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SEP 76 J B GASPIN, M L WILEY, G B PETERS

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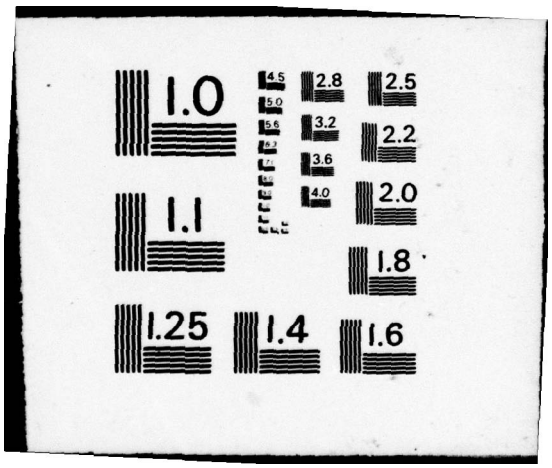
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NSWC TECHNICAL REPORT

WHITE OAK LABORATORY

EXPERIMENTAL INVESTIGATIONS OF THE EFFECTS OF UNDERWATER EXPLOSIONS ON SWIMBLADDER FISH, II: 1975 CHESAPEAKE BAY TESTS

21 SEPTEMBER 1976

NAVAL SURFACE WEAPONS CENTER
WHITE OAK LABORATORY
SILVER SPRING, MARYLAND 20910

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The experiment described in this report was designed to validate a theory of damage by underwater explosions to swimbladder fish. The theory is based on the dynamics of the swimbladder under the influence of an underwater explosion shock wave. Caged fish of twelve different species were paced in the vicinity of explosions. The pressure-time history at each fish location was recorded, and the damage to each fish specimen was determined by dissection.

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Pentolite charges weighing 0.6 and 32 Kg were detonated at depths of 3.0 and 9.1 meters. Fish were arrayed to depths of up to 30 meters. Six shots were fired. This report describes the experiment and presents the fish damage and pressure-time data. Laboratory work to determine the time necessary for fish to acclimate to various depths in the water column is summarized. The analysis of this data in terms of theory will be presented separately.

NSWC/WOL/TR 76-61 21 September 1976

EXPERIMENTAL INVESTIGATIONS OF THE EFFECTS OF UNDERWATER EXPLOSIONS ON SWIMBLADDER FISH, II: 1975 CHESAPEAKE BAY TESTS

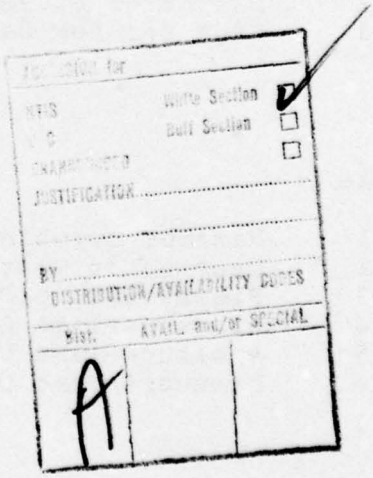
The Navy is required to consider the possible adverse environmental effects of its research operations. When such operations involve the detonation of underwater explosions, one of the environmental factors to be evaluated is the effect of these explosions on nearby marine life. Up to the present time, the state of knowledge has not been adequate to realistically predict such effects.

The experiment which is the subject of this report, is part of a continuing study of the effects of underwater explosions on swimbladder fish. This class of fish is particularly vulnerable to explosions, and includes the majority of fish with sports and commercial value. This study will result in an improved capability to predict such effects, and will be useful in connection with a variety of Naval research operations.

This study is part of the pollution abatement program of the Naval Sea Systems Command and was supported by Task SEA SSL55/19373, "Environmental Effects of Explosive Testing".

Julius W. Enig

JULIUS W. ENIG
By direction



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INTRODUCTION

As part of a continuing study, a series of experimental tests was conducted in the Spring of 1975 to investigate the effect of underwater explosions on fish. The tests were done by the Naval Surface Weapons Center in association with the Chesapeake Biological Laboratory of the University of Maryland. The approach of the program was to detonate charges in the vicinity of caged fish specimens. The pressure time history at each fish location was recorded, and each fish specimen was dissected and damage to it assessed in terms of specific criteria. This report will document the experimental program and present the data. The data analysis will be reported separately.[1]

BACKGROUND

Prior to 1973, there were a number of experiments performed to study the effects of underwater explosions on marine organisms. A summary of the implications of this work is given by Christian[2] and an extensive bibliography was compiled by Simenstad.[3] The data from these experiments are of limited usefulness due to several factors. The documentation of the experimental arrangements makes reconstruction of the shot geometries impossible in many cases. The pressure recording is generally inadequate or non-existent. In addition, many of the tests used non-standard explosive configurations, such as charges buried in the bottom, so that calculation of the pressures is prohibitively difficult. Two main pieces of information are provided by this early work. First swimbladder fish are far more vulnerable than those lacking swimbladders. Second, negative pressures (relative to ambient) are an important factor in swimbladder fish damage.

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1. Goertner, J. F., "Dynamical Model for Explosion Injury to Fish" NSWC/WOL/TR in preparation
2. Christian, E. A., 1973, "The Effects of Underwater Explosions on Swimbladder Fish," NOL Technical Report NOLTR 73-103.
3. Simenstad, Charles A., 1974, "Biological Effects of Underground Nuclear Testing on Marine Organisms. I. Review of Documented Shock Effects, Discussion of Mechanisms of Damage, and Predictions of Amchitka Test Effect." In "Proceedings of the First Conference on the Environmental Effects of Explosives and Explosions," compiled by George A. Young, Naval Ordnance Laboratory Report NOLTR 73-223, 12 February 1974.

In 1973, this Center conducted an experimental program[4] to gather data needed to validate a preliminary theory of swimbladder fish damage. The theory postulated that the zone in which most fish damage occurred could be equated to the region of bulk cavitation. The data showed that this theory was an oversimplified view of the situation, and its predictions were inaccurate. The data gathered in this program provided a high quality set of pressure measurements with corresponding fish damage evaluations, to be used as the basis for a second theoretical analysis of the problem. The fundamental limitations of this set of data are that only two species, spot (Leiostomus xanthurus) and white perch (Morone americana), were used, and that good data were limited to fish shallower than about 6.1 meters (20 feet). At greater depths, there was not enough dissolved oxygen to support fish life, due to local, seasonal conditions. Although some specimens were placed at depths down to 12.2 meters (40 feet), their condition at shot time was uncertain. The value of these deeper data is, therefore, open to question.

An additional set of data was gathered by the Lovelace Foundation in 1975.[5] Pressure-time and fish mortality data were gathered for 0.45 Kg (1 lb) charges in a shallow test pond. The majority of the data were obtained with the charge at a depth of 3 meters (10 feet) and the fish at a depth of 0.3 meters (1 ft). In all cases the fish were no more than 3 meters deep. For this set of shallow data, shock wave impulse was shown to be the explosive parameter which correlates with fish mortality. The impulse required for various levels of mortality was shown to increase linearly with the mass of the fish. These conclusions, while valid for the very shallow test conditions of reference 5, are not valid for conditions where either the charge or the fish is deeper than 3 meters. This is demonstrated in reference 4, as well as by the data of the present report. In some situations, where the charge and fish are both shallow, the Lovelace results may be useful for predicting the fish kill from explosive operations.

We have been concerned, however, with obtaining a more general method of predicting fish damage. Goertner[1] has developed a theory of swimbladder fish mortality based on the dynamics of the swimbladder. The bladder is modeled as a spherical air bubble, and its motion under the influence of an explosion pressure wave is calculated. The fish damage is related to the parameters of the calculated motion. This calculation implies that for a given fish size, there is a strong variation of damage with depth at a given horizontal stand-off from an explosion. As the available data were for shallow fish, an experimental program to gather deeper data to validate this calculation was performed.

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4. Gaspin, Joel B., "Experimental Investigations of the Effects of Underwater Explosions on Swimbladder Fish, I: 1973 Chesapeake Bay Tests," NSWC/WOL/TR 75-58, 20 June 1975.
5. Yelverton, J. T., et al, "The Relationship Between Fish Size and Their Response to Underwater Blast," Lovelace Foundation, DNA Report 3677T, 18 June 1975.

In addition, a limited amount of data on the effects of explosions on blue crabs, oysters and other invertebrates in shallow water was obtained. This data is presented in Appendix A.

EXPERIMENTAL PROCEDURES

Test Site

The explosion tests were performed in May and June of 1975. The test site was the deepest part of the Chesapeake Bay, where the water depth is ∿46 meters (150 feet). This site was chosen in order to minimize perturbations due to reflections of the explosion pressure waves from the bottom. All explosive test operations were conducted from the deck of a self powered barge.

Rigging

Based on the significant variation in predicted mortality with depth, for a given size of fish and horizontal standoff, the field tests were configured with a vertical string of caged fish at a single horizontal range from the charge on each shot. With this arrangement, fish specimens could be arrayed at any desired depth from 1.5 to 30.5 meters (5 to 100 feet). Fish specimens, along with pressure gages, were placed at up to ten depths in this interval. The depths were selected on the basis of predicted mortality for each species and size class.

The fish cages were similar to those used in our 1973 tests.[4] They were roughly semi-circular right cylinders constructed of plastic mesh over a framework of thin steel rods. The cages had an access door at one end to allow for loading the specimens. The cages were roughly 0.5 meters (20 inches) long and 0.3 meters (12 inches) in diameter. At each depth station, three to five fish cages were attached to a supporting-frame of thin steel rods along with a piezo-electric (PE) gage. All the stations were placed in a vertical array by attaching them to two parallel vertical steel cables with heavy weights at the bottoms. A sketch of the experimental array is shown in Figure 1.

Biological Specimens

Twelve species of fish were used in the deep water explosion tests. They were white perch (Morone americana), spot (Leiostomus xanthurus), croaker (Micropogon undulatus), oyster toadfish (Opsanus tau), white catfish (Ictalurus catus), hogchoker (Trinectes maculatus), striped killifish (Fundulus majalis), mummichog (Fundulus heteroclitus), sheepshead minnow (Cyprinodon variegatus), Atlantic menhaden (Brevoortia tyrannus), blueback herring (Alosa aestivalis), and bluefish (Pomatomus saltatrix). All test organisms were collected from the Patuxent River and the Chesapeake Bay in the vicinity of Solomons, Maryland. Because of limited holding facilites, only dead bluefish were used in the explosion tests; all other specimens were used alive.

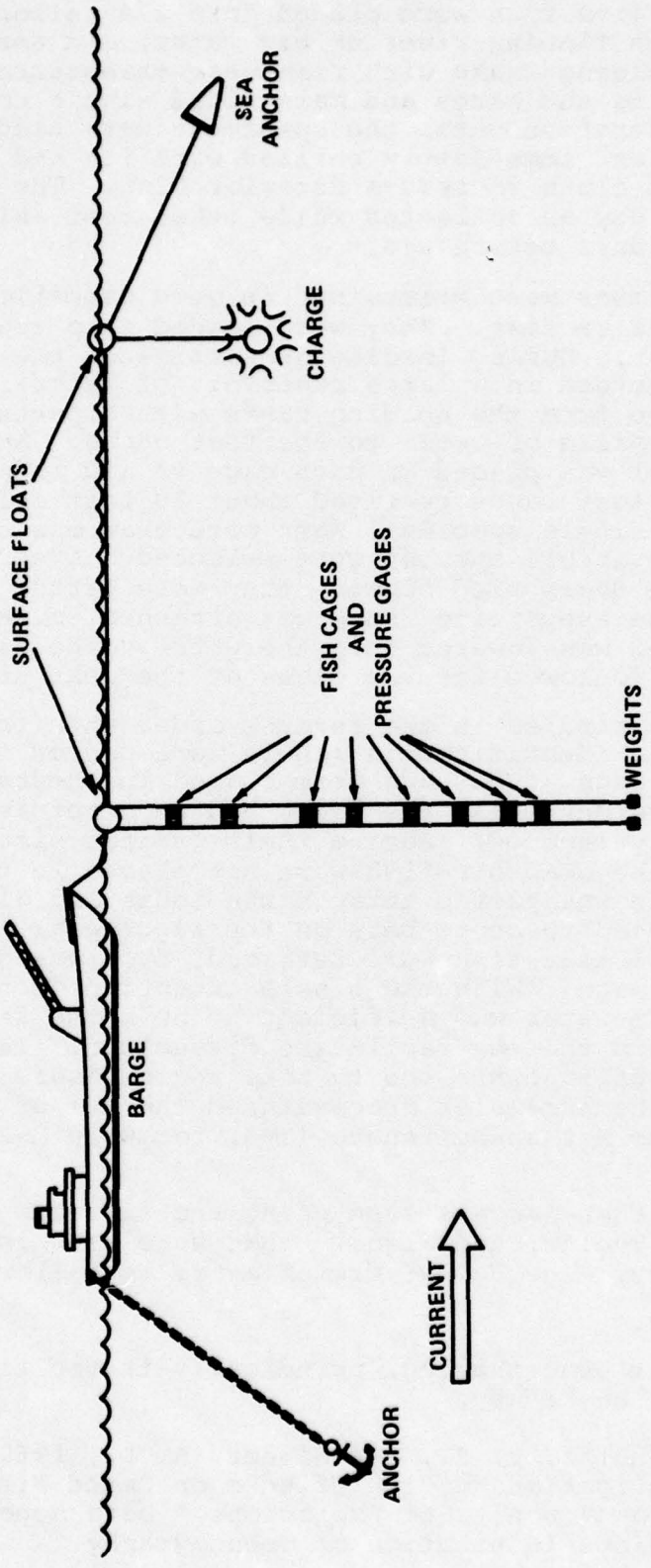

FIG. 1 EXPERIMENTAL ARRAY

Upon capture, live fish were placed into 275 gallon holding tanks, supplied with flowing river or bay water, and aerated with compressed air. Holding tanks with fish were transferred from the collecting vessels to the barge and maintained with a continuous flow of water and aeration until the specimens were used. Bluefish were obtained live and immediately chilled with ice and covered with wet papers and cloth to reduce deterioration. The bluefish were used the same day as collected while other test animals were often held several days before use.

The live specimens were maintained in good condition until needed for an explosive test. They were loaded into test cages as needed for each shot. During loading of specimens, the cages were held partially submerged in a large reservoir of water. Test animals were removed from the holding tanks with dipnets and transferred within pails of water to the test cages. An identification label was placed in each cage to aid in processing the results. Most test cages received about 10 test animals, normally of only a single species. When more than one species was held in a cage, compatible species were selected. After the cages were loaded and the doors tied closed, they were lifted out of the water reservoir, the supporting frame was attached to the test rigging, the rigging was lowered into the water. The same procedure was then followed for the cages at the next station.

The cages were handled in the reverse order when they were retrieved. Fish and identification labels were poured from the cages into plastic bags. The bags were placed in chests of ice-water and held there until all the cages had been retrieved and the test fish similarily removed. Due to their greater size and their biological state, the dead bluefish were not placed in test cages. Instead, marlin line was passed through the mouth and gills and each specimen was tied to cross-bars on the rigging at the desired stations. After all test fish were retrived, each was dissected and examined for damage. With the single exception of toadfish, the chill of the ice-water was sufficient to numb the fish into an immobile state and thereby facilitate dissection. The greater resistance that toadfish exhibited to both the exposure to the explosions and to the ice-water necessitated the use of an anesthetic, Tricaine Methanesulfonate (TMS, formerly MS222), with this species.

The damage to fish was assessed using the same numerical criteria of Hubbs, Shultz, and Wisner[6] that were used in the 1973 explosion study. The damage criteria are as follows:

(0) No damage.

(1) Only light hemorrhaging, principally in the tissues covering the kidney.

6. Hubbs, C. L., Shultz, E. P., and Wisner, R. L., 1960, "Preliminary Report on Investigations of the Effects on Caged Fishes of Underwater Nitro-carbonitrate Explosions," Data Report, U. of California, Scripps Institution of Oceanography.

(2) Gasbladder intact, but with light hemorrhaging throughout the body cavity, with some damage to the kidney.

(3) No external indication of damage but with the gasbladder usually burst. Hemorrhaging and organ disruption less extreme than in (4) and (5) but with gross damage to the kidney.

(4) Incomplete break-through the body wall but with bleeding about the anus. The gasbladder is almost invariably broken and the other organs damaged as noted under (5).

(5) Rupture of the body cavity. The break is usually a slit just to the side of the midventral line. Associated with this severe damage is a burst gasbladder and gross damage to other internal organs. The abdominal contents are often completely lost or homogenized.

Control organisms were used during all field test and during all holding periods within the laboratory. Cages containing control animals were placed overboard prior to any of the cages containing test animals. The controls were held at the maximum, minimum, and occasionally the median depths that were used as stations in the explosion tests. Control cages were retrieved just prior to the detonation of each explosive charge and handling of these organisms was the same as that used with the test animals. A vertical profile of temperature and salinity was recorded before each explosion test. By analysis of this water column profile and the survival of the control animals, the depth of the thermocline and the adequacy of the dissolved oxygen concentration was indicated for each test. Only during the last deep-water explosion test was the oxygen concentration depressed to a lethal level at some test stations.

Explosive Charges

The explosive charges used in the series were cylindrical cast pentolite charges, manufactured at the Naval Surface Weapons Center. The nominal charge weights were 32.2 kg (71 lbs) and 0.57 Kg (1.25 lb). The charges were centrally initiated by electric detonators.

