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OPERATION DOMINIC

Shot SWORD FISH
Project Officers Report — Project 3.1
Shock Motions of Ships and Equipment

David Taylor Model Basin
Washington, D.C.

October 24, 1963

NOTICE

This is an extract of POR-2005 (WT-2005), Operation DOMINIC, Shot SWORD FISH, which remains classified SECRET/FORMERLY RESTRICTED DATA as of this date.

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The objectives were to determine the motions produced by the Sword Fish shock waves on ships (hull and equipment) and platforms in the vicinity of the burst; to correlate Sword Fish ship and platform motion with the shock waves and equipment damage; and to document by photographic film the surface gravity waves produced by the Sword Fish burst.

Gages and recording equipment were installed in DD-845, DD-826, DD-786, DD-681, and SS-394 and in two pontoon platforms to document structure and equpment response. The basic instrument employed in the shock measurements was the velocity meter. High-speed

20. Abstract (Continued)

motion-picture cameras recorded the response of selected equipment on DD-845, the ship closest to the burst. Cameras equipped with long-focal length lenses were used in documenting the response of DD-845 to surface gravity waves. Measurements, including photography, were made at a total of about 80 stations.

Measurements were obtained on all of the instrumented ships. Test results secured from the instrumentation effort are presented. The shock motions and their relation to free-water pressures are discussed. Measurements are compared with results of HE shock tests of DD-826 and SS-394.

The following conclusions refer to underwater nuclear bursts and are specifically concerned with Sword Fish conditions. The term "Sword Fish conditions" includes yield, shot geometry, bottom reflections, thermal-gradient characteristics, and target-ship types.

On a destroyer at 6,500 feet from the burst, vertical shock velocities resulting from the direct and reflected shock wave were about equal. On destroyers at 12,000 feet or greater, vertical shock velocities resulting from the reflected shock wave were two to ten times as great as the direct shock velocity. The shock loads on all ships were very low, and the shock velocities were less than 2 ft/sec. They were lower than those resulting from the HE shock tests conducted prior to Sword Fish. On all ships, the peak velocities and initial accelerations were appreciably reduced as a result of refraction.

Shock damage was less for Sword Fish than for the HE shock tests, because the shock velocities were lower for Sword Fish, and weaknesses revealed by the HE test were corrected prior to Sword Fish.

On ships at 12,000 feet or greater, damage resulted from the reflected shock waves rather than the direct.

In spite of the low shock levels, most ships within a radius of 15,000 feet of surface zero sustained appreciable impairment in their ASROC, conventional ASW, and antiaircraft capabilities. Ship mobility was not affected in any case.

FOREWORD

This report has had classified material removed in order to make the information available on an unclassified, open publication basis, to any interested parties. This effort to declassify this report has been accomplished specifically to support the Department of Defense Nuclear Test Personnel Review (NTPR) Program. The objective is to facilitate studies of the low levels of radiation received by some individuals during the atmospheric nuclear test program by making as much information as possible available to all interested parties.

The material which has been deleted is all currently classified as Restricted Data or Formerly Restricted Data under the provision of the Atomic Energy Act of 1954, (as amended) or is National Security Information.

This report has been reproduced directly from available copies of the original material. The locations from which material has been deleted is generally obvious by the spacings and "holes" in the text. Thus the context of the material deleted is identified to assist the reader in the determination of whether the deleted information is germane to his study.

It is the belief of the individuals who have participated in preparing this report by deleting the classified material and of the Defense Nuclear Agency that the report accurately portrays the contents of the original and that the deleted material is of little or no significance to studies into the amounts or types of radiation received by any individuals during the atmospheric nuclear test program.

ABSTRACT

The objectives were to determine the motions produced by the Sword Fish shock waves on ships (hull and equipment) and platforms in the vicinity of the burst; to correlate Sword Fish ship and platform motion with the shock waves and equipment damage; and to document by photographic film the surface gravity waves produced by the Sword Fish burst.

Gages and recording equipment were installed in DD-845, DD-826, DD-786, DD-681, and SS-394 and in two pontoon platforms to document structure and equipment response. The basic instrument employed in the shock measurements was the velocity meter. High-speed motion-picture cameras recorded the response of selected equipment on DD-845, the ship closest to the burst. Cameras equipped with long-focal-length lenses were used in documenting the response of DD-845 to surface gravity waves. Measurements, including photography, were made at a total of about 80 stations.

Measurements were obtained on all of the instrumented ships. Test results secured from the instrumentation effort are presented. The shock motions and their relation to free-water pressures are discussed. Measurements are compared with results of HE shock tests of DD-826 and SS-394.

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PREFACE

Shot Sword Fish was an underwater weapon-effects test conducted in the Pacific Ocean off the southwest coast of the United States in May 1962 as part of Operation Dominic. Sword Fish was the first fully operational test of the Navy's antisubmarine rocket (ASROC) weapon system in which a nuclear war reserve weapon was expended. Weapon effects information of importance to the advancement of surface-ship capability to conduct nuclear antisubmarine warfare was obtained. An overall description of the test efforts and a summary of preliminary results may be found in the Sword Fish Scientific Director's Summary Report which includes general information such as location and time of burst and a guide to Sword Fish Reports (Reference 28).

The planning and execution of this project were carried out by the Surface Ship Shock Section of the Shock Branch of the Structural Mechanics Laboratory of the David Taylor Model Basin. Important contributions during the operation were made by W. E. Carr, R. E. Baker, K. P. Shorrow, S. A. Denenberg, C. E. Lemich, M. E. Kegel, H. O. Snoots, J. P. Hendrican, W. F. Alexander, and C. R. Hilker.

Messrs Shorrow and Denenberg assisted materially in handling data used in this final report. The work of Mr. R. M. Burkley in programming refraction calculations for the IBM 7090 is gratefully acknowledged.

The close cooperation of the Naval Ordnance Laboratory Project 1.1 team and the Bureau of Ships Project 9.1 team assisted materially in the preparation of this report.

The assistance of the Naval Repair Facility at San Diego in the outfitting of the ships was worthy of special acknowledgment.

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INTRODUCTION

The overall purpose of this project was to obtain data on the effects of nuclear explosions on ships, particularly from the standpoint of shock damage to shipboard equipment. The data will be used to check theory, and to increase the knowledge of shock phenomena and effects. Accomplishment of the purpose would enable more reliable predictions of the effects of similar nuclear attacks and increase the reliability of extrapolation to other attack situations.

1.1 OBJECTIVES

The specific objectives of the project were to determine the motions produced by the Sword Fish shock waves on ships (hull and equipment) and platforms in the vicinity of the burst; to correlate Sword Fish ship and platform motions with the shock waves and equipment damage; and to document by photographic film the surface gravity waves produced by the Sword Fish burst.

1.2 BACKGROUND

A ship's ability to perform its major functions can be seriously disrupted by equipment damage under mild shock. This damage can result from enemy action or from delivery of its own weapons. Many examples of damage on destroyers resulting from self-delivered depth charges have been reported from structural firing trials (Reference 1). In these cases, damage was generally confined to areas of the ship near the stern, which was the closest part of the ship to the point of detonation. Because of the small size of the charge employed, the shock levels and damage decreased rapidly at greater distances from the charge.

With the development of nuclear depth charges such as the Mk 44 warhead for the antisubmarine rocket (ASROC), the ranges at which damage could be expected from a self-delivered charge were greatly increased. At these greater ranges, the effect of a ship length in decreasing the shock level became almost negligible. Consequently, equipment throughout the ship, subjected to very low shock levels in delivery of a conventional depth charge, could be subjected to considerably higher shock levels when delivering a nuclear depth charge.

World War II experience with influence mines and other near-miss explosions had pointed out the wartime aspects of the shock problem in ships when conventional charges were employed. Operation Crossroads pointed out the shock damaging aspects of nuclear devices when employed against naval and merchant ships. More extensive data on shock from underwater detonation of a nuclear device were obtained during Operation Wigwam (References 2 and 3). During Wigwam, instrumental measurements were obtained of the shock motions of simulated main machinery on simplified submarine targets (Squaws). Three surface units (YFNB's) were also instrumented during this Operation.

The Wigwam test showed that there were several successive shock excitations of the targets. At close ranges, the shock wave transmitted directly through the water produced the greater shock motion; however, at longer ranges a later motion caused by a shock wave reflected from the ocean floor was nearly as severe as that caused by the direct wave. The vertical motions of the YFNB's were observed to be approximately the same as the computed vertical motion of the surface water near the barges.

Shot Wahoo of Operation Hardtack provided considerably more data pertinent to problems resulting from the delivery of nuclear weapons. This shot involved surface ships under a simulated delivery in an offshore deepwater test. Shock motion and damage studies were made on structure and equipment in three destroyers and a merchant ship, which comprised the major elements in the test array (References 4, 5, and 6).

The destroyers had been removed from the reserve fleet and partially reactivated prior to Hardtack. The ships did not contain any of the electronic or weapon systems that are being installed in present construction. In fact, many of the items of electronic equipment that were aboard were removed prior to the test. The ships did serve to provide suitable testing units for main machinery items and for certain electrical equipment systems. Basic shock-motion data on the closest destroyers was not acquired, however, due to malfunctions of units in the timing and control systems.

Underwater-explosion shock tests on a variety of surface ships have indicated that weapons and electronic systems were particularly susceptible to shock damage (References 7 and 8). More recent tests sponsored by the Bureau of Ships, in accordance with a Chief of Naval Operations (CNO) Instruction (Reference 9) have supported the statements on the susceptibility of weapons and electronic systems to shock damage.

In the latter series of tests, large HE charges have been used to provide the shock-wave input to the ship. The charges have been detonated abeam of the ship in order to distribute the shock loading as evenly as possible over the entire length of the ship. Tests have been conducted to date in this program on an aircraft carrier, USS Midway (CVA-41) (Reference 10); a guided-missile cruiser, USS Galveston (CLG-3) (Reference 11); guided-missile destroyers USS Preble (DLG-15)(Reference 12) and USS Charles F. Adams (DDG-2) (Reference 13); the destroyer, USS Edson (DD-946) (Reference 14); and submarines USS Trout (SS-566) (Reference 15), USS Skate (SS(N)-578) (Reference 16), USS Bonefish (SS-582) (Reference 17), USS Skipjack (SS(N)-585) (Reference 18), and USS Thresher (SS(N)-593) (Reference 19).

