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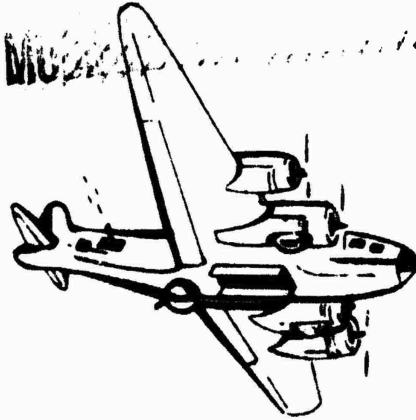
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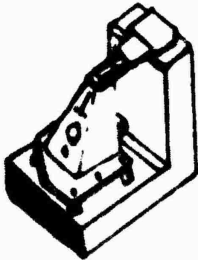
ABERDEEN PROVING GROUND, MD.

AD-A954 860

MEMORANDUM
REPORT No. 458



**SUMMARY OF ANALYSIS COMPARING
HOMOGENEOUS ROLLED AND
FACE-HARDENED ARMOR PLATE**



Frank E. Grubbs



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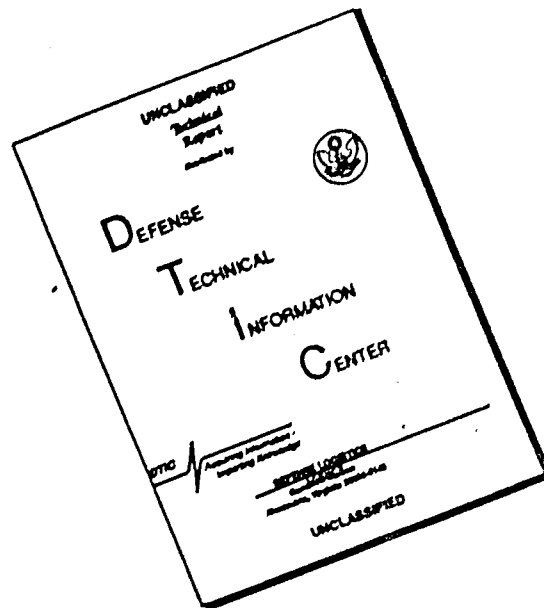
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ABERDEEN PROVING GROUND, MD.**

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BALLISTIC RESEARCH LABORATORIES
MEMORANDUM REPORT NO. 458

Grubbs/cvz
Aberdeen Proving Ground, Md.
27 March 1947

**SUMMARY OF ANALYSIS COMPARING HOMOGENEOUS ROLLED
AND FACE-HARDENED ARMOR PLATE**

ABSTRACT

This report is concerned with available comparisons of homogeneous rolled and face-hardened armor plate, using Army ballistic limits as the medium for making comparisons. Assuming average quality projectiles were used in firings on which this report is based, face-hardened armor is quite superior to homogeneous rolled armor in defeating Cal. .30 AP M2 and Cal. .50 AP M2 projectiles and hence a substantial saving in weight of armor can be effected for these conditions by using face-hardened armor (see Figs. 1-4). There are also indications (Table VIII) that face-hardened armor may be slightly superior to homogeneous rolled armor when comparisons are made with 20mm AP M75 and M95 projectiles. In comparing face-hardened plate with homogeneous rolled plate for 37mm APC M51, 57mm APC M86, 3" APC M62, 90mm AP M77, and 90mm APC M82 projectiles, appropriate data for arriving at legitimate conclusions are scant (see Figs. 5-9), and hence tests designed specifically for this purpose may prove worthwhile.

INTRODUCTION

In accordance with O.O. 470.5/170, a statistical analysis has been made of available data for thin and medium armor plate (1/4" to 4") in such a manner as to show the comparative effectiveness of homogeneous rolled and face-hardened armor in resisting AP and APC projectiles. In making the comparisons given in this report the phrase "resistance to penetration" will be used as being synonymous with the term "ballistic limit." Unless otherwise stated, all ballistic limits herein are of the two-round type, i.e., the average of two velocities -- the lowest velocity of complete penetrations (army criteria) and the highest velocity of the partial penetrations which is less than the lowest velocity of complete penetrations.

A direct comparison of homogeneous rolled and face-hardened armor is complicated by the fact that a major purpose of face-hardened armor is to effect breaking-up of the projectiles. Hence, in comparing the resistance to penetration of homogeneous rolled and face-hardened armor we may have a substantially higher percentage of projectiles breaking up on the face-hardened armor than on homogeneous rolled armor. There exists, therefore, the problem as to whether one should compare ballistic limits of the two types of armor for the best quality of projectiles, medium quality, poor quality or for the same percentage of breakage. The final answer depends, of course, on the quality of projectiles used by the enemy and this may not be known in advance. In this report comparisons between homogeneous rolled and face-hardened armor could be made only with the projectiles which happened to be used in determining ballistic limits; however, since it was general practice to use reference or standard lots of projectiles it is assumed that the comparisons given below are based on average quality (or better than average quality) projectiles.

In preparing and analyzing data for Figures 1 through 9, it was necessary to conduct a tedious search through existing firing records and in so doing it was found that appropriate information on face-hardened armor was unusually scant, except for tests of plate with Cal. .30 AP M2 and Cal. .50 AP M2 projectiles. In addition, it is remarked that firing programs were not necessarily designed to provide appropriate information for the purpose of comparing armor. The curves and the figures for homogeneous rolled armor were obtained from a program on the general effect of hardness in which one of the major purposes was to determine the optimum effective Brinell hardness of armor plate for a given projectile, thickness of plate and angle of obliquity. On the other hand, the curves or points depicting ballistic limits of face-hardened armor were by necessity obtained from acceptance test data on plate, special investigations and acceptance tests of projectiles. The average Brinell Hardness Number for face-hardened plate considered in this report turned out to be about 630.

COMPARISONS FOR CAL. .30 AP M2 PROJECTILES

Fig. 1 portrays the relation between ballistic limit and angle of obliquity for homogeneous rolled and face-hardened armor for several different plate thicknesses. The solid curves for homogeneous rolled armor were obtained using data from the hardness program. It is mentioned that for the hardness program the plates varied slightly in thickness about a nominal value and that Brinell hardness varied generally from plate to plate. As a matter of fact, by varying heat treatment, quench, etc., and using three manufacturer's plates it was possible to effect variations in Brinell hardness of the plates from about BHN 260 to BHN 470.

Nevertheless, by using a statistical method (partial regression analysis) the relation between Brinell hardness and ballistic limit could be determined, the variation in plate thickness being held constant; also, the relation between slight changes in plate thickness and ballistic limit could be determined, the effect of BHN being held constant. The curves of Fig. 1 were, of course, determined by drawing lines through the points at 0° obliquity, 20° , 30° , 40° and 50° and hence interpolation for an intervening angle of obliquity may be questionable. The curves for homogeneous rolled armor are plotted for a Brinell hardness number of 370. By use of the partial regression equations it is possible to obtain ballistic limits for any Brinell hardness from about 275 to about 450 for homogeneous rolled plate. The figure of BHN 370 was chosen simply as the average for the plates tested with Cal. .30 AP M2 projectiles. (A comparison between homogeneous rolled armor for BHN 450 and face-hardened armor is given in Fig. 2, which will be discussed later.)

The dashed curves for face-hardened armor were obtained from Armor Report AD-549. The three individual points for face-hardened armor ($1/4"$, $5/16"$, and $3/8"$ at 0° obliquity) were obtained from acceptance test data.

In making statements about the plotted points on Fig. 1 and in comparing homogeneous rolled armor and face-hardened armor in resisting Cal. .30 AP M2 projectiles, it is most important to say something about the precision of the ballistic limits or points graphed on Fig. 1. Table I gives this desired information for Fig. 1. For example, the ballistic limit of 1222 f/s for $1/4"$ homogeneous rolled armor at 0° obliquity is the average of 20 ballistic limits and is subject to a standard deviation or standard error of 5 f/s (this means that there are about five chances in 100 that the true value of ballistic limit lies outside the interval of $\pm 2 \times 5 = 10$ f/s about the plotted point. That is, it is predicted that if a very large number of plates were tested under the same conditions the average ballistic limit would very likely lie within the interval 1212 to 1232 f/s). As another example, the point for $1/4"$ homogeneous rolled armor at 30° obliquity, i.e. 1862 f/s, is not as precise as the preceding point referred to since probable limits for the true ballistic limit would be ± 90 f/s. Similar information for all of the plotted points on Fig. 1 can be obtained by referring to Table I.