Instrumentation

The pressure gages and recording instrumentation were similar to those used in our 1973 tests, and described in reference 4. Briefly, the gages were 1.9 cm (3/4-inch) PE gages made at the Naval Surface Weapons Center and sealed in an oil filled plastic boot. The recording instrumentation consisted of five dual-beam oscilloscopes and a fourteen channel FM tape recorder. The scopes were used to record the shock wave through the time of surface reflection arrival for each pressuregage. The tape recorder, an Ampex FR1300, provided thirteen channels for pressure data and one channel for a time code. On four channels, the outputs from four of the gages were recorded at a gain setting low enough so

that the peak overpressure was faithfully recorded. Nine channels were set so the peak pressure overloaded the tape recorder. This high gain setting allowed the details of the secondary pressure phenomena, such as cavitation, and surface and bottom reflections to be accurately measured. In some cases, these secondary pressures are believed to be important in fish damage The nominal frequency response of the tape recorder when run at 1.524 meters/sec (60 ips) is 0-20 KHz. The response of the scopes is 0-300 KHz, allowing the peak pressure to be resolved for the smaller charges used in the series.

ACCLIMATION OF FISH SPECIMENS

The technique of lowering cages of test fish to fixed depths immediately prior to the detonation of an explosive charge offers the fish very little time to adjust to the differences in water pressure encountered at the test stations. Because of the compressiblity of the swimbladder and its known susceptibility to injury, the effect of inadequate acclimation times might be much more pronounced in swimbladder fish than in organisms not possessing an internal reservoir of gas. The validity of using unacclimated swimbladder fish as indicators of the damage expected to occur in free-swimming fish of the same species and at the same depths is, therefore, uncertain. To determine the feasibility of acclimating fish prior to use as test animals, a series of laboratory pressure acclimation tests was conducted. Several of these tests were conducted in concurrence with research performed by Dan Levine, at the Chesapeake Biological Laboratory.

The test fish were held at 20 psi (138 KPa) applied pressure in a continuous flow system. The pressure to which the fish had become acclimated was determined periodically by the following procedure: The fish were anesthetized by introducing anesthetic into the water. Since they were not fully adjusted to the 20 psi applied pressure, they sank to the bottom. The pressure was then incrementally reduced. The pressure at which the fish became neutrally bouyant indicated the pressure to which it had become acclimated.

Several species of fish were used. However, time and equipment often placed serious limitations on the sample sizes. After determining the gas secretion and resorption rates for fish tested at 20 psi (138 KPa) applied pressure, extrapolations were made to cover the range of pressures that would be encountered at the stations in the deep-water explosion tests. Using this data, the feasibility of using acclimated test fish was assessed.

The maximum swimbladder gas secretion rates exhibited by specimens of eight fish species during laboratory exposure to an applied pressure of 20 psi (138 KPa) are presented in Table 1. These maximum secretion rates occurred during the first 1 to 2 days of each test; thereafter, the secretion rates steadily decreased.

Table 1

Maximum Swimbladder Gas Secretion Rates

Species	Ave. Length (mm)	Ave. Weight (g)	Sample Size (N)	Ave. Temp. (°C)	Maximum Gas Secretion Rate		Predicted Times For Equilibrium To 45 lbs/in^2 Applied Pressure	
					psi/hr	KPa/hr	hours	days
Spot	88	9.6	15	27	0.34	2.3	132	5.5
White Perch	162	79	5	19	0.20	1.4	226	9.4
Striped Bass	252	160	2	16	0.26	1.8	173	7.2
Croaker	117	13	2	27	0.67	4.6	67	2.8
Toadfish	215		2	21	0.42	2.9	108	4.5
Mummichog	74		5	25	0.30	2.1	149	6.2
	46		5	25	0.22	1.5	204	8.5
Striped Killifish	88		5	25	0.31	2.1	144	6.0
	54		5	25	0.19	1.3	240	10.0
Sheepshead Minnow			5	19	0.01	0.07	No Pred.	

Gas secretion stopped once fish had achieved equilibrium to a pressure somewhat less than the 20 psi to which exposed. This slight negative buoyancy is similar to that maintained by these fish when held in open tanks at one atmosphere pressure.

Excluding the sheepshead minnow, the predicted acclimation times calculated for 45 psi (310 KPa) applied pressure range from 2.8 days for croaker to 10.0 days for striped killifish. The sheepshead minnow exhibited minimal ability to secrete gas, reaching equilibrium to only 0.7 psi (4.8 KPa) in 5 days. Hence, no acclimation time prediction was calculated for this species.

The only reliable way to acclimate fish to the pressures which were encountered at the test stations would have been to place the fish at these stations for some period of time before detonation of the explosive charge. Use of anchored buoys to hold the test cages on station was impossible because of the main-channel location of the test area. The only alternate course of action available was to attach the line of test cages directly to the operations barge. This would have required anchoring the barge at or near the test area for several days before each explosion test. Even if all the acclimation times were assumed to be as short as the 2.8 days predicted for croaker, the required expenditure in both time and money was considered to be prohibitively high. Lengthy acclimation periods would have greatly reduced the time available for explosion tests and would have resulted in the collection of insufficient data to test the original swimbladder size vs. pressure-wave characteristic hypothesis.

Although numerous assumptions were made when calculating the predicted acclimation times, the values obtained are believed to be sufficiently accurate so that they can be used as originally planned -- to aid in assessing the feasibility of acclimating fish prior to use in explosion tests. The major assumptions were as follows: First, the maximum secretion rate exhibited by each species in the laboratory tests was assumed to be the same as that which will occur in caged fish exposed to pressures up to 45 psi (310 KPa). Secondly, as recorded for bluegills,[7] differences in water temperature were not expected to significantly alter the rates of gas secretion. Initial shock of the fish to increased pressure was also assumed to be minimal. Lastly, secretion rates were assumed to be constant and to continue unabated until the fish achieved neutral buoyancy at the applied pressure. As a result, the predicted acclimation times may be closer to the actual times than those that might be indicated by any single assumption. Because of the numerous assumptions that were made in the calculations and the small sample sizes used for each species in the laboratory tests, use of the data for more than gross rate estimations is not advisable.

7. Gallepp, G. W., and Magnuson, J. J. 1972. Effects of negative buoyancy on the behavior of the bluegill, Lepomis macrochirus Rafinesque. Trans. Amer. Fish. Soc. 101(3): 507-512.

RESULTS

A total of six shots was fired in deep water during the program. The test conditions for the series are given in Table 2. In general, high quality data were acquired for both biological damage and pressure histories.

Pressure-Time Data

The pressure-time data for this series consist of 140 pressure records, of a possible 150 (12 oscilloscope and 13 tape channels per shot for 6 shots). The data are generally of high quality with a high signal to noise ratio. By combining the oscilliscope and tape data, the peak pressure, shock waveform, surface cutoff time, plateau underpressure in the negative phase, and duration of the negative phase were determined for all caged fish positions. These data are summarized in Tables 3 through 8.

Since the ranges were very short for the smaller charges, refraction was not a factor. For the larger charges, however, refractive effects were important. Ray tracing calculations performed using temperature and salinity profiles obtained on-site show that a variation in peak pressure with gage depth was to be expected on the four shots using the larger charge size due to refraction effects even though the slant ranges do not vary significantly with depth. The peak pressure data, therefore, do not conform to a simple similitude relationship. For the most part, the waveforms were of the type expected for these conditions. (See the low gain records of Appendix B). There is a sharp rise to a peak pressure, followed by a roughly exponential decay up to the time of surface cutoff. At this time there is a sharp drop to a pressure below ambient hydrostatic pressure, which eventually returns to hydrostatic after cavitation closure occurs. A certain amount of the fine detail in these waveforms may be due to reflections and vibrations in the rigging. Some of the pressure waveforms were significantly distorted by refraction. These tended to be the shallower gages on the shots using the larger charge weights. A selection of these is shown in Figure 2. These waveforms do not show the monotonic decrease in pressure after the peak which we expect. Instead they show additional humps, indicative of probable refractive effects.

The tape records recorded at high gain to resolve the details of the secondary pressures were digitized along with the low gain records in order to facilitate further analysis. Reproduction of these digital records are presented in Appendix B. A set of high and low gain records from the same gage is shown in Figure 3. In the upper trace, the shock wave peak is well defined, and we see the true relationship between the secondary pressures and the peak pressure. In the lower trace, the shock wave causes system overload. After recovery from overload, we see the tail of the shock wave. The details of the secondary pressures are greatly

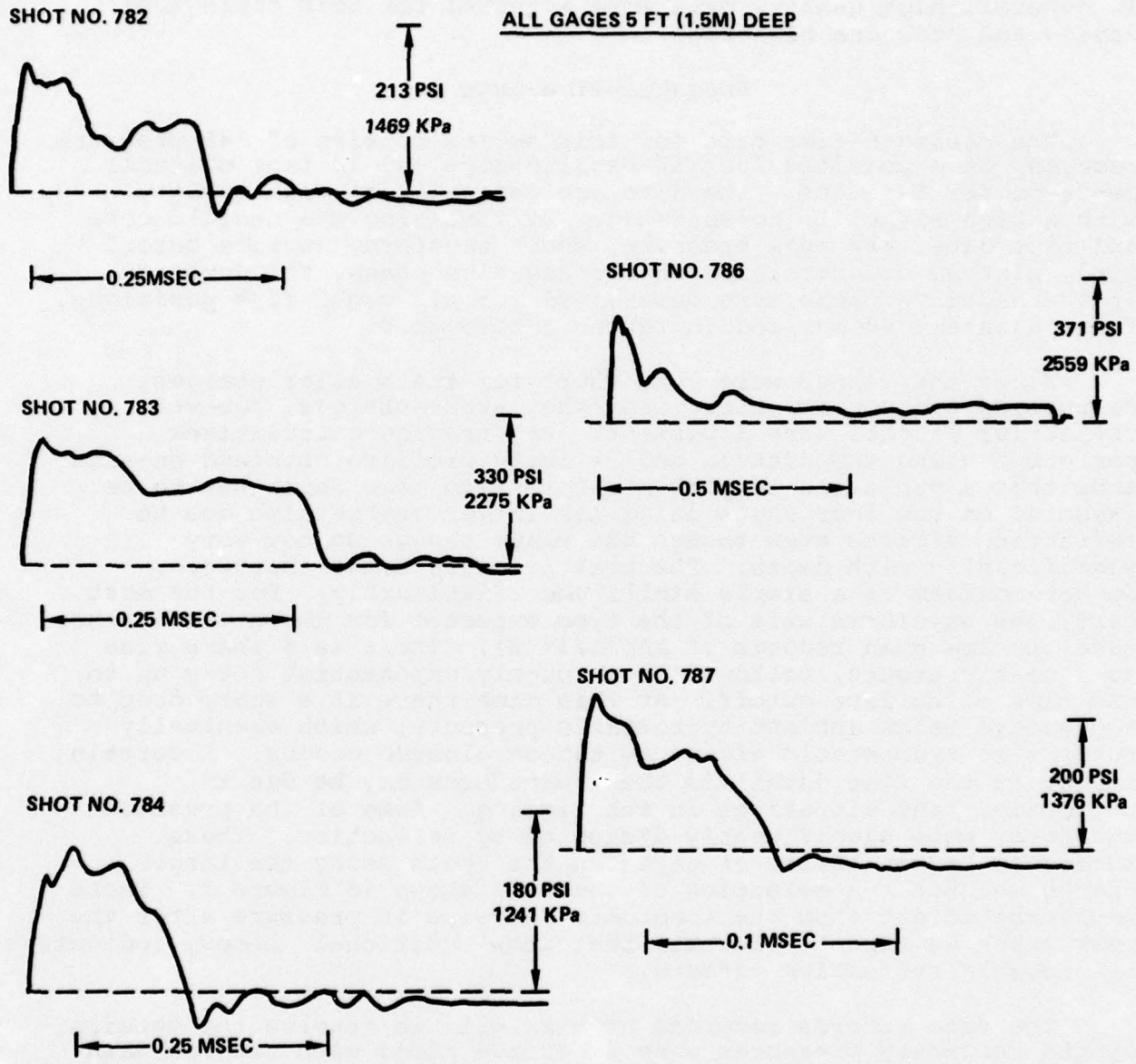

FIG. 2 DISTORTED PRESSURE WAVEFORMS.

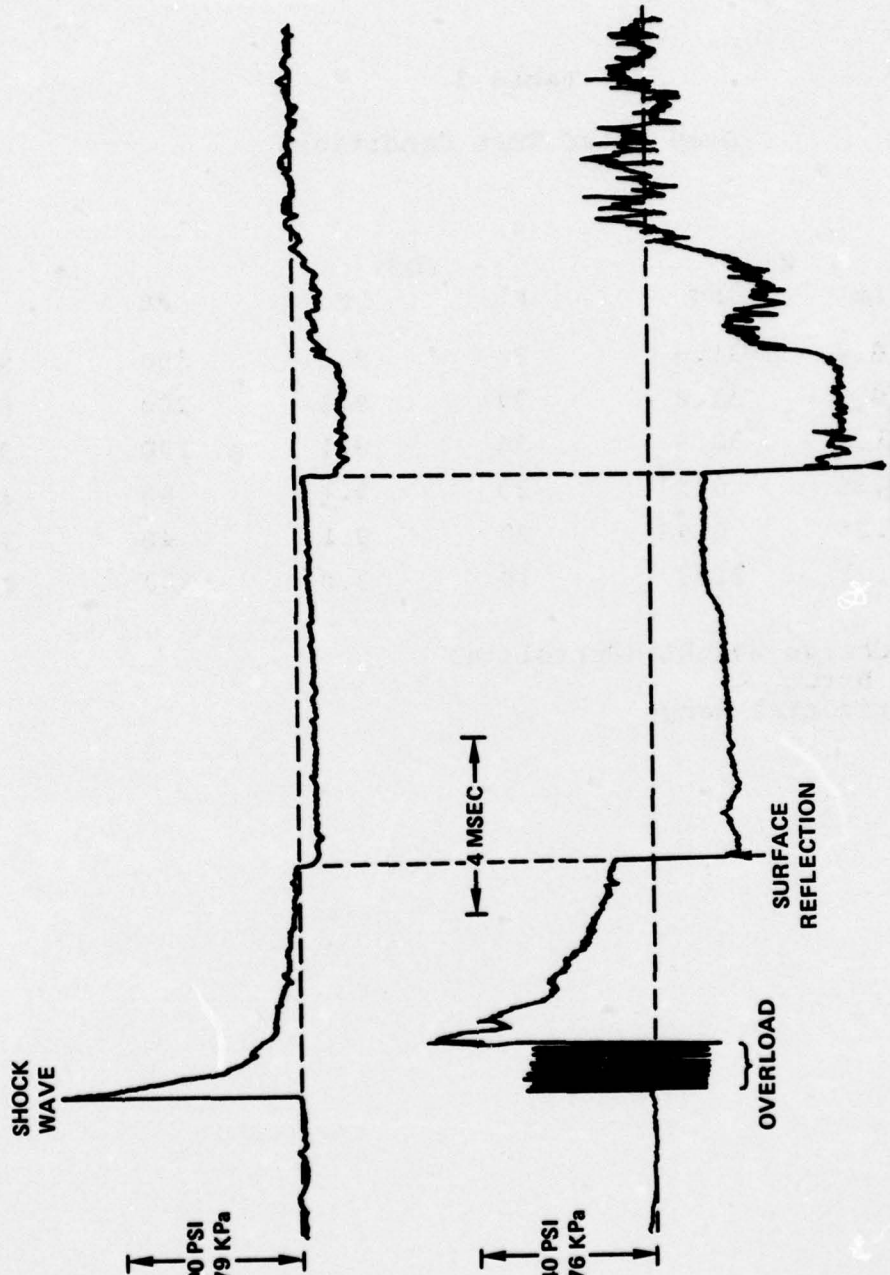

FIG. 3 HIGH AND LOW GAIN PRESSURE RECORDS
SHOT NO. 783, GAUGE DEPTH = 90 FT. (27.4M)
CHARGE WEIGHT = 70.2 LB (31.8Kg), BURST DEPTH = 30 FT. (9.1M)
NOMINAL HORIZONTAL RANGE - 200 FT (61.0M)

Table 2

Deep Water Test Conditions

Shot #	W		DOB		H	
	Lb	Kg	Ft	M	Ft	M
782	70.4	31.9	30	9.1	300	91.4
783	70.2	31.8	30	9.1	200	61.0
784	71.5	32.5	30	9.1	300	91.4
785	1.25	0.57	30	9.1	40	12.2
786	1.25	0.57	30	9.1	40	12.2
787	7.21	32.7	10	3.0	300	91.4

W - Explosive Charge Weight (Pentolite)
DOB - Depth of Burst
H - Nominal Horizontal Range

Table 3

Pressure-Time Data, Shot #782

Charge Weight = 70.4 lb (31.9 Kg), Burst Depth = 30 ft (9.1 m)
Nominal Horizontal Range = 300 ft (91.4 m)

D_G		P_{MAX}		P_{NEG}		Δt_{SURF}	Δt_{NEG}
Ft	m	psi	KPa	psi	KPa	msec	msec
5	1.5	166	1145	8	55	0.20	2.65
10	3.0	138	951	19	131	0.36	-
15	4.6	154	1062	21	145	0.52	-
40	12.2	189	1303	27	186	1.45	4.73
45	13.7	170	1172	24	165	1.68	5.10
50	15.2	178	1227	22	152	2.05	5.81
55	16.8	168	1158	22	152	2.13	5.89
57.5	17.5	155	1069	21	145	2.25	5.88
77.5	23.6	180	1241	30	138	3.10	6.54
87.5	26.7	145	1000	13	90	3.35	7.20
97.5	29.7	171	1179	15	103*	3.85	8.33

