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EXPLOSIONS OF 3540 POUNDS OF TNT ON BOTTOM IN 60 FEET OF WATER.(U)
JUL 48 F E HALE, G H CURL, A B FOCKE

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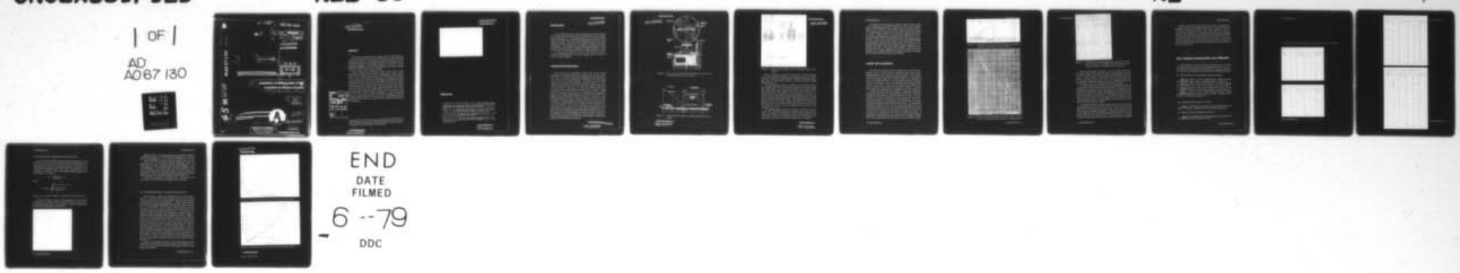

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FINAL REPORT

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explosions of 3540 pounds of TNT on bottom in 60 feet of water

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15 p.

U. S. NAVY ELECTRONICS LABORATORY
SAN DIEGO, CALIFORNIA

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abstract

The primary purpose of the explosion tests described was to inform the Seacoast Service Test Section, Army Ground Forces Board No. 1, of the effectiveness of large cast TNT submarine mines after extended exposure to sea water (Army Project SA 547). A secondary purpose, of interest to the authors, was the study of the application of crusher-gauge theory in explosions of large charges.

Three mines were detonated. Shot 1 was a "dry" mine exploded as a standard for later comparison. Shots 2 and 3 were "wet" mines, in which the charges had been exposed to sea water for several months by removing the two top covers from each mine and submerging. Comparison of the explosive forces was made by the effect on 32 ball crusher gauges placed at ranges varying from 75.5 to 157.8 feet. The effectiveness of the "wet" mines was found to be about 6 per cent and 5 per cent higher than that of the "dry" mine; but this slight apparent improvement, due to exposure, was not found to be statistically significant. Theory proposed by G. K. Hartmann on action of crusher gauges permitted absolute peak pressures to be computed. These agreed satisfactorily with pressures expected from purely theoretical calculations.

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1 Kirkwood, J.G. and Montroll, E.W., The Pressure Wave Produced by an Under-Water Explosion, II, Confidential NDRC No. 281 (OSRD No. 676) June 1942, NDRC Division B.

2 Fisher, R. A. Statistical Methods for Research Workers, Table IV, page 169, Oliver and Boyd, London, 1944.

3 Kenny, John F. Mathematics of Statistics, Part Two, page 117, Van Nostrand, New York, 1944.

4 Hartmann, G.K. Theory of Crusher Gauges, Navy Dept. BuOrd Memorandum for File, A16 (Re6b), 25 Sept. 1942. (Confidential)

introduction

The primary purpose of the explosion tests described was to inform the Seacoast Service Test Section, Army Ground Forces Board No. 1, of the effectiveness of large cast TNT submarine mines after extended exposure to sea water (Army Project SA 547). The tests were conducted aboard Army mine planters with Army personnel carrying out the placing of mines and gauges. The authors recommended the particular location for the test and the types of gauges and gauge rigs used. They also aided in conducting the tests and interpreting results.

A secondary purpose, of interest to the authors, was the study of the application of crusher-gauge theory in explosions of large charges.

experimental procedure

Three mines were detonated. Shot 1 was a "dry" mine exploded as a standard for later comparison. Shots 2 and 3 were "wet" mines, in which the charges had been exposed to sea water for several months by removing the two top covers from each mine and submerging. The charges were United States Army controlled submarine mines, type T-2, containing 3,540 pounds of cast TNT with six pounds of granular TNT as booster. (See fig. 1). They were detonated at sea, on sand bottom in approximately sixty feet of water. Firing location was 122° 35' West, 37° 50' North, which is just north of the Golden Gate entrance to San Francisco Harbor. Mines were detonated October 20, 22, and 23, 1947. The detailed gauge rig used is shown in figure 2, which has been annotated to show anchor weights, buoyancy of floats, etc. In order to maintain position of gauges as accurately as possible, the rig was laid cross current and the charge fired at slack current. Care was exercised to see that the connecting and retrieving line was taut and straight before firing. It was necessary to drag both gauge-line anchors to accomplish this, but photographic and line-of-sight checks indicated that an in-line arrangement was achieved. The direction of the gauge line was chosen to avoid possible complicating effects of the firing device cavity.

