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Impact Testing with the Darts from Caliber .50 AP Bullets

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By
George R. Irwin
R. Alden Webster

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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report of

Impact Testing with the Darts from Caliber .50 AP Bullets

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

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Prepared by:

George R. Irwin, Contract Employee

R. Alden Webster, Assoc. Electrical Engineer

Reviewed by:

Ross Gunn, Pr.Phys., Supt., Mechanics
and Electricity Division.

Approved by:

H. M. Cooley, Captain, USN, Director

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ABSTRACT

This report describes in detail a method of testing samples of armor with the darts from caliber .50 AP bullets. Improvements in apparatus and technique have been made since such tests were used with caliber .30 AP bullets, reference (b), for another purpose. By use of the equipment and methods described in this report, 1/2" armor samples may be subjected to high speed penetration by a hardened tungsten steel dart, 0.427" diameter, 412 grains weight, and the impact velocity required for penetration measured to an accuracy of at least 1%.

Results of tests performed on 24 samples of various armor compositions and heat treatments furnished by three steel companies are tabulated. Nine principal sources of error are discussed and the probable magnitude of their effect verified with experimental data.

Lack of similarity is considered great enough to prevent an exact model type correlation between dart impact test results and plate limits determined at the Naval Proving Grounds. The described method of testing small armor samples is, nevertheless, an accurate and a very appropriate impact test for armor material, and its use by manufacturers of armor plate is recommended.

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AUTHORIZATION

1. This problem was authorized by reference (a), and additional references pertinent to this problem are listed as (b) and (c).

Reference: (a) Bu.Ord. ltr. S13-1(4/173)(Q8) of 13 December 1934.
(b) NRL Report No. 0-1438 of 6 April 1938.
(c) BuOrd. ltr. S13-6(1509)(Q11) of 25 March 1939.

INTRODUCTION

2. Following Naval Research Laboratory Report No. 0-1438 of 6 April 1938, outlining the effect of the jacket of caliber .30 AP bullets upon penetration of steels, the use of impacts by small caliber AP cores or darts was proposed as an improved physical test of large caliber armor plate material. In view of the fact that armor plate manufacturers at the suggestion of the Bureau of Ordnance have announced their intention of using dart impact tests, the Naval Research Laboratory has made the additional impacts with caliber .50 AP bullets necessary to the development of such testing into a standard reliable method, in order that such tests may be of use in the present Naval building program.

3. The possibility of accumulating information of general interest to the light armor studies and of special value to the heavy armor improvement program as well, furnished a double motive for performing the experiments required for this report. Very little firing with caliber .50 AP bullets had previously been included in the light armor program. By means of the tests described in this report, it was possible to verify the extention of conclusions regarding the effect of the jacket upon penetration from caliber .30 AP to caliber .50 AP bullets, and to observe the amounts of breakage which occurred under various conditions of impact. Complete chemical analyses and physical properties were furnished by the steel companies, thus assisting investigation of the effect of these upon resistance to penetration. In addition, various improvements were made to the apparatus and technique of plate testing which are of general interest to the light armor program.

4. It is not necessary to emphasize the need for an improved physical test that can be easily applied to a small sample of armor material in order to judge its quality. It is hoped that the high speed impact test proposed in this report will go far toward filling this need. Accuracy of the data obtained and useful interpretation of such data require an understanding of the possible sources of error and the limitations which pertain to testing with the darts from AP bullets. Although the limitations are less than for notched bar tests such as the Charpy and Izod, they are still sufficiently restrictive to require caution in the interpretation of results.

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5. In favor of testing with caliber .50 AP darts, it can be fairly said that an impact test upon a laboratory size sample which tests resistance to high speed penetration is more appropriate for armor plate than the usual tensile, Charpy, and Izod tests. As described in this report, such a test can be made equally reliable with respect to repetition of results upon several samples of the same material. Moreover, with accumulation of data, the proposed tests can be expected to lead to a better understanding of the factors which control resistance to full scale impacts.

