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REPORT NO. 710/6

THE RELATION OF CHARPY IMPACT VALUES TO THE BALLISTIC LIMIT OF LIGHT ARMOR PLATE

BY

WM. J. LATIMER, JR.

1933

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THE RELATION OF CHARPY IMPACT VALUES TO THE BALLISTIC LIMIT OF LIGHT ARMOR PLATE.

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INTRODUCTION

The purpose of this investigation was to determine the relation between the Charpy impact test and the ballistic limit of light armor plate.

STATEMENT OF CONCLUSION

There is apparently a definite relation between the Charpy impact test and the ballistic limit of light armor plate. The curves of Charpy vs. plate thickness, Fig. 4, and ballistic limit vs. plate thickness, Fig. 2, are both straight line curves with equations of the form, $y = ax+b$. By combining these two curves, the resultant curve, Fig. 5, of Charpy vs. ballistic limit is a straight line curve of the form, $y = ax$. These conclusions, then, tend to show that for a plate of this composition and treatment, we can predict the ballistic limit by the simple expedient of measuring the Charpy of the given plate.

HISTORICAL DEVELOPMENT

As far as can be ascertained, no previous work has been attempted to correlate the Charpy impact test and ballistic limit of armor plates.

THEORETICAL CONSIDERATION

The energy absorbed in the Charpy impact test produces both elastic and plastic deformation and heat.

The kinetic energy of a bullet, when it strikes an armor plate, is dissipated in the following manner:

1. Punching a hole through the plate - as in a punch press.

2. Converted into heat (Ft.Lbs. x 778 = BTU) to raise temperature of bullet and plate.

3. Deforming the plate both elastically and plastically. It is believed that the energy used to deform the plate is again converted, into heat energy, absorbed by the plate.

   The difference, then, in the energy dissipation in the two cases, is that the ballistic energy, in addition to performing all the work done in Charpy test, is also absorbed in shear, and heating the bullet. Also, the difference in time of the two actions enters into the relation.

EXPERIMENTAL PROCEDURE

The apparatus used in ballistic tests was:

DISSTON homogeneous plates: 7 - 3/16" plates
8 - 1/4" "
8 - 3/8" "
2 - 1/2" "

126 Cartridges, caliber .30 A.P.; Model 1922, 165 gr. bullet.

1 Caliber .30 Mann barrel: Model 1903

1 Standard frame for supporting thin armor plate (drawing A.P.G. 1445-A3)

A.P.G. Chronograph, range and facilities

Apparatus used for Charpy impact test

Moulton-Pendule 300 kgm. Charpy impact machine.

14 Test specimens from 3/16" plates
32 " " " 1/4" "
16 " " " 3/8" "

A new Charpy specimen was developed for this test. Its dimensions are shown in Fig. 6. The standard test bar was tried at first but proved impracticable Trials on two 1/2" plates showed only 3 or 4 ft. lbs. A special fixture was used to hold the new type specimen in the Charpy machine.

8 Charpy values were used in calculations of 3/16" plate: 24 values for 1/4" plates; and 8 values for 3/8" plate. An equal number of specimens in each set were with and against major axes of rolling The reason for rejecting some values was the proximity of some of the specimens to bullet holes and the fact that the beginning of rupture could be definitely traced to prick-punch marks made to outline the specimen before cutting. Both of these effects caused results which were not in line with other results For these reasons, the values obtained from the 1/2" plates were not used in determinations.

There was a mean variation of 7.06 ft. lbs from the trend of values with a maximum variable of 65 ft. lbs., 105 ft. lbs. and 62 ft. lbs. for 1/16", 1/4" and 3/8" plates respectively. The Charpy machine is accurate within 5 ft. lbs.

Ballistic limits, in foot pounds, were taken from the "Fiftieth Partial Report on Test of Thin Armor Plate", Aberdeen Proving Ground, April 29, 1932. The results with 1/2" plates were too few in number to be used in determinations Ballistic limits are accurate within 30 ft. lbs.

EXPERIMENTAL RESULTS

TABLE I

Plate No.	Thickness Inches	A. P. G. Ballistic Limit Ft.Lbs.	Charpy - Ft.Lbs		Ave. Corrected Bal. Limit Ft. Lbs.	Ave. Corrected Charpy Ft. Lbs.
A-221	.195	809	485.1	493.8		
A123	.212	868	655.3	546.2		
B811	.212	860	-	537.4		
D611	.218	873	-	-		
D711	.215	824	564.1	-		
H221	.210	853	-	-		
H611	.210	891	537.4	590.1	720	455
A1E2	.276	1270	806.9 875.3	836.2 836.2		
A321	.260	1071	768.5 730.1	730.1 664.6		
A611	.258	1171	720.3 749.0	720.3 696.6		
A711	.255	1079	749.0 701.5	711.3 664.6		
B122	.273	1207	846.0 816.7	778.3 788.0		
C111	.287	1287	749.0 -	797.2 -		
D121	.273	1174	739.9 749.0	806.9 701.5		
H711	.280	1128	894.9 875.3	797.2 758.7	1050	675
A122	.377	1821	1082.8	-		
A211	.369	1660	1092.4	1073.6		
A311	.373	1813	-	1073.6		
A3-1	.388	1837	-	-		
A412	.378	1820	1112.0	1073.6		
A531	.377	1789	-	-		
B112	.395	1946	-	1092.4		
B221	.402	1898	1230.6	-	1760	1085

TABLE II

DISSTCN PLATE C-1

See "Fortieth Partial Report on Test of Light Armor Plate", A. F. G.

Bullet Caliber	Ballistic Limit Ft. Lbs.	Vol. of Metal Removed Cu. In.	Ballistic Limit per Cu. In. '#'s/cu.in.
.30	2584	.02455	105,300
.50	7964	.0753	105,900

DISCUSSION OF RESULTS

Figure 4 shows the relation of Charpy to thickness (and to volume) of plate. This is a straight line relation, as expected. This straight line relation has been observed in the laboratory at Watertown Arsenal for a great many years. Niles[1] and Warner[2] have conducted experiments on the relation of Charpy to volume (and thickness). Their results further confirm this relation.

Figure 2 shows the relation of ballistic limit to plate thickness, (and volume of metal removed by bullet). This curve is also a straight line. Reference to Figure 1, where individual plate ballistic limits are recorded, shows all plates passed specification requirements when tolerances of +.03",-.02" are taken into consideration.

