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U. S. NAVAL PROVING GROUND

DAHLGREN, VA.

REPORT NO. 7-43

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PENETRATION OF HOMOGENEOUS ARMOR BY 3-INCH FLAT-NOSED PROJECTILES.

CLASSIFICATION (CANCELLED) (~~CHANGED TO~~) Unclassified BY AUTHORITY OF NavOrd Itr 52/1178; PAH 5511/10/31/73

ON 6/24/76 (DATE) B. Bragler (SIGNATURE) (RANK)

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[redacted]

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PENETRATION OF HOMOGENEOUS ARMOR BY 3-INCH FLAT-NOSED PROJECTILES.

APPROVED:

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CAPTAIN, USN,
INSPECTOR OF ORDNANCE IN CHARGE.

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P R E F A C E

AUTHORIZATION

This study was authorized in Bureau of Ordnance letter NF9/A9(Re3) dated January 9, 1943 as part of N.P.G. Research Project APL-1.

OBJECT

This report describes the results of firing 3-inch flat-nosed projectiles at homogeneous armor and discusses the energy absorption in the punching type of failure which occurs in such firing.

SUMMARY

3-inch flat-nosed projectiles penetrated homogeneous armor by a high speed punching action, dislodging a disc-like punching from the plate at all obliquities tested from 0° to 60°. The residual velocity of the projectile and, in some cases, the velocity of the dislodged punching were measured.

The limit energy required for complete penetration by 3-inch flat-nosed projectiles was found to range from 90 per cent to 22 per cent of the energy required by standard projectiles of the same mass against the same plates for the same test conditions. The largest differences were noted for 1"36 STS (e/d - 0.45) at 0° (33%) and 0"73 STS (e/d - 0.24) at 60° (22%). The extremely small energy required by flat-nosed projectiles to penetrate homogeneous armor of good, standard quality is explained by the very small volume of armor that is subject to strain. Only that plate material in the immediate vicinity of the edge of the hole is deformed even at 60° obliquity, though at any oblique impacts the punching is somewhat bent in addition.

The energy absorption at 0° obliquity increases quite rapidly with striking velocity for the flat-nosed projectiles whereas it is essentially constant and equal to that at the limit velocity for projectiles producing the more usual piercing type of failure.

Limit energy and energy absorption were found to depend on the mass in the case of flat-nosed projectiles, the limit energy and the increase of energy absorption with velocity both being greater for the lighter projectiles.

In view of the extraordinary success of flat-nosed projectiles in penetrating plates at e/d values slightly less than 0.5, it is recommended that the tests be extended to A.P. bombs where conditions are essentially similar.

In view of the damage to the projectiles which results when e/d is greater than 0.5, it is recommended that various designs of caps be manufactured for flat-nosed projectiles and tested at the Proving Ground against both Class B and Class A plate.

CONTENTS

LIST OF FIGURES

I INTRODUCTION.

In the course of firing at the Naval Proving Ground, it was observed that failure by punching occurred in STS and Class B armor under two conditions, (1) when the plate was so thin that the projectile cap was undeformed by the impact, and (2) when the projectile flattened on impact. Since the caps producing the punchings were rather blunt, the observations suggested that punching could be produced in homogeneous armor by flat-nosed projectiles. This report deals with the high speed punching produced in homogeneous armor by uncapped 3-inch flat-nosed projectiles which did not deform appreciably on impact. The results will be of interest in investigations of the behavior against Class A armor since that type of plate invariably fails by a punching action.

II MATERIAL AND METHODS.

Plate:

1"36 STS Carnegie-Illinois Plate No. 107238 (Tensile Strength = 119,300 p.s.i.)

1"94 STS Carnegie-Illinois Plate No. 87547 (Tensile Strength - 130,000 p.s.i.)

0"73 STS Carnegie-Illinois Plate No. 83880 (Tensile Strength - 121,800 p.s.i.)

0"73 STS Carnegie-Illinois Plate No. 694385 (Tensile Strength - 130,300 p.s.i.)

Projectiles:

15-lb. Frankford Arsenal M79 A.P. projectile.

7.5-lb. Flat-nosed projectile supplied by Frankford Arsenal.

11-lb. Flat-nosed projectile made at APL by sawing the nose off M79 A.P. projectile.

15-lb. Flat-nosed projectile supplied by Frankford Arsenal.

Test Conditions.

Limit velocities were obtained against the 0"73 STS plate (No. 83880) at 0° obliquity using the M79 and the 11-lb. flat-nosed projectiles.

Limit velocities were obtained at 60° obliquity for the 0"73 STS plate (No. 694,385) with the M79 and the 15-lb. flat-nosed projectiles.

Limit velocities and residual energy measurements were taken against the 1"36 STS plate at 0° obliquity with all four projectiles. Only limit velocities were obtained at 30° obliquity for the M79 and the 11-lb. flat-nosed projectiles.

Method

Striking velocities were measured by means of the regular photographically recording oscillograph using two solenoids connected in series and a magnetized projectile. Residual velocities of projectiles were measured using two contact screens behind the plate in a manner developed for routine residual velocity measurements at 3-inch scale. The screens were successively shorted by the projectile in passing through them. The residual and striking velocities are obtained on the same record. In the contact screens the contact area separation is about four inches; thus small fragments and punchings will not produce a short circuit of the screens. To measure the velocities of the punchings, an additional pair of screens with a separation of contact areas of 1-1/2 inches was used. These screens were placed in front of the projectile residual velocity screens so that the velocity of the punching was given by the first pair and the residual velocity of the projectile by the second pair. Cards incorporated in the screens gave the trajectory of the projectile between screens as well as its orientation so that the true distance of travel and the correction for tumble could be made.

Yaw cards placed in front of the plate did not reveal any measurable yaw for the incident projectiles.

III RESULTS.

In the analysis of the results, the following terms are defined:

$$F^2 \text{ (Residual)} = F_R^2 = \frac{1728 M V_R^2 \cos^2\theta}{ed^2}$$

$$F^2 \text{ (Punching)} = F_P^2 = \frac{1728 M_P V_P^2 \cos^2\theta}{ed^2}$$

$$F^2 \text{ (Striking)} = F_S^2 = \frac{1728MV_S^2\cos^2\theta}{ed^2}$$

$$F^2 \text{ (Limit)} = F_L^2 = \frac{1728MV_L^2\cos^2\theta}{ed^2}$$

The various symbols used have the significance shown below:

M = mass of projectile in pounds.

M_P= mass of the punching in pounds.

V_R= residual velocity of the projectile in feet per second.

V_P= velocity of the punching in feet per second.

V_S= striking velocity of the projectile in feet per second.

V_L= limit velocity of the projectile in feet per second. (The minimum velocity the projectile must have to pass completely through the plate.)

e = plate thickness in inches at point of impact.

θ = angle between plate normal and projectile line of flight.

d = projectile diameter in inches.

$F(e/d,\theta)$ = the Thompson F-coefficient, the square root of F_L^2.

The Thompson coefficient, $F(e/d,\theta)$, is computed for all limit shots. It is more convenient to use the square of this coefficient, which contains a correction for small variations in angle of attack and in plate thickness, and which is directly related to energy, than to calculate true energy in most cases. For this reason F^2 has also been calculated for the projectile after penetration and for the punching. These F^2 (residual) values have been plotted as ordinates and F^2 (striking) as abscissae to indicate the dependence of energy absorption on the variation of striking energy.