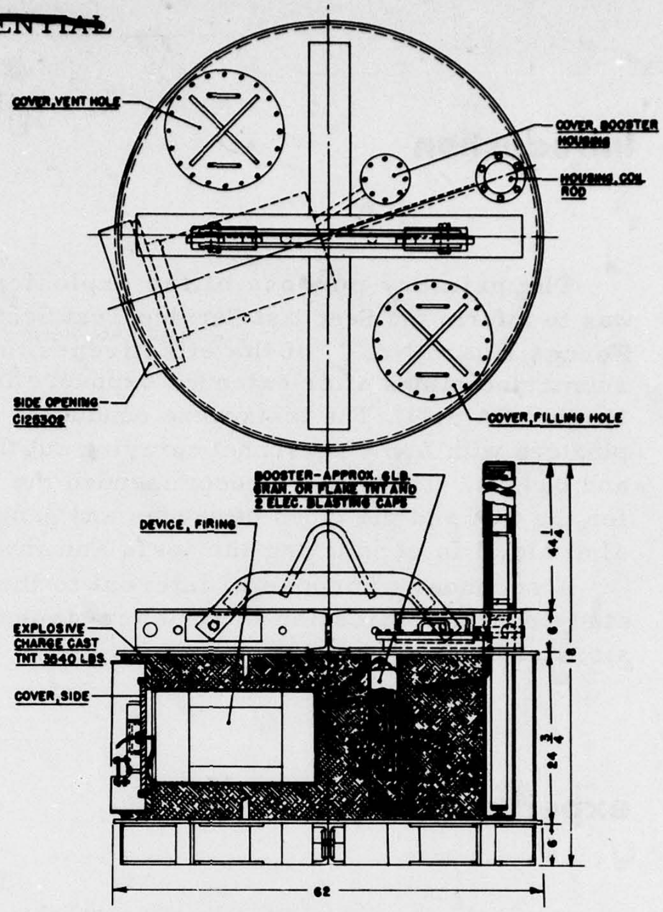

Figure 1. U.S. Army controlled submarine mine, type T2. (All dimensions are in inches.)

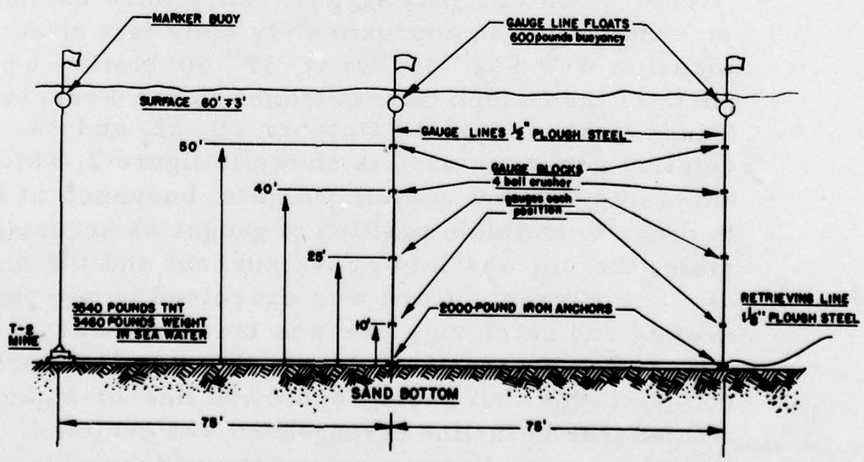

Figure 2. Experimental setup for crusher gauge measurements.