It may be noted that the three individual points determined from acceptance test data on $1/4"$, $5/16"$, and $3/8"$ face-hardened armor at 0° obliquity do not appear to agree with the corresponding points or ballistic limits (on the dashed curves) determined from Report AD-549 covering tests of face-hardened plate. For example, the single point for $5/16"$ face-hardened armor at 0° obliquity from acceptance test data indicates a ballistic limit of about 2274 f/s, whereas the corresponding point from Report AD-549 has a ballistic limit of 2182 f/s. However, an examination of Table I shows that the former point is subject to a standard error of 30 f/s (based on nine rounds), whereas the latter point is subject to a standard error of 178 f/s (based on only three rounds); hence, the difference is not statistically significant. As a matter of fact, from Table I, it is apparent that the entire curve for $5/16"$ face-hardened armor is not very precise because of the rather large standard errors of the points.

Using Fig. 1, a comparison may be made of $1/4"$ homogeneous rolled armor and $1/4"$ face-hardened armor, $5/16"$ homogeneous rolled and face-hardened armor, and $3/8"$ homogeneous rolled and face-hardened armor. It is seen that for the Cal. .30 AP M2 projectile face-hardened armor is definitely superior to homogeneous rolled armor since it gives much higher ballistic limits, at least up to about 30° obliquity. For the

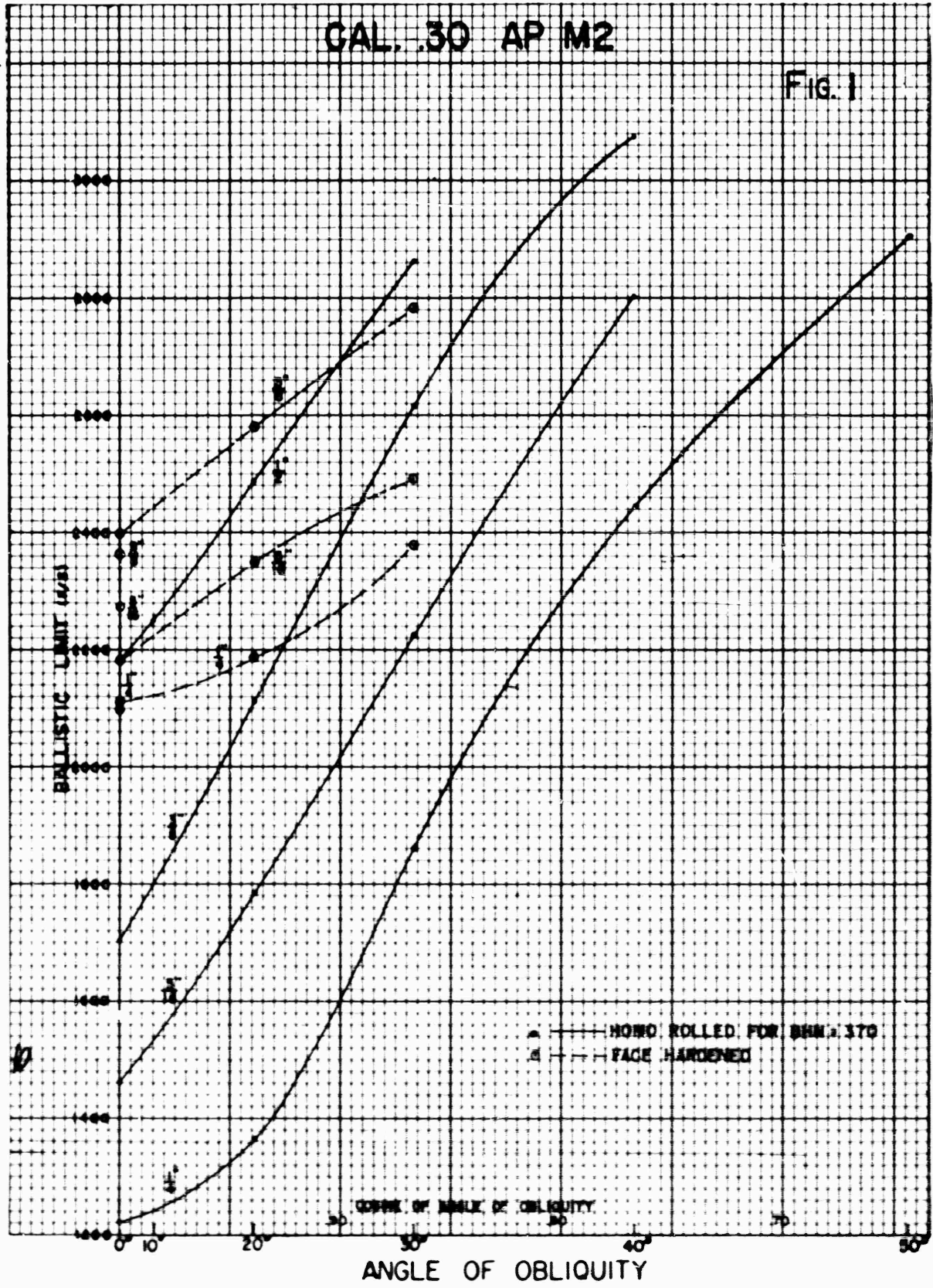


TABLE I
Standard Errors of Plotted Points in Fig. 1

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point t/s | Source of Information |
|---------------|-----------------|--------------------|----------------------------|---------------------------------|-----------------------|
| Homo | 1/4" | 0° | 20 | 5 | Hardness Program |
| " | " | 20° | 20 | 40 | " |
| " | " | 30° | 20 | 45 | " |
| " | " | 40° | 20 | 24 | " |
| " | " | 50° | 19 | 17 | " |
| " | 5/16" | 0° | 20 | 10 | " |
| " | " | 20° | 19 | 23 | " |
| " | " | 30° | 14 | 33 | " |
| " | " | 40° | 11 | 22 | " |
| " | 3/8" | 0° | 20 | 7 | " |
| " | " | 20° | 7 | 23 | " |
| " | " | 30° | 7 | 13 | " |
| " | " | 40° | 5 | 63 | " |
| " | 1/2" | 0° | 20 | 6 | " |
| " | " | 10° | 7 | 11 | " |
| " | " | 20° | 7 | 12 | " |
| " | " | 30° | 5 | 3 | " |
| Face-hardened | 1/4" | 0° | 73 | 8 | Armor Report AD-549 |
| " | " | 20° | 73 | 10 | " |
| " | " | 30° | 73 | 11 | " |
| " | 5/16" | 0° | 3 | 178 | " |
| " | " | 20° | 4 | 36 | " |
| " | " | 30° | 4 | 52 | " |
| " | 3/8" | 0° | 16 | 34 | " |
| " | " | 20° | 16 | 24 | " |
| " | " | 30° | 16 | 23 | " |
| " | 1/4" | 0° | 20 | 18 | Acceptance Data |
| " | 5/16" | 0° | 9 | 30 | " |
| " | 3/8" | 0° | 20 | 21 | " |

higher angles of obliquity, the curves for the face-hardened armor appear to approach those for the homogeneous rolled plate. In addition, Fig. 1 indicates that a given change in angle of obliquity results in a substantial increase in ballistic limit for homogeneous rolled armor, whereas for the same change in angle of obliquity the increase in ballistic limit for face-hardened armor is not correspondingly pronounced. It is concluded from Fig. 1 that for BHN = 370 a decided saving in weight of armor could be effected by using face-hardened plate instead of homogeneous rolled plate when compared as to ability to defeat Cal. .30 AP M2 projectiles.