6. Samples of standard STS armor composition and of other compositions under consideration for use in armor plate manufacture were received from Midvale, Carnegie, and Bethlehem steel companies. The stripped caliber .50 AP core impacts, made upon these plates, provided the data for this report. Two groups of annealed boiler plate, a sample of 1010 steel and several samples of 1035 steel (furnished gratis by Bethlehem Steel Company), were tried as stripper plates to remove the jacket from the caliber .50 AP bullet. The armor test plates were 1/2 inch thick and the stripper plates about 3/4 inch thick. During the course of the firing program, improvements were made in the recording indicator of the ballistic pendulum, the effect of small amounts of yaw at impact was studied, and caliber .50 loading data were assembled.

METHODS

7. The projectiles used were Model 1923 caliber .50 AP bullets averaging 755 grains weight for the full bullet. About 90 per cent of the darts of these bullets weighed within 0.5 per cent of 412 grains and all measured 0.427 inch diameter. Loadings at 7-1/2 grain intervals from 115 grains to 160 grains of DuPont IMR 4320 powder gave velocities at 100 yards of from 1700 feet per second to 2300 feet per second as is shown on Plate 3, Figure 1.

8. The caliber .50 AP bullets were fired in a Mann barrel at 100 yards in the enclosed range at the Naval Research Laboratory. Impact velocities of the full bullets were measured with an Aberdeen chronograph, the chronograph screens being 18 feet and 34 feet in front of the test plate. A 120-pound ballistic pendulum was used to record remaining velocities.

9. To make a test with stripped caliber .50 AP darts, a mild steel stripper plate generally 3' x 10" x 3/4", was fastened to the plate mounting accurately normal to the trajectory of the bullets. The 1/2-inch test plate was then fixed 2 inches behind the 3/4-inch stripper plate by means of C clamps and 2-inch wood blocks. Impacts were made against the two plate combination until the limit velocity (V_1) was obtained by the "bullet through with zero remaining velocity" criterion. The test plate was removed and impacts made against the stripper plate at velocities in the neighborhood of V_1. The object

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was to deduce the remaining velocity (V_2) of the AP dart just sufficient to penetrate the test plate. It was found that, when the residual velocities of the dart beyond the stripper plate as measured by the pendulum were converted into foot pounds energy, the difference between this remaining energy and the energy of the dart at impact held about constant for the range of velocities, ±50 foot seconds used. The energy absorbed from the dart by the stripper plate was found with sufficient accuracy by averaging results from three reliable impacts. Subtraction of this absorbed energy from the impact energy (E_1) at the limit of the two plate combination yielded the dart energy (E_2) just sufficient to penetrate the test plate.

10. The merit coefficient for the plate tested was deduced from the formula,

$$F = \left(\frac{m^{\frac{1}{2}} V_2}{e^{\frac{1}{2}} d} \right) = \left(\frac{2gE_2}{ed^2} \right)^{\frac{1}{2}}$$

where m is the mass of the dart, V_2 is the remaining velocity of the dart after it emerges from the stripper plate, e is the thickness of the test plate, d is the diameter of the dart, g is the acceleration of gravity, and E_2 is the remaining energy of the dart after it has gone through the stripper plate. The units employed are mass in pounds, velocity in feet per second, lengths in feet, energy in foot pounds.

DATA OBTAINED

11. Stripped dart limits were obtained upon twenty-four 1/2-inch thick samples of prospective armor plate compositions submitted by Midvale Steel Company (5 samples), Carnegie Steel Company (13 samples), and Bethlehem Steel Company (6 samples). Additional plates from Midvale Steel Company were received too late for immediate testing. The results are tabulated on Plate 2, together with chemical compositions and physical properties.