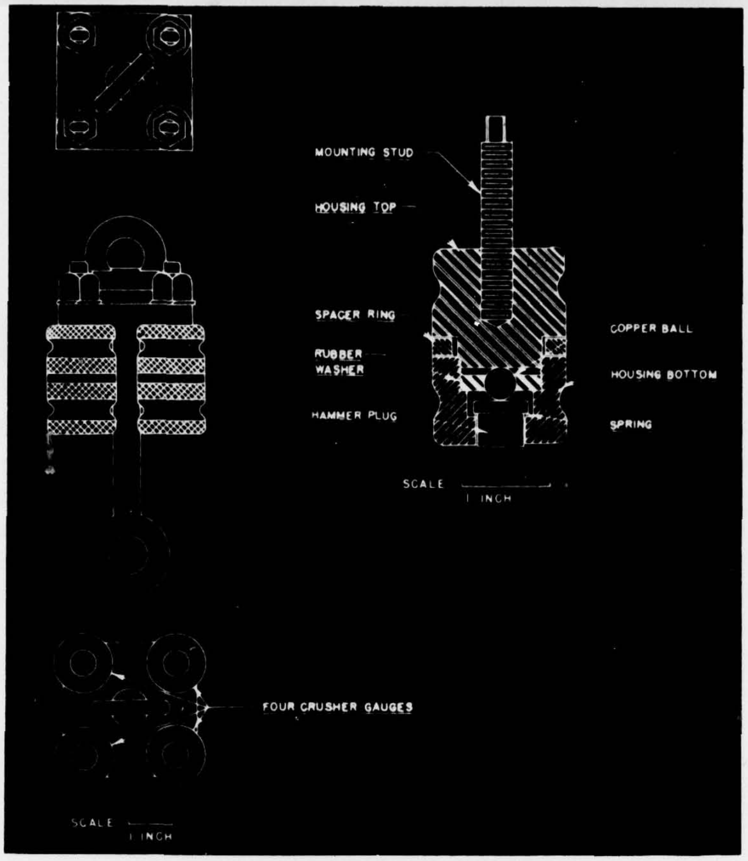

Figure 3. Ball crusher gauge and mounting block for four gauges.

Naval Ordnance Laboratory type ball-crusher gauges were used and deformations of annealed copper balls were obtained. Except as noted elsewhere, gauges and gauge mountings were as indicated in figure 3, with the hammer plugs facing downward.

In measurements on Shot 1, both 3/8- and 5/32-inch diameter copper balls were used, but the results of this shot showed that practically all of the deformations of the smaller balls were beyond the linear range of the static calibration curves. Since the theory of gauge action is based on a linear restoring force opposing motion of the gauge piston, the use of the smaller balls was discontinued and only the 3/8-inch size were used in the later shots. Unfortunately the measurements made at the longer ranges in these tests were in an awkward region where neither size of ball is completely satisfactory. This was not considered important for the purpose of the test.

The planned experimental procedure included measurements with a Hilliar Gauge, and a gauge of this type was actually mounted at mid-depth on the closer gauge line for each shot. Difficulty in keeping water out of this gauge was encountered, however, and the results were not useful.

In addition to the gauges mounted on lines as described above, additional data were obtained on Shot 3 from gauges which were mounted on other mine cases set on the bottom. These mines were set out for the purpose of determining what deformations might be expected to neighboring mines in a field. This paper is not concerned with that subject, but the gauge deformations obtained were found to be of some interest. Four ball-crusher gauges were mounted face up on top of each of two mine cases. The gauge pistons were approximately three feet from the bottom. One group of four gauges was 75 feet from the charge, another group was at a range of 100 feet. Placement was roughly as illustrated by the sketch at the top of figure 6; but the two mines on which gauges were mounted did not lie exactly opposite the gauge line as might be inferred from the sketch.

results and conclusions

Summarized results may be examined by reference to figures 4 and 5, which show a diagram of the rig used for placing gauges, and a graphical presentation of the results of the three shots in terms of peak pressures. The sketch of the rig shows ranges from charge center to the gauges in terms of multiples of R_0, the equivalent spherical charge radius (2.06 feet based on an assumed specific gravity of 1.55 for cast TNT). These same ranges are indicated by short vertical lines along the abscissa of figure 5 so that orientation and arrangement of gauges is at once apparent.

It should be noted that the ordinates of figure 5 represent both peak pressures and deformations, since the pressures divided by 77.0 will give the deformations in mils. The discussion of results in this paper is for the most part in terms of peak pressures resulting from the explosions. The well-known scaling laws of explosives and theoretical work done on explosive shock waves make this desirable. Interpretation of gauge readings in terms of this absolute quantity are not so well understood, however, and some emphasis must be placed on the fact that the primary purpose of these tests was to compare the relative effectiveness of different mines. In making this comparison, the results are the same whether pressure or deformation is used since one is a simple multiple of the other when data from only one size of balls are used.

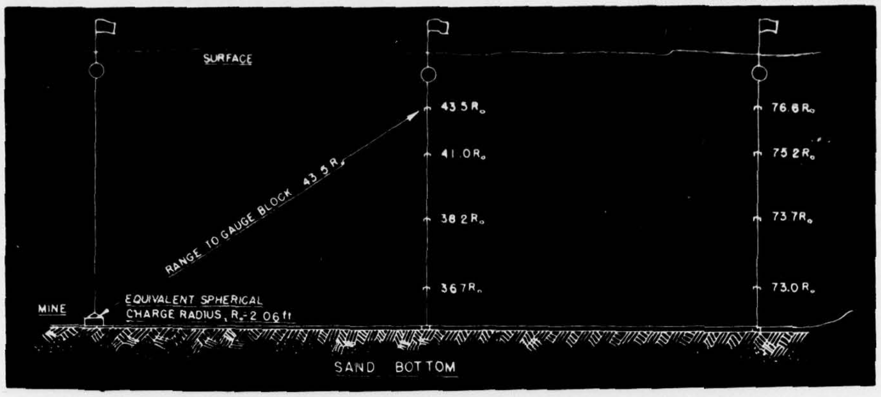

Figure 4. Experimental setup showing ranges to gauges in multiples of equivalent charge radius.