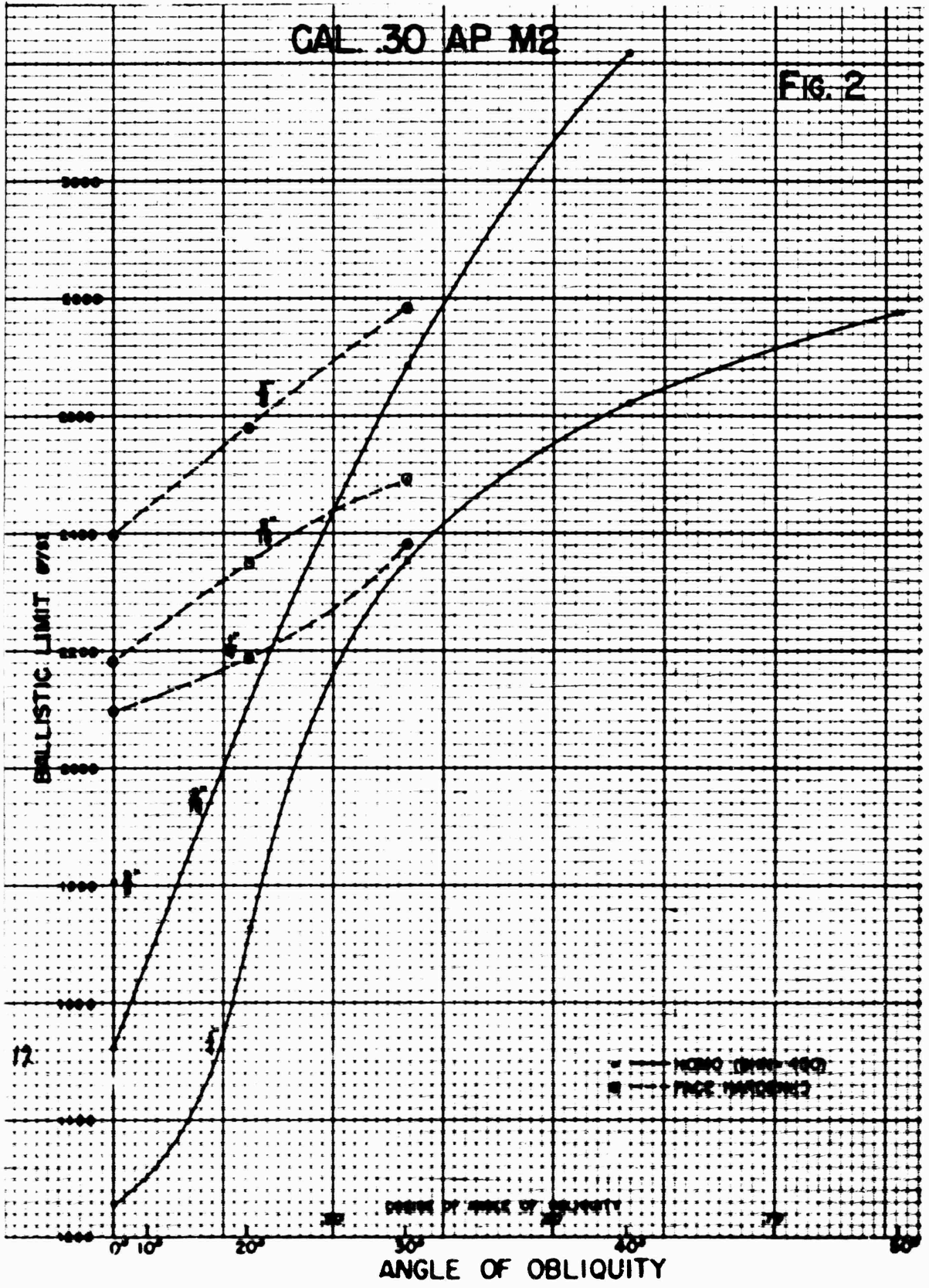


Fig. 2 gives the comparative relation between face-hardened plate and homogeneous rolled plate (same as in Fig. 1) except that ballistic limits for homo plate have been computed for a BHN of 450. The curves for Fig. 2 were inferred from the partial regression equations and whereas no precise statement will be made regarding the exact position or precision of the points, it is believed that at least qualitative comparisons between homo and face-hardened plate may be made. In any event, it appears that increasing Brinell hardness to 450 has a very decided effect on the ballistic limit of homogeneous rolled armor, especially for the higher angles of the obliquity. The curves for face-hardened armor in Fig. 2 are the same as the corresponding ones in Fig. 1.

COMPARISONS FOR CAL. .50 AP M2 PROJECTILES

Fig. 3 gives comparisons between homogeneous rolled plate and face-hardened plate when tested with the Cal. .50 AP M2 projectile. Table II contains the appropriate information regarding the number of ballistic limits each point on Fig. 3 is based on and also gives the standard error of each point or ballistic limit, the interpretation being as before. The point for 1/2" face-hardened armor, 0° obliquity, is represented by concentric circles -- this is because the average ballistic limit obtained from acceptance test data on 1/2" face-hardened plate turned out to be the same as that obtained from Armor Report AD-549. Using Fig. 3 and referring to Table II for appropriate standard errors, it is seen that face-hardened plate is superior to homogeneous rolled plate in so far as ballistic limit is concerned. Within the scope of the data presented in Fig. 3, this is true whether the diameter of the projectile over-matches, matches, or under-matches the thickness of the plate. The curves for homogeneous rolled armor in Fig. 3 have been drawn for a Brinell hardness number of 365 which is the average for plates tested with the Cal. .50 AP M2 projectile.

Fig. 4 gives comparisons between ballistic limits for (1) face-hardened armor plate and (2) homogeneous rolled plate of BHN 450. Here, we find that 1/4" face-hardened plate gives uniformly higher ballistic limits for all angles of obliquity than 1/4" homogeneous rolled plate of BHN 450. For the case where the diameter of the projectile matches the thickness of the plate, (i.e. 1/2") it is seen that for an angle of obliquity of about 30° the ballistic limits for face-hardened plate and homo (BHN 450) are approximately the same. It is cautioned that in using Fig. 4 only qualitative comparisons are recommended.

COMPARISONS WITH 37MM APC M51 PROJECTILES

Fig. 5 portrays the relation between ballistic limit and angle of obliquity for homogeneous rolled armor (BHN = 306) for plates of various thicknesses when tested with the 37mm APC M51 projectile. For the 37mm APC M51 projectile, only a single point could be obtained for face-hardened plate and this was for the 1-1/2" thickness at an angle of obliquity equal to 20°. The single point for 1-1/2" face-hardened plate was obtained using Jefferson Proving Ground's firing records on tests of 37mm APC M51 projectiles. Although no standard error is listed in Table III for the single face-hardened point, the ballistic limit is believed to be quite precise since it is based on tests against 61 plates. The ballistic limit for 1-1/2" homo