12. There are nine principal sources of error which must be considered. These errors which will presently be discussed are in addition to whatever random variations may exist in energy absorbed from the core of the AP bullet on account of variations in stripper plate quality or on account of variations, other than weight, of the bullets. An analysis of the nine errors and comparison of their probable magnitudes with the actual scatter obtained in determining a stripper plate calibration curve reveals sufficient agreement between calculated and observed scatter that any other errors present must be of relatively small magnitudes.

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13. Possibly the largest uncertainty present in the data is associated with the Aberdeen chronograph velocities. The magnitude of this error can be reduced through purchase of an instrument of best modern design. The principal defect in the Naval Research Laboratory Aberdeen chronograph is the variation in the path of the spark from the point to the rotating drum. Using a 16-foot base length, velocities in the neighborhood of 2000 feet per second are uncertain to the extent of ±10 feet per second. This leads to ±40 foot pounds or 2 per cent possible error in calculated energy of the dart after passing through a .75" stripper plate. It is probable that recent models of the Aberdeen chronograph are capable of at least ±5 foot per second accuracy for a 16-foot base length.

14. Variation in weights of darts is a less frequent source of error. More than half the caliber .50 AP bullets used at the Naval Research Laboratory weigh from 753 to 756 grains. However, some have been found to be as light as 750 grains and some as heavy as 758.5 grains. By extracting and weighing a set of AP darts from a weighed set of bullets, it was found that the weight of the dart can be predicted rather accurately in terms of the weight of the whole bullet. The results are shown on Plate 3, Figure 2. It appeared that within ±.75 grains the following formula represented the weights of the darts:

$$W_d = 412 \text{ grains} + (W_b - 754.5 \text{ grains})$$

where W_d is the weight in grains of the dart, and W_b, the weight in grains of the bullet. Unfortunately, the variation in dart weights and the means of ascertaining dart weight by weighing the bullets were not discovered prior to collection of the data in this report. The effect of a 1-per cent heavier than average dart, if unknown and not corrected for, is to produce a 60-foot pound (3 per cent) error in the stripper plate calibration curve. The variation in core weights present in the data for this report should have produced an average random error of about ±25 foot pounds, but occasional errors, as large as 120 foot pounds, due to projectile weight, are understandable. The proper method of procedure to reduce this error is, clearly, to weigh the caliber .50 bullets before loading and deduce the dart weight from a predetermined equation such as the equation for W_d given above.

15. The largest convenient length for the radius of the arc described by the Naval Research Laboratory pendulum was 72 inches. With the length of suspension limited by the ceiling of the target house, it was necessary to make the weight of the pendulum small enough so that readings of the deflection to ±0.02" gave a sufficiently accurate measure of the residual velocity of the AP dart. On account of vibration and the possibility of not stopping highest velocity projectiles, a pendulum weight of at least 115 pounds is recommended. With the 120-pound pendulum weight and 72-inch suspension used at

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the Naval Research Laboratory, the dart of a caliber .50 AP bullet striking the pendulum with 1500 feet per second velocity caused a deflection of 4 inches. Thus residual velocities of about 1500 feet per second of the caliber .50 AP dart could be measured to ±8 feet per second (1/2 per cent) and the calculated residual energies could scarcely be in error by more than ±20 foot pounds due to the pendulum reading error.

16. As AP darts are fired into the pendulum, the pendulum weight increases. For a 120 pound pendulum the error, through neglecting this weight increase, amounts to about 1 per cent when twenty darts have been added to the pendulum block. Since the pendulum blocks used at the Naval Research Laboratory did not require replacement prior to receiving some forty darts, the pendulum constant used for calculating residual velocities was corrected continually for change in pendulum weight and checked at convenient intervals by weighing the whole pendulum. Such a procedure eliminated any significant error due to changes in pendulum mass.

