projectiles used. The caliber .303 AP projectile seems to have a slight advantage over the caliber .30 AP projectile in securing perforations against this thickness of plastic armor.

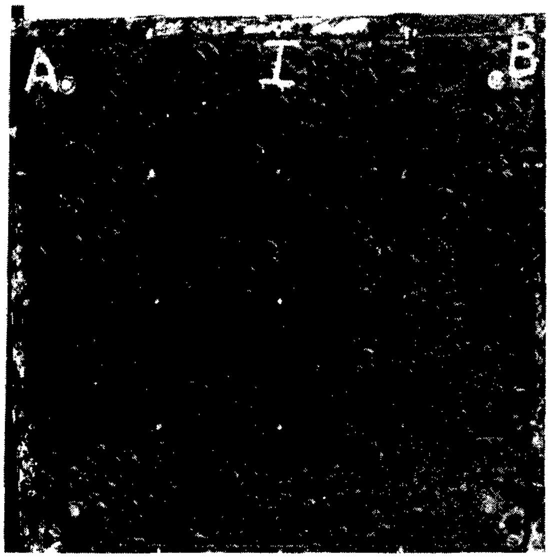

Fig. 2

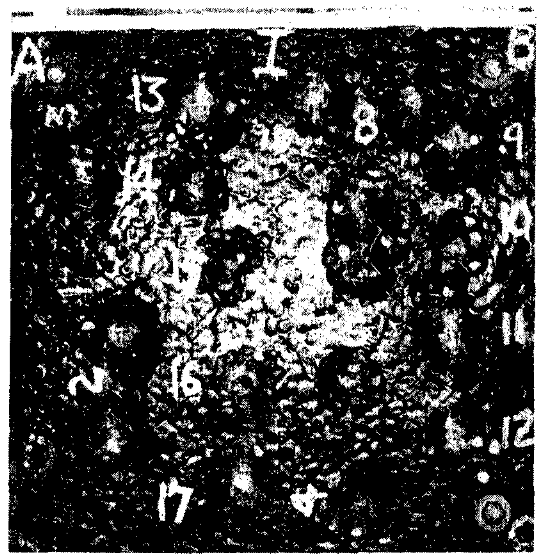

Fig. 3

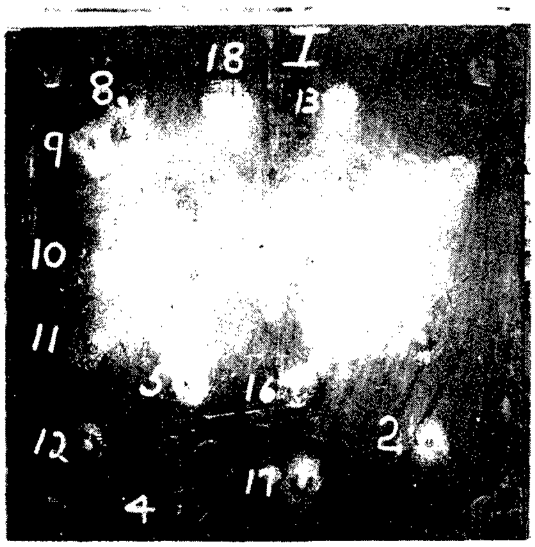

Fig. 4

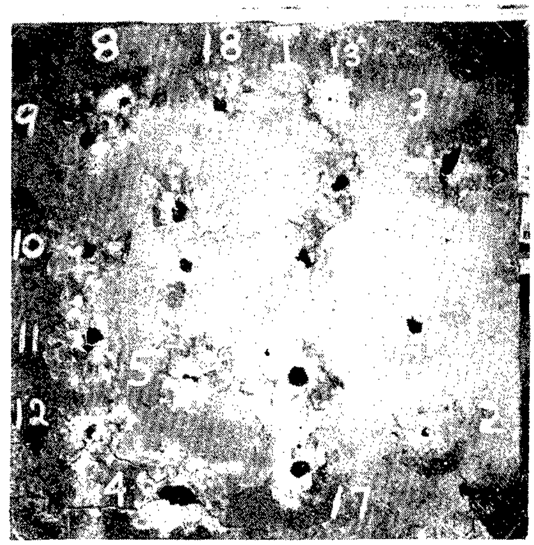

Fig. 5

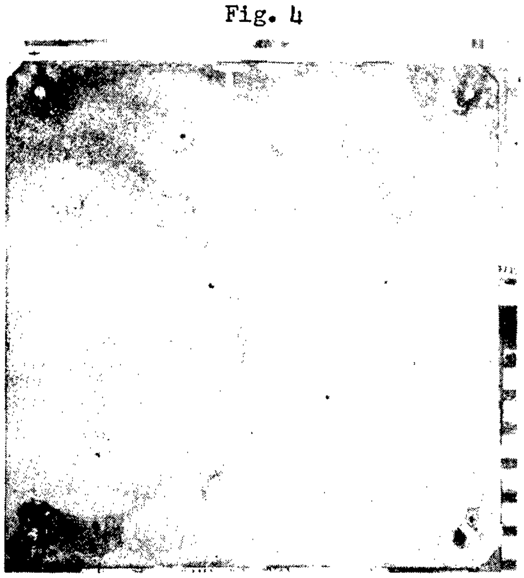

Fig. 6

Fig. 2. Front of Slab I before firing.