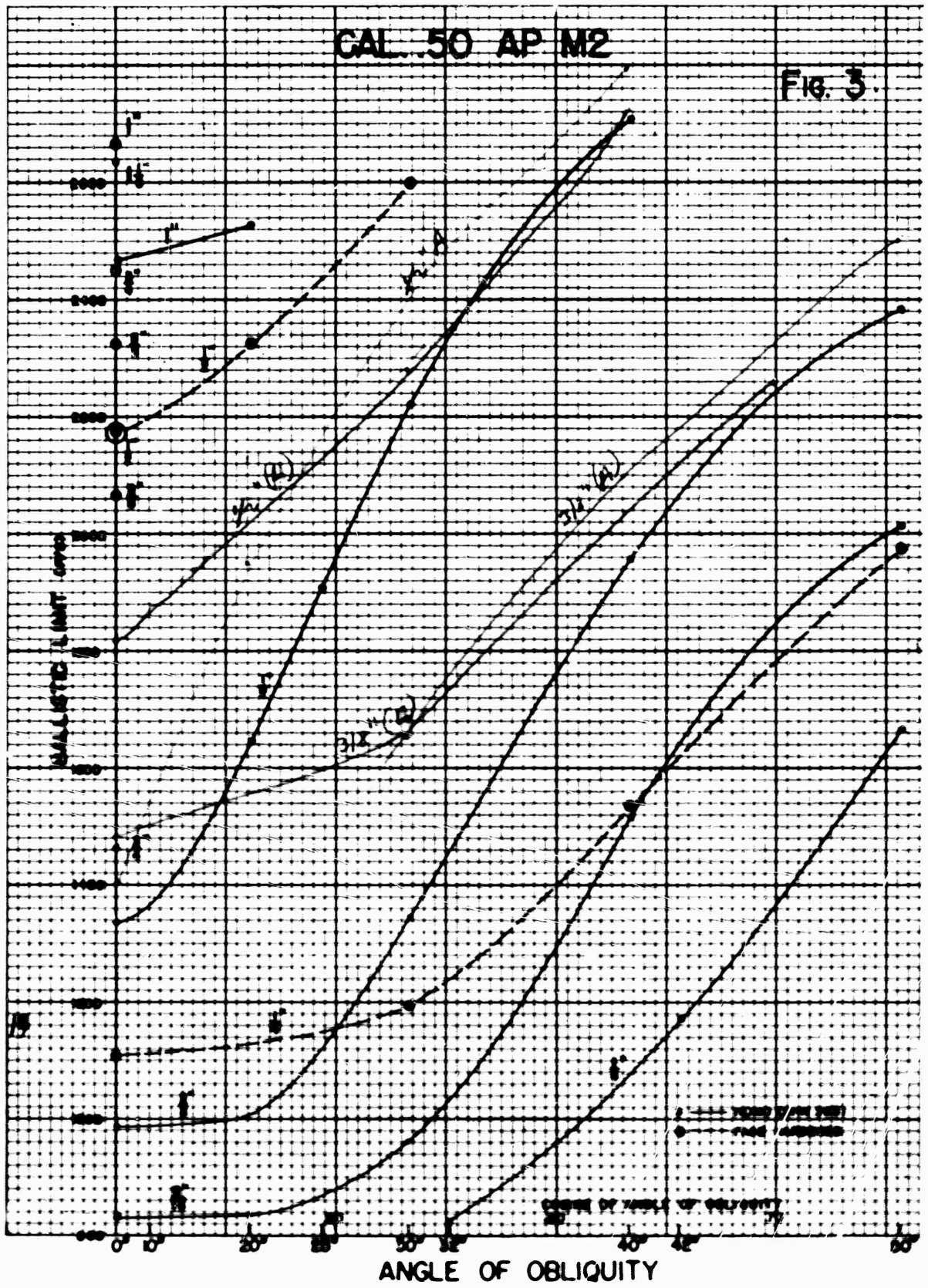


TABLE II
Standard Errors of Plotted Points in Fig. 3

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point t/s | Source of Information |
|---------------|-----------------|--------------------|----------------------------|-----------------------------------|-----------------------|
| Homo | 1/4" | 32° | 20 | 10 | Hardness Program |
| " | " | 42° | 20 | 28 | " |
| " | " | 50° | 20 | 17 | " |
| " | 5/16" | 0° | 20 | 6 | " |
| " | " | 30° | 15 | 16 | " |
| " | " | 40° | 15 | 40 | " |
| " | " | 50° | 16 | 27 | " |
| " | 3/8" | 0° | 20 | 7 | " |
| " | " | 30° | 12 | 24 | " |
| " | " | 40° | 13 | 27 | " |
| " | " | 50° | 13 | 18 | " |
| " | 1/2" | 0° | 20 | 3 | " |
| " | " | 20° | 9 | 38 | " |
| " | " | 25° | 7 | 36 | " |
| " | " | 30° | 10 | 38 | " |
| " | " | 40° | 7 | 29 | " |
| " | 3/4" | 0° | 20 | 6 | " |
| " | 1" | 0° | 20 | 6 | " |
| " | 1" | 20° | 8 | 29 | " |
| " | 1-1/8" | 0° | 14 | 7 | " |
| Face-hardened | 1/4" | 0° | 10 | 28 | Armor Report A11819 |
| " | " | 20° | 10 | 25 | " |
| " | " | 30° | 10 | 25 | " |
| " | " | 40° | 9 | 20 | " |
| " | " | 50° | 9 | 39 | " |
| " | 1/2" | 0° | 32 | 16 | Armor Report AD-549 |
| " | " | 20° | 32 | 12 | " |
| " | " | 30° | 32 | 10 | " |
| " | 3/8" | 0° | 13 | 12 | Armor Report AD-1079 |
| " | 1/2" | 0° | 20 | 15 | Acceptance Data |
| " | 5/8" | 0° | 16 | 32 | " |
| " | 3/4" | 0° | 5 | 59 | " |
| " | 1" | 0° | 12 | 36 | " |

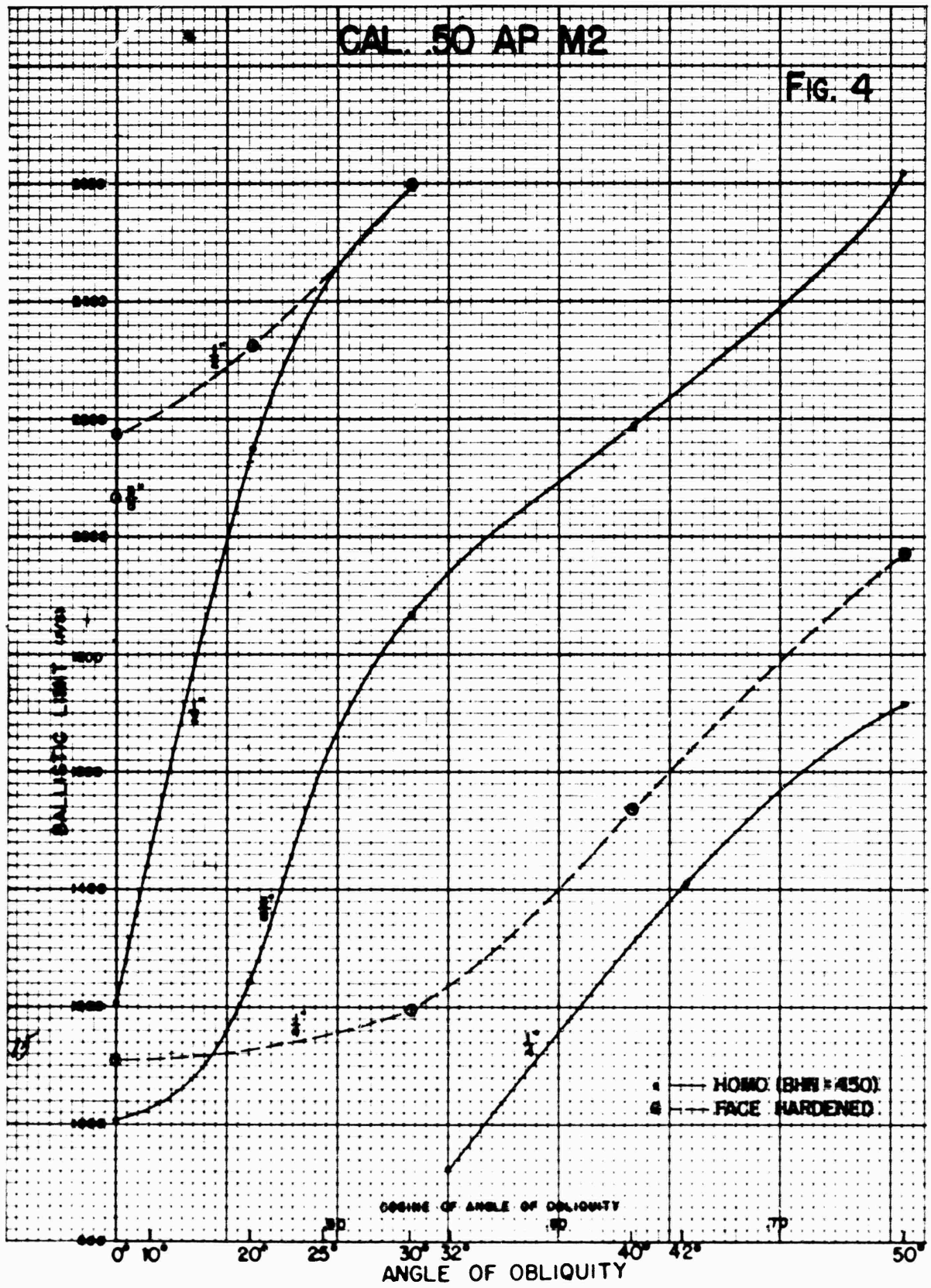


plate (BHN 308) at 20° obliquity was obtained from data on the hardness program and as indicated by Table III has a standard error of 17 f/s. Hence, for the single comparison available here between the two types of armor, it appears that 1-1/2" face-hardened plate gave a higher ballistic limit than 1-1/2" homo plate for the 37mm APC M51 projectile, 20° obliquity. This is understood to contradict general opinion on the subject and consequently, if an anomaly exists it may be attributable to the fact that ballistic limits for the homogeneous rolled plate were obtained from firings at Aberdeen Proving Ground, whereas those for the 1-1/2" face-hardened plate were obtained from Jefferson Proving Ground firings; also there may be some difference in either projectile or plate quality at the two proving grounds. As a matter of interest, it is remarked that the data for 1-1/2" homo plate, 20° obliquity, cannot be used to predict the ballistic limit for, say, BHN 350 or 400.

COMPARISONS WITH 57MM APC M86 PROJECTILES

In Fig. 6, we have available only a single comparison between face-hardened armor and homogeneous rolled armor (BHN 296) and that is for 2-1/2" plate at 20° obliquity. No precise statement with regard to superiority will be made here, since the curve for 2-1/2" homo plate was obtained from data on the hardness program conducted at Aberdeen Proving Ground and the single point for face-hardened plate was determined from firings of projectile lots GJM-1-1 and MCO-3-39 against 53 plates at Jefferson Proving Ground.