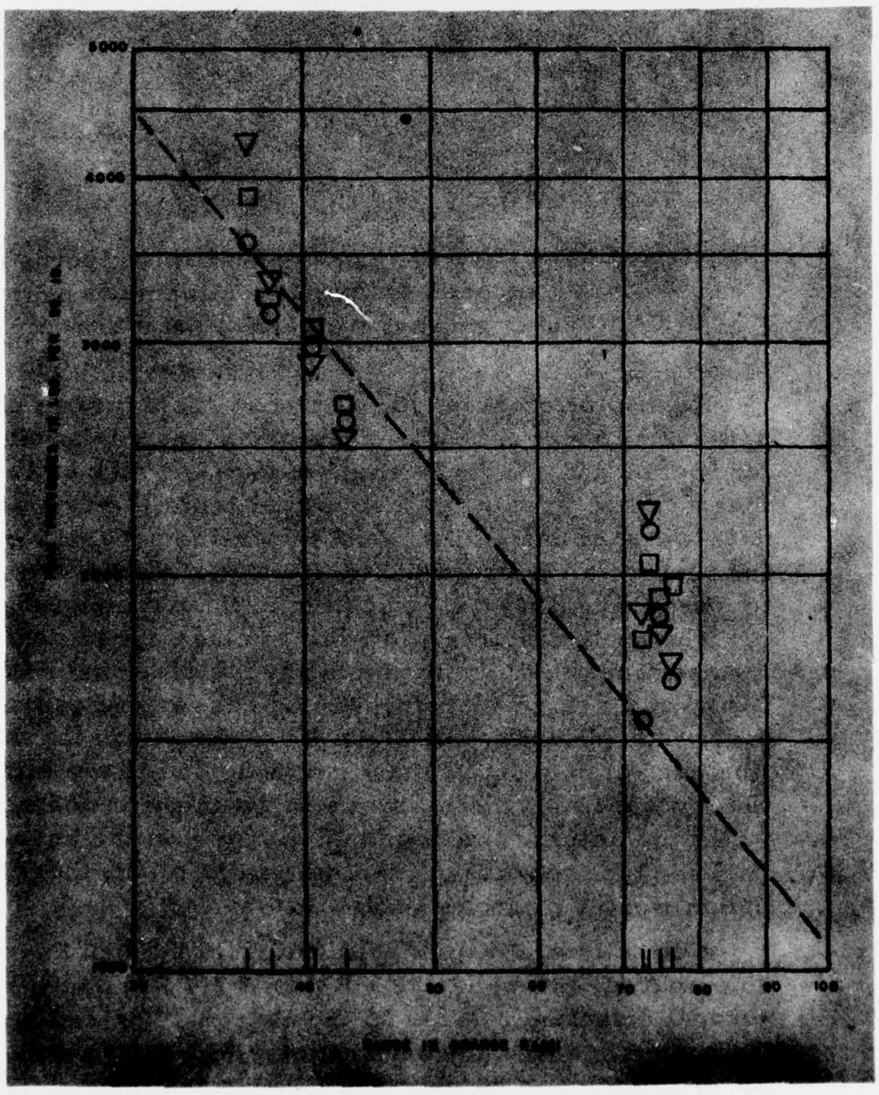

Figure 5. Peak pressures recorded from shots 1 (○), 2 (□), and 3 (▽), plotted against range to charge center.

