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NAVORD REPORT 2422

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SMALL SCALE PLATE DENT TEST FOR CONFINED CHARGES,

NOL-Re2c-1-1,
NOL-Re2b-41-1-52

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NAVORD Report 2422

SMALL SCALE PLATE DENT TEST FOR CONFINED CHARGES

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Approved by: Russell McGill
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ABSTRACT: Brisance tests of small diameter highly confined charges of pure explosive compounds have been made. The diameter of the confined charge varied from one tenth inch to one quarter inch. The experiments indicated a nearly linear relationship between the total brisance measured by the depth of the dent, and the detonation velocity. An expression relating the depth of dent for confined charges to properties of the explosive and the metal used has been developed. The results indicated that small scale brisance tests may be used to estimate whether new explosive compounds would be superior to those in use in ordnance.

Explosives Research Department
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NAVORD Report 2422 23 April 1952

Investigation of a promising means of evaluating explosives where small quantities of explosive and only limited experimental facilities are available is reported. This investigation was authorized by Task Assignment NOL-Re2c-1-1(?) and NOL-Re2b-[illegible]-1-52. The technique shows considerable promise for this purpose and for the evaluation of detonators. The conclusions presented herein are preliminary and subject to modification after further study. However, the consistency of the data inspires confidence in the accuracy of the conclusions. The data and interpretation presented herein are for information only and not intended as a basis for action.

EDWARD L. WOODYARD
Captain, USN
Commander

J. E. Ablard

J. E. ABLARD
By direction

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INTRODUCTION

Of the various means of investigating the vigor of an explosion, the simplest are those in which the damage wrought by the explosion on surrounding material is used as a criterion. Such tests include the sand test, reference (a), the bent nail test, reference (b), the Trauzl lead block test, reference (c), copper block test, lead disc test, and the plate dent test, references (d) and (e). On the basis that naming a thing makes it more understandable, the numbers obtained in such measurements are called the "brisance" of the explosive or explosive device whose action caused the damage.

The plate dent test, in addition to being one of the more easily performed experiments, is one which yields results which correlate with physical properties of the detonation in a theoretically significant manner. The success of the small scale detonation velocity technique, reference (f), encouraged the belief that similar methods might be applied to the plate dent test to yield a means of evaluating new explosive compounds which are available only in quantities of a few grams. Such a method would have the advantage of requiring neither complex techniques nor expensive equipment. The present report is an account of some exploratory experiments to determine the prospective usefulness and feasibility of small scale plate dent tests.

EXPERIMENTAL TECHNIQUE AND ARRANGEMENT

Detonations of highly confined columns of explosive were allowed to impinge upon the surface of metal blocks. The depths of the resulting dents were measured and compared. The general arrangement is shown in Figure 1.

The explosive was loaded into heavy walled brass tubes made by drilling and reaming bar stock. The tubes were counterbored at one end for the insertion of an electric initiator. Most of the tubes were two inches long with about a half inch deep counterbore, leaving about one and a half inches for the explosive column. Several sizes of tubes were used including 0"10, 0"15, 0"20 and 0"25 inside diameters. The ratio of the outside diameter of the tubes to the inside diameter of the tubes was never less than 6.67. It is believed that this ratio was large enough for adequate confinement in each case, and that any further increase would have had a negligible effect. The blocks in which the dents were made were two inch long pieces cut from one by two inch cold finished, SAE 1020 steel bars. The dent was made in one of the broad faces which was cold finished.

The explosive was loaded by increments at [illegible],000 psi, 8,000 psi, and [illegible],000 psi. Increments were limited in length to not more than the diameter of the hole in order to reduce the variations in density due to wall friction which occur when longer increments are used. Densities were determined from the loading pressures using the relations given in reference (g). In some cases, these values were verified by measurements of the volume and mass of explosive columns.

Electric initiators with bridge wires attached by the spray-metal process, reference (h) loaded with flash charges of fifty milligrams of milled lead azide at 4,000 psi were used.

MEASUREMENTS

After each set of shots the blocks were washed with carbon tetrachloride to clean the surface. Deposits of lead on the surface of the block were removed before any measurements were made. All measurements of depth of dent were made by means of an Ames #3822 shockless dial indicator. A round point feeler was used and four readings were made on each block, one from each edge. The depth of dent for each reading was taken as the maximum deflection of the dial from the zero position. The average of these four readings was taken as the depth of dent for this particular block. In cases where several samples were made to the same specifications an average of their depth of dent was taken as the depth of dent for the group.

The dents obtained, Figure 2, were more or less cylindrical with nearly flat bottoms. The charges used were small enough so that the only measurable deformation of the plate other than the dent was a slight swelling, about 0.002" which was radially symmetrical to the dent. In Figure 3 the depths of dent obtained with four high explosives and four column diameters are plotted versus the detonation velocities of the explosives loaded at the same densities. The velocities used in this plot and elsewhere in this report were determined from the loading densities using detonation velocity-density data from reference (i). Note the linear relationship of depth of dent to detonation velocity. The convergence of the lines at a point is probably not significant. The charge was detonated with a few increments of lead azide between the initiator and the main charge, Figure 1. This detonator charge could cause considerable difficulty if it had to be considered in the interpretation of results. However, if the assumption can be made that the dent is caused entirely by the charge material, a fairly simple relationship between the depth of dent and the properties of the explosive may be derived. It was therefore necessary to determine the variation of depth of dent with length of explosive column.

A study of the effect of charge dimensions on the depth of dent was undertaken. Charges of lead azide and tetryl in which the fractional column lengths of the two materials was varied were detonated on the surface of metal plates and a measure of the depth of dent was made. The explosives were loaded in columns of total length 0"5, 1"0, and 1"5 at 8,000 psi in heavy walled containers.

The results of these experiments are plotted in Figures 4 and 5. Note that both the total column length (Y) and the length of the tetryl column (y) affect the depth of dent when these quantities are small, but when the total column length exceeds about an inch and the length of the tetryl column is over approximately five diameters, the depth of dent becomes independent of both of these dimensions. A similar experiment was performed in which the depth of dent was determined as a function of total column length for lead azide, Figure 6. In this experiment a standard length of tube was used so that the air gap between the initiator and the column decreased as the column length increased. The shape of the curve seems to indicate that the effect of this change in gap between the initiator and explosive column is negligible. The depth of dent becomes independent of the length of the column when the column length exceeds about a half inch. The larger relative dispersion with lead azide may be attributed at least in part to the residue of lead which had to be removed from the dent before measurements.

