NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 12-44

PENETRATION OF HOMOGENEOUS PLATE BY 3" FLAT NOSED PROJECTILES - PARTIAL REPORT.

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PREFACE

AUTHORIZATION

This study was authorized in the Bureau of Ordnance ltr NP9/A9(Re3) dated 9 January, 1943, as part of NPG Research Project APL-1.

OBJECT

The investigation described in this report was carried out for the purpose of extending the information on the performance of 3", flat-nosed monoblock projectiles against homogeneous plate.

SUMMARY

For this investigation 3-inch 15-lb. flat-nosed monoblock projectiles manufactured by Frankford Arsenal were tested against homogeneous plate under widely varied conditions. The limits obtained were compared with limits under similar conditions for 3-inch 15-lb. M79 monoblock projectiles also manufactured by Frankford Arsenal.

The limit velocities for 3-inch flat-nosed projectiles against homogeneous plate were in general much lower than those required for 3-inch M79 projectiles under the same conditions. The lower limits observed for flat-nosed projectiles result from the punching type of plate failure which occurs. In this type of failure a smaller volume of metal is worked than in the usual type of penetration and the energy required for penetration is therefore lower.

At e/d (ratio of plate thickness to projectile diameter) of 0.20 the limit velocities for flat-nosed and M79 projectiles are about equal at normal obliquity, but at 45° the flat-nose limit is less than 67% of the M79 limit. This marked advantage of flat-nosed projectiles over the M79 in the attack of thin armor at high obliquity has also been noted in earlier observations. (NPG Report No. 7-43 dated 19 April, 1943.)

At e/d of 0.49 15-lb. flat-nosed projectiles penetrated at 0°, 30°, 45° and 60° with limit velocities of 62% to 73% of the M79 limits. M79 projectiles were unable to penetrate at 45° and 60° obliquity without

breaking up, whereas the flat-nosed projectiles penetrated in a whole though somewhat deformed condition.

At e/d of 0.67 flat-nosed projectiles were found to have limits lower than the M79 projectiles up to 40° obliquity where they were about equal. At normal obliquity the flat-nose limit was 62% of the M79 limit. At 20° and 30° the flat-nose limit was 86% and 93% respectively of the M79 limits.

At e/d of 0.80 the limit for flat-nosed projectiles was 86% of the M79 limit at normal obliquity. The flat-nosed projectiles were, however, badly deformed and tests were not extended to higher obliquities.

Flat-nosed projectiles failed to penetrate and were shattered at 103% of the M79 limit for e/d of 1.1 at normal obliquity.

A comparative test of M79 and flat-nosed projectiles was carried out against a divided armor structure consisting of 3/8", 1.5 and 1/4" STS spaced 2-feet apart at 30° obliquity. The limit for the flat-nosed projectiles was 78% of the M79 limit.

From the results summarized here it is apparent that the flat-nosed principle can result in penetrations of homogeneous plate at velocities much lower than those required for monoblock M79 projectiles. The advantage is particularly striking in the attack of homogeneous armor at e/d values of 0.5 or less at high obliquity, where the limit velocity may be less than one-half that required for other projectiles . For some test conditios (e/d of 0.5 at high obliquity) flat-nosed projectiles penetrate in a whole condition while M79 projectiles are broken up. At normal obliquity for e/d values approaching 1.0 flat-nosed projectiles shatter and fail to penetrate.

Flat-nosed projectiles fitted with caps were unsuccessful in that plate failure by punching was not produced and therefore low limits were not obtained.

Recommendations are included in the report for tests of flat-nosed AP bombs and for common projectiles up to 5-inch for the attack of lightly armored targets (e/d of 0.5 and below).

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LIST OF FIGURES

LIST OF FIGURES (Cont'd.)

I INTRODUCTION.

Preliminary tests of 3" flat-nosed projectiles at the Naval Proving Ground against homogeneous plate were carried out in early 1943. The results of those tests reported in reference (1) indicated that under certain conditions · flat-nosed projectiles were able to penetrate homogeneous plate at considerably lower velocities than were required for pointed projectiles. At e/d values of 0.5 or less the advantage of flat-nosed projectiles was particularly pronounced - the limit velocity was less than one-half the value obtained with M79 projectiles. At e/d of 0.67 and 0° obliquity flat-nosed projectiles shattered and failed to penetrate. It was considered that flat-nosed projectiles of higher quality could be obtained and additional flat-nosed projectiles were accordingly obtained from Frankford Arsenal. The results of the test of these projectiles are discussed in this report.

II MATERIAL AND METHODS.

Plate: 0"6 STS Carnegie-Illinois Plate No. 125687 (Tensile Strength 123,000 psi.)

1"5 STS Carnegie-Illinois Plate No. 40500 (Tensile Strength - 122,000 psi.)

1"5 STS Carnegie-Illinois Plate No. 40915 (Tensile Strength-127,000 psi.)

2"0 STS Carnegie-Illinois No. X18305 (Tensile Strength-127,000 psi.)

2"0 STS Carnegie-Illinois No. F-1790 (Tensile Strength-116,000 psi.)

2"4 STS Carnegie-Illinois No. 29533 (Tensile Strength - 127,000 psi.)

3"0 Class B Carnegie-Illinois No. 85187 (Tensile Strength -120,000 psi.)

3"2 Class B Carnegie-Illinois No.X9021 (Tensile Strength-124,000 psi.)

NPG PHOTO NO. 1224 (APL) -
Frankford Arsenal Experimental 3" Flat-nosed projectiles (15.0 lb.)

1. Solid Shot
2. Grooved Cap (5%)
3. Grooved Cap (15%)
4. Welded Cap (5%)
5. Welded Cap (5%)

22 November 1943

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Projec- 3" M79 AP projectiles (15.0-lb.)
tiles: manufactured by Frankford Arsenal.

3" Flat-Nosed projectiles (15.0-lb.) manufactured by Frankford Arsenal. The following different types were provided (the cap weights are expressed in per cent of total projectile weight). See Fig.1.

(a) No cap.
(b) 5% welded flat cap.
(c) 15% welded flat cap.
(d) 5% grooved cap.
(e) 15% grooved cap.

All of the above projectiles, both M79 and flat-nosed, were manufactured from WD4150 steel and were heat treated to a uniform hardness of 55-60 R_C except for a base draw to about 40 R_C. This is the standard hardness distribution for the M79 projectile and is believed to be the best one for flat-nosed projectiles.

The test conditions are summarized below:

0"6 STS at 0° and 45° obliquity.
1"5 STS at 0°, 30°, 45° and 60° obliquity.
2"0 STS at 0°, 20°, 30° and 40° obliquity.
2"4 STS at 0° obliquity.
3"0 Class B at 0° obliquity.
Divided structure. 3/8", 1"5 and 1/4" STS plates spaced 2 feet apart at 30° obliquity.

Method

All limits reported herein are expressed in terms of F(e/d,θ) values, where F(e/d,θ) is defined as follows:

$$F(e/d,\theta)= \frac{41.57\ M^{1/2} V_L \cos\theta}{e^{1/2}\ d} \qquad (1)$$

M is the projectile mass in pounds, V_L is the limit velocity in feet per second(the minimum velocity required for a projectile to pass completely through the plate), θ, the obliquity, is the angle between the normal to the plate and the line of flight, e is the plate thickness at the point of impact in inches, and d is the projectile diameter in inches. All of the above quantities are measured directly except V_L, the limit velocity, and its measurement is described in the following.

Limit velocities for each test condition were determined using a routine procedure developed at the Naval Proving Ground for 3-inch tests (references (1) and (2)). With this method the first round was fired at a velocity slightly in excess of the estimated limit. From the striking and residual velocities the limit was then calculated and one or more rounds fired at that limit for confirmation. For most of the subject test conditions both complete and incomplete penetrations were obtained to give a bracket of the limit. Using the limit velocity so obtained a limit $F(e/d,\theta)$ value was calculated for the particular test condition. When a bracket was not obtained an $F(e/d,\theta)$ value was calculated using either the lowest velocity giving a complete penetration or the highest velocity giving an incomplete penetration. This value was marked with the appropriate sign to indicate that the true limit had some higher or lower value.

The calculated $F(e/d,\theta)$ values are compared with the standard Navy $F(e/d,\theta)$ - values given by the 1931 empirical formula, (Buord Sk. 78841),

$$F(e/d,\theta) = 6(e/d - 0.45)(\theta^2 + 2000) + 40,000 \qquad (2)$$

where e/d is the ratio of plate thickness to projectile diameter, both in the same units, and θ is the obliquity in degrees. The calculated values of $F(e/d,\theta)$ in the present report are expressed as percentages of these empirical $F(e/d,\theta)$ values.

III RESULTS.

The results, which are given in detail in the Appendix, are summarized below.

SYMBOLS

Projectile Condition

E. . . . . Projectile undeformed
D . . . . Projectile deformed but not broken
NC . . . . Projectile nose chipped.
X . . . . Projectile shattered.

TABLE I

SUMMARY OF BALLISTIC DATA

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
			0° Obliquity			
0.20	0"6	M79	34,300±200	494	93	E
		Flat-Nose (No cap)	35,000±200	504	94	D
0.49	1"5	M79	46,500±200	1050	115	
		Flat-Nose (No cap	28,500±200	644	71	D
0.67	2"0	M79	46,100±400	1210	108	E
		Flat-Nose (No cap)	28,600±500	748	67	D
0.80	2"4	M79	47,900±800	1378	108	E
		Flat-Nose (No cap)	41,000±1000	1190	93	D
1.1	3"2	M79	48,100±300	1598	103	E
		Flat-Nose (No cap)	>49,300	>1642	>104	X
		Flat-Nose (15% welded cap)	>41,500	>1396	>88	X
		Flat-Nose (15% slotted cap)	>42,200	>1392	>89	X
			20° Obliquity			
0.67	2"0	M79	44,000±300	1229	102	E
		Flat-Nose (No cap)	37,800±500	1056	88	D
		Flat-Nose (15% welded cap	>38,900	>1085	>90	D
		Flat-Nose (15% slotted nose	>38,900	>1077	>90	D
			30° Obliquity			
0.5	1"5	M79	41,200±300	1082	101	E
		Flat-Nose (No cap)	30,100±300	791	74	D
		Flat-Nose (5% welded cap)	>33,700	>866	>83	NC
		Flat-Nose (5% slotted cap)	>33,900	>872	>83	NC

30° Obliquity (Cont'd.)

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
		Flat-Nose (15% welded cap)	>35,000	>902	>86	NC
		Flat-Nose (15% slotted cap)	>33,600	>866	>83	NC
0.67	2"0	M79	42,100±200	1276	96	D
		Flat-Nose (No cap)	39,200±200	1188	90	D

40° Obliquity

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
0.67	2"0	M79	47,400±800	1625	106	D
		Flat-Nose (No cap)	48,000±500	1645	108	D

45° Obliquity

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
0.20	0"6	M79	35,000±300	712	94	E
		Flat-Nose (No cap)	>23,600	>480	>69	D
0.5	1"5	M79	>45,500	>1464	>110	X
		Flat-Nose (No cap)	32,600±200	1049	79	D

60° Obliquity

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
0.20	0"6	M79	34,700±300	999	110	E
0.5	1"5	M79	>50,000	>2274	>120	X
		Flat-Nose (No cap)	31,000±500	1411	75	D

Deck Structure

3/8", 1"5 and 1/4" STS plates spaced 2 feet apart in the order named at 30° obliquity.