Fig. 3. Front of Slab I after firing showing spall craters. The bright patches are due to reflected light and do not indicate variations in the surfaces themselves.

Fig. 4. Back of steel plate of Slab I after firing. The bright patches are due to reflected light and do not indicate variations in the surfaces themselves.

Fig. 5. Back of asphaltic plastic armor of Slab I after removal of steel backing plate, showing scab craters.

Fig. 6. Front, or inside, surface of steel backing plate after removal from asphaltic plastic armor.

Table III. Firing data. The data for a given type of projectile and slab are arranged in order of increasing velocities.

Slab I

Shot No.	Measured Velocity (ft/sec)	Degree of Perforation: Bulge	Crack or Nose Through	Through	Degree of Core Breakup: Completely Shattered	Small Pieces	Larger Pieces	Core Intact
Caliber .30 AP								
7	2382	x	—	—	—	—	x	
1	2397	x	—	—	—	x		
8	2426	x	—	—	—	—	x	
2	Missed (2500+?)			x	—	—	x	
6	2534			x	—	—	—	x
4	2538	x	—	—	x			
3	2618		x	—	—	—	x	
5	2645			x	—	—	x	
Caliber .303 AP								
17	2392	x	—	—	—	—	x	
13	2392			x	—	—	—	x
18	2410	x	—	—	—	x		
14	2422	x	—	—	—	—	x	
16	2428	x	—	—	—	x		
12	2464	x	—	—	—	x		
15	2464			x	—	—	x	
11	2532			x	—	—	—	x
10	2555		x	—	—	x		
9	2630			x	—	—	x	

Slab II

Shot No.	Measured Velocity (ft/sec)	Degree of Perforation: Bulge	Crack or Nose Through	Through	Degree of Core Breakup: Completely Shattered	Small Pieces	Larger Pieces	Core Intact
Caliber .30 AP								
20	2284		x	—	—	—	x	
25	2288	x	—	—	—	x		
34	2336	x	—	—	—	—	x	
21	2392	x	—	—	—	x		
24	2410	x	—	—	x			
22	2426	x	—	—	—	x		
23	2482			x	—	—	—	x
36	2538			x	—	—	x	
37	2552	x	—	—	—	x		
35	2565	x	—	—	—	—	x	
19	2565			x	—	—	x	
Caliber .303 AP								
26	1798	x	—	—	—	—	x	
29	2195		x	—	—	—	x	
30	2315	x	—	—	—	x		
27	2358			x	—	—	x	
31	2392	x	—	—	—	—	x	
33	2410		x	—	—	—	x	
28	2415			x	—	—	x	
32	2426	x	—	—	—	x		

After firing, the steel backing plates were carefully removed from the asphaltic mass. During this process all the loose material held in the back craters fell to the floor. A magnet was used to extract the intact and broken up cores from this detritus. Although this was done rather thoroughly, only one unbroken core was found (caliber .303). The core pieces ranged in size from roughly one-third of a complete core down to a quantity of fine dust. All but the smallest pieces and the dust are shown in the photograph of Fig. 7. Also shown are two intact cores of each type which were recovered before the removal of the backing plates, as well as a caliber .303 core found in the detritus. Since the caliber .303 core has a square base while the caliber .30 core has a boattail base, many of the pieces from the respective bases could be identified and these are grouped with the corresponding cores in Fig. 7. No further identification of the pieces as belonging to the two core types was attempted, but the larger core tip pieces are segregated in the first "miscellaneous" row of the figure.

Figure 7 shows that these cores are very likely to break up in this type of plastic protection. The difference, if any, between the two projectiles seems to be that the caliber .303 cores may not shatter as completely as do the caliber .30 cores. If this is true it may be due both to the 3-percent difference in core diameters and to a possible difference in toughness or brittleness of the respective core materials.