*Negative bottom reflection arrives before closure, lowering P_{NEG} to 50 psi (345 KPa)

D_G - Gage Depth

P_{MAX} - Peak Pressure

P_{NEG} - Plateau Underpressure

Δt_{surf} - Arrival time of surface reflected arrival after direct arrival

Δt_{NEG} - Duration of negative phase

Table 4

Pressure-Time Data, Shot #783

Charge Weight = 70.2 lb (31.8 kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 200 ft (61.0 m)

D_G		P_{MAX}		P_{NEG}		Δt_{SURF}	Δt_{NEG}
Ft	m	psi	KPa	psi	KPa	msec	msec
5	1.5	272	1875[1]	16	110	0.30	7.46
10	3.0	261	1800	20	138	0.54	-
15	4.6	290	1999	25	172	0.82	-
40	12.2	296	2041	31	214	2.31	9.73
45	13.7	233	1606	31	214	2.62	10.33
50	15.2	271	1868	31	214	2.94	10.77
55	16.8	233	1606	25	172	3.28	11.13
60	18.3	283	1951	24	165	3.58	11.79
80	24.4	229	1579	23	159[2]	4.73	15.17
90	27.4	296	2041	19	131[3]	5.24	14.26
100	30.5	258	1779	20	138[4]	5.80	15.86

See Table 3 for symbol definitions

1. Two gages at this depth. Other gage read 283 psi (1951 KPa)

Negative Bottom reflection arrives before closure lowering

P_{NEG} to (2): 51 psi (352 KPa)
(3): 43 psi (296 KPa)
(4): 63 psi (434 KPa)

Table 5

Pressure-Time Data, Shot #784

Charge Weight = 71.5 lb (32.5 kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 300 ft. (91.4 m)

D_G		P_{MAX}		P_{NEG}		Δt_{SURF}	Δt_{NEG}
Ft	m	psi	KPa	psi	KPa	msec	msec
5	1.5	138	951[1]	14	97	0.17	1.50
10	3.0	-	-	22	152	0.28	1.45
20	6.1	138	951	22	152	0.59	5.35
40	12.2	189	1303	26	179	1.20	7.40
45	13.7	179	1234	36	248	1.41	6.28
50	15.2	163	1124	31	214	1.62	6.15
55	16.8	153	1055	24	165	1.77	5.20
60	18.3	184	1269	22	152	2.02	5.70
80	24.4	164	1131	-	-	-	-
90	27.4	192	1324	-	-	-	-
100	30.5	171	1179	18	124	3.59	1.18[2]

See Table 3 for symbol definitions

1. Two gages at this depth. Other gage read 173 psi (1193 KPa)

2. Cut off by positive bottom reflection.

Table 6

Pressure-Time Data, Shot #785

Charge Weight = 1.25 lb (0.57 kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 40 ft. (12.2 m)

D_G		P_{MAX}		P_{NEG}		Δt_{SURF}	Δt_{NEG}
Ft	m	psi	KPa	psi	KPa	msec	msec
5	1.5	283	1951	15	103	1.24	3.80
10	3.0	311	2144	18	124	2.48	4.68
20	6.1	312	2151	19	131	4.78	5.17
30	9.1	363	2503	22	152	6.87	5.45
40	12.2	274	1889	31	214	8.64	5.95
50	15.2	325	2241	12	83	9.66	6.12
60	18.3	307	2117	13	90	10.37	6.43
70	21.3	275	1896	13	90	10.97	6.57
80	24.4	166	1145	12	83	11.23	6.94
90	27.4	139	958	12	83	11.30	6.90
100	30.5	155	1069	8	55	11.52	6.89

See Table 3 for symbol definitions

Table 7

Pressure-Time Data, Shot #786

Charge Weight = 1.25 lb (0.51 kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 40 ft. (12.2 m)

D_G		P_{MAX}		P_{NEG}		Δt_{SURF}	Δt_{NEG}
Ft	m	psi	KPa	psi	KPa	msec	msec
5	1.5	280	1931[1]	14	97	1.06	3.57
10	3.0	-	-	19	131	2.37	5.10
20	6.1	416	2868	20	138	4.68	5.39
30	9.1	443	3054	-	-	-	-
50	15.2	331	2282	11	76	10.09	6.60
60	18.3	349	2406	8	55	10.79	6.66
65	19.8	372	2565	10	69	11.18	7.22
70	21.3	361	2489	9	62	11.19	7.40
75	22.9	248	1710	9	62	11.42	7.38
80	24.4	211	1455	10	69	11.50	7.17

See Table 3 for symbol definitions

1. Two gages at this depth. Other gage read 304 psi (2096 KPa)

Table 8

Pressure-Time Data, Shot #787

Charge Weight = 72.1 lb (32.7 kg), Burst Depth = 10 ft. (3.0 m)
Nominal Horizontal Range = 300 ft. (91.4 m)

D_G		P_{MAX}		P_{NEG}		Δt_{SURF}	Δt_{NEG}
Ft	m	psi	KPa	psi	KPa	msec	msec
5	1.5	-	-	7	48	0.28	0.95
10	3.0	264	1820	14	97	0.28	0.64
40	12.2	148	1020	14	97	0.47	5.47
50	15.2	166	1145	25	172	0.60	3.33
55	16.8	189	1303	21	145	0.75	4.08
60	18.3	193	1331	19	131	0.77	4.37
70	21.3	214	1475	20	138	0.87	5.78
80	24.4	202	1393	-	-	1.05	-
90	27.4	204	1407	17	117	1.21	6.03
100	30.5	209	1441	19	131	1.31	6.46[1]

See Table 3 for symbol definitions

1. Cut off by positive bottom reflection.

enhanced. In this case, the bottom reflection is negative, and arrives before the negative pressures caused by the surface reflection have subsided. In other records, on other shots, the bottom reflection is positive. This illustrates the difficulty in predicting bottom reflections for shots fired nominally in the same position.

Biological Data

Tables 9 through 14 contain the results of the dissections of all live test specimens from the deep water explosion tests.

In agreement with previous findings, hogchokers were found to be extremely tolerant to underwater explosions, greatly exceeding the tolerance of any other fish species tested. Even though several oysters and crabs were damaged in one test, no hogchokers ever suffered serious injury during any of the tests, and they are not included in the tables. The lack of a swimbladder appears to be most responsible for the tolerance exhibited by hogchokers. In addition, injury appears to be closely related to the swimbladder when considered as an entire organ rather than as simply a volume of gas. Hogchokers which had 0.88 ml of air injected into the abdominal cavity exhibited no greater sensitivity to explosions than specimens left in their normal state (Table 9, shot 782, 45 ft. (13.7 m)). In contrast, 70 percent of the white perch and 30 percent of the catfish suffered level three (3) damage at the same station.

Although body rigidity and scale size are probably related to susceptibility to injury, this appears to be an incomplete explanation. Toadfish and catfish were the least rigidly constructed of the swimbladder fish tested, yet they were the most resistant to damage. It is likely that the thick walls of their swimbladder reduced the incidence of rupture to that organ, and the inherent flexibility of their bodies cushioned the internal organs from rapid fluctuations in the size of the swimbladder. Incidence of internal hemorrhaging and bruising of the kidney was much greater in the more rigidly built fish.

In Atlantic menhaden, blueback herring, and striped killifish the swimbladders were burst most frequently along the lateral edges of the ventral surface. Dorsal to this area, the bladder wall is pressed firmly against the rib cage; ventrally, the bladder shape is less rigidly maintained by contact with the visera and by the elasticity of the bladder tissue. The additional stress that the bladder encounters at the interface of these two different types of support helps explain the high incidence of rupture exhibited there after an explosion test.

Table 9

Fish Damage: Shot #782

Charge Weight = 70.4 lb (31.9 Kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 300 ft. (91.4 m)

Depth Ft	Depth m	Fish	Length in.	Length cm	Sample Size	Observed Damage Level 0	1	2	3	4
						Number of Fish				
5	1.5	Perch	5.81	14.8	10	4	4	0	2	0
		Perch	6.49	16.5	9	4	1	2	2	0
		Perch	7.80	19.8	9	6	2	1	0	0
40	12.2	Perch	5.56	14.1	11	0	0	0	11	0
		Perch	6.07	15.4	10	0	0	0	9	1
		Perch	7.55	19.2	16	0	0	0	15	1
		Perch	8.70	22.1	3	0	0	0	3	0
45	13.7	Perch	5.88	14.9	9	0	0	1	8	0
		Perch	7.38	18.7	8	1	0	3	4	0
		Catfish	8.18	20.8	9	5	1	0	3	0
		Hog Choker	4.23	10.7	8	8	0	0	0	0
		Hog Choker*	4.85	12.3	10	8	2	0	0	0
50	15.2	Perch	5.78	14.7	20	0	0	1	19	0
		Toadfish	9.11	23.1	9	8	1	0	0	0
55	16.8	Perch	5.96	15.1	14	0	0	2	12	0
		Perch	6.89	17.5	6	0	0	5	1	0
		Perch	7.31	18.6	10	0	1	8	1	0
		Catfish	12.66	32.3	4	1	1	0	2	0
		Toadfish	7.09	18.0	2	2	0	0	0	0
		Toadfish	9.26	23.5	6	6	0	0	0	0
57.5	17.5	Perch	5.56	14.1	6	0	0	0	6	0
		Perch	6.40	16.3	14	0	0	3	11	0
		Catfish	14.84	37.7	2	0	2	0	0	0
77.5	23.6	Perch	5.92	15.0	10	0	1	8	1	0
87.5	26.7	Perch	5.47	13.9	4	0	0	3	1	0
		Perch	6.14	15.6	6	0	1	5	0	0
97.5	29.7	Perch	5.39	13.7	6	0	1	5	0	0
		Perch	6.04	15.3	15	0	6	8	1	0
		Perch	7.32	18.6	16	0	1	9	6	0
		Perch	8.83	22.4	3	0	0	3	0	0

*injected with 0.88 ml of air

Table 10

Fish Damage: Shot #783

Charge Weight = 70.2 lb (31.8 Kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 200 ft. (61.0 m)

Depth Ft	Depth m	Fish	Length in.	Length cm	Sample Size	Observed Damage Level 0	1	2	3	4
						Number of Fish				
5	1.5	Perch	5.62	14.3	11	0	0	0	6	5
		Perch	5.94	15.1	12	0	0	0	2	10
		Perch	7.33	18.6	6	0	0	0	1	5
		Toadfish	7.29	18.5	3	0	1	2	0	0
80	24.4	Perch	5.92	15.0	6	0	0	1	5	0
		Perch	6.60	16.8	24	0	0	2	22	0
		Perch	7.38	18.7	13	0	0	0	13	0
		Spot	5.02	12.8	2	0	0	1	1	0
		Hake	6.05	15.4	3	0	0	0	3	0
		Eel	18.70	47.5	2	0	1	1	0	0
100	30.5	Perch	5.76	14.6	9	0	0	1	8	0
		Perch	6.29	16.0	16	0	0	4	12	0
		Perch	7.13	18.1	4	0	0	1	3	0

Table 11

Fish Damage: Shot #784

Charge Weight = 71.5 lb (32.5 Kg), Burst Depth = 30 ft. (9.1 m)
Nominal Horizontal Range = 300 ft. (91.4 m)

Depth Ft	Depth m	Fish	Length in.	Length cm	Sample Size	Observed Damage Level 0	1	2	3	4
						Number of Fish				
5	1.5	Perch	5.97	15.2	9	0	0	0	9	0
		Perch	6.40	16.3	10	3	1	0	6	0
		Perch	7.53	19.1	9	1	3	0	5	0
10	3.0	Toadfish	7.44	18.9	3	2	0	0	1	0
		Toadfish	8.46	21.5	11	3	8	0	0	0
		Toadfish	9.58	24.3	15	1	13	0	1	0
		Toadfish	10.42	26.5	6	0	5	0	1	0
20	6.1	Toadfish	8.40	21.3	3	0	2	0	1	0
		Toadfish	9.53	24.2	5	1	4	0	0	0
		Toadfish	10.60	26.9	5	0	5	0	0	0
55	16.8	Perch	5.78	14.7	9	0	0	6	3	0
		Perch	6.24	15.8	15	0	0	6	9	0
		Perch	6.87	17.4	4	0	0	3	1	0
		Perch	7.44	18.9	19	0	0	17	2	0
		Catfish	8.52	21.6	3	2	1	0	0	0
		Catfish	10.86	27.6	4	4	0	0	0	0
		Catfish	13.27	33.7	6	4	2	0	0	0
60	18.3	Spot	5.64	14.3	6	3	3	0	0	0
		Spot	6.31	16.0	4	0	4	0	0	0
		Spot	7.39	18.8	5	4	0	1	0	0
		Perch	5.84	14.8	13	0	0	12	1	0
		Perch	6.33	16.1	5	0	0	3	2	0
		Catfish	8.20	20.8	6	6	0	0	0	0
		Catfish	9.23	23.4	4	4	0	0	0	0
		Catfish	13.13	33.4	5	4	1	0	0	0
		Catfish	15.13	38.4	4	3	1	0	0	0
100	30.5	Perch	5.70	14.5	10	0	0	9	1	0
		Perch	6.52	16.6	10	0	0	10	0	0
		Perch	7.05	17.9	10	0	0	11	0	0
		Perch	7.49	19.0	7	0	0	7	0	0
		Perch	8.65	22.0	3	0	0	3	0	0

Table 12

Fish Damage: Shot #785

Charge Weight = 1.25 lb (0.57 Kg), Burst Depth = 30 ft. (9.1 M)
Nominal Horizontal Range = 40 ft. (12.2 M)

Depth Ft	Depth m	Fish	Length in.	Length cm	Sample Size	Observed Damage Level 0	1	2	3	4
						Number of Fish				
5	1.5	Perch	6.01	15.3	11	0	0	1	10	0
		Perch	7.48	1.90	5	0	0	1	4	0
		Menhaden	8.32	21.1	4	0	0	0	0	4
		Menhaden	9.29	23.6	3	0	0	0	0	3
		Menhaden	10.85	27.6	3	0	0	0	0	3
50	15.2	Perch	7.44	18.9	9	0	0	9	0	0
		Menhaden	6.82	17.3	3	0	0	3	0	0
		Menhaden	7.83	19.9	5	1	1	1	2	0
		Menhaden	8.48	21.5	10	3	0	5	2	0
60	18.3	Menhaden	7.32	18.6	6	0	4	1	1	0
		Menhaden	8.40	21.3	12	6	4	2	0	0
		Menhaden	10.14	25.8	2	2	0	0	0	0
		Herring	9.51	24.2	9	1	1	3	4	0
		Herring	10.03	25.5	10	10	0	0	0	0
70	21.3	Perch	7.08	18.0	10	1	2	7	0	0
		Perch	7.63	19.4	9	0	4	5	0	0
		Menhaden	6.98	17.7	5	0	3	2	0	0
		Menhaden	7.92	20.1	13	2	3	7	1	0
		Menhaden	10.38	26.4	3	2	3	1	0	0
		Menhaden	12.30	31.2	3	3	0	0	0	0
80	24.4	Perch	7.01	17.8	10	1	5	4	0	0
		Perch	7.91	20.1	10	1	5	4	0	0
		Menhaden	5.20	13.2	2	0	2	0	0	0
		Menhaden	6.96	17.7	3	2	0	0	1	0
		Menhaden	7.75	19.7	11	8	1	2	0	0
		Menhaden	8.76	22.3	4	3	1	0	0	0
		Herring	9.51	24.2	12	9	2	1	0	0

Table 13

Fish Damage: Shot #786

Charge Weight = 1.25 lb (0.57 Kg), Burst Depth = 30 ft. (9.1 M)
Nominal Horizontal Range = 40 ft. (12.2 M)

Depth Ft	Depth m	Fish	Length in.	Length cm	Sample Size	Observed Damage Level 0	1	2	3	4
						Number of Fish				
5	1.5	Spot	7.58	19.3	7	0	0	2	4	1
		Spot	8.67	22.0	3	0	0	0	2	1
		Menhaden	6.36	16.2	3	0	0	0	3	0
		Menhaden	7.56	19.2	5	0	0	0	5	0
		Menhaden	9.19	23.3	2	0	0	0	2	0
10	3.0	Toadfish	4.96	12.6	3	0	3	0	0	0
		Toadfish	6.82	17.3	6	0	4	2	0	0
		Toadfish	9.28	23.6	6	0	6	0	0	0
		Toadfish	10.33	26.2	2	0	1	1	0	0
40	12.2	Catfish	7.83	19.9	2	0	0	0	2	0
50	15.2	Perch	7.61	19.3	9	0	1	8	0	0
		Perch	8.5	21.6	8	0	0	5	3	0
		Perch	9.69	24.6	2	0	0	2	0	0
		Menhaden	9.31	23.6	9	0	2	1	6	0
55	16.8	Perch	6.93	17.6	10	0	1	9	0	0
		Perch	8.46	21.5	11	0	0	10	1	0
60	18.3	Herring	10.12	25.7	5	0	0	3	2	0
		Herring	9.51	24.2	5	0	0	3	2	0
		Herring	9.76	24.8	5	0	2	3	0	0
65	19.8	Menhaden	7.35	18.7	9	0	0	5	4	0
70	21.3	Spot	7.78	19.8	10	0	4	3	3	0
		Menhaden	5.96	15.1	2	0	0	1	1	0
		Menhaden	8.85	22.5	3	0	1	2	0	0
		Menhaden	10.40	26.4	4	0	2	2	0	0
75	22.9	Menhaden	5.71	14.5	6	0	2	4	0	0
		Menhaden	6.42	16.3	8	0	5	3	0	0
		Menhaden	7.14	18.1	16	0	9	6	1	0
		Menhaden	7.13	18.1	5	0	1	0	4	0
		Menhaden	6.91	17.6	5	0	0	4	1	0
80	24.4	Spot	6.41	16.3	8	0	7	1	0	0
		Spot	7.20	18.3	4	0	4	0	0	0
		Spot	8.07	20.5	8	0	0	8	0	0
		Croaker	9.26	23.5	7	0	4	1	2	0
		Croaker	10.12	25.7	6	0	3	2	1	0

Table 14

Fish Damage: Shot #787

Charge Weight = 72.1 lb (32.7 Kg), Burst Depth = 10 ft. (3.0 M)
Nominal Horizontal Range = 300 ft. (91.4 M)

Depth Ft.	m	Fish	Length in.	cm	Sample Size	Observed Damage Level 0	1	2	3	4
						Number of Fish				
5	1.05	Menhaden	7.59	18.3	5	0	0	2	3	0
		Killifish	4.49	11.4	7	1	1	0	5	0
		Killifish	6.60	16.8	3	0	0	0	3	0
		Menhaden	1.92	4.9	5	2	0	0	3	0
		Mummichog	2.24	15.7	7	0	1	0	6	0
		Mummichog	2.60	16.6	5	1	1	0	3	0
		Sheepshead Minnow	2.07	15.3	5	0	0	0	5	0
10	3.0	Killifish	3.99	10.0	10	0	0	0	9	1
		Killifish	4.58	11.6	3	0	0	0	3	0
		Killifish	5.54	14.1	4	0	0	0	4	0
		Mummichog	3.41	8.7	4	0	2	0	2	0

Large variations in swimbladder volumes were often detected between equal sized specimens of many species. In addition to the natural physical differences, the handling of the test fish might have further contributed to the variability, particularly to the two physostomous species - blueback herring and Atlantic menhaden. Blueback herring often released gas during transfer to the test cages and when dissected they were commonly found to possess only a partially inflated swimbladder. Although the swimbladders in the Atlantic menhaden exhibited more uniformity than those in blueback herring, the variability was still sufficient to hamper both station placement and use of the species in the damage prediction model.