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
.70	2.10	M79	36,400	1130	82	E
		Flat-Nose (No cap)	28,400	880	64	D

TABLE II

SUMMARY OF RESULTS REPORTED IN REFERENCE (1)

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft./sec.	% Sk. 78841	Proj. Cond.
			0° Obliquity			
0.24	0"73	M79	37,100±200	589	99	E
		11-lb.Flat-nose	35,800±400	663	91	D
0.45	1"36	M79	46,000±400	996	115	E
		11-lb.Flat-Nose	30,500±300	771	76	D
		15-lb.Flat-Nose	26,600±300	576	67	D
			30° Obliquity			
0.45	1"36	M79	40,900±300	1023	102	E
		11-lb.Flat-Nose	31,000±300	905	78	D
			60° Obliquity			
0.24	0"73	M79	43,600±400	1384	133	E
		11-lb.Flat-Nose	20,300±300	644	62	D

TABLE III

Summary of Results of All Tests of 3" Flat-Nosed Projectiles carried out at the Naval Proving Ground. The values given are ratios of F-coefficients of Flat-Nosed Projectiles to F-coefficients for M79 Projectiles under the same test conditions.

e/d	0°	20°	30°	40°	45°	60°
0.20	1.02	--	--	--	0.67	--
0.24	(0.97)	--	--	--	--	(0.47)
0.45	0.58	--	--	--	--	--
0.45	(0.66)	--	(0.76)	--	--	--
0.49	0.62	--	0.73	--	0.72	0.62
0.67	0.62	0.86	0.93	1.01	--	--
0.80	0.86	--	--	--	--	--
1.10	1.03	--	--	--	--	--

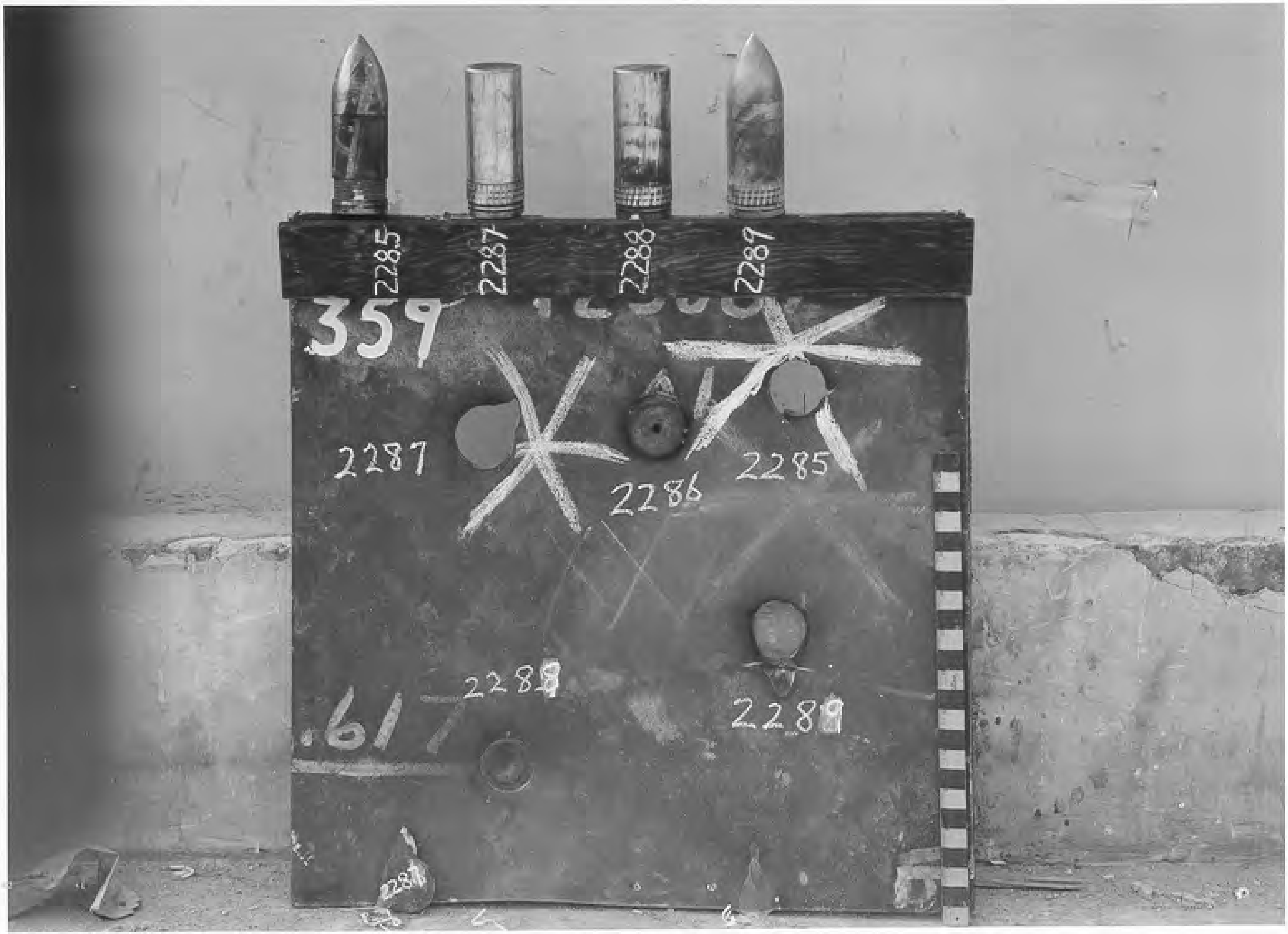
( ) The values in parentheses are for 11-lb. flat-nosed projectiles (reference (1)). All other values were obtained with 15-lb. flat nosed projectiles.

NPG PHOTO NO. 1442 (APL).
APL Plate No. 359 (Carn.-Ill. 0"6 STS Plate No. 125687) vs. F.A. 3" 15 lb. flat nose and 3" M79 AP projectiles at 0° and 45° obliquity. FRONT VIEW.
See NPG Photo No. 1443 APL for back view.

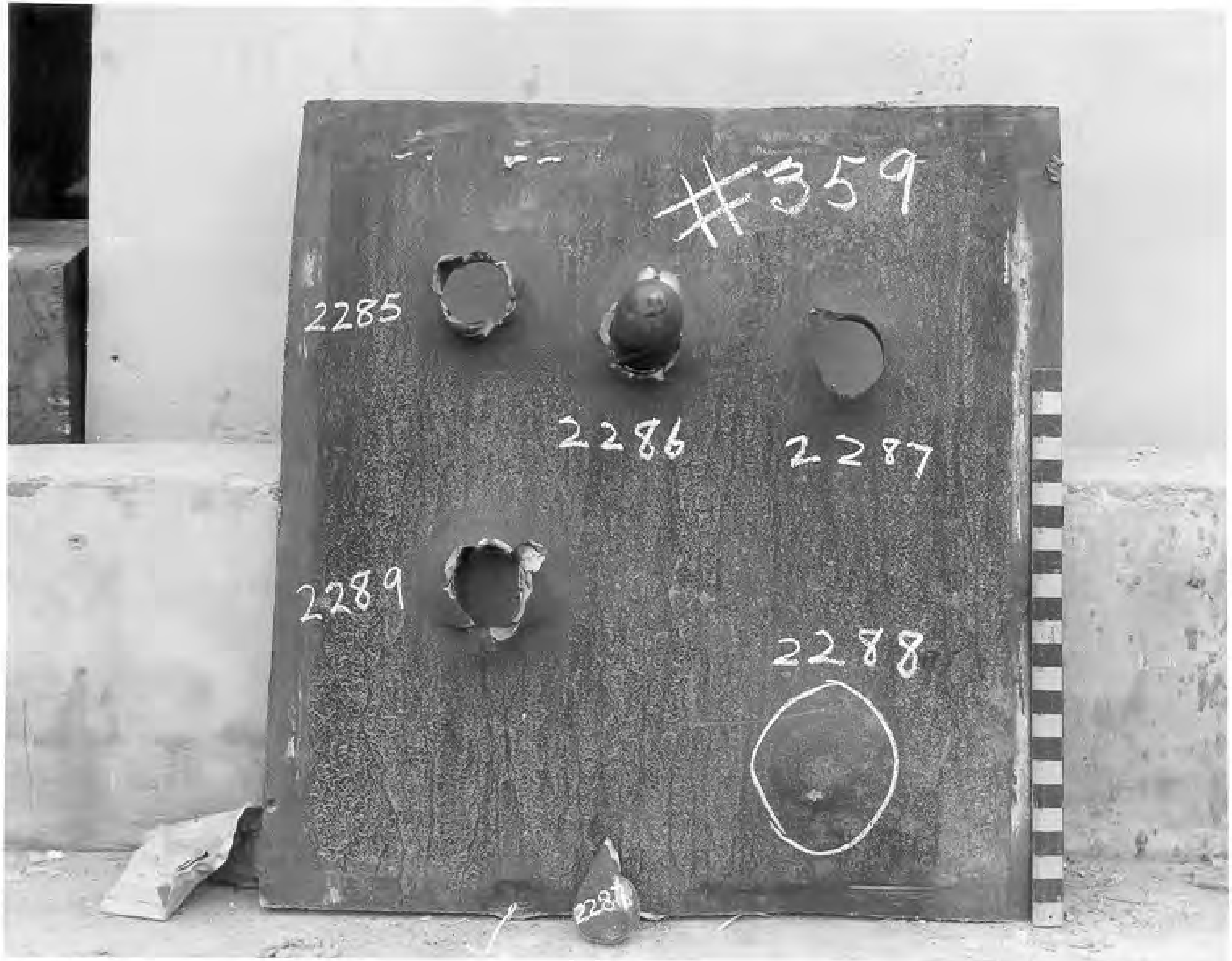
B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	R.V.,f.s.	Proj.Cond.
2285 APL	.617	0°20'	604	111	CP	--	Base chipped.
2286	.618	0°20'	500	92	SIP 8"	--	Whole.
2287	.619	0°10'	326	97	CP	123	Whole.
2288	.619	1°00'	509	94	Inc.1/2"	--	Whole.
2289	.619	45°00'	626	90	CP	184	Whole.

2, 3, 4 February 1944

- [redacted] -



NPG PHOTO NO. 1443 (APL).
APL Plate No. 359 (Carn.-Ill. 0"6 STS Plate No. 125687) BACK VIEW. See NPG Photo No. 1442 APL for front view and data on impacts.
2, 3, 4 February 1944 - [redacted] -



NPG PHOTO NO. 1444 (APL).
APL Plate No. 360 (Carn.-Ill. 0"6 STS Plate No. 125687) vs. F.A. 3" 15 lb. flat nosed and 3" M79 AP projectiles at 45° obliquity. FRONT VIEW. See NPG Photo No. 1445 APL for back view and data on impacts 2293-5 APL.

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	R.V.,f.s.	Proj.Cond.
2290 APL	.613	44°50'	570	82	Inc.	--	Base chipped.
2291	.614	45°00'	618	88	CP	173	Whole.
2292	.615	45°00'	574	81	Inc.2"	--	Whole.

