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UNDERWATER SYSTEMS, INC.

COMPARISON OF HYDROACOUSTIC SHOCK WAVES FROM FOUR DIFFERENT EXPLOSIVES

A Joint Report from the following facilities:

IIT Research Institute
10 West 35th Street, Chicago, Illinois

U. S. Army Waterways Experiment Station
Vicksburg, Miss.

Underwater Systems, Inc.
8121 Georgia Ave., Silver Spring, Md.

Sponsored by

Advanced Research Projects Agency (ARPA)

and

Office of Naval Research (ONR)

March 1967

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Chapter I. Introduction

Four different chemical explosives were compared for their efficiency in generating seismic signals when detonated underwater. Pressure time curves generated by the explosives were recorded to determine their relative efficiency in generating hydroacoustic energy,and to provide a control for studies of the resulting seismic disturbances. The method used was to compare the explosive properties of three materials with TNT, for which considerable experimental data has been acquired.

The experiment was conducted in Mono Lake and vicinity, in eastern California, during September 1966. One ton charges of four explosive materials of substantially different properties were detonated at a depth of 70 feet at the same location in the lake where the water depth was 124 feet. Hydroacoustic measurements were made in the water at distances ranging from 72 to 261 feet (about 30 to 100 charge radii) from the charge. Seismic disturbances were measured at eight mobile stations located at ranges of 20 to 72 Km from the shot, Ref. (1).

Chapter II. Properties of Explosive Charges

The explosive materials chosen for evaluation in these experiments were determined by a combination of economic and technical considerations connected with the ultimate use of the explosives for deep undersea detonation to induce seismic disturbances.

The materials* used were (1) ANOIL, a granular mixture of finely ground high density prilled ammonium nitrate with 5.8% by weight of No. 2 fuel oil, (2) SLURRY, a high energy gelled nitrocarbonitrate slurry containing 15 to 20% aluminum, (3) NM, liquid nitromethane (CH_3NO_2, 95% minimum purity), and (4) cast TNT (trinitrotoluene). The anoil was used at a compacted bulk density of 1.15 g/cc rather than the normal bulk density of about 0.9 g/cc because this granular explosive experiences a compression to a density of 1.15 upon exposure to a hydroacoustic head of 1,000 feet of sea water. Comparative technical data for these materials is given in Table 2.1. The advantages of using any one of the three materials in lieu of TNT are four: none are classified as explosives; none would require special safety precautions; all are readily available commercially; all can be transported aboard ocean going vessels without undue hazards.

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*ANOIL and nitromethane were supplied by Commercial Solvents Corporation. Aluminized slurry of proprietary composition (Spe N-C-N-11, *Reg. Trademark) was supplied by the Gulf Oil Corporation, Chemicals Department.

TABLE 2.1 DETONATION AND PERFORMANCE PARAMETERS OF EXPLOSIVES

Explosive	Anoil	Slurry	Nitromethane	Cast TNT
Bulk Density, g/cc	1.15	1.35[1]	1.125[1]	1.56[2]
Detonation Velocity, m/sec	3,900	5,500[1]	6,200[2]	6,640[2]
ΔH^o_d, Calc'd* Heat of Detonation kcal/g	0.89	No data**	1.46	1.27
E_S, Underwater Shock Energy, ft-tons/lb	138[1]	172[1]	193[1]	170[1]
E_B, Underwater Bubble Energy, ft-tons/lb	301[1]	384[1]	292[1]	301[1]
$E_S + E_B$, ft-tons/lb	439[1]	556[1]	485[1]	470[1]
<u>Performance Indices Relative to TNT:</u>				
$\frac{\Delta H^o_d}{\Delta H^o_d\text{, TNT}}$	0.70	No data**	1.15	1.00
$\frac{(E_S + E_B)}{(E_S + E_B)\text{ TNT}}$	0.93	1.18	1.03	1.00
Seismic Amplitude Equivalency per Unit Mass	0.73	1.05	1.06	1.00

NOTES:

[1] See Ref. (2)

[2] See Ref. (3)

*Assuming reaction to stable products CO_2, N_2, $H_2O(g)$, C, $Al_2O_3(s)$, at final temperature 25°C.

**Calculation not feasible because thermochemical data unavailable on natural products used in formulation.

2.2 Signal Properties of Explosive Charges, TNT

The characteristics of the signal generated by underwater detonation of spherical charges of TNT are well known. Initially, a shock wave is generated, followed by the formation of a gas bubble. The bubble diameter reaches a maximum, after which the bubble contracts. As the bubble approaches minimum diameter, a signal, referred to as a bubble pulse, is emitted, after which, the bubble diameter again increases. This oscillation continues until the available energy is exhausted, with the emission of a bubble pulse each time a minimum diameter is approached. Figure 2.1 shows the main features of the generated signal.

In addition to oscillation, the bubble will migrate towards the surface or bottom depending upon the geometry. When the bubble undergoes severe upward migration, energy is transferred from the oscillatory to the migratory mode. This results in a considerable reduction of the peak amplitude of the bubble pulse. In effect, the higher frequency components are lost. Finally, if the detonation depth is sufficiently shallow to permit the bubble to breach the surface prior to reaching the first minimum, a bubble pulse will not be emitted.

The shock wave can be approximately represented by a decaying exponential, Ref. (4), whose characteristics for TNT are given below:

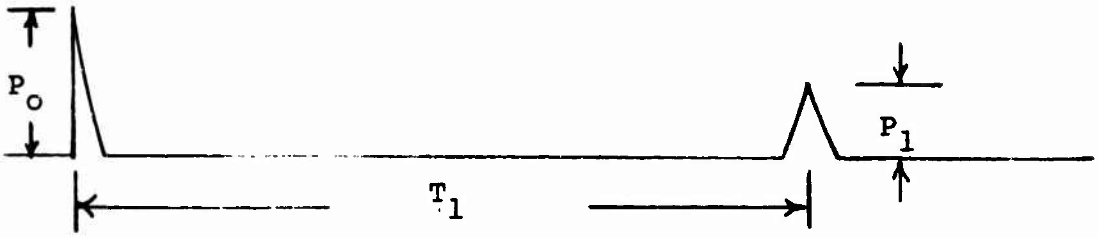


Figure (2.1)

Time sequence of signal generated by an underwater explosion, showing the shock wave, 1st bubble pulse, and 1st bubble pulse period

Let:

P_o = Peak pressure (psi)
W = Yield (pounds)
r = Range (feet)
I_o = Positive impulse (lb-sec/in^2)
t_o = Time constant (microseconds)

Then:

$$P_o = 2.16 \times 10^4 \left(\frac{W^{1/3}}{r}\right)^{1.13}$$

$$I_o = 1.78\ W^{1/3} \left(\frac{W^{1/3}}{r}\right)^{0.94}$$

$$t_o = 58\ W^{1/3} \left(\frac{W^{1/3}}{r}\right)^{-0.22}$$

The first bubble pulse period is determined by the yield and detonation depth.

Let:

T_1 = first bubble pulse period (seconds)
d_o = d + 33
d = detonation depth

Then: for TNT:

$$T_1 = 4.36\ W^{1/3}\ d_o^{\ -5/6}$$

The bubble pulses are fairly symmetrical and can be approximated by back to back exponentials.

Let:

P_1 = Peak pressure (psi)

I_1 = Impulse (lb-sec/in^2)

t_1 = Time constant (seconds)

For TNT, in the absence of migration, we obtain:

$$P_1 = 3,450 \left(\frac{W^{1/3}}{r}\right)$$

$$I_1 = 9.58\ W^{1/3} \left(\frac{W^{1/3}}{r}\right) d_o^{\ -1/6}$$

$$t_1 = I_1/2P_1$$

For high explosives other than TNT, one would obtain similar relationships. In general, the amplitude constants are different. The exponentials, for example the 1.13, 0.94 and -0.22 powers in the shock wave equations, are also altered, but only slightly.

Formulas for other parameters of interest from Ref. (5) are given below.

The maximum bubble radius, a, is given by:

$$a = 12.6 \left(W/d_o\right)^{1/3}$$

The minimum bubble radius, b, is given by:

$$b = 74.5 \frac{W^{5/9}}{d_o^{11/9}} + 0.149 W^{5/16}$$

The migration, h_1, to the first bubble minimum is given by, Ref. (6):

$$h \approx \frac{80 W^{1/2}}{d_o}$$

For a one ton charge at a depth of 70 feet the maximum and minimum bubble radii, neglecting migration, are 34 and 19 feet respectively; however, an upward migration of the bubble of about 35 feet can be expected.

Thus, neglecting the effect of the bottom on migration, one would expect that the bubble pulse would be quite weak, if it existed at all.

Chapter III. Test Conditions

3.1 Charges and Charge Placement

The test program involved the detonation of three shots of each of the four different types of explosives. Each charge weighed approximately 2,000 lbs (one ton).

The anoil, slurry, and NM were loaded into standard 55-gallon fuel drums and shipped to the U. S. Naval Ammunition Depot (NAD), Hawthorne, Nevada. The one-ton, spherical TNT charges were cast at NAD and transported to the site with the other explosives.

To facilitate lifting and handling the TNT charges, a nylon lifting sling was fitted into the bottom of the mold prior to casting.

The other charges in 55-gallon containers were placed on a plywood base and 1/4" steel cables threaded over and under each drum to provide a lifting sling. The drums were then banded with 5/8" steel straps to prevent any later movement or slippage (Figure 3.1). Each drum of nitromethane weighed 500 lbs; the slurry weighed 625 lbs/drum,and the anoil weight ranged from 535 to 550 lbs per drum. Four drums were used in the makeup of the NM and anoil charges (Figure 3.1), but since the anoil weighed more, approximately 35 to 50 lbs of the explosive material had to be removed from each barrel. Each slurry charge weighed a total of 1,875 lbs and consisted of three 625-lb drums arranged as shown in Figure 3.2. A plastic-type explosive, C-4, with a detonation

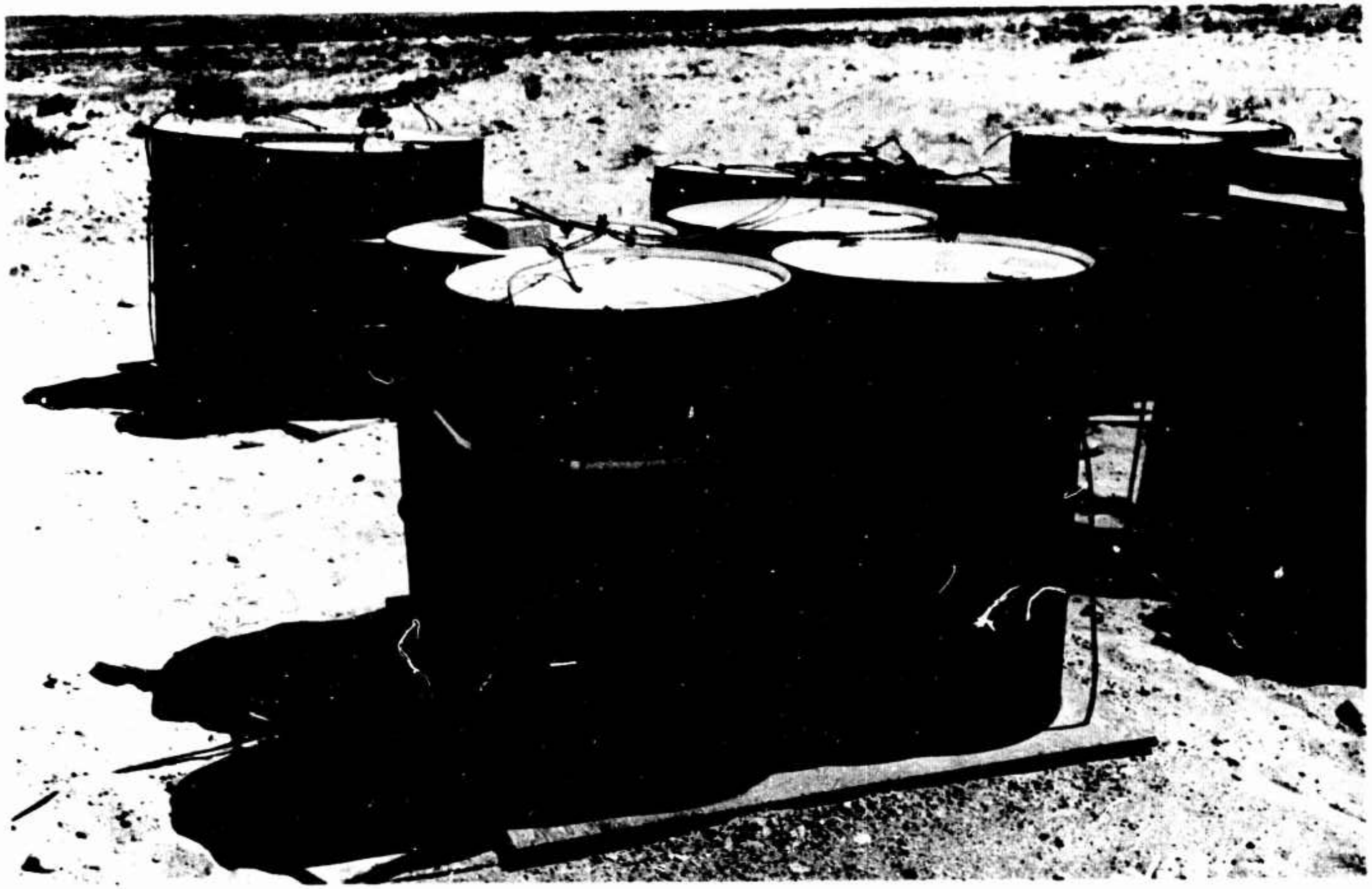


Figure 3.1 Typical example of nitromethane and anoil charges.

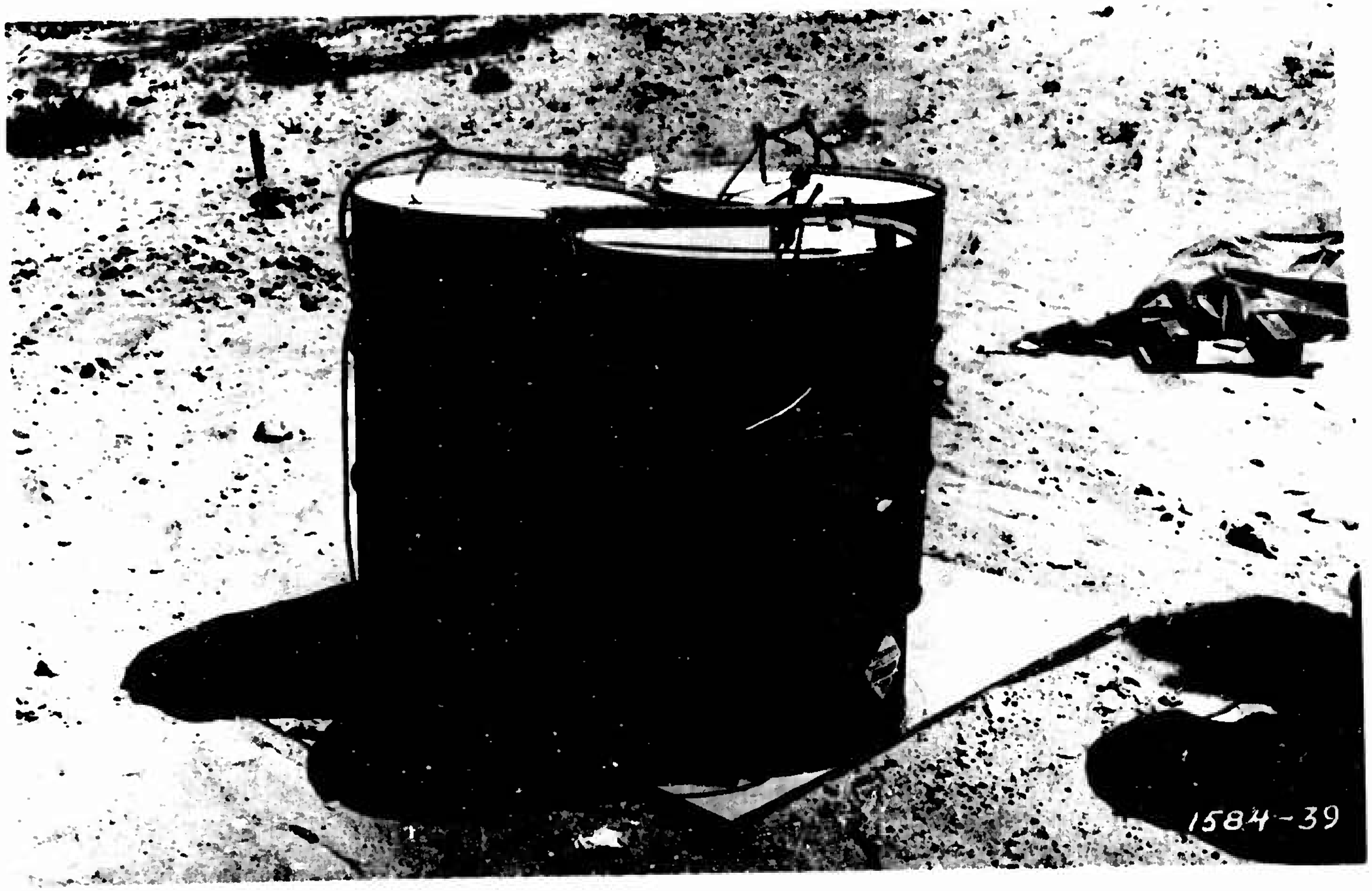


Figure 3.2 Typical arrangement for the slurry charge.

velocity of about 25,000 ft/sec, was used as the booster. Cylindrical aluminum tubes,1½ inches in diameter with a threaded 2" shoulder (Figure 3.3),were hand packed with 3 lbs of C-4 and inserted in the 2" opening (bung hole) in the drums. A hard rubber stopper, cut more than halfway through, closed the upper end of the cylinder, but allowed the detonator leads to pass through the cut. Each drum was individually armed, as shown in Figure 3.3, and the four detonator leads connected in series.

