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U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA

REPORT NO. 14-43

THE PENETRATION OF HOMOGENEOUS LIGHT ARMOR BY JACKETED PROJECTILES AT NORMAL OBLIQUITY

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THE PENETRATION OF HOMOGENEOUS LIGHT ARMOR BY JACKETED PROJECTILES AT NORMAL OBLIQUITY

APPROVED:

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PREFACE

AUTHORIZATION

This investigation is a part of Project No. 61, of the Experimental Department.

OBJECT

To provide a unified framework by which to correlate the ballistic performance of homogeneous light armor at different hardnesses and thicknesses; to discuss the results thus far obtained on the performance of such armor.

SUMMARY

The result of heavy Class B armor investigations, that the limit energy function (Mv^2/d^3) is a linear function of thickness of armor in calibers, is confirmed for homogeneous light armor attacked by jacketed armor-piercing projectiles at normal obliquity. The effect of changing the hardness of the armor is investigated; and some information on the effect of chemical composition gained. Other principal results are:

(1) At a given thickness in calibers (e/d), the ballistic performance of armor of a given composition improves with increasing hardness until it reaches a maximum and then deteriorates with further increase in hardness. The hardness corresponding to maximum performance, or optimum hardness, increases with increasing e/d. The improvement in ballistic performance obtainable by increasing the hardness also increases with increasing e/d.

(2) The ballistic performance of armor steel of otherwise constant composition increases with increasing carbon content over the whole range tested (0.29% to 0.48%).

(3) A method has been developed by which the ballistic merits of armor steels of different compositions may be compared even though their ballistic test plates have different thicknesses and hardnesses.

C O N T E N T S

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I INTRODUCTION

Until recently, no valid procedure had been developed by which ballistic results on homogeneous armor of different hardnesses and thicknesses, tested with different projectiles, could be intercompared. The usefulness of a general scheme which would permit such a comparison is obvious; it would indicate the answer to such questions as which of two chemical compositions makes the better armor, or to what hardness should a plate of given composition and thickness be brought to afford best protection. It is usually not possible to test ballistically plates of all thicknesses and hardnesses of interest, or even to produce two plates of exactly the same thickness and hardness, so that direct comparison is difficult. A unifying framework, in addition, would permit the making of useful generalizations about armor behavior.

Recent work on penetration ballistics at the Naval Proving Ground has led to an hypothesis concerning armor penetration by armor-piercing projectiles, which is very useful in formulating a general scheme of the kind desired. If conditions are limited to firing at normal obliquity, which will be the case throughout this report, this hypothesis states that the penetration resistance of homogeneous armor is governed by the equation

$$U = -A + B\, e/d \quad \text{- - - - - - -} \quad (1)$$

$$U = Mv^2/d^3 \times 10^{-8} = (e/d)F^2 \times 10^{-8} \quad \text{- -} \quad (2)$$

where: e is thickness of armor in feet.
d is diameter of projectile (or core of jacketed projectile) in feet.
e/d is thickness of armor in calibers.
M is mass of projectile (or core of jacketed projectile) in pounds.
v is limit velocity in feet per second.
F is the usual Navy penetration limit coefficient.

The factor of 10^{-8} is inserted purely for numerical convenience, and A and B are constants which are independent of e and d, but may vary with the chemical composition and physical properties of the armor. U is the limit energy of the projectile, divided by $(1/2)d^3$ to reduce to a common scale, and shall be called the limit energy function.

Equation (1) is subject to certain limitations: first, the limit velocity must be the Navy limit, that is, the velocity at which the complete projectile (or, in the case of jacketed bullets, the complete core) just passes through the plate and falls undeformed on the other side; secondly, the major portion of the energy required to produce a hole in the plate must go into causing the plate material to flow plastically. The first limitation rules out, at present, the application to firing at obliquities of 30° (where there exist some data) with service .30 and .50 caliber AP bullets, since at 30° obliquity these deform so badly that to obtain a limit with undeformed projectiles is impracticable. The second limitation rules out very thin plates (e/d less than about 0.5), which fail primarily by stretching and tearing, and very hard plates, which are characterized by punching (or spalling) upon complete penetration.

The physical interpretation of the quantities A and B is not difficult to see: B is the amount of energy required to increase (by a process of plastic flow) by one caliber the depth of a hole part way through a very thick plate; A is the deficit of energy associated with the ends of the hole in the plate, since the metal not reenforced by other metal will deform more easily; for example, by forming petals.

II RESULTS OF EXPERIMENTAL PROGRAM

Equation (1) was developed on the basis of a study of relatively heavy Class B armor attacked by uncapped projectiles. To determine whether it also held for the jacketed AP projectiles used against light armor, and to discover how the ballistic resistance of homogeneous light armor depends on the hardness to which it is treated, a preliminary investigation was made of the already existing data. From the Naval Proving Ground files were assembled all ballistic limits obtained on Jessop Steel Co. plates up to August, 1942, when this investigation began. This manufacturer was chosen as a successful producer who had submitted a sufficiently large and varied sample of plates of the same chemical composition to represent an adequate body of data. From each limit U was computed by equation (2) and plotted against e/d. The appearance of the plot was distinctly encouraging, and it was decided to obtain more data under conditions designed to test the hypothesis, and for armor steels of different chemical compositions.

Accordingly, two Carnegie-Illinois plates of 3/8" and 1/2" thickness were cut up and the pieces heat treated at the Armor and Projectile Laboratory to a series of measured Brinell hardnesses. Ballistic limits were then carefully determined, with Cal. .30 AP M2 and Cal. .50 AP M2 bullets at normal obliquity, on each piece of plate. Two Great Lakes 1/2" plates and two Disston 1/2" plates were also put through the same procedure. Again U was computed for each limit and plotted against e/d. The results are shown in Figs. 1 to 4 for Carnegie, Great Lakes, Disston, and Jessop, respectively. The points on these charts are experimental; the lines are obtained as outlined below. For the benefit of those who may not be familiar with this mode of presentation, Table I may be of assistance.

TABLE I

Projectile	Cal. .30 AP M2	Cal. .50 AP M2
d (in.)	0.2445	0.4275
M/d^3 (lb./ft.^{3})	1401	1290
e/d for plate of thickness: 0".250	1.022	0.585
0".375	1.534	0.877
0".500	2.045	1.170

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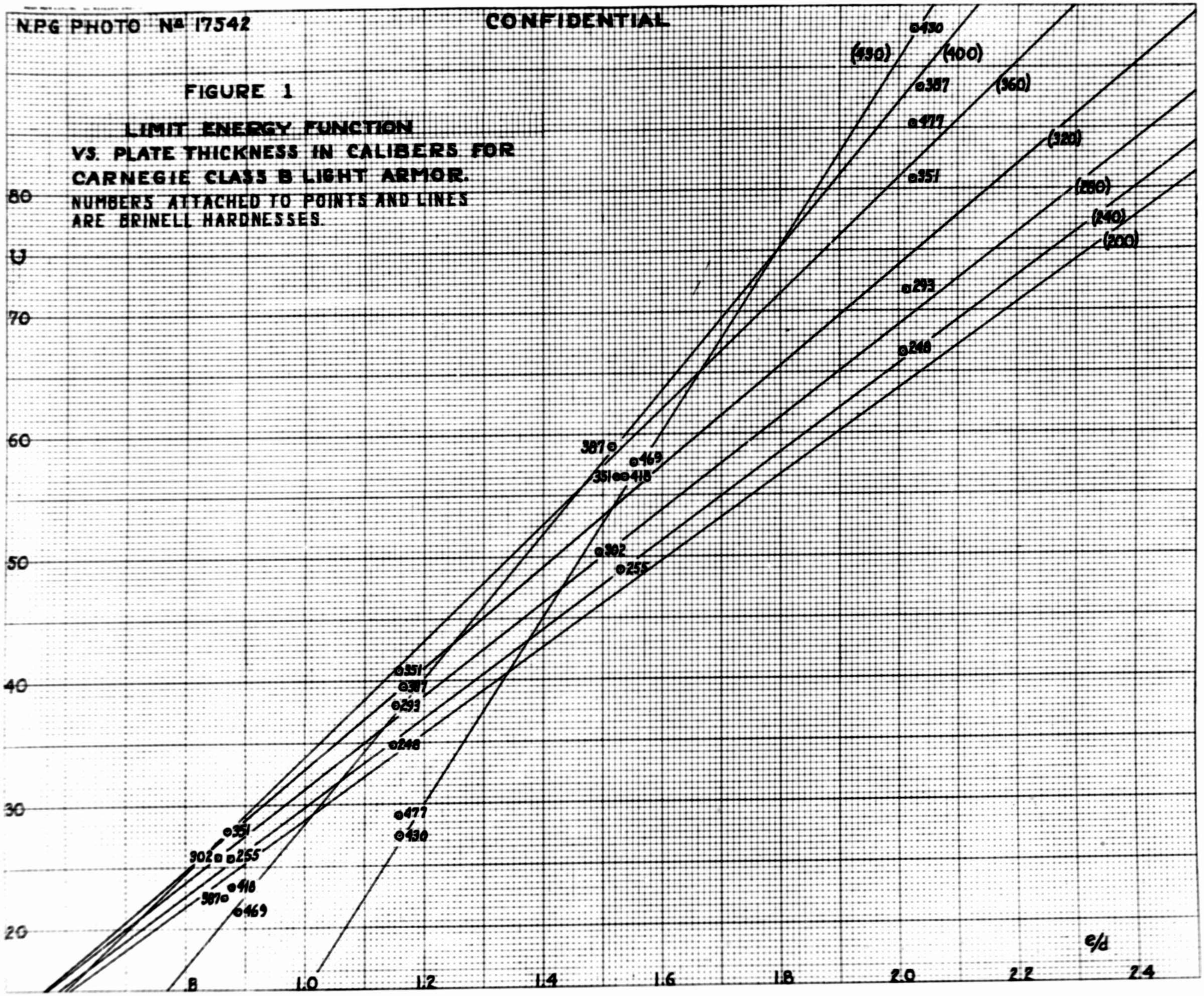

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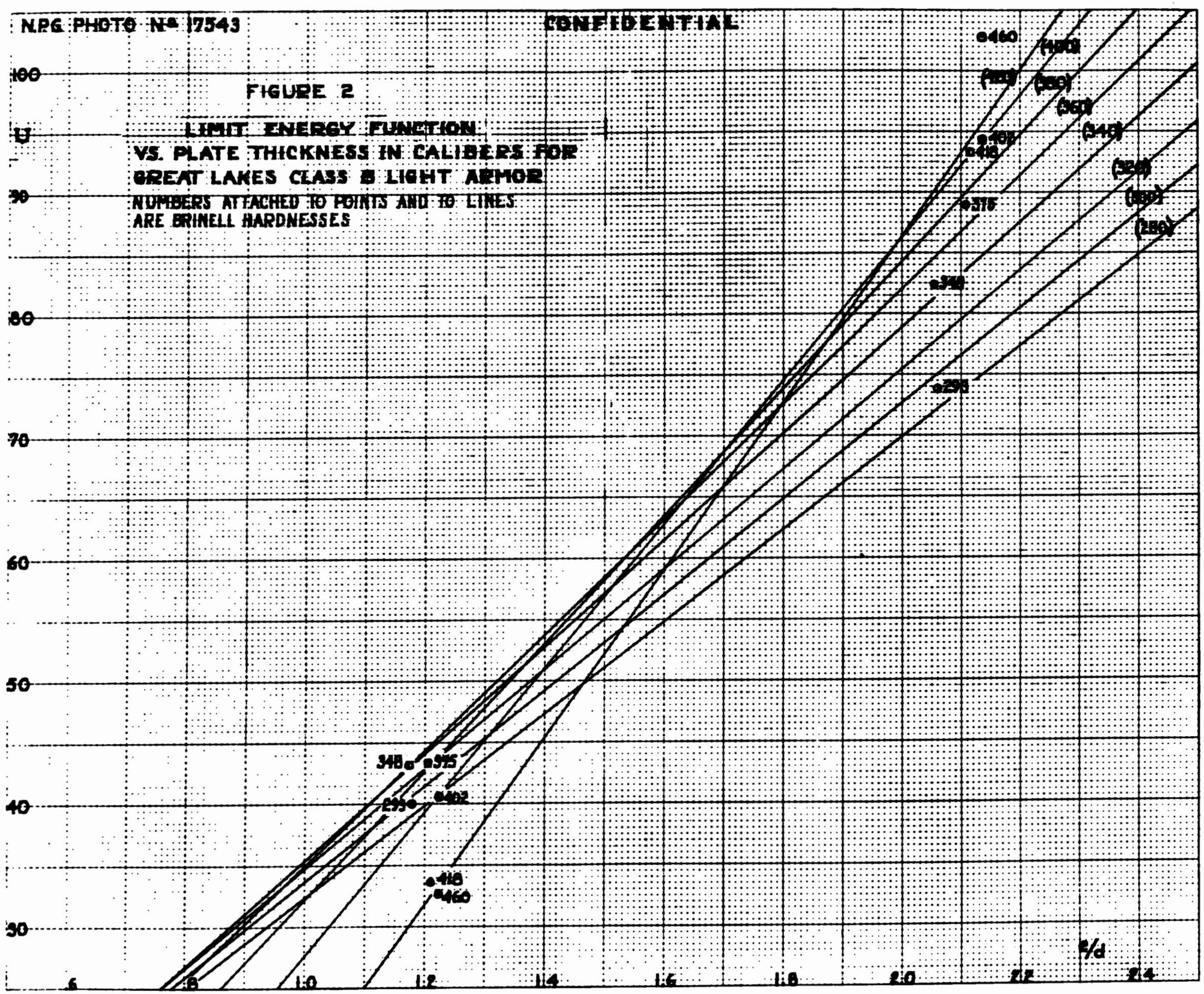

