AD NUMBER
AD226207
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 01 JUN 1959. Other requests shall be referred to Naval Ordnance Laboratory, White Oak, MD.**
AUTHORITY
USNOL ltr, 29 Aug 1974

"NOTICE: When Government or other drawings, specifications or other data are used for any purpose other than in connection wit a definitely related Government procurement operation, the U.S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulate furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise a in any manner licensing the holder or any other person or corpor tion, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related theret

NAVORD REPORT 6634

UNDERWATER SHOCKWAVE PARAMETERS FOR TNT (U)

1 JUNE 1959

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NAVORD Report 6634

UNDERWATER SHOCKWAVE PARAMETERS FOR TNT

by

John P. Slifko
and
Thomas E. Farley

Approved by: E. Swift, Jr.
Chief, Underwater Explosions Division

Investigational Group

W. W. Hammack J. H. Rowe
C. E. Hopkins B. W. Scott
J. E. Morgan H. G. Thomas

ABSTRACT: Free water shockwave parameters obtained from 80-pound spherical TNT charges, covering the scaled reciprocal range of $W^{1/3}/R$ from 0.08 to 0.6 $lbs^{1/3}/ft$, and similitude lines for peak pressure, time constant, impulse and energy are presented. Equations derived from the similitude lines are as follows:

$$P_m = 2.11 \times 10^4 \, (W^{1/3}/R)^{1.11} \text{ lbs/in.}^2$$

$$\theta = 0.052 \, W^{1/3} \, (W^{1/3}/R)^{-0.23} \text{ millisecond}$$

$$I = 1.33 \, W^{1/3} \, (W^{1/3}/R)^{0.87} \text{ lbs-sec/in.}^2$$

$$E = 2.25 \times 10^3 \, W^{1/3} \, (W^{1/3}/R)^{1.98} \text{ in-lbs/in.}^2$$

where W is the charge weight in pounds and
R is the range in feet

Over the range of measurement the peak pressure similitude line agreed to within 3% with a prior determination made by the Underwater Explosives Research Laboratory at Woods Hole, Massachusetts, but was found to be 20% higher than a determination made in Great Britain by the Naval Construction Research Establishment. Although some of the factors which have contributed to the latter discrepancy have been uncovered, the entire discrepancy has not as yet been resolved.

The work presented here was carried out in order to get reliable values for the underwater performance of TNT, which is used as a standard of performance both of high explosives and nuclear weapons. Over the range of measurement no significant difference was noted between the shockwave parameter values obtained during this investigation and prior determinations made by the Underwater Explosives Research Laboratory (UERL). Continued use of the UERL shockwave parameter values for TNT is therefore recommended. Serious discrepancies, however, still exist between these values and values obtained in Great Britain. Until these discrepancies are resolved the UERL values cannot be considered definitive.

This work was done under Task NO 301-664/43003/01. The work is applicable to the solution of Key Problems 3.6.1, 3.6.2, NAVORD Report 3906, "Key Problems in Research and Development".

MELL A. PETERSON
Captain, USN
Commander

C. J. Aronson

C. J. ARONSON
By direction

CONTENTS

TABLES

FIGURES

UNDERWATER SHOCKWAVE PARAMETERS FOR TNT

INTRODUCTION

For a number of years TNT has been the standard used to judge the effectiveness of new underwater explosives, and has, therefore, been the subject of a number of studies [1, 2, 3, 4*]. In a recent review of the available data, it was found that a controlled determination of the underwater shockwave parameters of TNT had not been carried out in this country since 1946 and that recent work in Great Britain [4] had shown considerable discrepancies from the values found in this country.

In planning an investigation of the propagation of shockwaves near the bottom in deep water, it was believed necessary to have reliable values of the free water shockwave parameters. It was therefore decided to fire a new series of TNT charges. Since improvements have been made both in instrumentation and analytical techniques, it was expected that the results could be used as a basis for determining the best values for TNT.

EXPERIMENTAL ARRANGEMENT

A. Charges. The charges were cast at the U. S. Naval Mine Depot at Yorktown, Virginia, in spherical steel cases 14 inches in diameter with 0.03 inch case thickness. Three lugs were welded to the case 90° apart for mounting to the fore-and-aft rig and to a surface float. An 0.8 pound spherical pentolite booster was located at the center of the casing and the molten TNT poured around it. A well, about 5/16-inch in diameter was provided for the insertion of a single U. S. Army Engineer's

*All such numbers refer to the list of references on Page 22.

Special Electric Detonator to the center of the pentolite booster. The total explosive weight, i.e., the weight of the TNT plus the weight of the pentolite booster, was 81.7 ± 0.6 pounds. The specific gravity of the TNT was 1.57 - 1.58.

<u>B. Instrumentation.</u> Eight charges were fired from the USS ELSMERE (EPCS-1413) in the Potomac River off Indian Head, Maryland. The charge and gages were towed 28 feet below the water surface by a modified fore and aft rig [5] in a total water depth of approximately 70 feet. The gage train consisted of eight tourmaline gages mounted in pairs at distances varying from 7.5 feet to 55 feet from the charge center. Two sets of gage distances were used, thus giving pressure-time records at eight positions. To avoid systematic errors due to individual gage variation, gages were shifted at random from one position in the rig to another during the series. The gages were mounted on Simplex twin-coaxial low noise cables and were coated with Zophar C-276 wax.

The gages used were constructed from four 1/4-inch diameter tourmaline discs and were similar to the Type B gages [6, 7], except that the latex edge insulation was replaced with an Araldite epoxy resin and the steel central tab was replaced with two smaller steel tabs for mounting the two cable leads.

Each of the eight 800-foot twin-coaxial cables was terminated aboard the USS ELSMERE (EPCS-1413) in a compensating network consisting of two series surge resistors and two 0.1 micro-farad shunting (standard) condensers (one for each coaxial cable) for optimum response in accordance with Reference [8]. The output of each network was connected directly to a push-pull cathode follower circuit, the input impedance of which was 10^8 ohms; thus an input time constant of about 12 seconds was obtained. The low impedance outputs of the cathode follower were connected to a push-pull pre-amplifier, the single ended output stage of which was connected to the input of a DuMont 247 cathode ray oscilloscope. The excursions of the cathode ray tube spot were photographed on 16-1/2 inch lengths of 35mm film moving at right angles to the spot deflections. The film was mounted inside a cylindrical lucite drum which was driven by a synchro motor at film speeds of 0.45 in. per millisecond. A new voltage step generator [9] with a rise time of 1/2 microsecond, provided Q step voltages [6] to all channels simultaneously about 3 seconds before the charge was detonated. The desired calibration voltage was obtained from a 100 ohm attenuator provided in each channel. Through a separate optical system employing a cylindrical lens, light flashing from a crater tube at a rate of 1000 times a second was photographed as lines on the film simultaneously with the pressure-time record. The electronic instrumentation mentioned above is described in detail in Reference [10], and modifications to the equipment are described in References [5], [11], and [12]. The overall frequency response of a recording channel was found to be flat to better than 2% between 100 cps and about 50 kc. The response gradually decreases at higher frequencies, and is down to 70% at 200 kc. The overall response at the low frequencies is affected by the A.C. oscilloscope (and pre-amplifier) and is down to 70% at about 1/3 cps.