In addition to herring and menhaden, bluefish also exhibited large variations in swimbladder volumes. Some specimens contained bladders that were totally deflated while others had gas volumes greater than 180 ml. The reason for the large variability in bluefish is probably two-fold. First, bluefish are voracious feeders; the stomachs of many specimens were completely filled. The food in the stomach directly alters the shape of the swimbladder and might indirectly affect the volume of gas maintained within the bladder as well. Secondly, bluefish possess the ability to rapidly secrete gas into their swimbladder (Wittenberg, Schwend, and Wittenberg).[8] A bluefish requires less than four hours to refill its swimbladder after all the gas has been surgically removed. The rate of gas resorption is believed to be even faster. Levine[9] and the present authors have found the maximum gas secretion and resorption rates for white perch to be 0.20 psi/hr (1.4 KPa/hr) and 9.5 psi/hr (66 KPa/hr) respectively, and for spot to be 0.34 psi/hr (2.3 KPa/hr) and 16.5 psi/hr (114 KPa/hr) respectively. The ratio of the resorption rate to secretion rate is 48 to 1 for white perch, 49 to 1 for spot. If the ratio of resorption rate to resorb all the gas from its swimbladder in approximately five minutes. Thus, slight differences in the elapsed time between capture and death could cause large variations in the ultimate bladder volumes, provided the fish are actively resorbing gas during this period. Although the bluefish were uniformly handled when they were placed on ice and left to die, some variation in their survival times was apparent. Rapid deaths through administration of a lethal dose of an anesthetic would probably have been preferable and might have reduced the variation in bladder volumes that was observed.

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8. Wittenberg, J. B., Schwend, M. J., Witternberg, B. A., 1964, "The secretion of oxygen into the Swimbladder of Fish. III. The role of carbon dioxide," J. Gen. Physiol. 48: 377-355
9. Levine, D. M. 1975, Swimbladder physiology and function as related to the ecology of some estuarine fishes. Chesapeake Biological Laboratory, Solomons, Maryland. Unpubl. report. 12 pp.

Table 15

Effect of Shielding

Damage levels exhibited by fish held in three cages oriented broadside to an explosive charge. The blueback herring were held 60 feet deep during shot number 786; Atlantic menhaden were held 55 feet deep during shot number 787.

FISH SPECIES	CAGE LOCATION	SAMPLE SIZE	NUMBER OF INDIVIDUALS EXHIBITING EACH DAMAGE LEVEL DAMAGE LEVELS: 0 1 2 3 4
blueback herring	nearest the charge	5	0 0 3 2 0
	center position	5	0 0 3 2 0
	furthest from charge	5	0 2 3 0 0
Atlantic menhaden	nearest the charge	5	5 0 0 0 0
	center position	5	1 4 0 0 0
	furthest from charge	4	0 2 1 1 0

To test the extent to which test organisms might be shielded and protected from an explosive charge by adjacent organisms, two experiments using cages oriented broadside to an explosive charge were conducted. When a series of three cages of blueback herring was used in test shot number 786, the fish in the cages nearest the charge suffered the most damage (Table 15). The opposite phenomenon occurred in three cages of Atlantic menhaden in test shot number 787 (Table 15). The interaction between adjacent organisms during an underwater explosion cannot apparently be explained in terms of shielding alone.

Although test fish possessing damages of level 2 and 3 were often still alive when the cages were retrieved, it is doubtful that these fish could have survived if they had been released. The injury to the kidney and swimbladder that is characteristic of these two damage levels seriously interferes with the well-being of the fish. Efficient osmoregulation (maintainance of the salt balance) is very important in estuarine fishes; even slight bruises to the kidney, which has an important function in the process, could seriously affect this efficiency, causing at least a higher expenditure of energy. A burst swimbladder causes the fish to have a similarly heightened energy requirement. As a result, migrations might be seriously reduced and vulnerability to predators increased. Although the recuperative power of fish possessing burst swimbladders was found to be quite remarkable during post-explosion holding periods in a laboratory (Wiley and Wilson),[10] other field and laboratory evidence indicates that free-swimming fish suffering such an injury have very little chance to survive. Three spot, which had their swimbladders burst from rapid decompression during capture, were held at 20 psi (138 KPa) applied pressure in the pressure acclimation tests. After 10 days the three fish had still not reached any stability in gas secretion and retention in the swimbladder. The reason for this instability seems to be directly linked to the initial injury to the swimbladders.

After four days, the walls of the swimbladders had apparently healed, because secreted gas was being retained within the bladder. After the equilibrium pressure had risen for 24 hours or longer, wild oscillations became common. These fluctuations greatly exceeded those exhibited by both uninjured fish held at 20 psi (138 KPa) pressure and uninjured fish not subjected to increased pressures. It appears that after sufficient internal gas pressures were attained, the injured walls of the swimbladders reopened and gas leaked out. This happened several times during the test. That the applied pressure and resulting gas secretion interfered with the healing of the bladder wall is supported by dissection data obtained at the termination of the pressure acclimation test. Spot captured at the same time, but not subjected

10. Wiley, M. L. and Wilson, J. S., 1974 Environmental effects of explosive testing. Ref. No. 74-9. Nat. Res. Inst., Univ. of Maryland. 17 pp. Appendix B to Reference 4.

to the 20 psi (138 KPa) applied pressure, exhibited much faster healing rates than those of the 3 test fish. Since spot are commonly found at the depth simulated by 20 psi (178 KPa) applied pressure, 45 feet (13.7 M), the delayed healing exhibited by the test fish might be more indicative of what can be expected to occur in the natural environment.[11] This may also be true for the other fish species used in the explosion tests.

11. Dawson, C. E. 1958. A study of the biology and life history of the spot, Leiostomis xanthurus Lacepede, with special reference to South Carolina. Contrib. Bears Bluff Laboratories, Wadmalaw Island. No. 28. 48 pp.

APPENDIX A

DATA ON OYSTER AND BLUE CRAB MORTALITY

At the conclusion of the deep water portion of the tests, an attempt was made to gather data on the mortality of blue crabs (Callinectes sapidus), oysters (Ostrea virginiea) and assorted polychaetes, anemones and other invertebrates found in association with the oysters. Due to difficulties encountered in the shallow water field operations, only one successful shot, #799, was fired.

The shallow water tests were conducted in about 25 feet (7.6 m) of water in the Patuxent River. The rigging was arranged so cages could be placed at a depth of 5 feet (1.5 m), referred to as surface cages, and on the bottom, at six horizontal standoffs from the charge. Crabs were placed in both the surface and bottom cages, while oysters were placed only on the bottom. The pressure recording instrumentation was similar to that in the deep water tests.

The charge used was a 106 lb (48.1 Kg) spherical pentolite charge, placed on the bottom.

Test oysters were collected with an oyster dredge in the vicinity of Solomons Island. Blue crabs were either captured by otter trawl and oyster dredge, or purchased.

After collection, oysters were transferred to wet tables at the Chesapeake Biological Lab and held there until the day they were used in the field tests. To reduce cannibalism and facilitate handling, the claws of all blue crabs were tied closed soon after collection. The claws were tied with plastic-coated wire, following the basic technique described by Newman and Ward.[12] Crabs were held either in wet tables at the laboratory or in the holding tanks on the barge until use in the explosion tests. As in the deep water tests, control organisms were treated in the same manner as the test organisms, but were retrieved from the water just prior to the detonation. Although mortality due to handling was minimal for test fish and oysters, blue crabs exhibited high mortality rates throughout the holding periods, and thus, the reliability of the results obtained was reduced.

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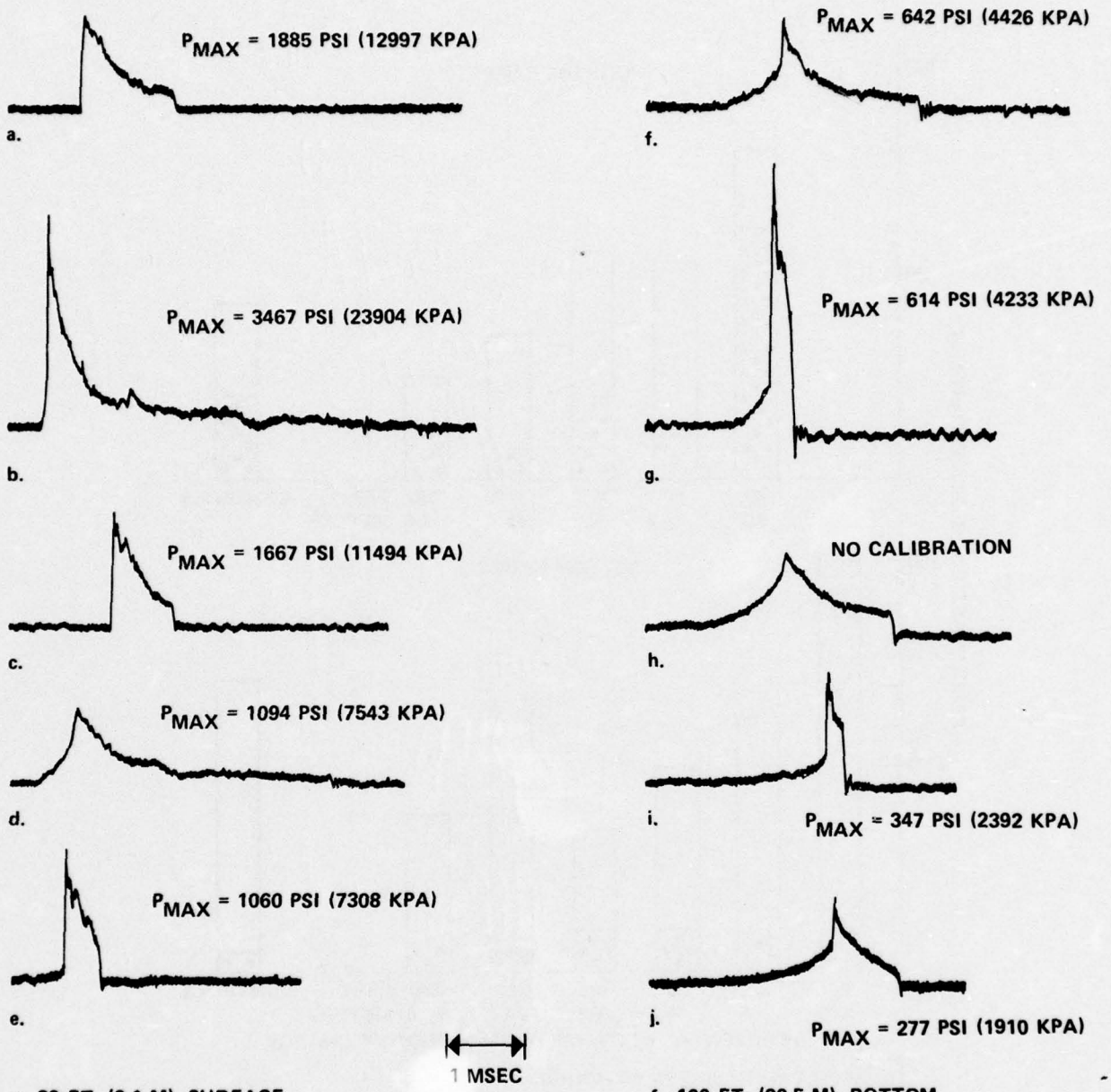
12. Newman, M. W. and Ward, G. E., Jr., 1973. A technique for the immobilzation of the chelae of blue crabs and identification of individual animals. Chesapeake Science 14 (1): 68-69

After exposure to Shot #799, crabs and oysters were examined for obvious external damage and then the test cages were immediately submerged in the holding tanks, later to be transferred and held in wet tables at the Chesapeake Biologicl Laboratory. The crabs were fed scrap fish daily and the survival of all test invertebrates was monitored for several days after each test. Initially a small sample of test crabs was dissected and examined for internal damage, but all examinations were inconclusive and this procedure was later abandoned. With the exception of the severed muscle tissue and ruptured organs that resulted from massive fractures in the carapace, no internal damage was ever discernable.

A summary of the pressure-time data for shot #799 is presented in figure A1. The waveforms displayed are from the low gain tape recordings. All the bottom records, and the more distant surface records, show a precursor arriving before the main shock. This is due to energy propagating through the bottom at a higher speed than in the water.

Percentage cumulative mortality for the test crabs used in shallow water shot number 799 is presented in Figure A2. The initial mortality at the 30 feet surface station, and the 48-hour mortality at the 20 feet bottom station are much higher than that for crabs held at any other stations. The high mortalities which occurred within the control groups might be in part attributable to the differences in handling between these crabs and the test crabs. Due to space limitations within the holding tanks, the cages containing the controls were held out of water several hours longer than were the test cages during transfer to the labratory. As exhibited in tests conducted by Cronin and others (1948) and Wiley and Wilson (1974), no trends in damage level were indicated in the data for stations beyond 30 feet.