Figure 5, a combination of Figures 2 and 4, shows the relation of ballistic limit to Charpy. This is a straight line, as would be expected, since both figures 2 and 4 are straight lines. This line also passes through the origin, which again is as expected.

---

1. W. E. NILES, 2nd Lt., C. D., in thesis for degree at Massachusetts Institute of Technology, "Effect of Width of Notch in Tensile Charpy Bar". Thesis #32, May 13, 1931.

2. W. I. WARNER, welding engineer at Watertown Arsenal, conducted Charpy tests with bars similar to those used in these tests; January-February, 1933.

The thickness of Charpy specimens differed slightly, due to irregularities in thickness of plates as manufactured. The Charpy results were plotted against actual thicknesses in figures 3A, 3B and 3C, and Charpy values for 3/16", 1/4" and 3/8" plate thicknesses taken from trend shown for plotted values.

This same procedure was followed in determining the ballistic limit for plates of 1/4" and 3/8" thickness, (see figures 1A and 1B). The trend for Ballistic limit for 3/16" plates was indeterminate, therefore the average ballistic limit of 854 ft. lbs. for average plate thickness of .2103" was used in figure 2 to determine the actual trend of all plates.

Figure 2 shows ballistic limit vs plate thickness and volume of metal removed. To determine the volume of metal removed, the pierced holes in all sets of plates were measured. The .30 caliber bullet pierced a hole approximately 1/4" in diameter. The .50 caliber bullet pierced a hole approximately 7/16" in diameter. Since volume is equal to $\frac{\pi d^2}{4} \times t$, or Kt for same caliber bullet, it is evident that the ballistic limit varies with an increase in volume. An interesting fact, which perhaps should receive some further investigation, was discovered in connection with this relation of ballistic limit to volume of metal removed. From the "Fortieth Partial Report on Test of Light Armor Plate", Aberdeen Proving Ground, wherein are results of firing with both .30 and .50 caliber bullets at plate C-1,

can be calculated the ballistic limit per cubic inch of metal removed. These show 105,300 ft. lbs per cu. in. for .30 caliber and 105,900 ft. lbs. per cu. in. for .50 caliber. See Table II. These results tend to indicate that the ballistic limit per cu. in. of metal removed is the same for all calibers on same plate. However, this should be further substantiated by additional tests.

CONCLUSIONS

From the foregoing it is evident that ballistic limit and Charpy values are correlated, and that by determining the Charpy for a given plate thickness, the ballistic limit of that plate can be read from curve, figure 5.

This is true for these plates tested. Whether or not it is true for other makes and compositions of plates, remains to be confirmed or disproved by further tests.

No conclusion will be drawn at present regarding the percentage dissipation of ballistic energy. This will be attempted later.

Respectfully submitted,

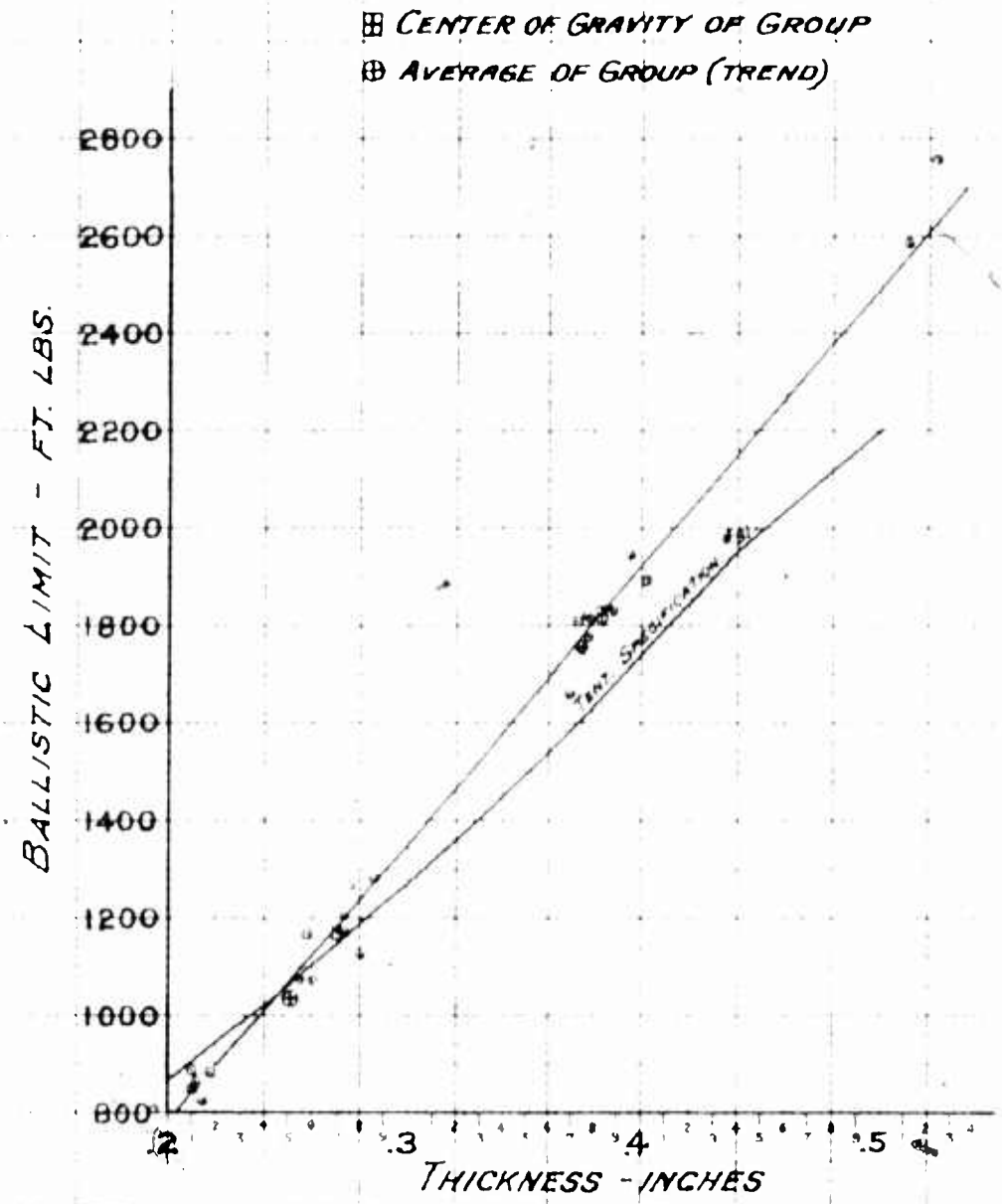
Wm. J. Latimer, Jr.
2nd Lt., Ord. Dept.