4 February 1944

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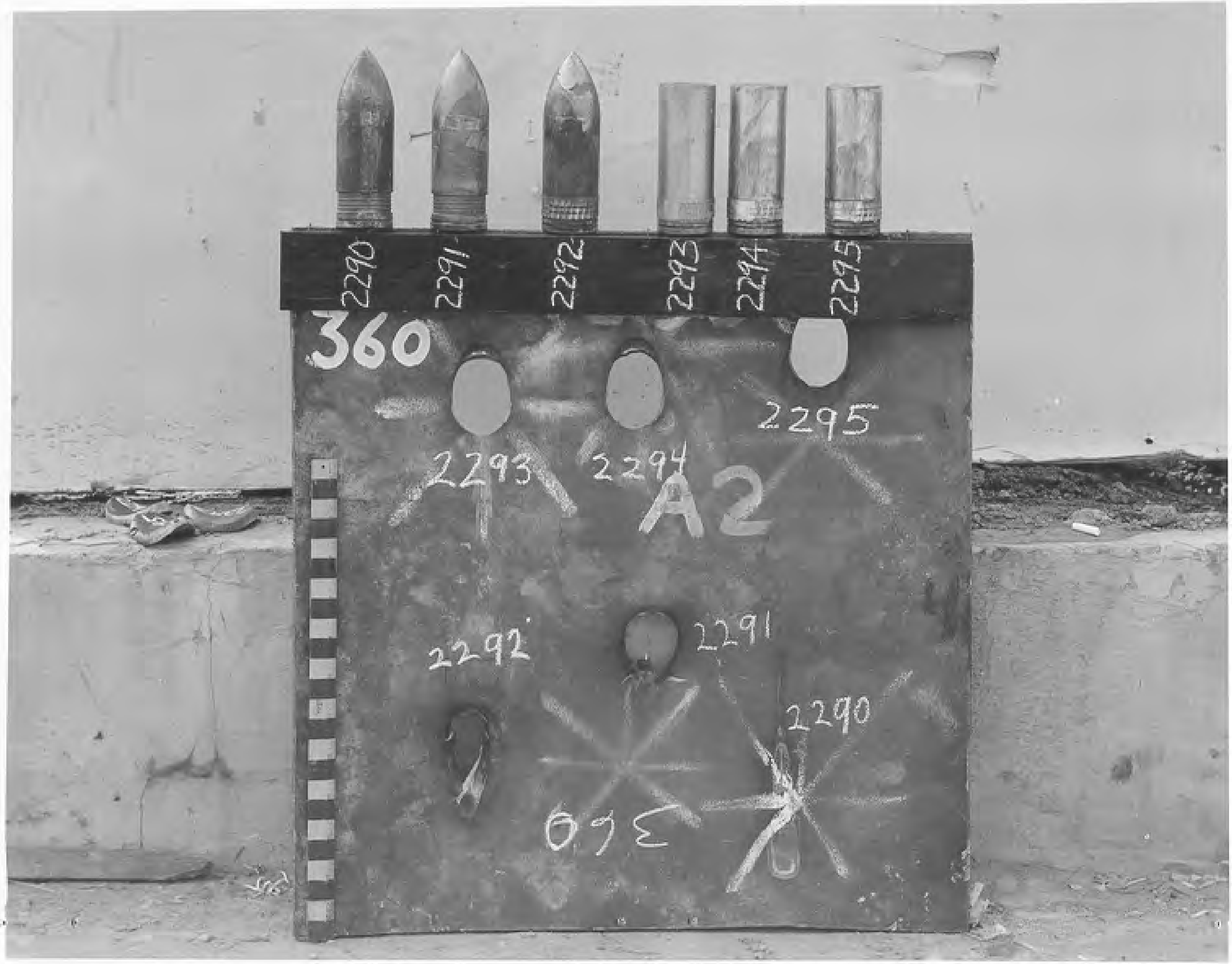
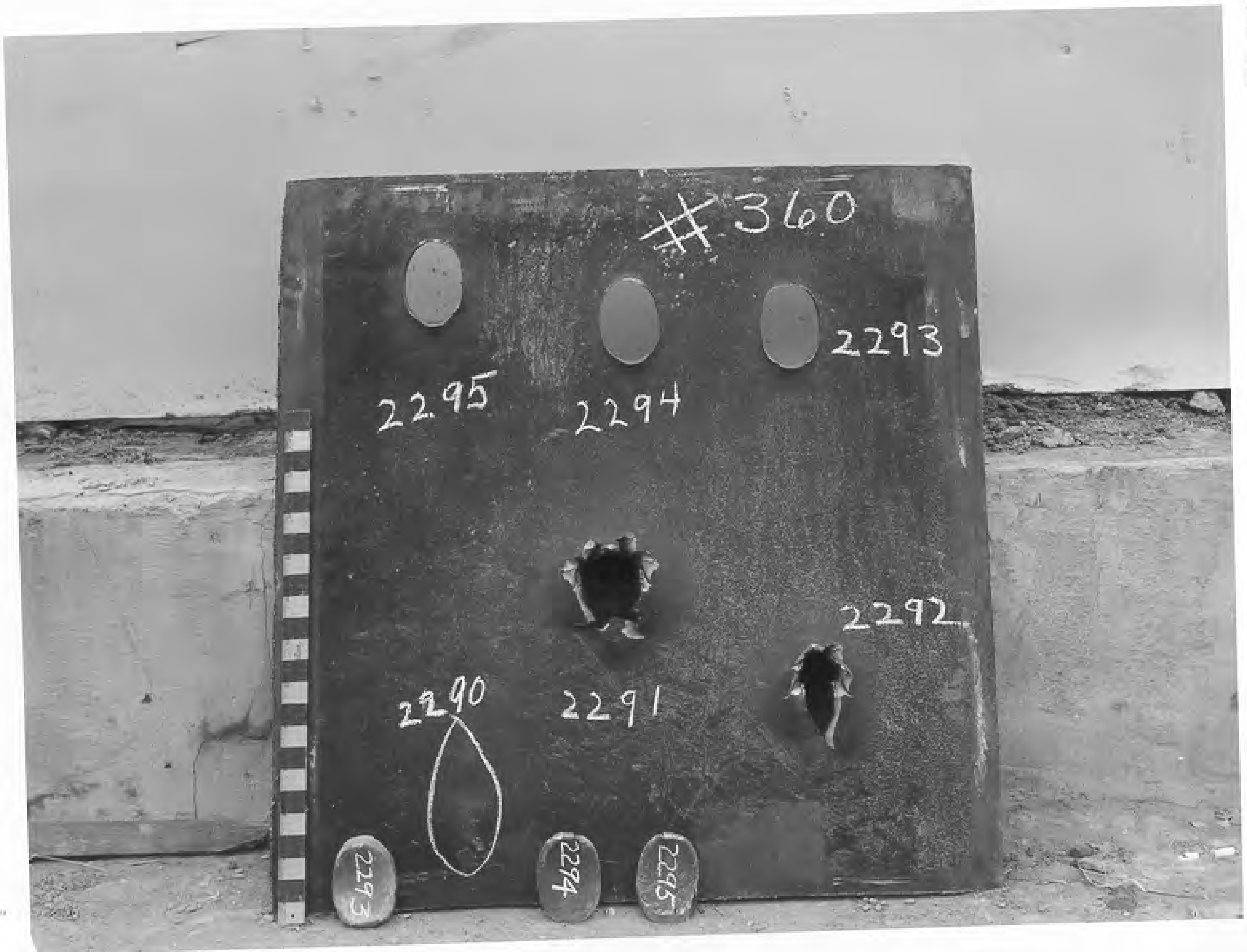


NPG PHOTO NO. 1445 (APL).
APL Plate No. 360 (Carn.-Ill. 0"6 STS Plate No. 125687) BACK VIEW. See NPG Photo No. 1444 APL for front view and data on impacts 2290-2292 APL.

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	R.V.,f.s.	Proj.Cond.
2293 APL	.616	45°00'	566	80	CP	285	Whole.
2294	.615	45°00'	501	71	CP	85	Whole.
2295	.614	45°00'	487	69	CP	-	Nose chipped.
						-	[redacted] -

4 February 1944.



NPG PHOTO NO. 1457 (APL).
APL Plate No. 318 (Carn.-Ill. 1"5 STS No. 40500) vs. 3" 15 lb. flat nose AP projectiles at 45° obliquity. FRONT VIEW. See NPG Photo No. 1458 APL for back view.

B.I.No.	"e"	"θ"	S.V., f.s.	Pene.	Proj. Cond.
2296 APL	1"483	45°00'	1039	SIP 7"	Whole.
2297	1"484	44°50'	1084	CP	Nose offset.
2298	1"481	44°50'	1323	INC. 1/2"	Whole.

7 February 1944

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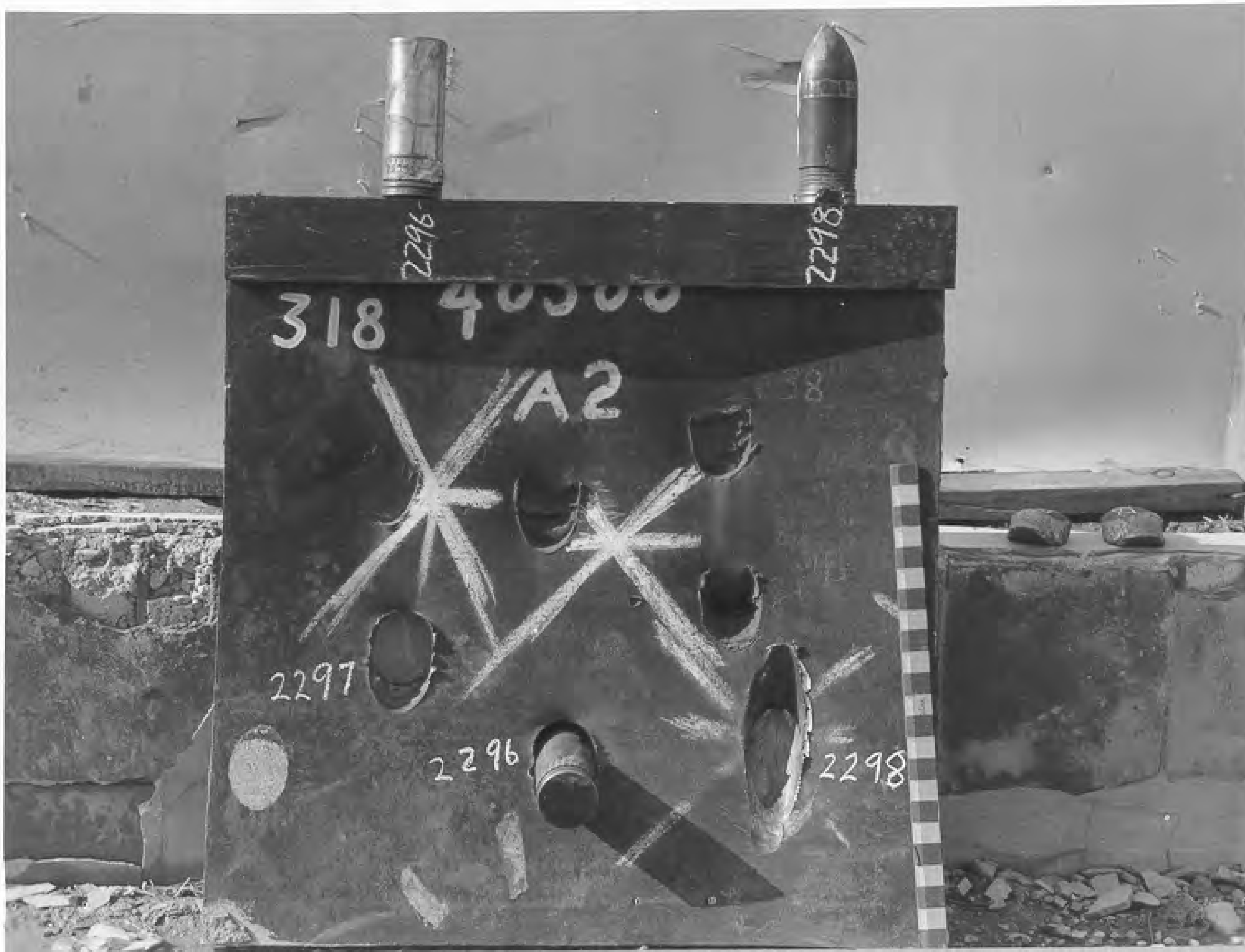

NPG PHOTO NO. 1458 (APL).
APL Plate No. 318 (Carn.-Ill. 1"5 STS No. 40500) BACK VIEW. See NPG
Photo No. 1457 APL for front view and data on impacts Nos. 2296-98 APL.
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7 February 1944

NPG PHOTO NO. 1459 (APL).
APL Plate No. 361 (Carn.-Ill. 1"5 STS No. 40500) vs. 3" 15 lb. flat nose AP projectiles at 60° obliquity. FRONT VIEW. See NPG Photo No. 1460 APL for back view.

B.I.No.	"e"	"θ"	S.V.,f.s.	Pene.	Proj. Cond.
2299 APL	1"476	60°00'	1704	CP	Whole.
2300	1"479	59°50'	1512	CP	Whole.
2301	1"477	60°00'	1360	Inc.	Whole.

7, 8 February 1944.