The only oyster mortalities occurred at the 20-ft. (6.1 m) bottom station. Twenty hours after the shot, 5 of 20 oysters from this station were dead. Between 20 and 41 hours, one more oyster died. There was no change after 140 hours, giving a mortality of 6 out of 20 (30%). There were no other oyster mortalities in 140 hours of observation. Preliminary laboratory experiments revealed that oysters will open and feed within 30 minutes after rough handling and transfer to a container having a different water flow and temperature. All caged oysters were held on the bottom and left undisturbed for greater than one hour prior to detonation of the explosive charge. The great resistance exhibited by the test oysters is, therefore, a good indication of the reaction that can be expected to occur in natural oyster populations. No damage to other invertebrates (sea anemones, polychaete worms, isopods and amphipods) was observed.



a. 30 FT. (9.1 M), SURFACE
b. 30 FT. (9.1 M), BOTTOM
c. 50 FT. (15.2 M), SURFACE
d. 50 FT. (15.2 M), BOTTOM
e. 100 FT. (30.5 M), SURFACE
f. 100 FT. (30.5 M), BOTTOM
g. 150 FT. (45.7 M), SURFACE
h. 150 FT. (45.7 M), BOTTOM
i. 200 FT. (61.0 M), SURFACE
j. 200 FT. (61.0 M), BOTTOM

FIG. A1 PRESSURE–TIME DATA SHOT NO. 799

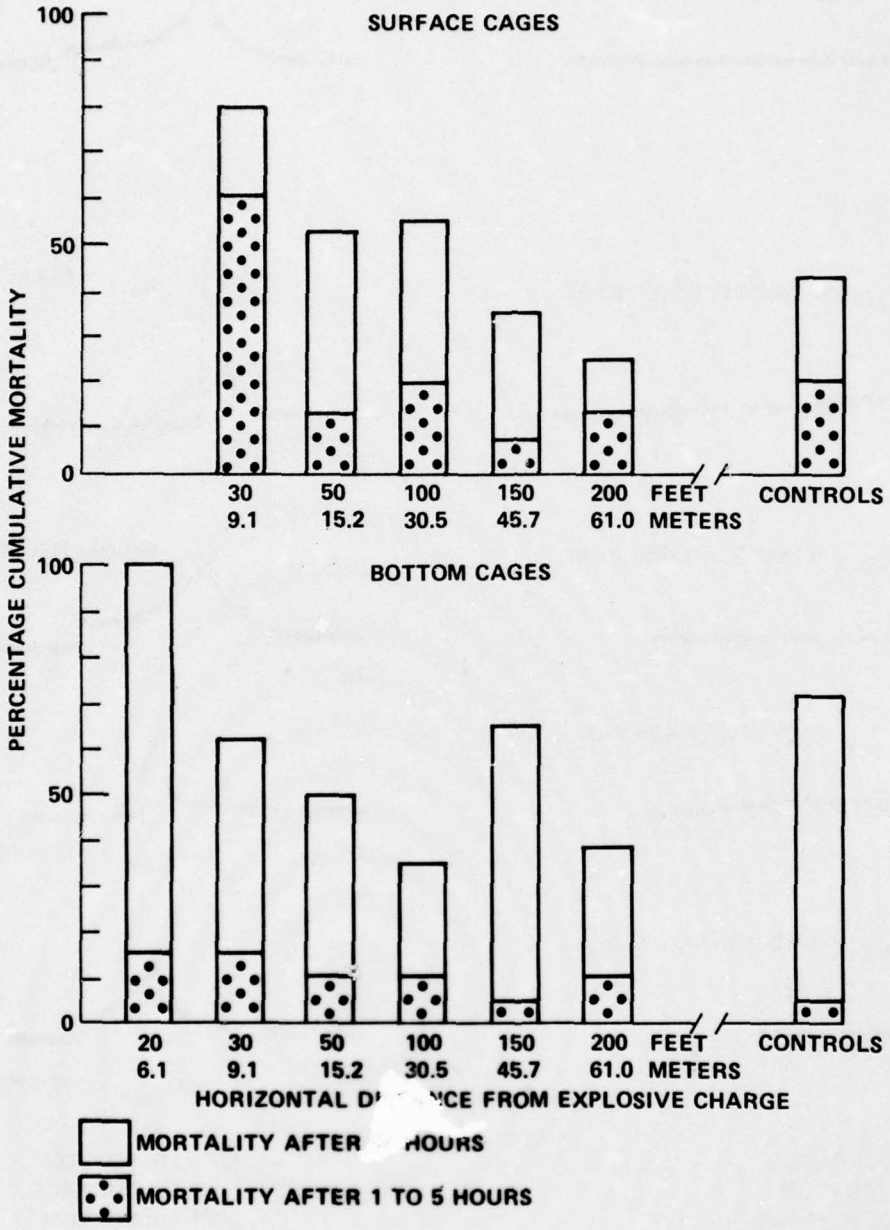


FIG. A2 CUMULATIVE BLUE CRAB MORTALITY, SHOT NO. 799

APPENDIX B

DIGITAL PRESSURE - TIME PLAYOUTS

Explanation of Symbols in Plot Headings

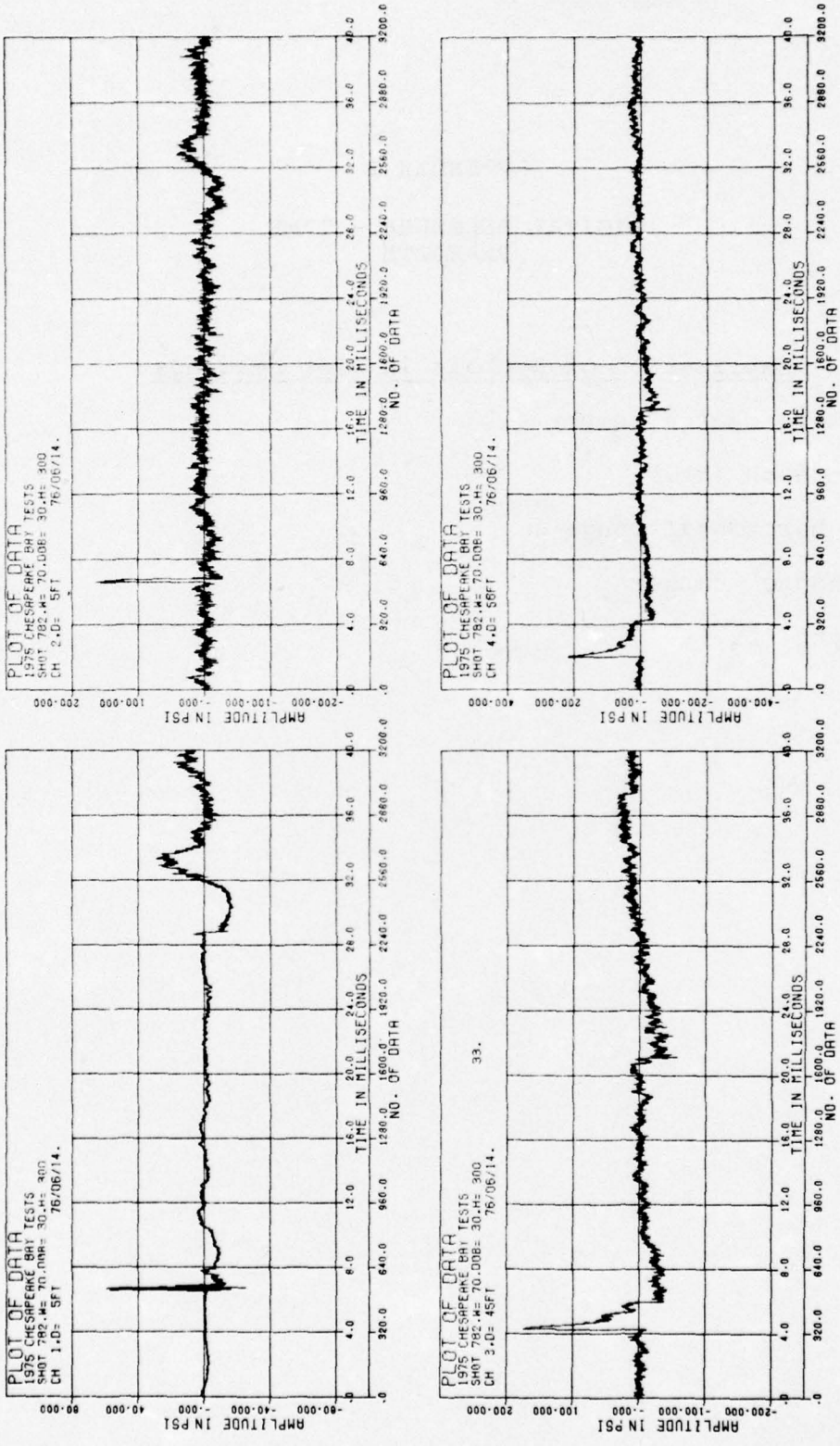
W - approximate charge weight (lb)

DOB - burst depth (ft.)