Empty fuel drums inclosed in a wooden platform with 4 x 4-inch timber supports, with a 5-ton capacity winch mounted on top, provided an excellent means of transporting and positioning all charges (Figure 3.4). Lateral positioning was accomplished using lines attached to three 1,500-lb-concrete anchors placed 120° apart on the lake bottom. The flotation rig was positioned in the near center of this triangle (formed by the three anchors), with final positioning controlled by transits on the beach. The winch allowed accurate depth placement,and, once positioned, the charge support line was secured and the winch removed.

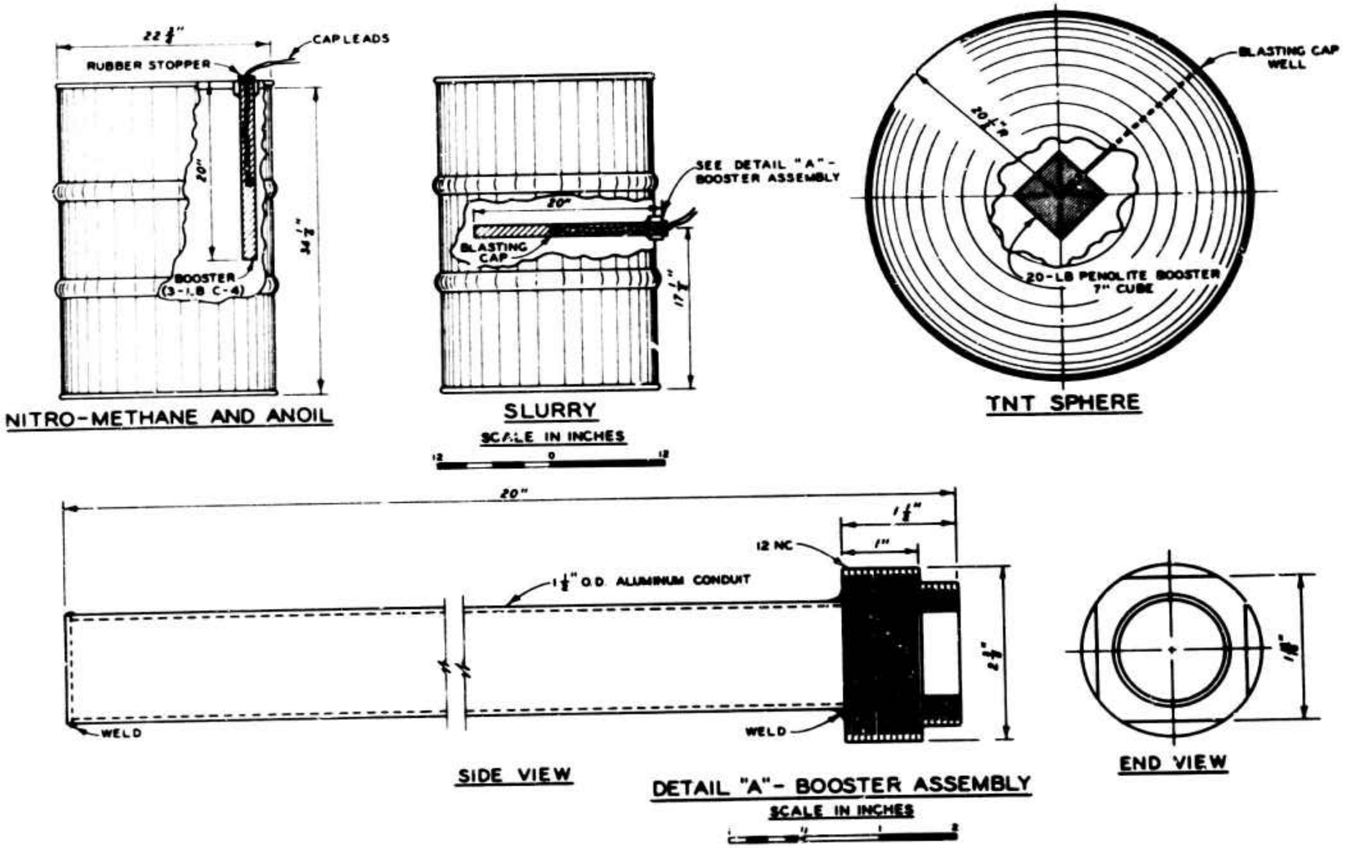


Figure 3.3 Schematic of explosive charge and booster assembly.

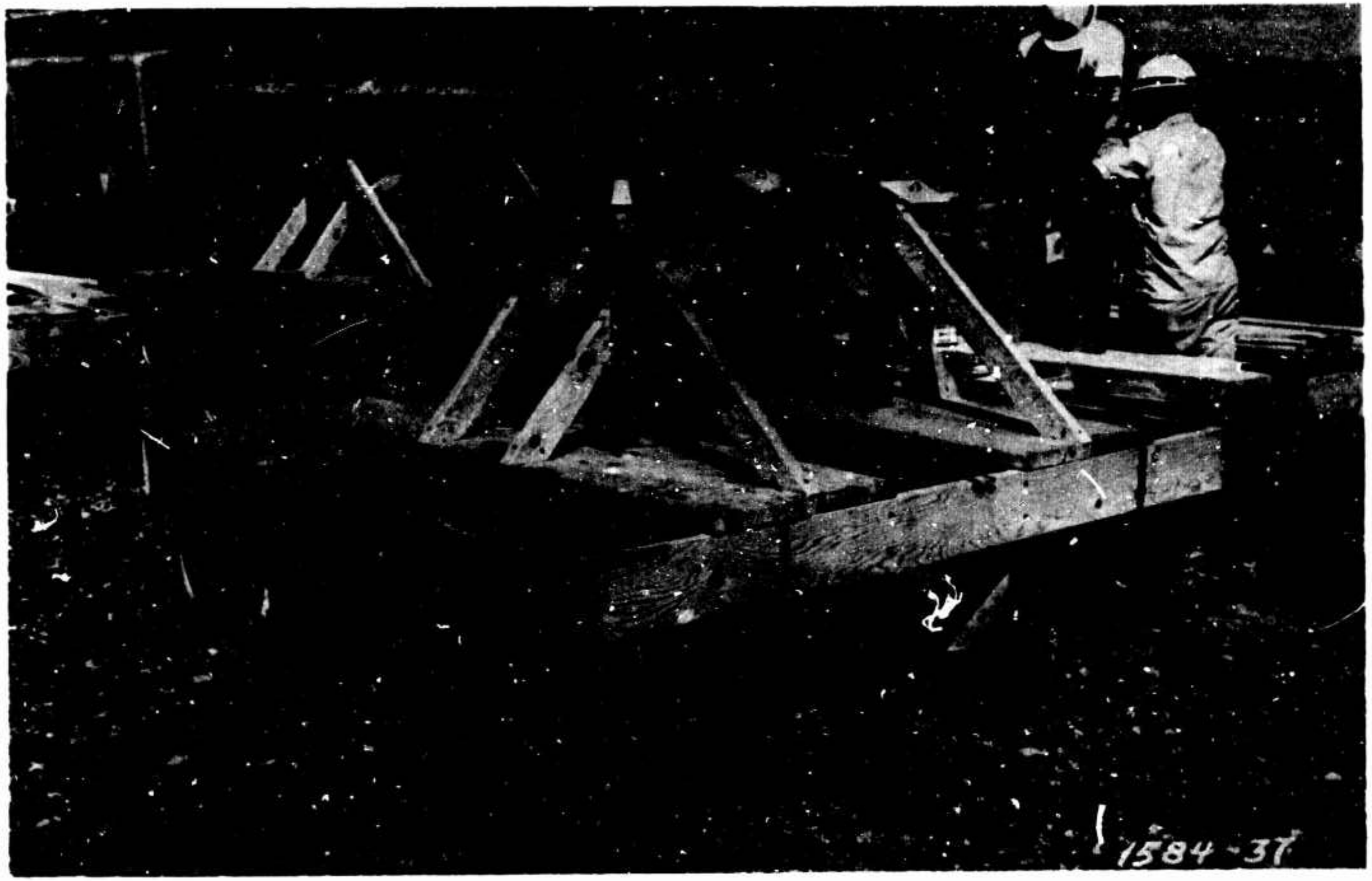


Figure 3.4 Charge flotation device.

3.2 Test Geometry

All charges were fired at a depth of 70 feet in 124 feet of water. Nine piezoelectric (tourmaline crystal) gages varying from 1/2 to 1-3/4 inch in diameter were positioned at distances corresponding to pressure levels ranging from 700 psi to 3,000 psi. Most gages were located at the same depth as the charge (-70 feet); however, three were positioned ten feet off the bottom to determine the influence of bottom reflection,and to obtain indications of the nature and density of the bottom materials.

WES provided five channels of underwater shock measurements; four gages at the 3,000 psi level,with two each paired at depths of 70 and 114 feet, and the fifth gage at the 70-ft depth, but at a pressure level of 2,000 psi (Figures 3.5 and 3.6). Underwater Systems, Inc. (USI) provided four channels of underwater shock measurement; two at the 2,000 psi level (one at the 70-ft level, the other at a 114-ft depth,and one each at pressure levels of 1,000 and 700 psi, at the 70-ft depth.

Shots 1-7 were fired with the test geometry shown in Figure 3.5. Prolonged exposures at the 3,000 psi level, and the long durations (8 to 10 msec) experienced during the tests resulted in an unusually short gage life,which necessitated an increase in the charge-to-gage distance. Shots 8-12 were then detonated using the geometry illustrated in Figure 3.6; the near position in this case was at the 2,500 psi level.

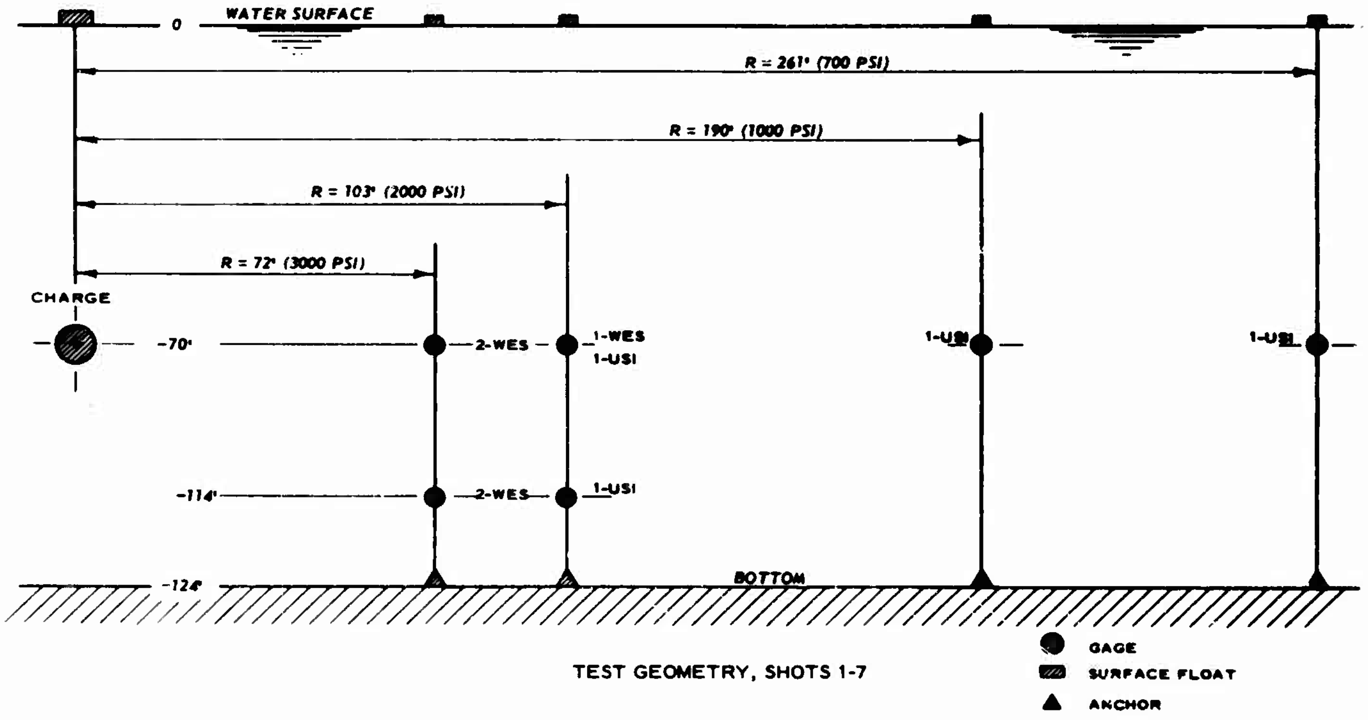


Figure 3.5 Test geometry for Shots 1 through 7.