DISCUSSION

A rather interesting feature of the results of these experiments is the nearly linear relationship between the depth of dent and the detonation velocity, Figure 3. These results may be contrasted with those obtained in larger scale experiments, Figure 7, in which it was found that the depth of dent varied linearly with ρD^2, where D is the detonation velocity and ρ is the density at which the explosive was loaded. This apparent contradiction may be explained by the fact that the larger charges were bare while the smaller charges discussed herein were highly confined in metal. It is believed that the following qualitative discussion may aid in understanding what was experimentally observed. Consideration of dents in metals has usually been in connection with measuring the hardness of metals. A generality which may be derived is that the work done in producing a dent is proportional to the volume of the dent.

This generality, expressed as

$$E_d = K \pi r_d^2 \delta \qquad (1)$$

where E_d = the energy expended in producing the dent

K = constant

r_d = the radius of the dent

δ = the depth of the dent

will be assumed to apply in the present discussion. However, hardness measurements are made mostly under conditions of static loading so that the same proportionality constant may not apply.

Detonations are frequently considered as one dimensional phenomena in which radial losses can be neglected. Actually all charges are finite so that rarefaction waves follow the detonation from the rear and close in radially. In columns with diameters larger than an inch or so for most explosives the effect of these rarefactions upon the reaction zone and hence upon the stability and velocity of the detonation are nearly negligible. When highly confined in metal, even quite small charges of most explosives show relatively little diameter effect, reference ([illegible]). In any size charge, however, the size and condition of the "head" of rapidly moving, high pressure gases which follows the detonation are directly determined by the nature of these rarefaction waves. In columns whose lengths are large enough compared with their diameters, the head reaches a stable condition which is determined by the boundary conditions at the cylindrical surface of the column. Both of the size of the head and the length of the column required for it to stabilize itself depend upon what is defined as part of the head. [illegible] and Finkelstein, reference ([illegible]), define the head as all of the forward moving gases, but for the purpose of the present discussion, it will be arbitrarily defined as the material which contributes measurably to the deformation of the steel block. By definition metal can be permanently deformed only by stresses in excess of its elastic limit. The pressure which a moving fluid can exert upon a surface is the sum of the static pressure (P) and the kinetic pressure $\rho u^2/2$, where ρ is the density and u is the particle velocity normal to the surface. This sum

$$\frac{\rho u^2}{2} + P = H \qquad (2)$$

will be known herein as the "total pressure". Figure 8 is a simplified diagram showing, among other things, a probable distribution of the total pressure in the detonation head of a highly confined charge of explosive. The converging rarefaction waves result in more or less flat surfaces of constant total pressure. Thus, at any distance (L) from the front, the total pressure is highest at the center and falls off radially.

The roughly cylindrical shape of the dent made by these charges may be taken as evidence that, as might be expected, the pressure is distributed almost uniformly across the surface. It may be assumed that only the gas from the region in which the "total pressure" H is greater than the elastic limit of the steel contributes measurably to the depth of dent.

It is quite obvious that the total pressure must decrease as the distance (L) from the front increases. Although it is improbable that the relationship is linear, the assumption of linearity will be made for the limited range under consideration, where H varies from the total pressure at the front, H_f, down to the elastic limit, S, of the metal. It is also reasonable to expect that the gradient of the average total pressure is directly proportional to the acoustic impedance ratio between the explosive products and the metal case, and inversely proportional to the charge radius, that is

$$H = H_f\left(1 - \frac{K_1 \rho_0 D L}{\rho_c D_c r_c}\right) \qquad (3)$$

where H = the average total pressure at any position

H_f = the total pressure at the detonation front

ρ_0 = the initial density of the explosive

D = the detonation velocity

D_c = the shock velocity in the confining medium

ρ_c = the density of the confining medium

L = distance from the front

r_c = radius of the charge

K_1 = constant

Since the "head" has been defined as the part of the reaction products which contributes measurably to the deformation and it has been assumed that this includes only that part of the products for which the total pressure H_f is greater than the elastic limit S of the steel blocks, the length of the "head" (λ) can be obtained from the equation

$$S = H_2 = H_f\left(1 - \frac{K_1 \rho_0 D \lambda}{\rho_c D_c r_e}\right) \text{ - - - - - - } (4)$$

obtained from (3) by setting

$$L = \lambda \qquad S = H_2$$

Since S, about five kilobars, is small compared with H_f, about 100 kilobars;

$$\lambda = \frac{\rho_c D_c r_e}{K_1 \rho_0 D} \quad \text{approximately} \qquad (5)$$

The equation of motion of the surface of the metal after the detonation head has impacted upon it depends among other things upon the flow pattern of the metal and that of the reaction products and the confining medium as well as the equations of state of the three media. Any analysis of this complex problem would perforce involve a number of approximations and assumptions. For the present, the rather simple approximation will be made that permanent work which a volume element of detonation products can do upon the metal surface is proportional to the difference between the total pressure of the products, (H), as defined above, and the elastic limit of the metal (S), thus

$$E_h = \int_0^V a(H-S)\,dv = a\pi r^2 \int_0^{\lambda} (H-S)\,dL \text{ - - } (6)$$

where E_h = total energy of the detonation head, a is a constant

and S = elastic limit of the metal.

From equation (3)

$$E_h = a\pi r^2 \int_0^{\lambda} \left[H_f\left(1 - \frac{K_1 \rho_0 D L}{\rho_c D_c r_e}\right) - S\right] dL \text{ - - - } (7)$$

$$E_h = a\pi r^2 \frac{\rho_c D_c r_e^2}{K_1 \rho_0 D}\left(\frac{H_f}{2} - S\right) \text{ - - - - - - - - } (8)$$

(substituting equation (5))

Assuming that the reaction zone is quite short compared to the length of the "head", the Chapman-Jouget point, where the reaction is complete, may be used as the front for purposes of calculations.

$$H_s = \rho_o D u + \rho_o \frac{u^2}{2} = K_p \rho_o D^2 \text{ ------ reference (m)} \quad (9)$$

from equation (2) since the ratios $\frac{\rho_s}{\rho}$ and $\frac{u}{D}$ are nearly constant. So, from equation (8).

$$E_h = \frac{2\pi r^2 \rho_c D_c r_c}{K_1}\left(\frac{K_p D}{2} - \frac{S}{\rho_o D}\right) \text{ ---------} (10)$$

Assuming that the energy expended in deforming the plate is proportional to that available in the head. That is $E_h = b E_d$

$$2\pi r^2 \frac{\rho_c D_c r_c}{K_1}\left(\frac{K_p D}{2} - \frac{S}{\rho_o D}\right) = b K \pi r_d^2 d \qquad (11)$$

from equations (1) and (10)

From experimental results $r_d = r_c$.