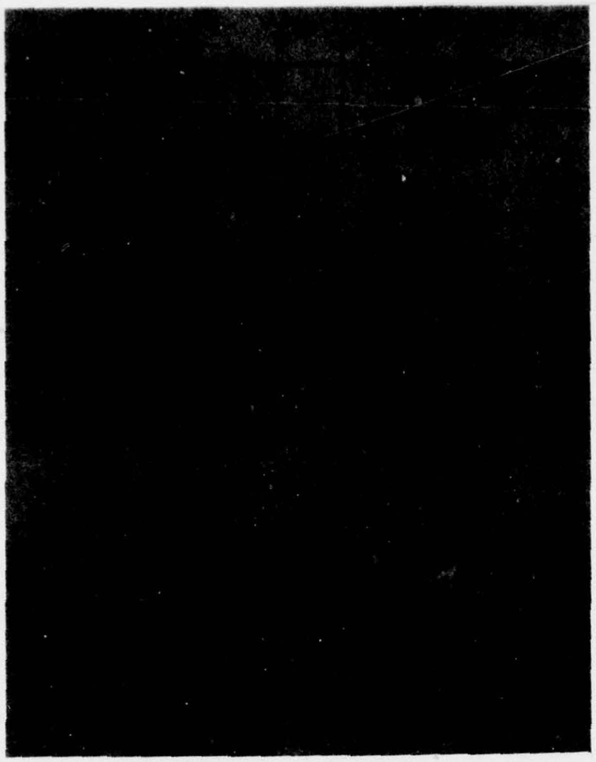

Figure 6. Comparison of regular gauge line records of shot 3 with records from gauges mounted near bottom. Regular gauges, ▽ ; gauges near bottom, ▲.

Each plotted point for Shot 1 is the average of the two 3/8-inch copper-ball measurements and each point plotted for Shots 2 and 3 is the average of four 3/8-inch ball measurements. The pressures calculated from the 5/32-inch ball data were about 16 per cent lower than those plotted, but for reasons already discussed, it was not considered advisable to use them. They are tabulated in the data section.

The plotted points show fairly close agreement with the dashed line which represents theoretical results based on Kirkwood's formula[1] for peak pressures resulting from underwater detonation of TNT. Deviations from the theoretical line are, of course, at least partially due to the fact that the theory applies to explosions in an infinite body of water; while the actual tests were of charges on the bottom and at only moderate depth. Keeping this in mind, there are still points worthy of special notice.

A directional effect is apparent from the fact that the large deformation groups (at 36.7 R_o and 73.7 R_o) are in the same general direction relative to the charge. The reflection from the bottom is a possible explanation. Additive pressures should not be effective at the mid-depth gauge positions on the nearer gauge line (38.2 R_o and 41.0 R_o). The pressures recorded at these positions are therefore considered the most reliable.

Another effect noticed was that the gauges mounted near the bottom gave lower readings than others at similar distances but farther from the bottom. This is not apparent from deformations obtained on the gauge line nearer the charge; but the lowest gauge on the second line and all gauges mounted on the two mines placed for the concurrent test of Shot 3 are consistently low. Some directional effect such as cratering may be responsible. Results are summarized in figure 6 where Kirkwood's theoretical peak pressures are again shown by the dashed line.

data, statistical interpretation, and calibration

The contents of this section are probably of interest to only those persons concerned with detailed analysis. In order to facilitate the location of specific data, it is presented for the most part in tabular form and under the following headings:

(A) Detailed Data and Calculated Peak Pressures.

Table 1-a. Shot 1, a "dry" standard mine. Gauge readings for 3/8-inch copper balls at positions shown in figure 4.

Table 1-b. Shot 1, same mine as table 1-a. Gauge readings for 5/32-inch copper balls at positions shown in figure 4.

Table 2. Shot 2, a "wet" mine exposed 12 months. Gauge readings for 3/8-inch balls at positions shown in figure 4.

Table 3. Shot 3, a "wet" mine exposed 9 months. Gauge readings at positions shown in figure 4, and at positions near bottom as indicated in figure 6.

(B) Statistical Interpretation of Data.

Table 4. Statistical measures of ratios of pressures for Shots 1, 2, and 3. Based on 3/8-inch copper balls only.

(C) Determination of Calibration Factor.

Table 5. Computations for determination of maximum deformation from 3,540 pounds of TNT.

(A) DETAILED DATA AND CALCULATED PEAK PRESSURES.

Table 1-a. Shot 1, a "dry" standard mine. Gauge readings for 3/8-inch copper balls at positions shown in figure 4.

Range (charge radii)	Gauge Serial Number	Diameter of Copper Ball (inches)		Deformation Δ (mils)	Peak Pressure (p.s.i.)	
		Original	Deformed		$\Delta \times 77.0$	Average
36.7 R_0	1597	0.3741	0.3257	48.4	3730	
	1658	.3748	.3302	44.6	3430	3580
38.2 R_0	687	.3742	.3328	41.4	3190	
	1514	.3747	.3335	41.2	3170	3180
41.0 R_0	2020	.3743	.3354	38.9	3000	
	425	.3746	.3361	38.5	2960	2980
43.5 R_0	1454	.3744	.3388	35.6	2740	
	804	.3745	.3398	34.7	2670	2705
73.0 R_0	1481	.3747	.3543	20.4	1570	
	1612	.3744	.3545	19.9	1530	1550
73.7 R_0	911	.3743	.3452	29.1	2240	
	781	.3744	.3470	27.4	2110	2175
75.2 R_0	2145	.3748	.3496	25.2	1940	
	1518	.3746	.3514	23.2	1790	1865
76.6 R_0	1054	.3748	.3529	21.9	1690	
	821	.3745	.3533	21.2	1630	1660

Table 1-b. Shot 1, a "dry" standard mine. Gauge readings for 5/32-inch copper balls at positions shown in figure 4.