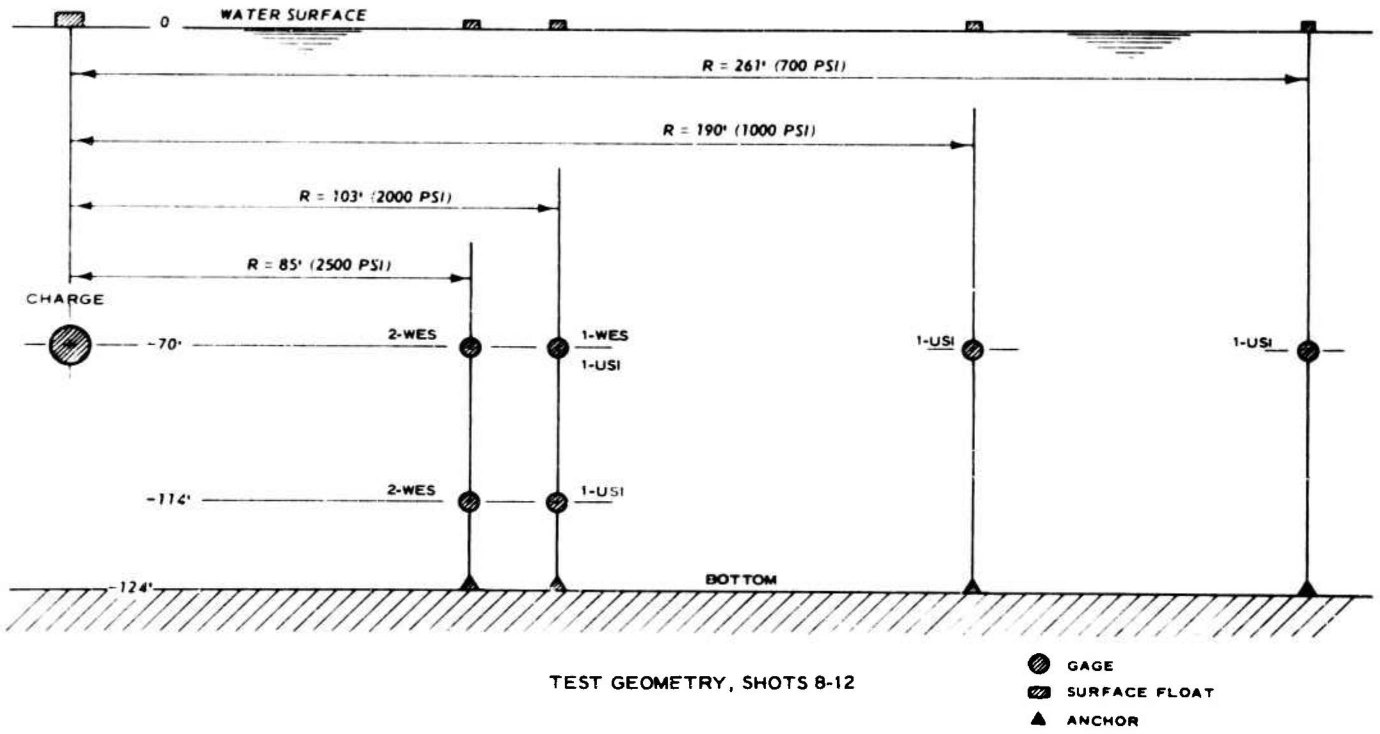


Figure 3.6 Test geometry for Shots 8 through 12.

3.3 Shock Refraction

Mono Lake possesses a sharp thermocline during the summer months. The depth of the thermocline and its stability depends on local weather conditions as well as the periodic seiches. Thus, movements of several feet in relatively short periods of time are to be expected.

Hydrodynamic shock waves behave very much like acoustic waves with regard to refraction, Ref. (7). Hence, refraction effects on the explosive generated shock waves can be evaluated by ray tracing techniques.

A number of temperature measurements were made between detonations, and converted to sound velocity profiles. These are shown in Figures 3.7 to 3.11. As may be noted, the thermocline is located between 40 and 70 feet, resulting in severe velocity gradients; above and below this range almost iso-velocity conditions prevail. It is important to note that the knee of the curve occurs within a few feet of the 70 foot depth. Ray path plots for the velocity gradients shown in Figures 3.7 and 3.8 are shown in Figures 3.12 and 3.13 respectively. For Figure 3.7, the depth of source and gages was arbitrarily shifted to 67 feet, corresponding to the knee of the sound velocity profile, in order to accentuate refraction effects.

As can be noted, when the source is located at the knee of the sound velocity profile, two arrivals would be received at the gages if they were actually several feet deeper, and only one arrival if several feet shallower. Since the knee

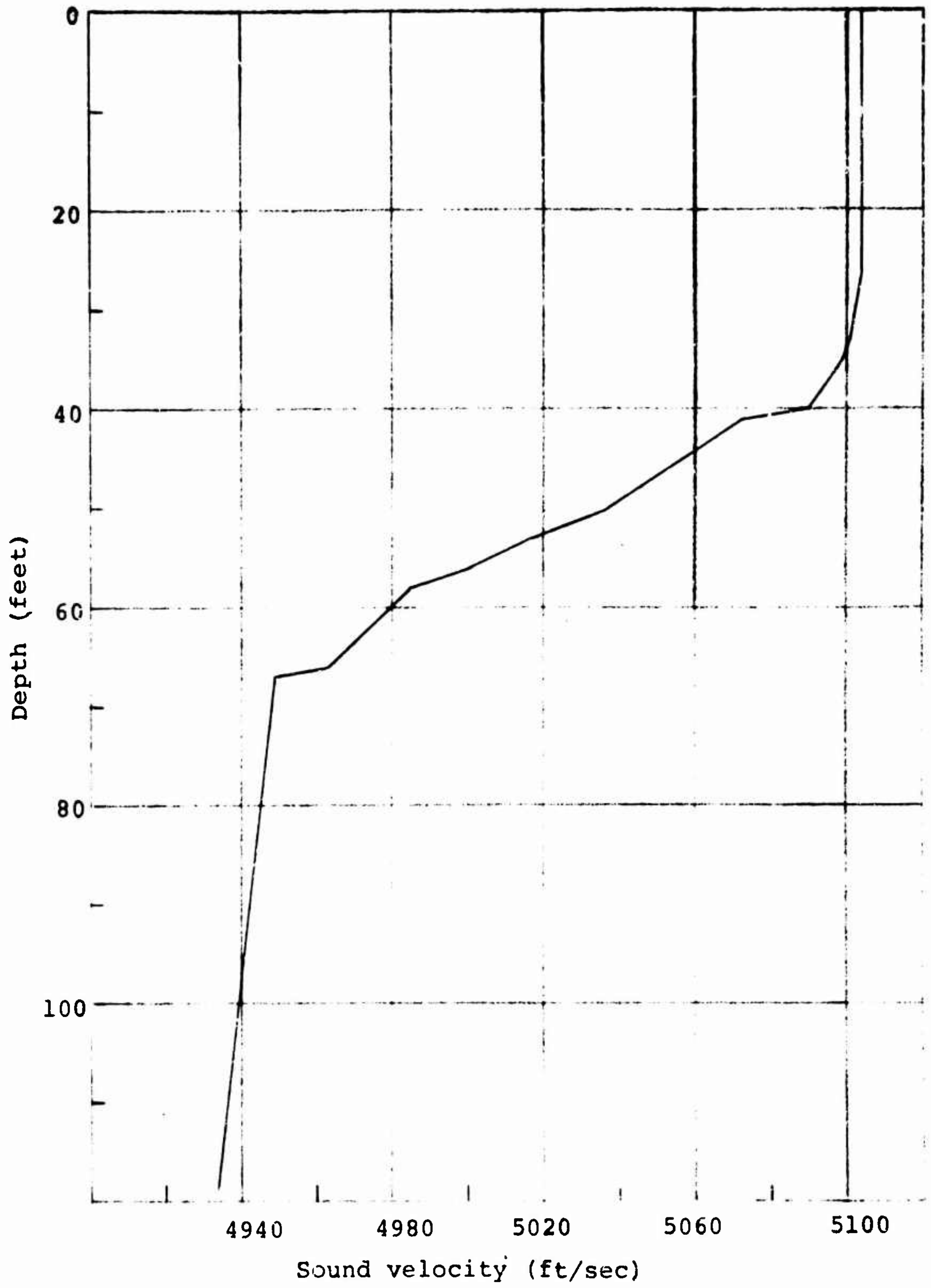


Figure 3.7
Velocity Profile (8/23/66 - 1030 PDT)

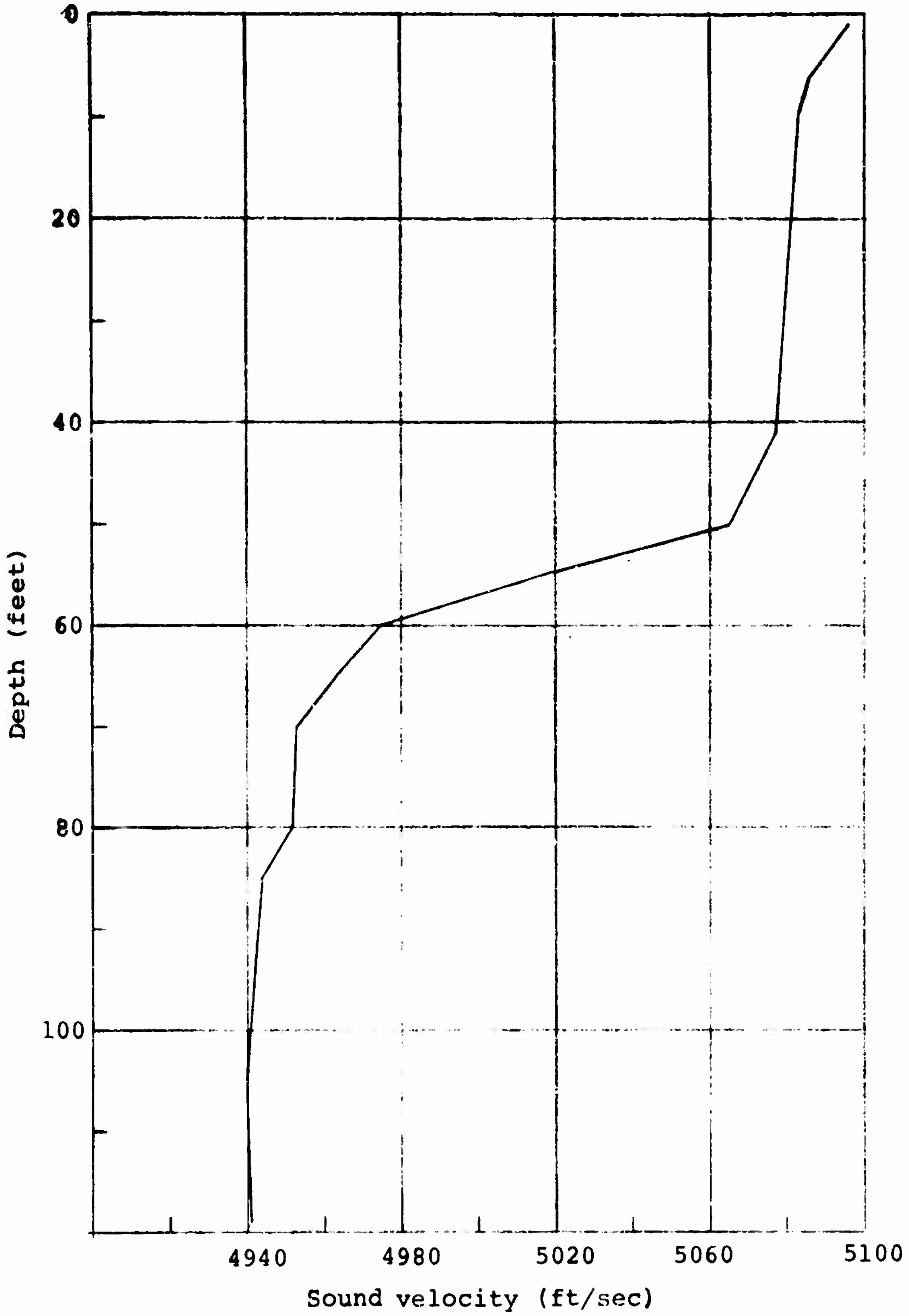


Figure 3.8

Velocity Profile (9/6/66 - 1300 PDT)

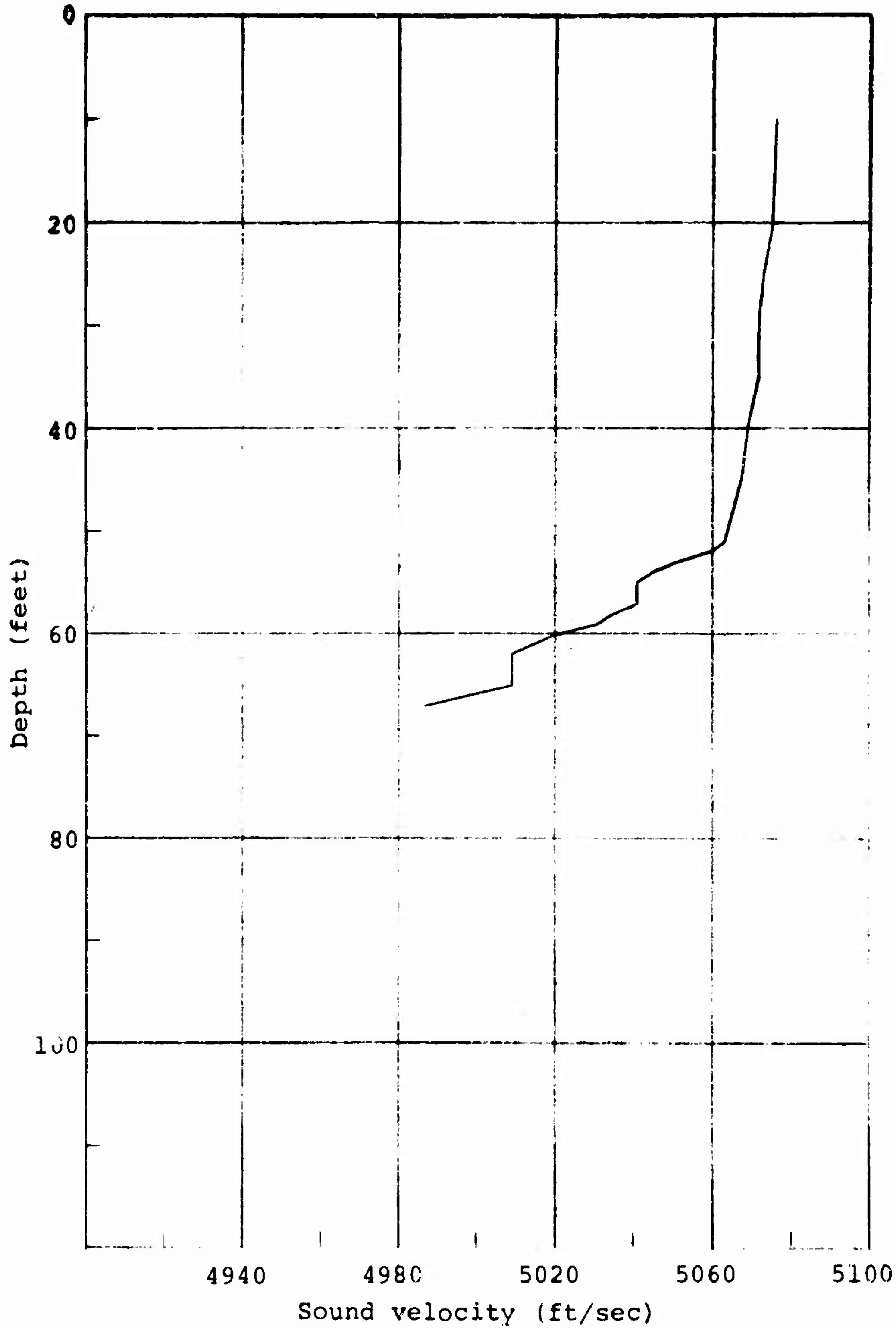


Figure 3.9

Velocity Profile (9/8/66 - 1150 PDT)