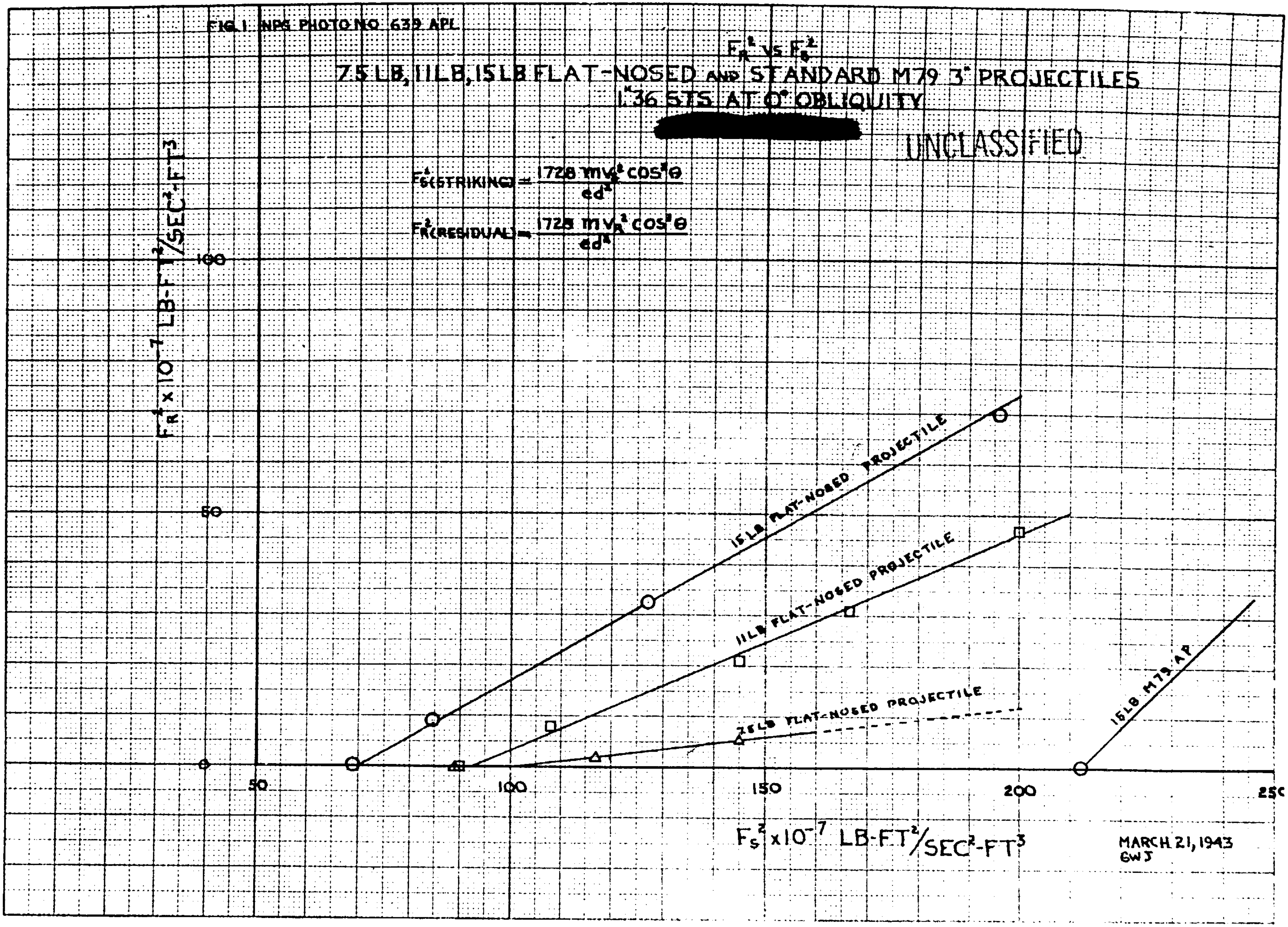
FIG. 1 NPG PHOTO NO. 639 APL
F_R^2 vs F_S^2
7.5 LB, 11 LB, 15 LB FLAT-NOSED AND STANDARD M79 3" PROJECTILES
1.36" STS AT 0° OBLIQUITY
[redacted]
UNCLASSIFIED
$F^2_{S(STRIKING)} = \frac{1728\, m v_S^2 \cos^2\theta}{e d^2}$
$F^2_{R(RESIDUAL)} = \frac{1728\, m v_R^2 \cos^2\theta}{e d^2}$
$F_R^2 \times 10^{-7}$ LB-FT²/SEC²-FT³
100
50
50
100
150
200
250
15 LB FLAT-NOSED PROJECTILE
11 LB FLAT-NOSED PROJECTILE
7.5 LB FLAT-NOSED PROJECTILE
15 LB M79 AP
$F_S^2 \times 10^{-7}$ LB-FT²/SEC²-FT³
MARCH 21, 1943
GWJ

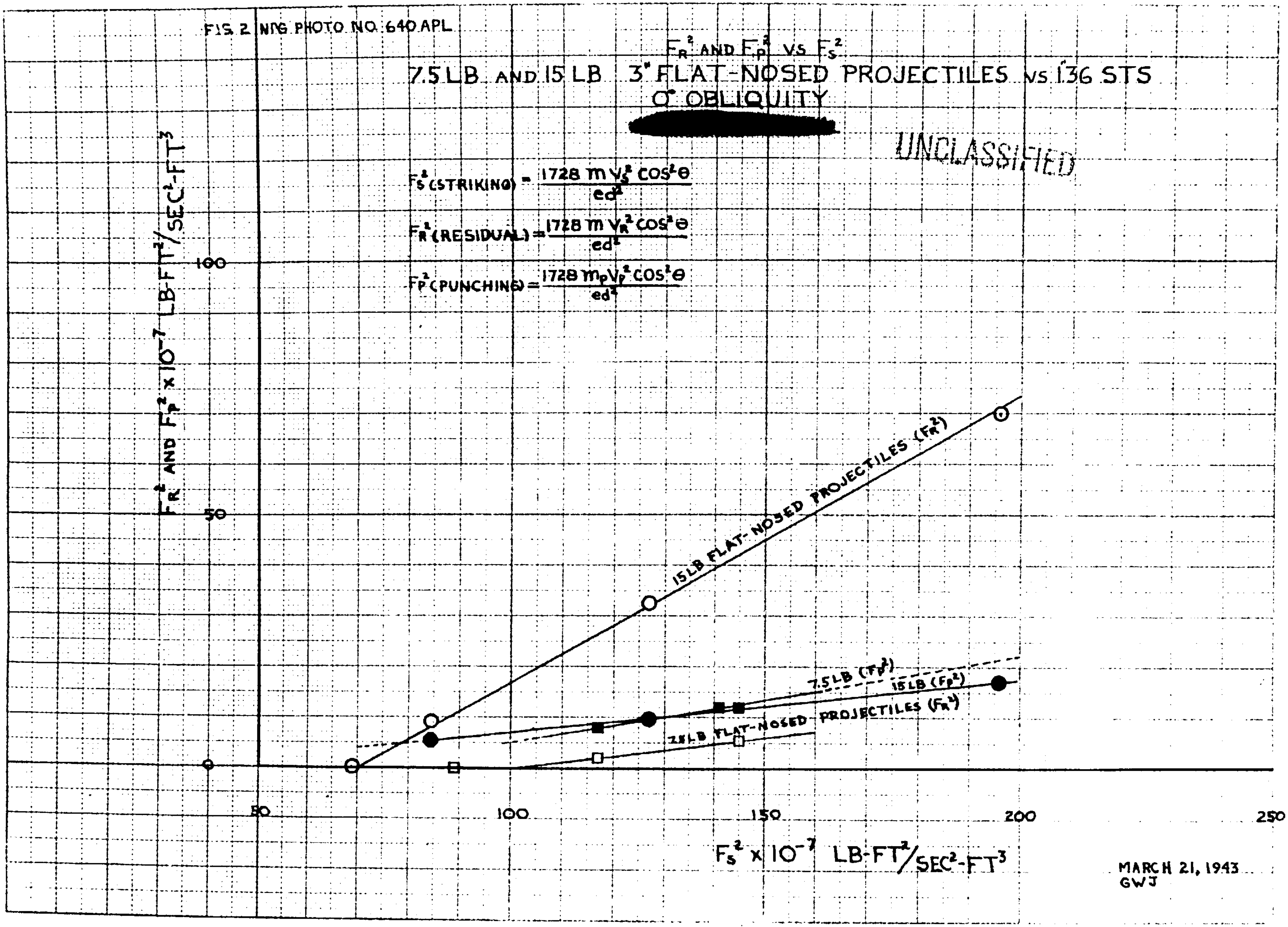
FIG. 2 NRG PHOTO NO. 640 APL
F_R^2 AND F_P^2 VS F_S^2
7.5 LB AND 15 LB 3" FLAT-NOSED PROJECTILES VS 1.36 STS
0° OBLIQUITY
[redacted]
UNCLASSIFIED
F_S^2 (STRIKING) = $\frac{1728\, m V_S^2 \cos^2\theta}{e d^2}$
F_R^2 (RESIDUAL) = $\frac{1728\, m V_R^2 \cos^2\theta}{e d^2}$
F_P^2 (PUNCHING) = $\frac{1728\, m_P V_P^2 \cos^2\theta}{e d^2}$
15 LB FLAT-NOSED PROJECTILES (F_R^2)
7.5 LB (F_P^2)
15 LB (F_P^2)
7.5 LB FLAT-NOSED PROJECTILES (F_R^2)
F_R^2 AND F_P^2 x 10^{-7} LB-FT²/SEC²-FT³
100
50
50
100
150
200
250
F_S^2 x 10^{-7} LB-FT²/SEC²-FT³
MARCH 21, 1943
GWJ