After removal of the backing plates their inside surfaces were examined with care. Here, too, there was much evidence of core

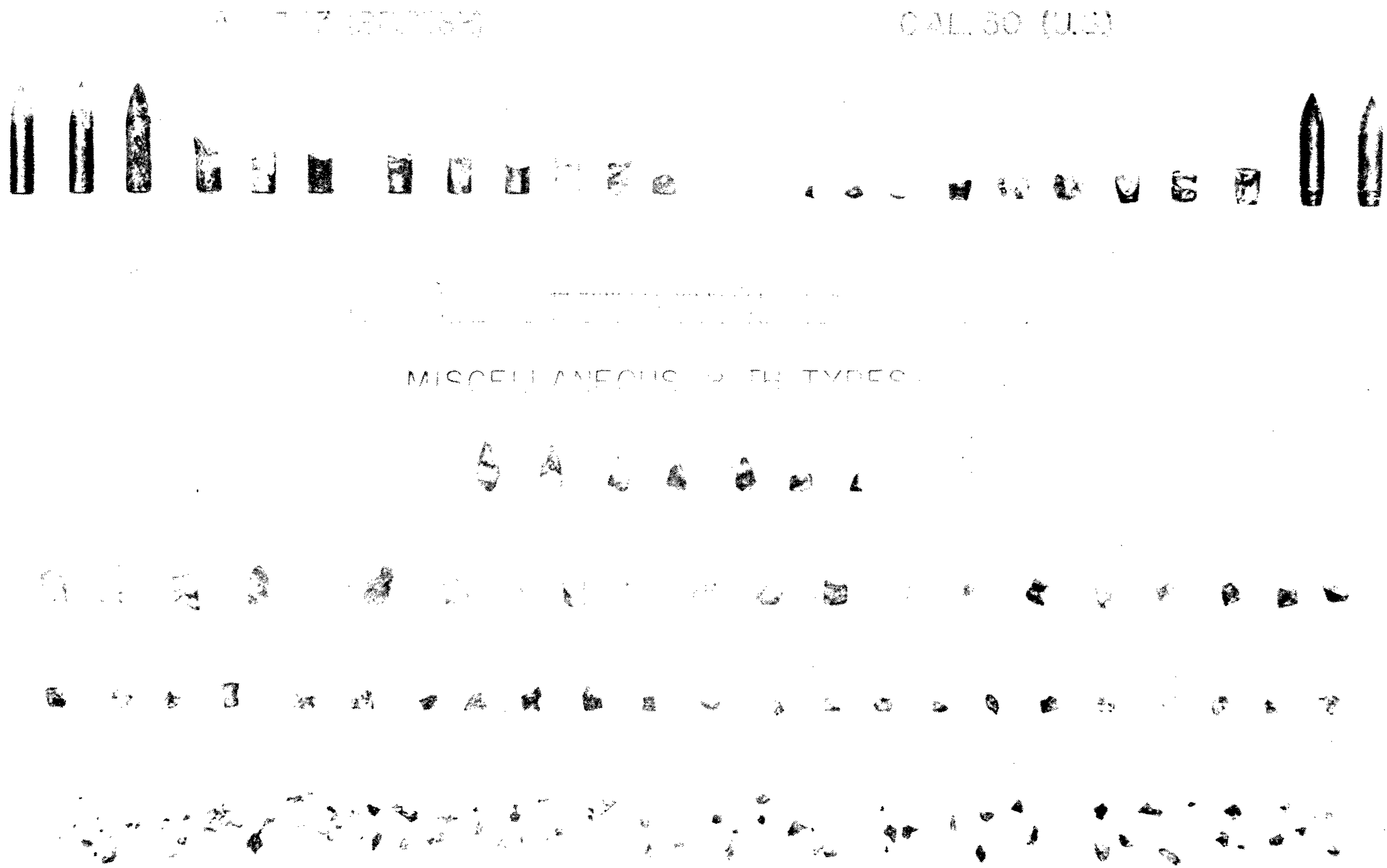

Fig. 7. Breakup of armor-piercing cores in plastic armor (Flintkote).

Table IV. Observations concerning each shot.

Round No.	Remarks
	Slab I, caliber .30 AP (U.S.)
1	Three small pits on the backplate indicate that the core shattered.
2	Fairly neat hole in the backplate. Large core fragments in the magazines. Bullet yawed on its way through the backplate.
3	At least one fragment went through and into the magazines. Two fairly large pieces were found in the hole in the backplate through which the other fragment passed.
4	Two very small pits on the backplate. Most of the core probably never reached the backplate.
5	Core fragments found in the magazines show that the core broke into rather large chunks.
6	Core found intact in the magazines. Rather neat perforation of the backplate with yaw.
7	From impression in the backplate — a groove cut by a core fragment, and another fragment imbedded beyond the end of the groove — the core must have arrived in some large and some very small pieces. Small pits appear around the groove.
8	At the center of the impression in the backplate are several small pits made by core fragments.
	Slab I, caliber .303 AP (British)
9	Part of the core went through the backplate. A small fragment is embedded near the perforation. Small pits appear around the fragment and perforation.
10	Several small core fragments in a deep gouge in the backplate. Another gouge off to the side.
11	Neat hole in the backplate. Some yaw. Core found intact in the magazines.
12	Gouge and several small pits in the backplate. Piece of core found in the front crater while the test was in progress.
13	Clean-cut perforation in the backplate. A little yaw. Core found intact in the magazines.
14	A large gouge in the center of the impression in the backplate. Smaller one nearby. Several small pits in the backplate.
15	Perforation of the backplate is considerably wider than the core diameter. Some yaw. Small pit in the backplate about $\frac{1}{2}$ in. from the hole. Pit made by core or part thereof.
16	Large gouge near the center of the impression in the backplate. Several small pits in the backplate.
7	Many small pits in the impression in the backplate. A large gouge about $\frac{1}{2}$ in. from the center of the impression.
18	Several small gouges and some pits in the impression in the backplate.