FIGURE 2

LIMIT ENERGY FUNCTION

VS. PLATE THICKNESS IN CALIBERS FOR GREAT LAKES CLASS B LIGHT ARMOR

NUMBERS ATTACHED TO POINTS AND TO LINES ARE BRINELL HARDNESSES

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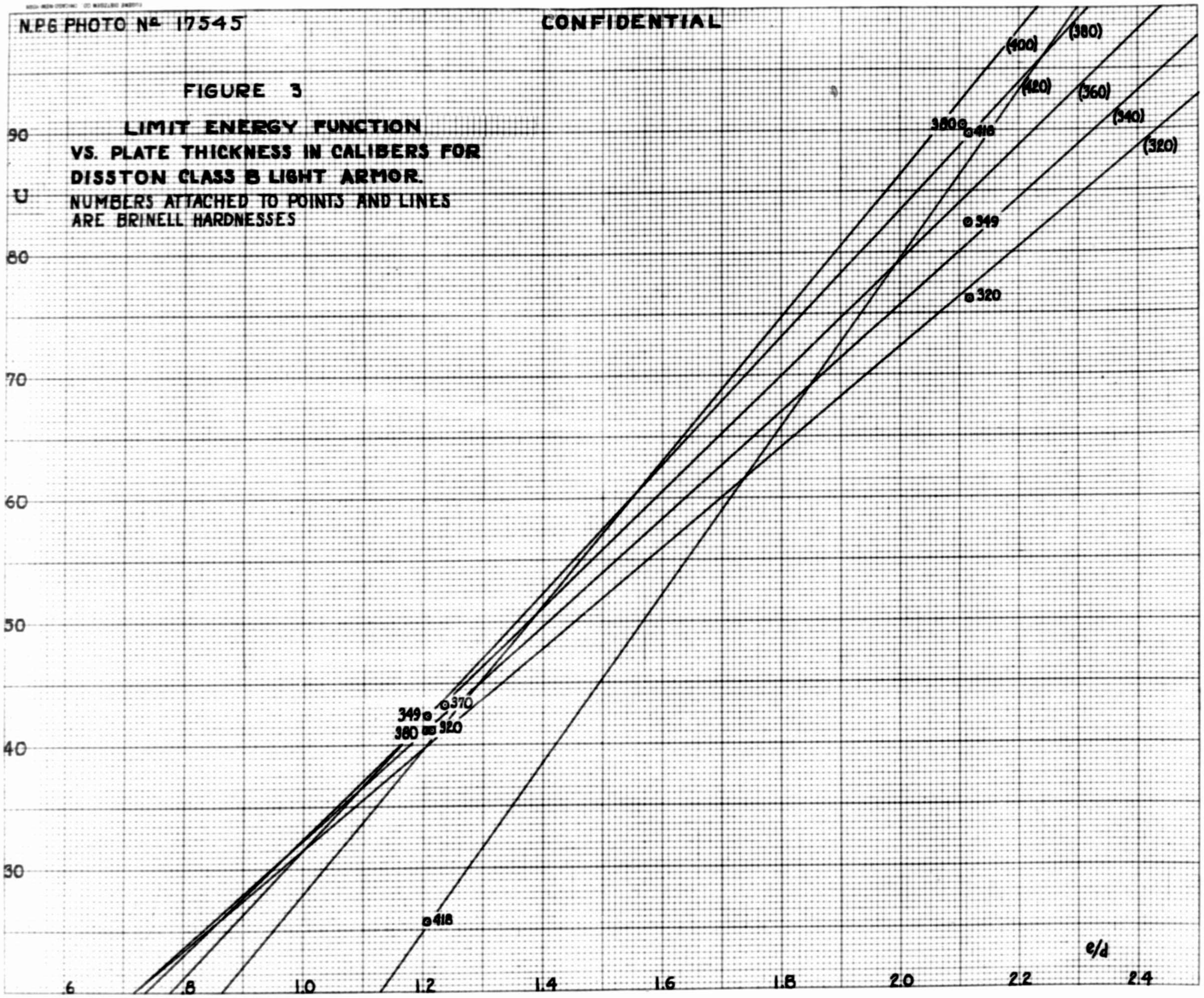

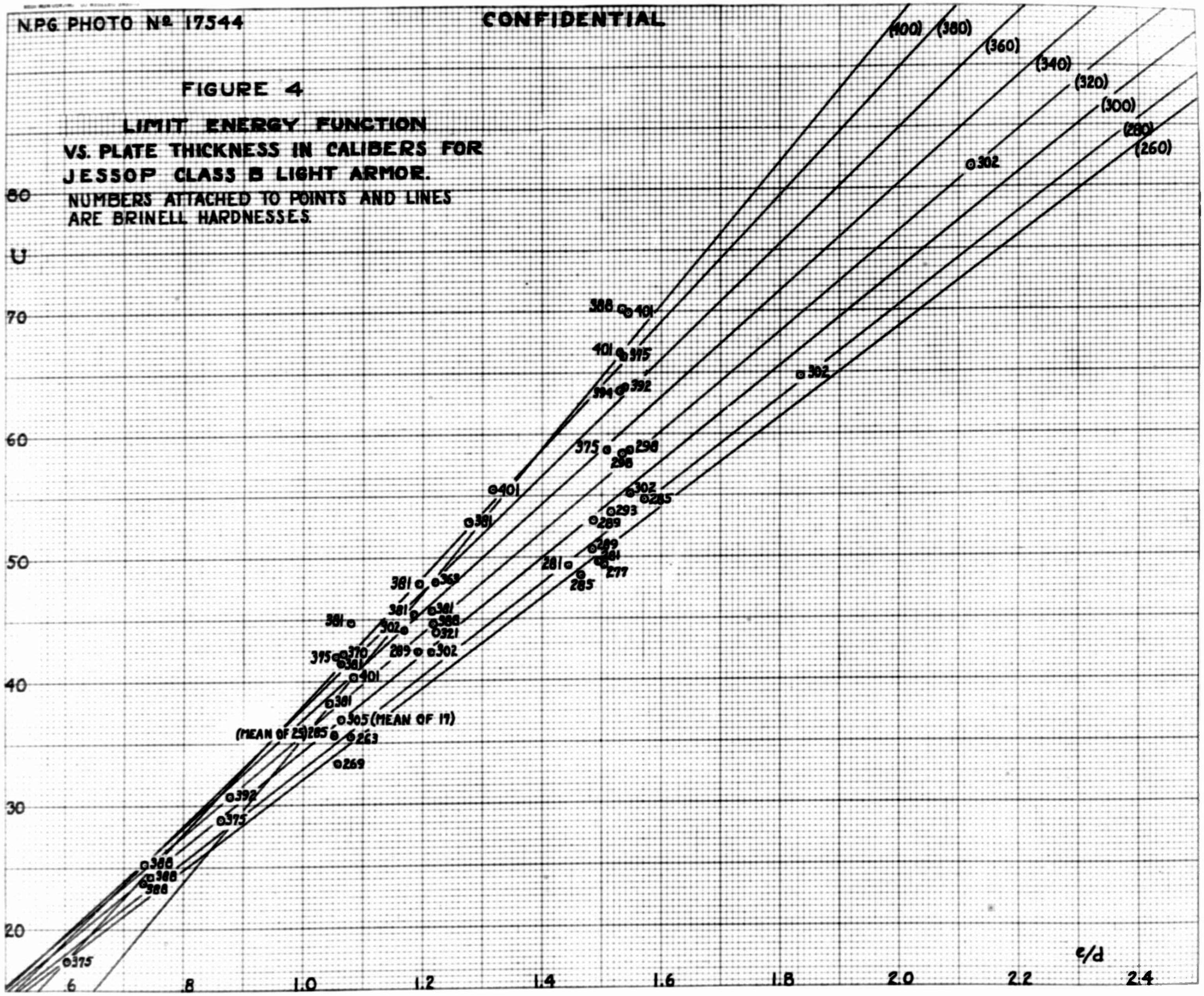

FIGURE 4

LIMIT ENERGY FUNCTION
VS. PLATE THICKNESS IN CALIBERS FOR
JESSOP CLASS B LIGHT ARMOR.
NUMBERS ATTACHED TO POINTS AND LINES
ARE BRINELL HARDNESSES.

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FIGURE 5

LIMIT ENERGY FUNCTION VS. HARDNESS

CARNEGIE CLASS B LIGHT ARMOR. PLATE THICKNESS IN CALIBERS ATTACHED TO EACH CURVE.

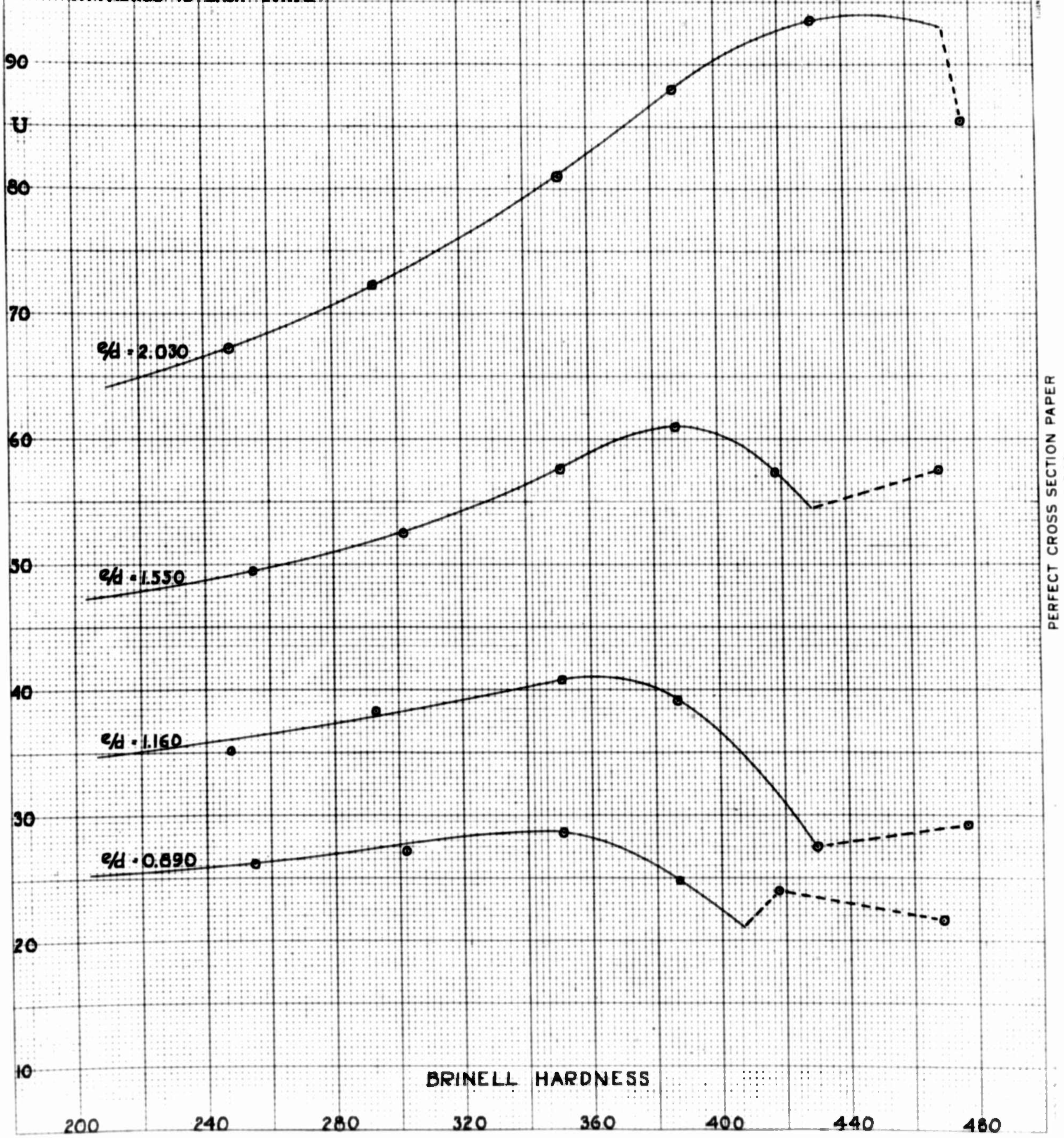

Table II shows the compositions of the four types of armor under consideration.