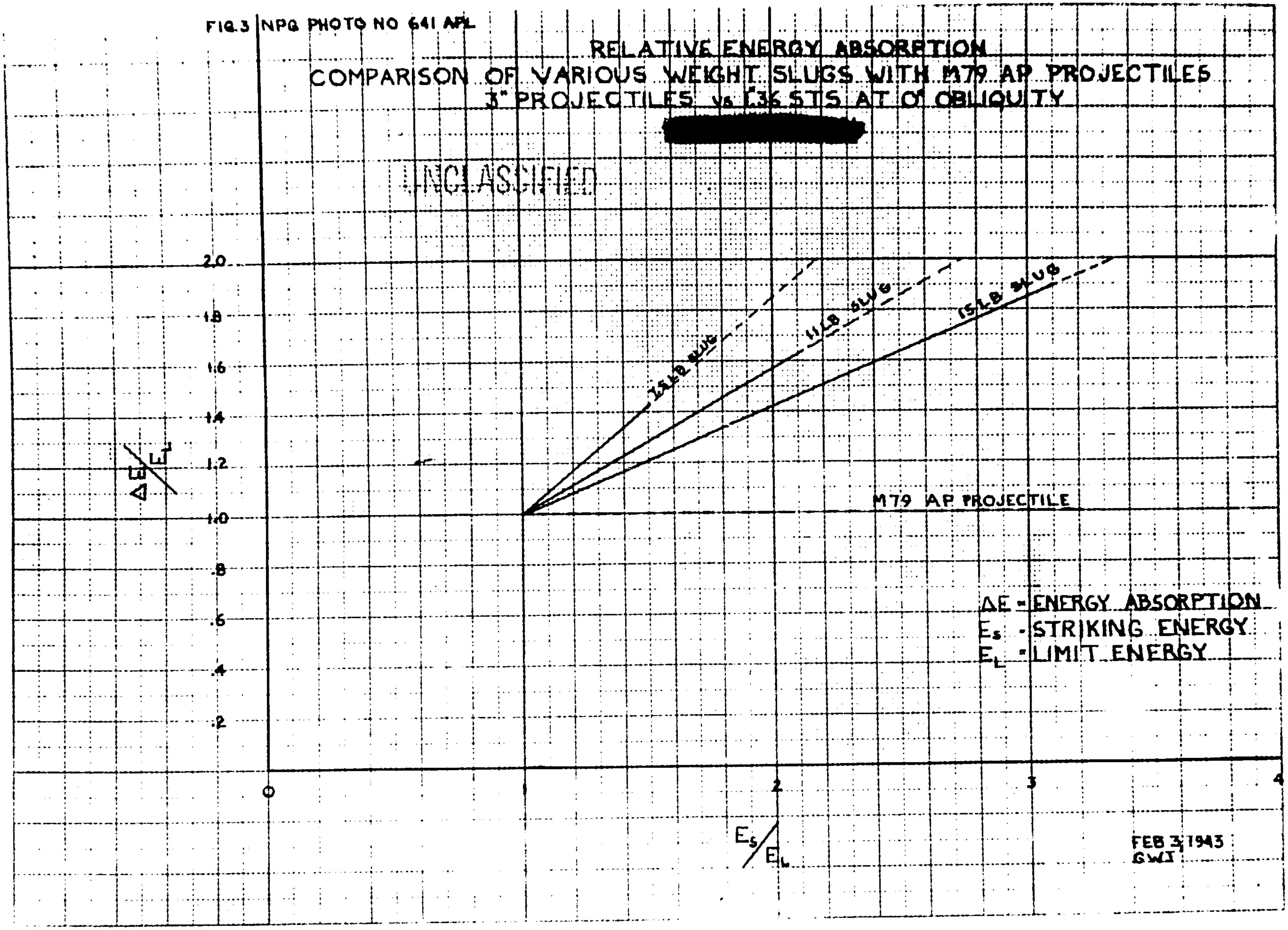
FIG.3 NPG PHOTO NO 641 APL
RELATIVE ENERGY ABSORPTION
COMPARISON OF VARIOUS WEIGHT SLUGS WITH M79 AP PROJECTILES
3" PROJECTILES vs 1.36 STS AT 0° OBLIQUITY
[redacted]
UNCLASSIFIED
25 LB SLUG
11 LB SLUG
15 LB SLUG
M79 AP PROJECTILE
ΔE/E_L
E_s/E_L
ΔE - ENERGY ABSORPTION
E_s - STRIKING ENERGY
E_L - LIMIT ENERGY
FEB 3 1943
GWI

These plots turn out to be straight lines, with the equation $F_R^2 = S(F_S^2 - F_L^2)$, where S is the slope of the line. The intercept of this line on the F_S^2 - axis is a measure of the limit energy, F_L^2, to penetrate the plate with no residual energy. A slope of unity for the line indicates that the energy absorbed in penetrating the plate is independent of the striking energy, while slopes of greater or less than unity indicate respectively that energy absorption decreases or increases with striking energy.

In Fig. 1 are shown the lines obtained for flat-nosed projectiles of various weights, together with, for comparison, the corresponding line for a 15-lb. M79 A.P. projectile. In Fig. 2, the lines for 15-lb. and 7.5-lb. flat-nosed projectiles are repeated, together with the lines obtained by plotting the residual energies of the punchings dislodged by these projectiles at various projectile striking energies. The punching lines have positive values for $F_S^2 = F_L^2$ and small slopes indicating that the punchings are first dislodged, at or even a little below the limit striking energy of the projectile, with a considerable energy, and that this energy increases only slowly with the projectile striking energy. The projectile lines have slopes considerably less than unity, indicating a fairly rapid increase in energy absorption by the plate with increase in striking energy. That the kinetic energy of the punchings does not depend on the mass of the projectile is shown by observations on 7.5 and 15-lb. flat-nosed projectiles.

These increases in energy absorption may also be demonstrated graphically by plotting the energy absorption in units of the limit energy, E/E_L, as a function of striking energy, also in units of the limit energy, E_S/E_L. The derivation in Appendix B indicates that these plots should also be straight lines with the equation

$$\Delta E/E_L = (1 - S)\ E_S/E_L + S.$$

These lines have the slope (1 - S), and are thus horizontal when S equals unity (constant energy absorption), and have positive slopes, as in the present case, when the energy absorption increases with striking energy. These relative-energy absorption curves for the present data are shown in Fig. 3. It will be seen from these curves, as well as from those of Fig. 1, that for the flat-nosed projectiles the energy absorbed by the plate increases rapidly with projectile striking-energy, and does so the more rapidly the lighter the slug.