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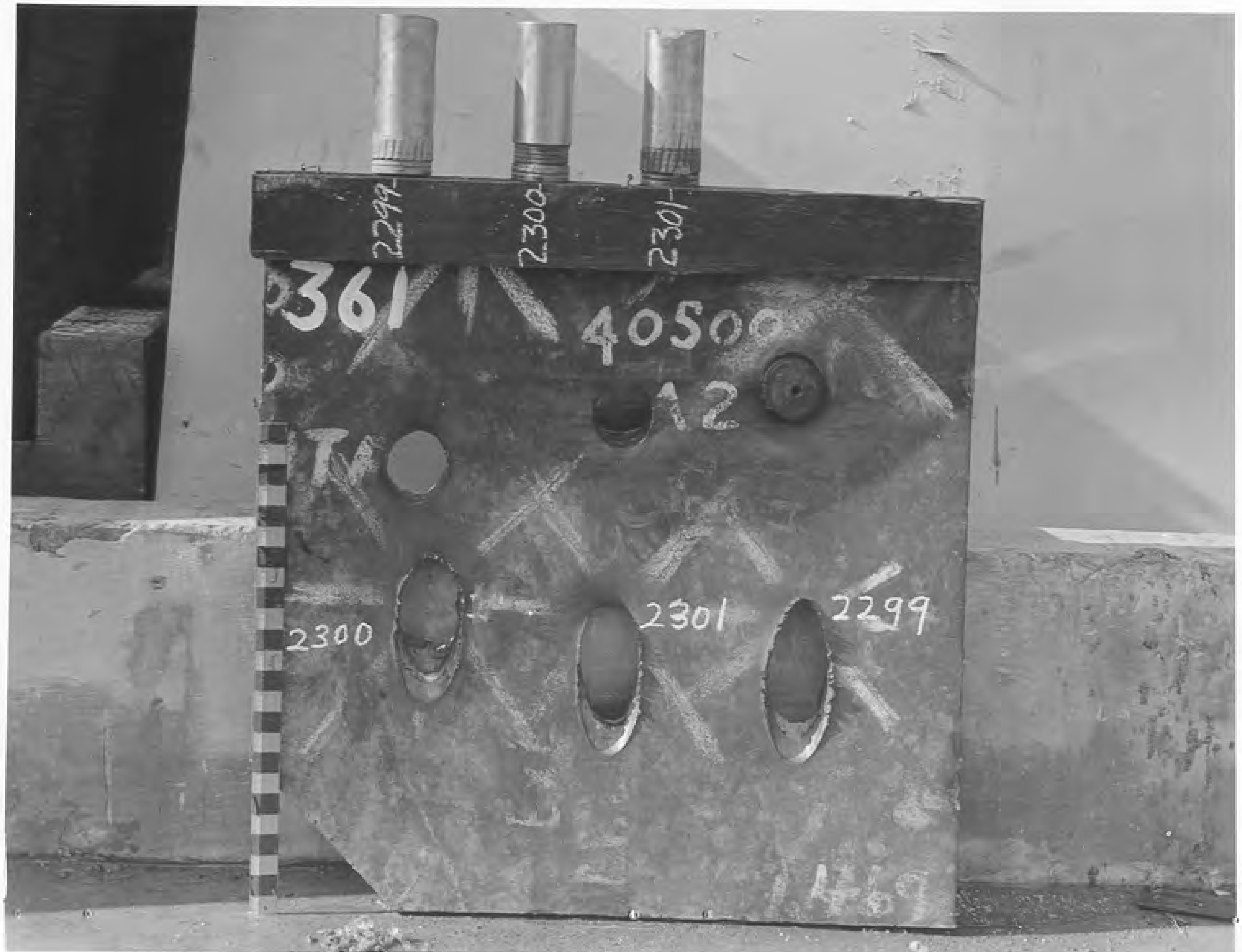

NPG PHOTO NO. 1460 (APL).
APL Plate No. 361 (Carn.-Ill. 1"5 STS No. 40500) BACK VIEW. See NPG Photo No. 1459 APL for front view and data on impacts Nos. 2299-2301 APL.
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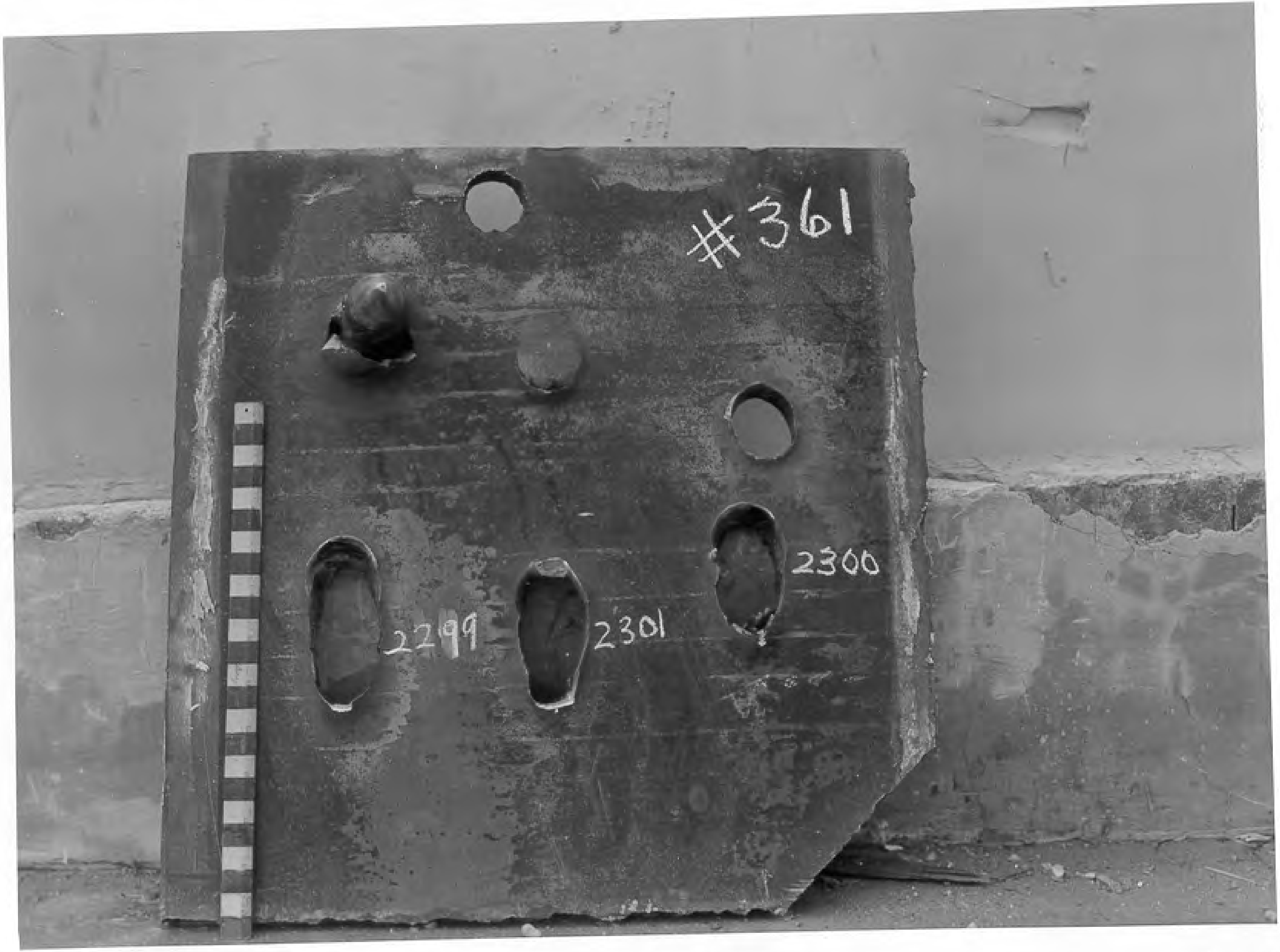
7, 8 February 1944



IV DISCUSSION.

An inspection of the results reveals immediately that 3" flat-nosed projectiles are able to penetrate homogeneous plate over a rather wide range of e/d and obliquity at velocities considerably lower than are required by 3" M79 projectiles. Flat-nosed projectiles completely penetrate a plate under some conditions which result in shatter of 3" M79 projectiles. The results are discussed in detail in the following. The term "limit" will mean the limit F(e/d,θ* value unless specifically stated otherwise.

At e/d of 0.20 15-lb. flat-nosed projectiles and M79 projectiles have about the same limits at normal obliquity. As the obliquity is increased to 45° the limit for the flat-nosed projectile becomes less than 67% (probably about 65%) of the M79 limit. As reported in reference (1) 11-lb. flat-nosed projectiles at a similar e/d value (0.24) were found to have about the same limit as M79 projectiles at normal obliquity but at 60° obliquity the flat-nosed projectile had a limit of 47% of the M79 limit. The difference in appearance of impacts of M79 and flat-nosed projectiles at high obliquity on thin plate is strik ng. The flat-nosed projectile cuts a disk out of plate with very little dishing whereas the M79 dishes a considerable area around the impact. The much larger plastically deformed zone in the case of the M79 probably accounts for most of the increased energy required for penetration at high obliquity. For typical impacts see Figures 2, 3, 4 and 5.

At e/d of 0.45 - 0.49, 15-lb. flat-nosed projectiles were found to have limits from 75% to less than 62% of M79 limits under the same test conditions. For e/d of 0.49 at 45° and 60° obliquity M79 projectiles are shattered whereas 15-lb. flat-nosed projectiles penetrate in a whole condition. 11-lb. flat-nosed projectiles gave comparable performance to that of the 15-lb. flat-nosed projectiles at 0° and 30° but had limits about 4% higher (reference (a)). Impacts by flat-nosed projectiles resulted in failure by "punching" characterized by the throwing of plugs from the plate. For view of plates, projectiles and punchings see Figures 6, 7, 8 and 9.

At e/d of 0.67 15-lb. flat-nosed projectiles had limits increasing from 62% of the M79 limit at normal obliquity to 100% at 40° obliquity. At 40° both flat-nosed and M79 projectiles were broken. For views of plate, projectiles and punchings see Figures 10, 11, 12 and 13.

At e/d of 0.80 15-lb. flat-nosed projectiles had a limit of 86% of the M79 limit at normal obliquity. Since the deformations of the flat-nosed projectiles were large on this test, it was apparent that the subject projectiles would not stand up to more severe tests. See Figures 14, 15 and 16 for views of plate and projectiles.

At e/d of 1.0 and normal obliquity 15-lb. flat-nosed projectiles were shattered with negligible penetration up to velocities 3% above the M79 limit. See Figures 20 and 21 for views of projectiles and plate.

From the preceding discussion it is apparent that the flat-nosed projectiles used in the present investigation were of considerably higher quality than those of reference (1). In those tests flat-nosed projectiles did not successfully penetrate 2" STS (e/d of 0.67) at 0° obliquity. On the other hand the present projectiles penetrated at e/d of 0.67 up to 40° and e/d of 0.80 at 0° obliquity. In view of the performance of the subject projectile it does not appear that successful penetrations at e/d of 1.0 can be achieved for projectile having a full caliber flat-nose unless perhaps an overweight projectile is used.

Against the divided plate structure (3/8", 1.5 and 1/4" STS spaced 2 feet apart at 30° obliquity) the M79 projectile penetrated the 3/8" plate and stuck in the 1.5 plate at a velocity of 1105 ft./sec. The flat-nosed projectile penetrated the entire structure at 940 ft./sec. and had a residual velocity of 234 ft./sec. From the residual velocity and the striking velocity the limit velocity of the structure for flat-nosed projectiles was calculated to be 880 f.s. using the equation developed in Appendix E. The limit velocity of the structure for the M79 projectile was estimated at 1130 ft./sec. Thus for this structure flat-nosed projectiles have a limit velocity of about 75% of that found for the M79 projectile.

Limit penetration coefficients for various 3-inch capped projectiles against homogeneous plate were reported in reference (3). The comparison of those limit values with values obtained for flat-nosed projectiles under similar test conditions gives the flat-nosed projectile a marked superiority provided that e/d is not above 0.67. For example in reference (3) 2" STS (e/d of 0.67) at 0° and 30°, and 0.73 STS (e/d of 0.24) at 60° obliquity

NPG PHOTO NO. 1466 (APL).
APL Plate No. 361. Divided Armor Structure (3/8" STS, 1"5 STS and 1/4" STS spaced 2 feet apart) vs. F.A. 15 lb. 3" M79 and flat-nosed projectiles at 30° obliquity. BACK VIEW. See NPG Photo No. 1465 APL for front view and data on impacts 2302-2304 APL. See NPG Photos Nos. 1459-1460 APL for previous impacts.
- [redacted] -
8, 9 February 1944

NPG PHOTO NO. 1465 (APL).
APL Plate No. 361. Divided Armor Structure (3/8" STS, 1"5 STS and 1/4" STS spaced 2 feet apart) vs. F.A. 15 lb. 3" M79 and flat-nosed projectiles at 30° obliquity. FRONT VIEW. See NPG Photo No. 1466 APL for back view, and NPG Photos Nos. 1459-60 APL for previous impacts.

B.I.No.	"e"	"θ"	S.V.,f.s.	Pene.	Proj. Cond.
2302 APL	2"09	30°00'	1105	SIP	Whole.
2303	2"10	29°20'	812	Inc.	Whole.
2304	2"10	29°20'	940	CP	Whole.

8, 9 February 1944

- [redacted] -

NPG PHOTO NO. 1520 (APL).
APL Plate No. 316 (Carn.-Ill. No. 59533) vs. F.A. 15 lb. flat-nose projectiles at 0° obliquity. FRONT VIEW. See NPG Photo No. 1521 APL for back view.
For previous impacts see NPG Photos Nos. 1208-09, 1232-33 APL.