The bubble period was recorded by a separate channel similar to the eight described above. However, a 1-1/8 inch diameter tourmaline gage was used to record the relatively small amplitude bubble pulse and a different camera motor was used to drive the film at 10 inches per second.

ANALYSIS

Introduction. The methods of record reading developed at this Laboratory [14, 15] have proven satisfactory for the analysis of shockwave records from large charges fired in free water. Except for the peak pressure measurements, the methods of analysis used were based on the above references. A re-examination of the basis of the peak pressure analysis was carried out, and the new method described below was the result. This method of analysis is more general and can be used on a wide variety of shockwaves.

Description of Records. The pressure-time record reproduced in Figure 1 is typical of the shockwave records obtained in this series. The coordinates were determined from the calibration voltage step or "Q step", and the short vertical one-millisecond timing lines. The grid was applied to the photographic paper by use of the "harp" arrangement described in Reference [16].

In order to facilitate the analysis, each pressure-time record was plotted on a semi-log scale (Figure 2). The region of interest, which extends out to 6.7θ, was closely approximated by a series of line segments. In general, fewer than eight straight line segments were required to reproduce the essential features of the decay.

The shockwave trace (Figure 1) is characterized by the usual abrupt rise, then an essentially exponential decay for about 0.5 millisecond, and a slower decay thereafter. However, superposed on the peak of the shockwave is a small amplitude signal called the "overshoot". The cause of the overshoot has not as yet been determined, but evidence indicates that it is not a real event occurring at the shock front, but is rather the result of a spurious signal emanating from the gage. An examination of Figures 1 and 2 will also reveal the presence of two slight oscillations superposed upon the initial exponential decay. The contribution which these oscillations made to the final parameter determination was quite small, and they did not introduce any significant uncertainty into the results.

Determination of Shockwave Parameters.

1. Peak Pressure (p_m). The maximum pressure produced by the shockwave from a centrally detonated spherical explosive charge appears at the shock front. The recorded peak pressures are distorted both by the limitations in the high frequency