COMPARISONS WITH 3" APC M62 PROJECTILES

Fig. 7 gives available information on homogeneous rolled plate (BHN 286) and face-hardened plate when tested with the 3" APC M62 projectile. For this case only a single comparison is available between homo and face-hardened plate and this is for the condition where the diameter of the projectile matches the thickness of the plate and for an angle of obliquity of 20° . Curves for homogeneous rolled plate were obtained from data on the hardness program. The single point for 3" face-hardened plate was determined from firings of projectile lots CM-3-39, CM-3-59, and CSA-1-2 against 81 plates tested at Jefferson Proving Ground. The single point for 3" homo plate, 20° obliquity, was determined from firings of projectile lots CM-3-59 and CSA-1-2 against 47 plates tested at Jefferson Proving Ground. Considering the last two points referred to, a direct comparison between 3" face-hardened and 3" homo plate is available from tests at Jefferson Proving Ground and it appears that the homo plate is slightly superior. The difference of approximately 120 f/s between the single 3" homo point (JPG data) and the corresponding point on the curve obtained from data on the hardness program may be due to inherent differences in measurement at the two proving grounds, difference in projectiles used at the two proving grounds, or perhaps because of a tendency to purposely obtain "low" ballistic limits in the hardness program. Although it would be of interest to predict just what the ballistic limit for 3" rolled homogeneous plate at 20° obliquity would be for a Brinell hardness of say, BHN = 350, an analysis of the data for this particular point indicates such is not possible.

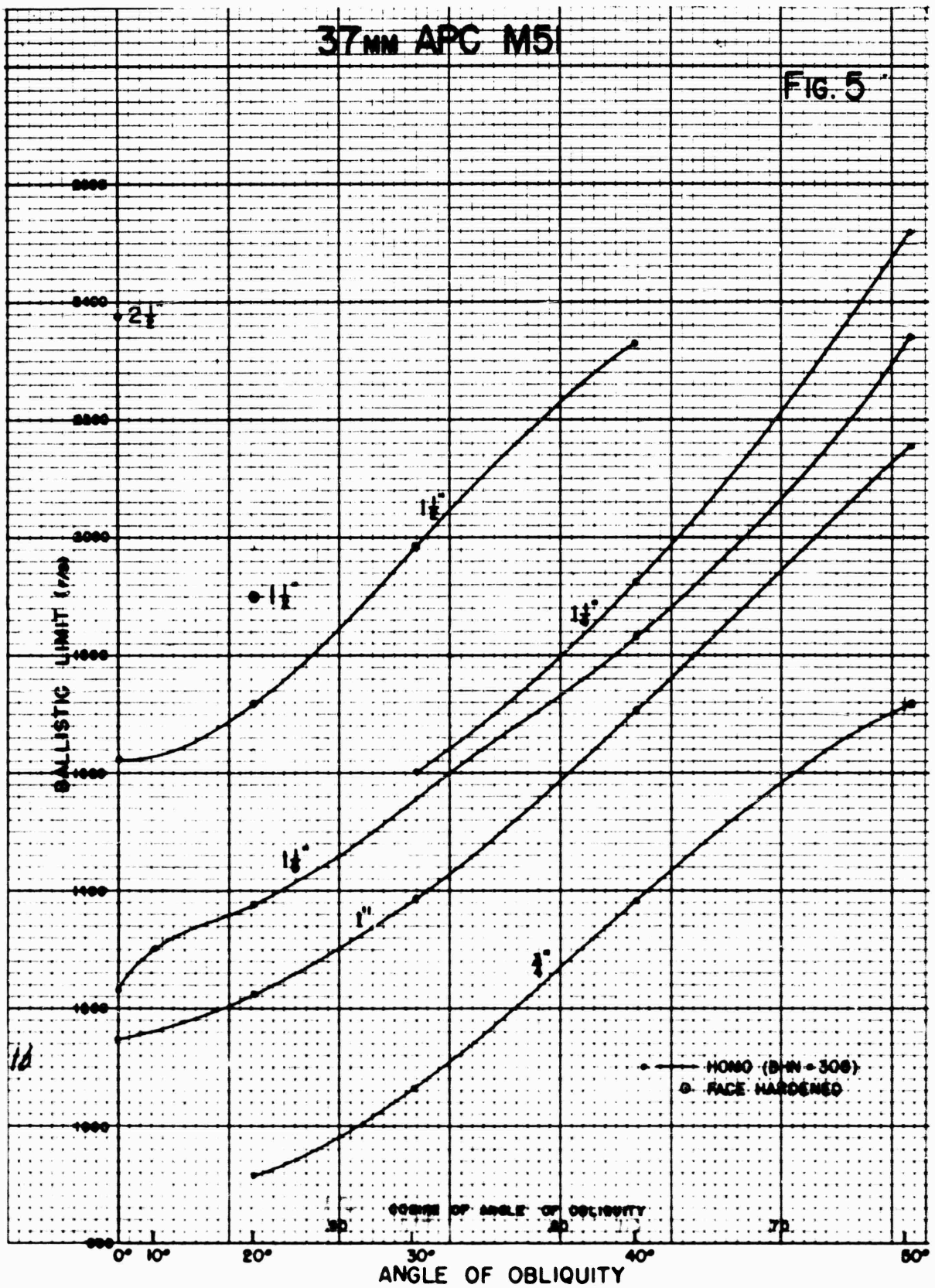


TABLE III
Standard Errors of Plotted Points in Fig. 5

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point t/s | Source of Information |
|---------------|-----------------|--------------------|---|---------------------------------|-----------------------|
| Homo | 3/4" | 20° | 5 | 19 | Hardness Program |
| " | " | 30° | 6 | 28 | " |
| " | " | 40° | 17 | 15 | " |
| " | " | 50° | 15 | 17 | " |
| " | 1" | 0° | 24 | 9 | " |
| " | " | 20° | 18 | 8 | " |
| " | " | 30° | 12 | 7 | " |
| " | " | 40° | 11 | 12 | " |
| " | " | 50° | 11 | 29 | " |
| " | 1-1/8" | 0° | 14 | 12 | " |
| " | " | 10° | 2 | 62 | " |
| " | " | 20° | 2 | 6 | " |
| " | " | 30° | 4 | 47 | " |
| " | " | 40° | 14 | 18 | " |
| " | " | 50° | 12 | 25 | " |
| " | 1-1/4" | 30° | 3 | 52 | " |
| " | " | 40° | 3 | 67 | " |
| " | " | 50° | 4 | 121 | " |
| " | 1-1/2" | 0° | 10 | 3 | " |
| " | " | 20° | 10 | 17 | " |
| " | " | 30° | 10 | 16 | " |
| " | " | 40° | 13 | 19 | " |
| " | 2-1/2" | 0° | 5 | 59 | " |
| Face-hardened | 1-1/2" | 20° | Based on Projectile lots 80-23140-30 & 22180-49. Firings against 81 plates considered | | J.P.G. |

COMPARISONS WITH 90MM AP M77 PROJECTILES

Fig. 8 gives available comparisons between homogeneous rolled plate and face-hardened plate when tested with the 90mm AP M77 projectile and Table VI gives standard errors of the plotted points where available. The two curves for homogeneous rolled armor (BHN 284 and plate thicknesses of 2-1/2" and 4") were obtained from data on the hardness program and are plotted merely for information. The other two curves for face-hardened and homo plate labeled 2-1/2" BL(P) were obtained from Armor Report AD-844. The designation BL(P) means the protection criteria for penetration. By examining the two curves labeled 2-1/2" BL(P) for face-hardened and rolled homogeneous plate in Fig. 6 one would infer that the homo plate