Range (charge radii)	Gauge Serial Number	Diameter of Copper Ball (inches)		Deformation (mils)	Peak Pressure (p.s.i.)	
		Original	Deformed		$\times 35.0$	Average
36.7 R_0	1001	0.1558	0.0781	77.7	2720	
	1573	.1560	.0778	78.2	2740	2730
38.2 R_0	2440	.1558	.0813	74.5	2610	2610
41.0 R_0	1210	.1555	.0844	71.1	2490	
	771	.1561	.0867	69.4	2430	2460
43.5 R_0	2058	.1561	.0908	65.3	2290	
	644	.1560	.0907	65.3	2290	
	1426	.1560	.0906	65.4	2290	2290
73.0 R_0	1312	.1558	.1145	41.3	1450	
	901	.1559	.1134	42.5	1490	1470
73.7 R_0	442	.1556	.1034	52.2	1830	
	707	.1559	.1015	54.4	1900	1865
75.2 R_0	1423	.1558	.1072	48.6	1700	
	1301	.1557	.1062	49.5	1730	1715
76.6 R_0	[illegible]	[illegible]	.1127	43.0	1500	
	[illegible]	[illegible]	.1108	45.3	1590	1545

Table 2. Shot 2, a "wet" mine, exposed 12 months. Gauge readings for 3/8-inch copper balls at positions shown in figure 4.

Range (charge radii)	Gauge Serial Number	Diameter of Copper Ball (inches) Original	Deformed	Deformation Δ (mils)	Peak Pressure (p.s.i.) Δx77.0	Average
36.7 R_0	442	0.3747	0.3236	51.1	3930	
	1054	.3747	.3242	50.5	3890	
	1423	.3746	.3249	49.7	3830	
	1301	.3744	.3240	50.4	3880	3882
38.2 R_0	1312	.3746	.3342	40.4	3110	
	901	.3748	.3331	41.7	3210	
	1518	.3745	.3316	42.9	3300	
	911	.3747	.3325	42.2	3250	3218
41.0 R_0	707	.3748	.3366	38.2	2940	
	671	.3747	.3391	35.6	2740	
	1612	.3744	.3284	46.0	3540	
	781	.3745	.3356	38.9	3000	3055
43.5 R_0	1427	.3745	.3357	38.8	2990	
	1481	.3747	.3379	36.8	2830	
	1488	.3748	.3372	37.6	2900	
	821	.3745	.3343	40.2	3100	2955
73.0 R_0	1514	.3748	.3509	23.9	1840	
	1573	.3748	.3520	22.8	1760	
	644	.3745	.3521	22.4	1720	
	1658	.3747	.3508	23.9	1840	1790
73.7 R_0	1426	.3747	.3493	25.4	1960	
	1001	.3745	.3492	25.3	1950	
	425	.3746	.3475	27.1	2090	
	1454	.3744	.3474	27.0	2080	2020
75.2 R_0	771	.3746	.3502	24.4	1880	
	804	.3748	.3493	25.5	1960	
	2440	.3748	.3510	23.8	1830	
	2020	.3748	.3509	23.9	1840	1878
76.6 R_0	1597	.3743	.3495	24.8	1910	
	2058	.3744	.3480	26.4	2030	
	1210	.3745	.3482	26.3	2030	
	687	.3746	.3502	24.4	1880	1962

Table 3. Shot 3, a "wet" mine, exposed 9 months. Gauge readings for 3/8-inch copper balls at positions shown in figure 4, and at 75 and 100 feet range near bottom.