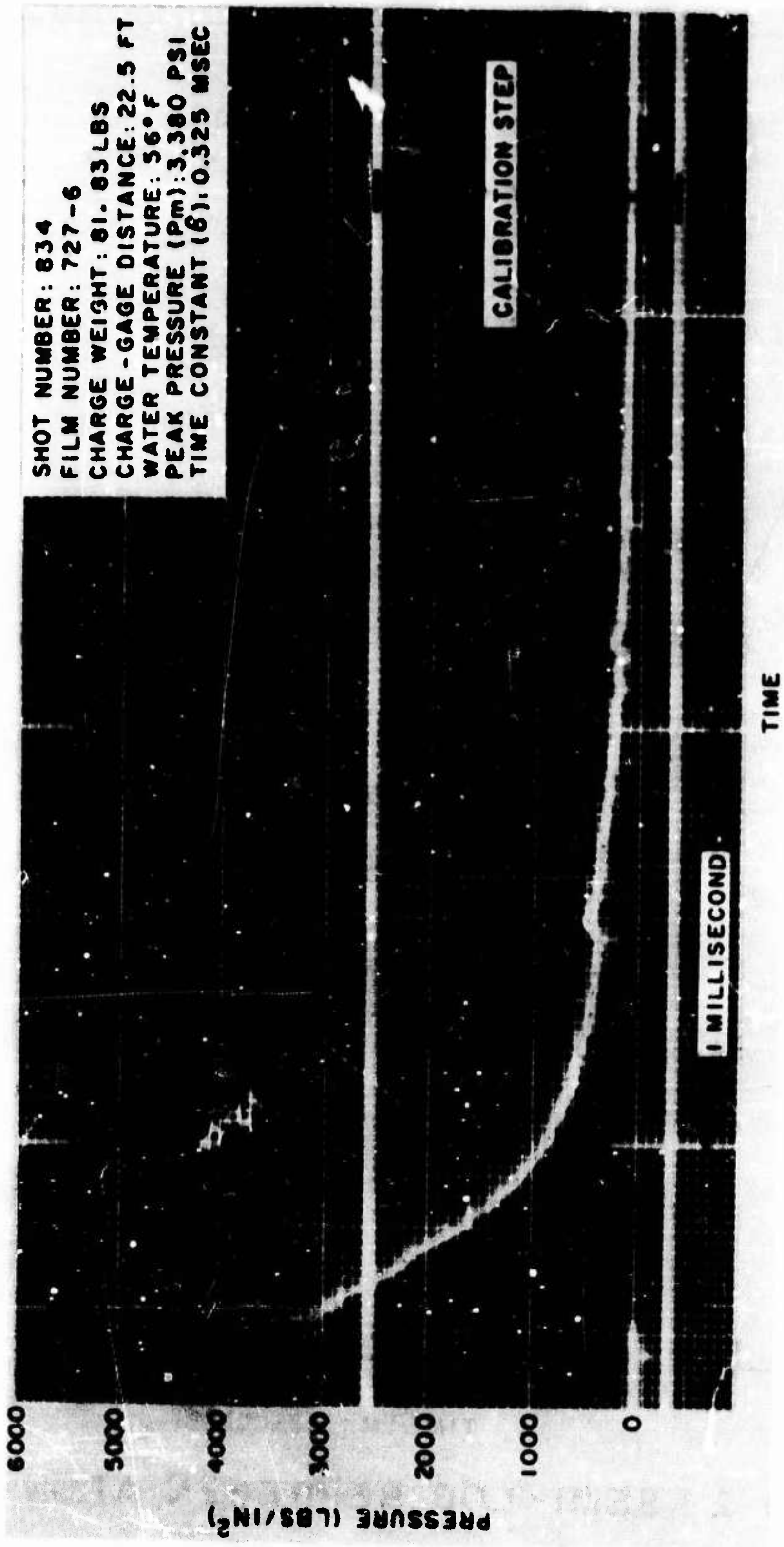

FIG.1 TYPICAL FREE WATER PRESSURE-TIME RECORD

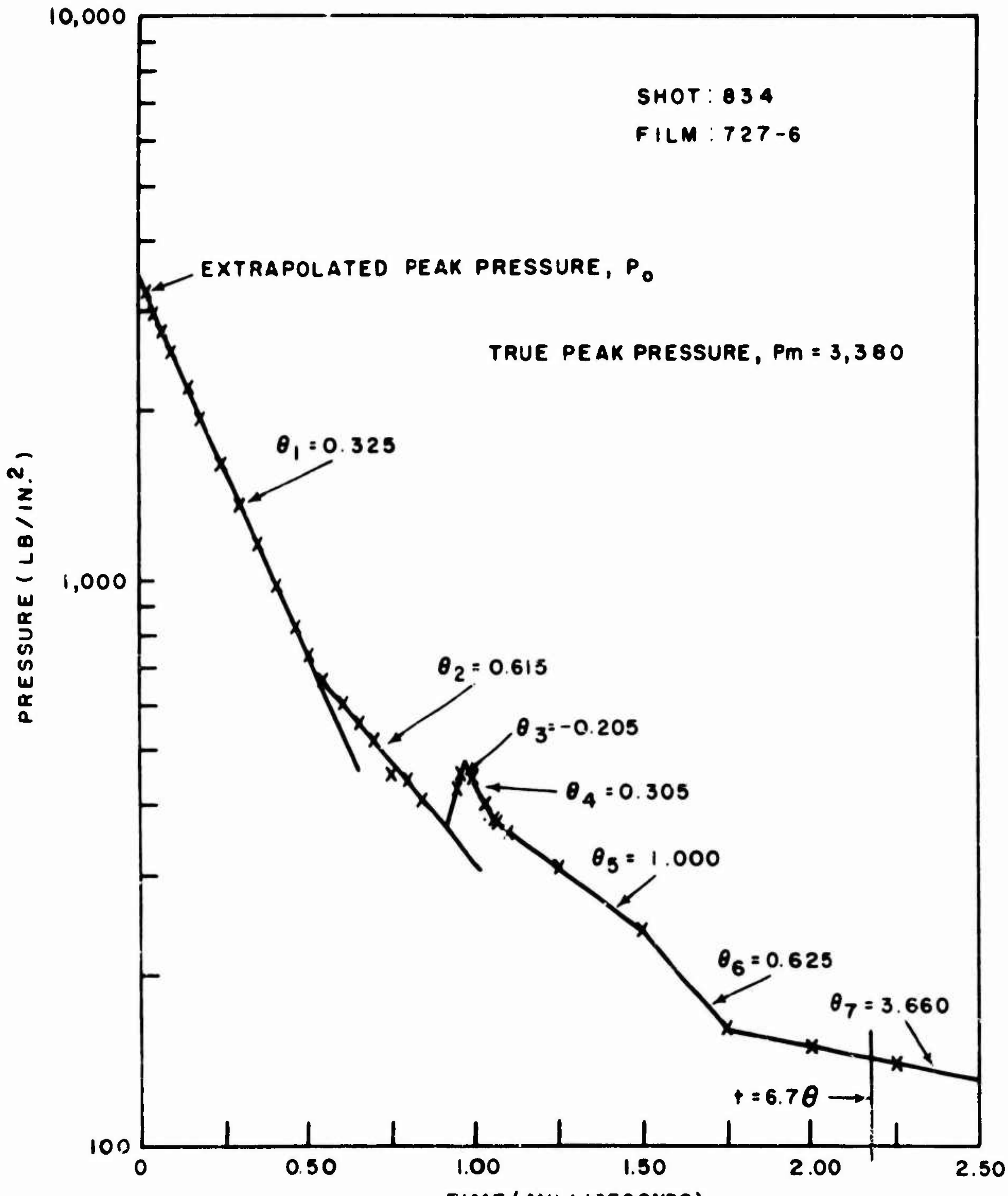

FIG. 2 SEMI-LOG REPRESENTATION OF PRESSURE-TIME RECORD

response of the equipment and by the effect of finite gage size. In order to improve the accuracy of the final parameter values, it is necessary to compensate for these limitations by the use of suitable corrections. These corrections and their method of use are discussed below.

The finite gage size correction is equal to approximately one-half the transit time of the shockwave across the gage; for the 1/4-inch diameter gages used this was about 2-1/2 microseconds. Tests made on the transmission cables and compensating networks on the amplifiers indicated that a 1.0 microsecond correction would compensate for the limitations in the high frequency response of the system. Since these corrections are essentially constants, and since the effects of finite gage size and finite amplifier response act in the same direction, a single correction term of 3.5 microseconds was applied to each record.

A third correction was applied, which compensated for the non-perpendicular alignment of the film in the rotating drum camera relative to the cathode ray oscilloscope deflection plates (see Appendix A). The effect of this misalignment is a time displacement of the recorded peak. Unlike the previous corrections, which remained constant for all records, the perpendicularity term had to be determined for each recording channel. Its absolute value ranged from zero to 20 microseconds, and averaged approximately 5 microseconds; the error involved in its measurement was probably about 3 microseconds. Since the deviation from perpendicular alignment varies in direction, this correction term may be either added to or subtracted from the 3.5 microsecond correction discussed above.

Since these corrections are independent of the sequence in which they are applied, they were grouped together to form one correction factor, namely

$$t = \frac{m}{2} + t_s \pm t_p = 3.5 \pm t_p \quad \text{(microseconds)}$$

m = gage transit time (microseconds)

t_s = high frequency response term (microseconds)

t_p = perpendicularity term (microseconds)

A correction value was determined for each pressure history by substituting the proper perpendicularity correction term into this relation.

The resulting correction term was then applied to the semi-log representation of the pressure history in the following manner. The initial line segment of the semi-log plot was extrapolated back to recorded "zero-time", i.e., the time at which the trace on the original pressure-time record initially departed from the hydrostatic pressure level or base line. The pressure, p_o, corresponding to this recorded zero time was then obtained from the semi-log plot and was used to determine the "true" peak pressure, p_m, from the following relation

$$p_m = p_o e^{-t/\theta} \quad \text{lbs/inch}^2$$

where t is the correction term and θ is the time constant of the initial decay.

2. Time Constant (θ). In free water the peak pressure is followed by an essentially exponential decay. The rate of this initial decay is characterized by the time constant, θ. It is equal to the time required for the shockwave peak pressure to decay to a value of p_m/e. The value is found by determining the negative reciprocal of the slope of the initial line segment on the semi-log plot (Figure 2).

3. Impulse (I). The impulse passing through a unit area parallel to the shock front up to a time t is given by

$$I = \int_0^t p\,dt$$

In order to conform to past determinations[1] the upper limit was set equal to 6.7θ.