H - nominal horizontal range

CH - Tape Channel number

D - gage depth (ft.)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AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
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SHOT 782.W= 70.00B= 30.H= 300
CH 4.0= 58ft 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
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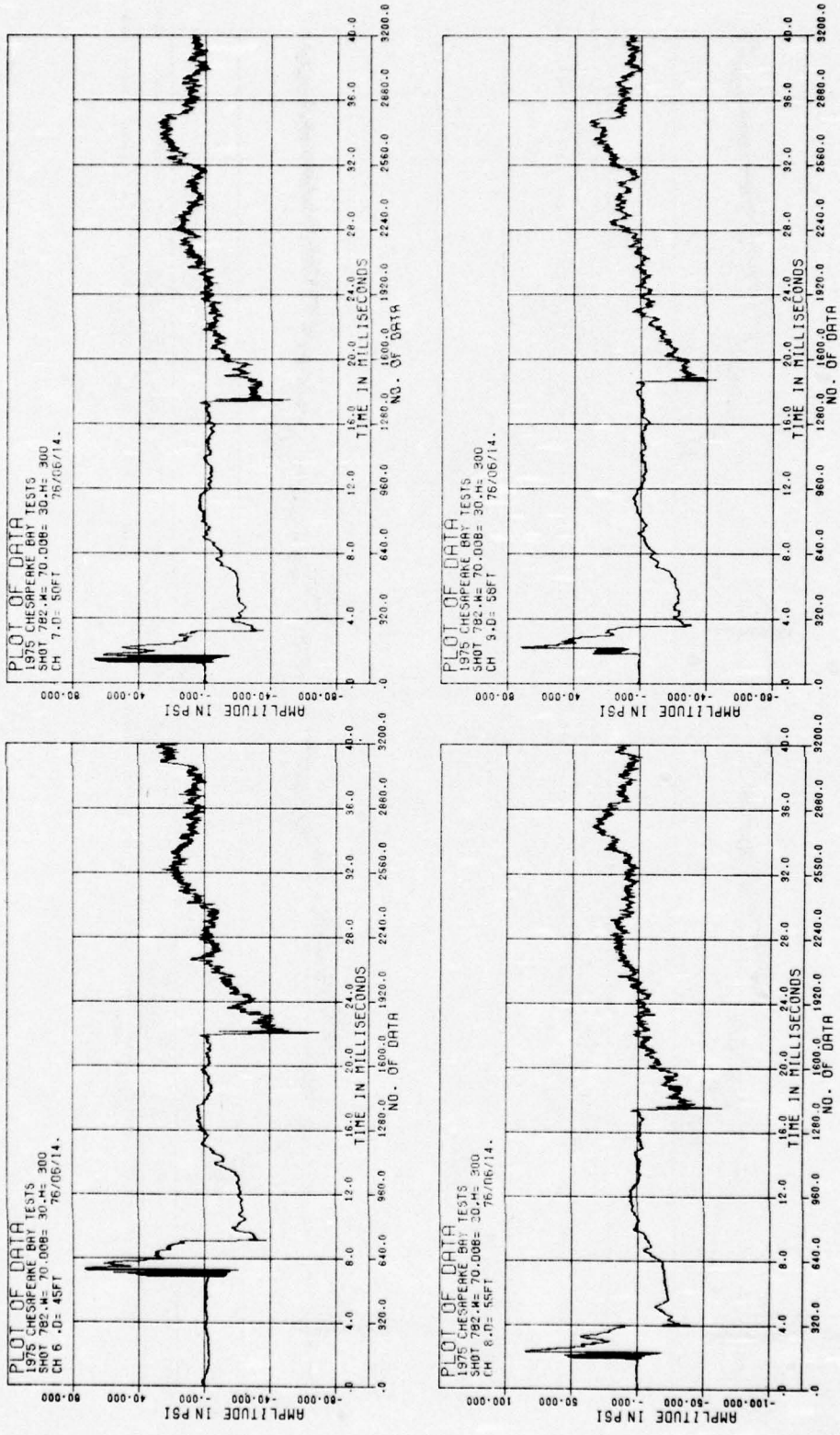
SHOT 782.W= 70.00A= 30.H= 300
CH 1.0= 5FT 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 782.W= 70.00B= 30.H= 300
CH 3.0= 45FT 76/06/14.
33.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA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PLOT OF DATA
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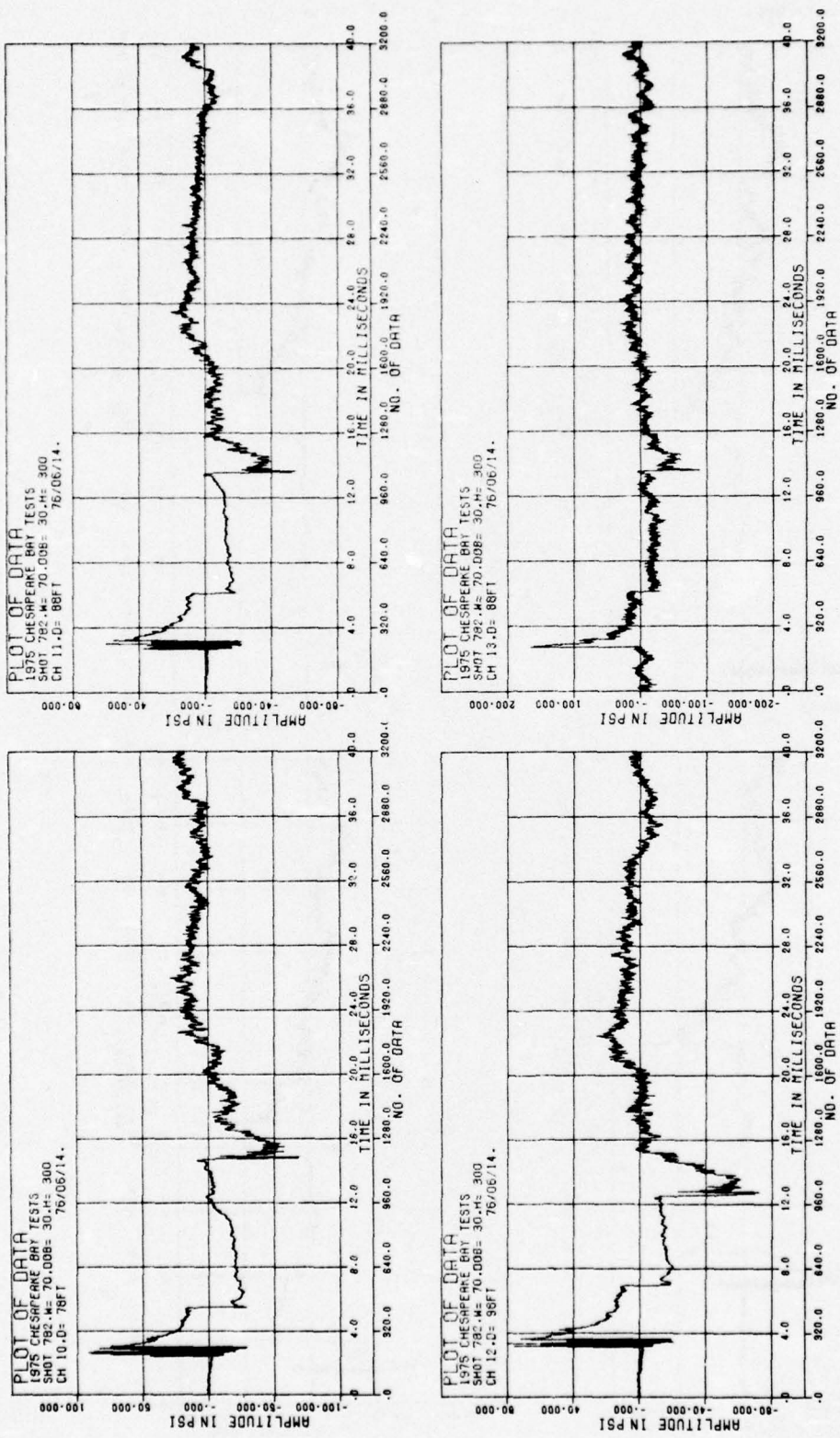
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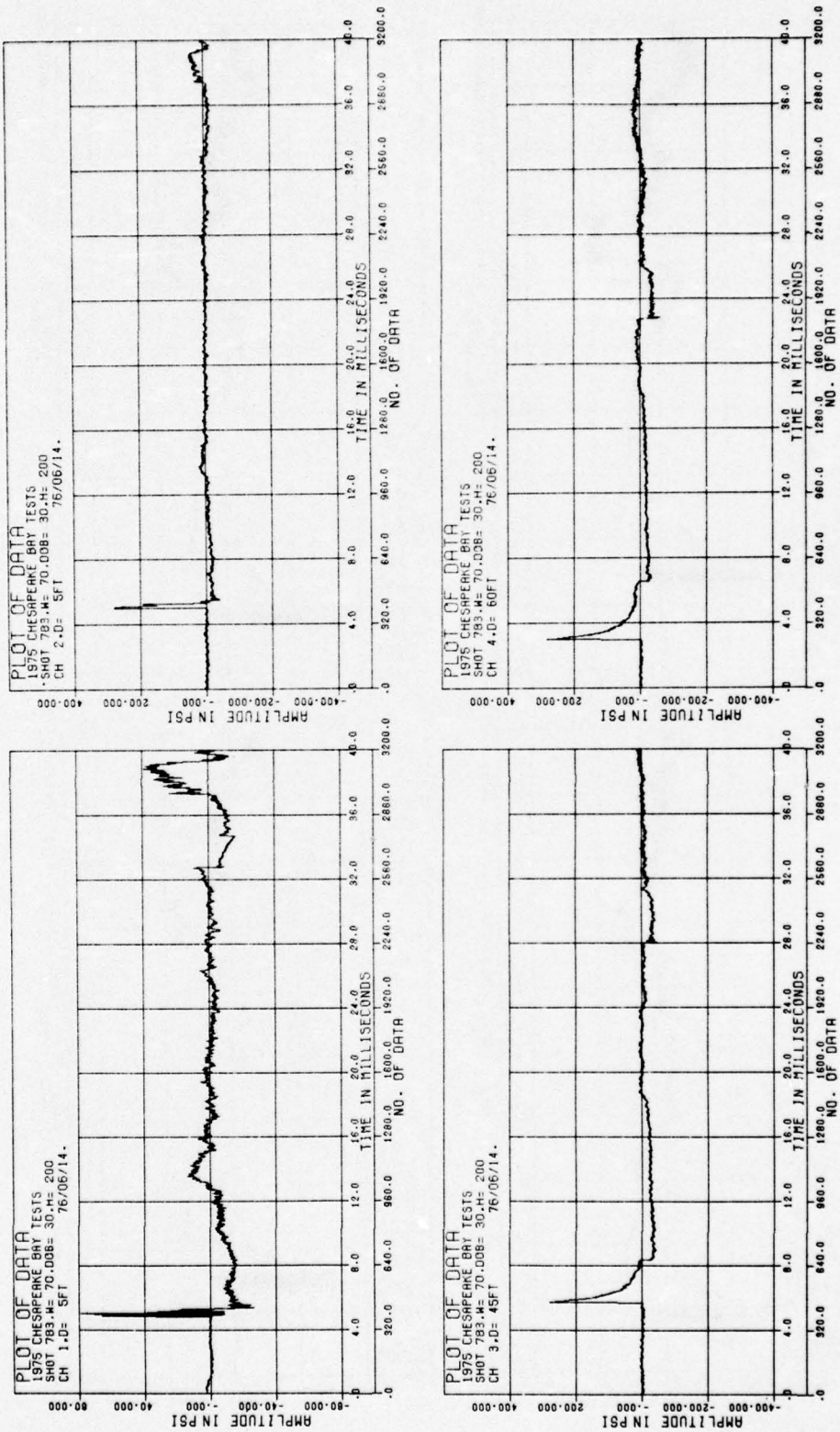
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NO. OF DATA
PLOT OF DATA
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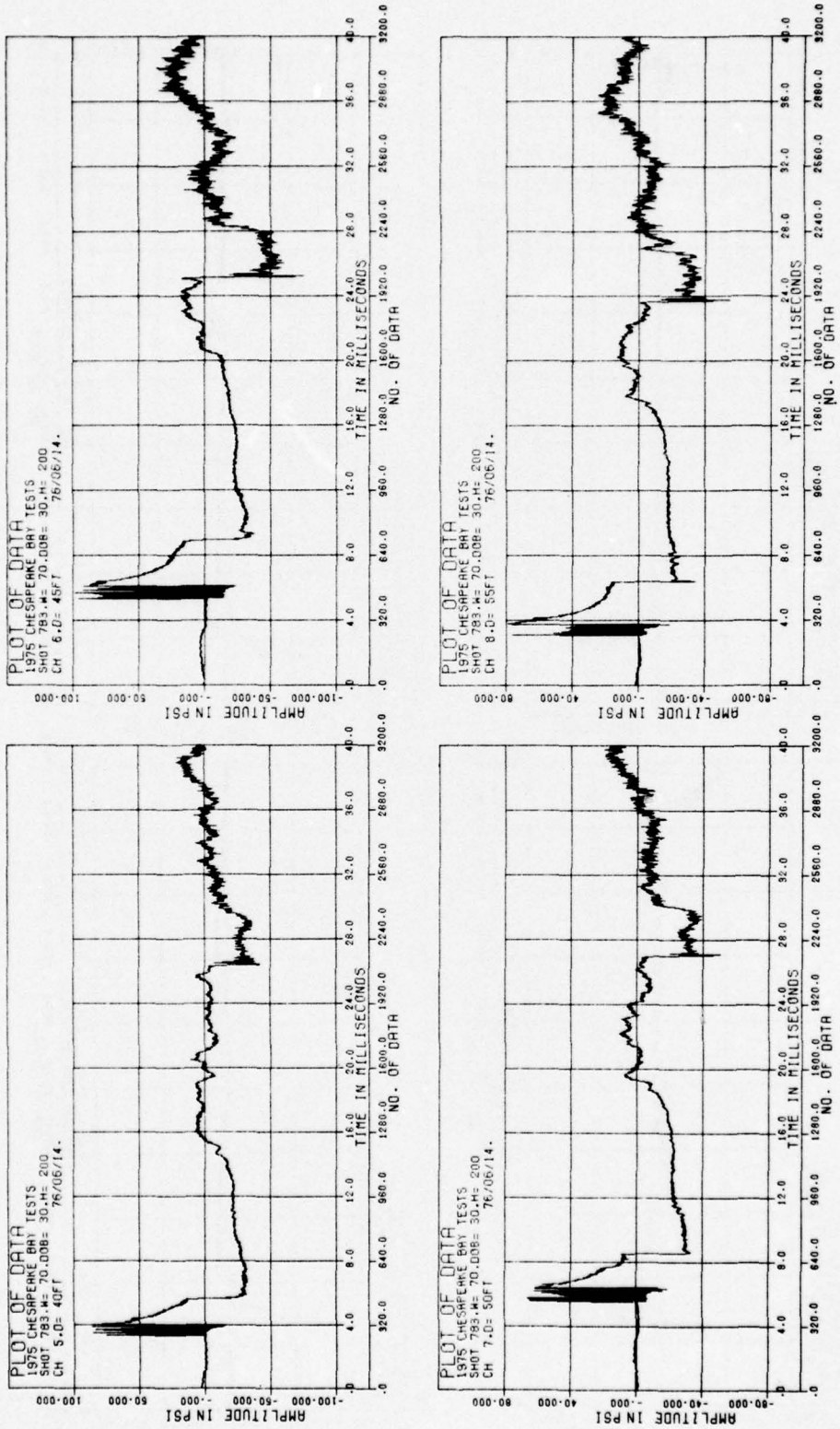
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CH 8.0= 55FT 76/06/14.
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 783.W= 70.00B= 30.H= 200
CH 5.0= 40FT 76/06/14.
PLOT OF DATA
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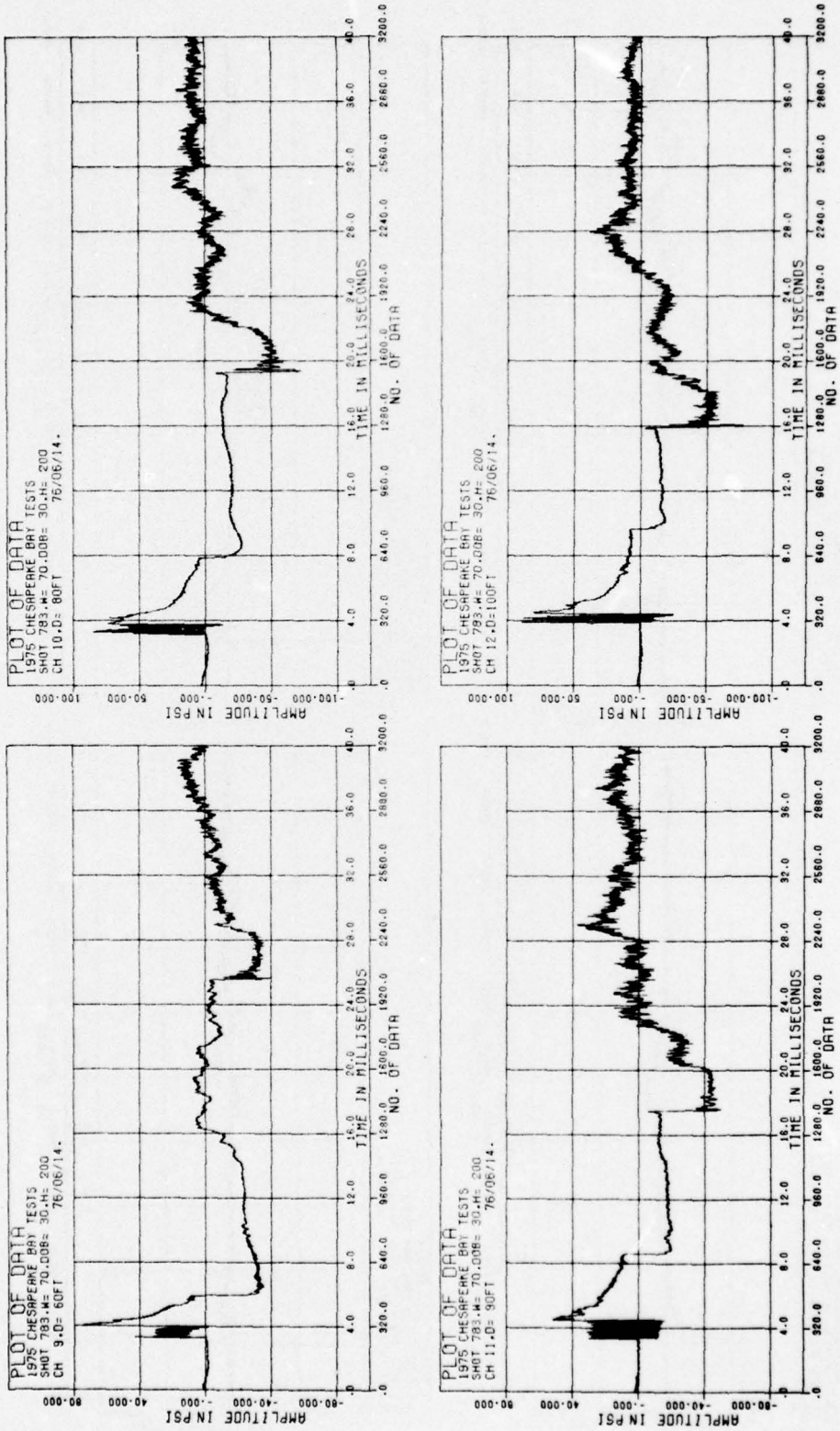
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PLOT OF DATA
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76/06/14.
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TIME IN MILLISECONDS
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PLOT OF DATA
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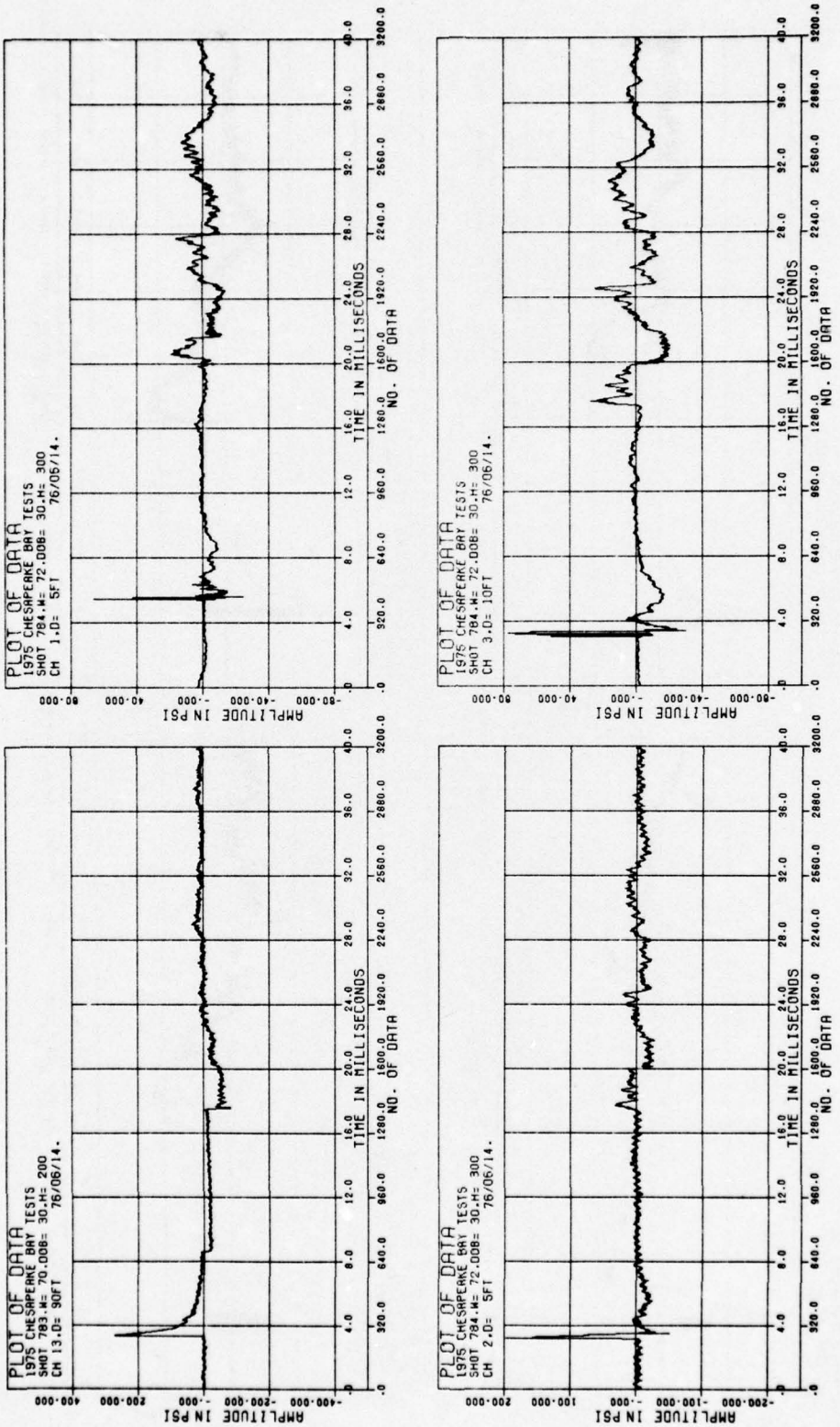
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NO. OF DATA