TABLE II

Typical Analyses of Armor

Jessop	.46	.55	.012	.012	.25	-	1.12	.60	.20	-
Great Lakes	.36	.89	.025	.022	.81	-	.73	.22	-	.09
Carnegie	.29	.25	.012	.012	.25	3.2	1.5	-	-	-
Disston	.19	.53	.017	.016	.22	2.60	.08	.32	-	-

Fig. 1 furnishes the best test of the variation of U with e/d; it is clear that the points for a given hardness fall rather well upon straight lines, except for those at about 470 BHN and the point at lowest e/d for 418 BHN. It may also be observed that as the hardness increases, the slope of the straight line increases, and its intercept with the U-axis becomes more negative. This is consistent with the physical interpretation presented in the Introduction, since with the hardness the yield strength increases, and with the yield strength the slope B must increase; and it is not unreasonable that with increasing hardness the rear face of the plate in the vicinity of the hole should fracture more easily, rather than undergo plastic deformation. It is common observation that petals are more completely developed on soft plates and frequently break off before they are fully formed on hard plates. This would have the effect of increasing A, as is observed.

The behavior of U as a function of hardness is perhaps better illustrated by Fig. 5, which contains the data of Fig. 1 corrected by small amounts along the straight lines to the common values of e/d shown. For a given e/d, as the hardness increases, the ballistic resistance increases to a maximum and then falls off. The increase becomes more marked, and the maximum moves toward higher hardnesses as e/d increases. For very hard plates, inconsistencies occur; the points do not lie on a smooth curve with those at lower hardnesses and depart from the curve in a somewhat erratic fashion. These inconsistencies are believed to be associated with a transition from a ductile to a brittle type of failure, since the very hard plate threw punchings instead of petalling. It is to be noted that for lower e/d the inconsistencies occur at lower hardnesses, as evidenced by the point at e/d = 0.890 and 418 BHN. The maxima of the U vs. hardness curves occur somewhere near that hardness at which the petals were observed to just begin to break off from the back of the plate.

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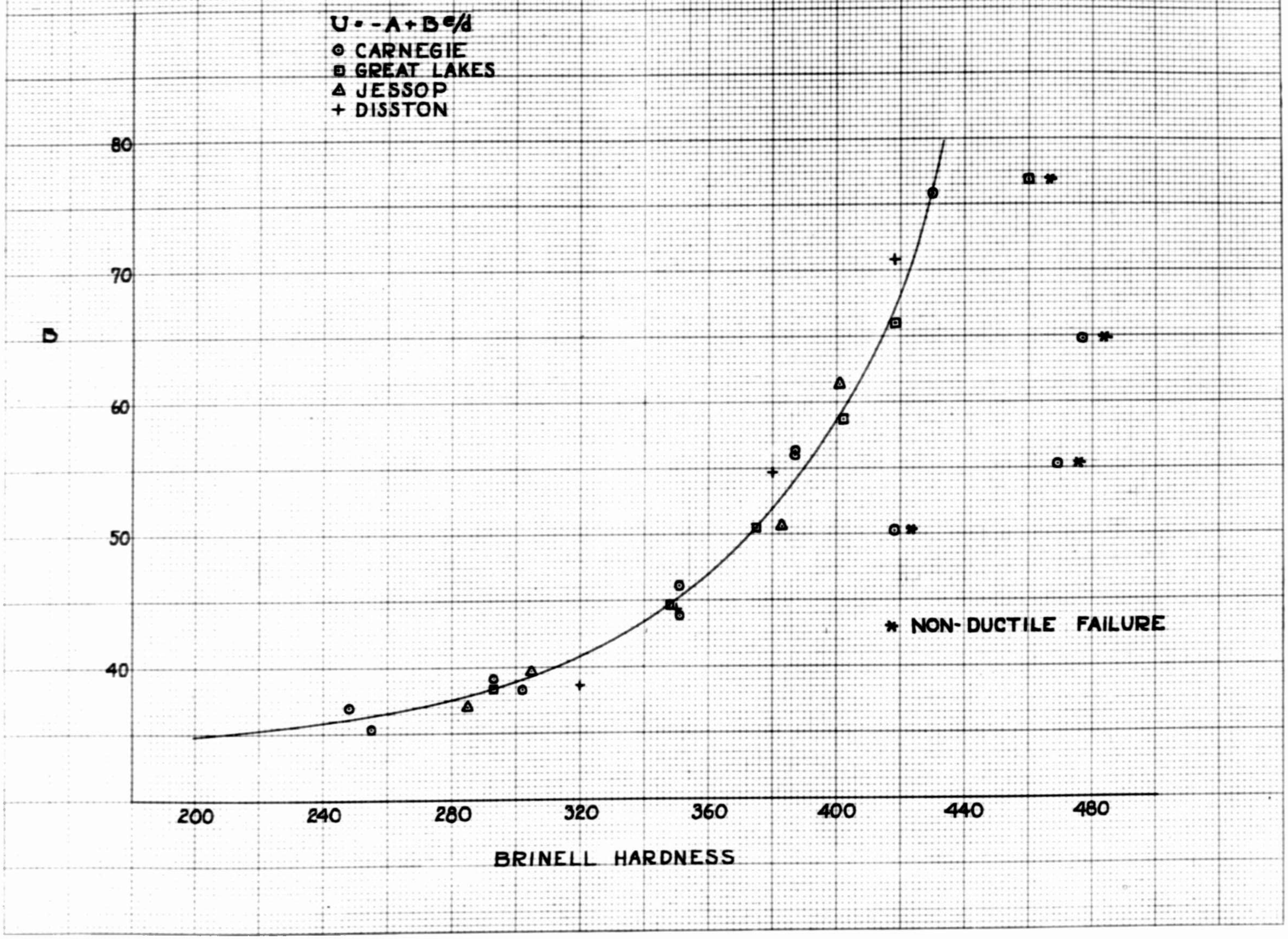
FIGURE 6

SLOPE OF LIMIT ENERGY FUNCTION
FOR CLASS B LIGHT ARMOR VS. HARDNESS.



It is shown by Figs. 2 to 4 that the general behavior of the armor of the other compositions is quite similar to that of the Carnegie steel discussed above. The greater dispersion of the points of Fig. 4 about the straight lines may be attributed to the fact that these were Jessop production plates and at the time this program began had already been disposed of. The BHN's of the plates are therefore those reported by the manufacturer, which are as a rule subject to more error than those determined under laboratory conditions. In view of the large size of the sample, it is believed that these random errors in hardness should average out. It is estimated that the probable error in the hardness measurements carried out in the laboratory is approximately ±1% and that the limit velocities have a probable error of about the same amount.

Each straight line is determined completely by its intercept and slope, and these are evidently functions of hardness. Plots of A and B versus hardness, then, will present the behavior of all thicknesses and hardnesses of armor of a given composition in the shape of two curves, by which one can easily interpolate between experimental values to predict performance under intermediate conditions of e/d and hardness. If two limits with different caliber projectiles are determined on one plate, this gives a value of U at each of the two values of e/d and from Equation (1) one can determine the value of B for this plate. In this manner, B was computed for each of the experimental plates. For the Jessop data it was necessary to draw straight lines, each through a set of points of a restricted range of hardness, on the plot of Fig. 4, and take the resulting slope of each line as applying to the mean hardness. When all these points are plotted against hardness, Fig. 6 results. On this plot no distinction between compositions is apparent -- one curve will fit all points, except those at high hardnesses, where the above-mentioned erratic behavior occurs. It is evident that the whole method is inapplicable at hardnesses above somewhere between 387 and 420 Brinell for e/d about 0.9 and at hardnesses above somewhere between 430 and 460 for e/d in the range of 1.2 to 2. The hardness ranges given above apply, of course, to the Carnegie armor tested, but as the results of Section III show, they are in reasonable agreement with ranges obtained for other compositions. Fortunately, this is of no practical interest in the production of armor, since these very hard plates have in no case been found to have penetration resistance superior to that of the softer plates, and their lack of ductility makes them unsuitable for other reasons, such as their low shock resistance. In what follows, therefore, plates harder than 430 BHN will not be considered, and it will be no surprise to find that plates of low e/d