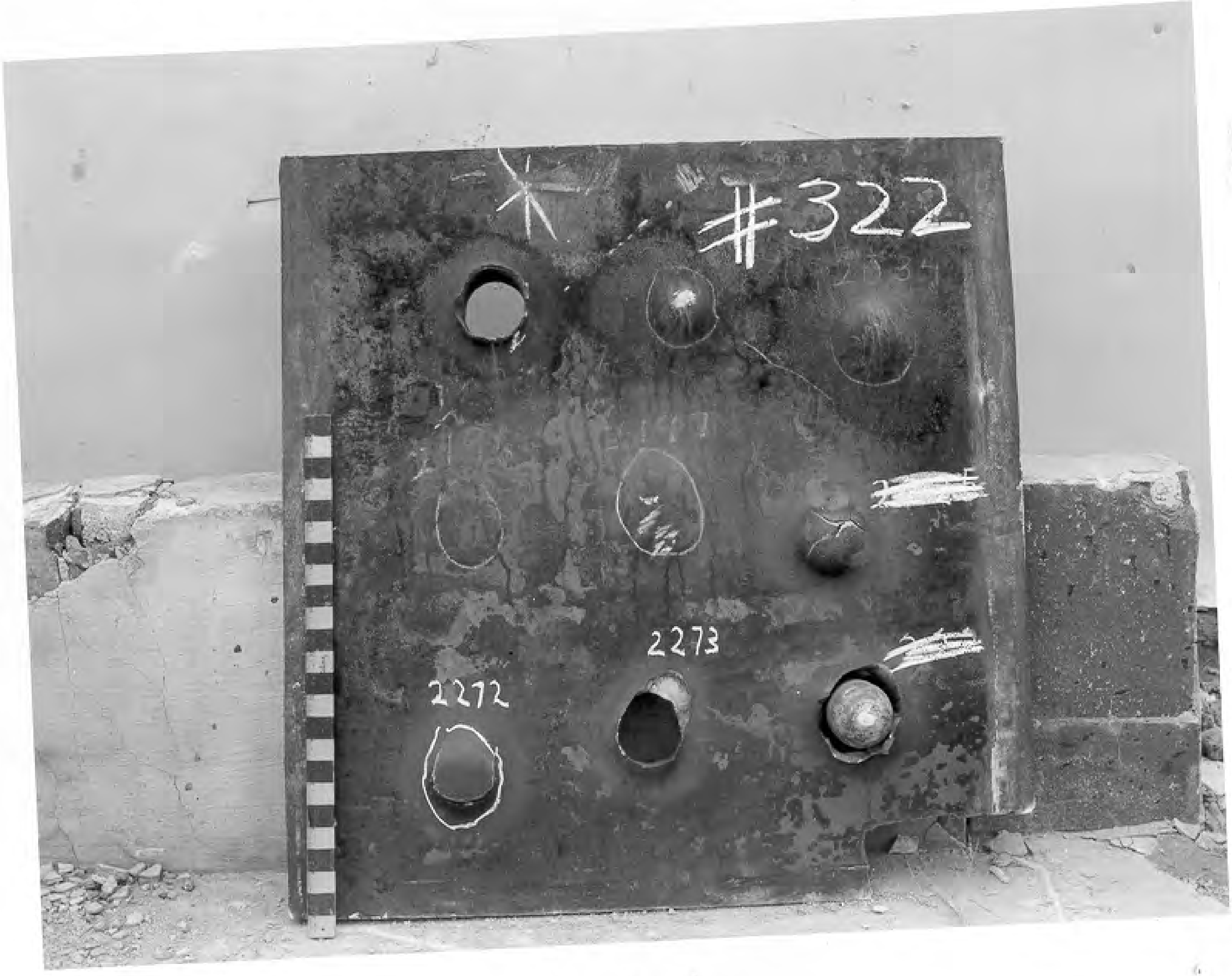
B.I.No.	"e"	"θ"	S.V.,f.s.	Pene.	%	Proj.Cond.
2385 APL	2".430	0°30'	1387	Comp.	108	Nose offset.

March 6, 1944

- [redacted] -

NPG PHOTO NO. 1451 (APL).
APL Plate No. 322 (Carn.-Ill. 2" STS Plate No. X18305) BACK VIEW. See NPG
Photo No. 1450 for front view and data on impacts.
31 January 1944

- [redacted] -

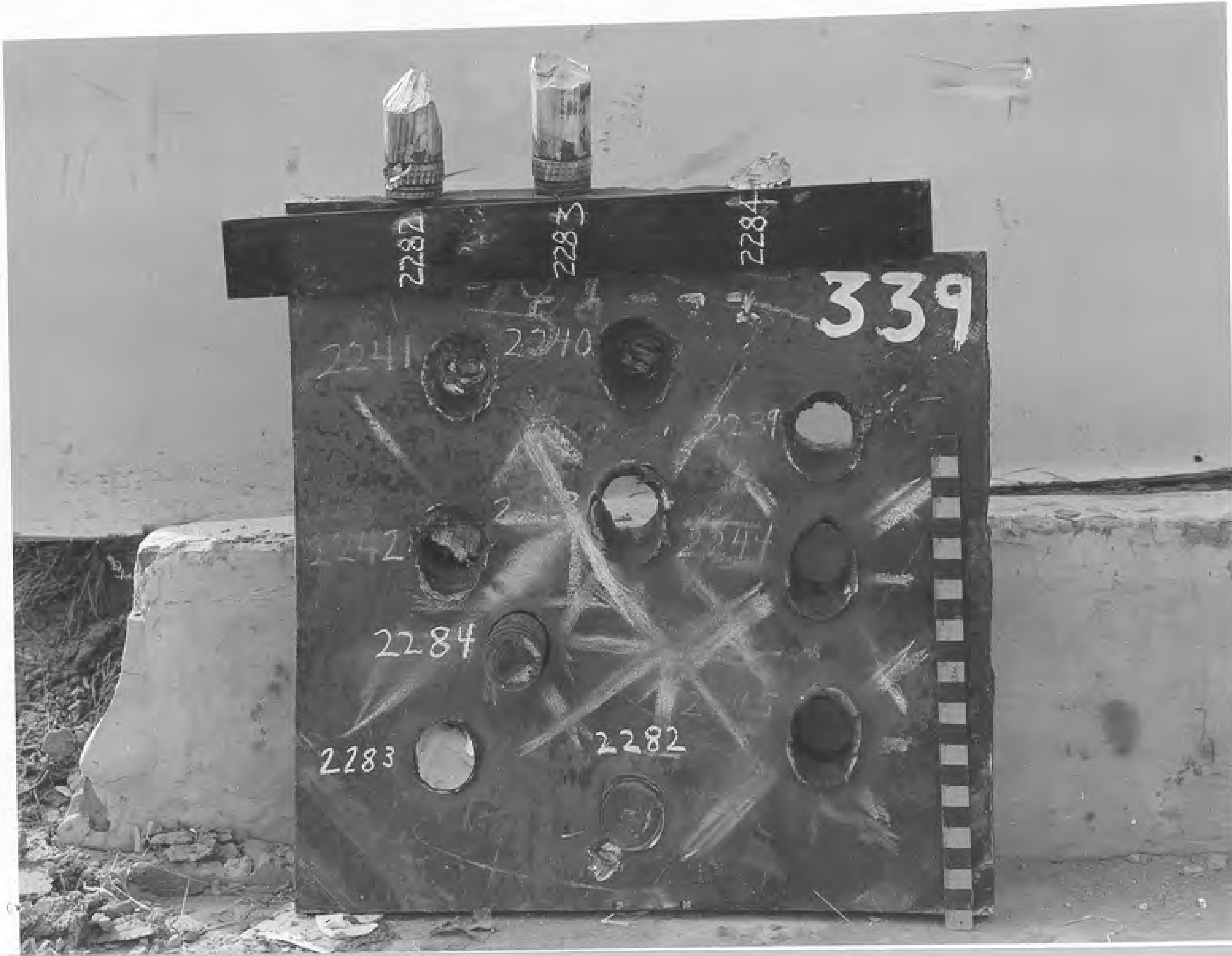


NPG PHOTO NO. 1448 (APL).
APL Plate No. 339 (Car.-Ill. 2"5 STS Plate No. 59533) vs. F.A. 3" 15-lb. flat nosed projectiles at 0° obliquity. FRONT VIEW. See NPG Photo No. 1449 APL for back view.

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	Proj. Cond.
2282 APL	2"429	0°20'	905	70	Inc.3/8"	Nose shattered.
2283	2"431	0°20'	1082	84	Inc.	Nose shattered.
2284	2"429	0°10'	1139	88	SIP 3"	Nose off.

- [redacted]

2 February 1944

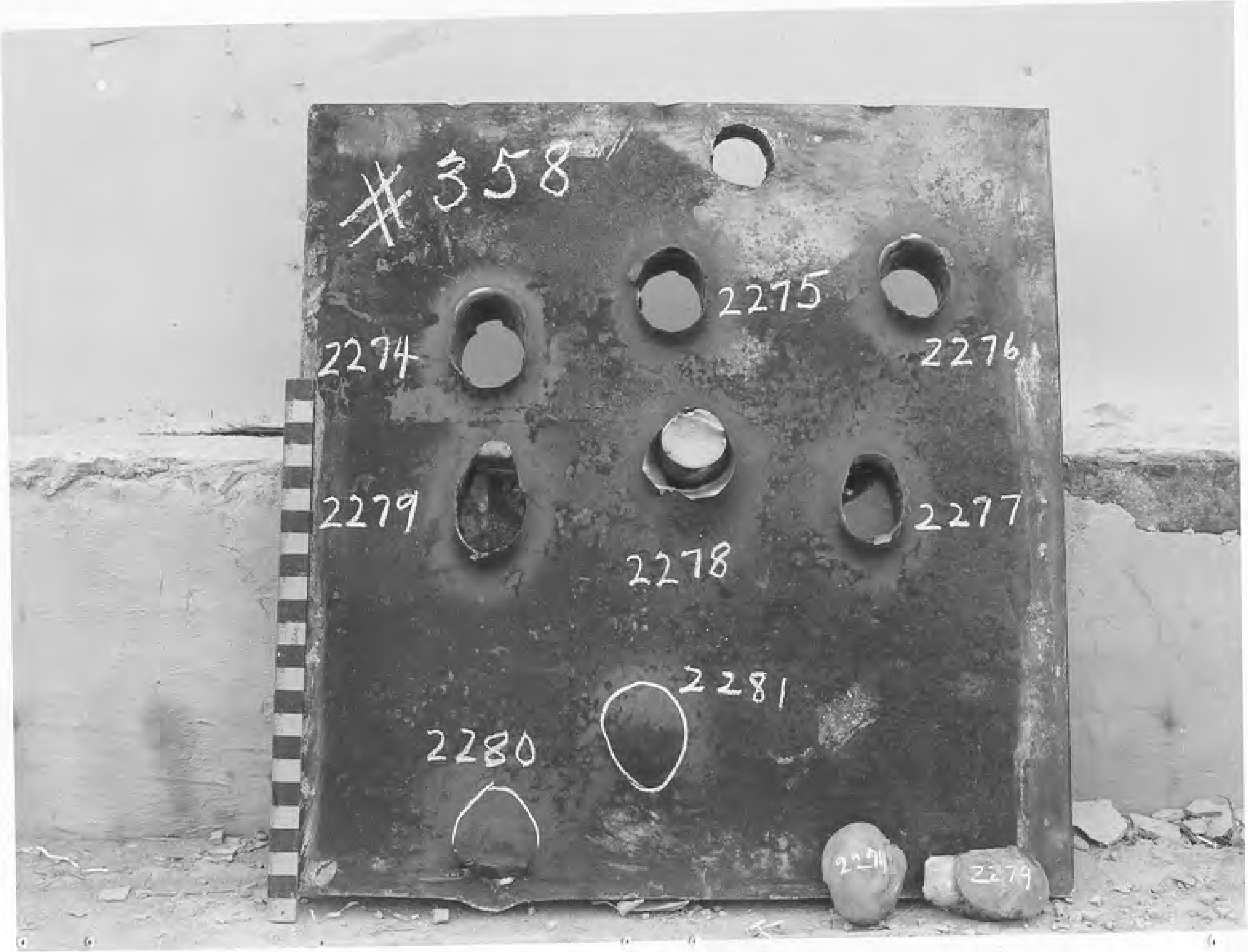


NPG PHOTO NO. 1447 (APL).
APL Plate No. 358 (Carn.-Ill. 2" STS Plate No. F-1790) BACK VIEW. See NPG Photo No. 1446 APL for front view and data on impacts Nos. 2274-2277 APL