PLOT OF DATA
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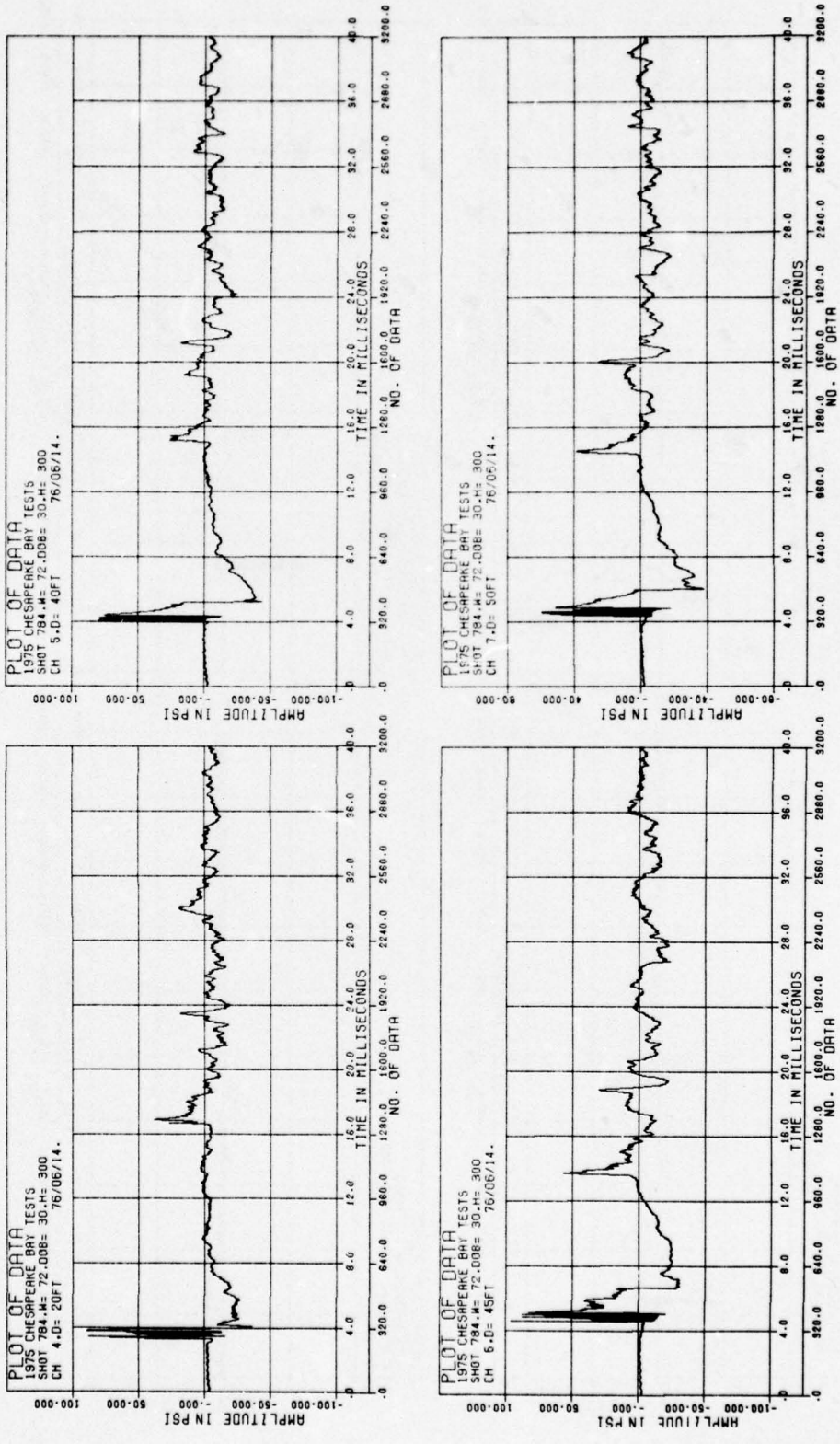
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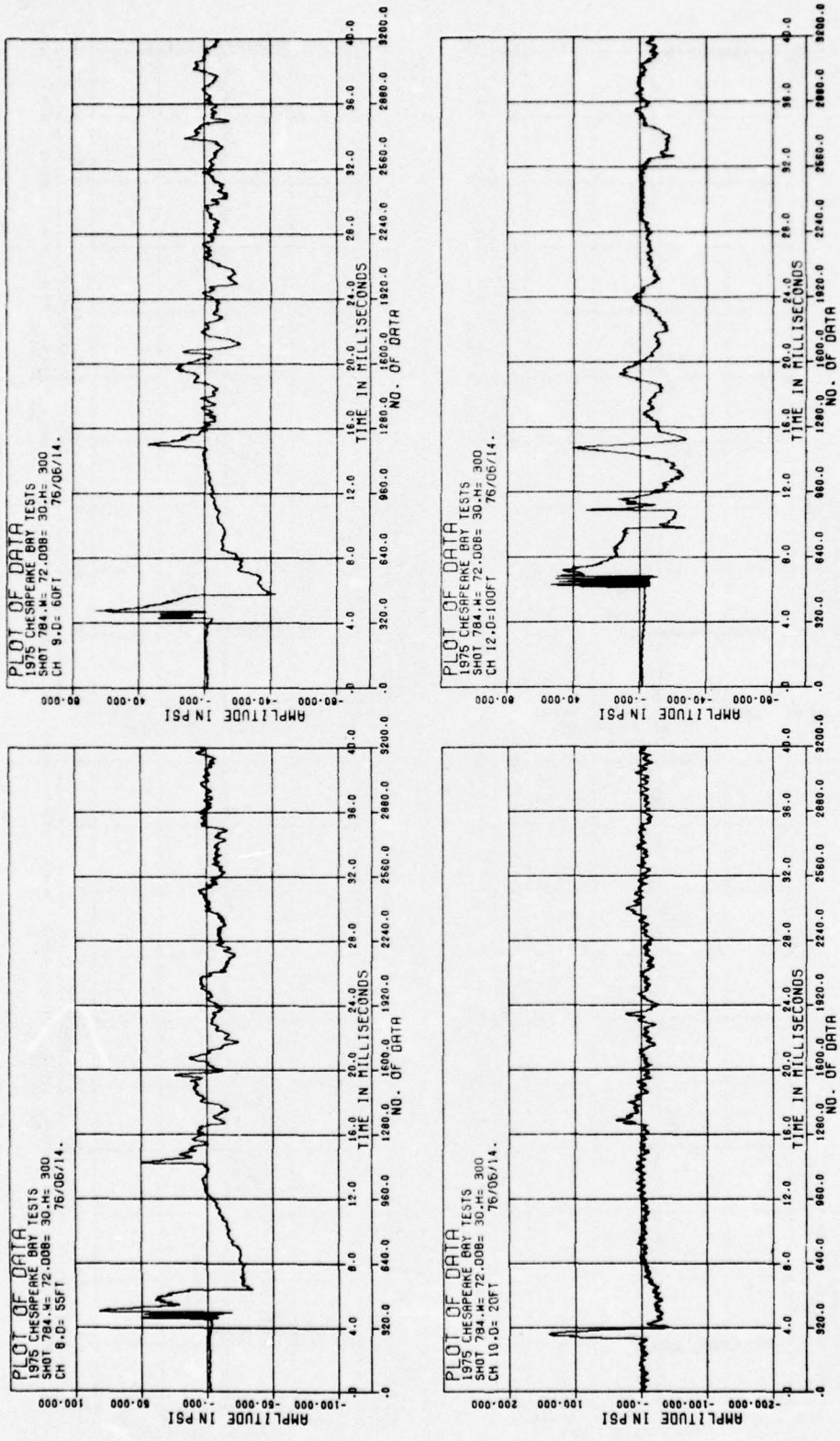
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PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
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TIME IN MILLISECONDS
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PLOT OF DATA
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TIME IN MILLISECONDS
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PLOT OF DATA
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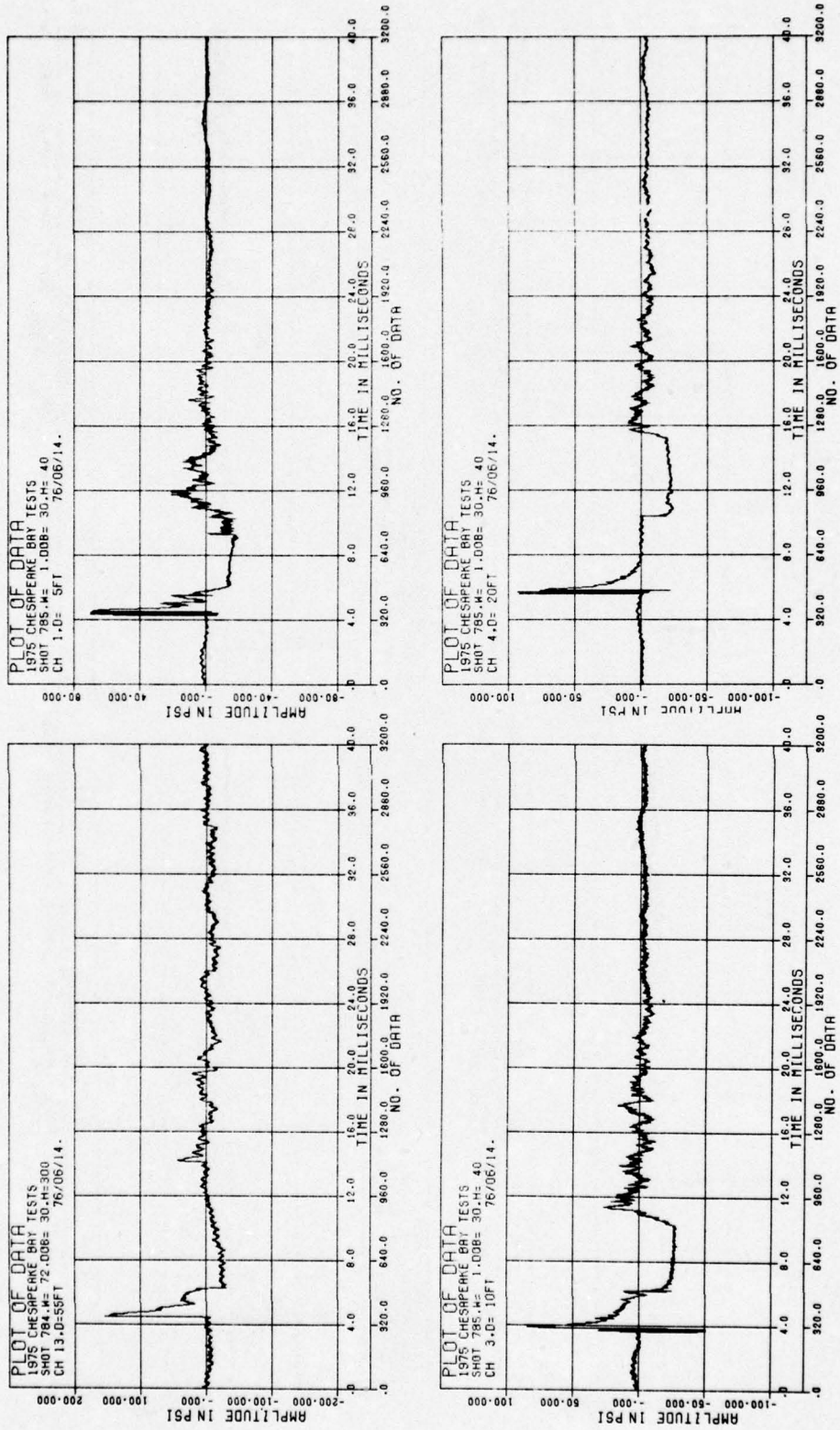
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PLOT OF DATA
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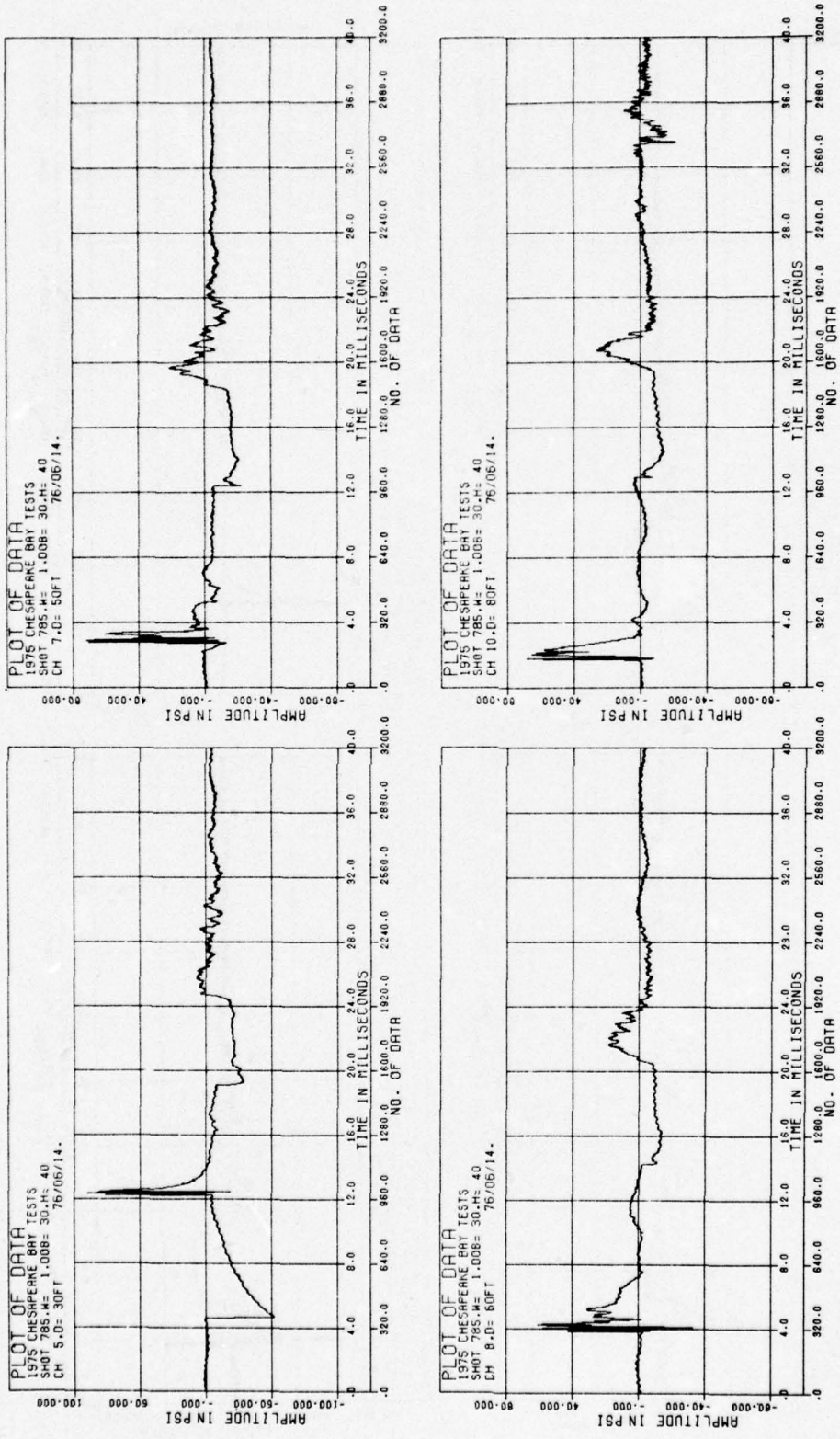
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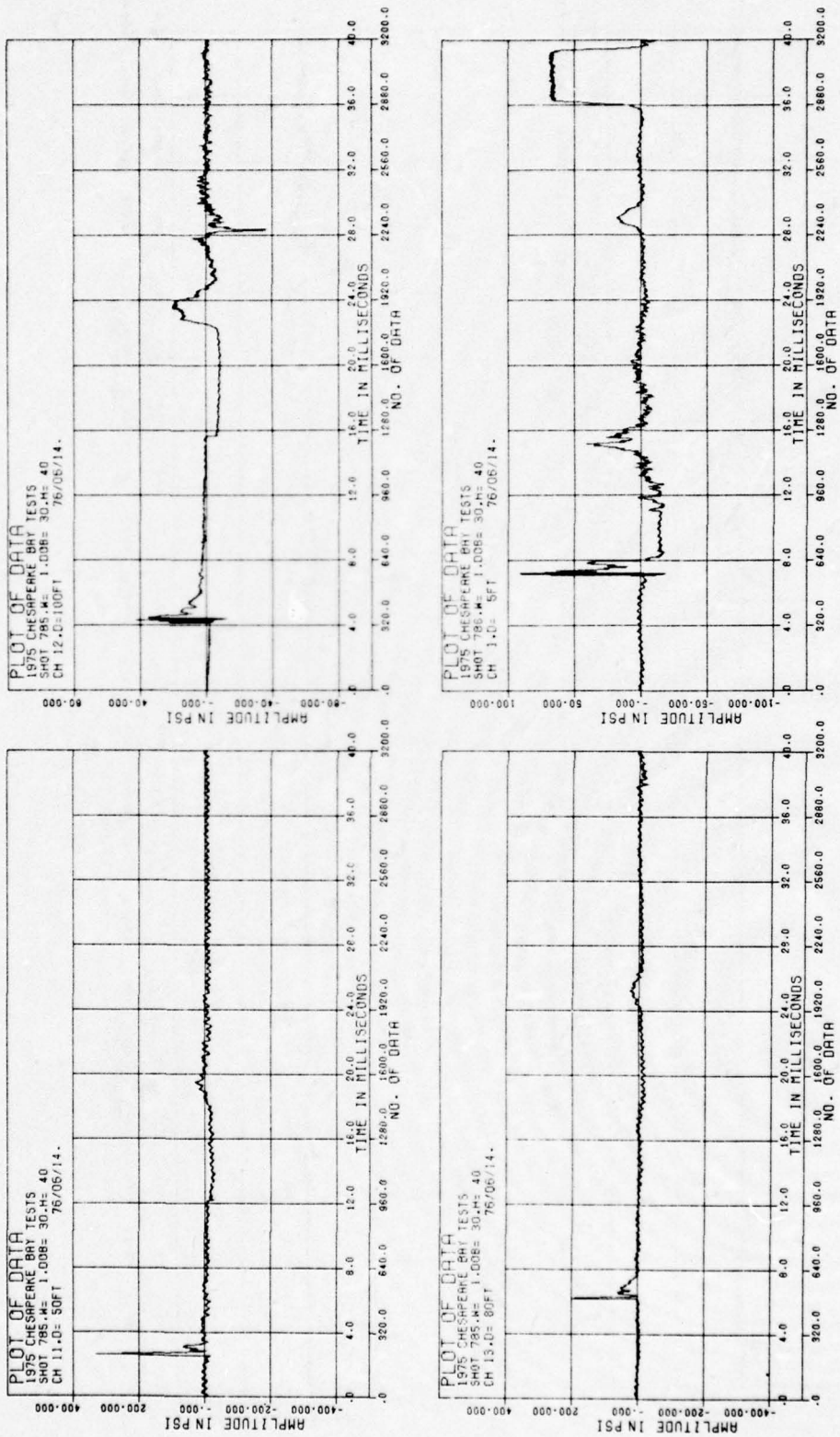
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NO. OF DATA
PLOT OF DATA
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CH 1.D= 5FT 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 785.W= 1.0DB= 30.H= 40
CH 11.D= 50FT 76/06/14.
AMPLITUDE IN PSI
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NO. OF DATA
PLOT OF DATA
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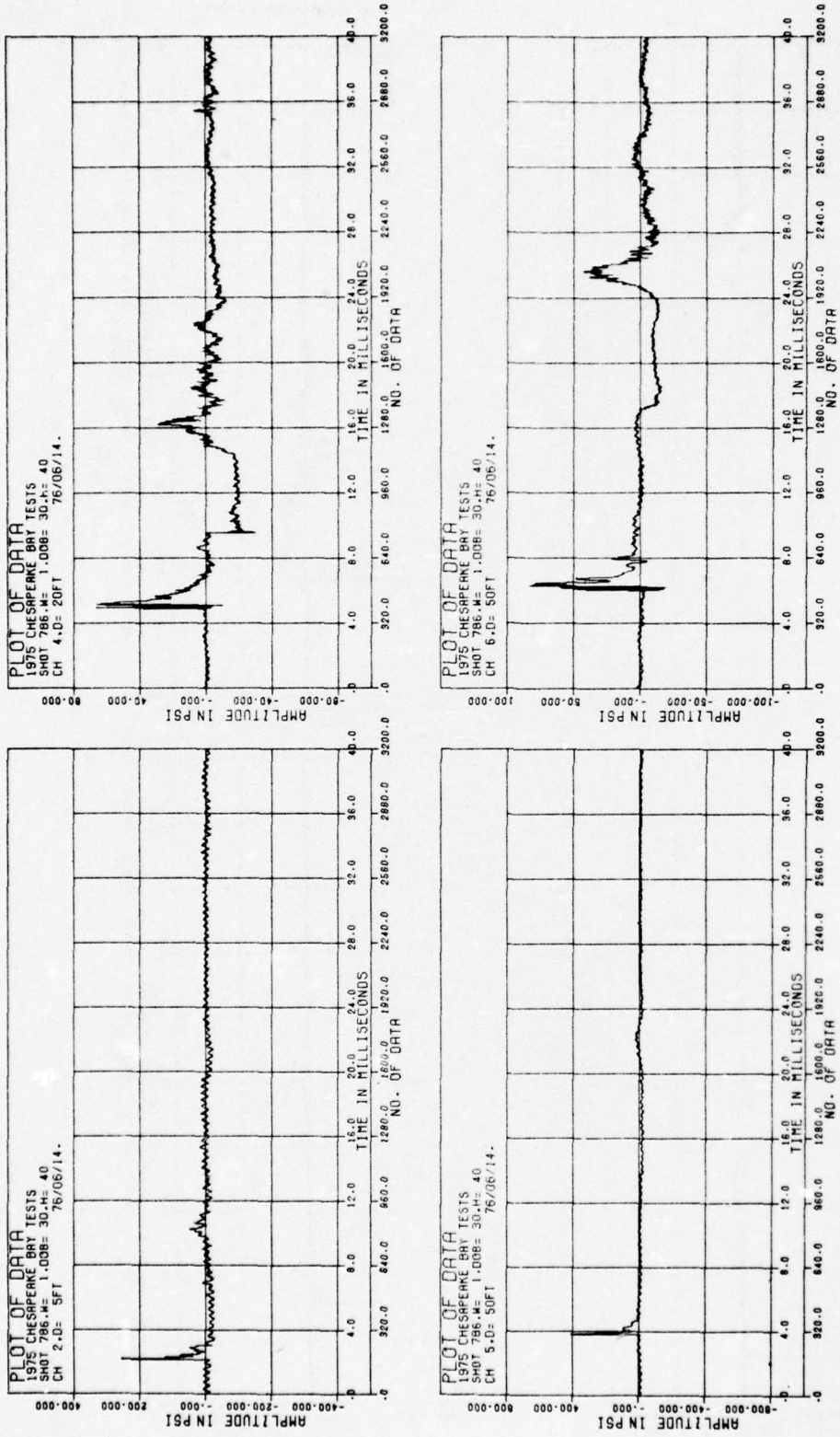
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TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 786.W= 1.00B= 30.H= 40
CH 6.0= 50FT 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 786.W= 1.00B= 30.H= 40
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AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