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FIGURE 7

INTERCEPT OF LIMIT ENERGY FUNCTION
FOR CARNEGIE CLASS B LIGHT ARMOR VS. HARDNESS

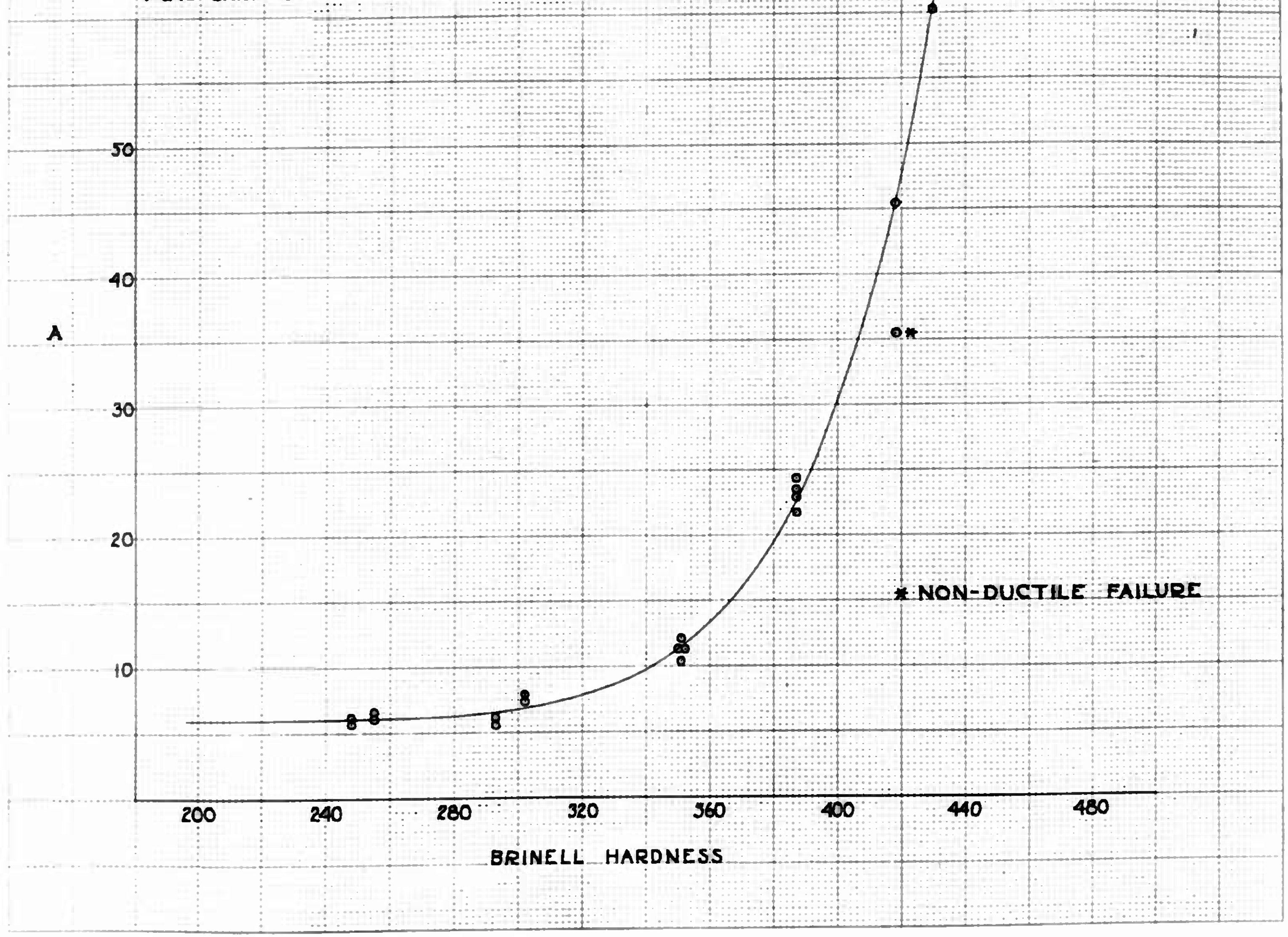

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FIGURE 8

INTERCEPT OF LIMIT ENERGY FUNCTION
FOR GREAT LAKES CLASS B LIGHT ARMOR VS. HARDNESS

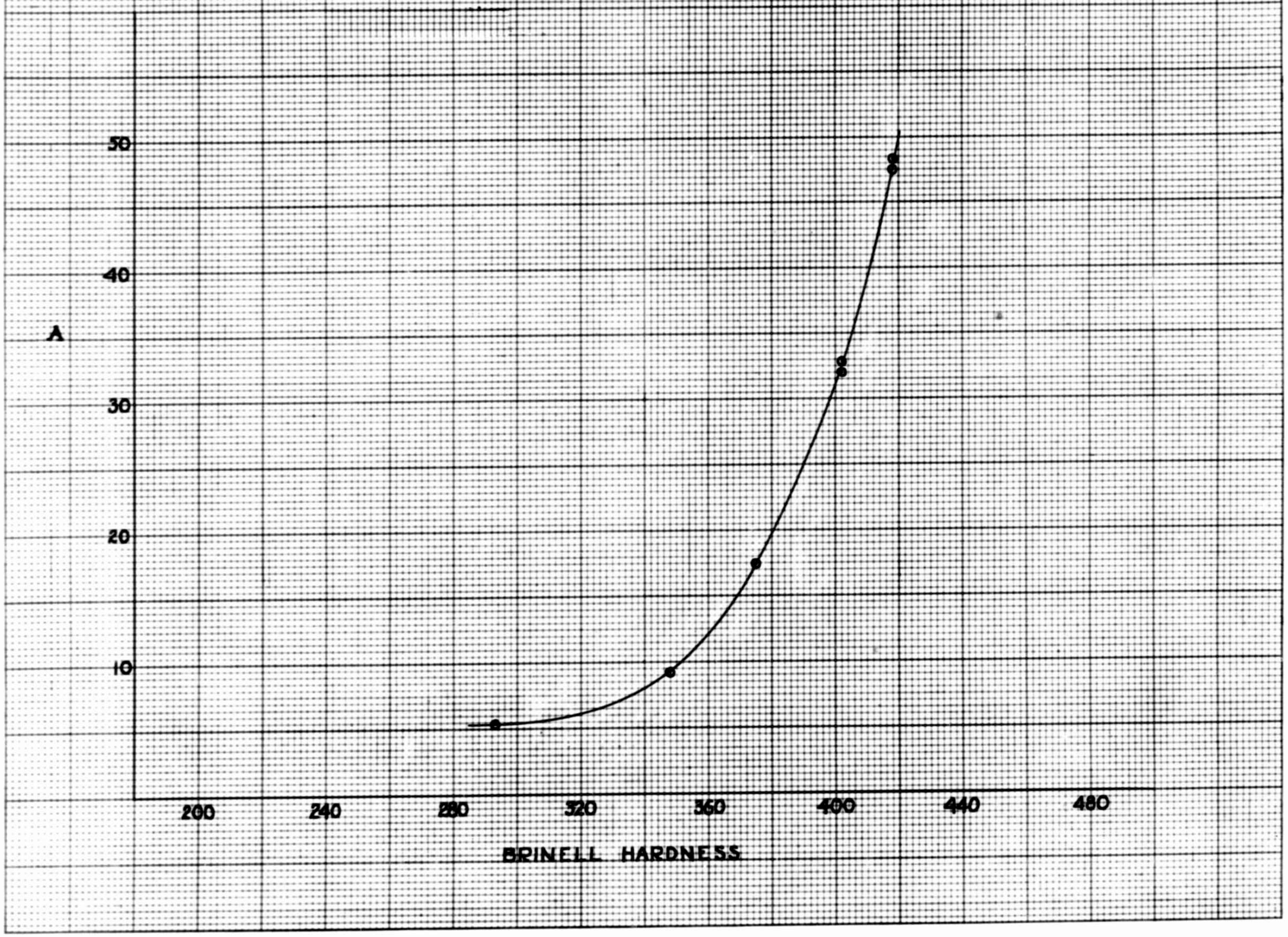

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FIGURE 9

INTERCEPT OF LIMIT ENERGY FUNCTION
FOR DISSTON CLASS B LIGHT ARMOR VS. HARDNESS

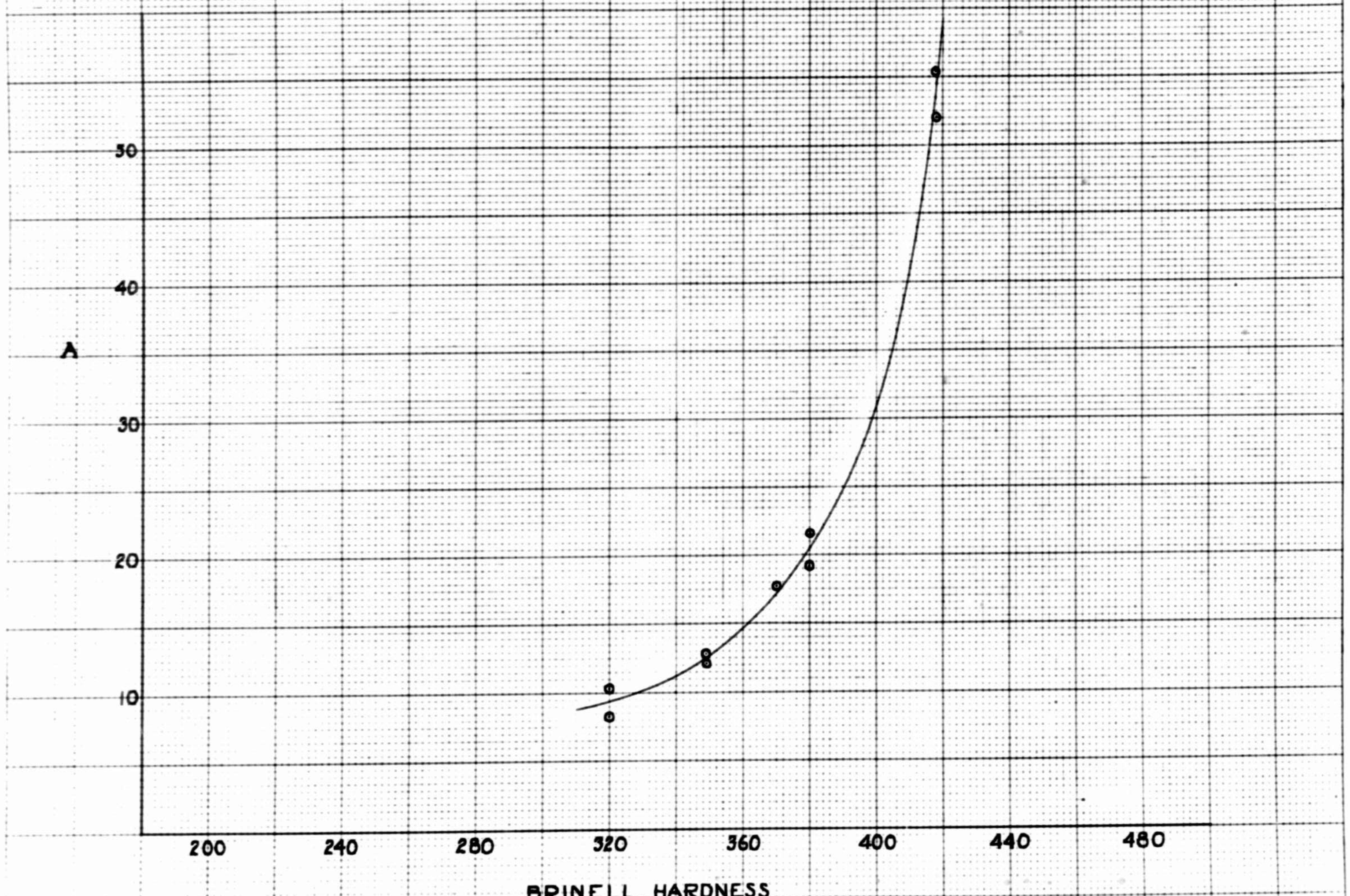

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FIGURE 10

INTERCEPT OF LIMIT ENERGY FUNCTION
FOR JESSOP CLASS B LIGHT ARMOR VS. HARDNESS

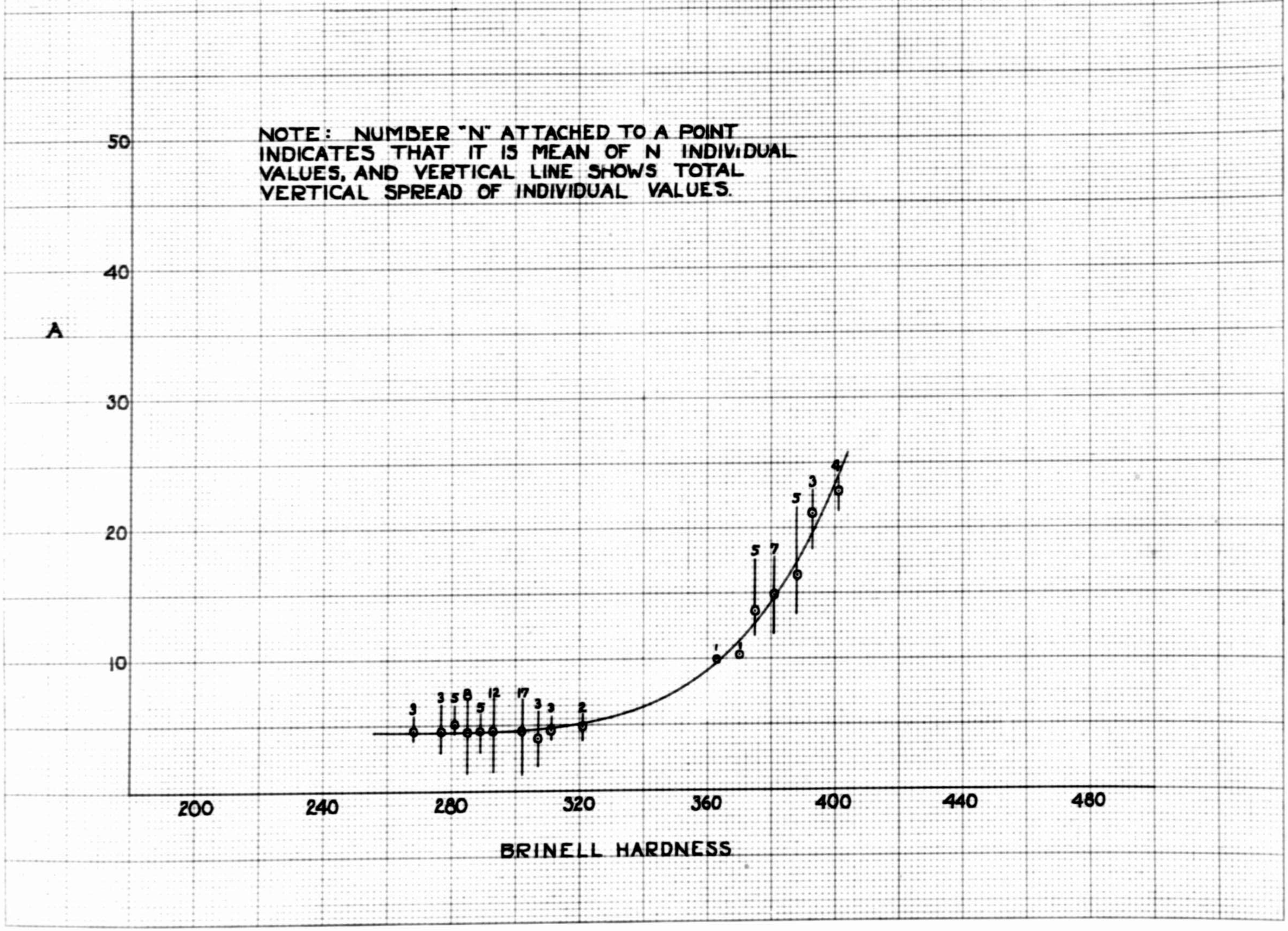

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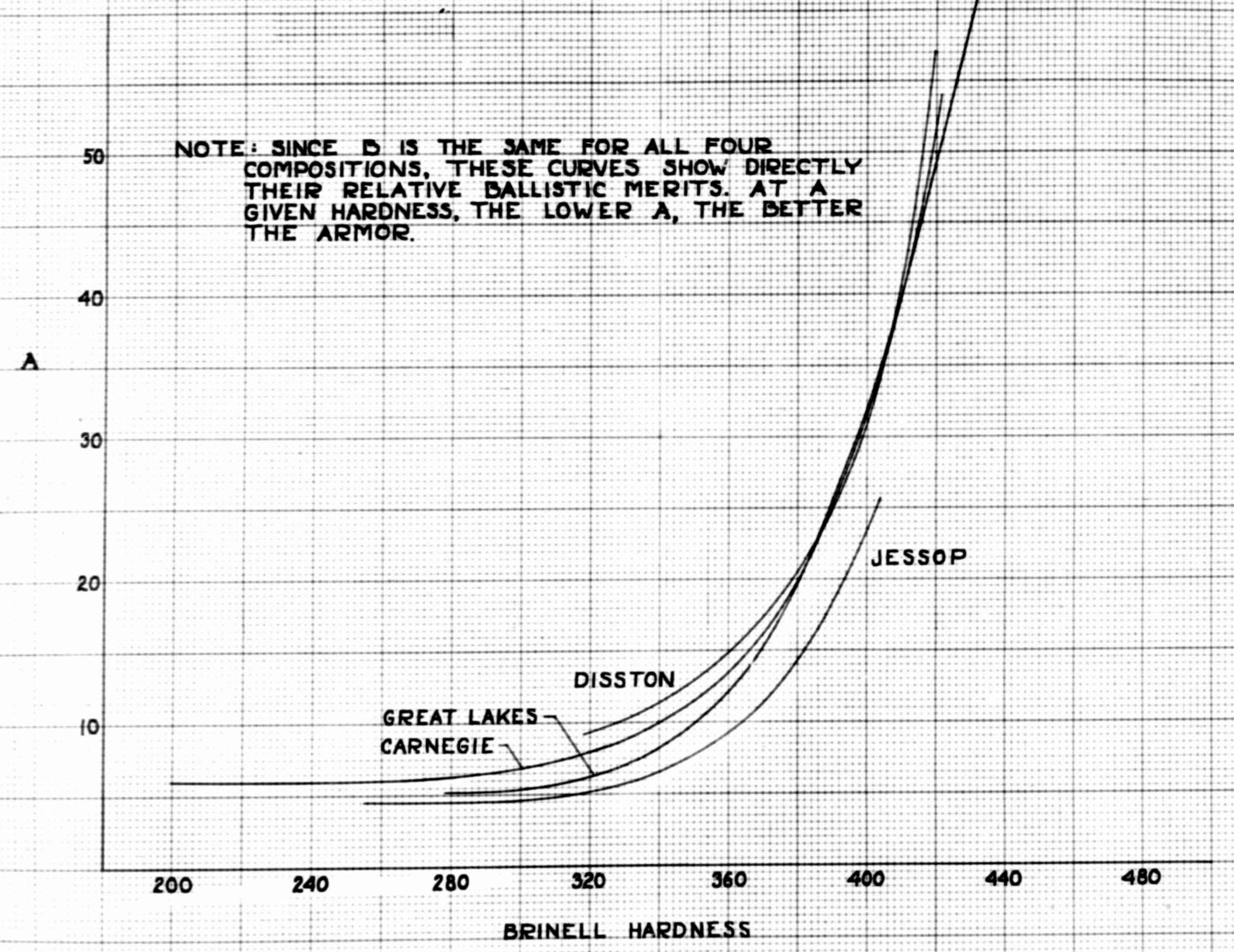
FIGURE 11

INTERCEPT OF LIMIT ENERGY FUNCTION FOR VARIOUS CLASS B LIGHT ARMOR VS. HARDNESS



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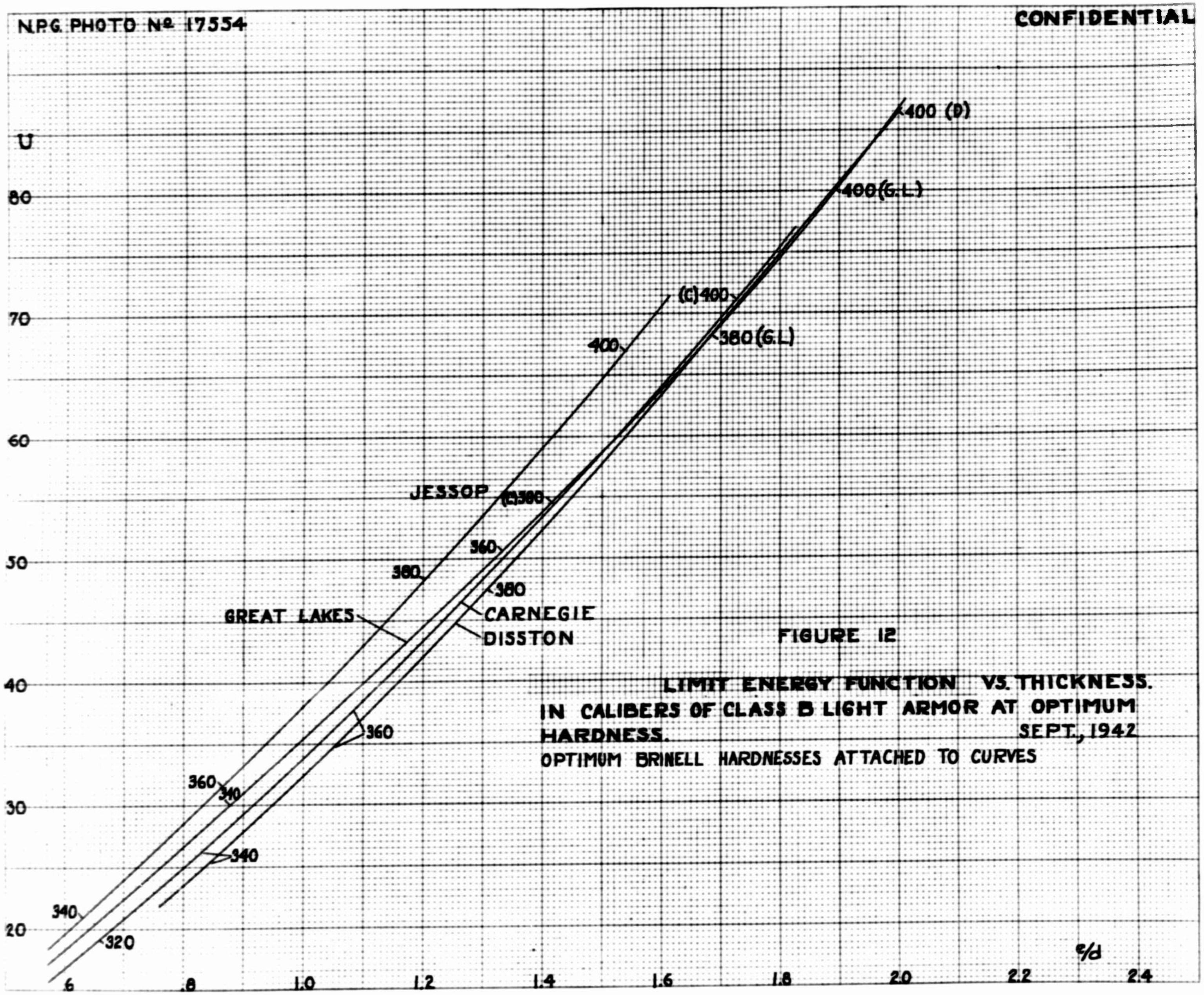


FIGURE 12

LIMIT ENERGY FUNCTION VS. THICKNESS. IN CALIBERS OF CLASS B LIGHT ARMOR AT OPTIMUM HARDNESS.

SEPT., 1942

OPTIMUM BRINELL HARDNESSES ATTACHED TO CURVES approaching this hardness will be anomalous (and undesirable). That one curve will fit the points of Fig. 6 suggests that B may be the same for all compositions at