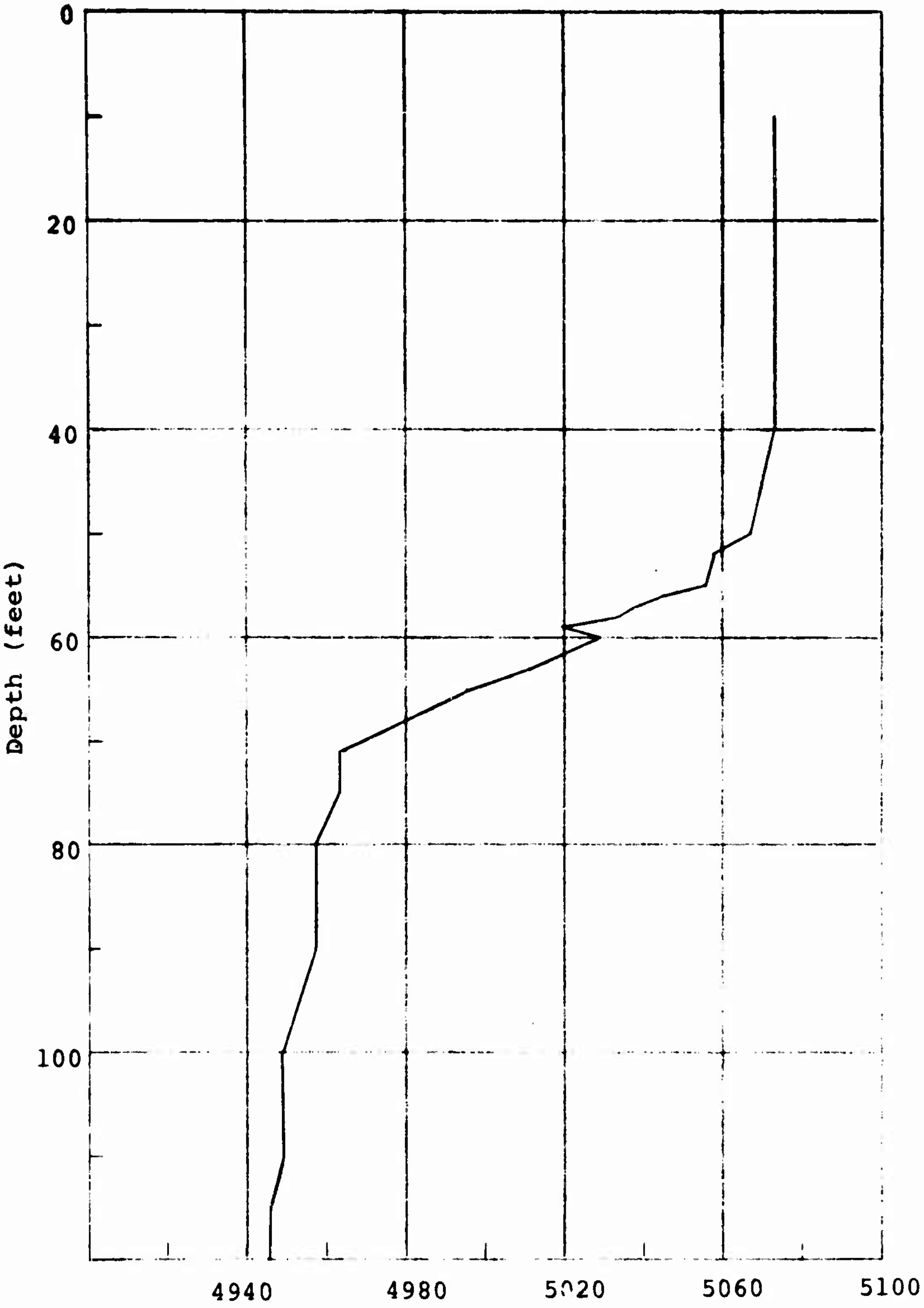


Figure 3.10
Velocity Profile (9/9/66 - 0750 PDT)

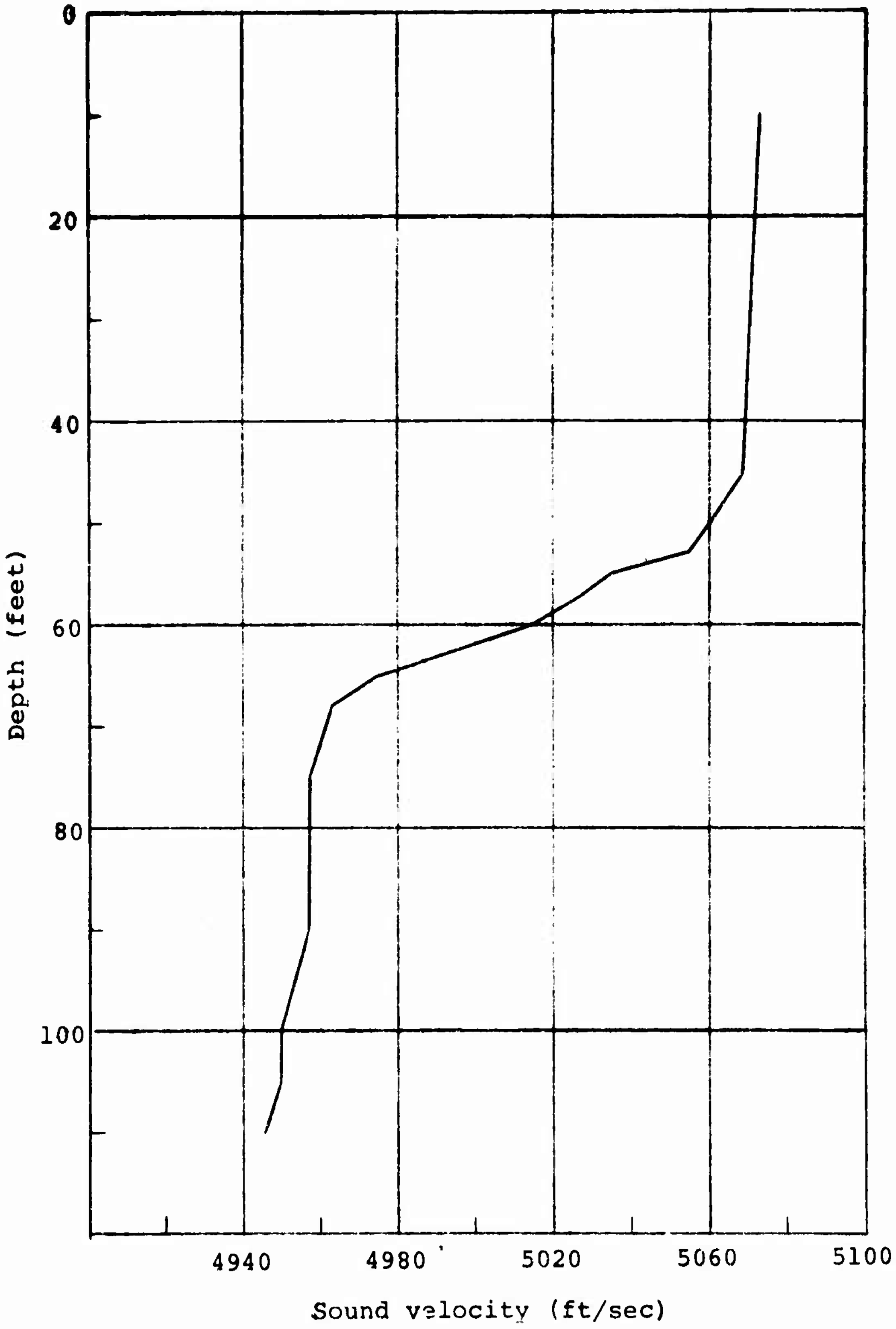
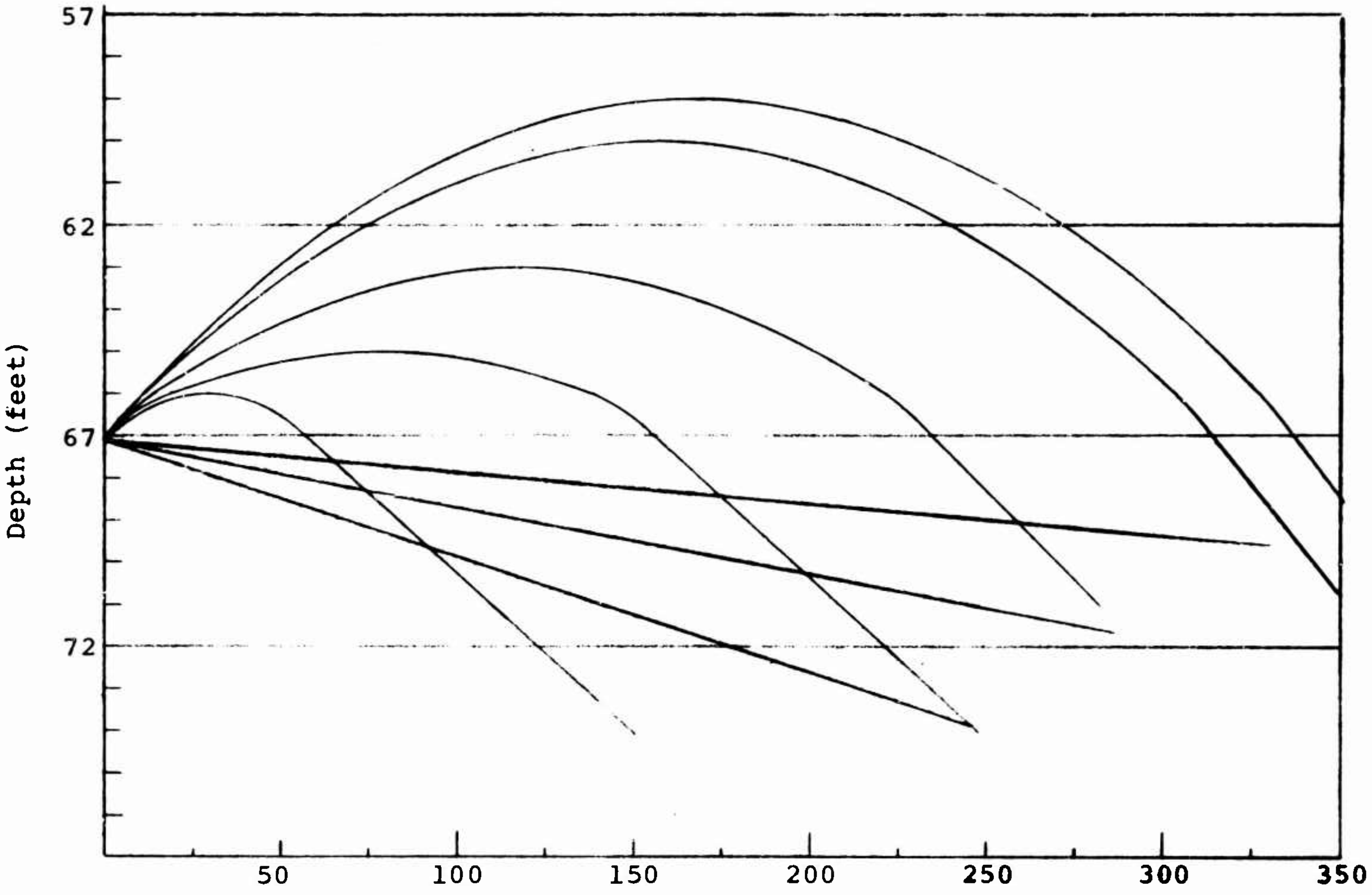


Figure 3.11
Velocity Profile (9/9/66 - 1015 PDT)



Range (feet)

Figure 3.12

Ray Path Diagram for Velocity Profile of Figure 3.7

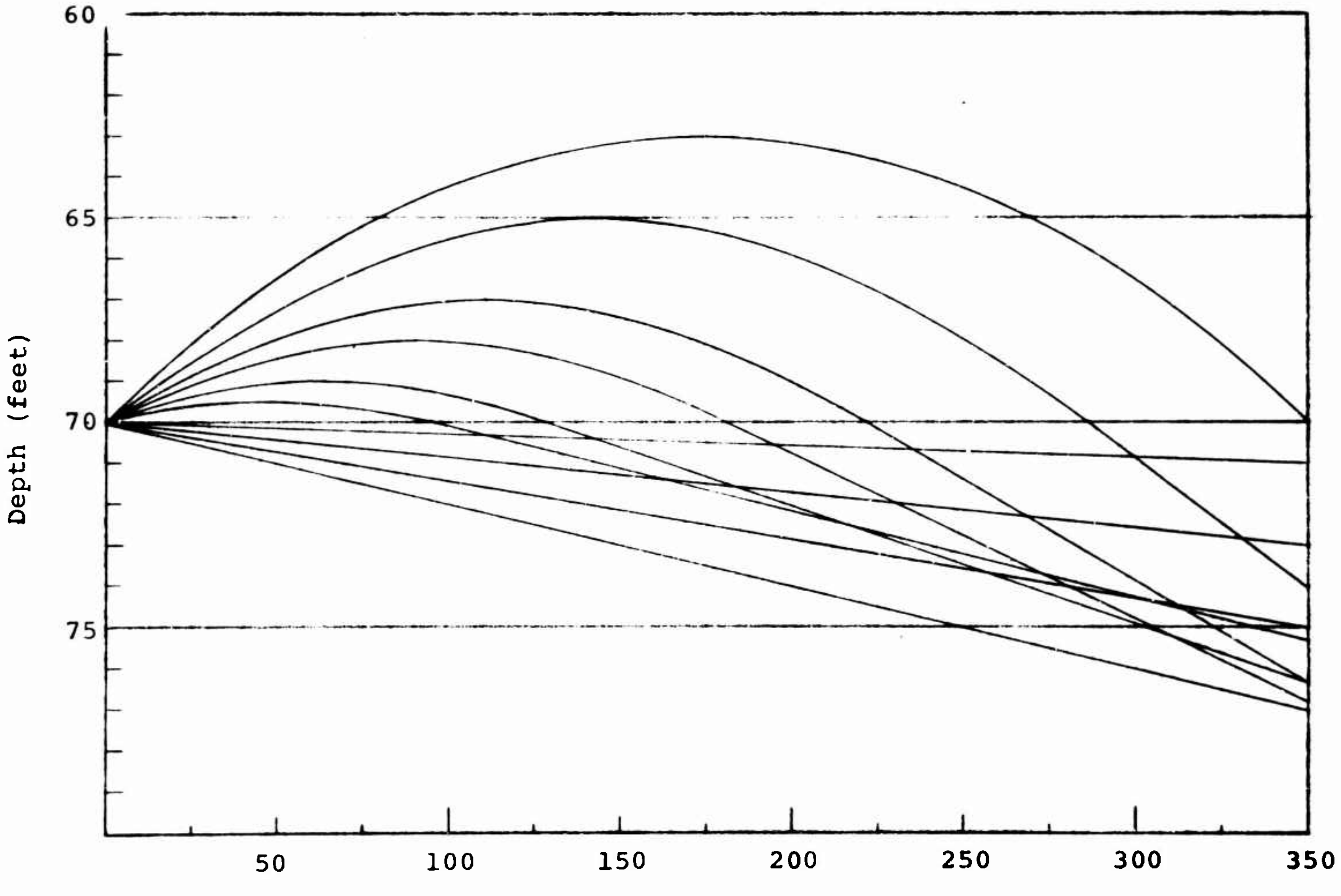


Figure 3.13

Ray Path Diagram for Velocity Profile of Figure 3.8

of the curve will shift upward or downward by several feet, the position of the gages with respect to the knee is not precisely known for each detonation.

These results imply that the levels obtained at the 70 foot depth gages may be somewhat in error, by different amounts for each detonation. It is likely that this error is not too large. The ray paths shown cover a vertical range of only a few feet,and it is questionable whether they are applicable at frequencies below the order of several hundred Hz.

These difficulties are not present for the gages located 10 feet above the bottom. Thus, peak shock wave pressure levels are more appropriately measured at the deep gages.

Chapter IV. Instrumentation

4.1 WES Equipment

The WES recording equipment was located on an aluminum pontoon barge anchored 1,200 feet from surface zero (SZ). Six channels of cathode followers (impedance modifiers) were shock mounted on a flotation rig that was anchored 600 feet from SZ. Signals from the five WES gages were recorded simultaneously on dual-beam, Tektronic 502 oscilloscopes and an Ampex CP-100, magnetic tape recorder. The oscilloscopes were set for a sweep speed of 5 cm/msec or a total recording time of 50 msec. The CP-100 tape recorder has a 20 kc response in the FM mode and was operated at a speed of 60 inches/sec.

The WES gages were 1/2 inch, tourmaline cyrstal, piezoelectric transducers. Each gage was attached to a 1,000-ft length of low-noise coaxial cable that terminated at the cathode followers. Another 1,000 ft length of four-conductor, shielded, plastic-coated cable connected each gage from the cathode followers to the instrument barge.

4.2 USI Equipment

Block diagrams of the monitoring instrumentation used by USI are shown in Figures 4.1 and 4.2. A dual recording system was utilized, four tourmaline gage outputs being both recorded on a local IRIG FM tape recorder and telemetered to a receiving station on shore. The instrumentation in Figure 4.1 was housed in a waterproofed box suspended by shock cord inside a buoy situated approximately 650 feet from SZ. The shore based telemetry receiving station was approximately one mile from SZ. The four tourmaline gages, three 7/8" gages at the closer in positions, and one 1-3/4" gage at the 700 psi position, were connected by 1,000 feet of low noise cable to the instrumentation buoy. The gage outputs were impedance transformed by 4 solid state differential amplifiers functioning as electrometers. The telemetry system consisted of four constant bandwidth channels driving a 2 watt transmitter operating FM with a center carrier frequency of 241.5 MHz. Discriminator outputs were recorded on an IRIG wide band FM tape recorder, (operating at 7-12 ips). The overall frequency response of the telemetry system was DC-2 kHz, while that of the local recording system was DC-1 kHz. A fifth channel was used as a timing channel, recording the output from a chronometer with an accuracy of better than 10^{-9}/day. The chronometer was checked frequently against WWV. Voice identifications of time marks and upcoming events were also made on this channel.