D. J Martin
1st Lt., Ord. Dept.

FIGURE 1.

DISSTON LIGHT ARMOR PLATE
HOMOGENEOUS

BALLISTIC LIMIT VS.
THICKNESS



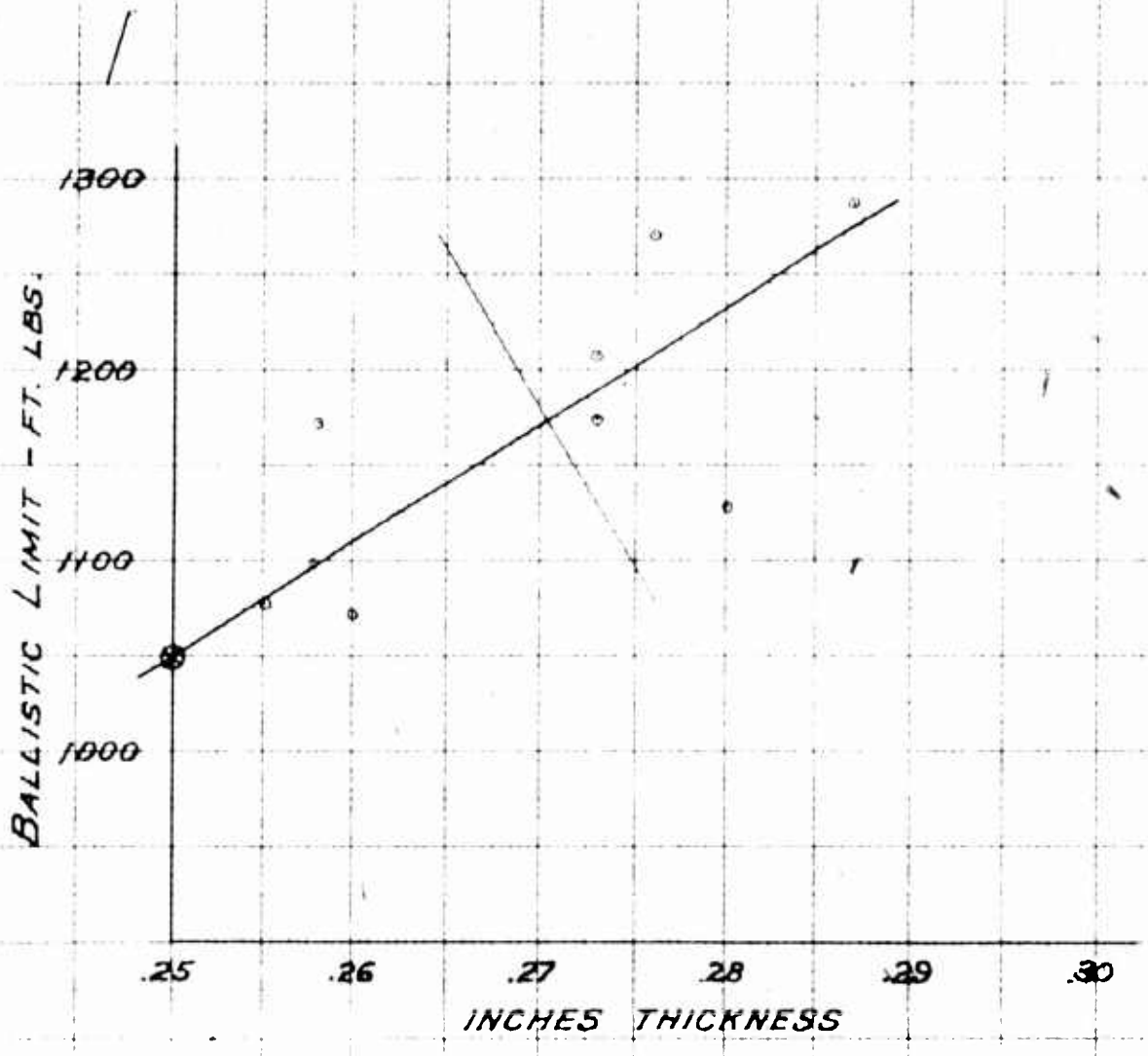
SOURCE ___ A.P.G. PARTIAL REPORT #50.

FIGURE 1A.