the same hardness, which would be true if all armor steels of given hardness had the same stress-strain relationship in the penetration cycle. The curve of Fig. 6 and the A curves were fitted by inspection since attempts at least squares fitting indicated that no simple function would fit the points.

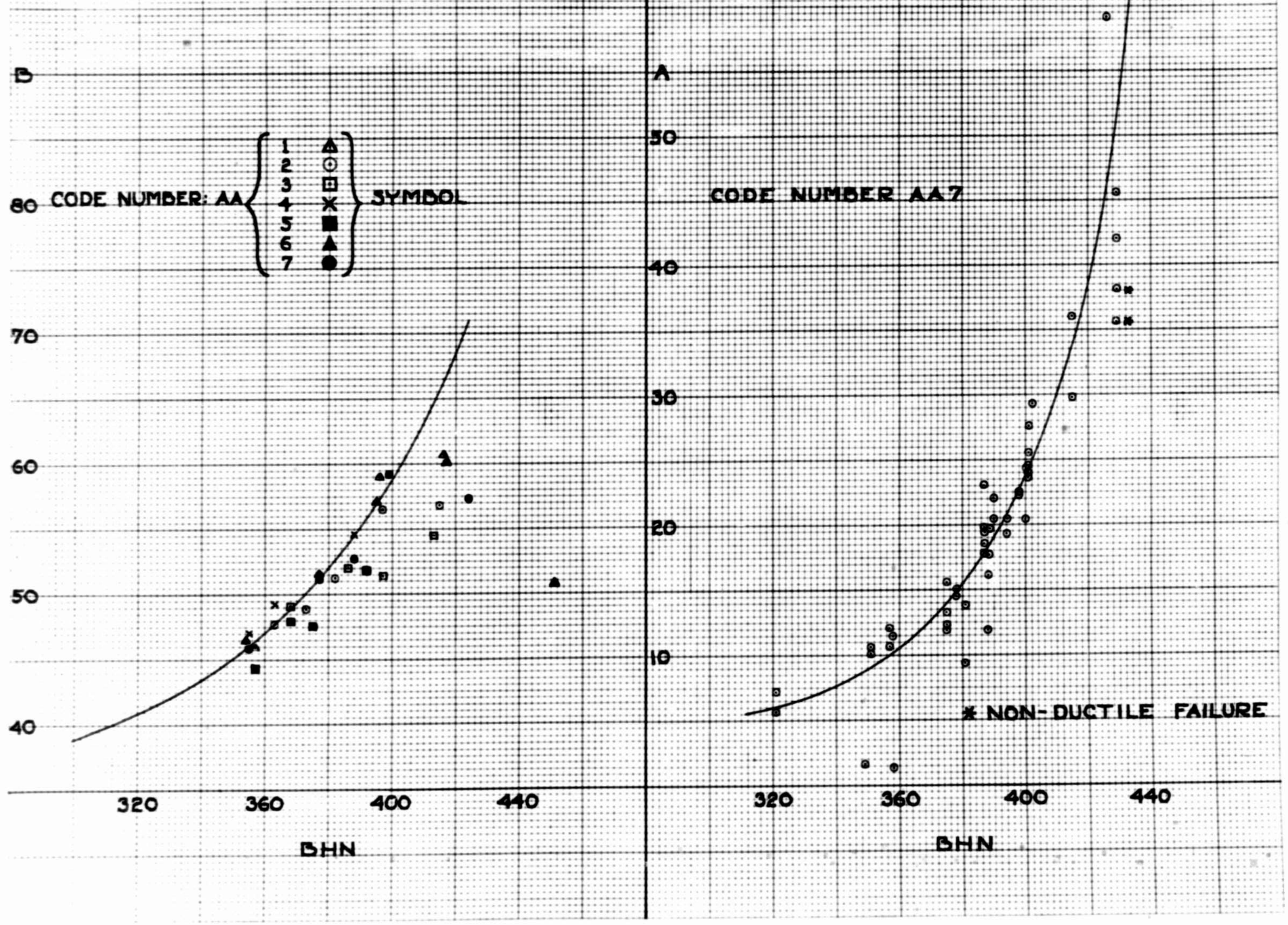
A value of A can be found for each limit, if the curve for B versus hardness is taken as correct. For the hardness of the plate in question, B is taken from the curve, and along with U and e/d substituted in equation (1) to find A. This procedure obviously throws all of the experimental error into A. Plots of A versus hardness for the four compositions are shown in Figs. 7 to 10, and for comparison the four curves are shown together in Fig. 11. Clearly if the B curves are the same for two analyses, their A curves decide their ballistic merits, and the lower A at a given hardness, the better is the armor.

From the A and B curves it is possible to pick off the values for any hardness and draw the corresponding line on a U vs. e/d chart, and it is thus that the lines on Figs. 1 to 4 were drawn. In addition, it is possible to find for any e/d the curve for U versus hardness and from it the maximum ballistic resistance and the corresponding optimum hardness for that e/d and composition, as shown in Fig. 12.