Range (charge radii)	Gauge Serial Number	Diameter of Copper Ball (inches) Original	Deformed	Deformation (mils)	Peak Pressure (p.s.i.) x77.0	Average
36.7 R_0	1514	0.3748	0.3207	54.1	4170	
	771	.3744	.3203	54.1	4170	
	644	.3743	.3194	54.9	4230	
	1597	.3747	.3181	56.6	4360	4232
38.2 R_0	707	.3747	.3300	44.7	3440	
	425	.3748	.3339	40.9	3150	
	1001	.3747	.3316	43.1	3320	
	14[illegible]	.3747	.3314	43.3	3330	3310
41.0 R_0	671	.3747	.3367	38.0	2930	
	1658	.3747	.3363	38.4	2960	
	804	.3744	.3375	36.9	2840	
	1454	.3746	.3355	39.1	3010	2935
43.5 R_0	2440	.3744	.3366	37.8	2910	
	1003	.3743	.3360	38.3	2950	
	781	.3743	.3435	30.8	2370	
	1612	.3744	.3393	35.1	2700	2732
73.0 R_0	687	.3748	.3496	25.2	1940	
	1054	.3744	.3500	24.4	1880	
	442	.3747	.3502	24.5	1890	
	821	.3748	.3513	23.5	1810	1880
73.7 R_0	1573	.3744	.3467	27.7	2130	
	1423	.3748	.3454	29.4	2260	
	1518	.3743	.3458	28.5	2190	
	901	.3747	.3460	28.7	2210	2198
75.2 R_0	911	.3747	.3508	23.9	1840	
	2058	.3747	.3521	22.6	1740	
	1301	.3747	.3525	22.2	1710	
	1312	.3747	.3520	22.7	1750	1760
76.6 R_0	1481	.3745	.3517	22.8	1760	
	1597	.3745	.35[illegible]	22.3	1720	
	2145	.3743	.3529	21.4	1650	
	1210	.3744	.35[illegible]	22.3	1720	1712
48.5 R_0	1207	.3743	.35[illegible]	21.8	1680	
	[illegible]	.3744	.3483	26.1	2010	
	[illegible]	.3745	.3480	26.5	2040	
	[illegible]	.3743	.3544	19.9	1530	1815
[illegible].4 R_0	[illegible]	.3745	.3429	31.6	2430	
	[illegible]	.3744	.3506	23.8	1830	
	[illegible]	.3746	.3498	24.8	1910	
	[illegible]	.3743	.3397	34.6	2660	2208

(B) STATISTICAL INTERPRETATION OF DATA

For each of the eight standard gauge positions $Q_{2/1}$, the quotient of the pressure from Shot 2 (wet mine) divided by the pressure from Shot 1 (dry mine) was computed. $\overline{Q}_{2/1}$, the arithmetic mean of these eight quotients was found to be 1.061 with a standard error, S.E. of $\overline{Q}_{2/1}$, of ± 0.030. To investigate as to whether this mean quotient differs significantly from unity, we compute

$$t_{2/1} = \frac{(\overline{Q}_{2/1} - 1)}{(SE\ of\ \overline{Q}_{2/1})} = 2.0$$

Here

$$SE\ of\ \overline{Q}_{2/1} = \sqrt{\frac{\sum_{i=1}^{N} (Q_{2/1\,i} - \overline{Q}_{2/1})^2}{N(N-1)}}$$

where N is 8, and the number of degrees of freedom is $N-1$.

Fisher's[2] table of t gives a probability $P_{2/1}$ of 0.09 that the mean of a random sample would fall further from unity, the expected mean, than $t = 2.0$ indicates. Table 4 summarizes these and the following calculations.

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Similarly $\overline{Q}_{3/1}$, the mean quotient of pressure of Shot 3 to pressure of Shot 1, is 1.052 with a standard error of ± 0.034. The corresponding $t_{3/1}$ is 1.5 with a resultant $P_{3/1}$ of 0.18.

Usual statistical practice[3] requires that P must be less than 0.05 for t to be considered at all significant. Since all of the above values of P exceed 0.05, the corresponding t's are not significant. Thus, the fact that wet mines of Shots 2 and 3 were measured as respectively 6 per cent and 5 per cent more powerful than the dry mine of Shot 1 is not statistically significant. Other calculations based on differences of pressures instead of ratios gave similar large values of P.

The close agreement of Shots 2 and 3 is shown by the fact that $\overline{Q}_{3/2}$ is 0.994 with a standard error of 0.029.

(C) DETERMINATION OF CALIBRATION FACTOR

The action of a copper ball annealed so as to retain practically no elasticity and then crushed between two parallel plates is such that over a considerable range the deformation is proportional to the deforming force. In this range, a theory of the action of gauges utilizing these balls has been proposed by G. K. Hartmann.[4] This theory is based in part on a load increase of 15 per cent over static calibration load for the dynamic effect of an explosive shock wave. This method was used to calculate absolute peak pressures from the gauge deformations and was found to give satisfactory results. Figure 7 shows a static calibration of 3/8-inch copper balls with the upper curve indicating the result of increasing the static calibration by 15 per cent. The short linear calibration curve in this figure was obtained by applying the methods, proposed by Hartmann, to a 3,540-pound charge. While it is not apparent from the curve, the calibration is less accurate for deformations of less than about 40 mils, because of some tendency of static calibrations to show curvature in this region. Where the deformations of the 3/8-inch balls are found to be small, the 5/32-inch size are usually satisfactory and similar calibration curves for these are shown in figure 8.

As it is not feasible to show all the steps involved in the calibration correction for charge weight, the calculation results are summarized in table 5 for possible use with the referenced report.