DISSTON $\frac{1}{4}$" PLATE

HOMOGENEOUS

BALLISTIC LIMIT VS. THICKNESS



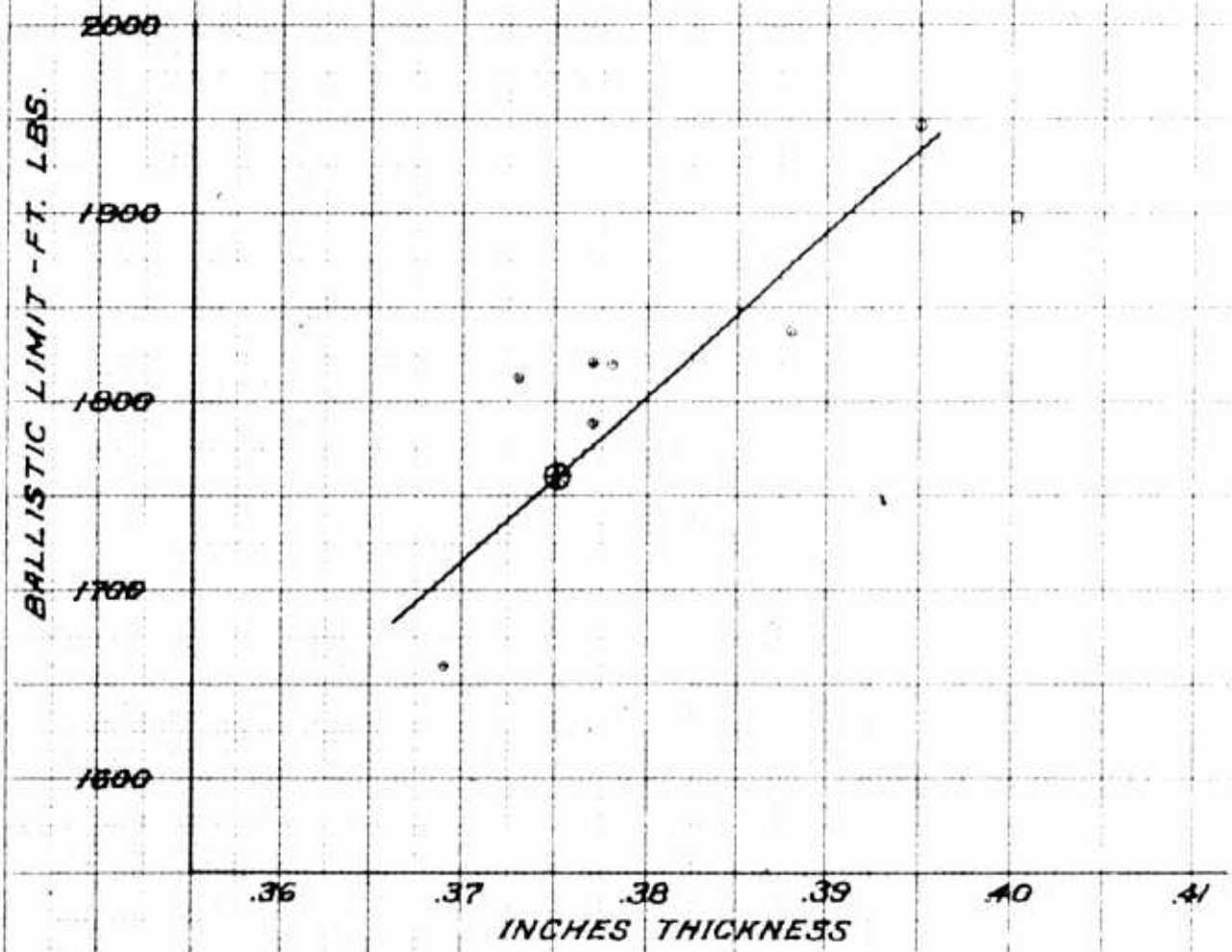
SOURCE: A.P.G. PARTIAL REPORT #50.

FIGURE 1B.

DISSTON $\frac{3}{8}$" PLATE

HOMOGENEOUS

BALLISTIC LIMIT VS. THICKNESS



SOURCE: A.P.G. PARTIAL REPORT #50.

FIGURE 2.

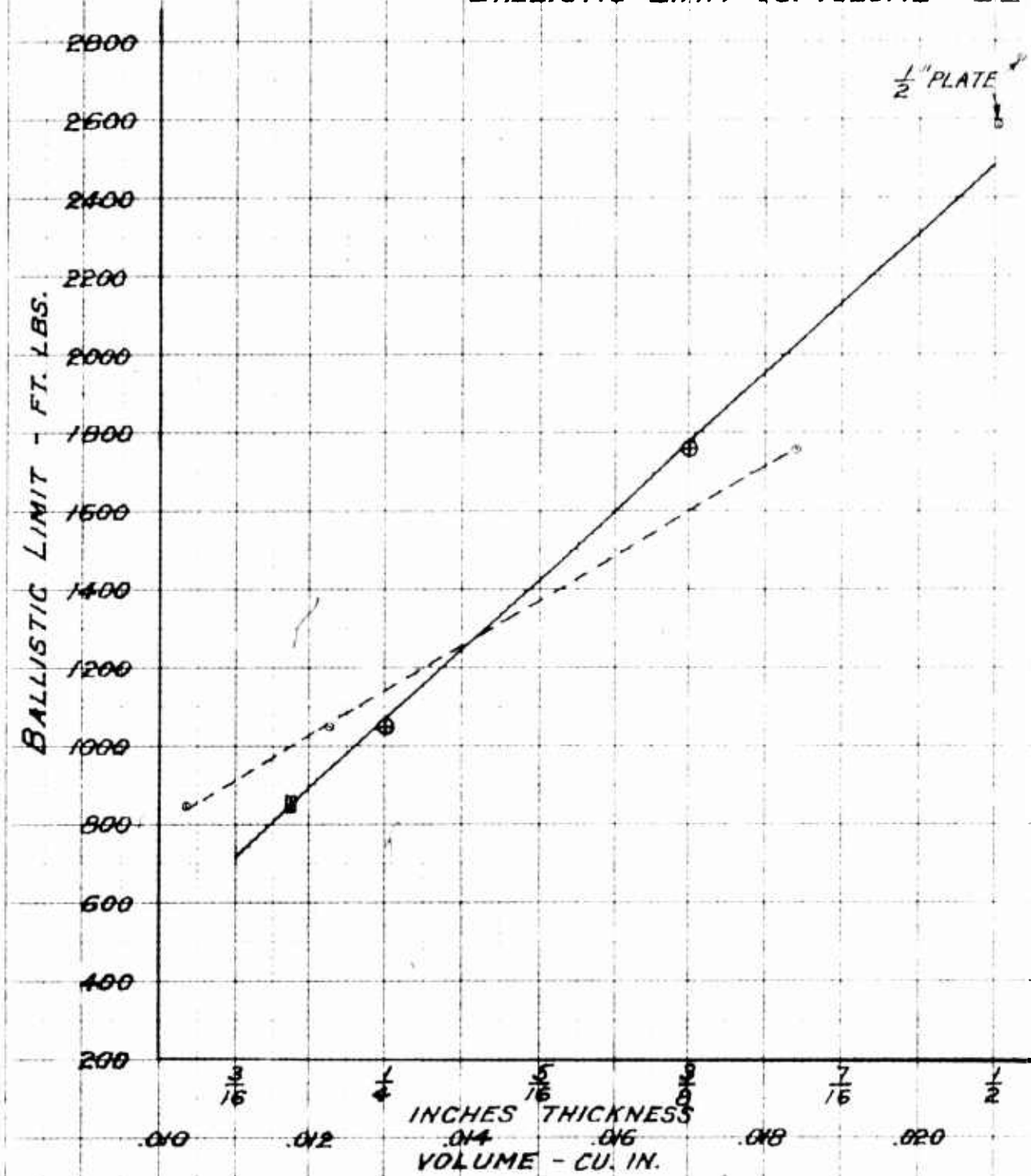
DISSTON ARMOR PLATE

HOMOGENEOUS

BALLISTIC LIMIT VS. THICKNESS

(COMPOSITE RESULTS)

BALLISTIC LIMIT VS. VOLUME



SOURCE: FIGURES 1, 1A, 1B.