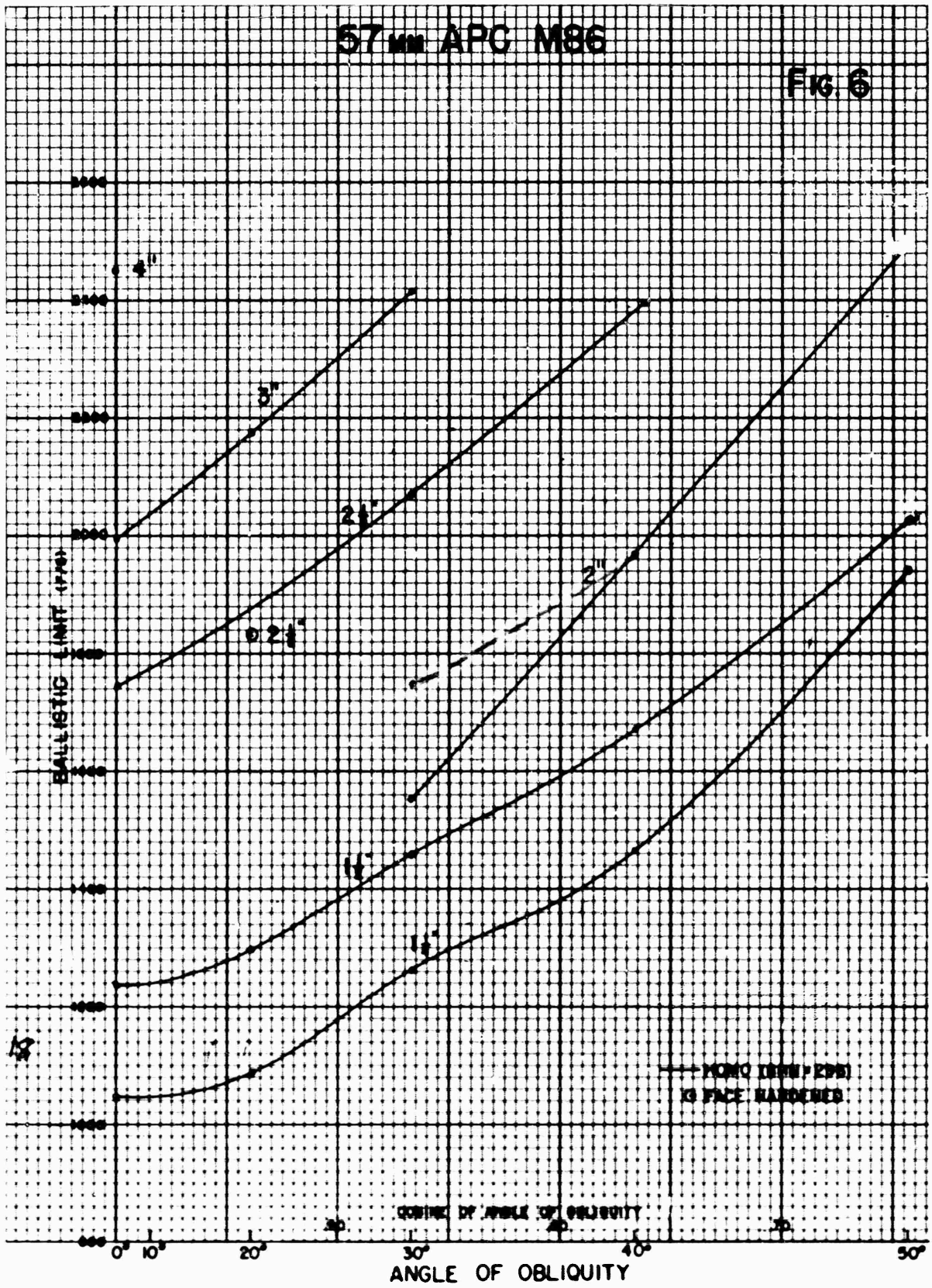


TABLE IV
Standard Errors of Plotted Points in Fig. 6

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point f/s | Source of Information |
|---------------|-----------------|--------------------|--|---------------------------------|-----------------------|
| Homo | 1-1/4" | 0° | 1 | | Hardness Program |
| " | " | 20° | 1 | | " |
| " | " | 30° | 1 | | " |
| " | " | 40° | 2 | 9 | " |
| " | " | 50° | 1 | | " |
| " | 1-1/2" | 0° | 9 | 36 | " |
| " | " | 20° | 6 | 41 | " |
| " | " | 30° | 6 | 11 | " |
| " | " | 40° | 7 | 16 | " |
| " | " | 50° | 11 | 11 | " |
| " | 2" | 30° | 5 | 14 | " |
| " | " | 40° | 6 | 9 | " |
| " | " | 50° | 6 | 28 | " |
| " | 2-1/2" | 0° | 6 | 3 | " |
| " | " | 30° | 6 | 52 | " |
| " | " | 40° | 4 | 72 | " |
| " | 3" | 0° | 4 | 54 | " |
| " | " | 20° | 4 | 18 | " |
| " | " | 30° | 4 | 53 | " |
| " | 4" | 0° | 4 | 51 | " |
| Face-hardened | 2-1/2" | 20° | Projectile lots GJM-1-1 & MCC-3-39 considered. Firings against 53 plates analyzed. | | J.P.G. |

is superior at 0°, the face-hardened plate is superior from about 10° to 35° and the homo plate is superior from about 35° to 45°; however, accurate knowledge of the standard errors of the points is not available and hence no such conclusions will be given here. Also, it is remarked that for this case the diameter of the projectile over-matches the thickness of the plate. It is desired to point out that had the Army definition of complete penetration been used in place of the protection criterion, the relation between the curves for 2-1/2" rolled homogeneous and face-hardened plate would have been approximately the same as that depicted in Fig. 6 -- see Armor Report AD-844.

3" APC M62

FIG. 7

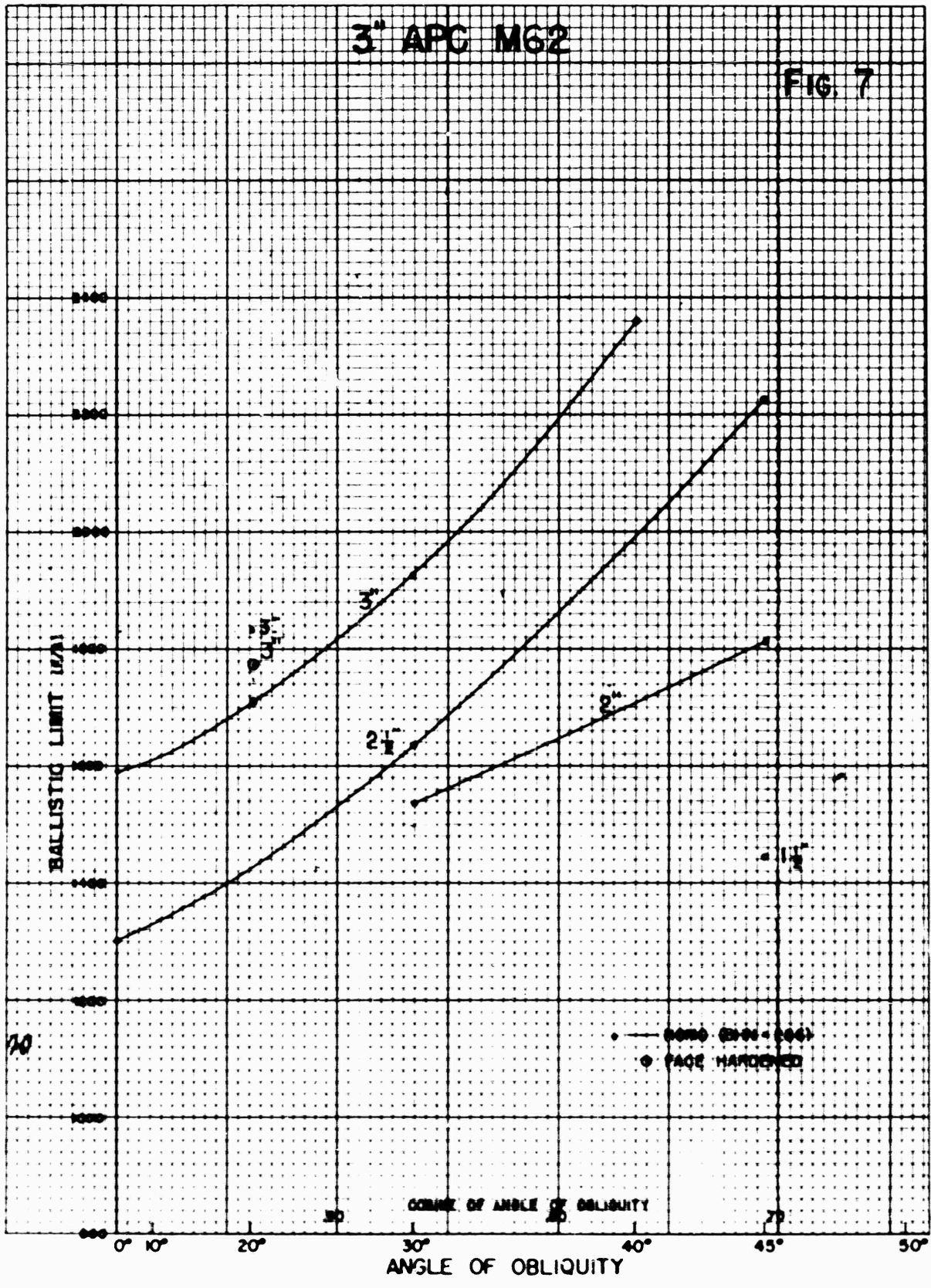


TABLE V
Standard Errors of Plotted Points in Fig. 7

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point t/s | Source of Information |
|---------------|-----------------|--------------------|--|---------------------------------|-----------------------|
| Homo | 1-1/2" | 45° | 11 | 17 | Hardness Program |
| " | 2" | 30° | 3 | 6 | " |
| " | 2" | 45° | 6 | 27 | " |
| " | 2-1/2" | 0° | 5 | 17 | " |
| " | " | 30° | 6 | 28 | " |
| " | " | 45° | 7 | 42 | " |
| " | 3" | 0° | 3 | 140 | " |
| " | " | 20° | 2 | 99 | " |
| " | " | 30° | 23 | 18 | " |
| " | " | 40° | 6 | 72 | " |
| " | 3" | 20° | 47 plates & projectile lots CM-3-59 & CSA-1-2 considered | | J.P.G. |
| Face-hardened | 3" | 20° | Point obtained from firings against 81 plates, projectile lots CM-3-39, CM-3-59, & CSA-1-2 considered. | | J.P.G. |