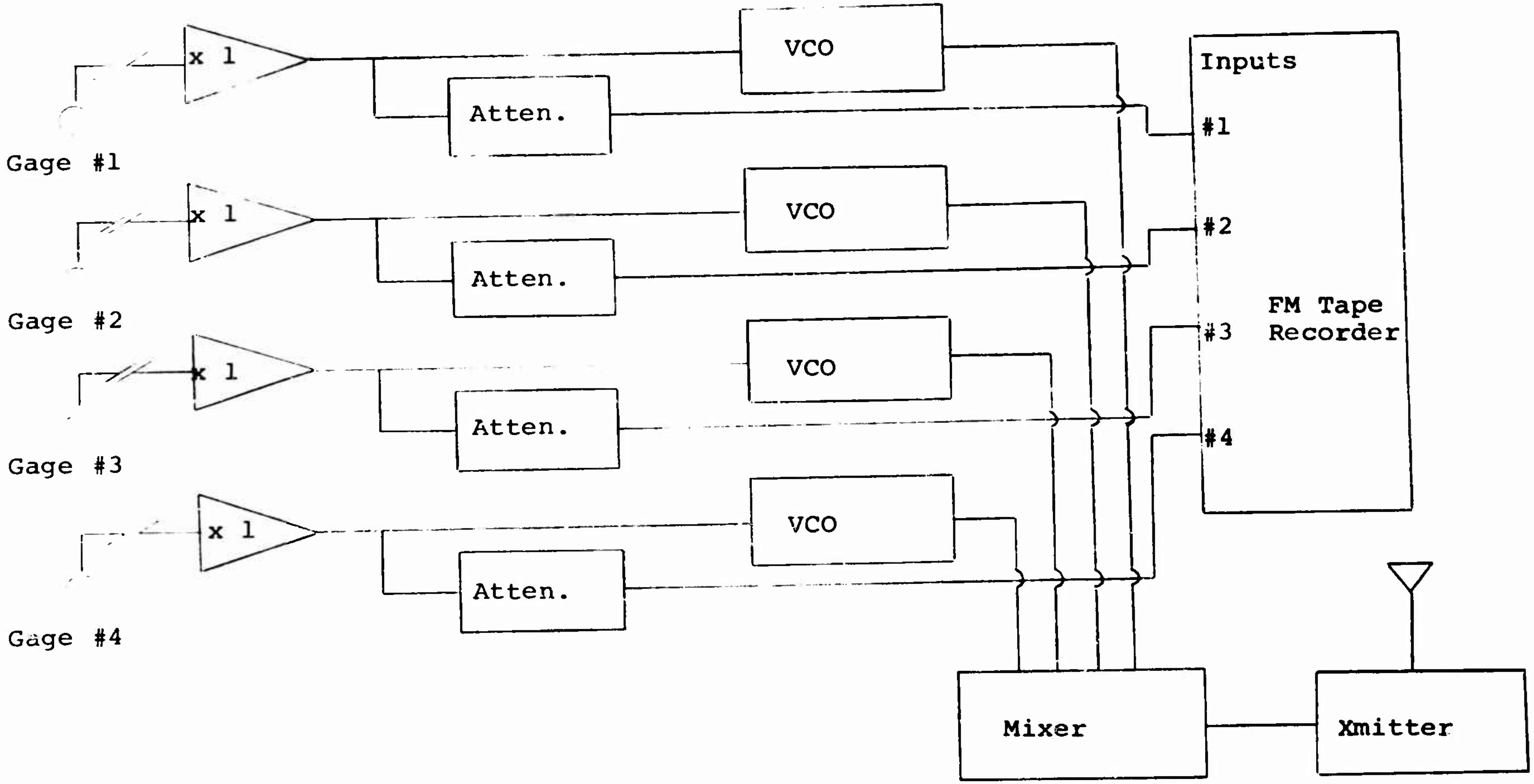


Figure (4.1) Block Diagram of Buoy Instrumentation

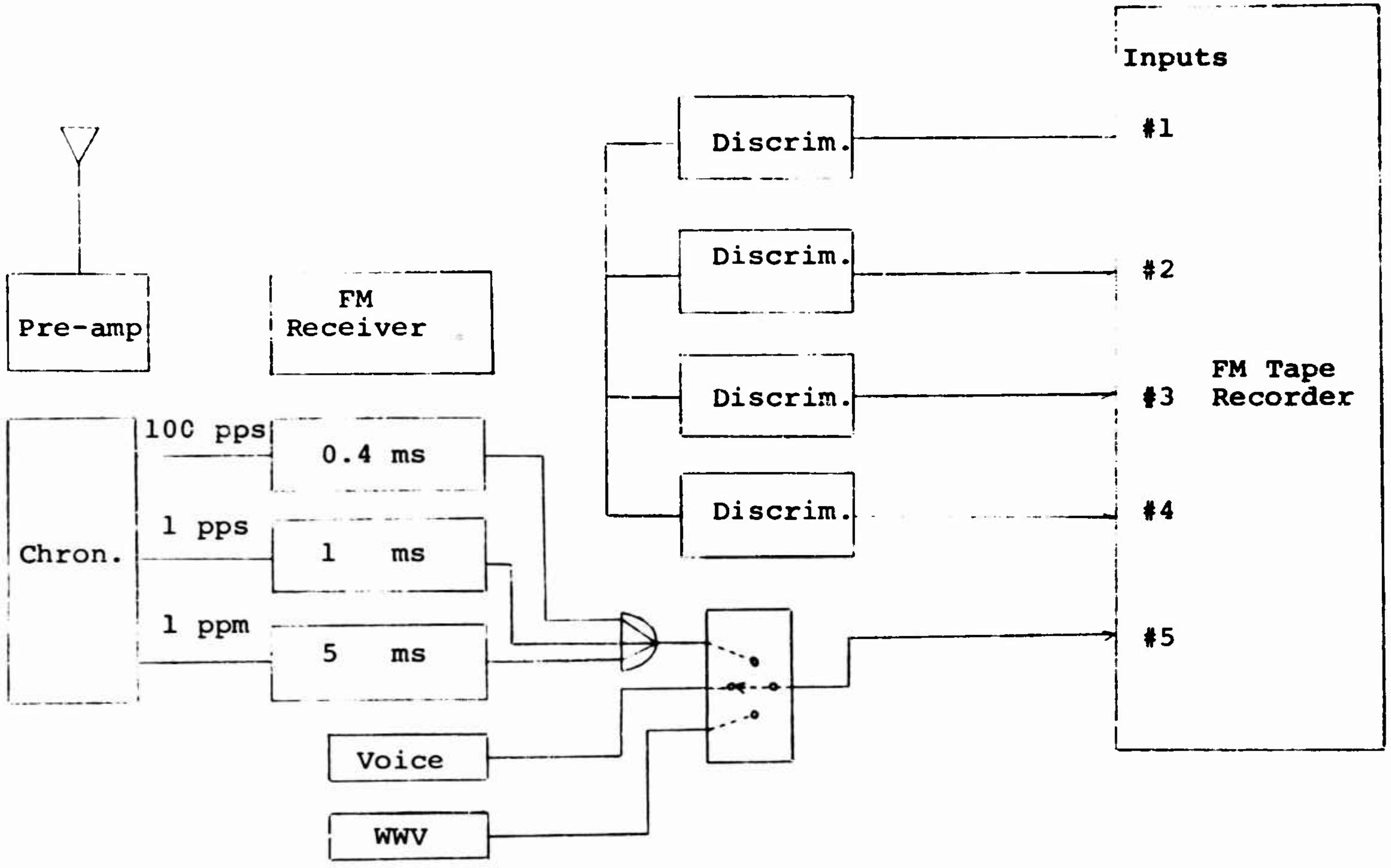


Figure (4.2) Block Diagram of Shore Based Instrumentation

Chapter V

5.1 Results

The firing program was conducted during the period 2-9 September 1966. Information relative to each shot, including the type of explosive, its weight, date, time of detonation, etc., is listed in Table 5.1.

The underwater shock parameters as recorded at the two close-in positions during each shot were tabulated according to type of explosive and are shown in Tables 5.2 through 5.5. Plots of the parameters, pressure, impulse, energy, duration and arrival times are shown in Figures 5.1 through 5.3. The P-t signals (wave forms) recorded at the positions were reproduced and are presented in the appendix.

A listing of the relative peak pressure levels for each shot is shown in Table 5.6. These levels were extracted from USI's telemetered deep gage data. The average relative peak pressure levels for each explosive type have been found to be in excellent agreement with those obtained by WES.

Relative pressure levels were also obtained from USI's local recording system. These are in substantial agreement with the telemetered data, and with the results obtained at other USI gage locations, and are omitted here to avoid unnecessary duplication.

TABLE 5.1 CHARGE INFORMATION

Shot No.	Type Explosive	Charge Depth	Water Depth	Date	Time of Detonation (Greenwich Mean)	Charge Weight
		ft	ft		±0.005	lbs
1	TNT	70	124	9-2-66	00:35:00.344	1997
2	Nitromethane	70	124	9-3-66	21:25:00.234	2000
3	Slurry	70	124	9-3-66	24:00:00.352	1875
4	Anoil	70	124	9-6-66	17:30:00.278	2000
5	TNT	70	124	9-6-66	20:00:00.572	1995
6	Anoil	70	124	9-6-66	22:05:01.106	2000
7	Nitromethane	70	124	9-6-66	24:00:00.729	2000
*8	Slurry	70	124	9-8-66	17:00:00	1875
9	TNT	70	124	9-8-66	18:40:00.328	1995
10	Slurry	70	124	9-8-66	20:30:00.684	1875
11	Nitromethane	70	124	9-9-66	16:00:00.574	2000
*12	Anoil	70	124	9-9-66	18:00:00	2000

*Partial detonation

Surface Zero Coordinates:

Latitude: 37° 57' 21.129"

Longitude: 119° 00' 25.124"

TABLE 5.2 UNDERWATER SHOCK PARAMETERS; TNT CHARGES

Gage Position x	Gage Position y	Shot No.	Peak Pressure	Reduced Positive Impulse	Reduced Energy	Reduced Positive Duration	Arrival Time	Average Velocity
feet	feet		psi	$lb\text{-}msec/in^2/lb^{1/3}$	$in\text{-}lb/in^2/lb^{1/3}$	$msec/lb^{1/3}$	msec	ft/sec
R_s = 72 feet, λ_s = 5.71:								
72	-70	1	3,300	1,200	210	1.99	13.36	5,400
		5	3,400	510	92	1.26	13.57	5,300
		5	2,500	370	56	1.24	13.53	5,300
Average			3,100 (3,000)[a]	690	120	1.50	13.49	5,300
R_s = 84 feet, λ_s = 6.67:								
72	-114	1	3,600	1,700	300	2.77	15.68	5,400
		1	3,200	1,100	190	1.81	15.61	5,400
		5	2,500	460	62	1.35	16.11	5,200
		5	2,300	470	57	1.65	16.10	5,200
Average			2,900 (2,500)	930	150	1.90	15.88	5,300
R_s = 85 feet, λ_s = 6.75:								
85	-70	9	2,800 (2,500)	820	120	1.37	15.95	5,300
R_s = 96 feet, λ_s = 7.62:								
85	-114	9	2,100 (2,200)	390	47	1.33	17.82	5,400
R_s = 103 feet, λ_s = 8.17:								
103	-70	1	1,900	320	39	1.03	20.64	5,000
		5	2,000	340	42	1.08	20.77	5,000
		9	2,300	350	45	1.08	20.51	5,000
Average			2,100 (2,000)	340	42	1.06	20.64	5,000

[a] Expected free-water values shown in parenthesis.

TABLE 5.3 UNDERWATER SHOCK PARAMETERS; NITROMETHANE CHARGES

Gage Position		Shot No.	Peak Pressure	Reduced Positive Impulse	Reduced Energy	Reduced Positive Duration	Arrival Time	Average Velocity
x	y							
feet	feet		psi	lb-msec/in^2/lb$^{1/3}$	in-lb/in^2/lb$^{1/3}$	msec/lb$^{1/3}$	msec	ft/sec
R_s = 72 feet, λ_s = 5.71:								
72	-70	2	3,100	620	88	1.36	14.40	5,000
		2	3,200	510	96	1.27	14.40	5,000
		7	4,100	530	120	1.35	14.75	4,900
		7	2.800	370	67	1.35	14.75	4,900
Average			3,300	510	93	1.33	14.58	5,000
R_s = 84 feet, λ_s = 6.67:								
72	-114	2	2,600	480	70	1.34	16.52	5,100
		2	2,600	480	72	1.35	16.51	5,100
Average			2.600	480	71	1.34	16.52	5,100
R_s = 85 feet, λ_s = 6.75:								
85	-70	11	3,100	390	70	1.17	17.16	5,000
R_s = 96 feet, λ_s = 7.62:								
85	-114	11	2,400	410	54	1.30	19.08	5,000
R_s = 103 feet, λ_s = 8.17:								
103	-70	2	2,100	360	46	1.01	21.68	4,800
		7	2,400	390	55	1.10	21.37	4,800
		11	2.600	350	50	1.06	21.42	4,800
Average			2,400	370	50	1.06	21.49	4,800

TABLE 5.[illegible] UNDERWATER SHOCK PARAMETERS; SLURRY CHARGES

Gage Position x	Gage Position y	Shot No.	Peak Pressure	Reduced Positive Impulse	Reduced Energy	Reduced Positive Duration	Arrival Time	Average Velocity
feet	feet		psi	$lb\text{-}msec/in^2/lb^{1/3}$	$in\text{-}lb/in^2/lb^{1/3}$	$msec/lb^{1/3}$	msec	ft/sec
R_s = 7[illegible] feet, λ_s = 5.71:								
[illegible]	-7[illegible]	3 5	2,7[illegible] 2,[illegible]	560 510	83 76	1.30 1.30	15.33 15.32	4,700 4,700
Average			[illegible]	540	80	1.30	15.32	4,700
R_s = [illegible] feet, λ_s [illegible] 6.67:								
7[illegible]	-114	3 5	2,200 2,200	530 510	62 63	1.48 1.38	17.89 17.83	4,700 4,700
Average			2,200	520	62	1.43	17.86	4,700
R_s = [illegible]5 feet, λ_s = 6.75:								
[illegible]5	-7[illegible]	10	2,200	310	37	1.17	18.25	4,700
R_s = [illegible] feet, λ_s = 7.62:								
[illegible]	-114	10	1,600	340	30	1.31	20.07	4,800
R_s = 1[illegible]3 feet, λ_s = [illegible].17:								
1[illegible]3	-7[illegible]	3 10	1,700 1,600	390 300	40 28	1.20 1.11	22.84 22.33	4,500 4,600
Average			1,600	340	34	1.16	22.58	4,600

TABLE 5.5 UNDERWATER SHOCK PARAMETERS; ANOIL CHARGES

Gage Position x	Gage Position y	Shot No.	Peak Pressure	Reduced Positive Impulse	Reduced Energy	Reduced Positive Duration	Arrival Time	Average Velocity
feet	feet		psi	$lb\text{-}msec/in^2/lb^{1/3}$	$in\text{-}lb/in^2/lb^{1/3}$	$msec/lb^{1/3}$	msec	ft/sec
R_s = 72 feet, λ_s = 5.71:								
72	-70	4	2,200	410	44	1.32	14.33	5,000
		4	1,700	280	25	1.31	14.37	5,000
		6	2,000	440	53	1.22	16.29	4,400
		6	1,600	330	34	1.22	16.31	4,400
Average			1,900	360	39	1.27	15.32	4,700
R_s = 84 feet, λ_s = 6.67:								
72	-114	4	1,700	350	28	1.34	16.93	5,000
		4	1,800	310	28	1.34	16.92	5,000
Average			1,800	330	28	1.34	16.92	5,000
R_s = 103 feet. λ_s = 8.17:								
103	-70	4	1,400	260	18	1.08	21.75	4,700
		6	1,400	290	27	0.99	23.19	4,400
Average			1,400	280	22	1.04	22.47	4,600