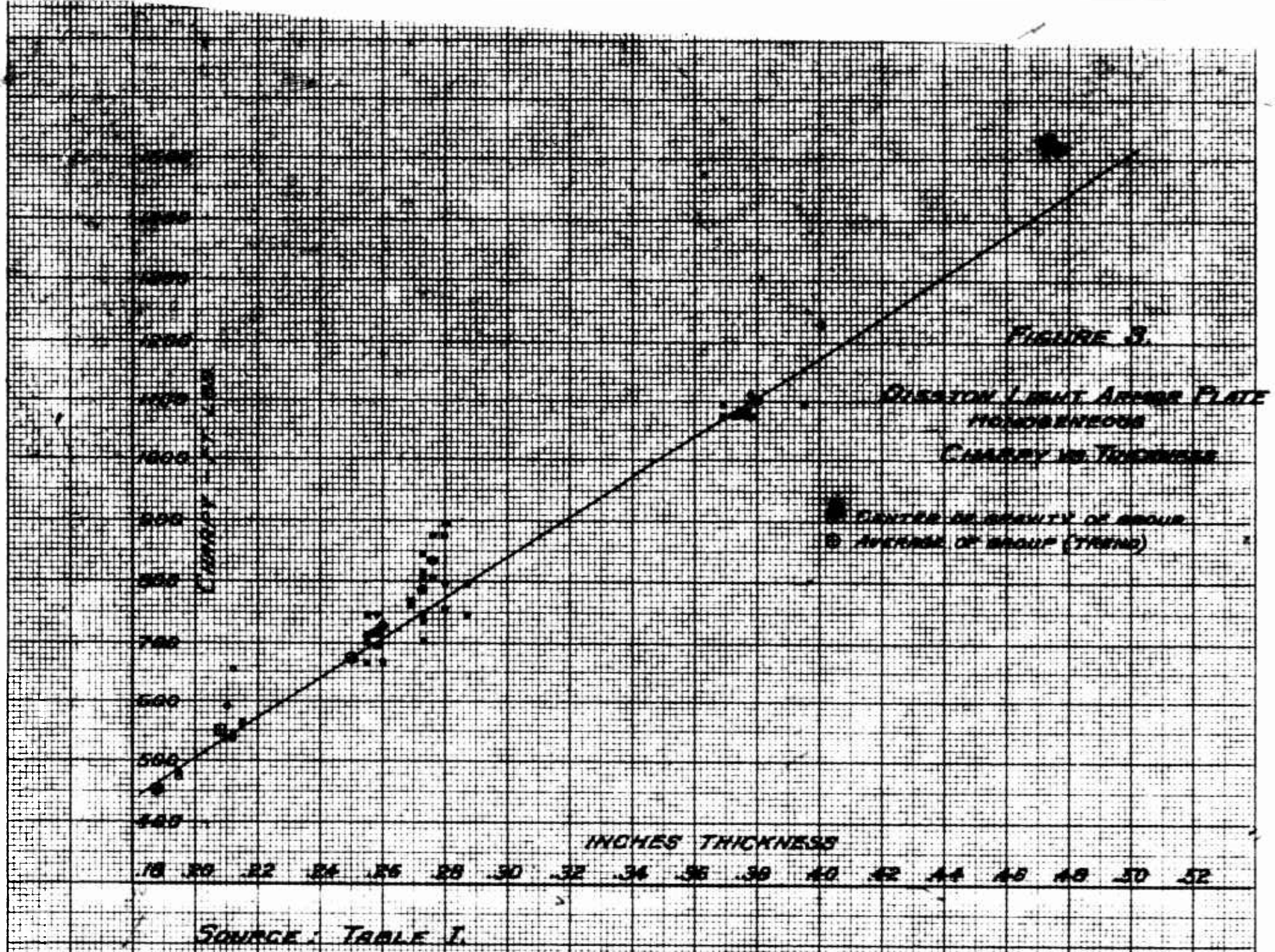
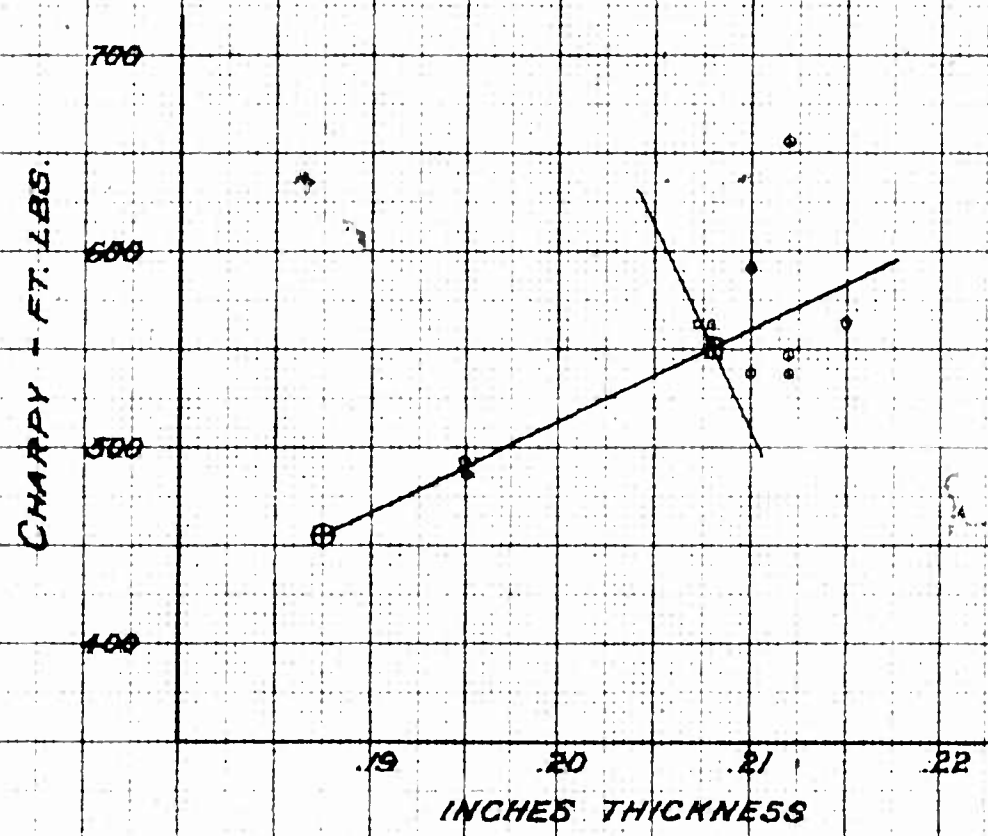

CHARPY
INCHES THICKNESS
.18 .20 .22 .24 .26 .28 .30 .32 .34 .36 .38 .40 .42 .44 .46 .48 .50 .52
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
2500
2600
2700
2800
2900
3000
3100
3200
3300
3400
3500
3600
3700
3800
3900
4000
4100
4200
4300
4400
4500

FIGURE 3A.