COMPARISONS WITH 90MM APC M83 PROJECTILES

Fig. 9 gives available comparisons of homogeneous rolled plate (BHN 272) and face-hardened plate, Table VII giving available information on standard errors of the plotted points. The curves for 2-1/2", 3", and 4" homogeneous rolled plate (BHN 272) were obtained from data on the hardness program. The single point for 3" homogeneous rolled armor (BHN unknown) at 20° obliquity was obtained from Jefferson Proving Ground firing records and is based on information given in Table VII. The latter point exceeds the corresponding point from the hardness program by approximately 80 t/s, this being due probably to differences in measurements or tests at the two proving grounds, different projectile lots or quality, or a tendency in the hardness program to obtain "low" ballistic limits. The two points for face-hardened armor at 20° and 30° obliquity were obtained from Jefferson Proving Ground firing records. It is to be noted here that a direct comparison between 3" homogeneous rolled plate and 3" face-hardened plate, 20° obliquity, is available from tests at Jefferson Proving Ground and that homogeneous rolled plate appears to be superior.

Curves for 2-1/2" homo and 2-1/2" face-hardened plate are also given in Fig. 9 and are based on the protection criteria of penetration, the data being obtained from Armor Report AD-844. Although no standard errors of the points are available because of only one or two determinations of ballistic limit for each point,

90mm AP M77

FIG. 8

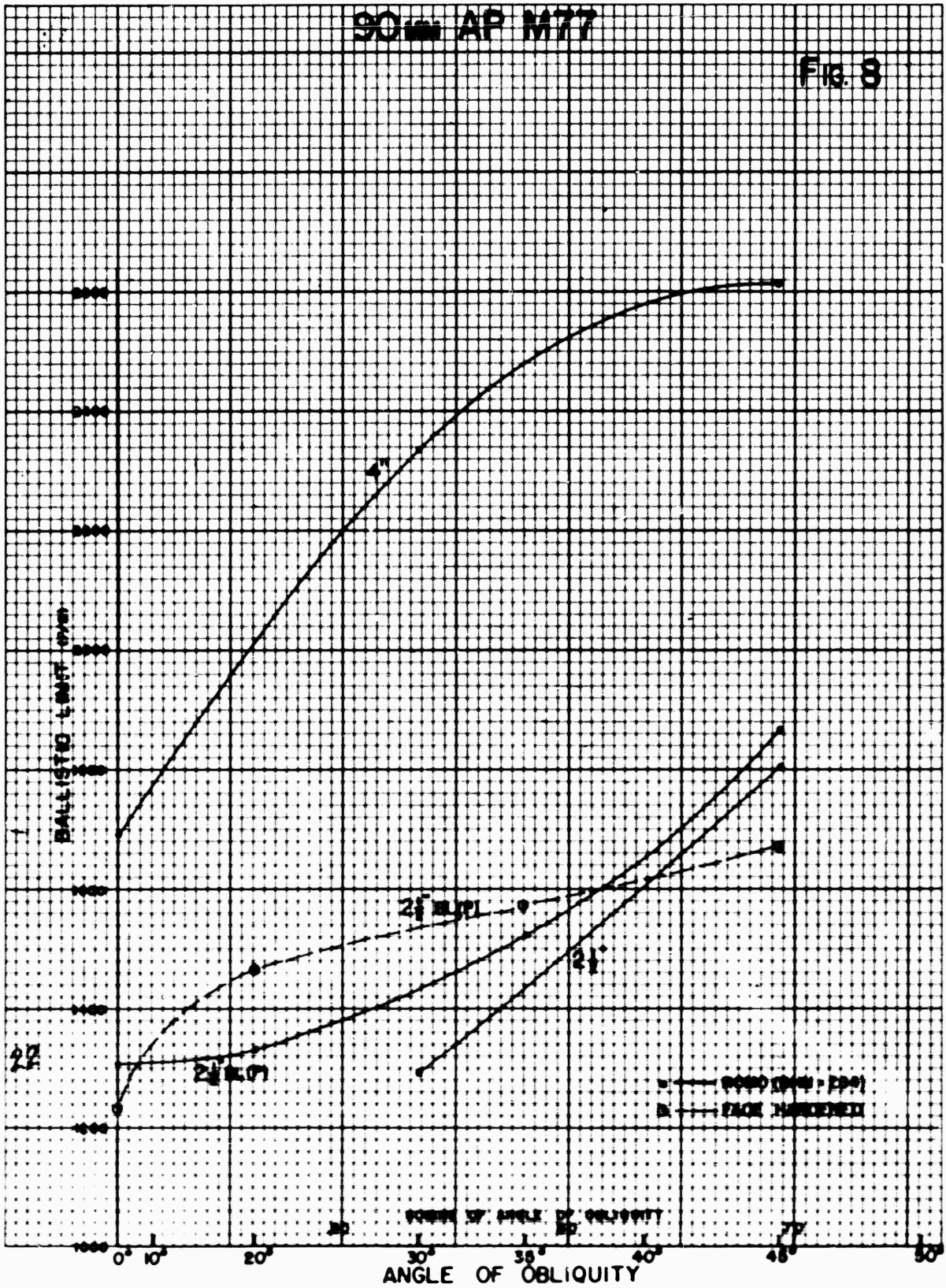


TABLE VI
Standard Errors of Plotted Points in Fig. 8

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point t/s | Source of Information |
|-----------------------|-----------------|--------------------|----------------------------|---------------------------------|-----------------------|
| Homo | 2-1/2" | 30° | 5 | 9 | Hardness Program |
| " | " | 45° | 5 | 7 | " |
| " | 4" | 0° | 5 | 35 | " |
| " | " | 30° | 3 | 31 | " |
| " | " | 45° | 3 | 37 | " |
| Homo [BL(P)] | 2-1/2" | 0° | 1 | | Armor Report AD-844 |
| " | " | 20° | 1 | | " |
| " | " | 35° | 2 | | " |
| " | " | 45° | 2 | | " |
| Face-hardened [BL(P)] | 2-1/2" | 0° | 1 | | " |
| " | " | 20° | 1 | | " |
| " | " | 35° | 2 | | " |
| " | " | 45° | 2 | | " |

It can be seen that the curve for 2-1/2" BL(P) homo plate is uniformly higher than the curve for 2-1/2" BL(P) face-hardened plate and hence, the indication is that for these conditions homogeneous plate is superior to face-hardened plate.

COMPARISONS WITH 20MM AP M75 AND AP M95 PROJECTILES

Because of the heterogeneous nature of the data for 20mm M75 and M95 projectiles no figures are given. However, Table VIII gives ballistic limits for homogeneous and face-hardened plate for M75 and M95 projectiles for various conditions of test, the information being obtained from Report ADP-159. Two of the columns of Table VIII list the algebraic signs + or -, the + sign meaning that face-hardened plate gave a higher BL and the - sign meaning that the homogeneous plate gave the higher BL for a given condition. Simply by counting the + signs for the M75 projectile, we find that the face-hardened plate is superior in 14 out of 19 conditions. The preponderance of higher ballistic limits for the face-hardened plate is nearly significant statistically although not positively so. In any event, there is an indication that face-hardened plate is superior to homogeneous plate when tested with the M75 projectile.

For the M95 projectile and a variety of test conditions, it happens that the face-hardened plate gave higher ballistic limits in 14 out of 19 cases available for comparison also. Hence, conclusions for the M95 projectile are essentially the same as for the M75 projectile.