N.P.G. PHOTO Nº 20827 FIGURE 13 CONFIDENTIAL

SLOPE OF LIMIT ENERGY FUNCTION FOR ARMOR OF HOMOGENEOUS AIRCRAFT ARMOR DEVELOPMENT PROGRAM VS. HARDNESS

INTERCEPT OF LIMIT ENERGY FUNCTION FOR ARMOR OF HOMOGENEOUS AIRCRAFT ARMOR DEVELOPMENT PROGRAM VS. HARDNESS



III RESULTS OF DEVELOPMENT PROGRAM

The results of the homogeneous aircraft armor development program recently conducted by the Army and the Navy have been analyzed by the procedure developed in Section II. Table III shows the chemical analyses of the seven compositions used in this program.

TABLE III

Code No.	C	Mn	S	P	Si	Ni	Cr	Mo	V	Cu	Cb
AA1	.46	.53	.012	.014	.23	-	1.16	.60	.20	-	-
AA2	.36	.24	.015	.015	.24	3.13	1.17	-	-	--	-
AA3	.35	.50	.013	.006	.23	2.33	-	.27	-	.91	-
AA4	.29	1.05	.020	.017	.33	1.05	.14	.32	-	-	.27
AA5	.35	.52	.007	.013	.20	3.50	-	.27	-	-	-
AA6	.39	.80	.011	.012	.17	-	1.16	.61	.20	-	-
AA7	.48	.27	.017	.013	.28	3.04	1.32	-	-	-	-

AA1 is the same as the Jessop composition of Section II; AA6 is about the same except for the reduced carbon content. AA2 and AA7 are the same as the Carnegie composition of Section II except for the increased carbon contents.

In this program plates of each composition and of nominal thicknesses 5/16", 3/8", 1/2" and 7/8" were submitted by each of seven fabricators, heat treated as he saw fit. Among other tests, ballistic limits were obtained on all plates with Cal. .50 AP M2 and on all but the 7/8" plates with Cal. .30 AP M2, at normal obliquity. For each limit, a value of U and a value of e/d were computed. Values of B were then obtained by plotting U against e/d for all plates of a given composition and of a narrow range of hardness (about 10 points in Brinell), and drawing the best straight line through the points

Fig. 13 shows the results of plotting the slopes of these lines against the mean hardness of the group of plates. It is seen that the points are somewhat low with respect to the curve, which is that drawn for the experimental program in Fig. 6, but with no marked differentiation between the analyses. Again it seems that one curve can be drawn for all the compositions, and this curve has been taken to be that of Fig. 6, in view of the greater reliability to be expected from the experimental program. There the hardnesses were all measured on the same machine under laboratory conditions, whereas the large number of plates in the development program precluded

N.P.G. PHOTO No. 20828 FIGURE 14 CONFIDENTIAL

INTERCEPT OF LIMIT ENERGY FUNCTION FOR ARMOR OF HOMOGENEOUS AIRCRAFT ARMOR DEVELOPMENT PROGRAM VS. HARDNESS

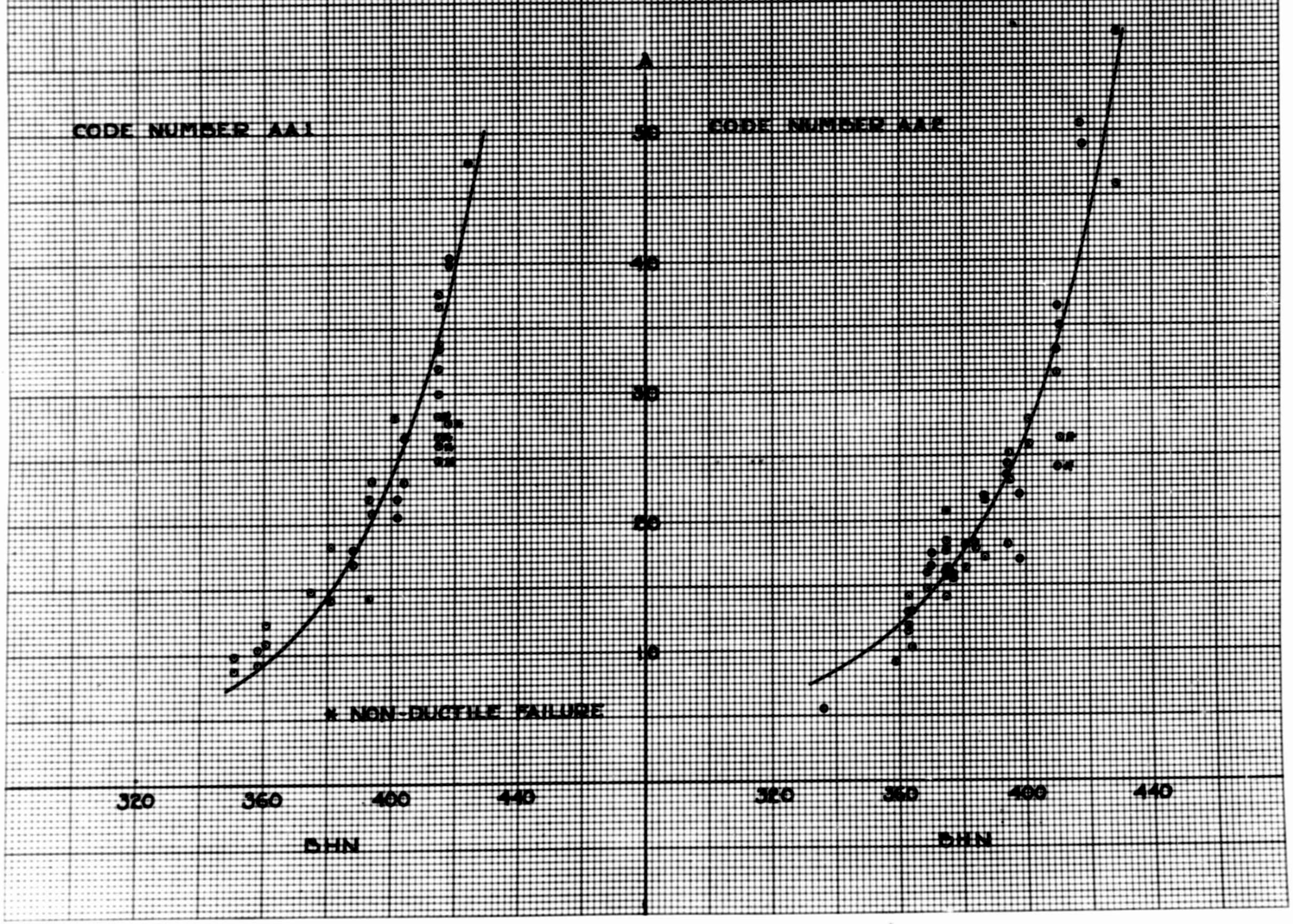


FIGURE 15

INTERCEPT OF LIMIT ENERGY FUNCTION FOR ARMOR OF HOMOGENEOUS AIRCRAFT ARMOR DEVELOPMENT PROGRAM VS. HARDNESS

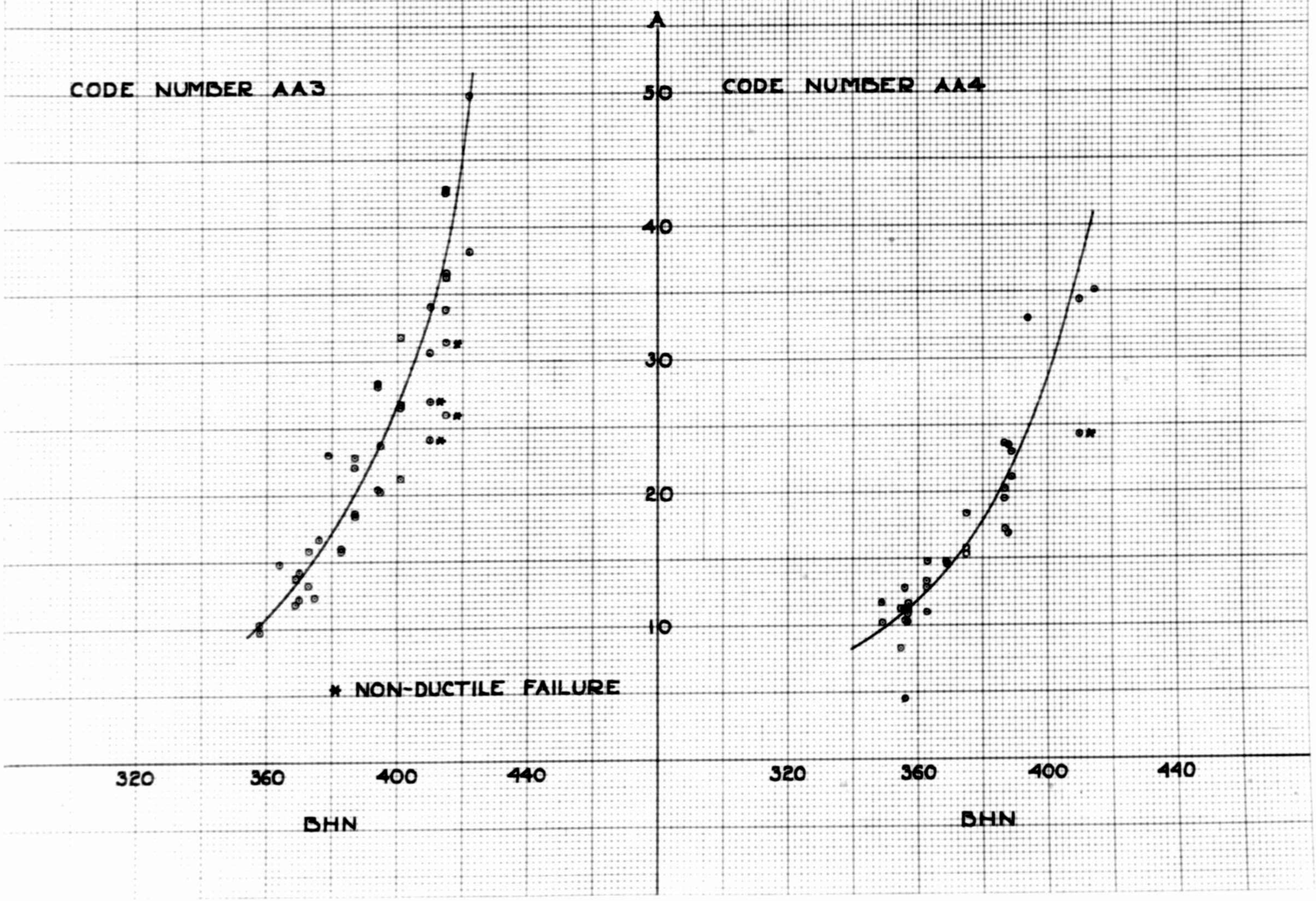


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FIGURE 16

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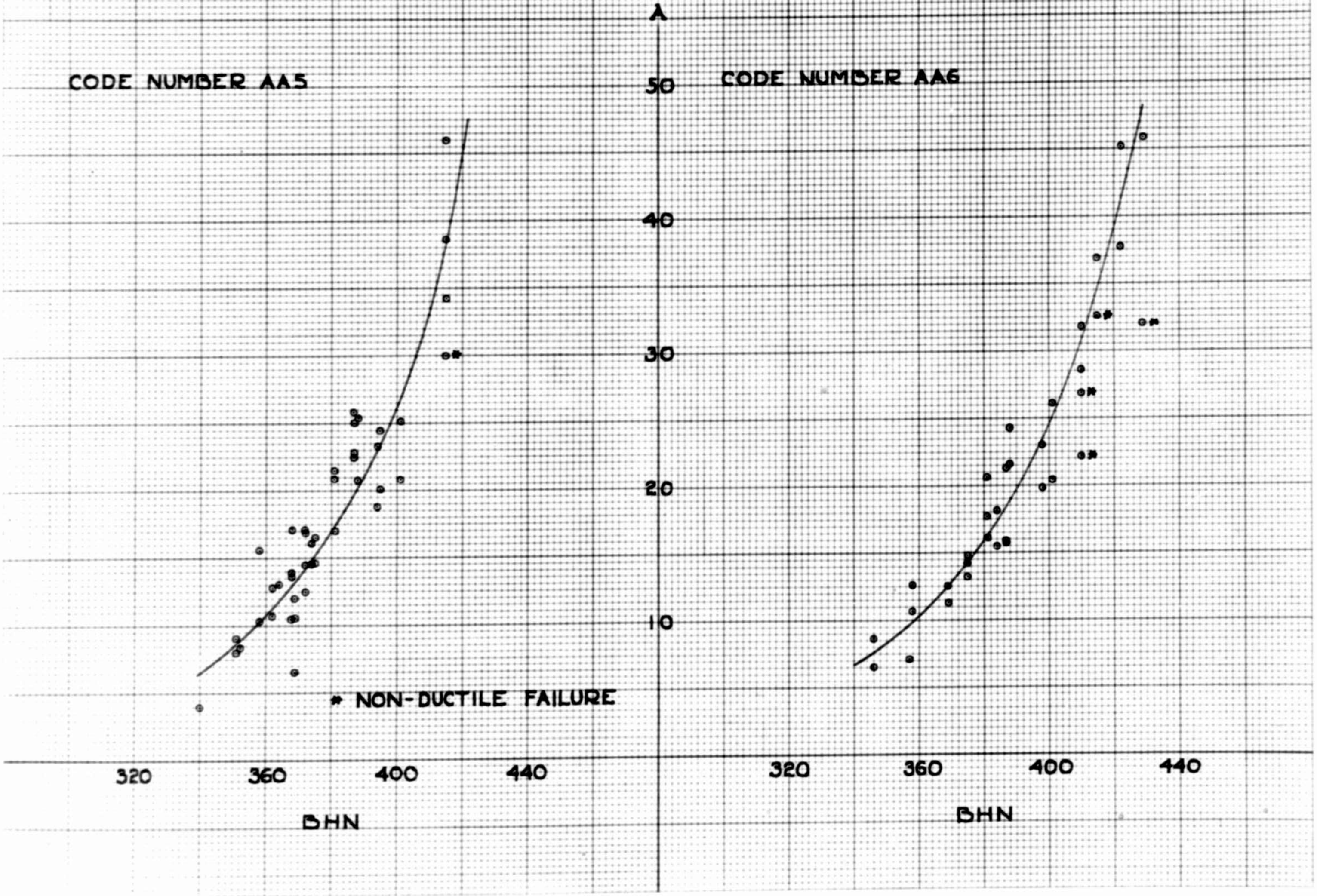
INTERCEPT OF LIMIT ENERGY FUNCTION FOR ARMOR OF HOMOGENEOUS AIRCRAFT ARMOR DEVELOPMENT PROGRAM VS. HARDNESS