The results, which are given in detail in Appendix A, are summarized below in Table I. The true limit energies,

E_L, given in column four, were calculated for punching failures and are listed in the following table. The last column in the table lists the limit energies obtained with flat-nosed projectiles as percentages of the limit energies obtained with the 3-inch M79 projectile.

TABLE I

SUMMARY OF BALLISTIC DATA.

0° Obliquity

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft.sec.	E_L ft.lbs.	% M79
0.24	0"73	15-lb. M79	37,100±200	589	80,000	100
		11-lb. Slug	35,800±400	663	73,000	91
0.45	1"36	15-lb. M79	46,000±400	996	230,000	100
		7.5-lb. Slug	31,900±500	977	111,000	48
		11-lb. Slug	30,500±300	771	101,000	44
		15-lb. Slug	26,600±300	576	77,000	33

30° Obliquity

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft.sec.	E_L ft.lbs.	% M79
0.45	1"36	15-lb. M79	40,900±300	1023	243,000	100
		11-lb. Slug	31,000±300	905	140,000	58

60° Obliquity

e/d	Plate Gauge	Projectile	F(e/d,θ)	V_L ft.sec.	E_L ft.lbs.	% M79
0.24	0"73	15-lb. M79	43,600±400	1384	445,000	100
		11-lb. Slug	20,300±300	644	96,600	22

Values of Slope (S)

1"36 STS at 0° Obliquity

Projectile	Slope
3-Inch M79	1.0*
7.5-lb. Slug	.15
11-lb. Slug	.43
15-lb. Slug	.58

* From data against 1"2 STS.

NPG PHOTO NO. 381 (APL) - Plate 139 (C.I. 14 [illegible]) at 0° obl. FRONT VIEW [illegible] pro-
jectiles, with and without noses cut off at bourrelet, at 0° obl.
See NPG Photo 3[illegible] for back view and data on impacts 868-371.

B.I.No.	"e"	"θ"	S.V. f.s.	Pene.	R.V. f.s.	Proj.Wt.	Condition
864-APL	1".36	0°00'	1117	Comp.	-	Slug 11.25-lb.	Slightly swelled.
865	1".36	[illegible]	1021	"	442	" 11.20-lb.	Lost wedge-shaped piece.
866	1".35	0°40'	934	5-1/8"	-	M-79 15.10	Undeformed.
867	1".35	1°5[illegible]	2003	Comp.	-	" 14.85	"

20 October, 194[illegible].

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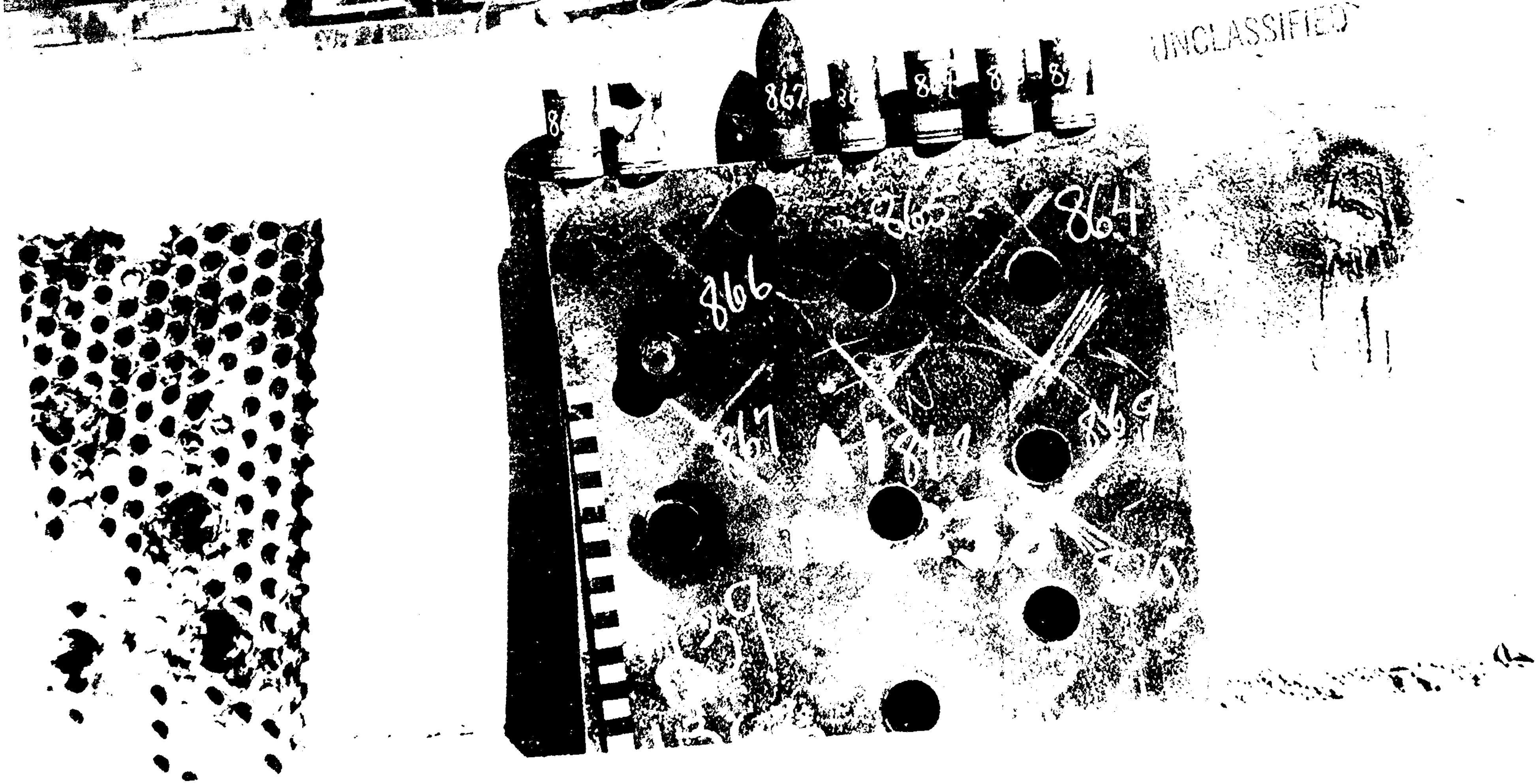

[illegible] PHOTO NO. 382 (APL) – Plate [illegible] [illegible]-pro-
jectile, with and without [illegible] cut off [illegible] bourrelet, [illegible] BACK VIEW. See
NPG Photo 382 APL for front view and data on impacts [illegible]7.

B.I. No.	"e"	"θ"	S.V., f.s.	Pene.	R.V., f.s.	Proj. Wt.	Condition
868-APL	1"35	1°10'	951	Comp.	325	Slug 11.25-lb.	Slightly chipped.
869	1"36	0°30'	897	"	–	" 11.05	" "
870	1"36	1°40'	853	"	–	" 11.80	" "
871	1"36	3°10'	796	"	240	" 11.30	" "