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	R.V.,f.s.	Proj.Cond.	Proj.
2279 APL	1"979	40°00'	1376	90	Inc.2-1/4"	--	Nose upset.	Flat-nose.
2280	(Unfair shot hit bolt		1427	-	--	--	Shattered.	"
2281	1"980	40°30'	1400	91	Inc. 1"	--	Shattered.	"

- [redacted] -

31 January and 1 February 1944

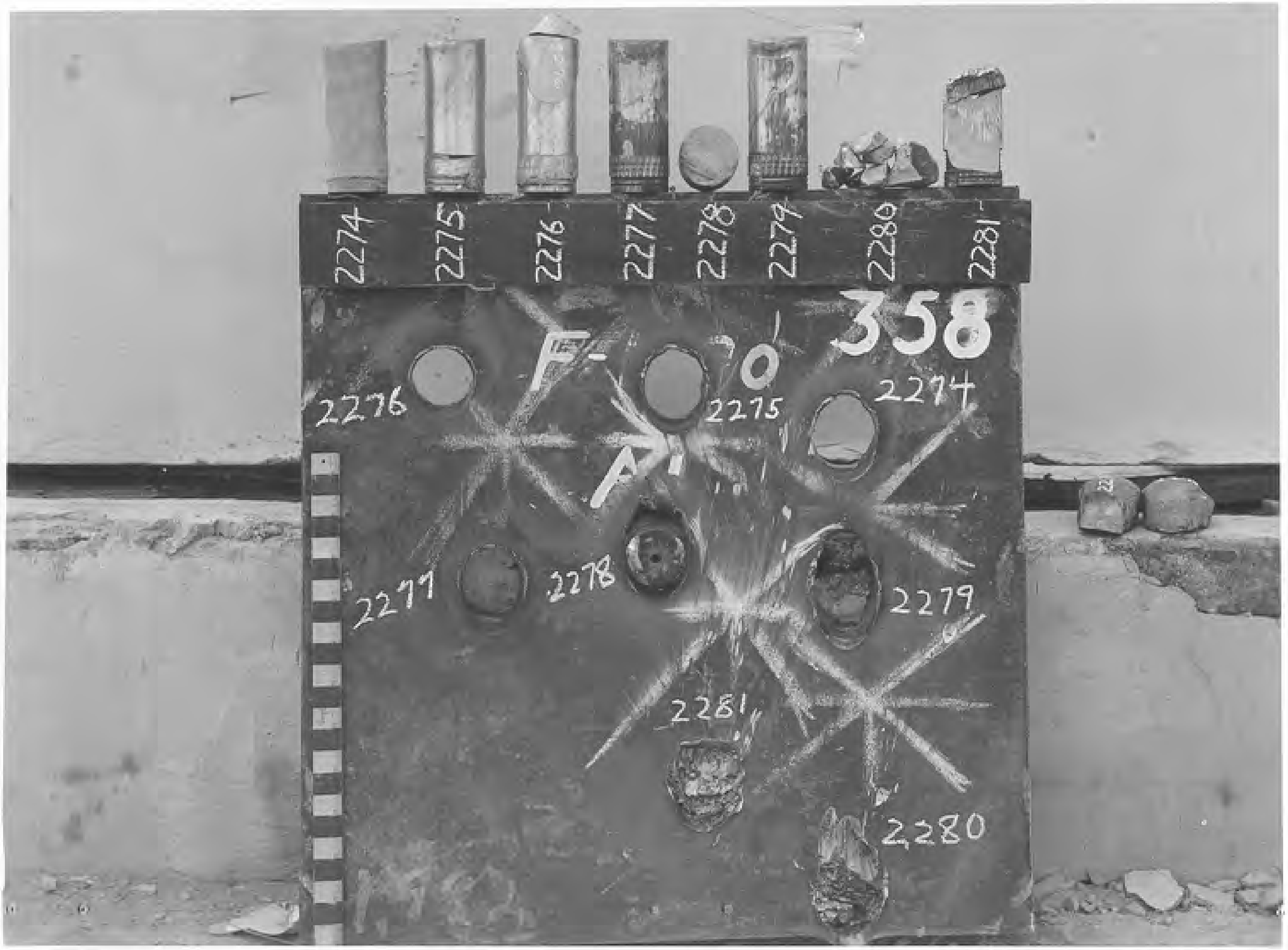


NPG PHOTO NO. 1446 (APL).
APL Plate No. 358 (Carn.-Ill. 2" STS Plate No. F-1790) vs. F.A. 3" 15 lb. flat nose and 3" M79 AP projectiles at 30° and 40° obliquity. FRONT VIEW. See NPG Photo No. 1447 APL for back view and data on impacts Nos. 2278-2281 APL.

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	R.V.,f.s.	Proj.Cond.	Proj.
2274 APL	1".979	29°50'	1435	109	CP	527	Nose offset.	Flat-nose
2275	1".980	29°50'	1271	97	CP	127	Nose offset.	"
2276	1".981	29°50'	1253	95	CP	-	Broken.	"
2277	1".981	30°00'	1181	89	SIP 3-1/2"	-	Body cracked.	"
2278	1".980	30°00'	1322	100	SIP 7-1/2"	-	Nose broken off.	M79

31 January and 1 February 1944

- [redacted]



NPG PHOTO NO. 1449 (APL).
APL Plate No. 339 (Carn.-Ill. 2"5 STS Plate No. 59533) BACK VIEW. See NPG Photo
No. 1448 APL for back view and data on impacts.
2 February 1944

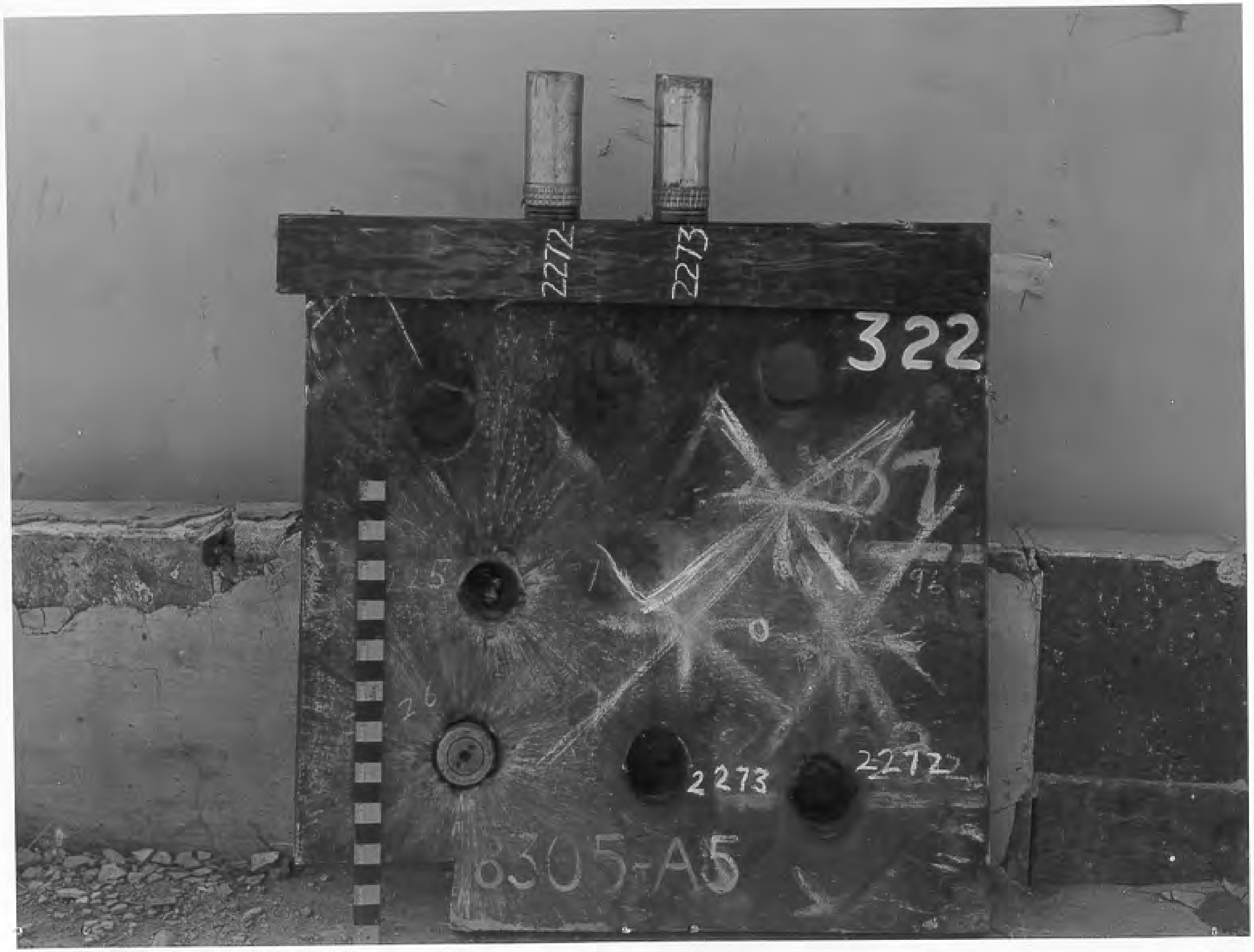
- [redacted] -

NPG PHOTO NO. 1450 (APL).
APL Plate No. 322 (Carn.-Ill. 2" STS Plate No. X18305) vs. F.A. 3" 15 lb. flat nosed projectiles at 20° obliquity. FRONT VIEW. See NPG Photo No. 1451 APL for back view.

B.I.No.	"e"	"θ"	S.V.,f.s.	%	Pene.	Proj.Cond.
2272 APL	2"012	20°10'	998	82	Inc. 2"	Nose offset.
2273	2"013	20°10'	1065	88	Inc. 2-3/4"	Nose offset.