Let $\frac{2 K_p}{2 K_1 K b} = K_2$ ------------------ (12)

Then,

$$d = K_2 r_c \rho_c D_c \left(D - \frac{S_1}{\rho_o D}\right) \text{ -----------------} (13)$$

$$\text{where } S_1 = \frac{2S}{K_p} \text{ -----------------} (14)$$

$$d/r_c = K_2 \rho_c D_c \left(D - S_1/\rho_o D\right) \text{ -----------------} (15)$$

The constants, S_1 and $K_2 \rho_c D_c$, can now be determined using two experimental points obtained with explosives for which the relationship between loading density and velocity are known. The curves in Figure 9 were plotted from equation (15) using constants obtained in this manner. Average values of the constants as determined from several points were used. The same set of constants was used in computing each of the curves. Note that in the range of velocities considered all of the curves are so close to a straight line that only the most precise measurements could be expected to distinguish them from the line. With the exception of the curve for the 0.1 diameter columns, the experimental data fits these curves, and the straight line within the relatively small experimental error.

The constant S_1 is proportional to the elastic limit of the steel block. It is possible to make a rough check of the value which was obtained if we assume that the particle velocity (u) at the detonation front is equal to one fourth of the detonation velocity (D) and that the density behind the front (ρ) is 1.33 times the initial density (ρ_0).

These assumed values are reasonably good averages of the values obtained in calculations of detonation conditions, references (m) and (n). Thus:

$$K_p \rho_0 D^2 = \rho_0 D u + \rho \frac{u^2}{2} \qquad \text{(equation no. (9))}$$

$$\rho_0 D^2 K_p = \frac{\rho_0 D^2}{4} + \frac{1.33 \rho_0 D^2}{32}$$

$$K_p = 0.29$$

and from equation (14) and Figure 10

$$S = \frac{K_p S_1}{2} = 0.145 S_1 = .92 \left(\frac{km}{sec}\right)^2 \left(\frac{g}{cm^3}\right)$$

$$S = 0.92 \times 10^{10} \frac{dynes}{cm^2} = 94\ kg/mm^2$$

$$= 133{,}000\ psi$$

This may be compared with the hardness of the steel used, 70 to 85 Rockwell B, 125 to 163 Brinell. The Brinell number is defined, reference (c), as the load divided by the area of the dent in kilograms per square millimeter. It may also be compared with yield points of about 130,000 psi as indicated by the dent vs. static pressure curves, Figure 16. This agreement is probably as good as might be expected.

The foregoing discussion is based upon a number of approximations and assumptions many of which apply only over a limited range of conditions. For example, they would not be expected to apply to data obtained with unconfined charges such as that plotted in Figure 7. The assumptions apparently apply to the conditions of most of the experiments described herein with the notable exceptions of the data obtained with 0.100" diameter columns of high explosives and those obtained with lead azide. The assumption that the reaction zone is short compared with the detonation head may fail in the case of the 0.1" diameter explosive columns. Lead azide gives deeper dents than predicted by the theory, perhaps because the ratio of its acoustic impedance to that of the metal is so high that the pressure drop in the head no longer retains the simple relationship to this ratio that was assumed.

Other experiments and more complete and rigorous analyses are in progress and will form the subjects of future reports.

CONCLUSIONS

It may be concluded that the miniature plate dent test provides a nearly direct means of measuring detonation velocities of organic high explosives containing carbon, hydrogen, nitrogen and oxygen. The effect of metals either in mixtures or in chemical combination has yet to be determined. For the diameters of column used herein, one and one half inch of column length appears to be sufficient to achieve stability.

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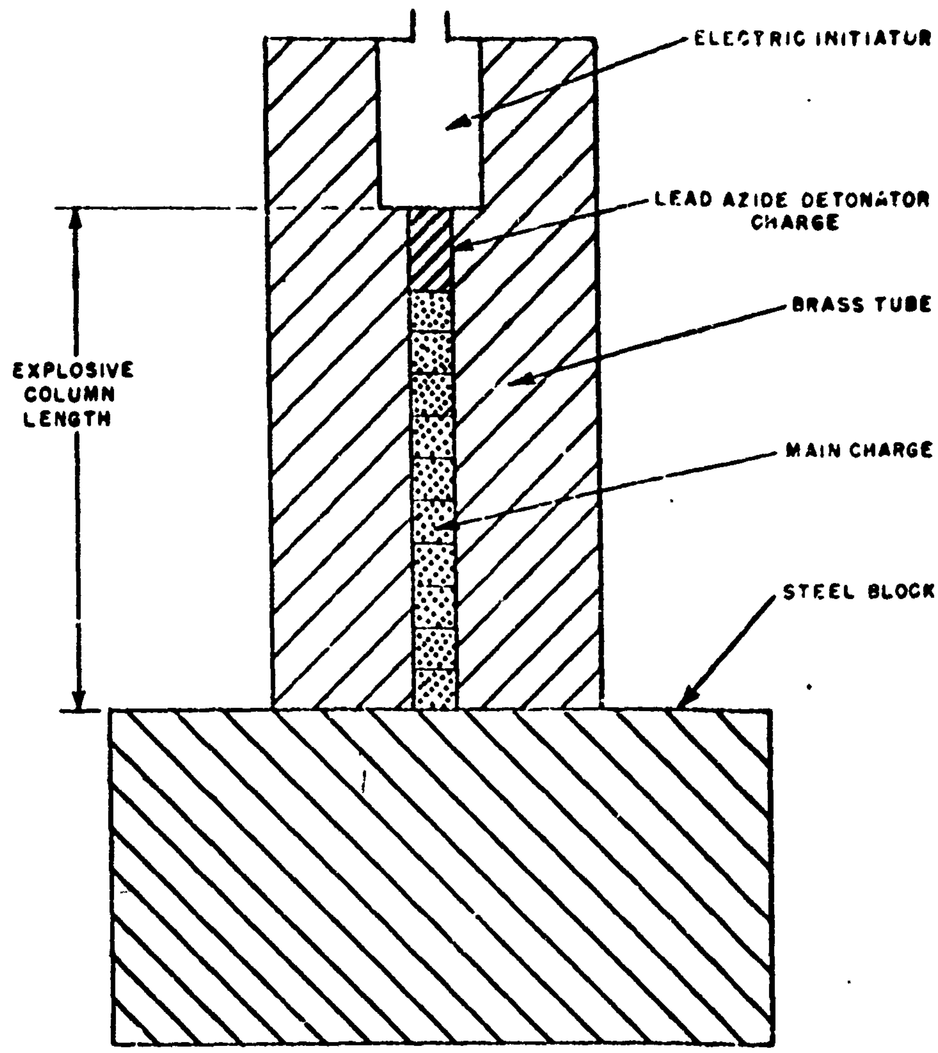