21 October, 1942

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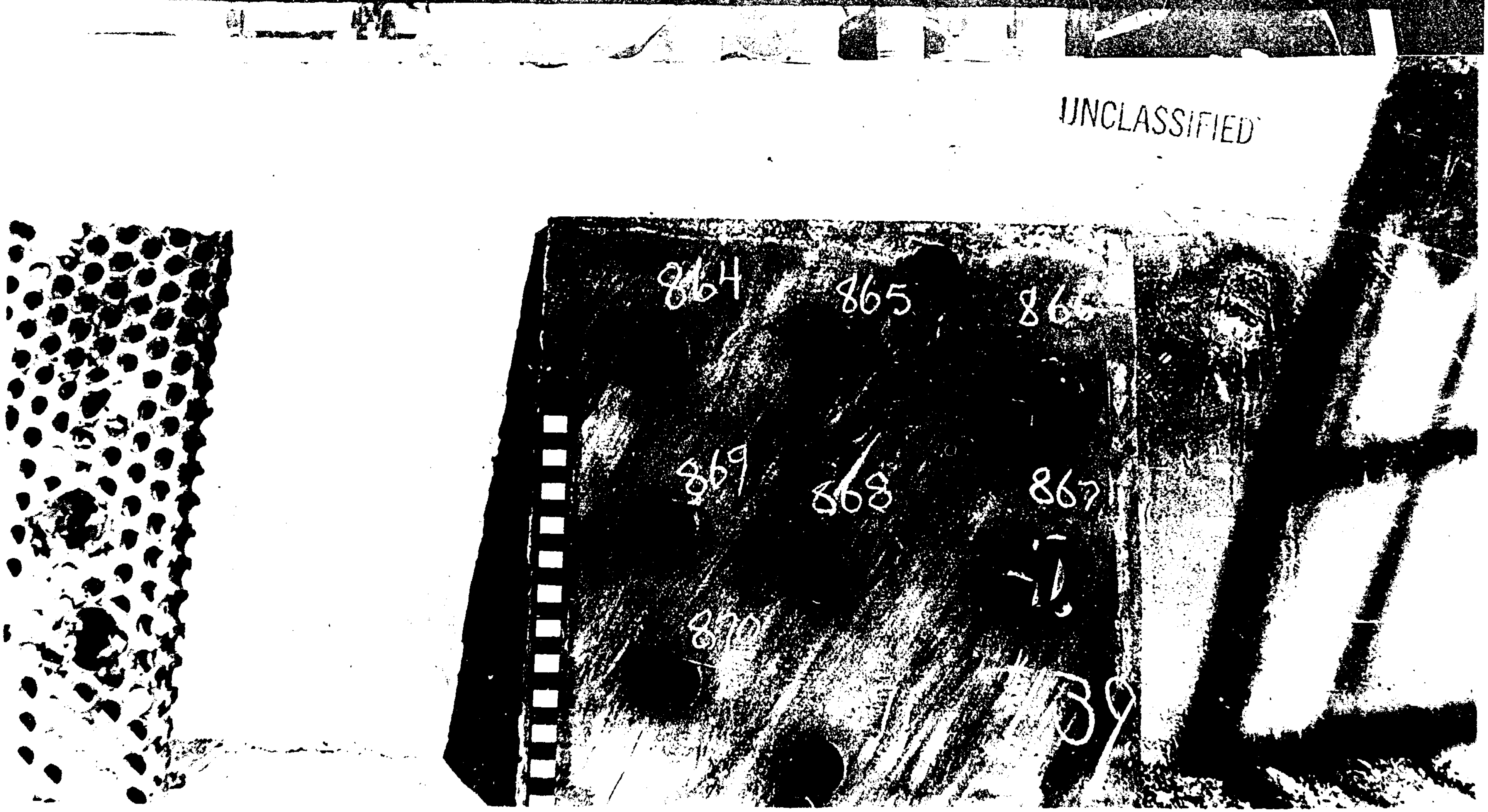


IV DISCUSSION.

The most striking result of this firing is the observation of the extremely low limit energy required to punch a hole in a plate by the use of a flat-nosed projectile as compared with the energy required to pierce a hole of the same size by the use of a pointed projectile. For example, it will be seen that to punch a hole in a 1"36 plate (e/d - 0.45) at 0° requires about one-third as much energy, and in a 0"73 plate (e/d - 0.24) at 60° less than one fourth as much energy, as to pierce a hole with the M79 projectile under the same conditions.

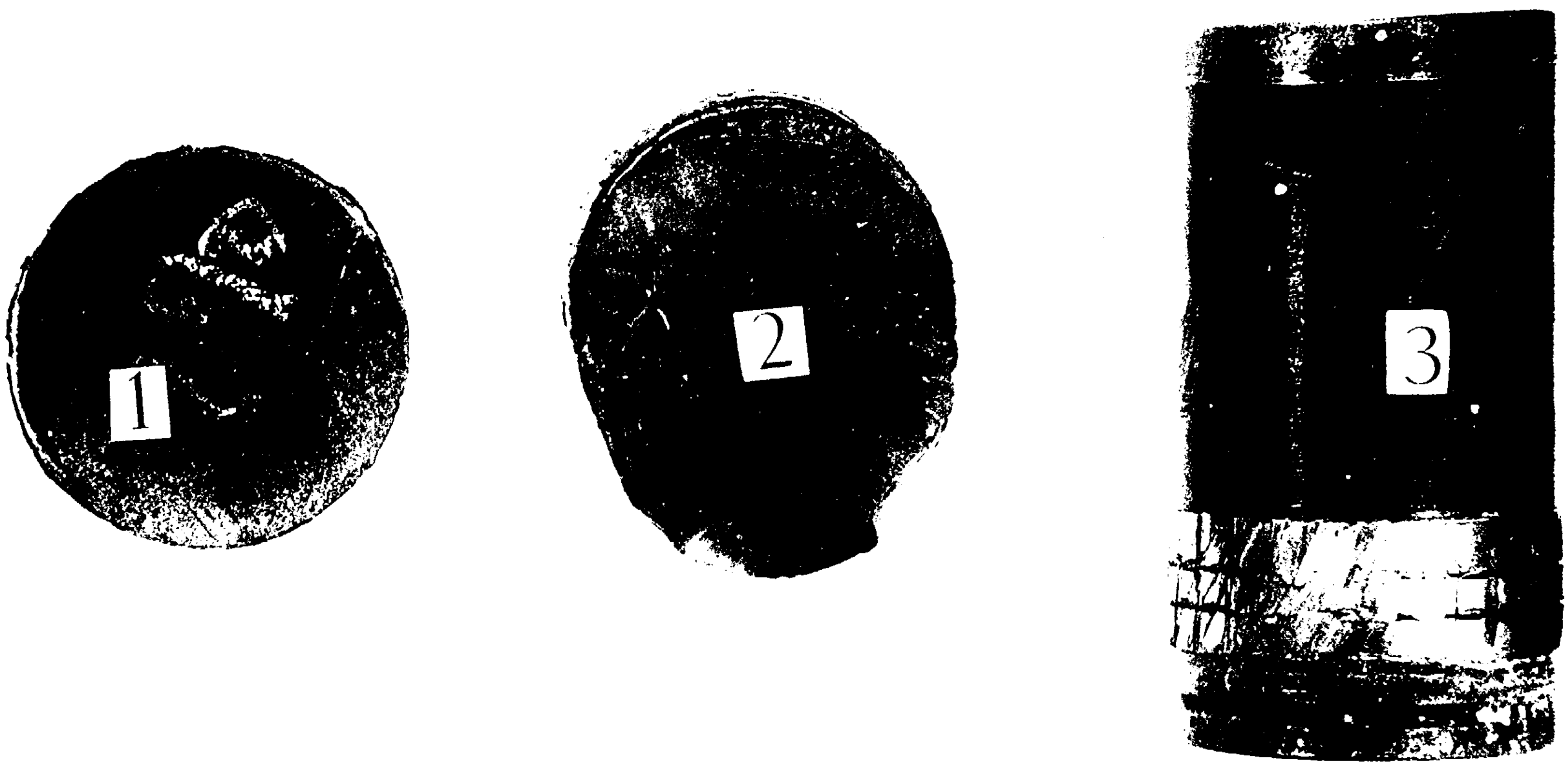
This large energy difference in favor of punching is undoubtedly accounted for by the extremely small volume of armor that is worked in the process of punching compared with the worked volume in the case of piercing with more pointed projectiles, for in punching only the plate material in the immediate vicinity of the edge of the hole and of the punching is deformed or worked. There is little or no dishing of the plate, except for very thin plate, even at high obliquities, and the punching itself shows little evidence of working, except for some bending of the punched disk at high obliquities. Dishing involves stretching and bending of the plate material and may consume a considerable part of the absorbed energy of plate piercing, especially in the case of greatly overmatched plate. The greatest economy of energy in punching however is realized in dislodging the punching intact and relatively undistorted. In the case of ordinary uncapped A.P. projectiles the energy absorption results chiefly from the cold working and plastic deformation of virtually the entire mass of the armor that occupied the site of the hole and working less drastically an even larger volume of material surrounding the hole.