17. The ballistic pendulum swings so that each point of the pendulum describes an equal 72-inch radius arc about a center directly over it. Thus the measured movement of any part of the pendulum gives the movement of the center of gravity. However, on account of vibrations, the part of the pendulum whose motion is measured should be as close as convenient to the pendulum's center of gravity. On the Naval Research Laboratory pendulum the displacement is measured by means of a collar set back about 10 inches behind the center of gravity of the pendulum. A polished rod 8 inches in length and 1/4 inch in diameter, fixed parallel to the motion of the pendulum, projects through a 3/8-inch opening in the collar. The collar moves a light slider along the rod. Friction of the slider against the rod brings it to rest at the end of the backward swing of the pendulum. Since the pendulum motion is relatively slow, changing from about one foot per second to zero velocity at the end of the swing, the friction of the slider against the rod can and must be made very small. Early measurements including some of the data in this report, were taken before the possible errors from slider friction were appreciated and the friction reduced to a negligible amount. Analysis carried through for the Naval Research Laboratory pendulum shows that the per cent error in calculated residual velocities is about 4 f/s, where f is the average slider friction in ounces and s is the pendulum deflection in inches. The following was a satisfactory method of adjusting the slider friction. The rod and slider were removed from the mounting and placed in a vertical position. Weights were placed on the slider and the friction adjusted by lapping and otherwise relieving contact between the slider and the polished rod. Adjustment was considered satisfactory when the starting friction was less than one ounce and the sliding friction no more than 1/4 ounce.

18. The Naval Research Laboratory pendulum in its present improved form appears to respond satisfactorily to impacts as far as

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8 inches away from the center of the face of the pendulum. Unless this result is given positive confirmation upon the instrument to which it is applied, impacts should be aimed so as to strike the pendulum face within a circle of somewhat smaller, say 5-inch, radius about the center of gravity of the pendulum.

19. When a caliber .50 AP penetration is made at about 2000 feet per second velocity in a piece of .75" mild steel of the type used for stripper plates, plate deformation and work hardening effects can be detected as far as 1 inch from the center of the perforation. If a second perforation is made so that the center lines of the two perforations are 1-1/2" apart, the remaining velocity in the case of the second perforation does not differ measurably from that in the case of the first penetration in spite of overlapping of the cold worked zones. A perforation which has less than the above 1-1/2-inch separation from a previous impact may show either more or less than the average absorbed energy.

20. It is important that the projectiles strike the stripper plate with small or zero yaw. The effect of yaw is to change the direction of the trajectory of the dart and give it various amounts of rotational momentum about a transverse axis. Tests were made at the Naval Research Laboratory in which a piece of fabric board was placed so as to measure the amount of tumbling of the darts 6 inches behind a .75" mild steel stripper plate. The turning was less than 3 degrees, the minimum yaw measurable, in 80 per cent of the penetrations. Notice was taken during collection of the data in this report of deviations of the dart trajectory as shown by alignment of holes in the stripper plate with those in the face of the pendulum block. The deviation averaged less than 2 degrees from the trajectory at impact in 75 per cent of the penetrations. Impacts which show the effect of considerable amount of bullet yaw at impact are of no benefit in determining the accurate limit velocities and residual velocities needed for testing with caliber .50 darts. The number of impacts wasted for this reason can be reduced somewhat by adjustment of the Aberdeen screens so that several inches of flat screen area around the expected perforation are perpendicular to the trajectory and free from other perforations.

21. Assigning probable errors of 25, 25, 15, and 10 foot pounds respectively to errors caused by Aberdeen chronograph record, projectile weight variation, pendulum reading, and other effects, one anticipates an average scatter of the order of $\pm$40 foot pounds in absorption data plotted for a stripper plate of uniform quality and thickness. Plate 4 shows results of an experiment performed with a section of stripper plate selected upon the basis of best previous results and performed with effects of slider friction and of bullet yaw minimized. Eleven impacts were performed. One impact was wasted through failure of the velocity recording equipment. The impact which had greatest (2 degrees) deviation of the dart trajectory gave an

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energy absorption 200 foot pounds less than did other impacts at neighboring velocities and was disregarded. The remaining nine impacts are well represented by a straight line sloping toward smaller energy absorptions at greater impact energies. The average scatter of the nine points above and below this line is ±42 foot pounds in agreement with the amount anticipated in view of the preceding discussion of errors.