FIG. I
SMALL SCALE DENT TEST
(EXPERIMENTAL ARRANGEMENT)

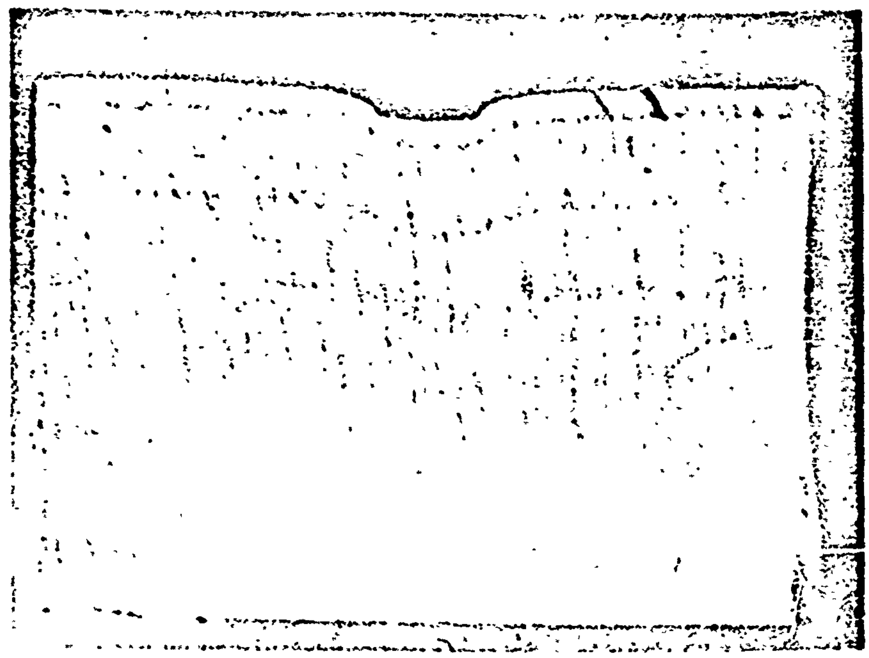


FIG. 2

CROSS SECTIONAL CUT OF METAL BLOCK SHOWING DENT

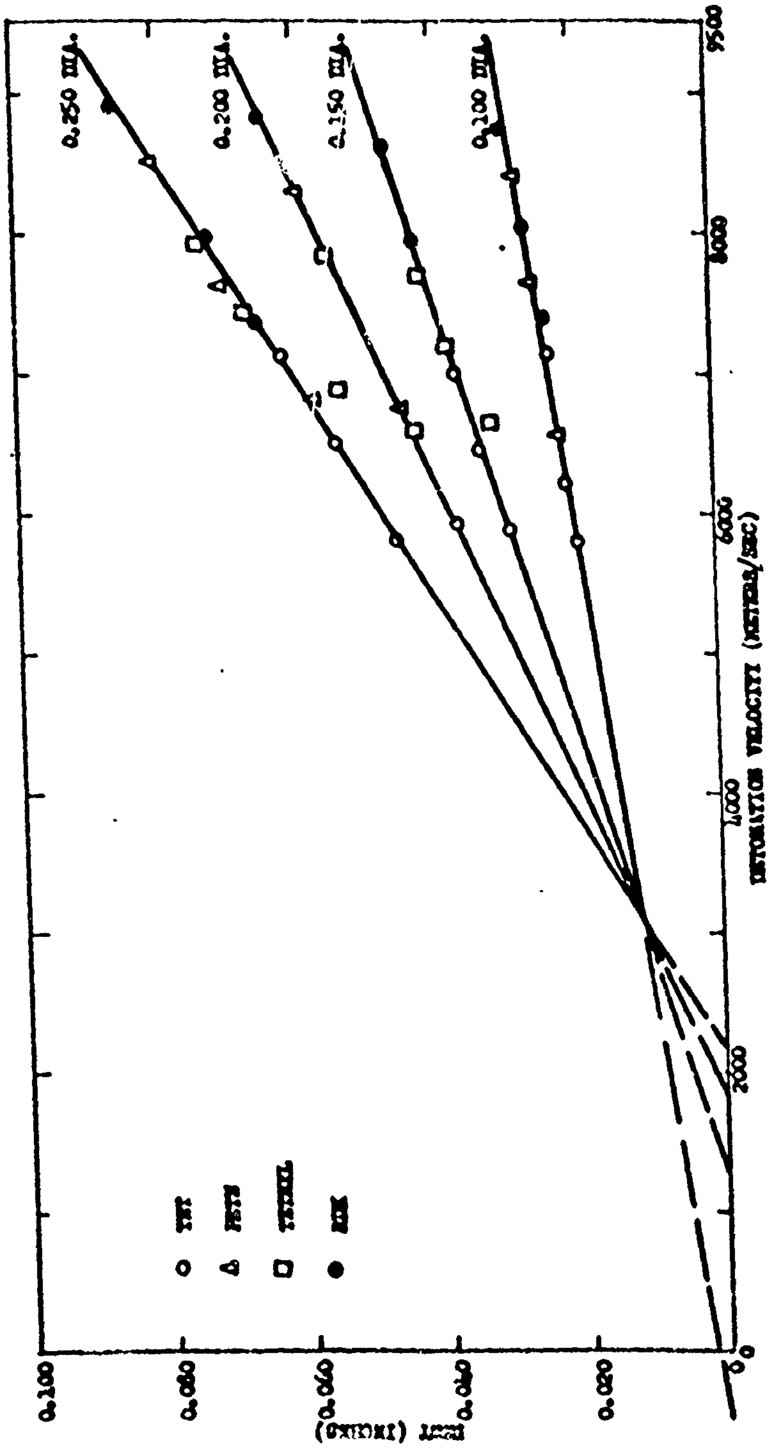


FIG. 3 DEPTH OF DENT IN STEEL BLOCK vs DETONATION VELOCITY

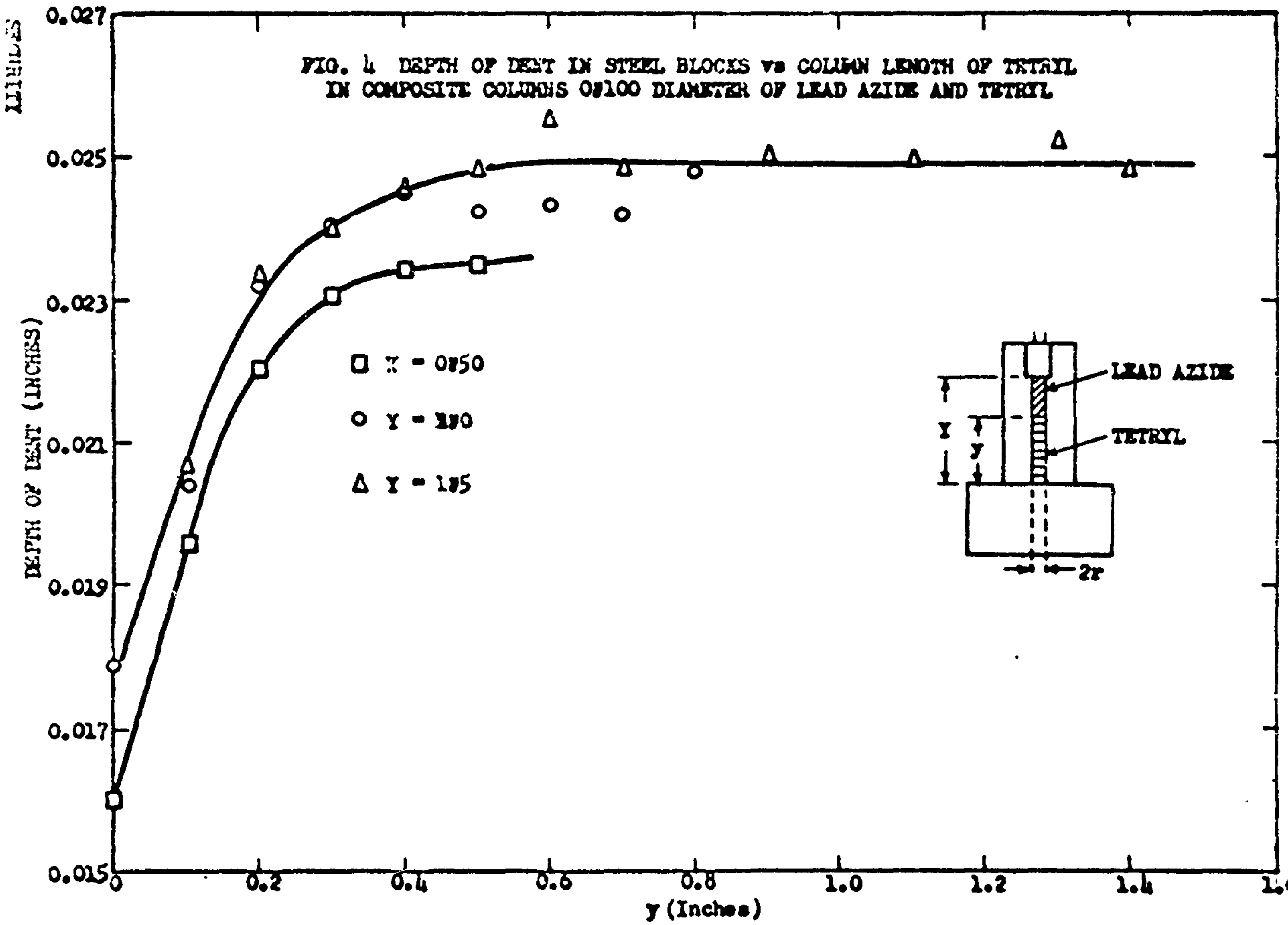