31 January 1944

- [redacted] -

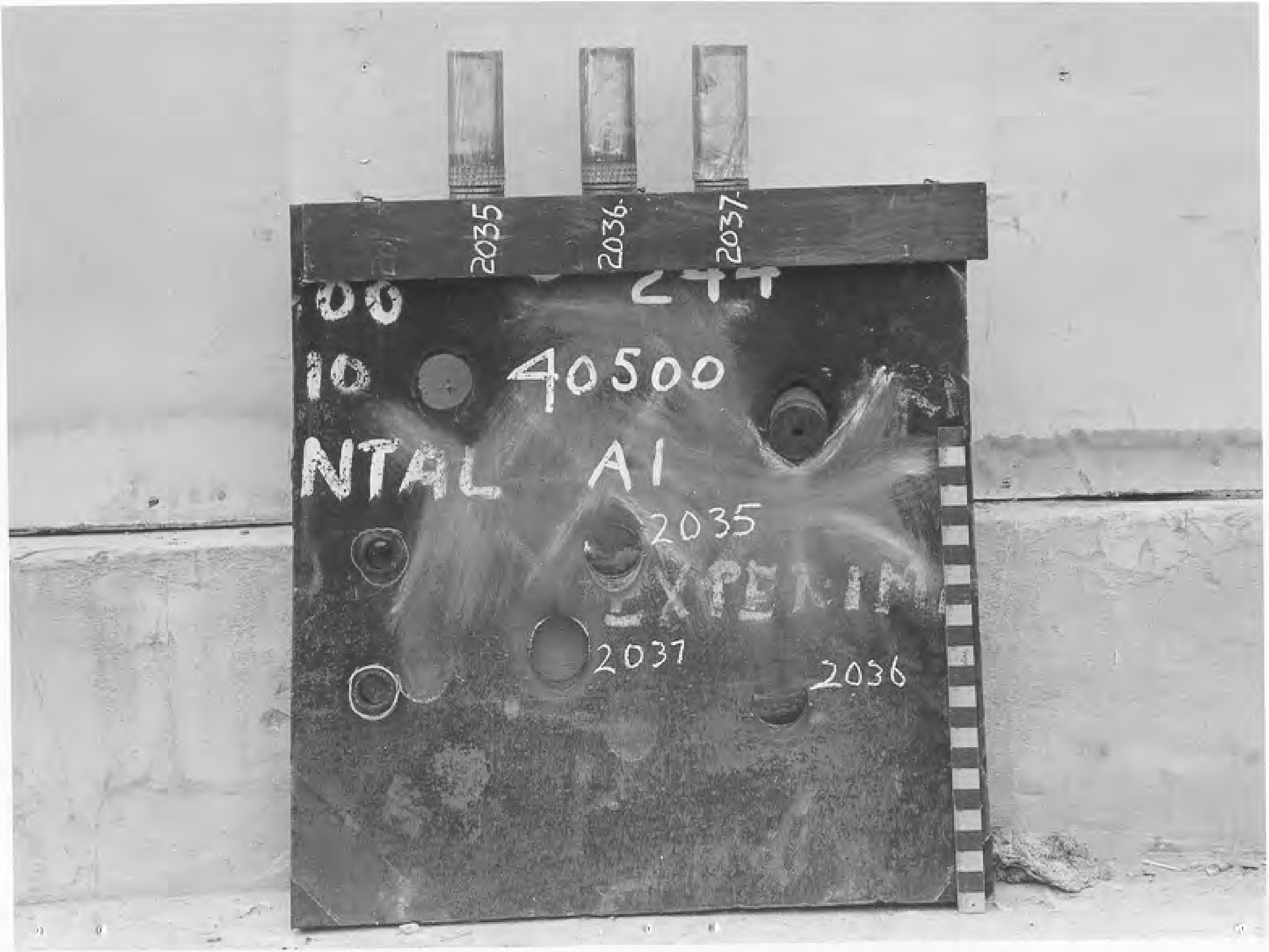


NPG PHOTO NO. 1254 (APL) - APL Plate No. 244 (Carn.-Ill. 1"5 STS 40500) vs. Frankford Arsenal 15 lb. Experimental flat-nosed projectiles at 30° obliquity. FRONT VIEW. See NPG Photo No. 1255 APL for back view and NPG Photos Nos. 883-4 APL and Nos. 1121-1122 APL for previous impacts.

B.I.No.	"e"	"θ"	S.V.,f.s.	S.V.%	Pene.	R.V.,f.s.	Proj.Cond.
2035 APL	1"460	29°50'	657	63	Inc.1-1/4	--	Excellent.
2036	1"470	30°20'	688	65	Inc. 1"	--	Excellent.
2037	1"460	29°50'	812	78	Comp.	184	Excellent.

23 November 1943

- [redacted]



NPG PHOTO NO. 1255 (APL) - APL Plate No. 244 (Carn.-Ill. 1"5 STS 40500) vs. Frankford Arsenal 15 lb. Experimental flat-nosed projectiles at 30° obliquity. BACK VIEW. See NPG Photo No. 1254 APL for front view and data on impacts.
- [redacted] -
23 November 1943

NPG PHOTO NO. 1256 (APL).
APL Plate No. 321 (Carn.-Ill. 3"0 Class B No. X9021) vs. Frankford Arsenal 15 lb.
Experimental flat-nosed projectiles at 0° obliquity. FRONT VIEW. See NPG Photo
No. 1257 APL for back view.

B.I.No.	"e"	"θ"	S.V.,f.s.	S.V.%	Pene.	Proj.Cond.	Proj.
2028 APL	3"20	0°20'	1077	69	Inc.3/8"	Nose shattered.	No cap.
2029	3"20	0°10'	1389	89	Inc.3/4"	Shattered.	No cap.
2030	3"20	0°20'	1396	88	Inc.7/8"	Shattered.	15% welded cap.
2031	3"20	1°10'	1392	89	Inc. 1"	Shattered.	15% slotted nose.

- [redacted] -

19, 22 November 1943

NPG PHOTO NO. 1257 (APL) - APL Plate No. 321 (Carn.-Ill. 3"O Class B No. X9021) vs. Frankford Arsenal 15 lb. Experimental flat-nosed projectiles at 0° obliquity. BACK VIEW. See NPG Photo No. 1256 APL for front view and data on impacts. - [redacted] - 19, 22 November 1943.

against 3" M61 capped AP projectiles gave F(e/d,θ) values of 116%, 114% and 86% respectively of the values for 3" M79 projectiles under the same test conditions. Referring to Table III of this report flat-nosed projectiles under similar test conditions gave F(e/d,θ) values 62%, 93% and 47% of the M79 values. (The 3" M61 capped AP projectile is a 15-lb projectile with a cap weighing 15% of the total projectile weight).

Flat-nosed projectiles fitted with caps of various types did not succeed in completely penetrating homogeneous plate at velocities comparable with those required for plain flat-nosed projectiles. The caps in general prevented the punching action characteristic of flat-nosed projectiles. A type of punching occurred with the projectiles having grooved caps. On impact part of the nose was chipped off to the slot which produced, in effect, a flat-nosed projectile having a reduced diameter on the nose. This projectile had no advantages over the plain flat-nose and lost in efficiency of penetration because of the smaller flat area on the nose. The results of testing of the several capped projectile types showed clearly that to cap a flat-nosed projectile is to destroy its ability to produce a plug-type of plate failure.

V CONCLUSIONS.

1. 3-inch 15-lb. flat-nosed projectiles penetrate homogeneous plate at remarkably lower velocities than do 3-inch M79 or 3-inch capped M61 AP projectiles over a wide range of test conditions which included a divided armor test.

2. Caps on flat-nosed projectiles destroy the punching action and therefore nullify the advantages of flat-nosed projectiles.

VI RECOMMENDATIONS.

It is recommended that the Bureau of Ordnance initiate a program at full scale for the development flat-nosed AP bombs. It is further recommended that flat-nosed common projectiles from 3-inch to 5-inch scale be obtained since such projectiles may be considerably more efficient than current projectiles in the attack of lightly armored vessels.

VII REFERENCES:

1. Penetration of Homogeneous Armor by 3-inch flat-nosed projectiles. U. S. Naval Proving Ground Report No. 7-43 dated 19 April, 1943.

2. Penetration of Homogeneous Plate of one Tensile Strength (110,000 psi.) vs. 3" M79 AP projectiles - Partial Report. U. S. Naval Proving Ground Report No. 8-44 dated 18 April, 1944.

3. Effect of Cap Design on 3-inch projectile Performance - Partial Report. U. S. Naval Proving Ground Report No. 16-43 dated 14 December, 1943.

VIII APPENDIX

SYMBOLS

e .... Plate thickness at impact in inches.

θ .... Obliquity. Angle between trajectory and normal to plate at point of impact.

M .... Projectile mass in pounds.

V_S (f.s.). Striking velocity in feet per second.

V_S (%) ... Striking velocity in percentage of limit value calculated from Navy 1931 empirical formula using Buord Sk. 78841.

Pene. .... Depth of penetration in inches measured from front surface normal to the plane of the plate.

V_R .... Residual velocity after penetration of the plate.

F(e/d,θ).. Thompson F-coefficient defined by the relation.

$$F(e/d,\theta) = \frac{41.57M^{1/2}V_L \cos\theta}{e^{1/2}d}$$

where V_L is the limit velocity (minimum velocity for complete penetration.

Δd ...... Increase in diameter in inches of the forward bourrelet of the projectile as a result of the impact.

NO ...... Nose offset. For M79 projectiles the distance in inches the nose is displaced from the longitudinal axis of the projectile. For <u>flat-nosed projectiles</u> the maximum displacement of one side of the flat-nose with respect to the other along the longitudinal axis of the projectile.

E .... Projectile undeformed.
D .... Projectile deformed but not broken.
B .... Projectile broken into two or three pieces.
B(2) .... Projectile broken on secondary impact against butt structure.
X ...... Projectile shattered.

APPENDIX A BALLISTIC DATA

3" 15-lb. Flat-Nosed Projectiles

APL Impact No.	e in.	θ	m lbs.	V_S f.s.	V_S %	Pene.	V_R f.s.	Projectile Cond. Δd(in)	NO (in)	
				0° Obliquity						
				0"60 STS Carn. Ill. No. 125687						
2288	0"619	1°00'	14.95	509	94	Inc.1/2"	-	0.008	0.00	D
2287	0"619	0°10'	14.95	526	97	CP	123	0.008	0.00	D
			F = 35,000±200 (94%)							
				45° Obliquity						
2295	0"614	45°00'	14.95	487	69	CP	-	0.002	0.00	D
2294	0"615	45°00'	14.95	501	71	CP	-	0.003	0.00	D
2293	0"616	45°00'	14.95	566	80	CP	285	0.002	0.00	D
			F = 23,600 - (69%) Near Limit							
				1"5 STS Carn.-Ill. No. 40500						
				0° Obliquity						
2388	1"457	0°40'	14.90	588	64	Inc.1/4"	-	0"020	0.00	D
2389	1"455	0°30'	14.90	620	68	Inc.3/8"	-	0"022	0.00	D
2387	1"459	0°40'	14.90	647	71	CP	-	0"040	0.00	D
2390	1"459	1°00'	14.90	653	72	CP	84	0"032	0.00	D
			F = 28,600±200 (71%)							
				30° Obliquity						
2035	1"460	29°50'	15.30	657	63	Inc.1"75	-	0"007	0.00	D
2036	1"470	30°20'	15.30	688	65	Inc.1"0	-	0"006	0.00	D
2037	1"460	29°50'	15.30	812	78	CP	184	0"012	0.00	D
			F = 30,100±300 (74%)							

APPENDIX A. BALLISTIC DATA (CONT'D)

APL Impact No.	e in.	θ	m lbs.	V_S f.s.	V_S %	Pene.	V_R f.s.	Projectile Cond. Δd(in)	NO(in)	
				45° Obliquity						
2296	1"483	45°00'	14.95	1039	79	SIP 7"	-	-	-	D
2297	1"484	44°50'	14.90	1084	82	CP	-	0.010	0.06	D
				F = 32,600±200 (79%)						
				60° Obliquity						
2301	1"477	60°00'	14.90	1360	73	Inc.	-	0.003-0.024	0.06	D
2300	1"479	59°50'	14.95	1512	81	CP	-	0.009-0.059	0.13	D
2299	1"476	60°00'	14.90	1704	91	CP	-	0.022-0.110	0.25	D
				F = 31,000±500 (75%)						
				2"0 STS Carn.-Ill. No. X18305						
				0° Obliquity						
2024	2"013	1°20'	15.30	733	66	Inc.1"5	-	0.063	0.00	D
2023	2"013	1°00'	15.30	804	72	CP	-	0.076	0.00	D
2022	2"013	1°20'	15.30	993	89	CP	376	0.143	0.00	D
				F = 28,500±500 (67%)						
				20° Obliquity						
2025	2"014	20°00'	15.30	866	72	Inc.1"	-	0.041	0.25	D
2026	2"012	20°00'	15.30	953	79	Inc.1"5	-	0.046	0.25	D
2272	2"012	20°10'	14.90	998	82	Inc.2"0	-	0.068	0.25	D
2027	2"013	20°20'	15.30	1033	86	SIP 2"	-	-	-	-
2273	2"013	20°10'	14.90	1065	88	Inc. 2"75	-	0.070	0.25	D
				F = 37, 800±500 (88%)						

APPENDIX A. BALLISTIC DATA (CONT'D)

APL Impact No.	e in.	θ	m lbs.	V_S f.s.	V_S %	Pene.	V_R f.s.	Projectile Cond. Δd (in)	NO(in)	
				2"0 STS Carn.-Ill. No. F-1790						
				30° Obliquity						
2277	1"981	30°00'	14.90	1181	89	SIP 3"5	-	0.070	0.25	D
2276	1"981	29°50'	14.90	1253	95	CP	-	Projectile Broken.		
2275	1"980	29°50'	14.90	1271	97	CP	-	0.085	0.25	D
2274	1"979	29°50'	14.90	1435	109	CP	527	0.184	0.38	D
				F = 39,200±200 (90%)						
				40° Obliquity						
2279	1"979	40°00'	14.90	1376	90	Inc. 2"25	-	0.048	0.25	D
2281	1"980	40°30'	14.90	1400	91	Inc. 1"	-	Shattered		X
2381	1"979	40°00	14.90	1582	104	Partial	-	Base broken off		B
2382	1"980	40°00'	14.85	1628	107	SIP 3-3/4"	-	Nose upset.		D
				F = 48,000±500 (108%)						
				2"4 STS Carn.-Ill. No. 59533						
				0° Obliquity						
2282	2"429	0°20'	14.90	905	70	Inc. 3/8"	-	Shattered		X
2283	2"431	0°20'	14.95	1082	84	Inc.	-	Shattered		X
2284	2"429	0°10'	14.95	1139	89	SIP 3"	-	Nose broken off		X
2385	2"430	0°30'	14.90	1387	108	CP	-	0.360	-	D
				F = 41,000±1000 (93%)						
				3"20 Class B Carn.- Ill. No. X9021						
				0° Obliquity						
2028	3"20	0°20'	15.30	1077	69	Inc. 3/8"	-	Nose shattered.		
2029	3"20	0°10'	15.30	1389	89	Inc. 3/4"	-	Shattered.		
2384	3"20	0°00'	14.90	1642	104	Inc. 5/8"	-	Shattered.		
				F = 49,300 + (104%)						