22. On account of the presence of slider friction of unknown amounts in all of the 1/2-inch test plate results, the limit velocities on these plates are from 2 per cent to 4 per cent too low. Three of the Midvale samples were retested after a lapse of several weeks without obtaining appreciably different results from those found in their first testing. It thus seems reasonably certain that the relative performance exhibited by these tests can be trusted within the amounts of error stated for each plate, although the absolute limit values may be somewhat higher than the stated limits of error permit.

CONCLUSIONS

23. The energy absorption curve shown on Plate 4 is very similar to energy absorption curves previously found for annealed boiler plate with caliber .30 AP bullets. The effect of the jacket upon penetration for caliber .50 bullets must therefore be similar to the effect discussed in reference (b) for caliber .30 AP bullets.

24. Several attempts were made to determine limits with darts at 30 degree obliquity. Unfortunately, the tungsten steel core breaks at this obliquity against STS plates as thin as 1/4 inch. Testing with tungsten steel cores must be restricted to very small obliquities for the purposes of the impact test method described in this report. In other application where the samples tested are intended for protection against small caliber AP bullets the criticism of bullet fracture does not apply to the oblique angle testing as long as the test projectiles are similar to those expected in service. In event the additional expense is considered justified, projectiles which do not break at 30 degrees obliquity can, of course, be specially manufactured. The impact method, using normal impact as proposed in this report, presupposes use of average quality caliber .50 AP bullets.

25. The best stripper plates tried were annealed boiler plates slightly under 3/4-inch thick that averaged about Brinell 100. Samples of 1035 steel furnished by Bethlehem Steel Company, Brinell 163, gave fairly uniform results after annealing to Brinell 147. However, the AP dart turned during penetration of the stripper plate to such an extent that less than 50 per cent of the impacts against this material were useful for test purposes. An annealed sample of

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1010 steel was tried and found unsatisfactory. If the stripper material is too soft the bullet hole increases in size with the impact velocity and may open sufficiently to allow parts of the jacket to penetrate and strike the pendulum. A 3/8-inch STS plate, Brinell 250, gave worse results than the Bethlehem sample of 1035 steel. SAE 1020 steel annealed should duplicate very nearly the proporties of the annealed boiler plates found most satisfactory for use as stripper plates.

26. Velocities of from 1250 to 1750 feet per second of the caliber .50 AP dart after removal of the jacket can be obtained with the methods and accuracy described above. Higher velocities can be obtained if desired but one must arrange so that the boat-tailed rear portion of the projectile's copper jacket does not follow the dart through the stripper plate. This occurs at velocities above 2200 against 3/4-inch stripper plate material, but can be prevented by simply removing the portion of the jacket in question before loading. Five bullets so treated were fired at velocities of 2300 to 2400 feet per second. The average yaw at 100 yards for this group was no more than is usual for ordinary bullets.

27. Test specimens of armor plate 1/2-inch thick are recommended. At this thickness standard type STS armor at normal impact has a stripped dart limit, about 1500 feet per second, in the middle of the range of velocities conveniently obtained.

28. Construction of a suitable pendulum involves choosing a length of suspension and a weight such that the expected deflections will be easily measured to 1/2 per cent and such that the impacts will not cause large amplitude vibrations of the pendulum components. In addition the deflection of the pendulum should be measured as close as is convenient to the center of gravity. The satisfactory Naval Research Laboratory pendulum weighs 120 pounds and has a wire suspension system designed to prevent rotation of the pendulum and to allow parallel motion in an arc of 72-inch radius. The deflection is measured about 10 inches behind the pendulum's center of gravity by means of an indicator which slides along a rod against approximately 1/4 ounce of friction.