If the value of the impulse is determined from the semi-log plot (Figure 2), as has been done here, the impulse integral reduces to

$$I = \sum_{i=1}^{i=n} \theta_i (P_i - P_{i+1})$$

where θ_i = negative reciprocal of the slope of the ith line segment.

p_i = initial pressure of ith line segment

p_{i+1} = terminal pressure of ith line segment

n = the number of the line segment at t = 6.7θ

All the values of p_i and p_{i+1}, with the exception of p_1 were taken directly from the semi-log plots. For p_1 the peak pressure, p_m, was used. The final terminal pressure, p_{n+1}, is equal to the pressure at the time 6.7θ. The value of the impulse was found for each gage record. These values are presented in Table I.

4. Energy (E). The energy passing through a unit area parallel to the shock front up to a time t is given by

$$E = \frac{(1 - 1.7\times10^{-6} p_m)}{\rho_o c_o} \int_o^t p^2 dt$$

where ρ_o = ambient water density

c_o = velocity of sound through the undisturbed water.

The upper limit of integration was again set equal to 6.7θ, and the value of $\rho_o c_o$ was determined from the relation

$$\rho_o c_o = 5.14 + 0.0144T$$

where T = the temperature of the undisturbed water in ^oC. The water temperature ranged from 4 to 13^oC, and averaged approximately 7^oC.

As with the impulse, the shockwave energy integral was reduced to

$$E = \frac{(1 - 1.7\times10^{-6}\, p_m)}{\rho_o \; c_o} \sum_{i=1}^{i=n} \frac{\theta_i}{2} (p_i^{\,2} - p_{i+1}^{\,2})$$

when the integral was evaluated from the semi-log plot. The values for θ_i, p_i and p_{i+1} are identical to the values used in the determination of the impulse. The results of these energy measurements are also presented in Table I.

RESULTS

Free Water Shockwave Parameters. The data obtained from the individual gage records are presented in Table I. In Figures 3-6 these data points have either been plotted directly or in reduced form as functions of the scaled reciprocal distance, $W^{1/3}/R$. Similarity curves were fitted to these points by the method of least squares, and the standard deviation, σ, of the experimental points from these curves was determined. Expressions for these lines and the corresponding standard devistions are:

(1) Peak Pressure

$$p_m = 2.11\times10^4 \; (W^{1/3}/R)^{1.11} \text{ lbs/in}^2$$

$$\sigma = 5.6\%$$

(2) Time Constant

$$\theta = .052 \; W^{1/3} \; (W^{1/3}/R)^{-0.23} \text{ milliseconds}$$

$$\sigma = 6.7\%$$

(3) Impulse

$$I = 1.33 \; W^{1/3} \; (W^{1/3}/R)^{0.87} \text{ lbs-sec/in}^2$$

$$\sigma = 13\%$$

(4) Energy Flux

$$E = 2.25\times10^3 \; W^{1/3} \; (W^{1/3}/R)^{1.98} \text{ in-lb/in}^2$$

$$\sigma = 17\%$$

where R is the distance in feet, and W is the charge weight in pounds.

Bubble Period Measurements. The bubble period was recorded in five out of the eight shots. The first bubble periods were measured on the films and the period constants calculated by the method of Reference [13]. While the correction for the effect of the bottom and surface interfaces on the bubble period is included, no booster correction was made. The results are given in Table II. The period constants are slightly higher than the usual value of about 4.36; this is probably due to the large (15-20%) correction for surfaces. The above information on bubbles is included for completeness and is not considered germane to the basic topic of this report.

TABLE I SHOCKWAVE PARAMETERS FOR TNT

Shot No.	Gage No.	Charge-Gage Distance (ft)	Peak Pressure p_m (lb/in^2)	Time Constant θ (msec)	Impulse I (lbs/sec)/in^2	Energy E (in-lb)/in^2
827	862	10.5	7500	0.270	2.38	1480
	944	10.5	7670	0.280	2.61	1620
828	862	10.5		No Record	Obtained	
	944	10.5	7470	0.255	2.27	1390
829	862	10.5	7800	0.275	2.61	1650
	943	10.5	7630	0.270	2.56	1560
830	862	10.5	8100	0.265	2.71	1740
	943	10.5	7360	0.270	2.54	1470
827	941	16.5	5110	0.325	2.17	878
	943	16.5	4630	0.300	1.67	637
828	941	16.5	5410	0.305	2.10	903
	943	16.5	4510	0.295	1.61	592
829	941	16.5	4570	0.280	1.47	567
	1101	16.5	4900	0.325	1.99	782
830	941	16.5	4390	0.310	1.62	588
	1101	16.5	4600	0.325	1.85	688
827	1093	31.0	2460	0.375	1.23	239
	1100	31.0		No Record	Obtained	
828	1093	31.0	2130	0.330	0.852	149
	1100	31.0	2180	0.325	0.868	154
829	1093	31.0		Gage Failed		
	1111	31.0	2540	0.355	1.15	234
830	1098	31.0	2480	0.370	1.22	236
	1111	31.0	2510	0.340	1.06	215
827	1104	55.0	1240	0.420	0.687	67
	1111	55.0	1240	0.405	0.589	64
828	1104	55.0	1310	0.400	0.695	71
	1111	55.0	1340	0.395	0.638	70
829	1104	55.0	1260	0.420	0.703	69
	1100	55.0	1160	0.380	0.570	52
830	1104	55.0	1320	0.400	0.704	72.6
	1100	55.0	1160	0.385	0.569	52.8

TABLE I SHOCKWAVE PARAMETERS FOR TNT (Con't)

Shot No.	Gage No.	Charge-Gage Distance (ft)	Peak Pressure P_m (lb/in²)	Time Constant θ (msec)	Impulse I (lbs/sec)/in²	Energy E (in-lb)/in²
831	941	7.5	12,000	0.285	4.34	4060
	943	7.5	12,100	0.250	3.67	3550
832	941	7.5	11,100	0.275	3.60	3270
	863	7.5		Gage Failed		
833	941	7.5	11,800	0.260	3.93	3550
	1101	7.5	11,900	0.240	3.32	3200
834	943	7.5	12,000	0.250	3.75	3420
	1082	7.5	12,300	0.230	3.29	3290
831	862	13.5	5,670	0.320	2.27	1030
	1101	13.5	5,580	0.320	2.10	977
832	943	13.5	6,000	0.265	1.90	931
	1101	13.5	5,840	0.265	2.15	840
833	943	13.5	5,350	0.260	1.67	726
	1105	13.5	5,870	0.320	2.31	1450
834	941	13.5	6,530	0.315	2.70	1340
	1105	13.5		Gage Failed		
831	1104	22.5	3,370	0.360	1.56	418
	1111	22.5	3,620	0.355	1.62	470
832	1104	22.5	3,560	0.365	1.66	469
	1098	22.5	3,570	0.360	1.69	469
833	1104	22.5	3,560	0.355	1.57	447
	1100	22.5	3,420	0.340	1.52	406
834	1111	22.5	3,470	0.300	1.21	348
	1100	22.5	3,380	0.325	1.39	365
831	1098	41.5	1,780	0.395	0.923	130
	1100	41.5	1,660	0.375	0.790	106
832	1111	41.5	1,680	0.345	0.674	95
	1100	41.5	1,690	0.370	0.799	106
833	1111	41.5	1,560	0.350	0.569	81.8
	1098	41.5	1,670	0.405	0.922	125
834	1104	41.5	1,680	0.340	0.687	93.5
	1098	41.5	1,880	0.380	0.946	137