FIG. 4 DEPTH OF DENT IN STEEL BLOCKS vs COLUMN LENGTH OF TETRYL IN COMPOSITE COLUMNS 0.100 DIAMETER OF LEAD AZIDE AND TETRYL

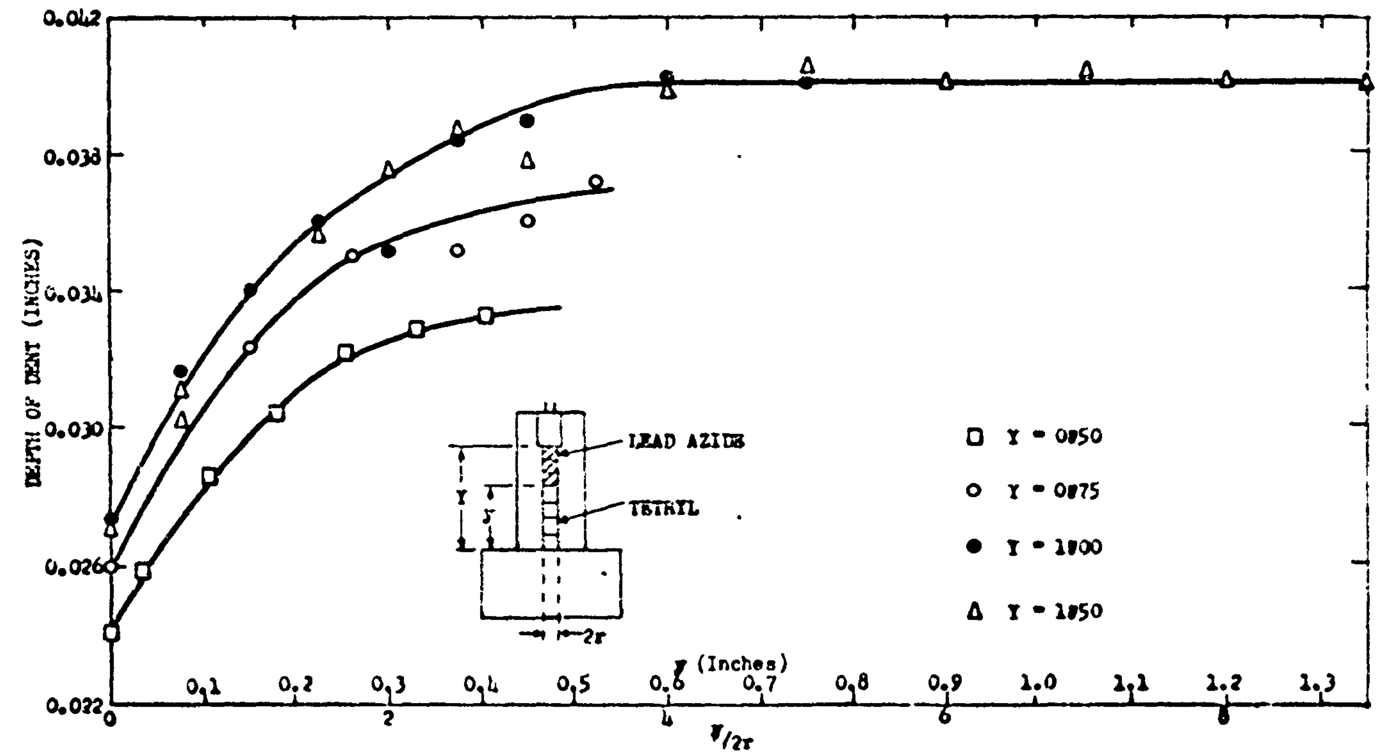


FIG. 5 DEPTH OF DENT IN STEEL BLOCKS vs COLUMN LENGTH OF TETRYL IN COMPOSITE COLUMNS 0.150 DIAMETER OF LEAD AZIDE AND TETRYL