29. For accurate work, bullets with less than 2-degree yaw at impact must be used. A good average with respect to impacts with small yaw can be obtained by using a 100-yard range and chronograph screens made of light flat metal sheets. Penetration in stripper plates should be two inches or more apart. When penetrations in the stripper plate come as close as 1-1/2 inches between centers, the results may still be given weight unless the trajectory of the dart has been turned. Impacts which show 2 degrees or more of turning of the dart trajectory should be disregarded in calculating limits.

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30. When performed under good conditions with respect to the sources of error described in this report, the proposed impact test method has the following features:

(a) One-half inch specimens are penetrated at nearly limit velocity.

(b) The projectile, a hardened tungsten steel dart, strikes at normal impact with less than 2 degrees of yaw and undergoes no appreciable deformation.

(c) The limit velocity of an armor sample is measured to ±20 feet per second (1.3 per cent).

(d) The dart impact velocity used is close to 1500 feet per second for average 1/2-inch STS armor.

31. The ballistic limit data available show no evidence of important velocity-dependent forces of the viscous type during high speed penetration of steel plates. This means that, in as far as an impact upon an armor plate at Naval Proving Grounds resembles a scaled up model of the armor sample impact test using the dart from a caliber .50 AP bullet, one can anticipate the same merit coefficient, F, for the dart test as for the full scale test. That such a simple correlation of the results of these two impact tests is not possible is caused by the lack of similarity of the plates, projectiles, and obliquities used. If the armor plate does not have the same composition, heat treatment, and grain size in all sections, one 1/2-inch sample cut from a chosen section of the plate cannot be representative of all sections. Any large laminations present in the plate could be duplicated only by chance in the 1/2-inch samples.

32. Judged as a scaled down copy of a major caliber armor piercer, the .427" dart is too long, too heavy, has too large radius on the ogive, and possesses neither cap nor windshield. Instead of testing with an e/d ratio of, say, 0.6 at 30 degrees obliquity, the dart impact test is made at normal incidence with an e/d of 1.17. It is a surprising and interesting fact that in spite of such differences, samples of deck armor and of somewhat harder STS armor plates, when tested with the darts, gave merit coefficients of from 46,000 to 50,000 in agreement with extrapolation of the Proving Grounds $F(e/d, \theta)$ vs. e/d curve for major calibers and normal impact.

33. The dart impact test proposed above was not designed as a small scale test of armor plate, but as a superior physical test. The above-mentioned dissimilarities in impact conditions will no doubt result in some disagreements between F coefficients at full scale and those obtained with the armor piercing dart. Nevertheless, the proposed impact tests with darts constitute the best practical

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method now known of testing small samples of heavy armor plates. The testing of samples of armor plate with darts is accurate, relatively simple, and measures ability to resist high speed penetration. Such a test has long been needed by armor manufacturers as a means of investigating improved chemical compositions, heat treatments, and some of the causes of plate failures.

SUMMARY

34. This report described in detail a method of testing samples of armor with the darts from caliber .50 AP bullets. Improvements in apparatus and technique have been made since such tests were used with caliber .30 AP bullets, reference (b), for another purpose. By use of the equipment and methods described in this report, 1/2-inch armor samples may be subjected to high speed penetration by a hardened tungsten steel dart, 0.427" diameter, 412 grains weight, and the impact velocity required for penetration measured to an accuracy of at least 1%.

35. Results of tests performed on 24 samples of various armor compositions and heat treatments furnished by three steel companies are tabulated. Nine principal sources of error are discussed and the probable magnitude of their effect verified with experimental data.

36. Lack of similarity is considered great enough to prevent an exact model type correlation between dart impact test results and plate limits determined at the Naval Proving Grounds. The described method of testing small armor samples is, nevertheless, an accurate and a very appropriate impact test for armor material, and its use by manufacturers of armor plate is recommended.