the possibility of remeasurement at the Naval Proving Ground and made it necessary to rely on the less accurate Brinells provided by the fabricators.

Furthermore, four of the seven analyses are very similar, as noted above, to those used in the experimental program, and would not be expected to give a different B curve.

Adopting, therefore, the original B versus hardness curve, one can compute a value of A for each limit as before and plot the results against hardness, as in Figs. 13 to 16. The dispersions about the mean curves are seen to be larger than for the curves of the experimental program, principally, it is believed, for the reason mentioned in the preceding paragraph. The points marked "non-ductile failure," however, depart from the curves for another reason. These points all represent hard plates tested at low e/d, that is, 5/16" and 3/8 plates with caliber .50 projectiles. As stated in the last section, such conditions do not fall within the limitations of the scheme here presented, and deviations from the curves must be expected.

From the A and B curves, U as a function of e/d and hardness may be computed for the compositions of the development program. By the equation $U = (e/d) F^2$, the usual Navy penetration limit coefficient F may be obtained from U, and plots of F versus e/d are shown for some of the compositions in Figs. 17 to 20. To provide a basis for comparison these plots also show the specifications ANOS-1 under which the plates were tested. The corresponding plots for the other analyses would differ qualitatively but little from those shown.

The order of merit of the seven compositions is: (1) AA1; (2) AA7; with (3) AA6 close behind; (4) AA3 and AA5 indistinguishable; (5) AA2; and (6) AA4.

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FIGURE 17

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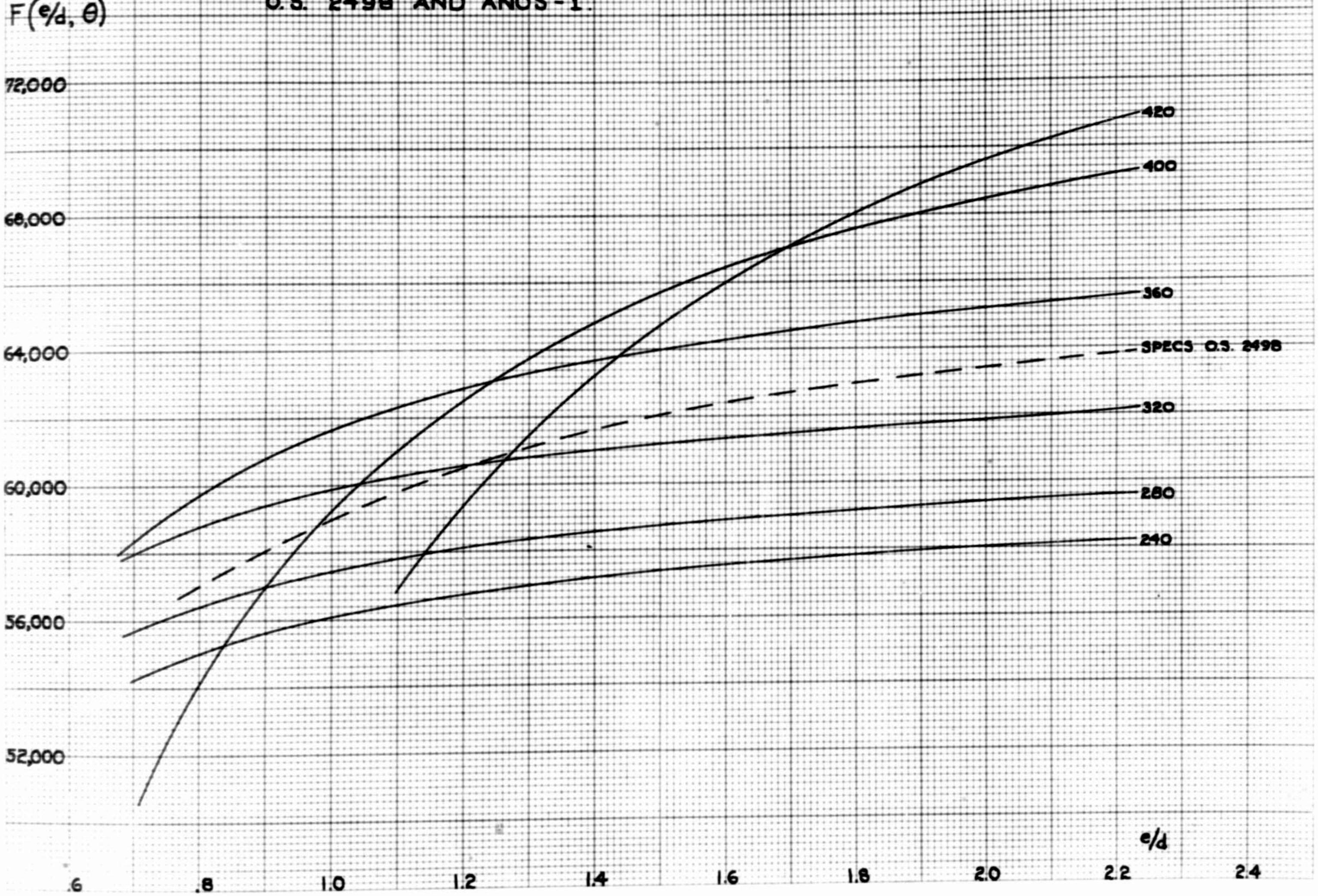
PENETRATION LIMIT COEFFICIENT VS. THICKNESS IN CALIBERS FOR JESSOP (AA1) CLASS B LIGHT ARMOR.

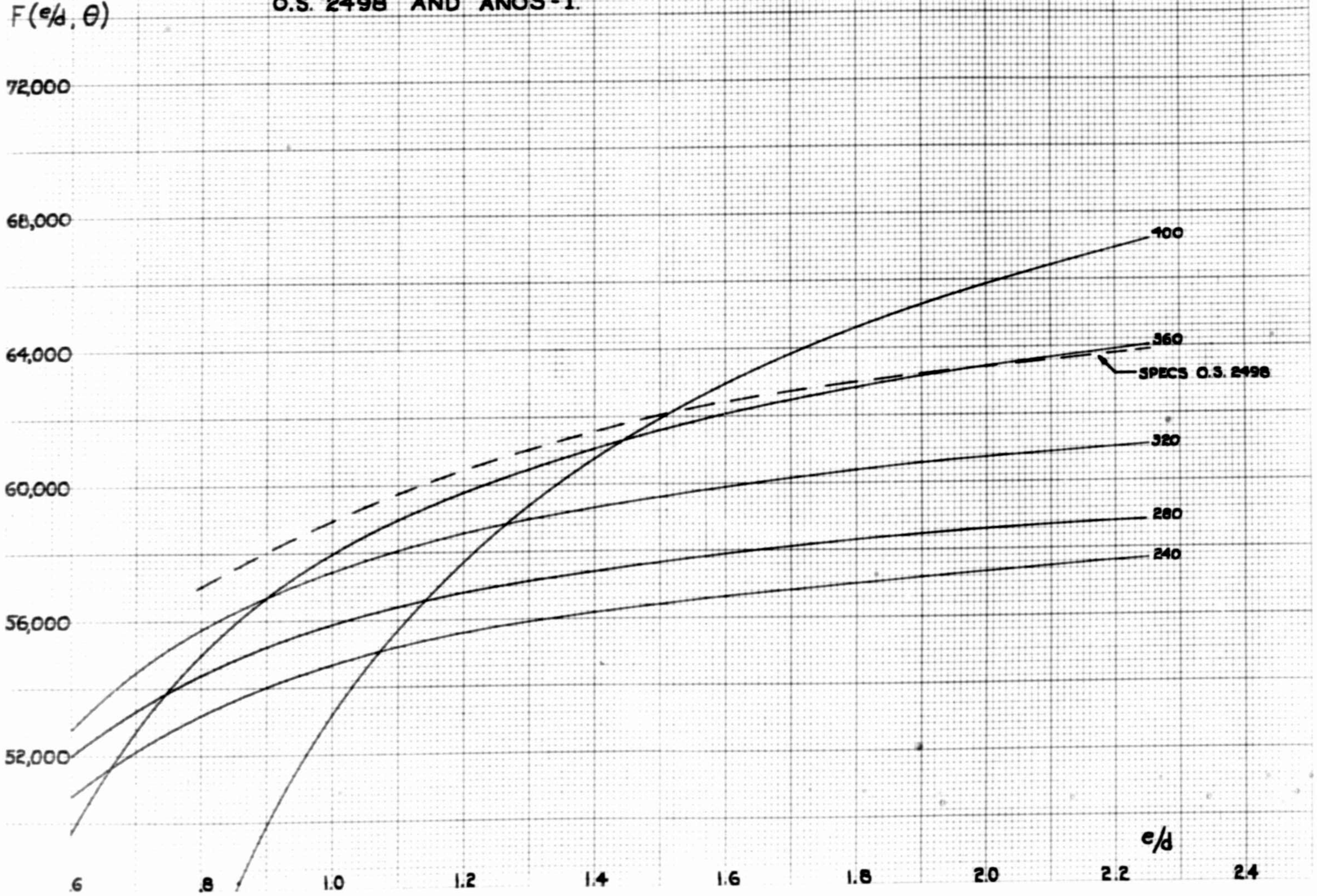
NUMBERS ATTACHED TO CURVES ARE BRINELL HARDNESSES.
BROKEN CURVE SHOWS REQUIREMENTS OF SPECIFICATIONS
O.S. 2498 AND ANOS-1.



NPG PHOTO № 20832 FIGURE 18 CONFIDENTIAL

PENETRATION LIMIT COEFFICIENT VS. THICKNESS IN CALIBERS FOR CARNEGIE CLASS B LIGHT ARMOR.