An extensive series of shock tests has been conducted using HE charges and the Hardtack destroyers USS Fullam (DD-474) and USS Killen (DD-593). For the tests on Fullam, many items of electronic equipment were installed on the ships and tested. Modifications were made to the supports for the turbines and reduction gear in the engineroom of both destroyers.

The initial phase of these tests (conducted with Fullam up to shock levels twice as great as those encountered in surface ships tested under CNO instruction) bore out this experience of the operating-ship tests. Considerable damage to electronic systems was encountered in the early test stages.

By incorporating shock-hardening techniques at the test site, improvements were made in many systems (References 20 and 21). For a second phase of tests, additional improvements were incorporated in damaged equipment, and various modifications of shipboard shock-isolation systems for equipment were installed and evaluated. An operating ASROC system was installed and tested (Reference 22).

A large number of recording instruments was employed in the Fullam tests. Both basic-structure response and equipment response were recorded throughout the ship. Instrument locations similar to those for the Hardtack tests were used extensively. Some comparison was made with the Hardtack data (Reference 23).

The test series was completed using USS Killen as a target. Tests on Killen were conducted to shock levels 50 percent greater than those to which Fullam was tested. Main and auxiliary machinery components were the principal items tested in this phase (Reference 24).

1.3 THEORY

Estimates of the effects expected from Shot Sword Fish were made on the basis of the results of Wigwam and Shot Wahoo of Operation Hardtack. Estimates were based on the following assumptions: (1) a weapon with a yield of about fired at a depth of 700 feet in water approximately 13,200 feet deep; (2) a TNT equivalent of percent of the expected yield; (3) acoustic-ray-path theory without refraction.

If instead of the above, a thermal structure similar to that at the Hardtack site is assumed, the estimates are conservatively high, particularly for ships at large standoff.

A pressure wave reflected from the ocean bottom was also expected. The effects of the reflected wave were computed by assigning an average reflection coefficient (pressure ratio) of about 30 percent to the ocean bottom.

In Shot Wahoo, a device had been fired at a depth of 500 feet over a sloping bottom with a depth at the charge location of 3,500 feet. With the larger yield and deeper placement of the ASROC depth charge in Sword Fish, the effects of the initial shock wave would be greater than for Wahoo for a surface target at a given standoff. With the greater depth of water, the effect of the bottom-reflected shock wave was expected to be less severe for Sword Fish than for Wahoo for a surface ship in the range of the Sword Fish targets.

1.4 SELECTION OF TARGET RANGES

Placement of the target ships for Sword Fish was based on current and proposed safe-delivery ranges for ASROC. Safe-delivery ranges are based on several factors: hull damage, equipment shock damage, personnel injury, and radiological effects. Hull damage was not expected on any of the target ships as a result of Shot Sword Fish. Radiological aspects are the subject of another project report. Personnel injuries, as a direct result of shock, would not be expected.

The selected locations for participating units of interest to Project 3.1 (promulgated in Reference 25) are shown in Table 1.1 and Figure 1.1. Preshot estimates of vertical velocity at the indicated locations are also given in Table 1.1. An estimated velocity as a result of the bottom-reflected wave is also indicated.

Because of the low shock severity expected, shock damage at these ranges should be less than that encountered on operating ships in the most severe of the shock trials described in References 10 through 19.

TABLE 1.1 PRESHOT ESTIMATES FOR SHOT SWORD FISH

Ship	Location from Surface Zero		Vertical Velocity	
	Range	Azimuth	Direct Wave[a]	Bottom Reflection
	feet	degree	ft/sec	ft/sec
DD-845	6,000	0	2.5	1.2
DD-826	12,000	270	0.6	1.0
DD-786	12,000	345	0.6	1.0
DD-681	12,000	15	0.6	1.0
Platform P-2	2,000	0	21.8	1.4
Platform P-1	3,000	0	9.2	1.4

[a] Refraction effects not included. Refraction would normally cause a decrease in each of the indicated velocities, primarily for the direct wave.

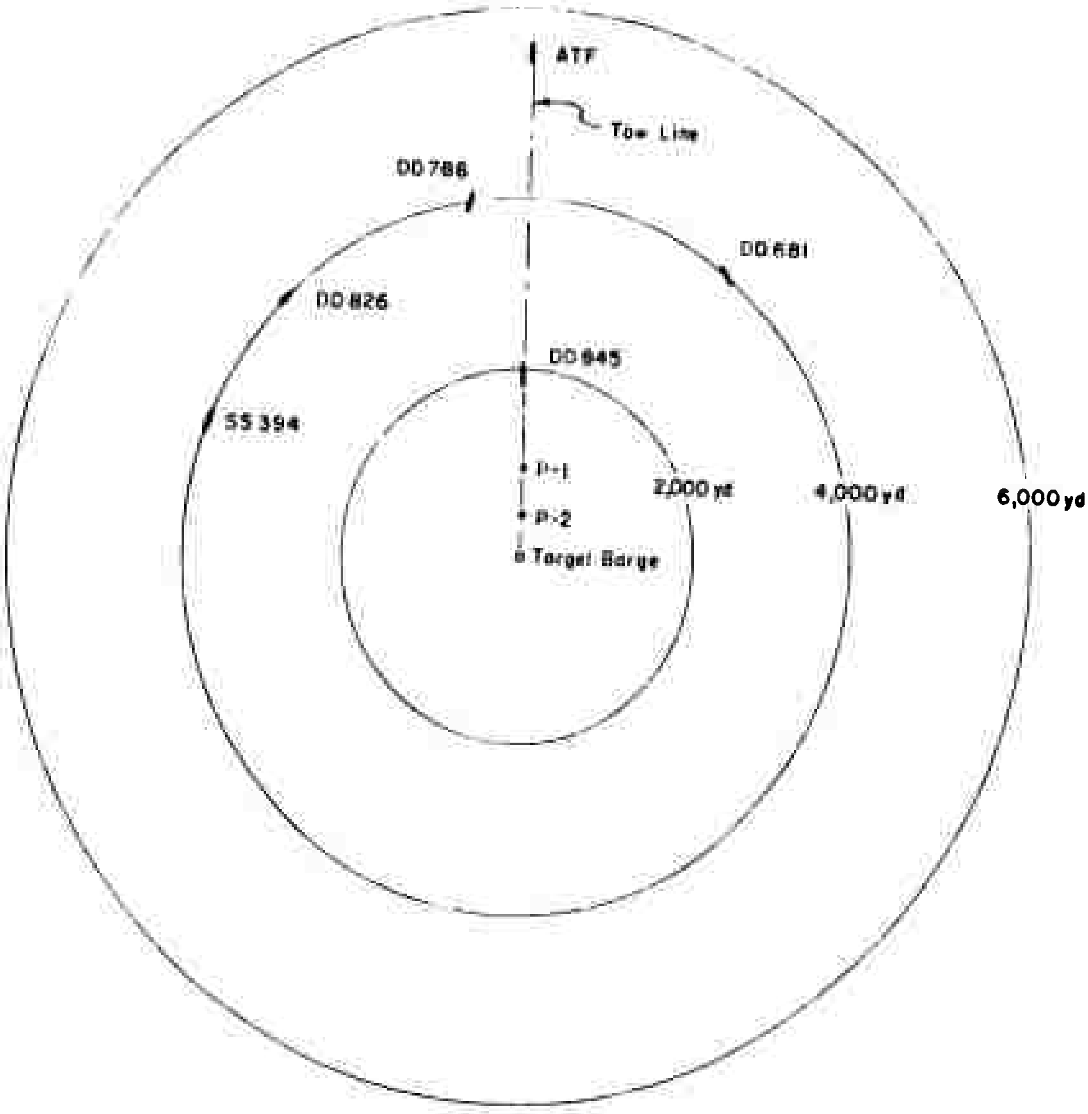

Figure 1.1 Planned array arrangement for Shot Sword Fish.

Chapter 2

PROCEDURE

To accomplish the project objectives, shock motions of structure and equipment foundations were recorded as functions of time on five ships and two platforms. High-speed motion pictures were made of the response of selected equipment on the ship closest to surface zero. Motion pictures were made of the surface-wave phenomena from three ships.

2.1 OPERATIONS

Shot Sword Fish consisted of the launching of an ASROC depth charge under operational conditions with instrumented ships and platforms in place to determine the effects of the detonation. The test array consisted of a fleet tug (ATF) towing a destroyer (USS Bausell, DD-845), instrumented platforms, coracles, and a target barge. A second destroyer (USS Agerholm, DD-826) projected the nuclear depth charge at the target barge. A standby ASROC-firing destroyer (USS Richard B. Anderson, DD-786), a submarine (USS Razorback, SS-394), and a destroyer (USS Hopewell, DD-681) equipped with special sonar, completed the array. An LSD served as a handling station for the smaller elements in the tow, and as a photographic platform.

Extensive measurements of shock motions were made on the towed destroyer. Fewer measurements were made on the three operating destroyers and the submarine, and a few measurements were made on two of the Project 1.1 instrument platforms.

DD-845, DD-826, and DD-786 were post-World War II ships which had received Fleet Repair and Maintenance (FRAM) Mark I conversions. These ships had an overall length of 390 feet, maximum breadth of 41 feet and a design draft of 13 feet. In tne conversion,the aft gun mounts and the amidship torpedo tubes were removed. An ASROC system was installed as well as a helicopter landing platform and a hangar.

All three ships were assigned directly from the Pacific Fleet. Prior to Sword Fish, all ships in the array except the tug and LSD were tested at a low shock level using HE charges, to detect any outstanding deficiencies in equipment behavior under shock. For the HE shock test, the submarine was surfaced. Equipment was carefully checked and adjusted on each of these ships by cognizant Navy and industrial engineers, prior to Sword Fish,to insure that ships were operating at full capability. Shock motions were recorded on DD-826 and SS-394 during the HE tests.

All of the ships were manned during Sword Fish except Bausell. This ship was in tow and recording systems on the ship were remotely operated by radio signals.

instruments on two instrument platforms were also remotely operated. These platforms were in the towed array astern of Bausell, and were primarily used for locating strings of pressure gages for Project 1.1. The location of the platforms is indicated as P-1 and P-2 in Figure 1.1.