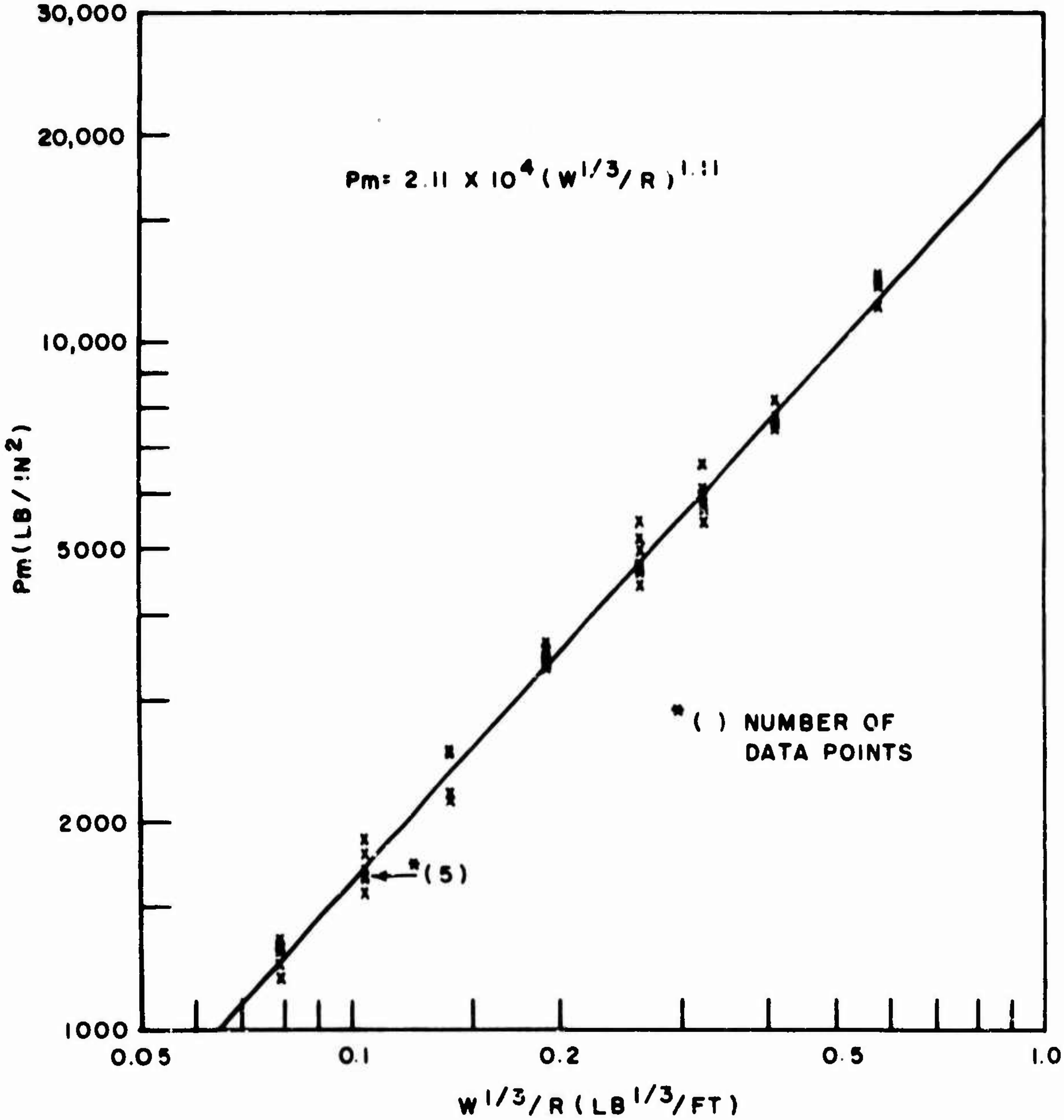

FIG. 3 SHOCKWAVE PEAK PRESSURE VS SCALED RECIPROCAL DISTANCE

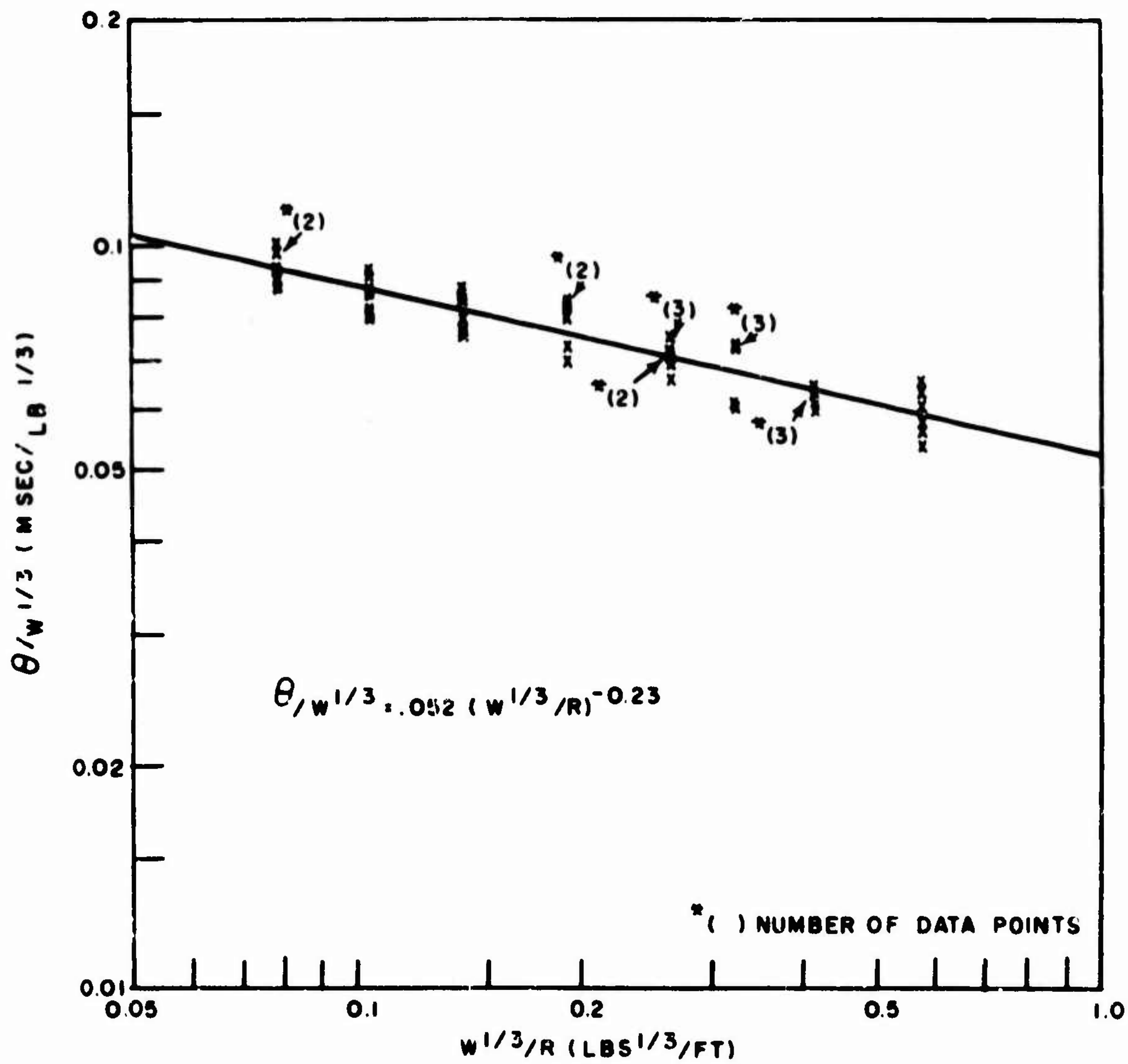

FIG. 4 REDUCED SHOCKWAVE TIME CONSTANT VS SCALED RECIPROCAL DISTANCE

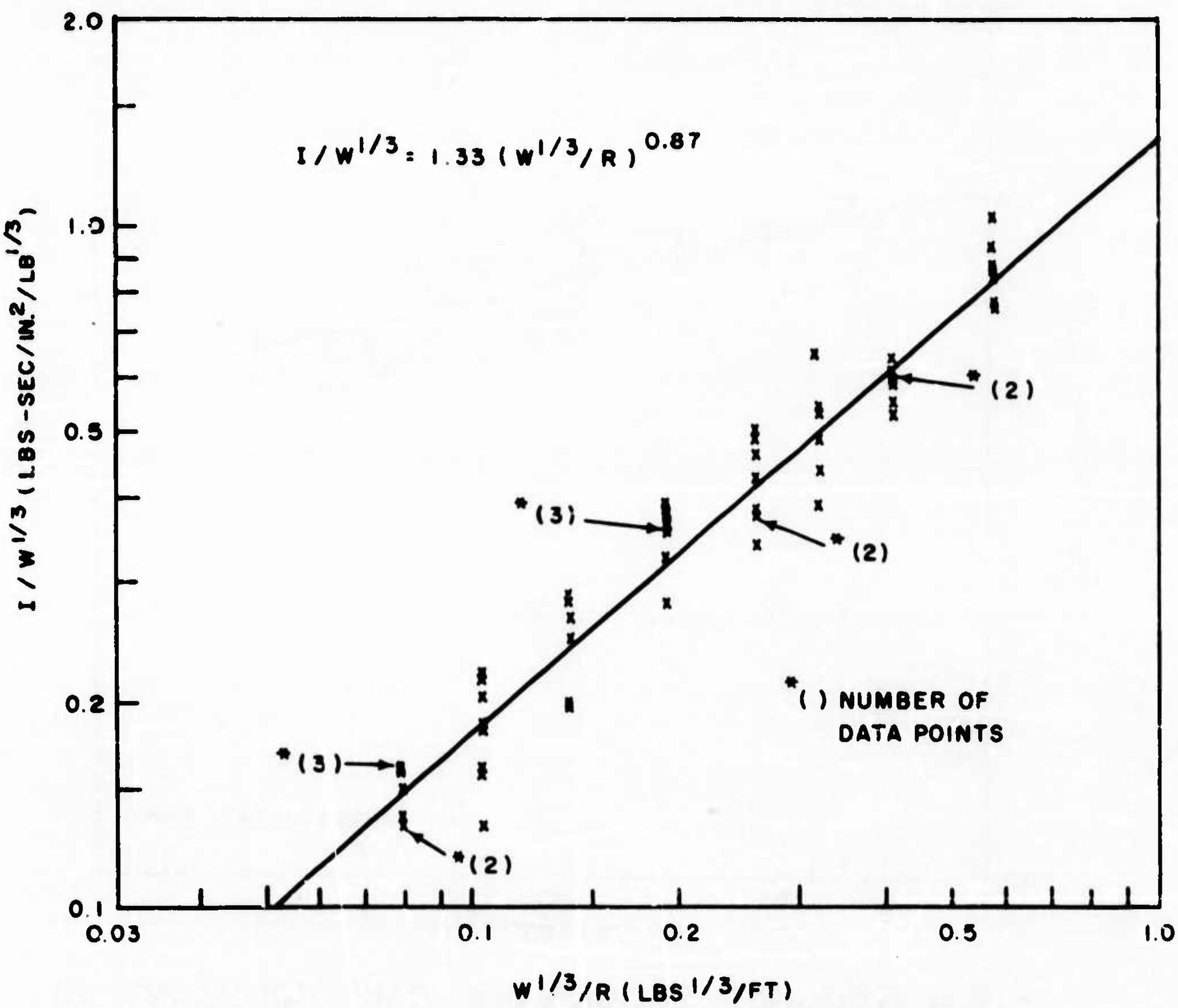

FIG. 5 REDUCED IMPULSE VS SCALED RECIPROCAL DISTANCE

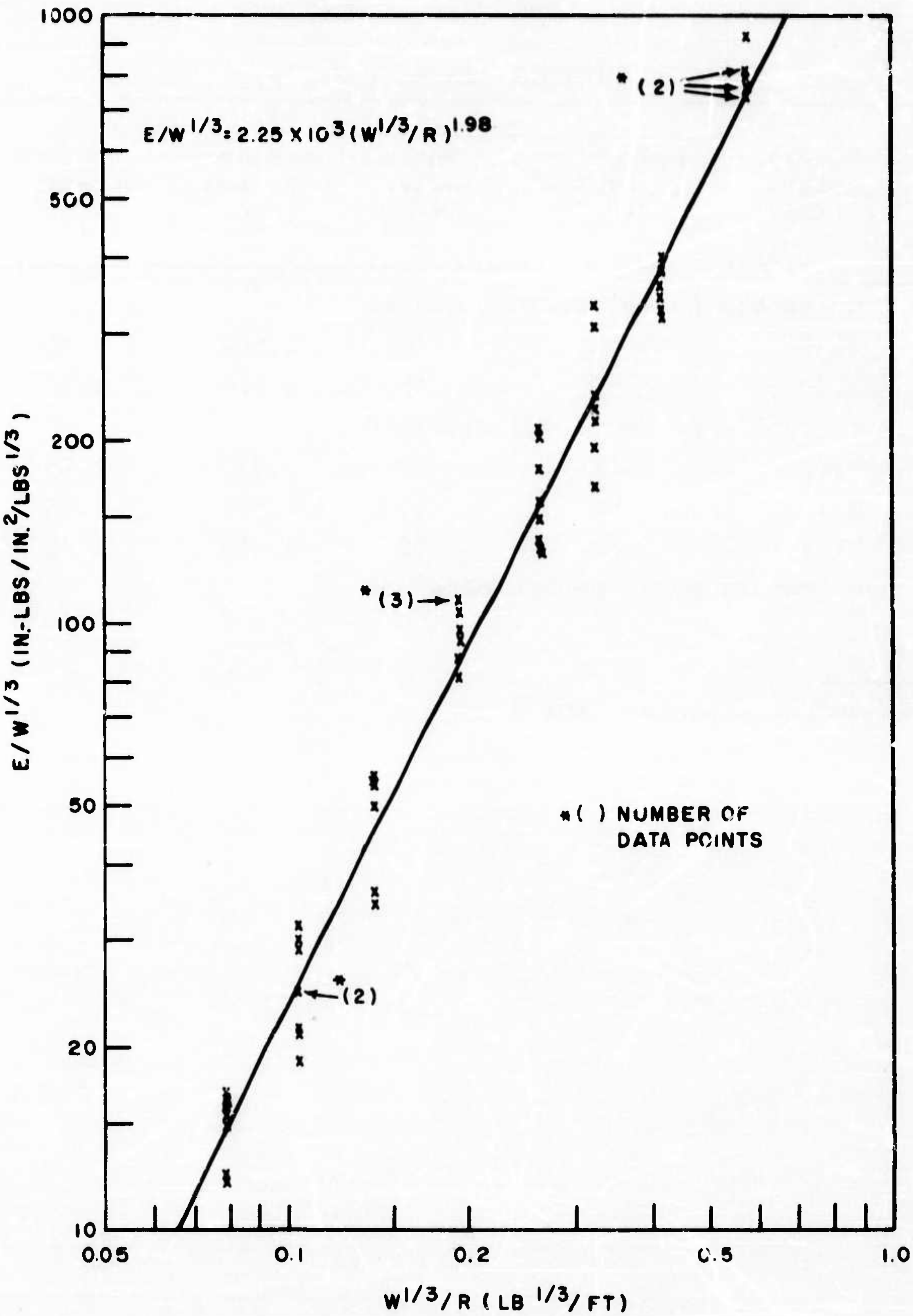

FIG. 6 REDUCED ENERGY FLUX VS SCALED RECIPROCAL DISTANCE

TABLE II BUBBLE PERIOD CONSTANTS

Shot No.	Charge Weight (lbs)	Hydrostatic Depth * (ft)	Total Water Depth (ft)	Measured Period (sec)	Corrected Constant K_1
827	no bubble pulse record obtained				
828	81.9	61	66	0.569	4.46
829	81.4	59	66	0.574	4.48
830	no bubble pulse record obtained				
831	81.7	61	70	0.567	4.45
832	81.4	61	70	0.565	4.45
833	81.3	62	62	0.560	4.43
834	no bubble pulse record obtained				

*Actual charge depth in feet + 33.

DISCUSSION

The results of this free water program are compared in Table III with values reported by the Naval Construction Research Establishment (NCRE) in Great Britain [3, 4], and with values obtained in this country by the Underwater Explosives Research Laboratory (UERL) at Woods Hole, Mass.