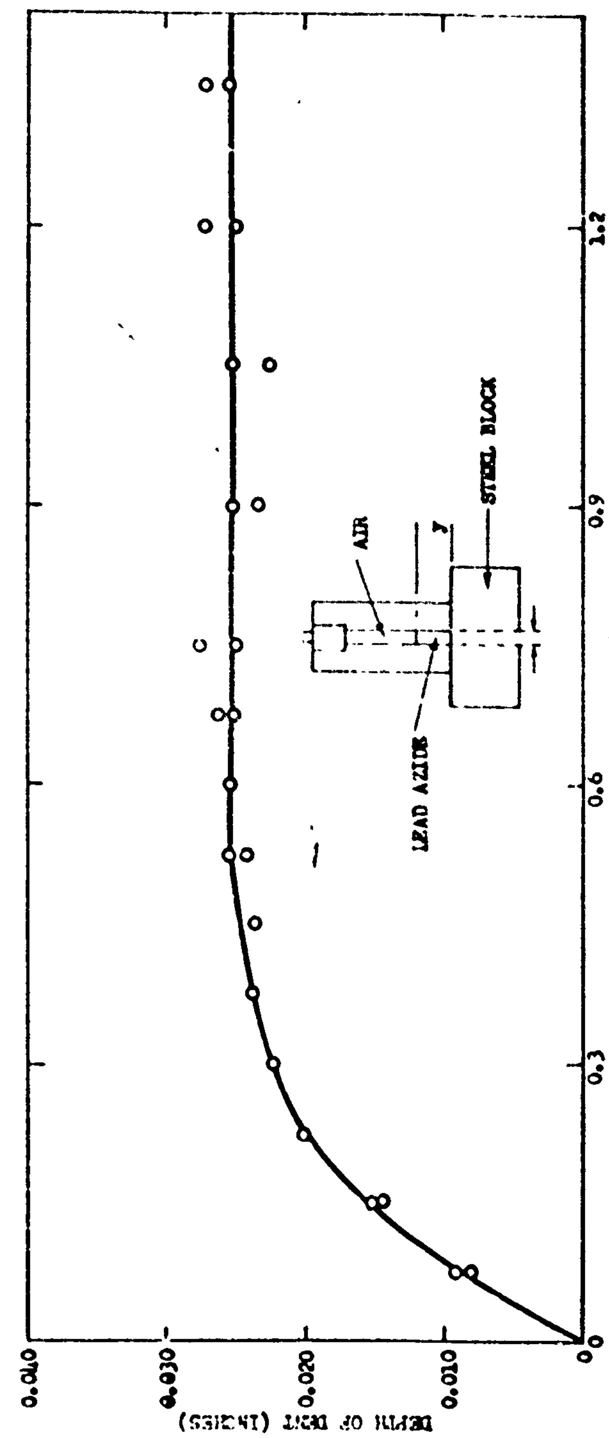


FIG. 6 DEPTH OF DENT vs COLUMN LENGTH LEAD AZIDE 0.150 IN DIAMETER

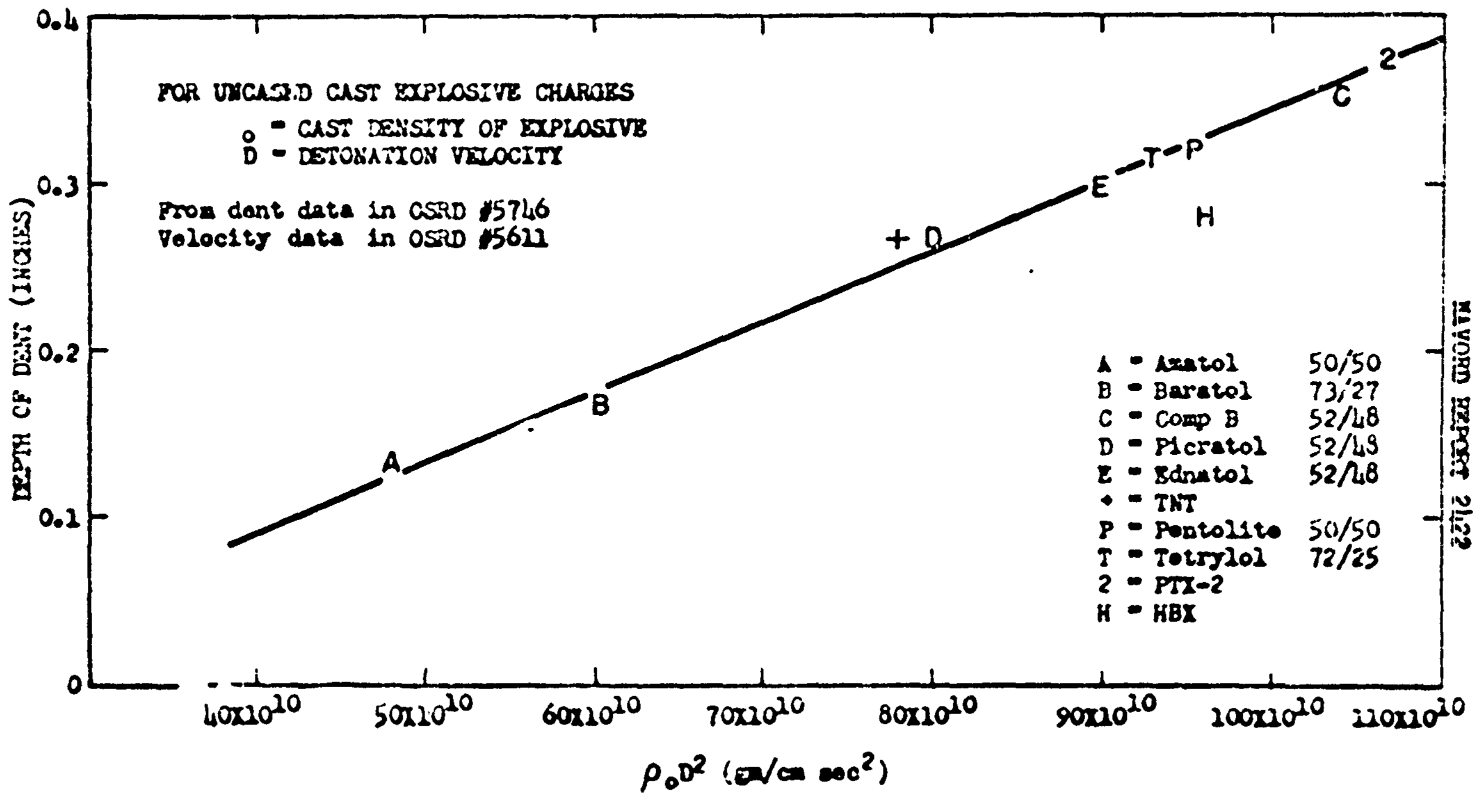
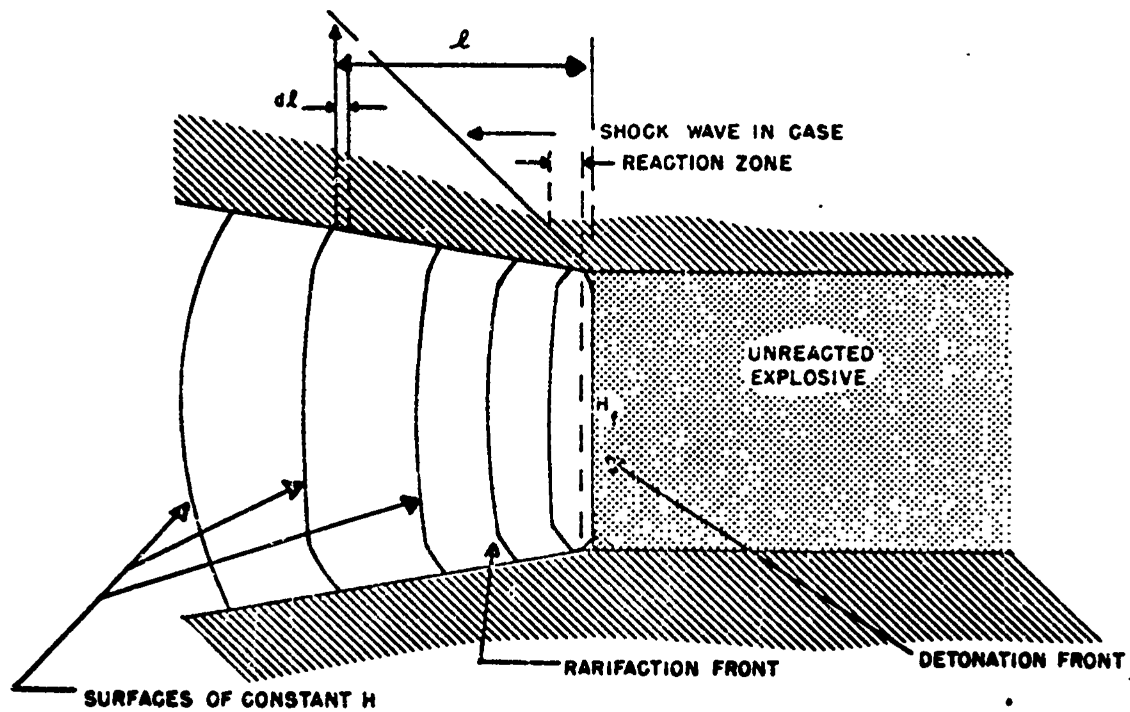