DISSTON $\frac{3}{16}$" PLATE

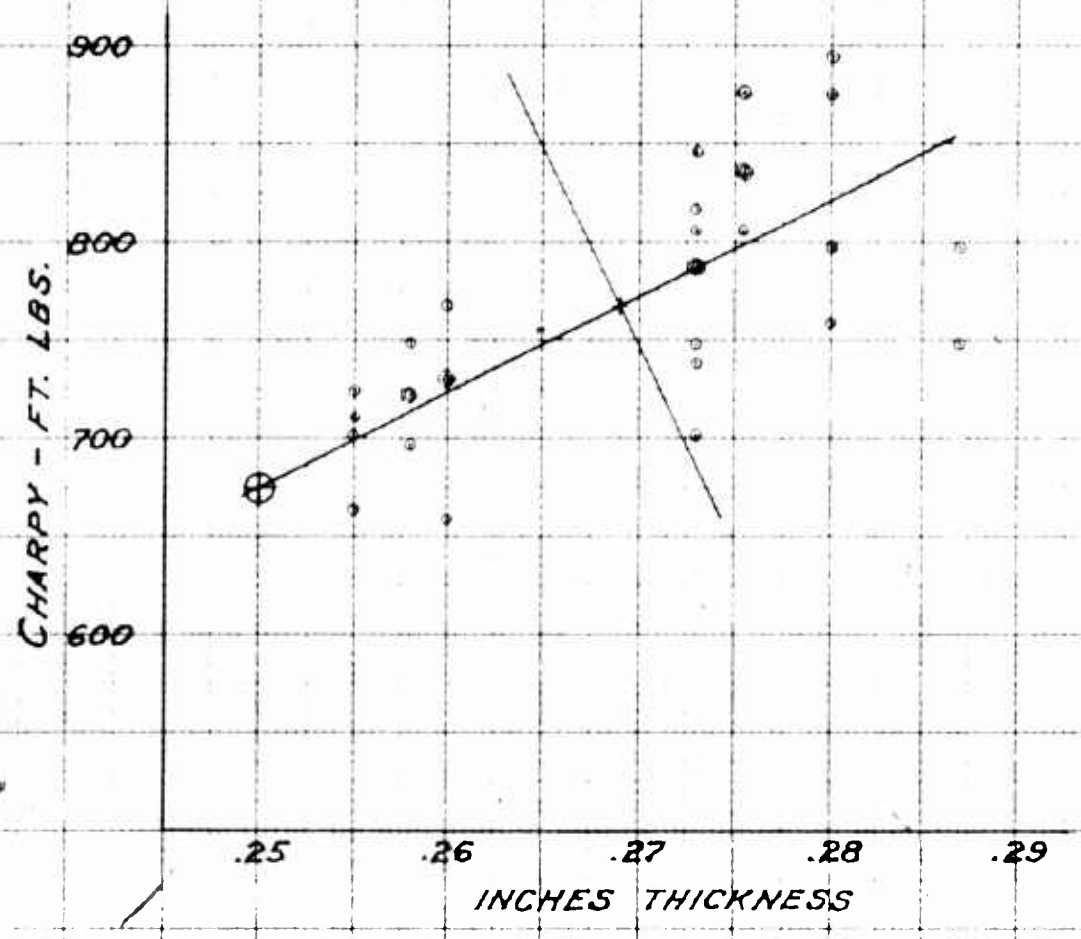
HOMOGENEOUS

CHARPY VS. THICKNESS



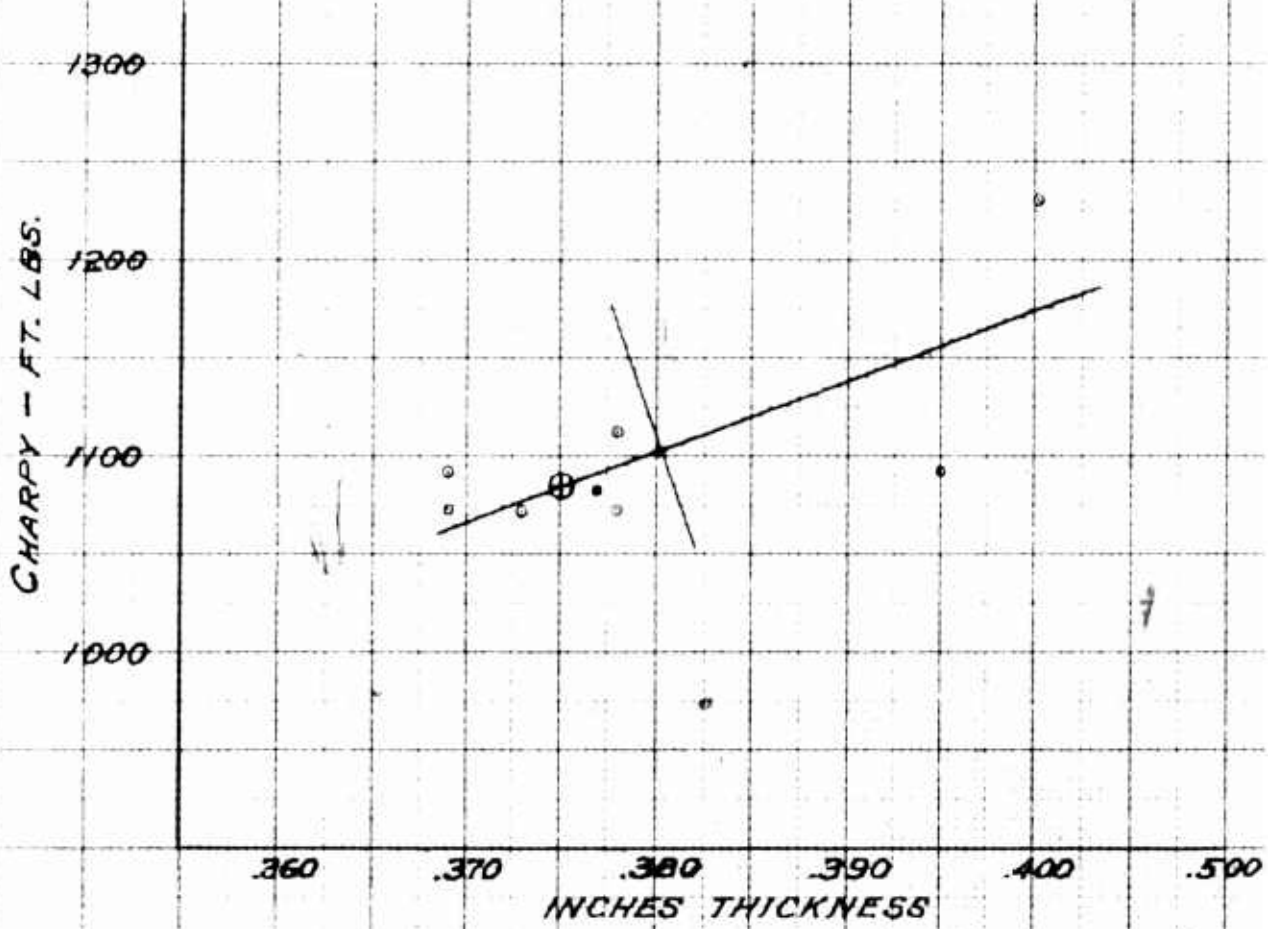
SOURCE: TABLE I.