Table IV. [Concluded.]

Round No.	Remarks
	Slab II, caliber .30 AP (U.S.)
19	Clean-cut perforation of the backplate with very slight yaw. A piece of core stuck in the hole in the backplate. A small gouge and pit near the hole.
20	Good sized core fragment — probably a piece of the nose, judging from its shape — stuck in the center of the impression in the backplate. No other pits or gouges.
21	Number of small pits in the impression in the backplate.
22	Several small pits and a small gouge in the backplate.
23	Clean-cut perforation of the backplate. No pits or gouges. Core found intact in the magazines.
24	Shallow, smooth impression in the backplate.
25	Several pits in the backplate. Three gouges.
	Slab II, caliber .303 AP (British)
26	Nose struck the backplate with large yaw and made a conical gouge in it. No other pits or gouges.
27	Perforation of the backplate with considerable yaw. Looks as if a second core fragment "beat" a short channel-like impression in the backplate near the hole.
28	Perforation of the backplate has pits around its circumference. Perforation not clean cut. Part of the core went into the magazines; part remained in the hole in the backplate.
29	Perforation of the backplate with large yaw. Gouge nearby. A rather small piece of core stuck in the hole in the backplate.
30	Two gouges and some small pits in the backplate. A small core fragment imbedded in the backplate just off the center of impression.
31	Core or piece thereof yawed and cut a channel in the backplate. Another piece cut a channel inside this one. Also a fragment "beat" a semicylindrical channel in the backplate.
32	Shallow impression in the backplate with a few small pits.
33	Army penetration, or better, of the backplate. The core is broken off at the inside surface of the plate. Some yaw. One small pit.
	Slab II, caliber .30 AP (U.S.)
34	Nose imbedded in the backplate with yaw. Another good sized fragment nearby. Two small pits.
35	Shallow smooth impression in the backplate. About half a core, including the base, was found in one piece in the plastic protection which bulged toward the plate, but probably no fragments hit the backplate.
36	Rough hole in backplate with yaw. No part of core found.
37	Several small pits in the backplate. The backplate is known to have been pulled away from the plastic armor before this shot; knocked away by shot No. 32. Figure 1 shows that shot No. 37 hit quite near No. 32.

breakup, with great variety of detail. There were small nicks, pits and large dents. In a number of cases core pieces were imbedded in the plate or apparently "welded" to it. In several cases a core tip or larger piece struck the plate a half inch or more away from the apparent center of impact as indicated by the general bulging of the plate. Many of the shots showed that the core or a core piece struck with considerable yaw, and there were examples of this for both perforating and nonperforating shots. For several shots, broken core pieces were found wedged in the hole in the plate made by the shot.

Since core breakup seems to be an important part of the action of plastic protection in stopping the projectiles, an attempt has been made in Table III to estimate the degree of core breakup for each shot, mainly on the evidence exhibited on the inside (front) surface of the backing plate. It will be understood that this evidence is very clear in some cases and ambiguous in others. Horizontal lines have been drawn in Table III in order to emphasize the partial correlation between the "degree of perforation" and the "degree of core breakup."

The observations made concerning each shot are given in Table IV in the order of firing. Magazines were wedged into a box behind the slab to catch perforating fragments or cores, some of which were found after certain of the shots.

6. Discussion

The experimental observations described in this report strongly suggest that yaw and core breakup are important factors in the physical action of asphaltic armor in stopping projectiles. Further work is needed to determine whether this is true for all effective plastic armor with various kinds and sizes of projectile, and to decide the relative importance of these factors compared to friction on the penetrating bullet, tensile strength of the mastic, crushing strength of the aggregate, and so forth. It should be possible to find the optimum ratio of aggregate size to projectile size both experimentally and theoretically. It has been suggested[7/] that the most effective aggregate mass may be about equal to the projectile mass, and this point of view is plausible on the supposition that yaw and core breakup are important.

At this time it is not clear how limit velocity depends on slab thickness, obliquity, caliber, length and mass of projectile, assuming that the thicknesses of the plastic mix and backing plate are held constant. Further experimental work on these points is needed.

7/ By Lt. Comdr. A. H. Laurie, R.N.V.R.