FIG. 7 DEPTH OF PLATE DENT vs $\rho_o D^2$



$H = P + \frac{\rho u^2}{2}$ ρ = DENSITY

P = PRESSURE u = AXIAL PARTICLE VELOCITY

FIG. 8
SIMPLIFIED DIAGRAM SHOWING CONDITIONS IN DETONATING HEAVILY CASED EXPLOSIVE CHARGE

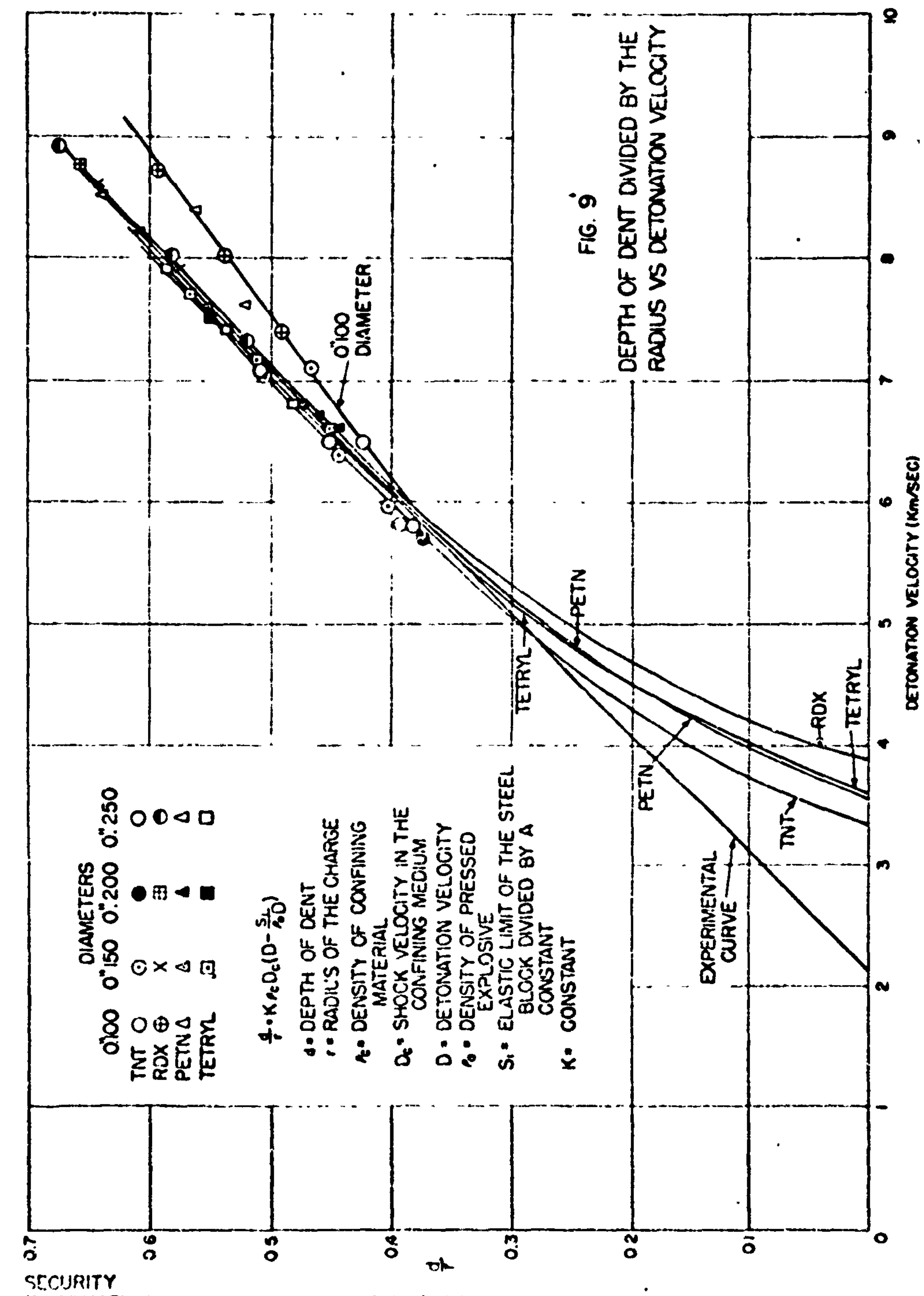


FIG. 9

DEPTH OF DENT DIVIDED BY THE RADIUS VS DETONATION VELOCITY

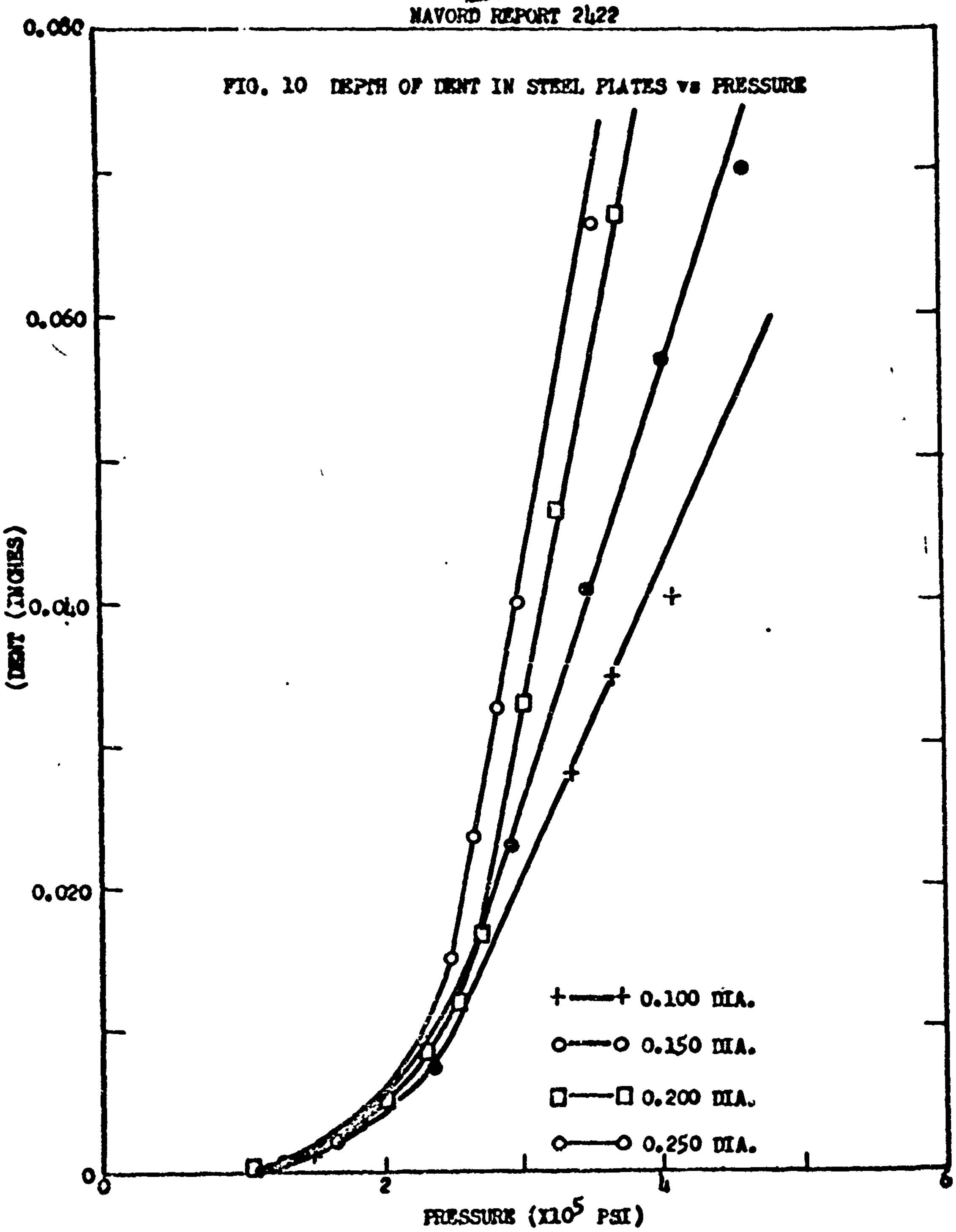


FIG. 10 DEPTH OF DENT IN STEEL PLATES vs PRESSURE

[redacted]

REFERENCES

(a) C. G. Storm, W. C. Cope, Technical Paper 125, Bureau of Mines, 1916, p. 10

(b) C. Hall, S. P. Howell, Bulletin 59, Bureau of Mines, Investigations of Detonators and Electric Detonators, p. 25-25

(c) C. E. Munroe, J. E. Tiffany, Bulletin 346, Bureau of Mines, Physical Testing of Explosives, p. 105

(d) L. C. Smith, E. H. Eyster, OSRD No. 5746, Physical Testing of Explosives, 1945

(e) L. C. Smith, S. R. Walton, NOLM 10381, Miscellaneous Physical Testing of Explosives, 1949

(f) L. D. Hampton, R. H. Stresau, Navord Report 2232, Small Scale Technique for Measurement of Detonation Velocities

(g) L. D. Hampton, NOLM 10765, Density of a Pressed Explosive as a Function of Loading Pressure

(h) R. H. Stresau, NOLM 8696, A Method for the Fabrication of Low Energy Electric Initiators (ML-159)

(i) M. D. Hurwitz, OSRD No. 5611, The Rate of Detonation of Various Explosive Compounds and Mixtures, Part III

(j) H. Eyring, R. E. Powell, G. H. Duffey, R. B. Parlin, Chemical Reviews, The Stability of Detonation, Vol. 45, p. 69-181

(k) R. J. Finkelstein, G. Gamow, Navord Report 50-45, Theory of the Detonation Process, p. 10

(l) R. Courant, K. O. Friedrichs, Supersonic Flow and Shock Waves, Interscience Publishers Inc., New York, 1948, p. 156, 101

(m) S. R. Brinkley, Jr., E. B. Wilson, OSRD No. 1510, Calculation of Detonation Properties of Some Pure Explosives, August 1943

(n) E. A. Christian, H. G. Snay, Navord Report 1508, Analysis of Experimental Data of Detonation Velocities, 1951

(o) O. W. Eshbach, Handbook of Engineering Fundamentals, Wiley New York, 1936, p. 5-89

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