2.2 INSTRUMENTATION

To accomplish the project objectives, the shock motion as a function of time and the response of selected ship equipment and structures were determined. The measurements included the determination of the shock motions and response at representative locations on four DD's, an SS, and on two instrument platforms. In all, 73 channels of time-based shock motions were recorded. In addition, high-speed movies of the shock response of equipment and motion pictures of the response of the towed destroyer to the surface gravity waves were taken.

Because of the difficult environmental conditions, reliable and simple instruments were chosen. Pickups and recording instruments susceptible to damage from dampness or sensitive to spurious mechanical, electrical or acoustical signals were avoided.

The system for measuring the shock motion on the manned ships consisted essentially of a bar-magnet velocity meter whose output was recorded on photographic paper in a multichannel electromagnetic (string) oscillograph. On the towed ship, the bulk of the data was recorded on magnetic tape, since there was a possibility of radiation exposure of photographic material. In addition, the magnetic-tape records lend themselves more readily to high-speed data-reduction techniques. Complete analysis of the motion of the closest ship was considered most desirable. Recording gear installed on DD-845 is shown in Figure 2.1.

2.2.1 Velocity Meters. Velocity meters were chosen as the primary instrument for measuring shock motion, because velocity as a function of time has been found to be the most useful parameter for characterizing shipboard shock motions. Peak accelerations can be measured from the slopes of the records, and displacements can be determined by a single integration. In recording shipboard shock motion, it has been frequently found that the comparatively high accelerations associated with the high-frequency modes of motion tend to obscure the generally more important lower frequency modes of motion which have larger displacements associated with them.

Two types of velocity meters were used for these tests, the David Taylor Model Basin (DTMB) bar magnet and a meter developed at the Underwater Explosions Research Division, Norfolk Naval Shipyard, Portsmouth, Virginia (UERD). The DTMB meter was designed to drive a string galvanometer directly, and the UERD meter was used with magnetic tape recording equipment.

The principle of operation of both meters was similar. In each, one pole of a bar magnet was suspended in a coaxial cylindrical coil. A spring mounting permitted the magnet to move along the axis of the coil, which was attached rigidly to the base of the instrument. Motions of the base produced a voltage in the coil proportional to the relative velocity between the coil and magnet. The output voltage was recorded directly on an oscillograph or tape recorder to obtain a time history of the velocity. Typical velocity-meter installations are shown in Figures 2.2 and 2.3.

The velocity-time records could be corrected to compensate for relative motion between the magnet and coil. The motion resulted from the excitation of the spring-mass system. In the case of records in which the target displacement exceeded the length of stroke, a second correction could be made to compensate for the record change which resulted when the magnet struck the stops at the ends of the stroke.

2.2.2 High-Speed Motion-Picture Cameras. Two types of high-speed motion-picture cameras were used to photograph the shock motion of selected equipment on the towed destroyer. One of these, the Fairchild HS-100, was the same type employed by the DTMB project in Hardtack (Reference 4). These cameras have a capacity of 100 feet of 16-mm film and were operated in Sword Fish at a speed of 500 frames/sec. In order to increase the effective running time of these cameras, two cameras were operated in sequence at each location giving an effective running time of about 16 seconds. The Fairchild cameras were protected from shock by utilizing a modification of the Hardtack camera-mounting arrangements. In this modification, the mount frequency was maintained by using lighter shock cord, since the heavy lead radiation housings used in Hardtack were not considered necessary.

The second type of camera was the Photo-Sonics 16-mm 1B. These cameras were equipped with 200-foot magazines for 16-mm film and were also operated at 500 frames/sec. A shock-mounting arrangement similar to that employed on the Fairchild installation was used. A typical high-speed camera installation is shown in Figure 2.4.

Light for the high-speed photography was obtained from long-burning flash bulbs. Sequential firing of bulbs resulted in a fairly uniform light source for a period of 16 seconds.

2.2.3 Motion-Picture Cameras for Surface Effects. Two cameras were installed on the towed ship to photograph surface effects and surface waves resulting from the burst. A 16-mm Milliken and a 16-mm Traid camera were utilized for this purpose.

The Milliken camera with 400 feet of film, operating at 64 frames/sec, recorded surface effects for 4 minutes following launch of the ASROC. The Traid with 100 feet of film, operating at 150 frames/sec, recorded these effects in the time period from 30 to 60 seconds after launch. Both cameras were in fixed mounts and were trained directly astern of the ship.

The response of DD-845 to surface waves generated by the Sword Fish burst was photographed from stations on the two other FRAM destroyers. On the firing ship, DD-826, a 70-mm Hulcher camera with a 36-inch lens operating at 5 frames/sec and a 35-mm Mitchell with a 12-inch lens operating at 24 frames/sec were utilized. On the standby destroyer, DD-786, a 5x5 K-24 aerial camera with a 20-inch lens operating at 30 frames/min and a 35-mm Mitchell with a 6-inch lens operating at 24 frames/sec were utilized.

2.3 INSTRUMENT LOCATIONS

The locations of velocity meters on the various ships are indicated in Tables 2.1 through 2.5. Locations of high-speed motion-picture cameras on the towed destroyer are indicated in Table 2.6 and locations of cameras for recording surface-gravity waves are listed in Table 2.7.

Profile views of the ships showing approximate locations of instruments are shown in Figures 2.5 through 2.7.

2.4 OPERATION OF RECORDING INSTRUMENTS

Oscillographs, cameras, and recorders installed on the target ships were powered by storage batteries. This arrangement increased reliability by making instrument operation independent of the ships' power systems.

On the closest target ship and on the instrument platforms, the recording instruments were operated automatically by means of sequence timers. Operation of the sequence timers was initiated by relay closures furnished by Edgerton, Germeshausen and Grier, Inc. (EG&G) by means of a radio link. Recording instruments on manned ships were started manually using the EG&G voice countdown for starting times.

Radio signals provided by EG&G included a sequence of five fiducial marks. These were recorded on all recorders to provide a common time base.

TABLE 2.1 LOCATION OF VELOCITY METERS ON DD-845

Position No.	Orientation (a)	Gage Attached To	Frame No.	LOCATION Vertical	Transverse
SONAR TRUNK					
1	V	Keel	33-1/2	Hold	Centerline
SONAR EQUIPMENT ROOM					
2	V	Bulkhead stiffener	33	1 ft above second platform	5 ft stbd of centerline
I.C. AND PLOTTING ROOM					
4	V	Bulkhead stiffener	63	1/2 ft above first platform	6 ft stbd of centerline
5	V	Bulkhead stiffener	72	1 ft above first platform	Centerline
RADAR TRANSMITTER ROOM					
6	V	Deck	79	01 level	Centerline
ASW EQUIPMENT ROOM					
7	V	Foundation of Mk 38 computer	85	1/2 ft above 02 level	6 ft port of centerline
8	A	Deck	85	02 level	8 ft port of centerline
ASROC LAUNCHER					
9	V	Foundation of launcher	104	Underside of 01 level	3 ft stbd of centerline
10	A	Foundation of launcher	103	Underside of 01 level	2 ft stbd of centerline
ASROC CONTROL STATION					
11	V	Deck	110	01 level	2 ft port of centerline
FORWARD ENGINE ROOM					
12	V	Keel at bulkhead	93	Hold	Centerline
13	V	Foundation of flexplate	93	Second platform	3 ft stbd of centerline

TABLE 2.1 (CONTINUED)

Position No.	Orientation (a)	Gage Attached To	Frame No.	LOCATION Vertical	LOCATION Transverse
LAUNDRY					
14	V	Deck	93	Main deck	Centerline
AFT FIRE ROOM					
15	V	Keel	120	Hold	Centerline
AFT ENGINE ROOM					
16	V	Keel at bulkhead	130-1/2	Hold	Centerline
17	V	Foundation of flexplate	130-1/2	Second platform	3 ft port of centerline
18	V	LP turbine girder	132	Second platform	3 ft port of centerline
19	V	Reduction gear foundation	140	Hold	4 ft port of centerline
20	V	Keel	145	Hold	Centerline
21	A	Keel	131	Hold	Centerline
22	L	Keel	132	Hold	Centerline
PASSAGE					
23	V	Deck	130-1/2	Main deck	Centerline
24	A	Deck	131	Main deck	Centerline
25	L	Deck	130-1/2	Main deck	Centerline
HELICOPTER HANGAR					
26	V	Deck	127	01 level	6 ft stbd of centerline
27	A	Deck	127	01 level	5 ft stbd of centerline
ECM ROOM					
28	V	Deck	139	02 level	3 ft stbd of centerline
STEERING GEAR ROOM					
29	V	Deck	209	First platform	Centerline
30	L	Deck	209	First platform	Centerline

(a) Direction of sensitive axis of meter: V, Vertical; A, Athwartship: L, Longitudinal.

TABLE 2.2 LOCATION OF VELOCITY METERS ON DD-826

Position No.	Orientation (a)	Gage Attached To	Frame No.	LOCATION: Vertical	LOCATION: Transverse
SONAR TRUNK					
1	V	Bulkhead stiffener	34	1/2 ft above keel	Centerline
SONAR EQUIPMENT ROOM					
2	V	Bulkhead	33	1/2 ft above second platform	Centerline
I.C. AND PLOTTING ROOM					
5	V	Bulkhead stiffener	72	1 ft above first platform	Centerline
ASW EQUIPMENT ROOM					
7	V	Bulkhead stiffener	84	1 ft above 02 level	10 ft port of centerline
ASROC LAUNCHER					
9	V	Foundation of launcher	103	Underside of 01 level	2 ft stbd of centerline
10	A	Foundation of launcher	103	Underside of 01 level	Centerline
FORWARD ENGINE ROOM					
12	V	Bulkhead stiffener	92-1/2	1/2 ft above keel	3 ft stbd of centerline
LAUNDRY					
14	V	Bulkhead	92-1/2	1/2 ft above main deck	1 ft stbd of centerline
AFT ENGINE ROOM					
16	V	Bulkhead stiffener	130-1/2	1/2 ft above keel	3 ft port of centerline
STEERING GEAR ROOM					
29	V	Deck	210	First platform	Centerline

(a) Direction of sensitive axis of meter: V, Vertical; A, Athwartship.