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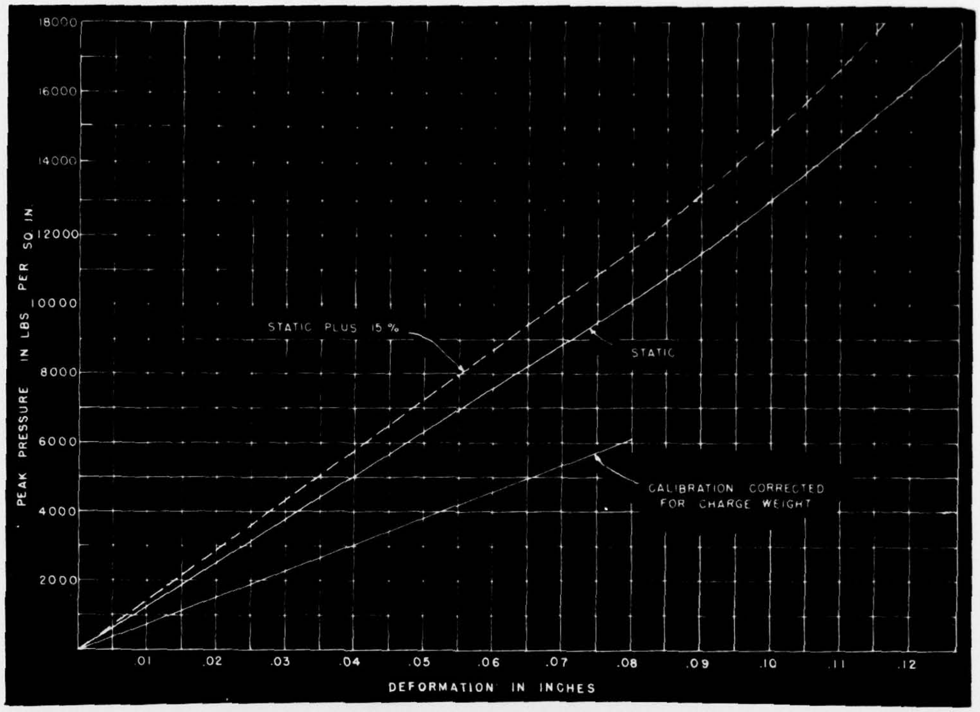

Figure 7. Calibration curves for 3/8-inch copper balls.

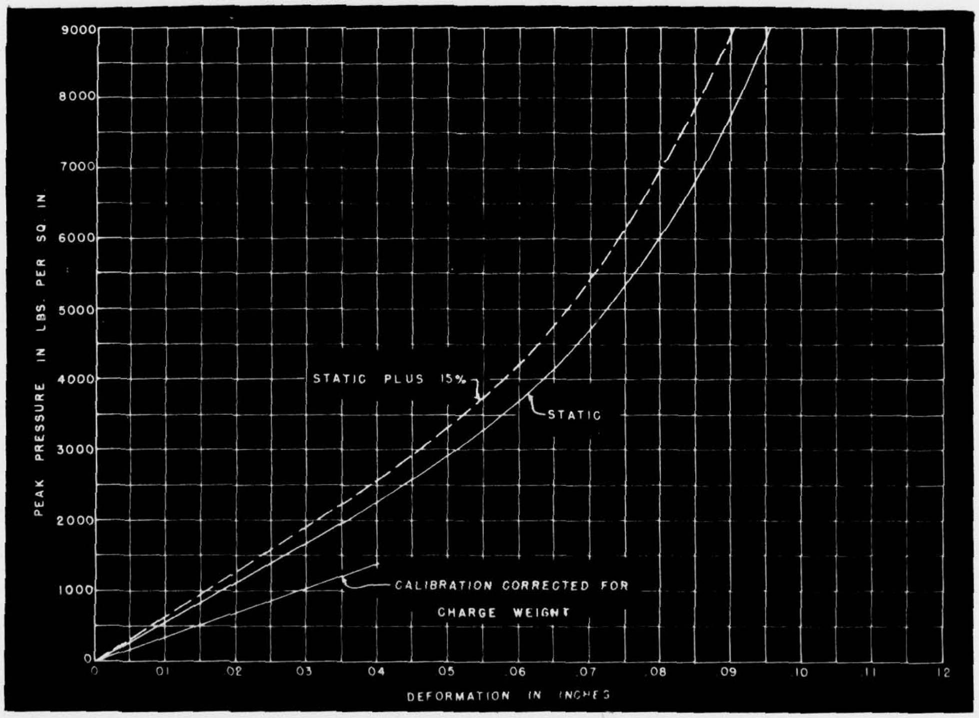

Figure 8. Calibration curves for 5/32-inch copper balls.

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