FIGURE 3B.
DISSTON $\frac{1}{4}$" PLATE
HOMOGENEOUS
CHARPY VS. THICKNESS



SOURCE: TABLE I.

FIGURE 3C.
DISSTON $\frac{3}{8}$" PLATE
HOMOGENEOUS
CHARPY VS. THICKNESS



SOURCE: TABLE I.

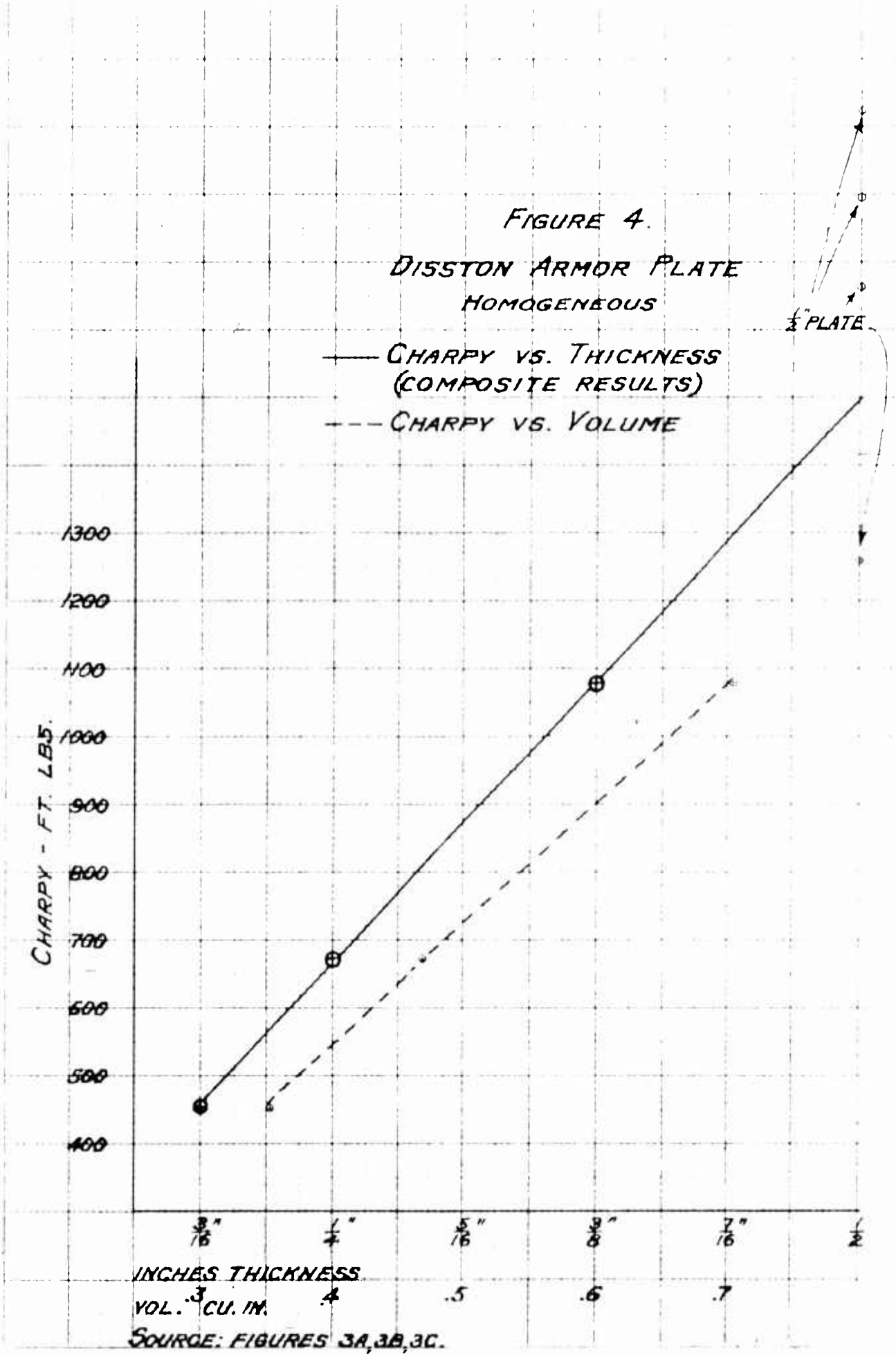
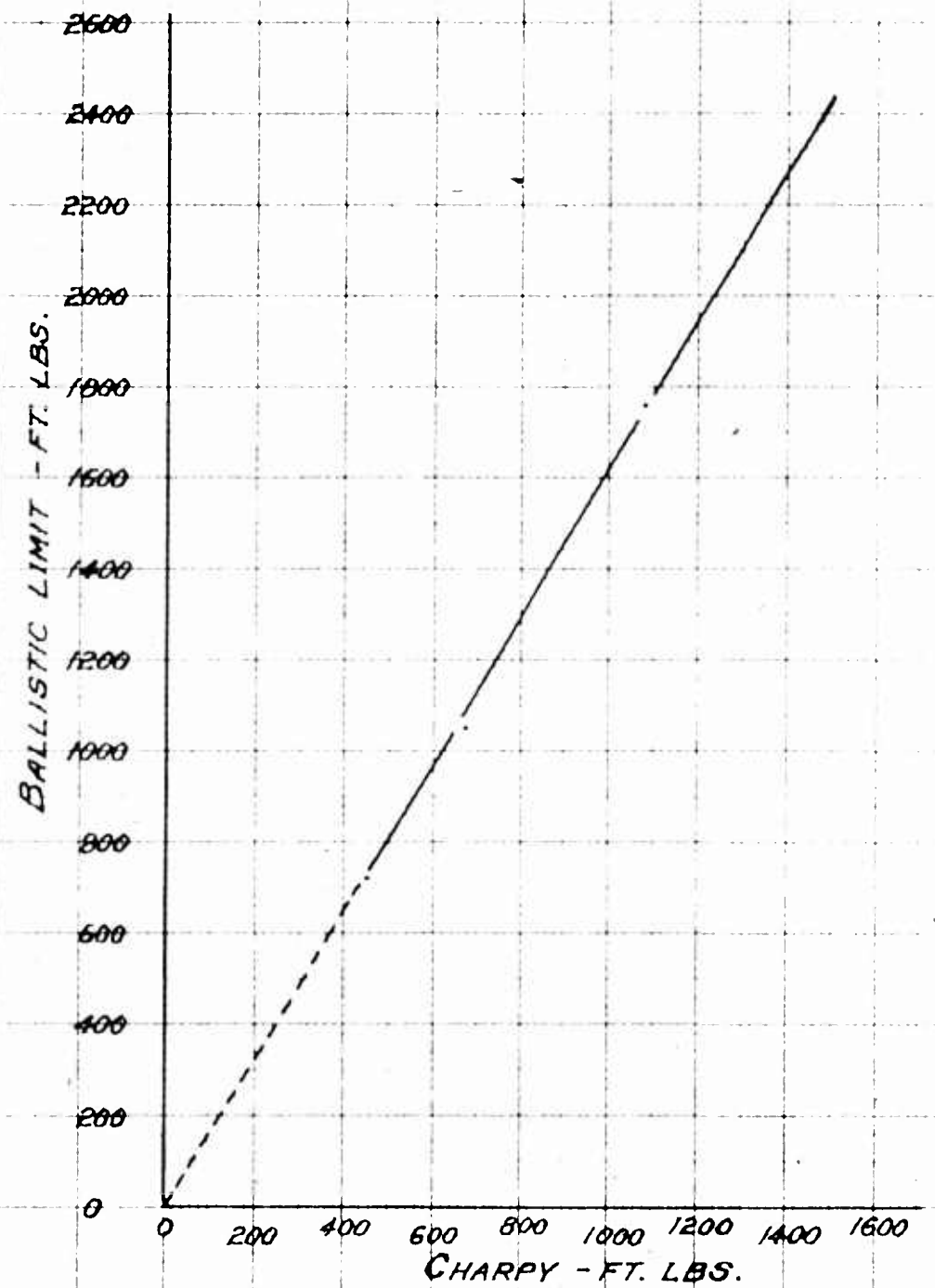