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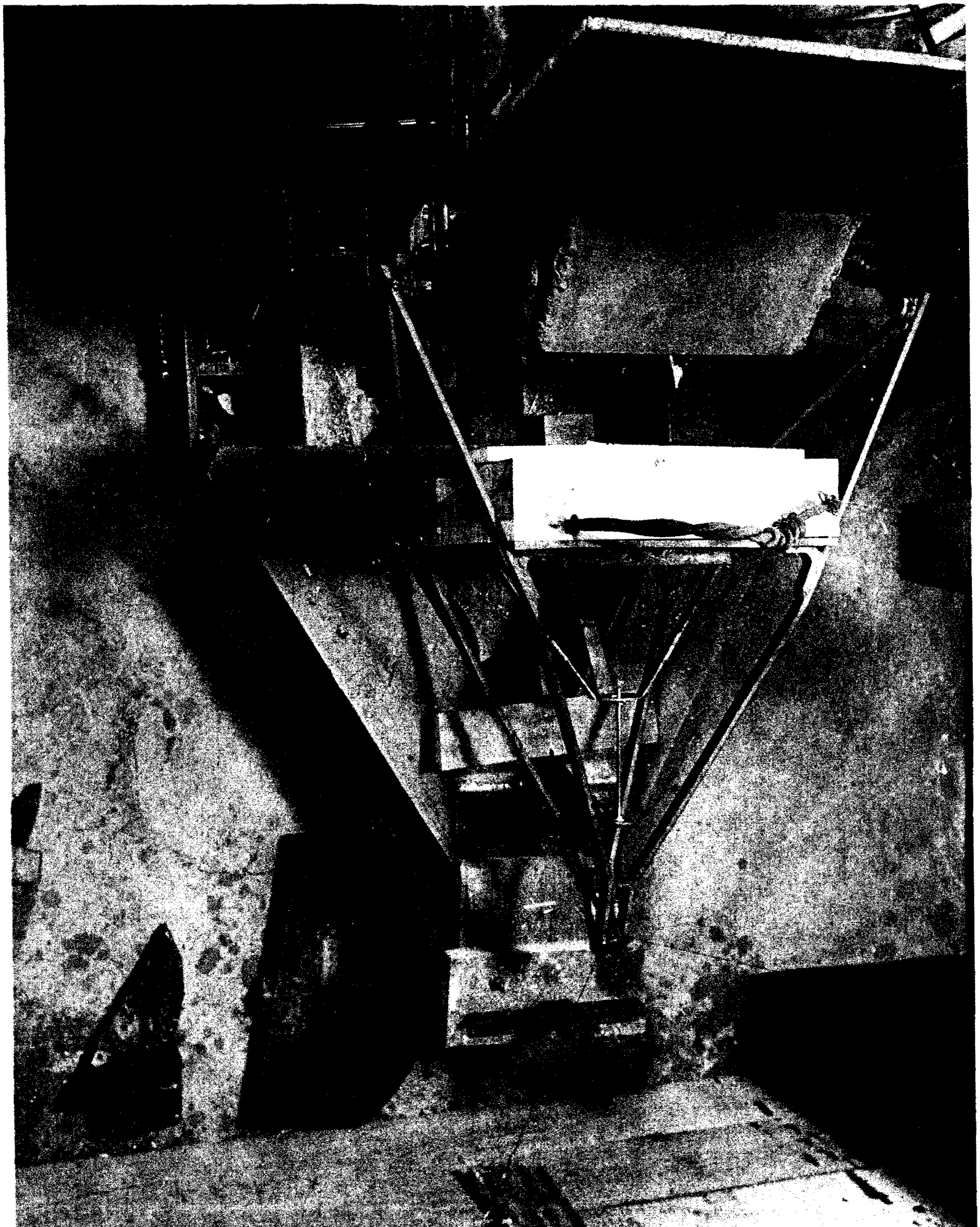

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PLATE 1