TABLE 5.6

RELATIVE PRESSURE LEVELS OBTAINED FROM USI's TELEMETERED DEEP GAGE DATA

Shot No.	Explosive Type	Pressure Level db, re: shot 5
1	TNT	-0.2
2	Nitromethane	-0.4
3	Slurry Mix	-1.4
4	Anoil	-5.2
5	TNT	0
6	Anoil	-1.9
7	Nitromethane	+1.0
8	Slurry Mix	-
9	TNT	+0.6
10	Slurry Mix	-1.9
11	Nitromethane	+0.8
12	Anoil	-

SUMMARY OF LEVELS

TNT:	-0.2, 0, +0.6	average = +0.1
Nitromethane:	-0.4, +1.0, +0.8	average = +0.5
Slurry Mix:	-1.4, -1.9	average = -1.6
Anoil:	-5.2, -1.9	average = -3.5

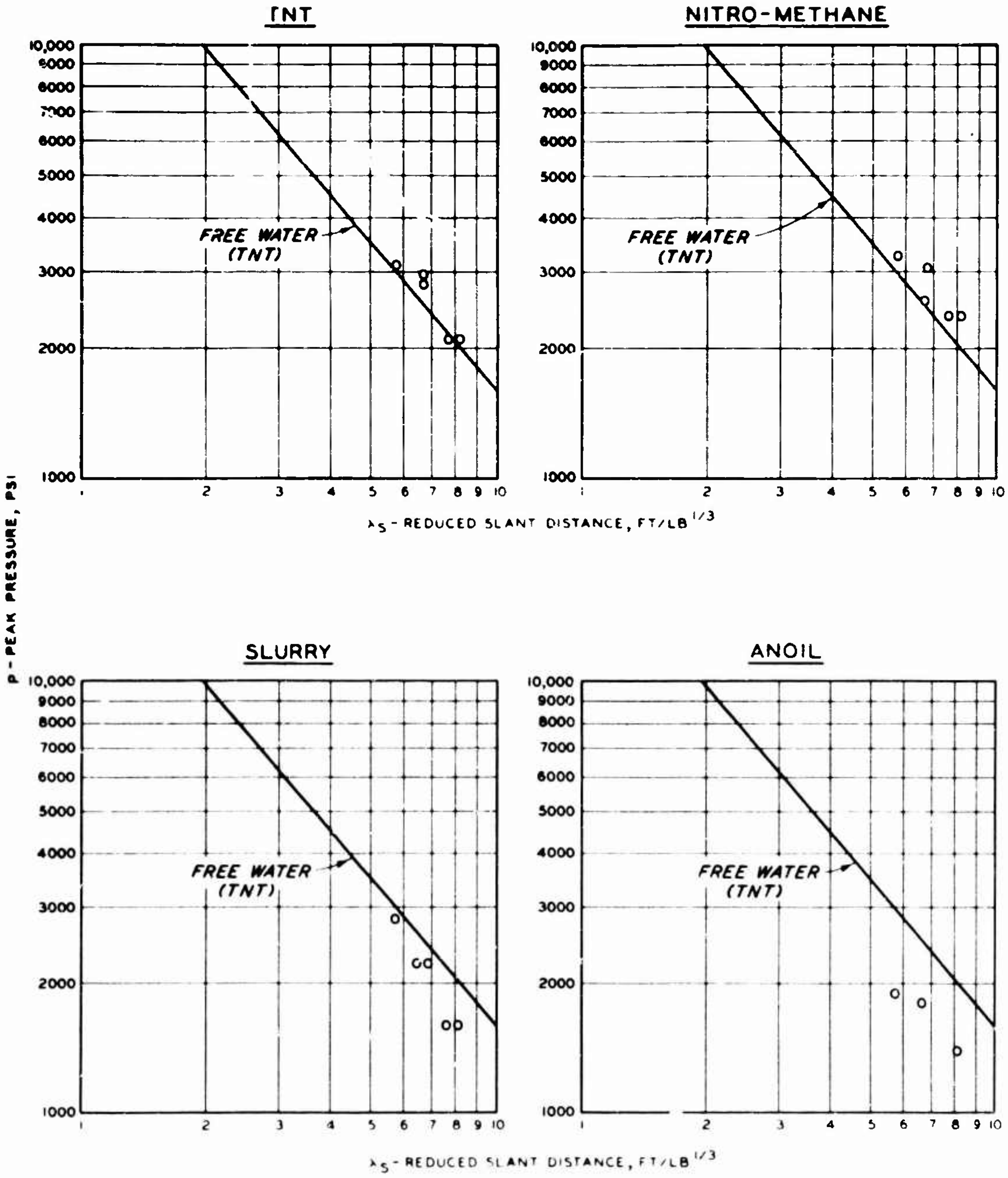


Figure 5.1 Pressure measurements from each explosive compared with the free-water TNT curve.

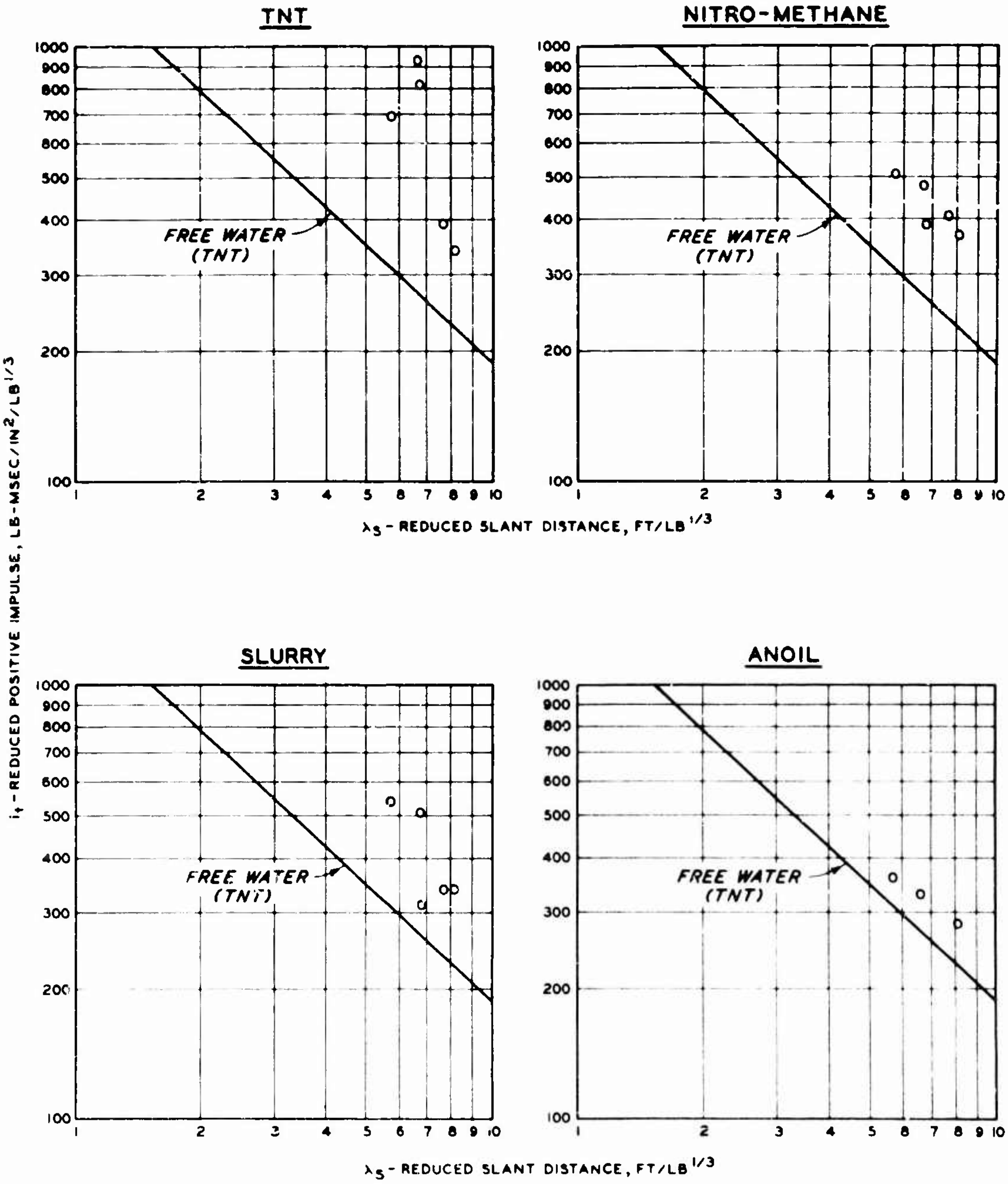


Figure 5.2 Positive impulse values compared with the free-water TNT curve.

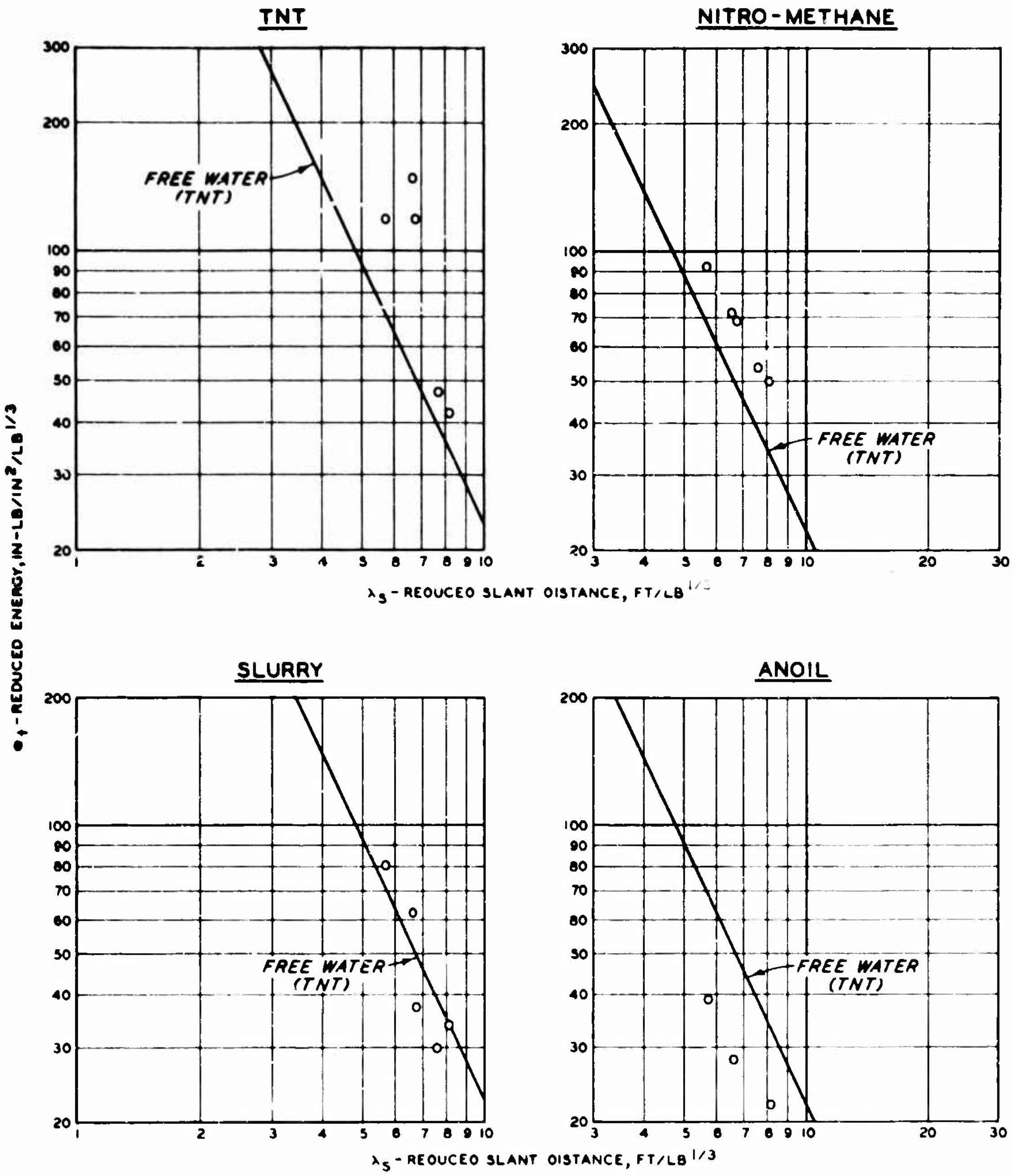


Figure 5.3 Energy-flux values compared with the free-water TNT curve.

Chapter VI Discussion of Results

6.1 Partial Detonations

Shot Nos. 8 (slurry) and 12 (anoil) were probably partial detonations. The booster explosive for each detonated in high order,but the parent material reacted passively.

The slurry charge, Shot No. 8, was positioned at the 70 ft depth and, due to operational circumstances, remained in place for more than 12 hours before detonation. At this depth the temperature is about 43°F; since the gums and resins are known to solidify at temperatures higher than this, it is believed that the prolonged exposure to the near-freezing temperature, adversely affected the explosive materials and resulted in its inert reaction.

Anoil is a mixture of ammonium nitrate (NH_4NO_3) and diesel fuel. Due to the availability of its contents and the ease of preparation, it is sometimes called the "homemade explosive."

Anoil is very susceptible to moisture,and experience has shown that the ammonium nitrate prills can break down during moderate temperature changes (>90°F). Though it would not be directly affected by exposure to near-freezing temperatures, any water in the anoil mix could cause an incomplete detonation. When used during these tests, it is conceivable that one or more of the drums leaked due to the rather high hydrostatic pressure ($\approx$30 psi), but it is highly improbable that all four experienced leakage during any one test. No valid explanation is available for the partial detonation of Shot No. 12.

6.2 Evaluation of Pressure-Time Results

In analyzing the water shock results listed in Tables 5.2 through 5.5 and plotted in Figures 5.1 through 5.3, only comparisons for TNT should be made, since controlled experiments involving the other explosives have not been conducted. In addition, the paucity of data limits detailed analysis, but comparisons with TNT results (free water) are shown.

Figure 5.1 shows peak pressure measurements from the different explosives compared with free-water results, and indicates that TNT agrees closely with predictions. Nitromethane appears to yield slightly higher pressure values than TNT. The slurry and anoil mixes result in lower pressures than TNT shots in free-water. The detonation velocity of TNT and NM are approximately equal, 21,000 and 20,500 ft/sec, respectively, while anoil has a value of 11,200 ft/sec. A detonation velocity for the slurry was not immediately available, but probably lies in a range of 11,000 to 13,000 ft/sec.

The impulse and energy values (Figures 5.2 and 5.3) are higher than free-water results. However, this is expected, since integrations were not stopped at 6.7 θ, the normal stopping point for free-water records. Here, θ is the time required for the shock wave pressure to decay to a value of ρ_m/e (ρ_m is the peak pressure). For the tests reported herein, the integrations were carried for the full duration of each shock; i.e., until the pressure curve went negative. Except for the closest gages, channels 1 and 2 of the Appendix, the time at which the signal goes negative corresponds quite closely with the computed arrival for the surface reflection. Thus, it is likely that the integration time was controlled, in part, by the arrival of the surface reflection. In addition, bottom reflections would increase the impulse and energy values.

6.3 Likelihood of a Bubble Pulse

The maximum bubble radius generated by a one ton TNT charge at a 70 foot depth was previously given as 34 feet. The vertical migration of the bubble due to its buoyancy is about 35 feet. The net effect of the migration is twofold: (1) To decrease the hydrostatic pressure surrounding the bubble so that its minimum is not much smaller than its maximum and (2) The bubble is very close to the surface and its migration will be strongly affected by the boundary. These two parameters point to a low peak amplitude bubble pulse,if it exists, and points out the possibility for non-existence.

From the geometry and charge size involved,Ref. (8) implies that a bubble pulse should occur approximately 1.2 sec. after detonation. The magnetic tape recorded was run more than 5 seconds after the arrival of the shock wave, but a thorough examination of the entire record does not indicate a bubble pulse. If the pulse is present,it is very weak and undiscernible.