By reference to Fig. 4, NPG Photo. No. 381 (APL) and Fig. 5, NPG Photo. No. 382 (APL) the difference in appearance between plate failure by pointed and flat-nosed projectiles is apparent. Impacts Nos. 866-867 show the typical plate failure by pointed projectiles at low obliquity and the other impacts are characteristic of flat-nosed projectile penetrations. There was considerable dishing associated with the pointed projectile impacts which is not very clearly shown by the photographs.

The limit energy of punching is seen to be relatively somewhat higher for the lighter projectiles, which in part may be due to the greater swelling of the end of these projectiles. This deformation in all cases increased with striking velocity and since the lighter projectiles necessarily had to be fired at higher velocities their deformation was somewhat greater. With due allowance for

[illegible] - Punching [illegible] produced by impact of flat nosed projectile [illegible] with nose cut off.
1. Punching at [illegible] obliquity.
2. Punching at 30° obliquity.
3. 3" M-79 with nose cut off.
11 November, 1942.

UNCLASSIFIED



NPG PHOTO NO. 553 (APL) - High Speed Punching. 7"5 lb. Flat nosed projectiles vs. 1"36 STS at 0° obliquity. Projectiles and punchings. See NPG Photo No. 556 APL.

B.I.No.	e	m(proj.)	m(punch)	V_S	V_R	$V_{(Punch)}$	Pene.
1139 APL	1"366	7.36	-	925	-	-	Inc.
1140	1"365	7.41	2.78	1061	70	454	CP
1141	1"367	7.42	4.30	1157	-	555	CP
1142	1"366	7.41	3.31	1178	227	508	CP
1143	1"366	7.39	2.90	1059	142	443	CP

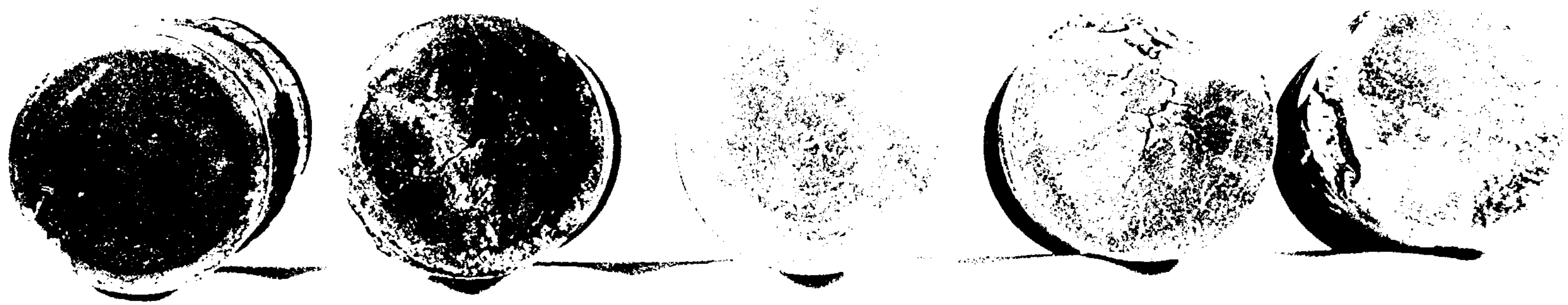
9 January, 1945

NPG PHOTO No. 556 [illegible] - High Speed Punching. 7.5 lb. Flat Nosed Projectiles vs. 1"36 STS at [illegible] obliquity. Nose of Projectiles after impact. End view.

H.T.No.	e	m(proj.)	m(punch)	Vs	V_R	V_R'	Zone.
1139 APL	1"366	7.36	–	925	–	–	Inc.
1140	1"365	7.41	2.78	1061	70	254	CP
1141	1"367	7.44	2.[illegible]	1147 }	–	[illegible]	[illegible]
1142	1"366	7.41	[illegible].31	1173	[illegible]	[illegible]8	CP
1143	1"366	7.39	2.[illegible]	1159	1[illegible]	443	[illegible]

9 January, 1943.

UNCLASSIFIED

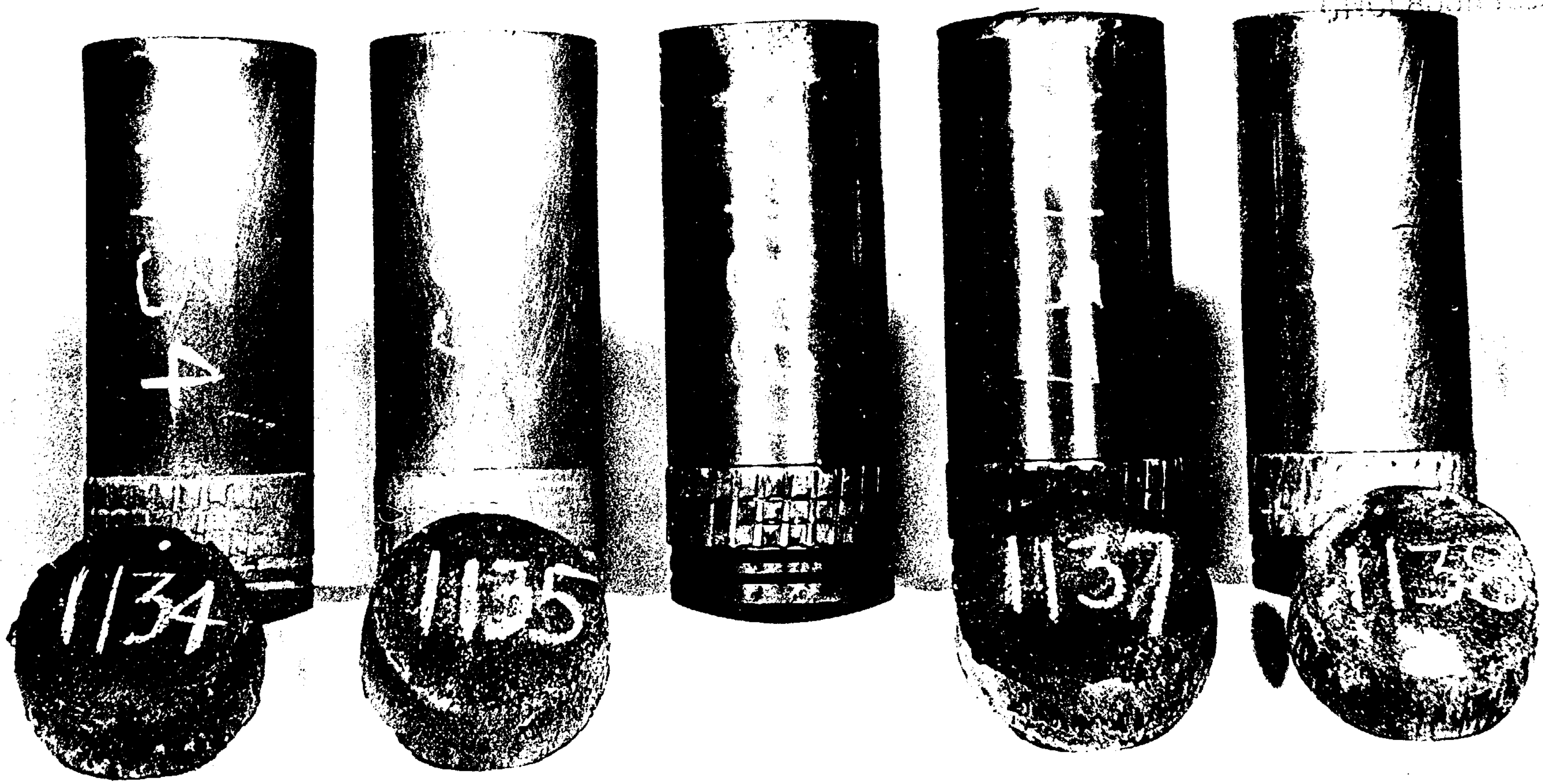


1140

NPG PHOTO NO. 554 (APL) - High Speed Punching. 15 lb. Flat Nosed Projectiles (F-A) vs. 1136 STS at [illegible] obliquity. View of projectiles and punchings. See NPG Photo No. 555 APL.