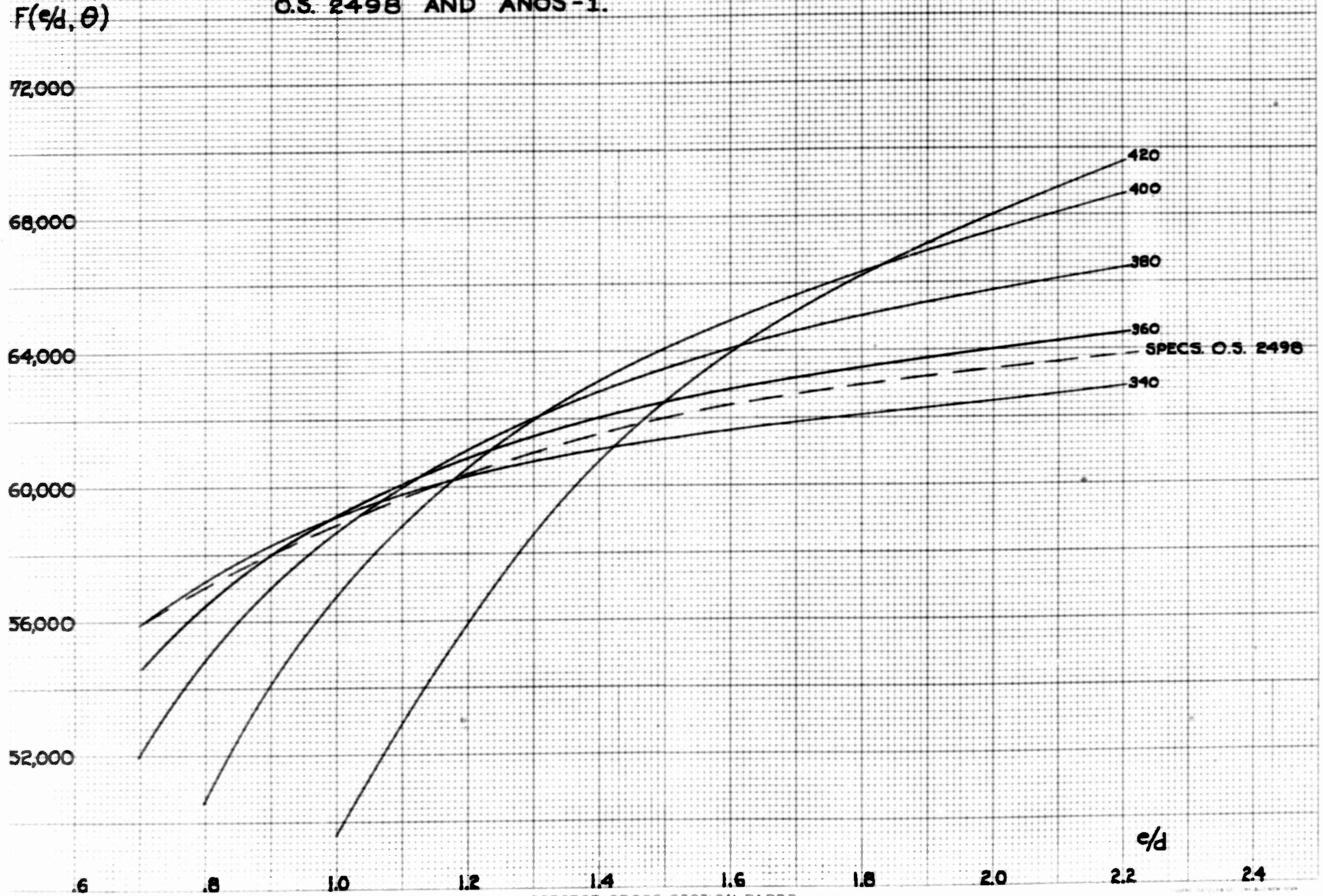
NUMBERS ATTACHED TO CURVES ARE BRINELL HARDNESSES. BROKEN CURVE SHOWS REQUIREMENTS OF SPECIFICATIONS O.S. 2498 AND ANOS-1.



N.P.G. PHOTO No. 20833 FIGURE 19 CONFIDENTIAL

PENETRATION LIMIT COEFFICIENT VS THICKNESS IN CALIBERS FOR CLASS B LIGHT ARMOR OF ANALYSIS AA2.

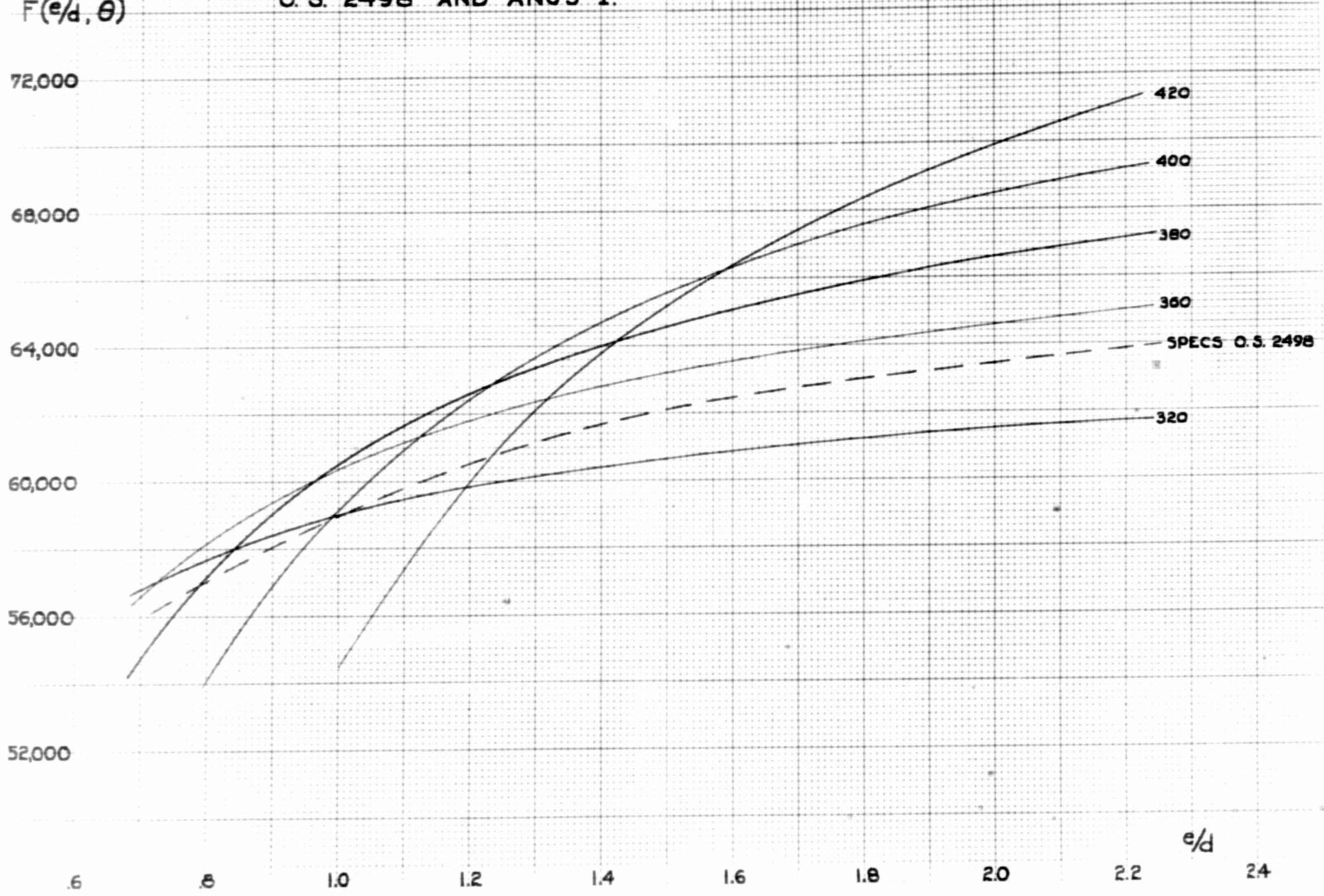
NUMBERS ATTACHED TO CURVES ARE BRINELL HARDNESSES. BROKEN CURVE SHOWS REQUIREMENTS OF SPECIFICATIONS O.S. 2498 AND ANOS-1.



N.P.G. PHOTO Nº 20834 FIGURE 20 CONFIDENTIAL

PENETRATION LIMIT COEFFICIENT VS THICKNESS IN CALIBERS FOR CLASS B LIGHT ARMOR OF ANALYSIS AA7.

NUMBERS ATTACHED TO CURVES ARE BRINELL HARDNESSES. BROKEN CURVE SHOWS REQUIREMENTS OF SPECIFICATIONS O. S. 2498 AND ANOS-1.



IV DISCUSSION

The general metallurgical aspects of this whole problem will be dealt with in a later Naval Proving Ground report, but it should be stated here that this report is based on the study of armor that has been quenched and tempered so as to produce a uniform microstructure of spheroidized carbide, and that it is only when the microstructure is thus kept constant that the results of the present report are applicable. Whether other microstructures, or indeed other armor materials, would fit a framework of the same type is at present unknown.

It may be that there is another cause of the dispersion about the curves shown in the results of the development program, besides the errors in Brinell hardness, and possible errors in limit determinations. It is quite possible that the hardness of a plate (of given thickness and composition) is the main parameter affecting its ballistic resistance, but not the only one, so that there would be real variations from the curve representing the mean. If this were the case, the low dispersion observed in Figs. 7, 8, and 9 would be attributed to these data's having been obtained on portions of one or two plates, the subsidiary parameter having the same value for all portions of one plate. Further evidence is required to prove the truth or falsity of this hypothesis.

The behavior of homogeneous armor at high hardnesses may be made more clear by stating that, when the hardness reaches a value well over 500 Brinell, the armor acquires a high resistance to penetration, comparable with that of Class A armor, and due to the same principal cause -- projectile breakage. The plots of Fig. 5, therefore, if continued toward higher hardnesses than those tested, should show an upturn, with perhaps an intermediate region of large dispersion in limit velocities, characteristic of a situation in which the individual projectile may or may not deform on striking the plate, depending on its quality. Finally, at the highest hardnesses, all of the projectiles would shatter on the plate, which would give a higher limit velocity than that represented by the maxima of Fig. 5. Such armor, however, is known to have very poor shock resistance, tending to shatter completely when it is struck heavily.

Available data on shock resistance of the softer armor under consideration here indicate little dependence on hardness, except that plates in the vicinity of 430 Brinell or higher are inferior to the softer plates in shock resistance.

The only considerable effect of chemical composition of the armor evident from the data is that as the carbon content increases from 0.19% to 0.48% there is a steady improvement in ballistic quality. Compare, in this connection, Figs. 18, 19, and 20, which show the effect of changing the carbon content from 0.29% to 0.36% to 0.48% without changing the analysis appreciably in any other way. It is also indicated, it is true, that there are other effects of composition, since the analysis AA1 is somewhat superior to AA7 which has a slightly higher carbon content.

The fact that armor performance is plotted against e/d may lead to confusion in one connection. It is to be noted that the same plate may occur on a chart at more than one e/d if it is attacked by more than one size of projectile. The optimum hardness for attack by one caliber projectile on a plate of given thickness will not be the same as that for attack by another. Consider, for example, a 3/8" plate of composition AA1 attacked by caliber .30 and caliber .50 AP bullets. The two values of e/d are 1.534 and 0.877. From Fig. 17 the plate will possess the best resistance to penetration by the caliber .30 bullets if its hardness is in the neighborhood of 400 Brinell, but a plate of this hardness will also possess poor resistance to the caliber .50 bullets. For the latter a hardness in the vicinity of 360 would give best performance. In other words, it is impossible to produce a plate which will have the maximum resistance to attack by all projectiles. It is therefore necessary to arrive at some sort of compromise if a given plate is expected to withstand attack by projectiles of more than one size.

The curves of Figs. 17 to 20 are recommended as presenting the results of this investigation in most convenient form for application to a specific problem. F is a more suitable quantity than U for this purpose since it is proportional to velocity rather than to the square of velocity and hence the scale of ordinates is not unduly compressed at the lower end. In fact, the only reason to prefer U over the long-established F coefficient is that it is easier to draw a straight line than a curve through experimental points.

In view of the somewhat high dispersion in Figs. 13 to 16, estimates have been made from these of the error to be expected in Figs. 17 to 20. The error will of course vary with e/d and with hardness, but it is estimated that on the average the probable error in predicting the mean performance of a number of plates of one composition is of the order of 0.5% in F, and the probable error in predicting the performance of a single plate is of the order of 2%. These estimates are not valid for plates over about 410 BHN, where the A curves become so steep that a small error in hardness can produce a large error in A. The probable errors here can be several times as large as the figures quoted above.

V CONTINUING INVESTIGATIONS

In continuation of the study represented by this report, it is intended to acquire further information about the effects of varying composition and heat treatment on the performance of homogeneous light armor as suitable materials become available for study. Further it is intended to investigate how far the conclusions concerning hardness may be carried over to other conditions, principally to attack by unjacketed projectiles. Finally, it appears necessary to carry out experiments to attempt to identify other parameters affecting ballistic performance besides hardness, composition and heat treatment, if such exist.

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Armor Piercing Ammunition

The penetration of homogeneous light armor of different hardnesses and thicknesses by jacketed projectiles at normal obliquity was investigated and the results so far obtained on the performance of such armor are discussed. As a result of the heavy class B armor investigation, which shows that the limit energy function is a linear function of thickness of armor in calibers, is also confirmed for homogeneous light armor attacked by jacketed armor-piercing projectiles at normal obliquity. The effect of changing the hardness of the armor was investigated, and some information on the chemical composition was gained. A method was developed by which the ballistic merits of armor steels of different compositions may be compared even though their ballistic test plates have different thicknesses and hardnesses.

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