Two test shots of 300 lb of TNT were detonated before the actual test began to make certain that all equipment was operational. The pressure time curves for these shots indicate a weak bubble pulse. Thus, the large charge size and shallow detonation depth precluded significant bubble pulse amplitudes, if at all present for the one ton charges.

6.4 Bottom Reflection

Reflected pressure waves of varying amplitudes were recorded during these tests, but in many cases their existence was not obvious; in most instances it was determined by means of arrival and travel times,which were based on test geometry. The amplitude of the reflection varies with the different explosives,and the weak signals (see the pressure-time traces reproduced in the Appendix) lead to the conclusion that the ρc (density-velocity) quantity for the bottom material is only slightly greater than that of water.

Chapter VII Conclusions and Recommendations

It should be recognized that the limited amount of data obtained during these tests precludes other than cursory observations concerning the underwater explosion characteristics of the material involved.

Completely reliable information describing the behavior of TNT under similar circumstances is readily available,and, where practicable, the performance of the other explosives used in this study has been compared with TNT.

In these experiments, the performance of TNT and nitromethane appears comparable when the pressure, impulse, and energy values are examined. Correspondingly, the slurry and anoil results closely resemble one another, but they are obviously less effective as generators of the various underwater shock parameters (Figures 5.1 through 5.3).

The experimental results indicate that nitromethane would be a suitable substitute for TNT should a liquid explosive be needed or required in underwater effects programs and/or experiments.

The test provided measurements of the seismic wave amplitude from the shock wave only, since the bubble pulse was very weak or non-existent. Hence, in the evaluation of these explosives for use as a source, if a few db change in source level becomes important, then the bubble pulse contribution from each explosive needs to be evaluated.

APPENDIX

Figures A1 through A8 present the pressure-time output signals as recorded from the 5 WES gages during each shot. The traces are arranged according to type of explosive, and represent, in graphic form, the values listed in Tables 5.2 through 5.5.

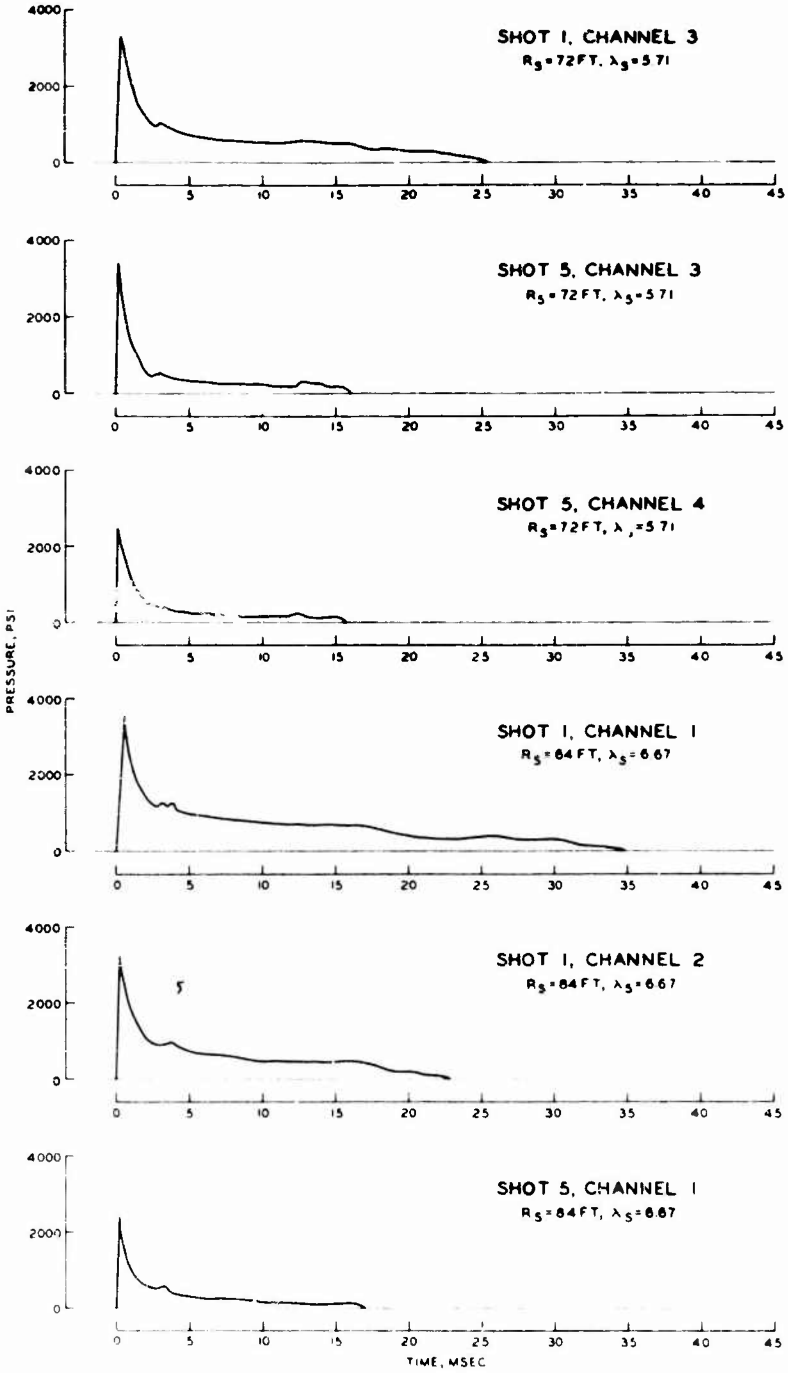


Figure A1 Pressure-time traces for values listed in Table 5.2.

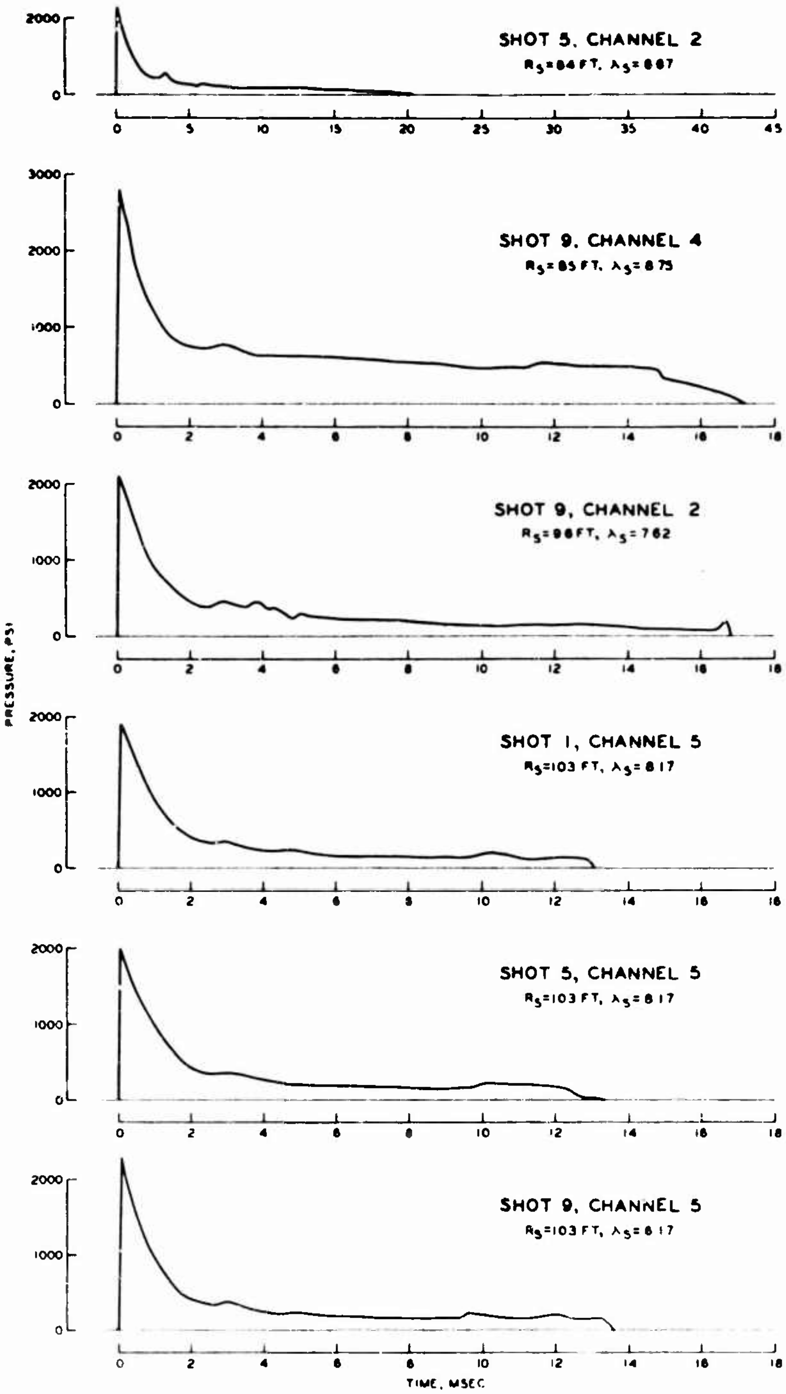


Figure A2 Pressure-time traces for values listed in Table 5.2.

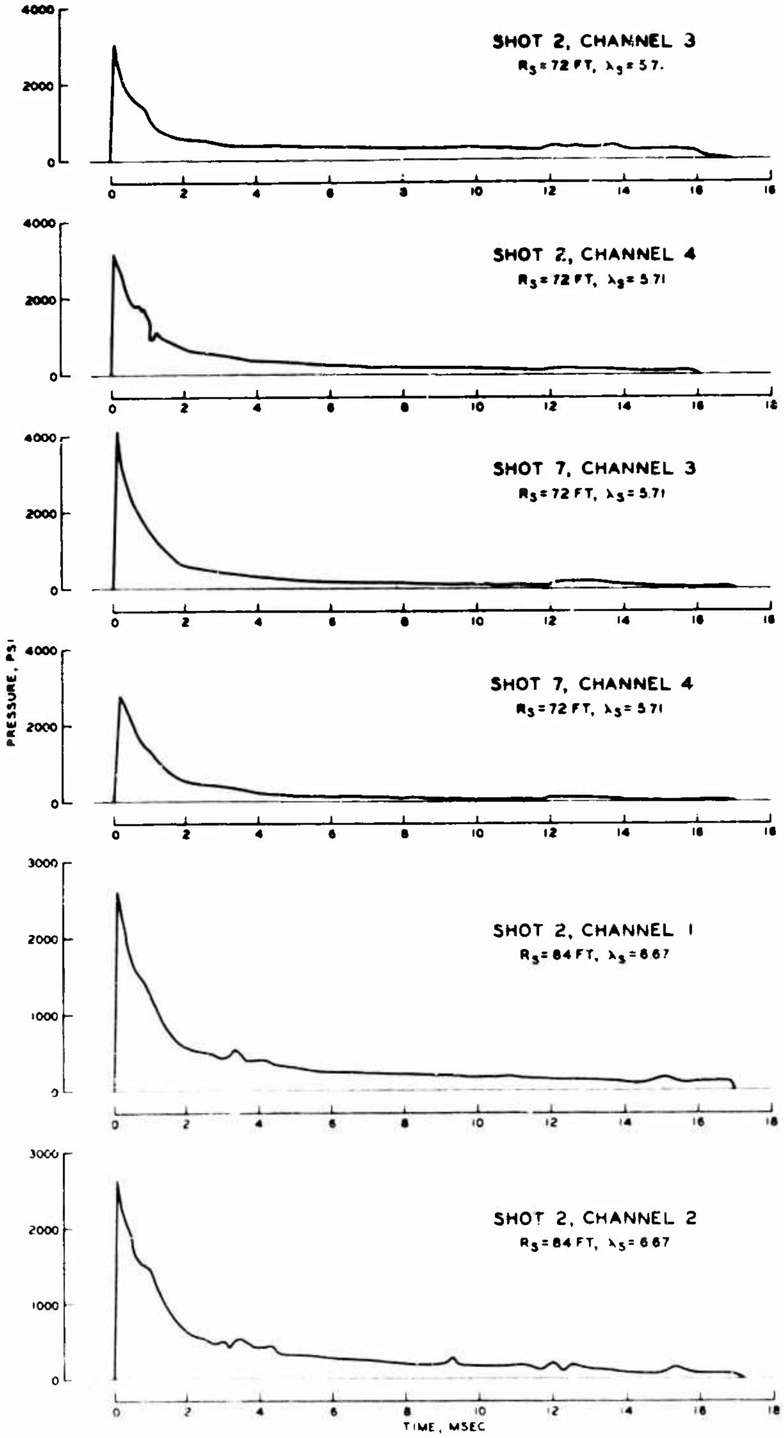


Figure A[illegible] Pressure-time traces for values listed in Table [illegible].3.

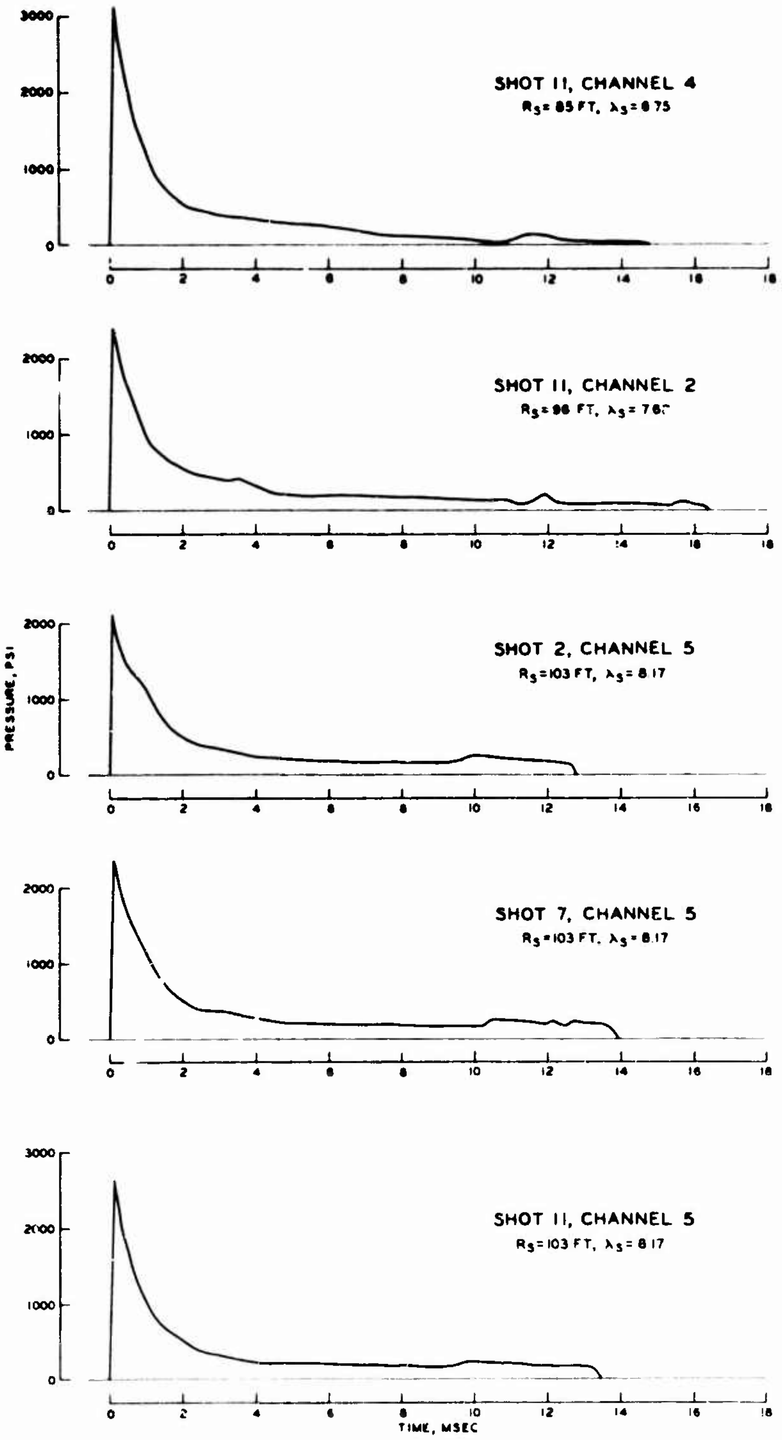


Figure A4 Pressure-time traces for values listed in Table 5.3.