B.I.No.	e	m(proj.)	m(punch)	V_s	V_r	V(punch)	[illegible]ne.
1134 APL	1.38[illegible]	[illegible]	.49	[illegible]74	575	692	JP
1135	1.387	[illegible]	.55	774	394	514	[illegible]
1137	1.3[illegible]4	[illegible]	-	[illegible]74	-	-	[illegible]
1138	1.075	[illegible]	.65	6[illegible]5	[illegible]	[illegible]45	[illegible]

9 January, 1943.

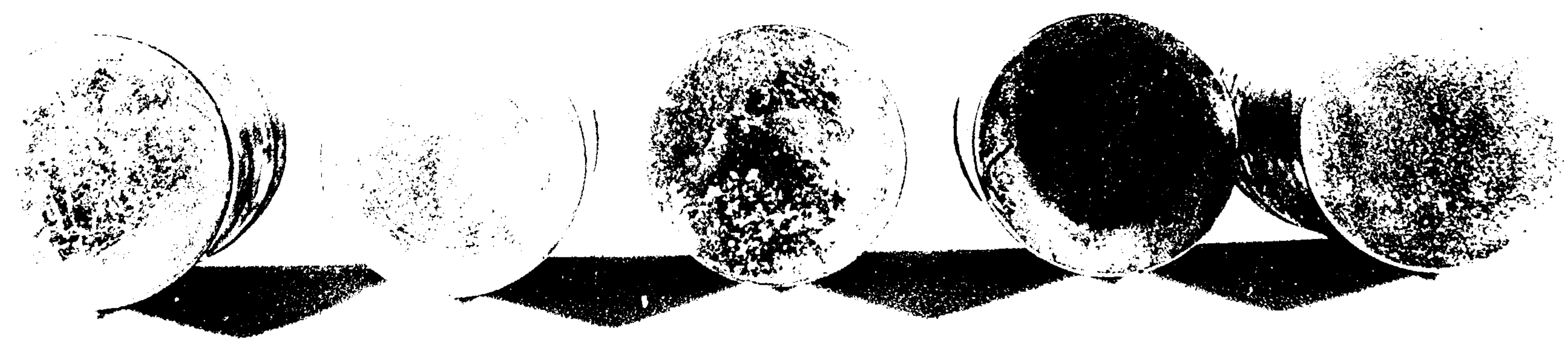


NPG PHOTO NO. 555 (APL) - High Speed Punching. 15 lb. Flat Nosed Projectiles (F.A.). vs. 1"36 STS at 0° obliquity. End view of projectiles. See NPG Photo No. 554 (APL).

B.I.No.	e	m(proj)	m(punch)	V_s	V_R	V(punch)	Pene.
1134 APL	1.363	14.88	[illegible].49	[illegible]	575	692	CP
1135	1.367	[illegible].83	2.55	779	394	514	CP
1137	1.374	14.90	-	[illegible]74	-	-	1"
1138	1.375	14.91	[illegible].65	635	[illegible]	[illegible]75	CP

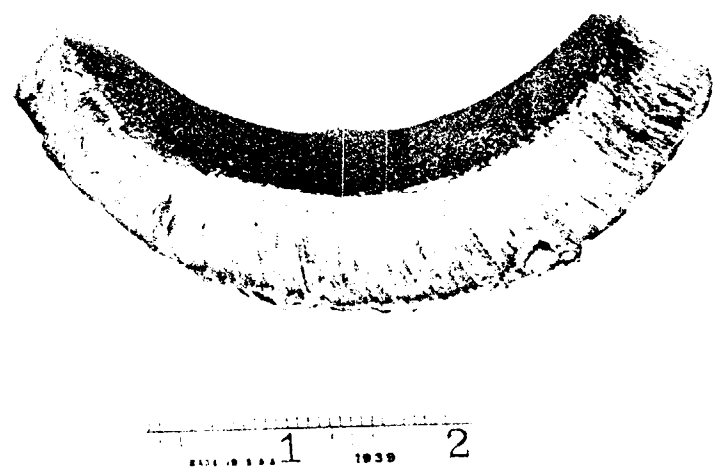
9 January, 1943.

UNCLASSIFIED



NPG PHOTO NO. 732 (APL) - Punching thrown from 0"73 STS after impact of 15-lb. 3" Flat Nosed Projectile at 60° Obliquity.
March 29, 1943.

UNCLASSIFIED



this however, there still seems to be a dependence on mass, since the 15-lb. flat-nosed projectile required 15 per cent less energy than the 7.5-lb. flat-nosed projectile to get through 1".36 plate (e/d - 0.45) at 0°.

One 11-lb. flat-nosed projectile was fired against 1".94 STS (e/d - 0.65) at 0° obliquity at a velocity of 947 f.s. The penetration was only 1/4 inch and the projectile was badly deformed indicating that complete penetration in good condition is not possible at this e/d with this projectile.

Fig. 6, NPG Photo. No. 410 (APL); Fig. 7, NPG Photo. No. 553 (APL); Fig. 8, NPG Photo. No. 556 (APL); Fig. 9, NPG Photo. No. 554 (APL). Fig. 10, NPG Photo. No. 555 (APL); and Fig. 11, NPG Photo. No. 732 (APL) shows the projectile condition after impact and the punchings thrown from plate under various conditions.

The energy absorption in punching increases with striking energy rather rapidly, whereas for piercing failure the energy given up by the projectile in passing through the plate is essentially independent of striking velocity. This energy absorption increase results in part from the energy carried off by the punching which necessarily increases with striking velocity of the projectile. Thus the energy lost by the projectile would be expected to increase with velocity. The measured energy carried off by the punching is not sufficient to account for all of the variation in energy absorption which indicates that there is an increase in energy absorption with velocity in addition to that accounted for by the punching. As an example, consider the case of the 15-lb. flat-nosed projectile against 1".36 STS (e/d - 0.45) at 0° obliquity. In Fig. 2 it can be seen that at an F^2 (striking) of 150 x 10^7 the F^2 (residual) of the projectile was 45 x 10^7 and of the punching 12 x 10^7, making total residual F^2, of 57 x 10^7. Now if the punching type of failure had been independent of striking velocity, i.e., assuming a slope of unity, the sum of the residual F^2 values would have totaled 80 x 10^7 for the same striking velocity.

The question might be raised as to the error introduced in residual velocity measurements by the energy required to penetrate the contact screens. By measurement, this energy turned out to be only 250 ft.-lbs., which is well within the experimental error of measurement, estimated at ±1%.

V CONCLUSIONS.

The energy required to penetrate a plate by punching is much less than that required to penetrate the same plate by piercing with the same weight projectile. This punching type of failure is produced by flat-nosed projectiles even at high obliquity.

The energy absorption increases with striking energy much more rapidly in punching than in piercing, a factor which requires consideration in connection with studies of the effectiveness of different projectiles against multiple armor structures.

The flat-nosed projectiles in their present virtually undeveloped forms are only effective at e/d values of less than 0.5

VI RECOMMENDATIONS.

1. It is recommended that further investigation of penetration at various e/d and obliquity values be made with flat-nosed projectiles.