TABLE 2.3 LOCATION OF VELOCITY METERS ON DD-786

Position No.	Orientation (a)	Gage Attached To	Frame No.	LOCATION Vertical	Transverse
SONAR TRUNK					
1	V	Bulkhead stiffener	34	1/2 ft above keel	Centerline
SONAR EQUIPMENT ROOM					
2	V	Bulkhead stiffener	33	1 ft above second platform	3 ft port of centerline
I.C. AND PLOTTING ROOM					
5	V	Bulkhead stiffener	72	1 ft above second platform	Centerline
ASW EQUIPMENT ROOM					
7	V	Bulkhead stiffener	84	1/2 ft above 02 level	10 ft port of centerline
ASROC LAUNCHER					
9	V	ASROC foundation	104	Underside of 01 level	2 ft stbd of centerline
10	A	ASROC foundation	103	Underside of 01 level	Centerline
FORWARD ENGINE ROOM					
12	V	Bulkhead	92-1/2	1 ft above keel	Centerline
LAUNDRY					
14	V	Bulkhead	92-1/2	1/2 ft above main deck	Centerline
AFT ENGINE ROOM					
16	V	Bulkhead	130-1/2	1/2 ft above keel	Centerline
STEERING GEAR ROOM					
29	V	Bulkhead	208	1 ft above first platform	3 ft stbd of centerline

(a) Direction of sensitive axis of meter: V, Vertical; A, Athwartc

TABLE 2.4 LOCATION OF VELOCITY METERS ON DD-681

Position No.	Orientation (a)	Gage Attached To	Frame No.	LOCATION Vertical	LOCATION Transverse
SONAR EQUIPMENT ROOM					
1	V	Keel	22	Hold	Centerline
2	V	Bulkhead stiffener	21	1/2 ft above third platform	Centerline
I.C. AND PLOTTING ROOM					
5	V	Bulkhead stiffener	72	1 ft above first platform	Centerline
RADAR TRANSMITTER ROOM					
6	V	Bulkhead stiffener	72	2 ft above main deck	2 ft stbd of centerline
SONAR ROOM					
7	V	Deck	72	02 level	1 ft stbd of centerline
FORWARD ENGINE ROOM					
12	V	Bulkhead	92-1/2	1 ft above keel	Centerline
13	V	Bulkhead stiffener	92-1/2	1 ft above first platform	2 ft stbd of centerline
SICKBAY					
14	V	Bulkhead stiffener	110	1 ft above main deck	1 ft stbd of centerline
AFT ENGINE ROOM					
16	V	Bulkhead	130-1/2	1 ft above keel	Centerline
STEERING GEAR ROOM					
29	V	Bulkhead stiffener	209	1/2 ft above keel	Centerline

(a) Direction of sensitive axis of meter: V, Vertical.

TABLE 2.5 LOCATION OF VELOCITY METERS ON SS-394

Position No.	Orientation (a)	Gage Attached To	Frame No.	LOCATION Vertical	LOCATION Transverse
SONAR ROOM					
1	V	Bulkhead stiffener	47-1/2	2 ft above bottom of hull	Centerline
2	A	Longitudinal bulkhead	47-1/2	1/2 above bottom of hull	Centerline
PUMP ROOM					
3	A	Foundation of LP blower and motor	53	5 ft above bottom of hull	7 ft stbd of centerline
CONTROL ROOM					
4	V	Deck at bulkhead	47-1/2	Platform deck	1 ft port of centerline
5	A	Deck	47-1/2	Platform deck	Centerline
6	V	Deck at base of master gyro	51	Platform deck	Centerline
7	A	Deck at hull	52	Platform deck	6 ft stbd of centerline
RADIO ROOM					
8	V	Bulkhead stiffener	57	1 ft above platform deck	Centerline

(a) Direction of sensitive axis of meter: V, Vertical; A, Athwartship.

TABLE 2.6 LOCATION OF HIGH-SPEED MOTION-PICTURE CAMERAS ON DD-845

Position No.	Equipment Photographed	Direction of View	Field of View
SONAR EQUIPMENT ROOM			
C 1	Sonar Amplifiers	Fwd and stbd	Lower part of a row of amplifiers along centerline
I.C. AND PLOTTING ROOM			
C 2	Master Gyro Compass	Aft and stbd	Forward side of Gyro, with covers removed
ASW EQUIPMENT ROOM			
C3	Mk 38 Attack Console	Aft	Lower half of attack console

TABLE 2.7 LOCATION OF CAMERAS RECORDING SURFACE GRAVITY WAVES

Camera Description	Speed Frames Frames /sec	Camera Location
DD-845		
16mm Milliken, 9mm Lens	64	Attached to port ECM antenna platform, facing aft, Fr. 141
16mm Traid, 1-inch Lens	150	Attached to stbd ECM antenna platform, facing aft, Fr. 141
DD-826		
70mm Hulcher, 36-inch Lens	5	Both cameras mounted on a tripod on top of helicopter
35mm Mitchell, 12-inch Lens	24	hangar, Fr. 143, centerline
DD-786		
5x5 K-24 Aerial, 20-inch Lens	1/2	Both cameras mounted on a tripod on top of helicopter
35mm Mitchell, 6-inch Lens	24	hangar, Fr. 143, centerline

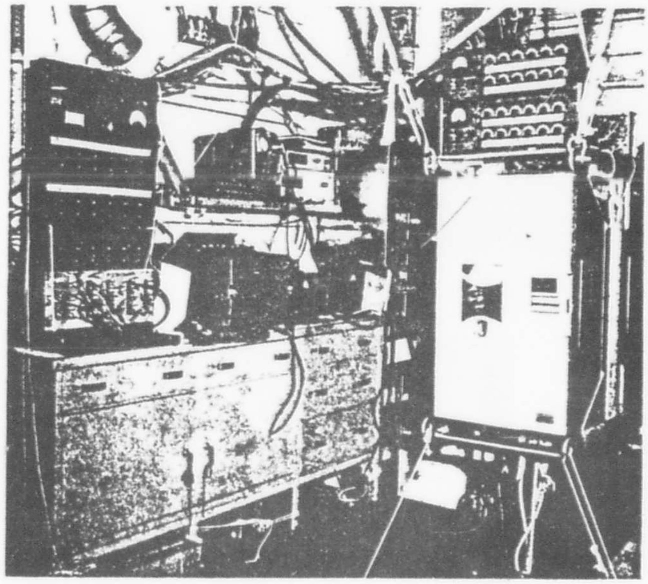

Figure 2.1 Recording equipment installed on DD-845. Two 14-channel tape recorders are suspended from overhead by shock cord. A direct-write oscillograph is installed on the bench. (DTMB photo)

Figure 2.2 Typical installation of velocity meter used with magnetic-tape recording system. (USNS, San Diego, California)

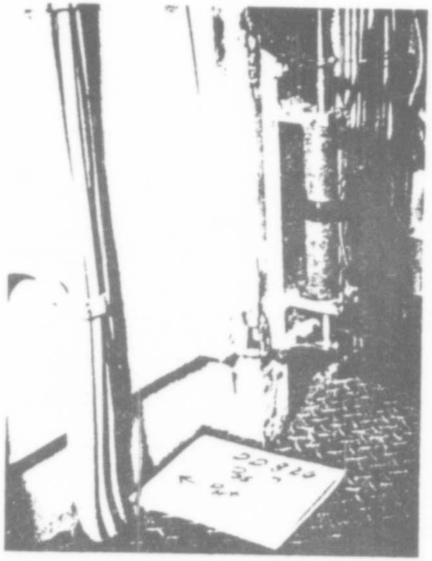

Figure 2.3 Typical installation of velocity meter used with galvanometer recording system. (USNS, San Diego, California)

Figure 2.4 Typical installation of high-speed motion-picture camera. (USNS, San Diego, California)

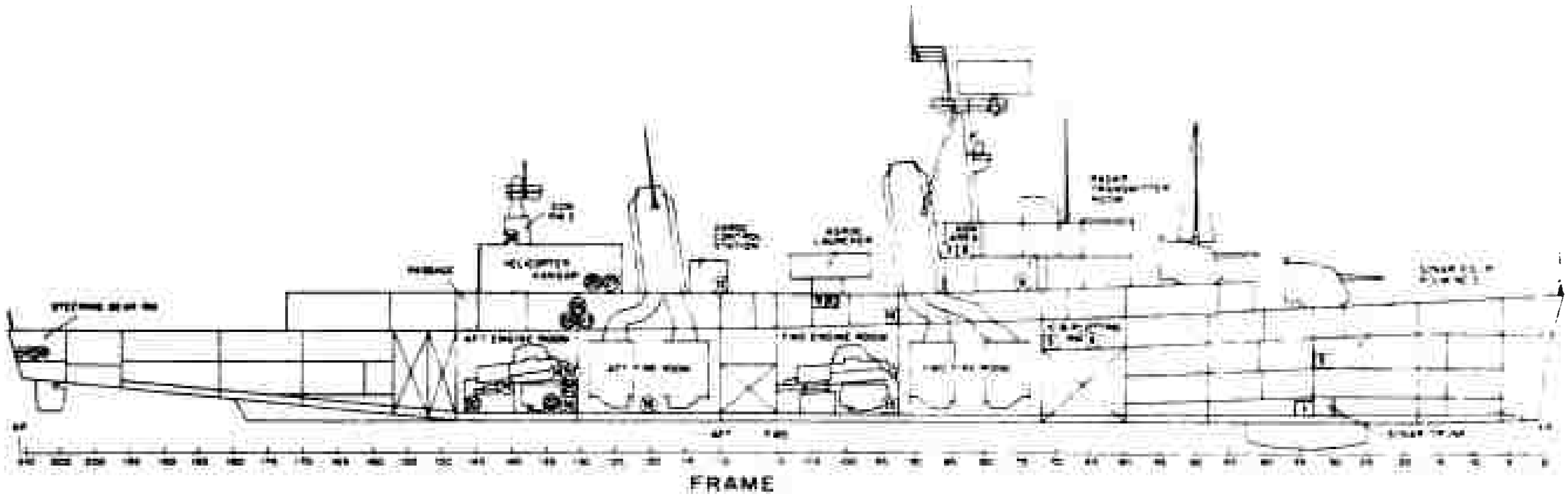

Figure 2.5 Inboard profile view showing locations of velocity meters on FRAM destroyers. Instruments were installed at all numbered positions on DD-845 and only at positions indicated by square symbol on DD-826 and DD-786.