[1]. The agreement between the present results and the UERL values is quite good, with the exception of the time constant*; there are, however, rather large discrepancies between the American values and the British results. These discrepancies are considerably greater than the normal spread of values obtained from standard charges by NOL over several years' work using the equipment and methods of this study.

The rather large differences between the American and British results are believed to be due largely to instrumentation effects. There is considerable evidence on hand to indicate that a pyro-electric effect occurring during the static calibration of the UERL and NOL gages can produce an error of about 4% in the gage constant. To correct for this error the American pressure and impulse values quoted in Table III would have to be lowered by approximately 4% and the corresponding energy value lowered by about 8%. In addition, it is believed that the response of the NCRE instrumentation could have caused recorded peak pressures to be about 8% too low.

While corrections for these two possible errors would bring the British and American values closer together, they do not account for the entire discrepancy. It is hoped that further work will resolve the differences.

---

*The disagreement in the NOL and UERL time constant determinations was found to be attributable, in large part, to differences in the methods employed to measure this parameter.

TABLE III

COMPARISON OF THE FREE WATER SHOCKWAVE PARAMETERS OF TNT

Investigational Group	Charge Weight (lbs)	P_m* K	P_m* α	$\theta/W^{1/3}$* K	$\theta/W^{1/3}$* α	$I/W^{1/3}$* K	$I/W^{1/3}$* α	$E/W^{1/3}$* K	$E/W^{1/3}$* α	Range	Limits of Integration
UERL (1)	76 and 48	2.16×10^4	1.13	0.060	-0.18	1.46	0.89	2440	2.04	$0.036 < W^{1/3}/R < 0.86$	6.7θ
UERL (2)	76, 48, 25 and 0.5	2.16×10^4	1.13	0.058	-0.22	Not Reported		Not Reported		$0.0005 < W^{1/3}/R < 0.86$	6.7θ
NCRE (3)	1.25	1.65×10^4	1.10	Not Reported		1.77	0.87	2100	1.99	$0.745 < W^{1/3}/R < 2.45$	10θ
NCRE (4)	300	1.65×10^4	1.10	Not Reported		1.22	0.81	1440	1.89	$0.068 < W^{1/3}/R < 0.41$	10θ
NOL	80	2.11×10^4	1.11	0.052	-0.23	1.33	0.87	2250	1.98	$0.079 < W^{1/3}/R < 0.578$	6.7θ

*Parameter = $K (W^{1/3}/R)^{\alpha}$

RECOMMENDATIONS

In light of this investigation it is recommended that the earlier UERL values given in lines (1) and (2) of Table III continue to be used.