2. It is recommended that further experimental flat-nosed projectiles be procured in sets of ten, subject to various heat treatments, manufactured of various compositions, and in particular fitted with caps of various thickness, shape, hardness, and method of fastening.

3. It is recommended that experimental flat-nosed A.P. bombs be provided and tested at the Proving Ground at once as the optimum performance of flat-nosed projectiles (even in the preliminary form) occurs in the range of velocities and e/d ratios characteristic of bombing.

4. It is recommended that the possibilities of flat-nosed projectiles for attack on underwater structures be considered, particularly in the light of well known non-ricocheting properties of such projectiles.

VII APPENDIX A – BALLISTIC DATA.

0° Obliquity

APL Impact No.	e in.	θ	m lbs.	m_P lbs.	V_S f.s.	Pene. in.	V_R f.s.	V_P f.s.	F_S^2 x10^7	F_R^2 x10^7	F_P^2 x10^7
3-Inch M79 15-lb. A.P. Projectile vs. 0".73 STS (e/d - 0.24)											
964	.729	4°10'	15.00	--	593	CP	50	--	139	1.0	
963	.730	3°10'	15.00	--	607	CP	169	--	146	11	
3-Inch Slug (11-lb.)(3" M79 - Nose Cut off) vs. ".73 STS (e/d - 0.24)											
973	.729	3°40'	10.88	--	657	1/4"	--		124	--	--
975	.729	3°10'	10.88	--	678	CP	388(?)		132	--	--
974	.730	3°00'	10.47	--	776	CP			166	--	--
3-Inch M79 15-lb. A.P. Projectile vs. 1".36 STS (e/d - 0.45)											
866	1.355	0°40'	15.10	--	985	5-1/8	--	--	209	--	--
867	1.353	1°50'	14.85	--	1008	CP	--	--	215	--	--
3-Inch F.A. 7".5-lb. Slug vs. 1".36 STS (e/d - 0.45)											
1139	1.366	0°20'	7.36	--	925	Inc.	--	--	89.0	--	--
1143	1.366	0°40'	7.39	2.90	1059	CP	142	443	117	2.1	8.05
1140	1.365	0°20'	7.41	2.78	1061	CP	--	454	118		8.1
1141	1.367	0°10'	7.42	2.80	1157	CP	--	555	140.5		12.2
1142	1.366	0°20'	7.41	3.31	1178	CP	227	508	145	5.4	12.1

3-Inch M79 (11-lb.) A.P. Projectile (Nose cut off) vs. 1"36 STS (e/d - 0.45)

APL Impact No.	e in.	θ	m lbs.	m_P lbs.	V_S f.s.	Pene. in.	V_R f.s.	V_P f.s.	F_S^2 x10^7	F_R^2 x10^7	F_P^2 x10^7
890	1.360	5°10'	10.82	--	767	Inc.	--	--	90	--	--
871	1.356	3°10'	11.30	--	818	CP	222	--	108	8	--
868	1.354	1°10'	11.25	--	951	CP	362	--	145	21	--
865	1.355	0°30'	11.20	--	1021	CP	442	--	166.5	31	--
864	1.355	0°00'	11.25	--	1116	CP	542	--	200	47	--
3-Inch F.A. 15-lb. Slug vs. 1"36 STS (e/d - 0.45)											
1137	1.374	0°40'	14.90	--	574	1"	--	--	69	--	--
1138	1.375	1°00'	14.91	2.65	635	CP	207	375	84.5	9.0	5.2
1135	1.367	0°10'	14.83	2.55	779	CP	394	514	127	32.5	9.5
1134	1.363	0°30'	14.88	2.49	964	CP	575	692	196	70.0	17.
30° Obliquity											
3-Inch M79 15-lb. A.P. Projectile vs. 1"36 STS (e/d - 0.45)											
889	1.363	30°20'	15.00	--	1058	CP	297	--	178	14	--
885	1.358	29°50'	15.10	--	1127	CP	456	--	205.5	34	--
3-Inch M79 (11-lb.) A.P. Projectile (Nose cut off) vs. 1"36 STS (e/d - 0.45)											
887	1.363	30°00'	10.65	--	918	SIP	--	--	95	--	--
884	1.359	30°00'	10.95	--	915	CP	--	--	98	--	--

60° Obliquity

3-Inch M79 15-lb. A.P. Projectile vs. 0"73 STS (e/d - 0.24)

APL Impact No.	e in.	θ	m lbs.	m_P lbs.	V_S f.s.	Pene. in.	V_R f.s.	V_P f.s.	F_S^2 x10[7]	F_R^2 x10[7]	F_P^2 x10[7]
1245	.731	60°00'	15.05	--	1415	CP	1037	--	199.2	107.0	
1267	.732	60°00'	14.99	--	1318	Inc.	--	--	171.9	--	
1268	.732	59°55'	14.97	--	1364	Inc.	--	--	184.9	--	
1269	.731	59°50'	14.96	--	1413	CP	--	--	198.9	--	

3-Inch 15-lb. Flat-nosed Projectile vs. 0"73 STS (e/d - 0.24)

APL Impact No.	e in.	θ	m lbs.	m_P lbs.	V_S f.s.	Pene. in.	V_R f.s.	V_P f.s.	F_S^2 x10[7]	F_R^2 x10[7]	F_P^2 x10[7]
1282	.733	59°55'	14.88	--	1160	CP	--	--	132.8	--	
1283	.739	58°±30'	14.85	--	967	CP	--	--	102.8	--	
1284	.737	59°55'	14.86	--	844	CP	100(est.)	-	69.9	9.8	
1285	.737	59°50'	14.88	--	798	CP	92	--	62.8	8.3	
1288	.738	60°05'	14.87	--	728	CP	--	--	51.3	--	
1294	.738	59°45'	14.90	2.12	641	SIP	--	282	40.4	--	78

APPENDIX B

DERIVATION OF ENERGY ABSORPTION EQUATION

DERIVATION.

In the treatment of residual velocity data it is found in general that a linear relationship results for moderate striking velocities above the limit when F^2 (residual) values are plotted as ordinates and F^2 (striking) values as abscissae. Since in practice from round to round there are small variations in projectile mass, plate thickness, and obliquity it is necessary to reduce all values to the same basis, to correct for these variations. This correction is conveniently made by plotting F^2 values instead of true energies. The equation of the linear part of the curve is expressed by

$$F_R^2 = S(F_S^2 - F_L^2) \qquad \text{(a)}$$

where F_R^2, F_S^2 and F_L^2 are computed respectively from the residual, striking and limit velocities, and where S is the slope of the curve. Although the results are usually plotted in this form, from a knowledge of the slope of the curve a relative energy absorption curve can be drawn. Thus the loss in F^2 value by the projectile in passing through the plate is given by

$$F_S^2 - F_R^2 = \Delta F^2 \qquad \text{(b).}$$

Substituting for F_R^2 from equation (a) we get

$$\Delta F^2 = (1 - S)F_S^2 + SF_L^2 \qquad \text{(c)}$$

and dividing through by F_L^2, we have finally

$$\frac{\Delta F^2}{F_L^2} = (1 - S)\, F_S^2/F_L^2 + S \qquad \text{(d).}$$

From this expression and knowledge of the slope of the residual energy plot of equation (a) a plot can be made of relative energy absorption versus relative striking energy. In ploting the results the following substitutions are made

$$\Delta E \propto \Delta F^2,\ E_S \propto F_S^2,\ E_L \propto F_L^2 \text{ and } E_R \propto F_R^2 .$$

Since F^2 appears in equation (d) only in ratios, these substitutions do not affect the equation and there follows

$$\frac{\Delta E}{E_L} = (1 - S) \frac{E_S}{E_L} + S \qquad \text{(e).}$$

An examination of equation (e) reveals that when S is less than unity the energy absorption is an increasing function of the striking energy, and when S is greater than unity the energy absorption is a decreasing function of the striking energy. Either condition may exist for some range above the limit velocity.