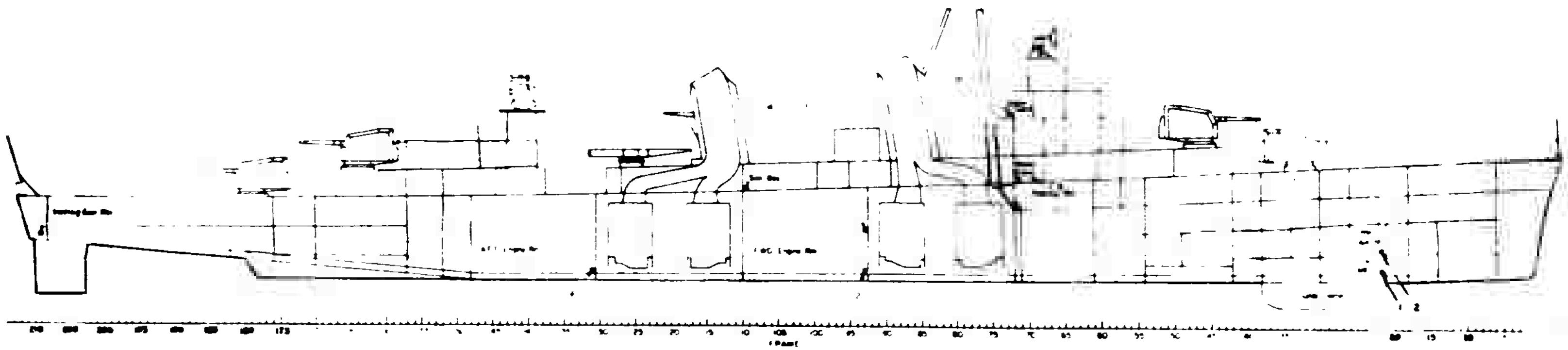

Figure 2.6 Inboard profile view showing approximate locations of velocity meters on DD-681.

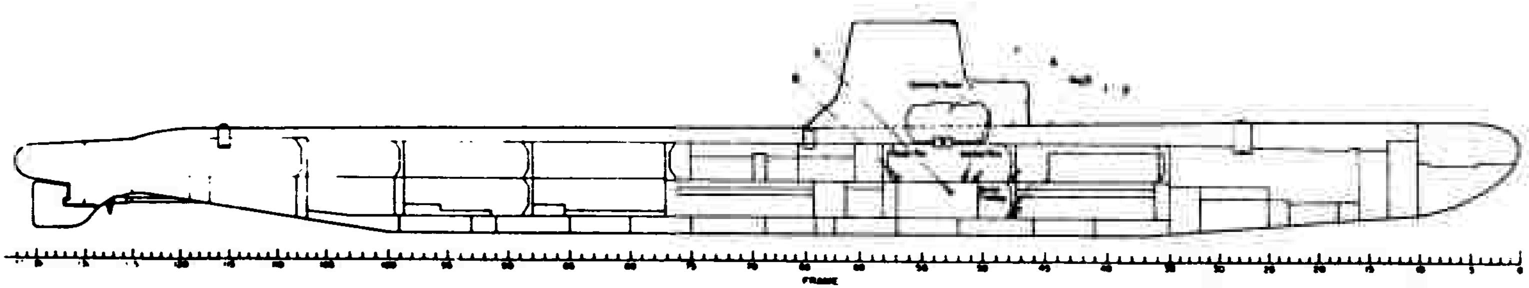

Figure 2.7 Inboard profile view showing approximate locations of velocity meters on SS-394.

Chapter 3

RESULTS

3.1 GENERAL OBSERVATIONS

On the five instrumented ships participating in Sword Fish, records of the shock motions as a function of time were obtained from all instruments. Only one channel of data was obtained from the instrument platforms. This record was made on the closest platform to the burst.

The high-speed cameras on the towed ship operated successfully. The cameras for photographing water-surface effects also operated successfully at all stations.

Fiducial time signals were received and recorded as planned.

Locations and orientations at shot time of instrumented ships in the test array, as well as other ships in the area, are shown in Figure 3.1. This figure was drawn from data supplied by various projects as well as from radar measurements.

3.2 VELOCITY METER DATA

Complete records of shock velocity versus time were obtained for at least the period from 13 seconds before to approximately 27 seconds after detonation on DD-845, DD-826, DD-781, DD-681, and SS-394. Recorders were operated for a long time period before detonation to obtain data in the event of a shallow burst. A long time period of operation was allowed subsequent to detonation to insure recording of motions resulting from the direct shock wave as well as significant reflections from the ocean floor.

Examination of the records showed that several excitations were received at each of the ships. Identifiable excitations included those caused by: (1) shock wave transmitted directly from the burst to the ships; (2) a shock wave which travels along the bottom and is a precursor to the shock wave reflected from the ocean bottom; (3) a shock wave reflected from the bottom surface; and (4) waves reflected from deeper bottom layers.

Figures 3.2 through 3.15 are reproductions of significant portions of velocity records obtained on the target ships. Traces on the reproductions are labeled with position numbers keyed to Tables 2.1 through

2.5. Each trace is also labeled with a calibration constant, which gives the velocity in feet per second corresponding to a trace deflection equal in magnitude to the length of the unit-deflection arrow shown on each reproduction.

The times of arrival of the shock waves at the selected instrument positions on each of the ships are given in Table 3.1. The peak velocities characterizing the shock motions are shown in Tables 3.2 through 3.6. Where measurable, the initial peak velocity resulting from the direct shock is indicated as well as the peak value. In Tables 3.3 and 3.6 respectively, the shock velocities resulting from the HE test of DD-826 and SS-394 are also indicated.

Figure 3.16 is a tracing of a typical record, showing the method of reading velocity values from the various excitations. This method was employed on the records from DD-826, DD-786, and SS-394. The method was also applicable to the direct shock on DD-845. For the reflected shock on DD-845, the magnet motion resulting from the direct shock was not damped out at the time of arrival of the reflected shock. As a result, a correction was made using a computer program. An example of the results of the program and the extraction of the velocity change resulting from the reflected wave at DD-845 is shown in Figure 3.17.

Shock-motion data were not obtained on the two platforms with the oscillograph recorders. On Platform P-1, the starting relay for the sequence timer was apparently tripped early by a spurious radio signal. The record obtained was processed, but no motion or fiducial signals were found over its entire length. Fogging of the record as a result of radiation would not have obscured the trace.

The record from Platform P-2 was processed using a kit specified by the paper manufacturer. The lack of contrast indicated that the radiation level on the platform was excessive and fogged the photographic paper to a level at which reading was impossible.

Playbacks of the Project 1.1 magnetic tapes on which velocity-meter data were recorded produced a record for the pontoon close to the bomb but no record for the pontoon away from the bomb. At both stations, the signal levels were lower than expected because of the increase in standoff of the pontoons and because of a significant reduction in shock-wave pressure as a result of refraction at these increased ranges. A preliminary reproduction of the record obtained at Platform P-1 is shown in Figure 3.18. The indicated initial peak velocity was 6.6 ft/sec. Further analysis of the data was planned; however, Project 1.1 has not been able to provide a suitable final copy of the record for analysis due to unexpected difficulties with their playback equipment.

3.3 MOTION PICTURES

High-speed motion pictures of the response of selected equipment in DD-845 were successfully obtained with the three cameras used. Good exposure and contrast were obtained on each film and there was no evidence of radiation exposure.

Equipment motions recorded with the cameras were small. The direct and reflected shock-wave arrivals could be detected on the film and the resulting equipment displacements were comparable for both shocks.

The cameras on DD-845 which recorded water-surface effects from the detonation operated successfully. Good quality records were obtained with both cameras.

The films of the response of DD-845 to the surface waves generated by the detonation showed significant wave amplitudes at this ship. Prints of frames from the films taken from DD-826 are shown in Figure 3.19. Frames reproduced in the figure were from the 35-mm camera on DD-826. Measurements of ship motion were made using data from the 35-mm cameras, which ran at 24 frames/sec. Figure 3.20 shows the results of measurements of the films from each ship.

The plots show the relative displacements between points on the ship structure and the apparent water surface directly below the point of interest. Measurements on each film were made at three locations along the length of the ship. Since there was no horizon or fixed point of reference in the field of view, absolute displacement measurements could not be made.

Differences in the magnitudes of the displacements between the two films are attributed to differences in the angle of view of the camera and in the image size on the frame of the original film. The films from DD-826 were taken nearly broadside and the image of the ship in the frame was large. In the case of DD-786, the cameras were located ahead of the target and the image of the ship in the film frame was smaller. Reading errors in the latter film were consequently magnified. The measurements from DD-826 are considered to be more reliable. The peak crest-to-trough displacement as measured from DD-826 was about 17 feet.

3.4 DAMAGE TO SHIP EQUIPMENT

Damage to ship equipment for Shot Sword Fish is described in detail in Reference 26. A brief summary of significant damage effects is given below.

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TABLE 3.1 ARRIVAL TIME OF SHOCK WAVES AT TARGETS

Target Ship	Position Number	Arrival Time in Seconds*		
		Direct Wave	Reflected Wave Precursor	Reflected Wave
Bausell (DD-845)	1	41.151	45.330	45.380
	12	41.130	45.325	45.376
	29	41.086	45.309	45.362
Agerholm (DD-826)	1	42.444	45.687	45.693
	12	42.433	45.6[illegible]	45.688
	29	42.413	45.673	45.681
Anderson (DD-786)	1	42.404	45.547	45.556
	12	42.385	45.537	45.548
	29	42.345	45.520	45.533
Hopewell (DD-681)	1	42.219	45.690	45.724
	12	42.243	45.702	45.734
	29	42.289	45.722	45.755
Razorback (SS-394)	2	42.525	45.744	
	1	42.528	45.742	45.749
	4	42.529	45.743	45.748

* All arrival times are indicated relative to the Sword Fish zero time. Zero time was the time of launch of the ASROC from the ship. The calculated time of burst was 39.8095 ± 0.010 seconds after zero time.

TABLE 3.2 PEAK VELOCITIES ON DD-845

DD-845 was located stern toward the burst at a range of 6,500 feet.