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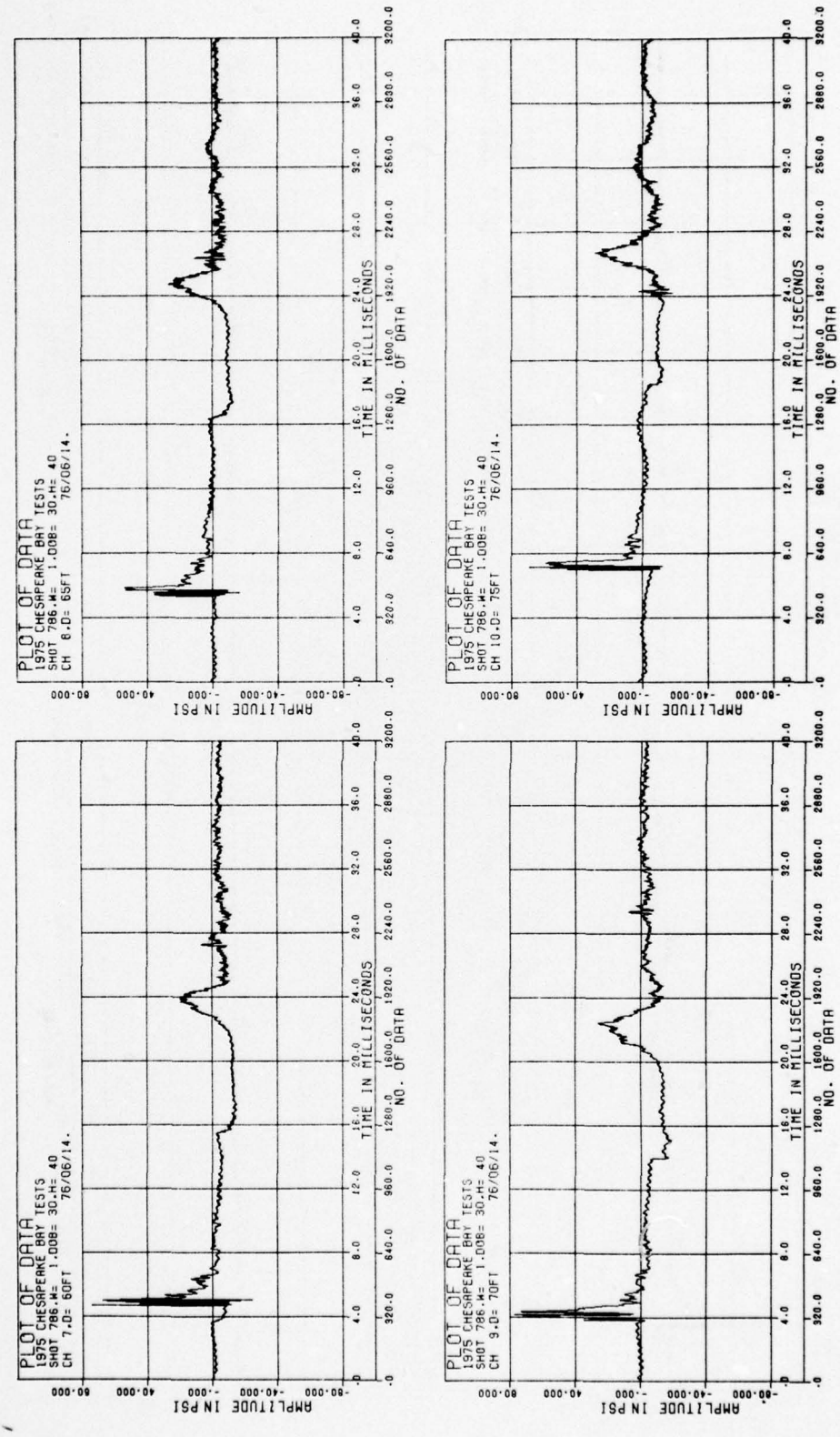
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SHOT 786.W= 1.00B= 30.H= 40
CH 8.D= 65FT 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
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SHOT 786.W= 1.00B= 30.H= 40
CH 7.D= 60FT 76/06/14.
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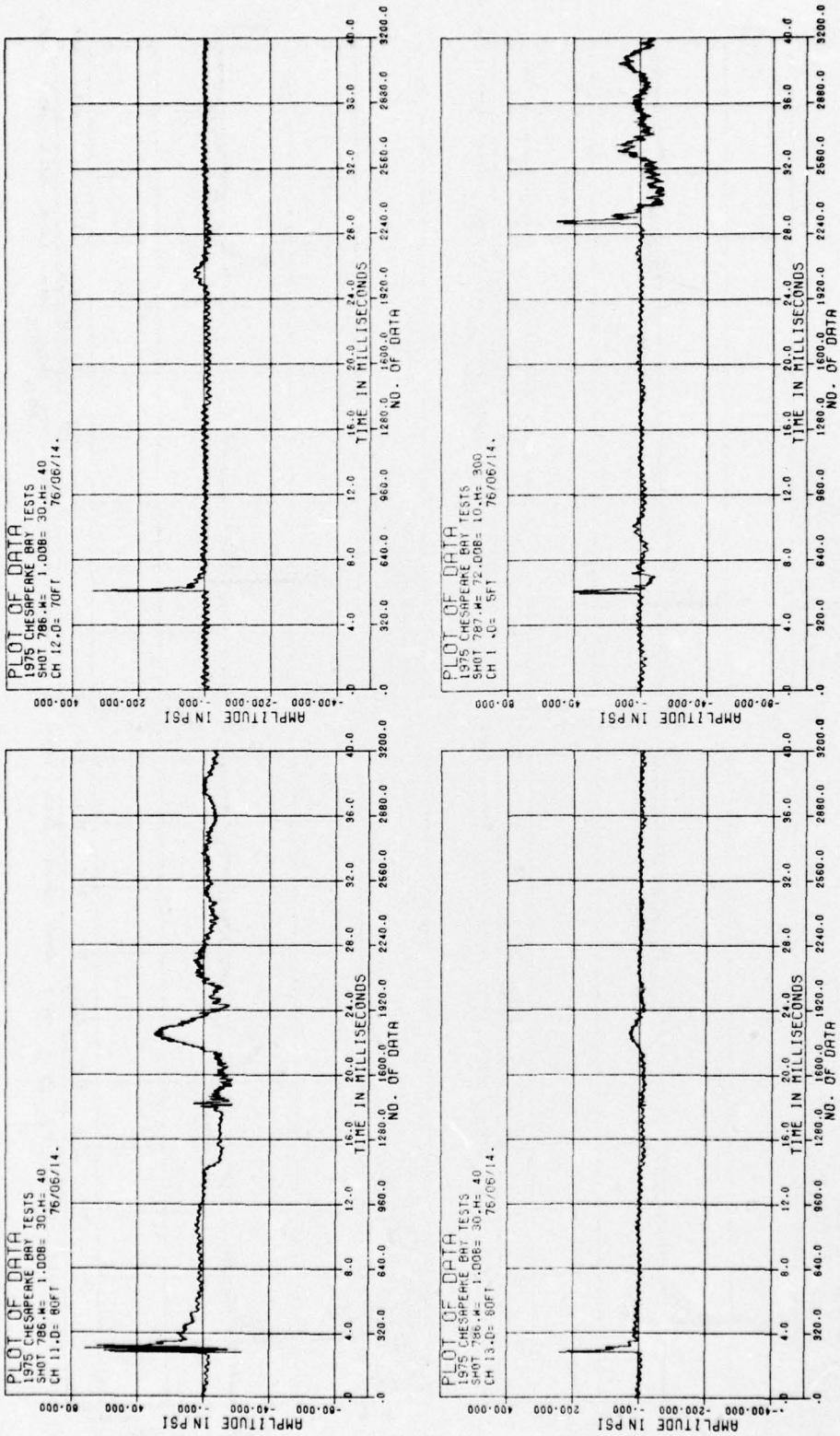
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SHOT 787.W= 72.00B= 100.H= 300
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CH 11.0= 80FT 76/06/14.
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CH 13.0= 60FT 76/06/14.
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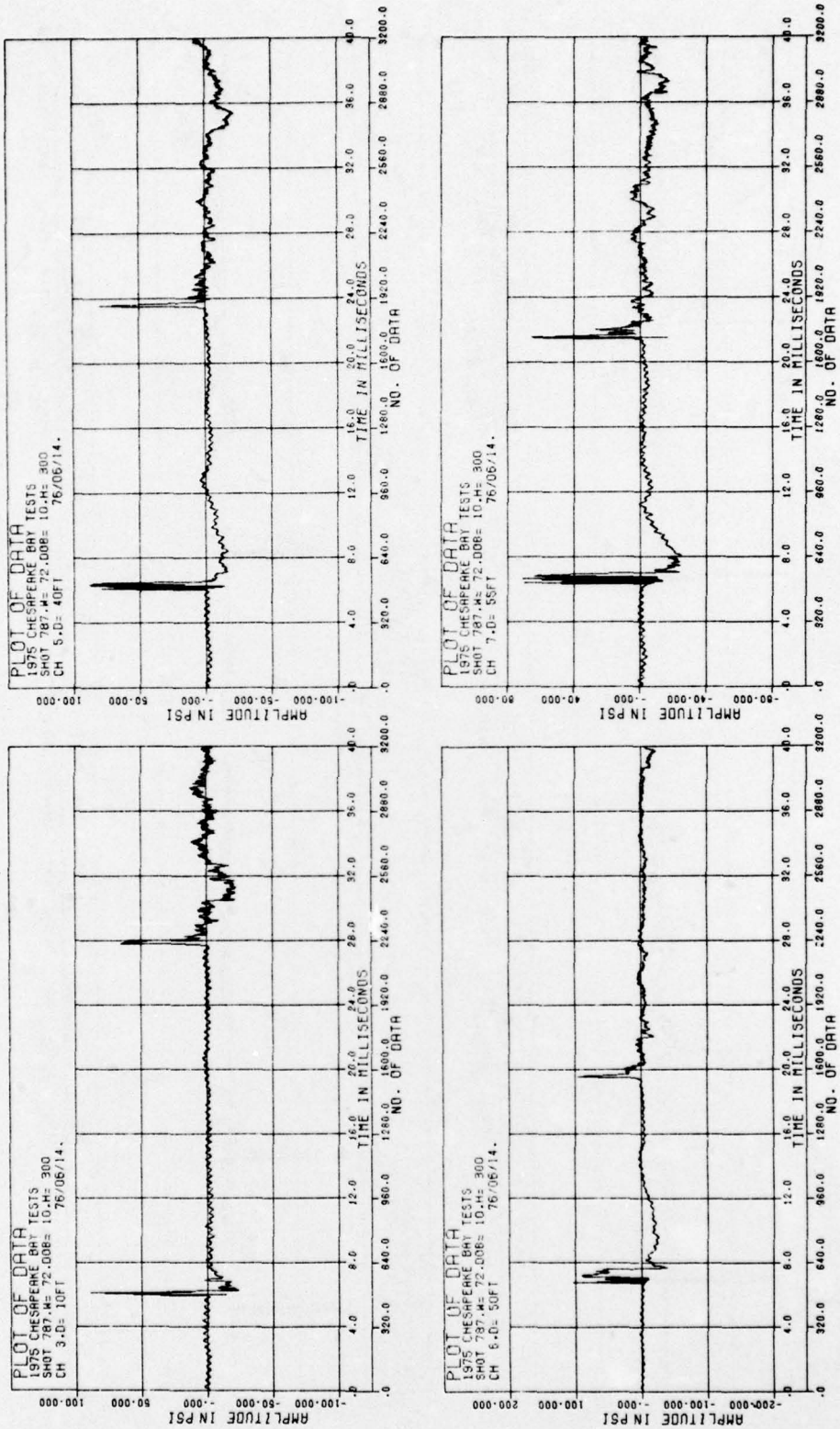
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CH 7.0= 55FT 76/06/14.
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SHOT 787.#= 72.00B= 10.H= 300
CH 3.0= 10FT 76/06/14.
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TIME IN MILLISECONDS
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1975 CHESAPEAKE BAY TESTS
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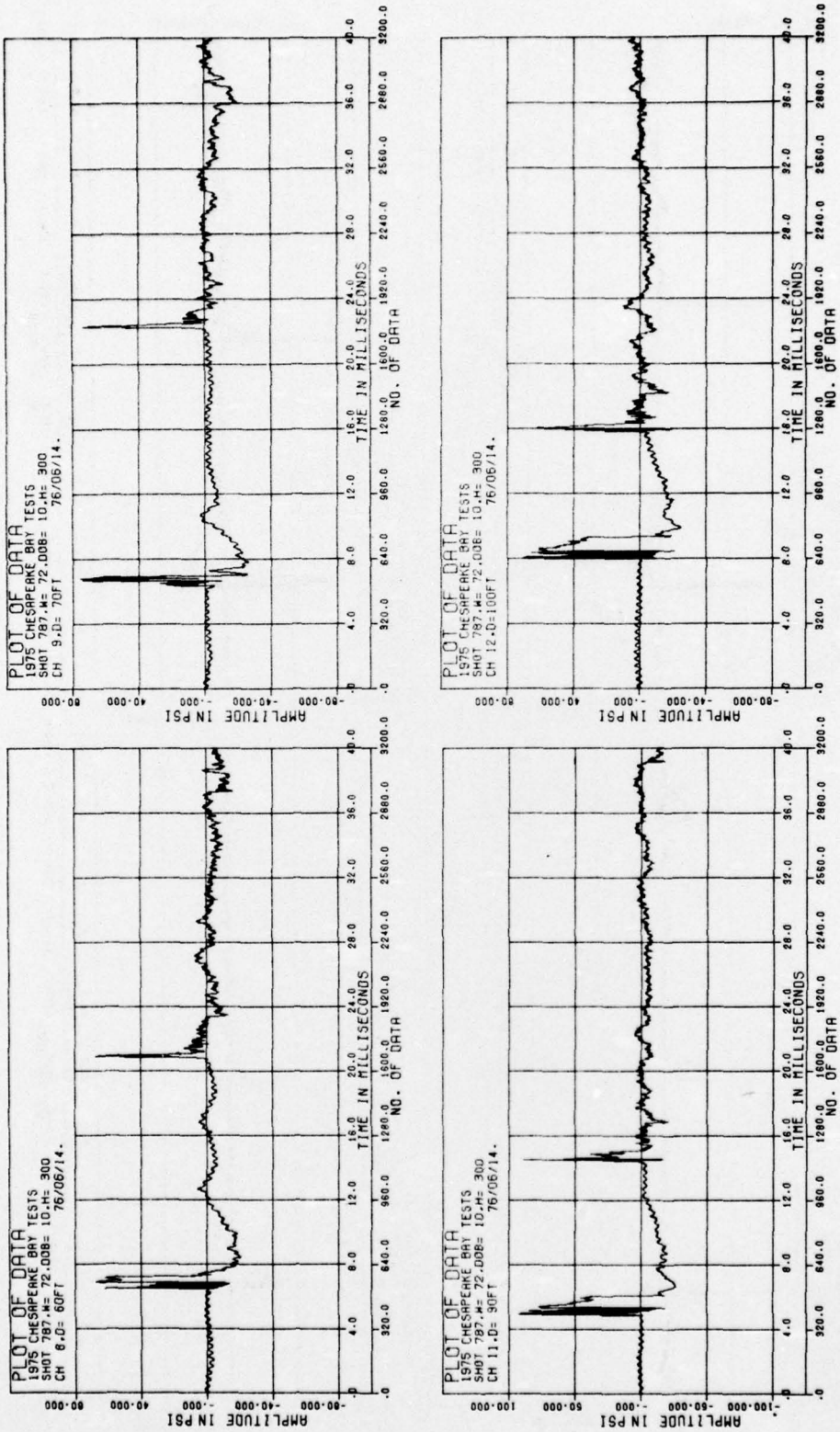
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NO. OF DATA
PLOT OF DATA
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SHOT 787.W= 72.00B= 10.H= 300
CH 12.0=100FT 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 787.W= 72.00B= 10.H= 300
CH 8.0= 60FT 76/06/14.
AMPLITUDE IN PSI
TIME IN MILLISECONDS
NO. OF DATA
PLOT OF DATA
1975 CHESAPEAKE BAY TESTS
SHOT 787.W= 72.00B= 10.H= 300
CH 11.0= 90FT 76/06/14.
AMPLITUDE IN PSI
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NO. OF DATA

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