APPENDIX A DETERMINATION OF PERPENDICULARITY CORRECTION TERM

Because of the method used to obtained the peak pressure values presented in this report, it was necessary to correct each pressure-time history for the non-perpendicular alignment of the film in the rotating drum camera relative to the cathode ray oscilloscope plates. The effect of this misalignment was essentially a displacement of the recorded peak pressure relative to the recorded zero time, i.e., the time at which the trace initially departed from the base line.

The magnitude and direction of this correction was obtained for each channel as follows: Prior to the series, a 35mm test film was placed in each rotating drum camera, the beam switched on, and the camera drum turned through a complete revolution. After applying this base line the drum was stopped and the beam deflected at several points along the film. The deviation of the lines thus produced from perpendicular alignment was then determined. Since the CRO tube is rigidly held in place, and since the camera construction is such as to allow little variation in film position, the value of the resulting correction did not vary appreciably in the course of an investigation.

The value of this angular deviation from the perpendicular ranged from zero to 67 minutes of arc, and averaged 18 minutes for the equipment used in this series. These values were accurate to approximately $\pm$ 10 minutes of arc. In order to apply these corrections they were transformed from angular to time units by the use of the relation

$$t_p = k\, p_a \tan x \text{ (microseconds)}$$

where p_a is the height of the apparent peak in millimeters, x is the value of the angular deviation, and k is the conversion factor in microseconds per millimeter. The value of k corresponds to the number of microseconds per millimeter along the base line. The absolute size of the correction, t_p, varied from zero to 20 microseconds and averaged 5 microseconds. These correction values were accurate to approximately ± 3 microseconds.

REFERENCES

[1] J. S. Coles, et al, "Shockwave Parameters from Spherical HBX and TNT Charges Detonated Underwater", NAVORD Report No. 103-46, (6 December 1946)

[2] A. B. Arons, "Underwater Explosion Shockwave Parameters at Large Distances from the Charge", The Journal of the Acoustical Society of America, Vol. 26, No. 3, 343-346 (May 1954)

[3] A. H. Bebb, "Measurements of Pressure, Momentum and Energy from Underwater Explosive Charges at Ranges from 100 to 1 Charge Radii", Report No. N.C.R.E./R 150, UNDEX 264 (November 1951)

[4] W. D. Hart, "Pressure, Momentum and Energy from 300 lb TNT Charges", Report No. N.C.R.E./R 152 (March 1950)

[5] Jean A. Goertner, et al., "The Effect of Aluminum on Underwater Explosive Performance: Shockwave Parameters from 50-lb Charges", NAVORD Report No. 2368 (1 March 1952)

[6] R. H. Cole, "Underwater Explosions", Princeton University Press (1948)

[7] A. B. Arons and R. H. Cole, "Design and Use of Piezoelectric Gages for Measurement of Large Transient Pressures", The Review of Scientific Instruments, Vol. 21, No. 1 (January 1950)

[8] Otto Meier, Jr., "A Study of Piezoelectric Gage Termination", NOLM 10467 (November 1949)

[9] J.P.Slifko and B.W. Scott, "Analysis of the Output Wave Form Produced by the Test Signal Generator Used Aboard the EPCS-1413", Internal Memo to EH Files (December 1955)

[10] H. H. Hall, "Instrumentation for Recording Underwater Shock Pressures Generated by Explosives", NAVORD Report 477, (March 1949)

[11] J. Petes and B. W. Scott, "Present Status of Pressure-Measuring Instrumentation Aboard EPCS-1413", NOLM 10866, (April 1950)

[12] E. A. Christian, et al, "A Comparison of the Underwater Explosive Efficiency of Baronex and HBX-1 in Weapon A", NOLM 9961 (23 December 1948)

REFERENCES (Con't)

[13] C. R. Niffenegger, "Comparisons of the Underwater Power of Explosives in Small Charges: I. Miscellaneous Compositions", NAVORD Report 2922 (1 July 1953)

[14] E. A. Christian, "Reading Techniques for Piezoelectric Gage Records", NOLM 10058 (4 April 1949)

[15] E. A. Christian and C. R. Niffenegger, "Underwater Performance of Explosives Containing Ammonium Perchlorate, III," NAVORD Report 3563 (1 November 1953)

[16] J. S. Coles, "The Measurement of Underwater Explosions from Service Weapons at the Underwater Explosives Research Laboratory (UERL)", NDRC A-362, OSRD 6240 (March 1946)

DISTRIBUTION

	Copies
Chief, Bureau of Ordnance, Attn: Ad3	2
Attn: Ad6	1
Attn: ReU3	1
Attn: Re06	1
Chief of Naval Research, Attn: Code 466	1
Attn: Code 418	1
Chief, Bureau of Ships, Attn: Code 423	2
Chief, Bureau of Aeronautics	2
Chief of Naval Operations	4
Chief, DASA, Box 2610, Washington 13, D. C.	9
Chief of Ordnance, Department of the Army, Washington 25, D.C. Attn: R and D Division	4
Chief of Engineers, Department of the Army, Washington 25, D. C. Attn: ENGNB	2
Attn: ENGEB	1
Commander, Norfolk Naval Shipyard, Portsmouth, Virginia Attn: Code 280, Underwater Explosions Research Div.	2
Commanding Officer, Naval Propellant Plant, Indian Head, Md.	1
Commander, Naval Proving Ground, Dahlgren, Virginia Attn: Experimental Officer	1
Commanding Officer, Naval Mine Depot, Yorktown, Va. Attn: J. T. Manley, Research and Development Div.	1
Commanding Officer, Picatinny Arsenal, Dover, N. J.	1
Commander, Naval Ordnance Test Station, China Lake, California, Attn: Technical Library	2
Commanding General, Ballistic Research Laboratories, Aberdeen, Maryland	1
Superintendent, U. S. Naval Postgraduate School, Monterey, California	1
Director, National Bureau of Standards, Washington,D.C. Attn: Security Officer	1
Director, Naval Research Laboratory, Washington, D. C.	2
Director, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, Attn: Dr. D. P. MacDougall	1
Director, David Taylor Model Basin, Carderock, Md.	2
Director, Waterways Experiment Station, Vicksburg, Miss., Attn: F. R. Brown	2
Armed Services Technical Information Agency, Arlington Hall Station, Arlington 12, Virginia, Attn: TIPDR	10
Commander, Ooama, Attn: Air Force Ammunition Services Office, Hill Air Force Base, Utah	1
Commander, Air Force Armament Center, Eglin Air Force Base, Florida, Attn: ACX	1
Commander, Air Material Command, Wright-Patterson Field, Air Force Base, Dayton, Ohio	1