Position Number	Orientation*	Location	Peak Velocity Direct Shock	Peak Velocity Reflected Shock
1	V	Keel at bulkhead Fr. 33-1/2	1.0	1.0
2	V	Bulkhead Fr. 33 sonar EQ rm.	1.1	0.9
4	V	I.C. and plot. bulkhead Fr. 63	1.0	0.6
5	V	I.C. and plot. bulkhead Fr. 72	1.3	0.6
6	V	01 deck at base of SPS-29 trans.	1.2	
7	V	Foundation Mk 38 attack console	1.2	0.9
8	A	Deck ASW equip. room Fr. 85	-0.1	0.1
9	V	Foundation of ASROC launcher	1.6	1.2
10	A	Foundation of ASROC launcher	-0.1	0.2
11	V	Deck at base ASROC control console	1.4	1.0
12	V	Keel at bulkhead Fr. 92-1/2	1.3	0.6
13	V	Foundation of flexplate Fr. 92-1/2	0.9	0.9
14	V	Laundry bulkhead Fr. 92-1/2	1.0	0.7
15	V	Keel Fr. 120	1.3	0.9
16	V	Keel at bulkhead Fr. 130-1/2	1.1	0.6
17	V	Foundation of flexplate Fr. 130-1/2	1.1	1.0
18	V	LP turbine girder Fr. 132	1.5	0.6
19	V	Reduction gear foundation Fr. 140	1.3	0.6
20	V	Keel Fr. 145	1.9	0.9
21	A	Keel Fr. 131	-0.3	0.3
22	L	Keel Fr 132	0.5	0.2
23	V	Main deck passage Fr. 130-1/2 C_L	1.0	0.6
24	A	Main deck passage Fr. 130-1/2 C_L	-0.2	-0.1
25	L	Main deck X.O. room Fr. 131	0.2	0.1
26	V	Deck of helo. hangar Fr. 127	1.1	0.6
27	A	Deck of helo. hangar Fr. 127	-0.3	-0.2
28	V	Deck in no. 2 ECM rm. Fr. 139	1.7	0.8
29	V	Deck in steering gear rm. Fr. 209	0.9	
30	L	Deck in steering gear rm. Fr. 209	0.3	0.1

*Orientation of sensitive axis of meter: V, vertical (motion upward is positive); A, athwartship (motion to starboard is positive); L, longitudinal (motion aft is positive).

TABLE 3.3 PEAK VELOCITIES ON DD-826

DD-826 was located starboard side and stern toward the burst at a range of 13,000 feet.

Position Number	Orientation*	Location	Velocity			
			Direct Shock		Reflected Shock	HE Test
			Initial	Peak		
1	V	Bulkhead at keel Fr. 34	0.050	0.12	0.4	
2	V	Bulkhead in sonar EQ rm. Fr. 33	+	0.14	0.5	2.5
5	V	Bulkhead in I.C. and plot. Fr. 72	+	0.14	0.6	1.2
7	V	Bulkhead Fr. 84 ASW EQ room	+	0.17	0.5	1.8
9	V	Foundation of ASROC launcher	+	0.27	0.6	1.4
10	A	Foundation of ASROC launcher	+	0.08	0.1	0.5
12	V	Fwd. eng. rm. bulkhead fr. 92-1/2	0.046	0.16	0.5	3.1
14	V	Bulkhead in laundry Fr. 92-1/2	+	0.13	0.4	1.5
16	V	Aft eng. rm. bulkhead Fr. 130-1/2	0.043	0.16	0.4	2.0
29	V	Deck in steering gear rm. Fr. 210	0.052	0.15	0.4	1.1

* Orientation of sensitive axis of meter: V, vertical (motion upward is positive); A, athwartship (motion to starboard is positive).

\+ No distinct velocity change observed on record.

TABLE 3.4 PEAK VELOCITIES ON DD-786

DD-786 was located stern toward burst at a range of 12,700 feet.

Position Number	Orientation*	Location	Velocity		
			Direct Shock		Reflected Shock
			Initial	Peak	
1	V	Bulkhead at keel Fr.34	0.020	0.13	0.4
2	V	Bulkhead in sonar EQ rm. Fr. 33	0.018	0.15	0.4
5	V	Bulkhead in I.C. and plot Fr 72	+	0.20	0.5
7	V	Bulkhead in ASW EQ rm. Fr. 84	+	0.20	0.6
9	V	Foundation of ASROC launcher	+	0.25	0.6
10	A	Foundation of ASROC launcher	+	+	0.1
12	V	Bulkhead at keel Fr. 92-1/2	0.024	0.15	0.5
14	V	Bulkhead in laundry Fr. 92-1/2	0.010	0.14	0.4
16	V	Bulkhead at keel Fr 130-1/2	0.031	0.18	0.6
29	V	Bulkhead at steering gear rm.	0.029	0.13	0.4

* Orientation of sensitive axis of meter: V, vertical (motion upward is positive); A, athwartship (motion to starboard is positive).

+ No distinct velocity change observed on record.

TABLE 3.5 PEAK VELOCITIES ON DD-681

DD-681 was located bow toward burst at a range of 12,000 feet.

Position Number	Orientation*	Location	Velocity: Direct Shock, Initial	Velocity: Direct Shock, Peak	Velocity: Reflected Shock
1	V	Keel Fr. 22	0.080	0.12	1.0
2	V	Bulkhead in sonar EQ rm. Fr. 33	0.040	0.13	1.0
5	V	Bulkhead in I.C. and plot. Fr 72	0.028	0.15	0.8
6	V	Bulkhead in radar trans. rm. Fr. 72	+	0.16	0.9
7	V	Deck in sonar control Fr. 72	+	0.17	0.8
12	V	Bulkhead at keel Fr. 92-1/2	0.027	0.16	1.1
13	V	Bulkhead at flexplate foundation Fr. 92-1/2	0.031	0.17	0.9
14	V	Bulkhead in sickbay Fr. 110	0.029	0.15	1.1
16	V	Bulkhead at keel Fr. 130-1/2	0.033	0.17	0.9
29	V	Bulkhead at keel Fr. 209	0.035	0.21	1.0

* Orientation of sensitive axis of meter: V, vertical (motion upward is positive).

+ No distinct velocity change observed on record.

TABLE 3.6 PEAK VELOCITIES ON SS-394

SS-394 was located starboard side toward burst at a range of 13,400 feet.

Position Number	Orientation*	Location	Velocity: Direct Shock, Initial	Velocity: Direct Shock, Peak	Velocity: Reflected Shock	Peak Velocity From Direct Shock of HE Test
1	V	Bulkhead at base of 3QB3A Fr. 47-1/2	0.047	0.06	0.4	2.2
2	A	Bulkhead base of 3QB3A Fr. 47-1/2	0.217	0.39	0.5	3.6
3	A	Foundation of LP blower Fr. 53	0.034	0.04	0.4	0.9
4	V	Deck in control room Fr. 47-1/2	0.046	0.07	0.7	2.5
5	A	Deck in control room Fr. 47-1/2	0.096	0.09	0.2	1.7
6	V	Base of master gyro Fr. 51	+	0.22	0.6	2.5
7	A	Deck at hull in control rm. Fr. 52	0.175	0.29	0.3	2.4
8	V	Bulkhead in radio rm. Fr. 57	0.048	0.12	0.5	2.2

* Orientation of sensitive axis of meter: V, vertical (motion upward is positive); A, athwartship (motion to starboard is positive).

\+ Initial peak blanked by trace interrupter in recorder.

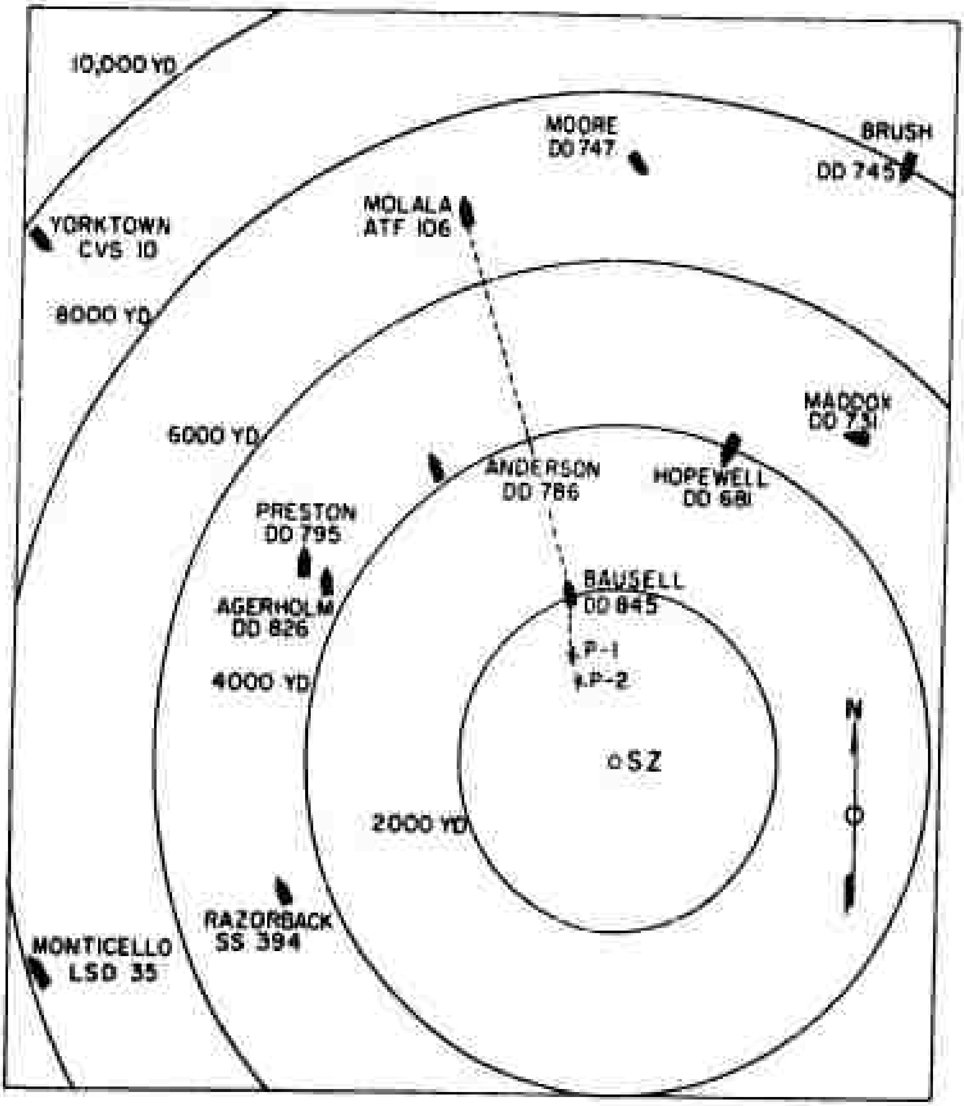

Figure 3.1 Orientation of ships on-site at time of burst.