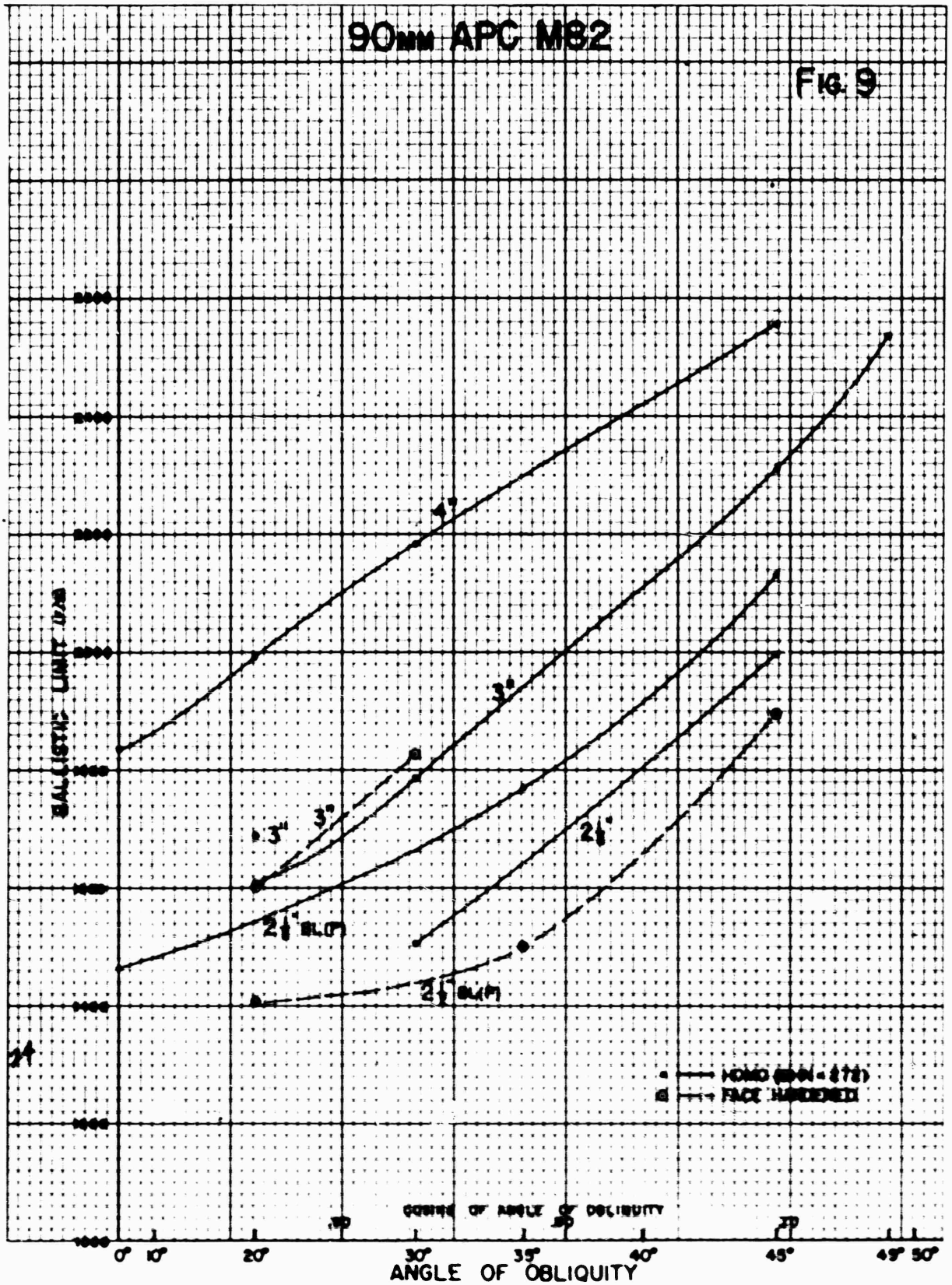


TABLE VII
Standard Errors of Plotted Points in Fig. 9

| Type Armor | Plate Thickness | Angle of Obliquity | No. BL's Point is Based on | Standard Deviation Of Point t/s | Source of Information |
|-----------------------|-----------------|--------------------|--|---------------------------------|-----------------------|
| Homo | 2-1/2" | 30° | 5 | 27 | Hardness Program |
| " | " | 45° | 7 | 13 | " |
| " | 3" | 20° | 3 | 24 | " |
| " | " | 30° | 10 | 8 | " |
| " | " | 45° | 32 | 14 | " |
| " | " | 49° | 4 | 79 | " |
| " | 4" | 0° | 4 | 63 | " |
| " | " | 20° | 5 | 35 | " |
| " | " | 30° | 9 | 6 | " |
| " | " | 45° | 1 | | " |
| " | 3" | 20° | Point obtained from data on projectile lots BS-3, -20, -33, -34, -37, -69, -82, -91 & 24 plates. | | J.P.G. |
| Homo [BL(P)] | 2-1/2" | 0° | 1 | | Armor Report AD-844 |
| " | " | 35° | 2 | | " |
| " | " | 45° | 2 | | " |
| Face-hardened [BL(P)] | 2-1/2" | 20° | 1 | | " |
| " | " | 35° | 2 | | " |
| " | " | 45° | 2 | | " |
| Face-hardened | 3" | 20° | Projectile lots BS-4, -6, -8, -34, -37, -40, -69, -77, -82, -91 & 27 plates considered. Projectile lots BS-8, -40, -69, -77, & 11 plates considered. | | J. P. G. |

TABLE VIII
20mm Summary
(From Report ADP-159)

| M75 AP Projectile | | | | | M95 AP Projectile | | | | |
|-------------------|-----------|--------------------|----------------|---|-------------------|-----------|--------------------|----------------|---|
| Thick- ness | Obliquity | Ballistic Limit | | | Thick- ness | Obliquity | Ballistic Limit | | |
| | | Homo | Face- hard. | | | | Homo | Face- hard. | |
| 3/8" | 40° | 1082 | 1240 | + | 3/8" | 40° | 1339 | 1602 | + |
| 3/8" | 40° | 1252 | 1205 | - | 3/8" | 40° | 1140 | 1341 | + |
| 1/2" | 30° | 1161 | 1753 | + | 1/2" | 0° | 1156 | 1718 | + |
| 1/2" | 30° | 1119 | 1570 | + | 1/2" | 30° | 1244 | 1689 | + |
| 1/2" | 40° | 1659 | 1865 | + | 1/2" | 30° | 1342 | 1385 | + |
| 1/2" | 40° | 1588 | 1681 | + | 1/2" | 40° | 1911 | 1817 | - |
| 1/2" | 50° | 1668 | 1900 | + | 1/2" | 40° | 1587 | 1789 | + |
| 3/4" | 0° | 1150 | 2008 | + | 1/2" | 50° | 2048 | 2023 | - |
| 3/4" | 0° | 1109 | 2062 | + | 3/4" | 0° | 1499 | 2124 | + |
| 3/4" | 20° | 1329 | 1966 | + | 3/4" | 0° | 1504 | 1946 | + |
| 3/4" | 30° | 1964 | 1840 | - | 3/4" | 20° | 1723 | 1771 | + |
| 3/4" | 30° | 2102 | 2012 | - | 3/4" | 30° | 1840 | 2052 | + |
| 7/8" | 0° | 1301 | 2056 | + | 7/8" | 0° | 1732 | 2107 | + |
| 7/8" | 20° | 2134 | 2232 | + | 7/8" | 20° | 1926 | 2205 | + |
| 7/8" | 30° | 2271 | 2204 | - | 7/8" | 30° | 2595 | 2396 | - |
| 7/8" | 30° | 2357 | 2258 | - | 7/8" | 30° | 2683 | 2355 | - |
| 1" | 0° | 1476 | 2345 | + | 7/8" | 40° | 2829 | 2583 | - |
| 1" | 0° | 1510 | 2221 | + | 1" | 0° | 2009 | 2614 | + |
| 1" | 0° | 1450 | 2356 | + | 1" | 0° | 1933 | 2916 | + |

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Details of the method of analysis and the partial regression equations are on file in the Surveillance Branch of the Ballistic Research Laboratories.

Frank E. Grubbs

Frank E. Grubbs

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ABSTRACT:

Army ballistic limits are used as medium for comparison of armor plate. Assuming average quality projectiles were used in firings on which this report is based, face-hardened armor is quite superior to homogeneous rolled armor in defeating cal. 0.30 AP M2 and cal. 0.50 AP M2 projectiles and hence a substantial saving in weight of armor can be effected for these conditions by using face-hardened armor. There are also indications that face-hardened armor may be slightly superior to homogeneous rolled armor when comparisons are made with 20 mm AP M75 and M95 projectiles.

(23) * Armor plate
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