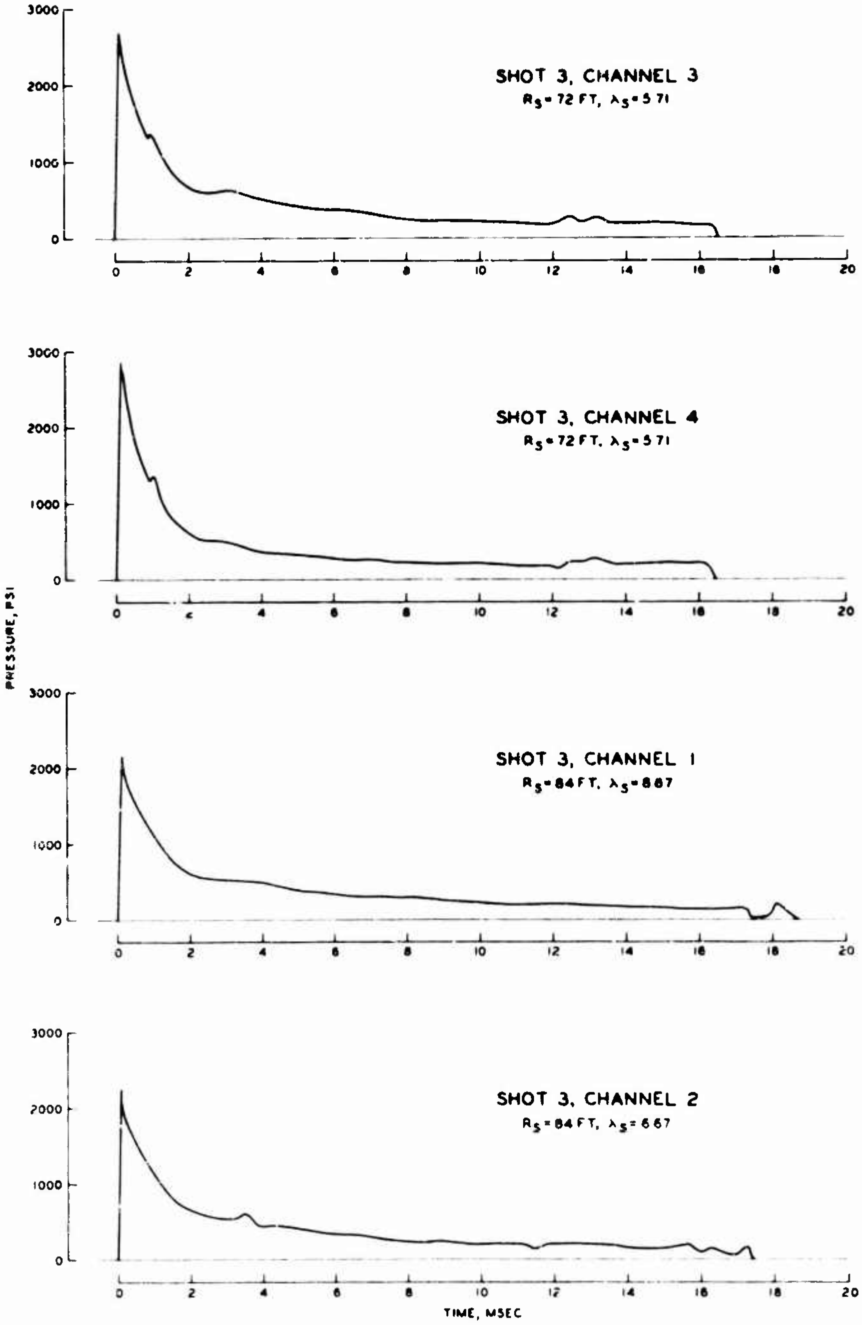


Figure A5 Pressure-time for values listed in Table 5.4.

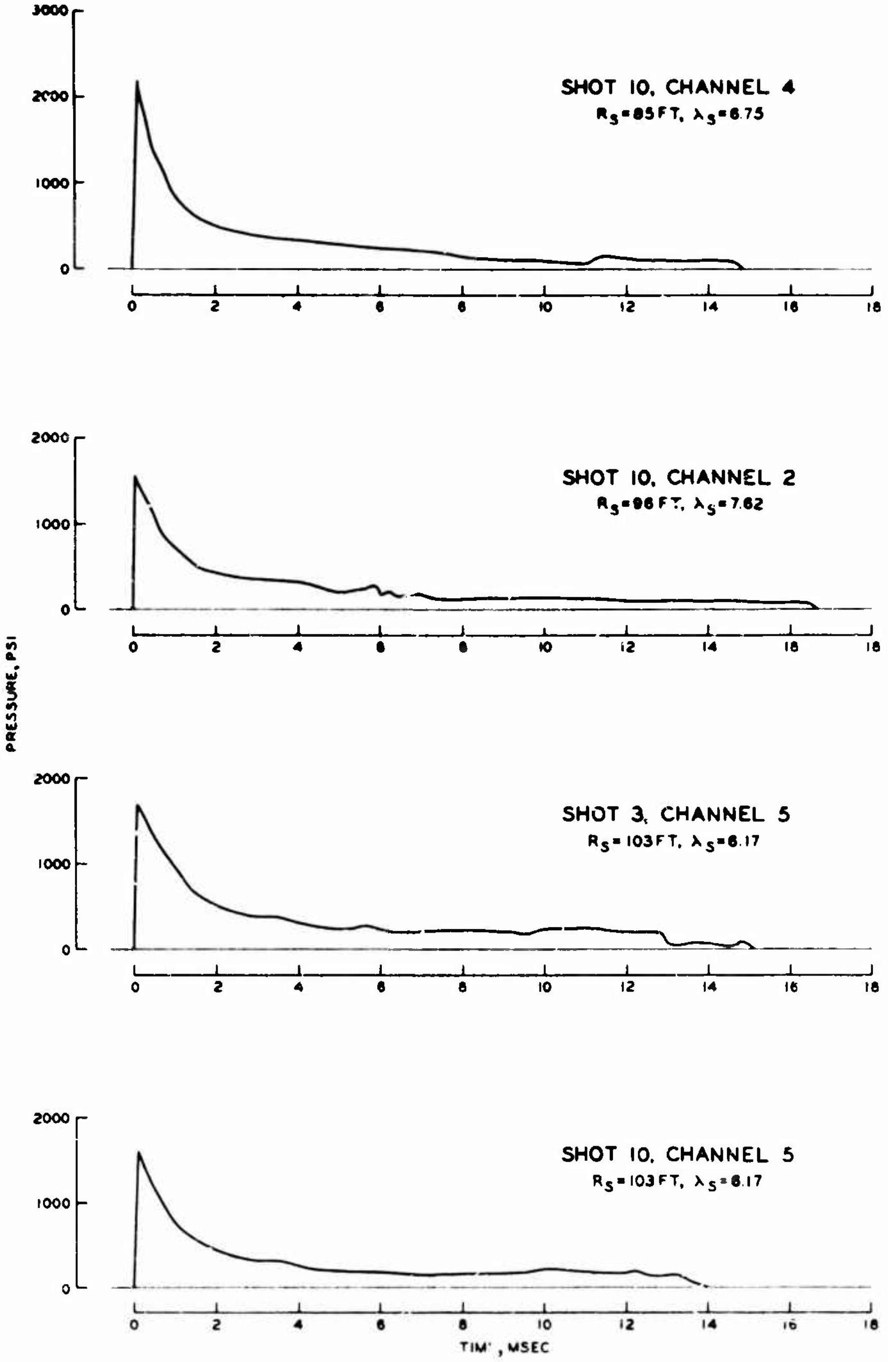


Figure A6 Pressure-time traces for values listed in Table 5.4.

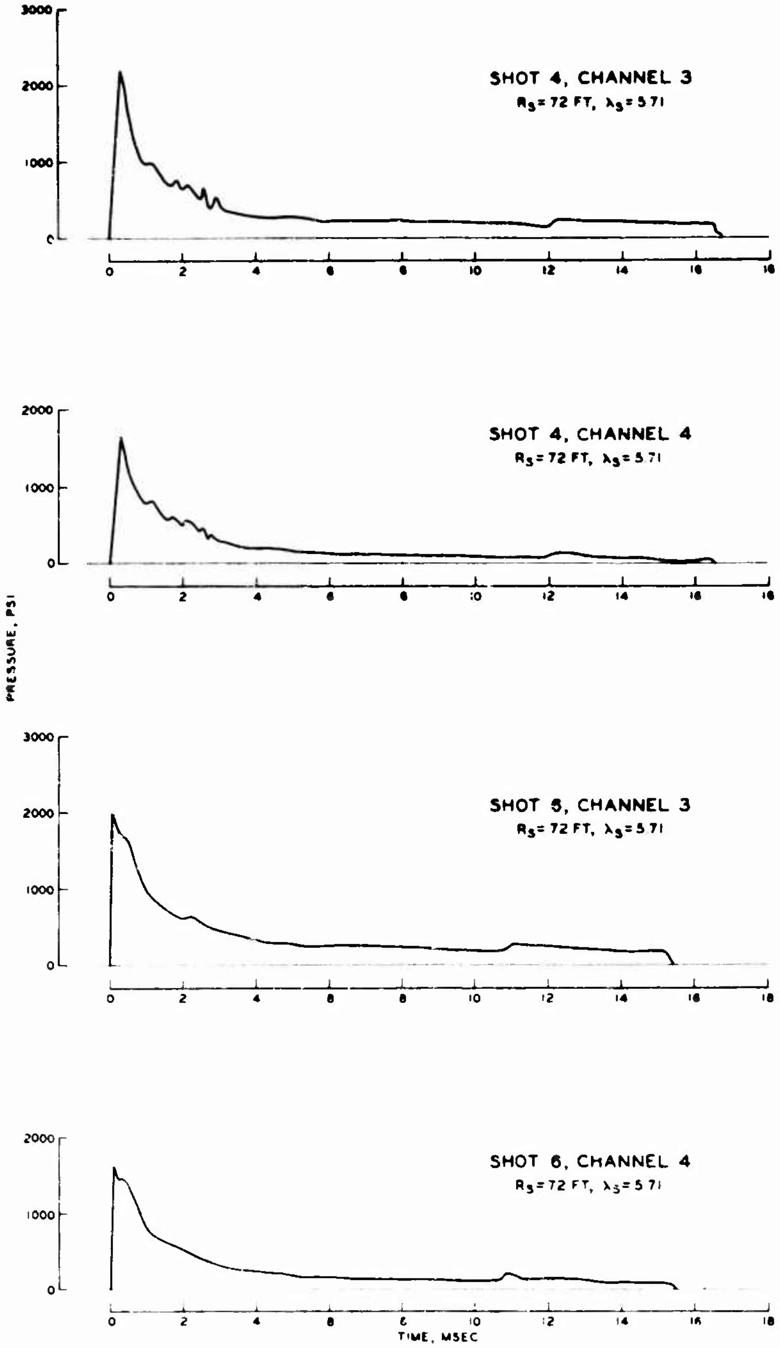


Figure A7 Pressure-time traces for values listed in Table 5.5.

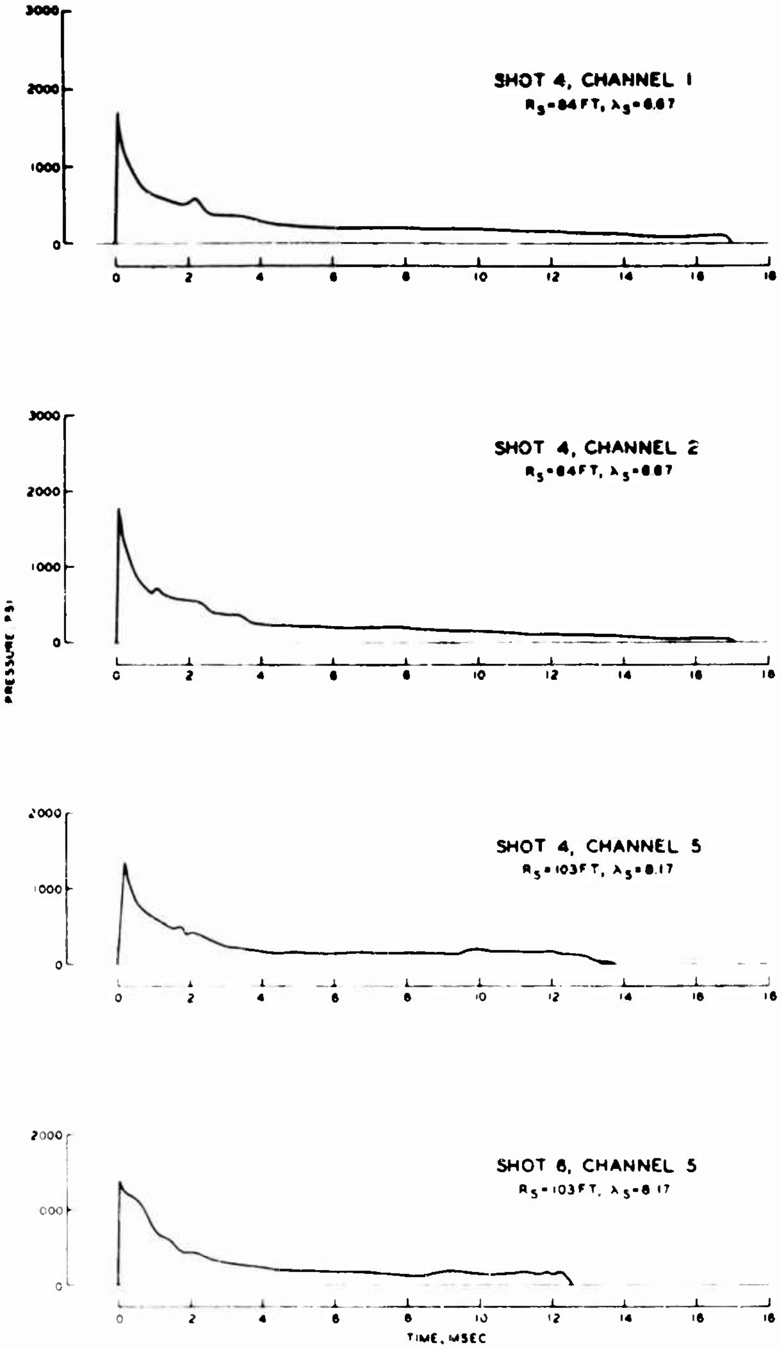


Figure A8 Pressure-time traces for values listed in Table 5.5.

REFERENCES

1. Roller, John C. A Comparison of Seismic Waves Generated by Four Different Types of Explosives. Technical Letter #47, U. S. Department of the Interior, Geological Survey, Nov. 1, 1966.

2. Partridge, D. S. Private communication. Gulf Oil Corp., Kansas City, Mo.

3. ——————— Properties of Explosives of Military Interest. Army Materiel Common Pamphlet, 706-777, August, 1963.

4. Weston, D. E. Underwater Explosions as Acoustic Sources. Proc. Phys. Soc. (London), 76, 223-249, 1960.

5. Bryant, A. R. The Behavior of an Underwater Explosion Bubble. Underwater Explosion Research II, ONR 1950.

6. Snay, H. G. Underwater Explosion Phenomena: The Parameters of Migrating Bubbles. NOL Report 4185, October 12, 1962.

7. Cole, R. H. Underwater Explosives. Princeton University Press, 1948.

8. Christian, Ermine A. and Fisher, Edward M. Explosion Effects Data Sheets. Navord Report #2986, U. S. Naval Ordnance Laboratory, White Oak, Maryland, June 16, 1955. Confidential.

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Four different chemical explosives were detonated at a depth of 70 feet in Mono Lake, California for the purpose of comparing their efficiency in generating seismic signals. The hydroacoustic shock waves were examined to determine source levels, for comparison with received seismic signal levels. Excellent agreement between hydroacoustic and seismic signal levels were observed.

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