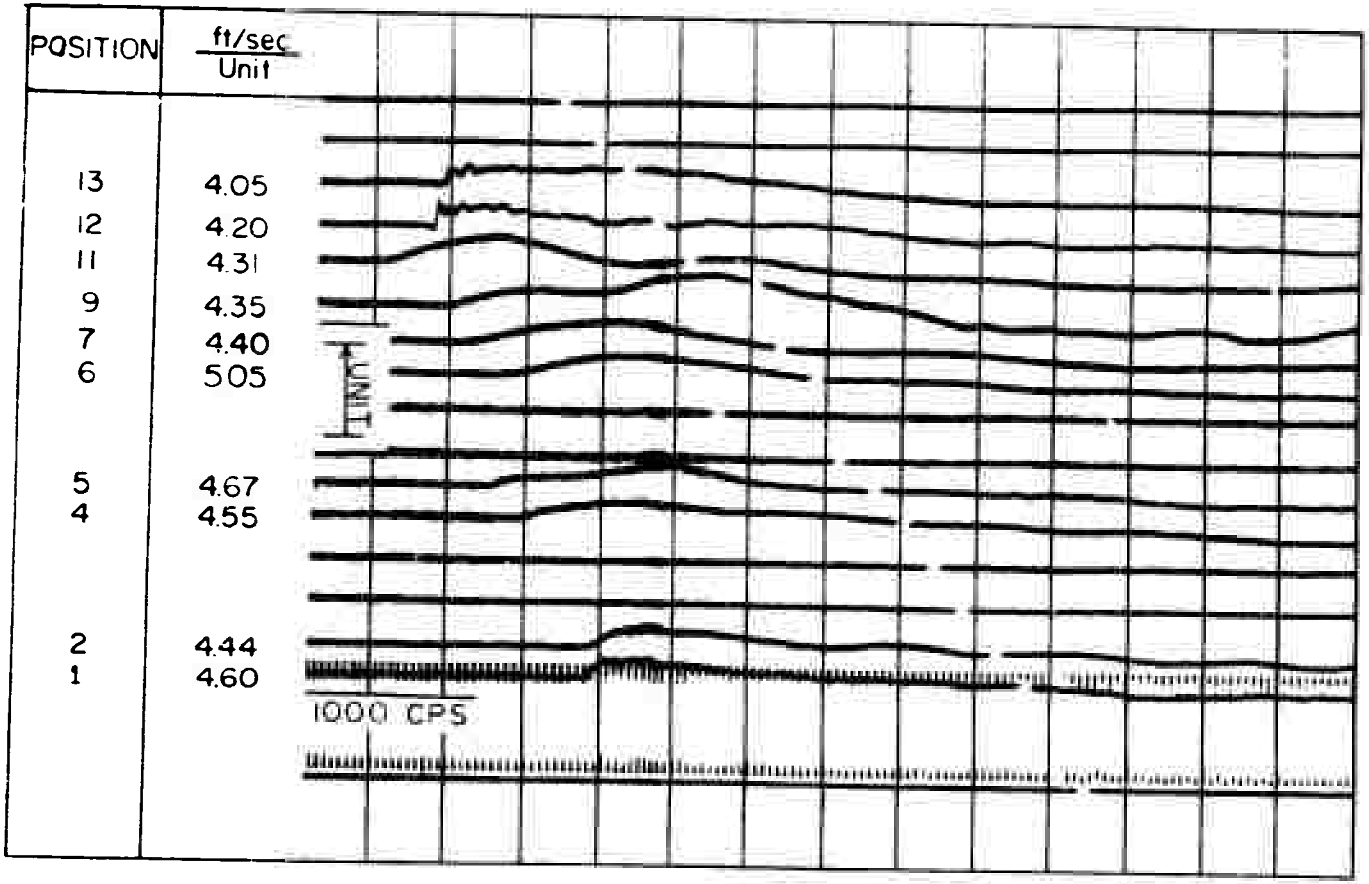

Figure 3.2 Oscillogram of velocities for Positions 1, 2, 4 through 7, 9, 11, 12 and 13 on DD-845 from direct shock wave. The column labeled ft/sec/unit gives the velocity corresponding to a galvanometer deflection in the direction of the unit-deflection arrow and equal in magnitude to the length of the arrow. Position numbers are keyed to Table 2.1.

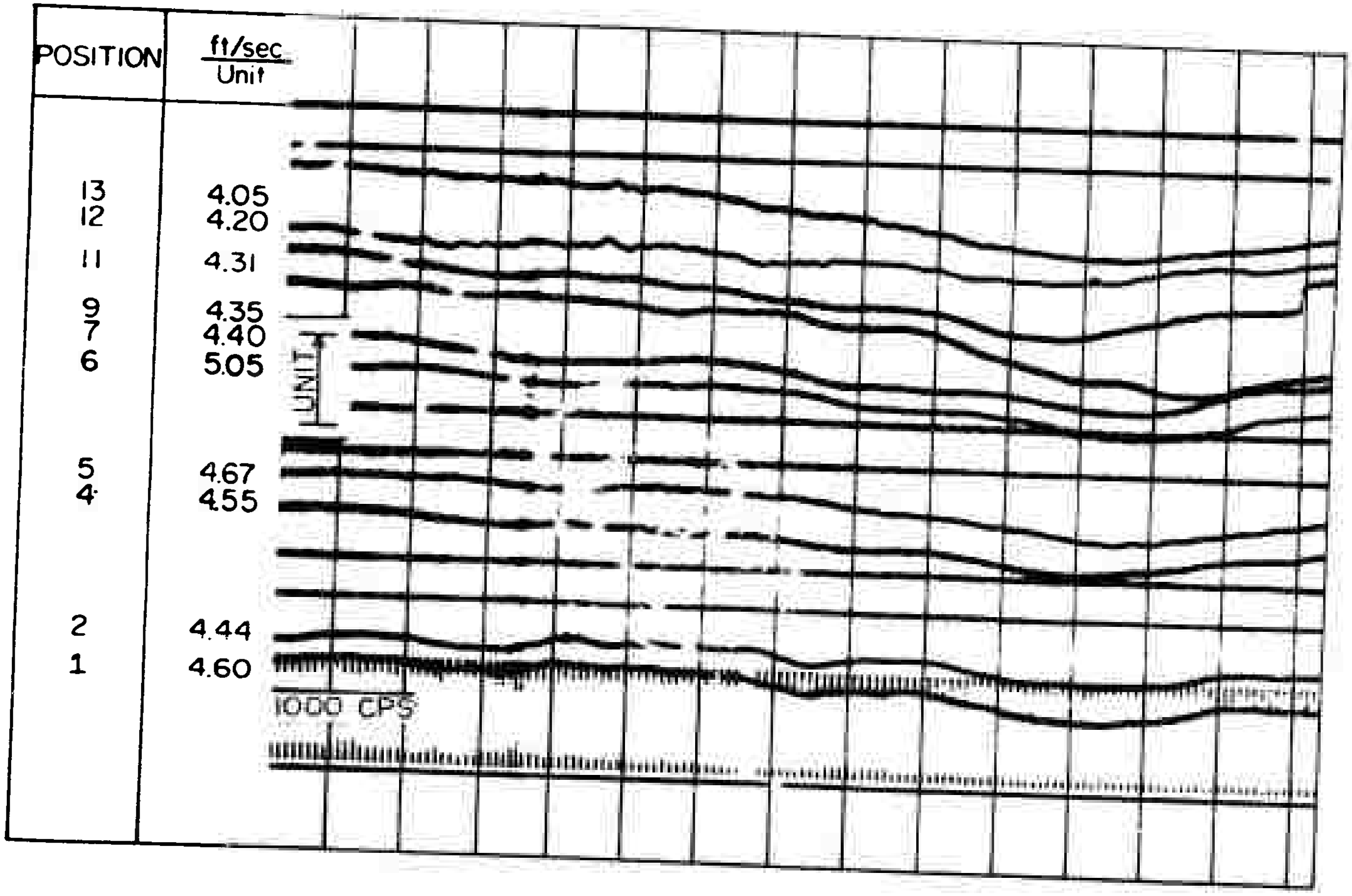

Figure 3.3 Oscillogram of velocities for Positions 1, 2, 4 through 7, 9, 11, 12 and 13 on DD-845 from reflected shock wave.