APPENDIX B. BALLISTIC DATA

3" 15-lb. M79 AP PROJECTILES

APL Impact No.	e in.	θ	m. lbs.	V_S f.s	V_S %	Pene.	V_R f.s.	Projectile Cond. Δd (in)	Projectile Cond. NO(in.)	
			0"60 STS Carn.-Ill. No. 125687							
			0° Obliquity							
2286	0"618	0°20'	14.95	500	92	SIP8"	-	0.000	0.00	E
2285	0"617	0°20'	14.95	604	111	CP	-	0.000	0.00	E
			F = 34,300±200 (93%)							
			45° Obliquity							
2292	0"615	45°00'	14.95	574	81	Inc.2"	-	0.000	0.00	E
2291	0"614	45°00'	14.95	618	88	CP	173	0.000	0.00	E
2289	0"619	45°00'	15.05	626	90	CP	184	0.000	0.00	E
			F = 28,800±300 (84%)							
			60° Obliquity							
2219	0"600	60°10'	14.95	958	105	Inc.	-	0.000	-	B(2)
2220	0"603	59°50'	14.95	976	108	Inc.	-	0.000	0.00	E
2221	0"609	60°00'	15.10	994	109	Inc.	--	0.000	0.00	E
2218	0"600	60°10'	14.85	1016	111	CP	-	0.000	0.00	E
			F = 34,700±300 (110%)							
			1"5 STS Carn.-Ill. No. 40500							
			0° Obliquity							
2156	1"478	0°50'	14.85	1001	109	Inc.3"	-	0.000	0.00	E
2157	1"475	1°00'	14.95	1032	113	Inc.4"	-	0.000	0.00	E
2158	1"478	1°10'	14.95	1050	114	CP	76	0.000	0.00	E
2173	1"470	0°50'	14.95	1053	115	SIP 8"	-	---	--	E
			F = 46,500±200 (114.5%)							
			30° Obliquity							
1505	1"464	29°50'	14.95	1061	101	SIP 6"	-	0.000	0.00	E
1506	1"456	29°40'	14.90	1089	103	CP	226	0.000	0.00	E
			F = 41,200±300 (101%)							

APPENDIX B BALLISTIC DATA (CONT'D)

1"5 STS Carn.-Ill. No. 40915 (Same heat as 40500)

APL Impact No.	e in.	θ	m lbs.	V_S f.s	V_S %	Pene.	V_R f.s.	Projectile Cond. Δd(in.)	NO(in.)	
				45° Obliquity						
2159	1"500	45°10'	14.95	1339	100	Inc.1-1/2"	-	Broken		B
2160	1"503	45°20'	14.95	1408	105	Inc. 1"	-	Broken		B
2161	1"500	45°05'	14.95	1473	110	Partial	-	Nose shattered		B
			F =	45,500 (110%)						
				55° Obliquity						
2208	1"511	55°00'	15.00	1949	118	CP	-	Shattered		X
2206	1"494	54°55'	14.95	2016	123	Partial	-	Shattered		X
2207	1"497	55°10'	15.00	2115	128	CP	-	Shattered		X
			F = About 50,000 (120 %)							
			2"0 STS Carn.-Ill. No. X18305							
				0° Obliquity						
1654	2"006	0°10'	15.00	1265	113	CP	359	0.000	0.00	E
			F = 46,100±400 (108%)							
				20° Obliquity						
1655	2"005	21°00'	15.00	1248	103	CP	154	0.000	0.00	E
			F = 44,000±300 (102%)							
				30° Obliquity						
1656	2"004	31°00'	14.80	1303	96	CP	87	0.005	0.06	D
			F = 42,100±200 (96%)							
				40° Obliquity						
1647	2"004	39°50'	15.05	1539	101	Inc.1"75	-	0.029	0.50	D
1648	2"004	39°50'	15.00	1591	104	Inc.1"75	-	--	--	B(2)
1649	2"003	39°50'	15.05	1652	108	CP	783	0.016	0.18	D
			F = 47,400±800 (106%)							

APPENDIX B BALLISTIC DATA (CONT'D)

APL Impact No.	e in.	θ	m lbs.	V_S f.s.	V_R %	Pene.	V_R f.s.	Projectile Cond. Δd(in.)	NO(in.)	
			2"4 STS Carn.-Ill. No. 59533 0° Obliquity							
2211	2"430	0°30'	14.95	1361	106	Inc.5"	-	0.000	0.00	E
2210	2"430	0°40'	14.95	1408	110	CP	219	0.000	0.00	E
2209	2"430	0.40'	15.00	1459	114	CP	-	0.000	0.00	E
			F = 47,900±200 (108%)							
			3"0 Class B Carn.-Ill. No. 85187 0° Obliquity							
1787	3"055	0°30'	15.05	1587	105	CP	301	0.000	0.00	E
			F = 48,100±300 (103%)							

APPENDIX C BALLISTIC DATA

DECK STRUCTURE
3/8", 1"5 and 1/4" STS spaced 2 feet apart in that order at 30° obliquity.

APL Impact No.	Total e in.	θ	m lbs.	Vs f.s.	Pene. 3/8"	Pene. 1"5	Pene. 1/4"	Est. V_L * f.s.	V_L %	V_R ** f.s.
				3" M79 AP Projectile						
2302	2"09	30°00'	14.95	1105	CP	SIP	--	1130	82	--
						F = 36,400				
				15-lb.-Flat-Nosed Projectile						
2302	2"10	29°20'	14.95	812	CP	Inc.1"5	--	--	--	--
2304	2"10	29°20'	14.90	940	CP	CP	CP	880	64	234
							F = 28,400			

* V_L - Limit velocity for structure.
** V_R = Residual velocity after penetrating entire structure

Limit for flat-nose = 78% of limit for M79

APPENDIX D BALLISTIC DATA

CAPPED FLAT NOSED PROJECTILES.

APL Impact No.	e in.	θ	m lbs.	V_S f.s	V_S %	Pene.	V_R f.s	Proj. Cond.
	1"5 STS Carn.-Ill No. 40500 at 30° Obliquity							
	15-lb. Flat-Nosed Projectile (5% Welded Cap)							
2040	1"480	30°00'		866	83	3/4"	-	Nose chipped
	15-lb. Flat-Nosed Projectile (5% Grooved Cap)							
2041	1"475	30°00'		872	83	2"	-	Nose chipped.
	15-lb. Flat-Nosed Projectile (15% Welded Cap)							
2038	1"474	29°50'		902	86	3/4"	-	Nose chipped.
	15-lb. Flat-Nosed Projectile (15% Grooved Cap)							
2039	1"478	29°50'		866	83	3/4"	-	Nose chipped
	2"0 STS Carn. - Ill. No. X18305 at 20° Obliquity							
2033	2"009	20°10'		1085	90	3/4"	-	Body Bent.
	15-lb. Flat-Nosed Projectile (15% Grooved Cap)							
2034	2"009	20°00'		1077	90	1-3/8"	-	Nose chipped.
	3"0 Class B Carn. - Ill No. X9021 at 0° Obliquity.							
	15-lb. Flat-Nosed Projectile (15% Welded Cap.)							
2030	3"20	0°20'		1396	88	3/8"	-	Shattered.
	15-lb. Flat-Nosed Projectile (15% Grooved Cap)							
2031	3"20	1°10'		1392	89	1"	-	Shattered.

APPENDIX E - CALCULATION OF RESIDUAL VELOCITIES IN MULTIPLE STRUCTURES.

In determining the efficiency of a projectile it is usually of prime importance to know how it will behave against divided structures. The problem is complicated by the action of successive plates in removing windshields and caps and by introducing yaw in the projectile flight. The following development ignores these factors and consideration is given only to a projectile which penetrates the structure in an unyawed and undamaged condition.

Consider the impact of a projectile having velocity V_S against a multiple structure consisting of N plates so spaced that the projectile completely clears one plate before striking the next one. Let the limit velocities for the successive plates be designated by V_{L1}, V_{L2}, V_{L3}, ... V_{LN} and the residual velocities after penetrating each plate by V_{R1}, V_{R2}, V_{R3} ....V_{RN}. Now it has been established for major caliber projectiles that the relation between V_S, V_L and V_R for the attack of homogeneous plate is of the following form.

$$V_R^2 = S(V_S^2 - V_L^2) \qquad (3)$$

where S is independent of velocity for a given test condition but depends on e/d, obliquity and projectile nose shape. Values of S are known for a great many test conditions, and usually it has a value approaching unity. Knowing the limit velocities and values of S for each plate the residual velocity after penetration of any set of plates can be calculated. The limit velocity for the set of plates can be calculated by setting the final residual velocity equal to zero and solving for V_S, the striking velocity satisfying that condition.
Thus for the first plate:

$$V_{R1}^2 = S(V_S^2 - V_{L1}^2)$$

Since V_{R1} becomes the striking velocity for the second plate and extending to a series of plates

$$V_{R2}^2 = S_2(V_{R1}^2 - V_{L2}^2)$$

$$V_{R3}^2 = S_3(V_{R2}^2 - V_{L3}^2)$$

$$V_{RN}^2 = S_N(V_{R(N-1)}^2 - V_N^2) \qquad (4)$$

Since, usually we are interested only in the final residual velocity we can eliminate the intermediate residual velocities by substitution. Making the substitutions and rearranging we get

$$V_{R2}^2 = S_1S_2(V_S^2 - V_{L1}^2) - S_2V_{L2}^2$$

$$V_{R3}^2 = S_1S_2S_3(V_S^2 - V_{L1}^2) - S_2S_3V_{L2}^2 - S_3V_{L3}^2$$

$$V_{RN}^2 = S_1 \ldots S_N(V_S^2 - V_{L1}^2) - S_2 \ldots S_N V_{L2}^2$$

$$-S_3 \ldots S_N V_{L3}^2 \ldots\ldots - S_N V_{LN}^2 \qquad (5)$$

The limit velocity of a structure consisting of N plates is the value of V_S for which V_{RN} is equal to zero. Therefore setting V_{RN} equal to zero and solving for V_S we get the limit velocity, V_L, for the structure in terms of the limit velocities and values of S for each member.

$$V_L^2 = V_{L1}^2 + \frac{V_{L2}^2}{S_1} + \frac{V_{L3}^2}{S_1S_2} + \ldots \frac{V_{LN}^2}{S_1S_2S_3 \ldots S_{N-1}} \qquad (6)$$

Rearranging equation (5) and using equation (6) an expression is obtained which permits the calculation of the limit of a structure through the measurement of the striking and residual velocities.

$$V_L^2 = V_S^2 - \frac{V_{RN}^2}{S_1 \ldots\ldots S_N} \qquad (7)$$

To use expression (7) it is noted that values of the constanes $S_1 \ldots\ldots S_N$ are necessary. Let us apply equation (7) to the divided armor structure of the subject report and compare the result so obtained with the result calculated from equation (6). The following tables gives the values of constants and measured limits of individual plates. (Limits are not available for plate of 1/4" and 3/8" gauge against flat-nosed projectiles. The slope values in parentheses are estimates).

	3/8"		1"5		1/4"	
	S_1	V_{L1}	S_2	V_{L2}	S_3	V_{L3}
M79	1.0	320	1.0	1070	1.0	250
Flat Nose	(.9)	--	.6	--	(.95)	--

From the results for flat-nosed projectiles against the divided structure we have for a striking velocity of 940 f.s., a residual velocity of 234 f.s. Applying equation (7), the limit velocity comes out to be 881 f.s.

The limit velocity for the divided armor structure against the M79 was found experimentally to be 1130 f.s. By substitution of values from the above table for M79 projectiles in equation (6) one gets 1145 f.s. which is in agreement with the experimental result.