FIGURE 4.
DISSTON ARMOR PLATE
HOMOGENEOUS
CHARPY VS. THICKNESS
(COMPOSITE RESULTS)
CHARPY VS. VOLUME
1/2" PLATE
CHARPY - FT. LBS.
1300
1200
1100
1000
900
800
700
600
500
400
3/16"
1/4"
5/16"
3/8"
7/16"
1/2
INCHES THICKNESS
VOL. CU. IN.
.3
.4
.5
.6
.7
SOURCE: FIGURES 3A, 3B, 3C.

FIGURE 5.
DISSTON ARMOR PLATE
BALLISTIC LIMIT VS. CHARPY



SOURCE: FIGURES 2 & 4

FIGURE 6.

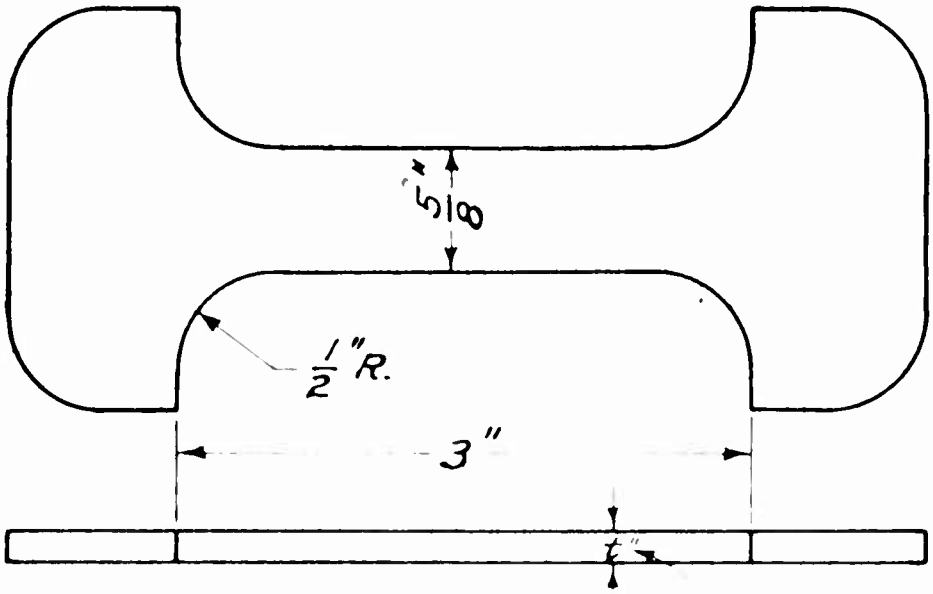


PLATE THICKNESS