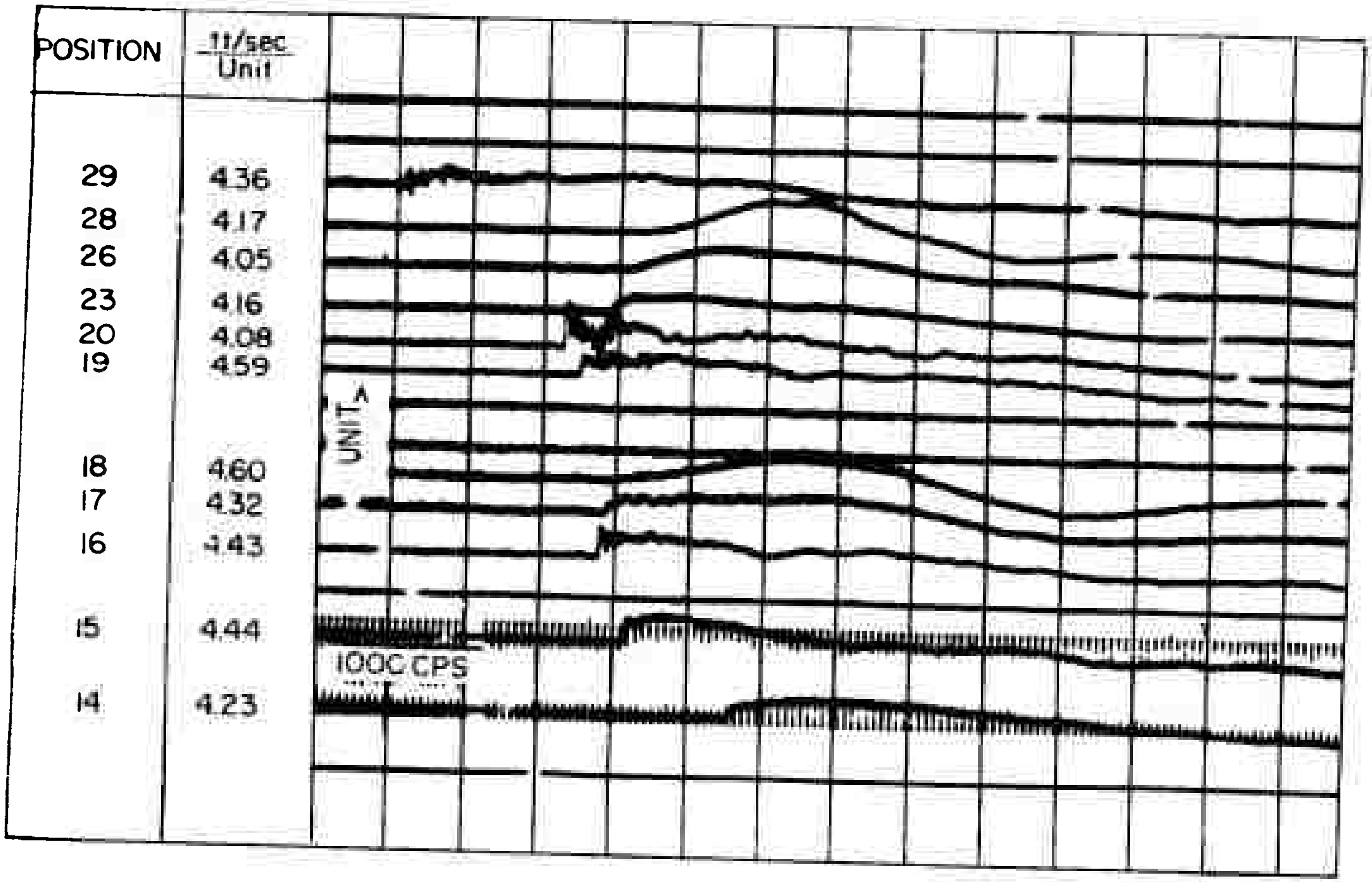

Figure 3.4 Oscillogram of velocities for Positions 14 through 20, 23, 26, 28 and 29 on DD-845 from direct shock wave.

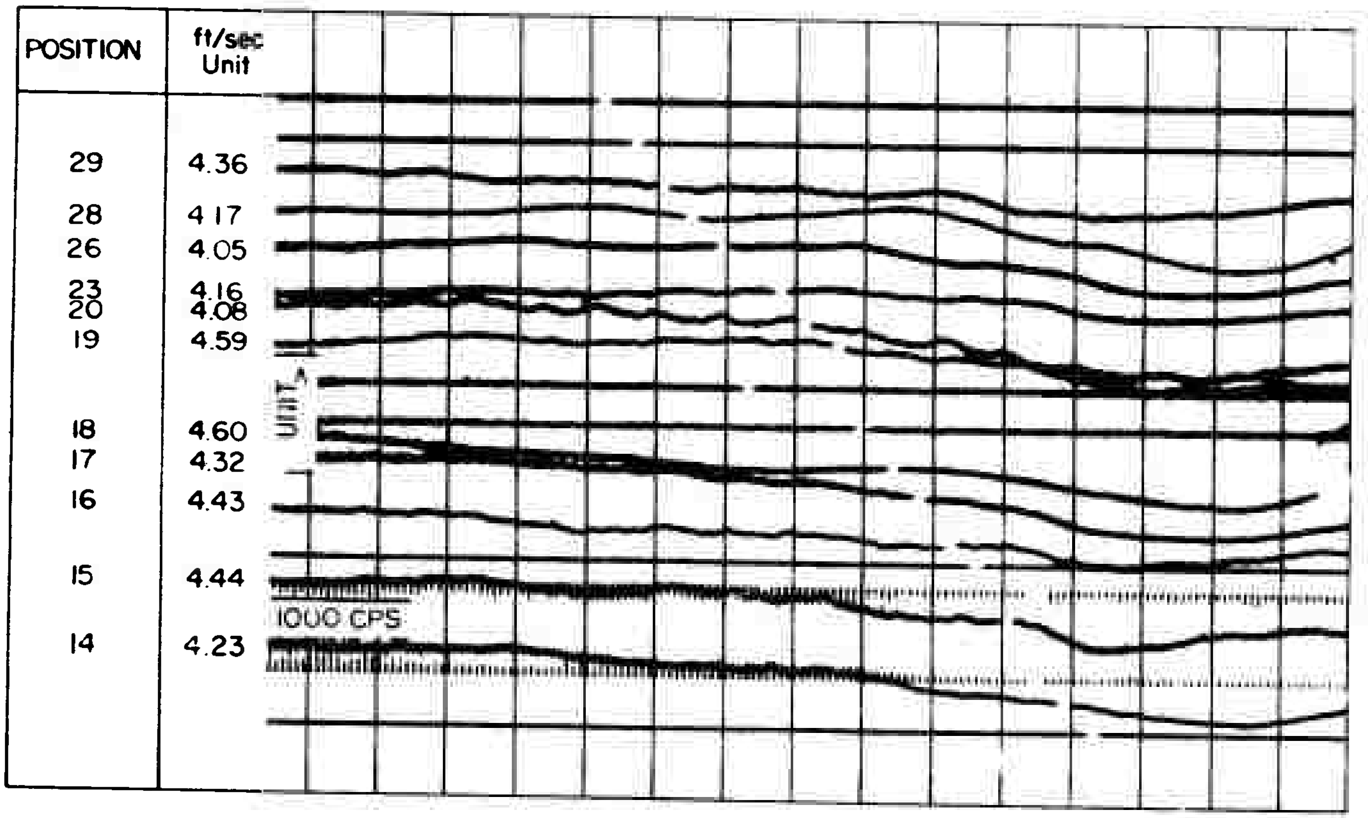

Figure 3.5 Oscillogram of velocities from Positions 14 through 20, 23, 26, 28 and 29 on DD-845 from reflected shock wave.

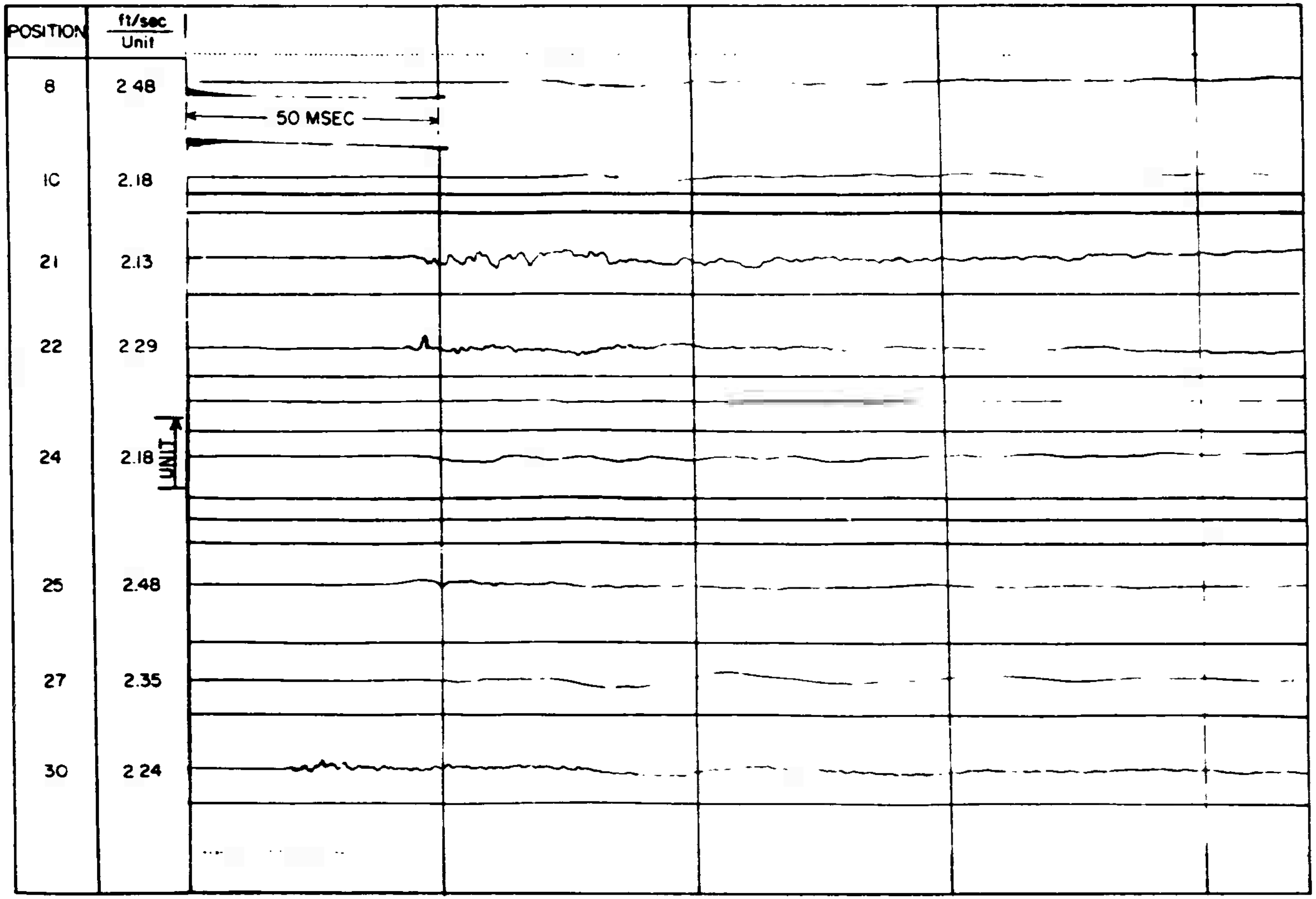

Figure 3.6 Oscillogram of velocities for Positions 8, 10, 21, 22, 24, 25, 27 and 30 on DD-845 from direct shock wave.

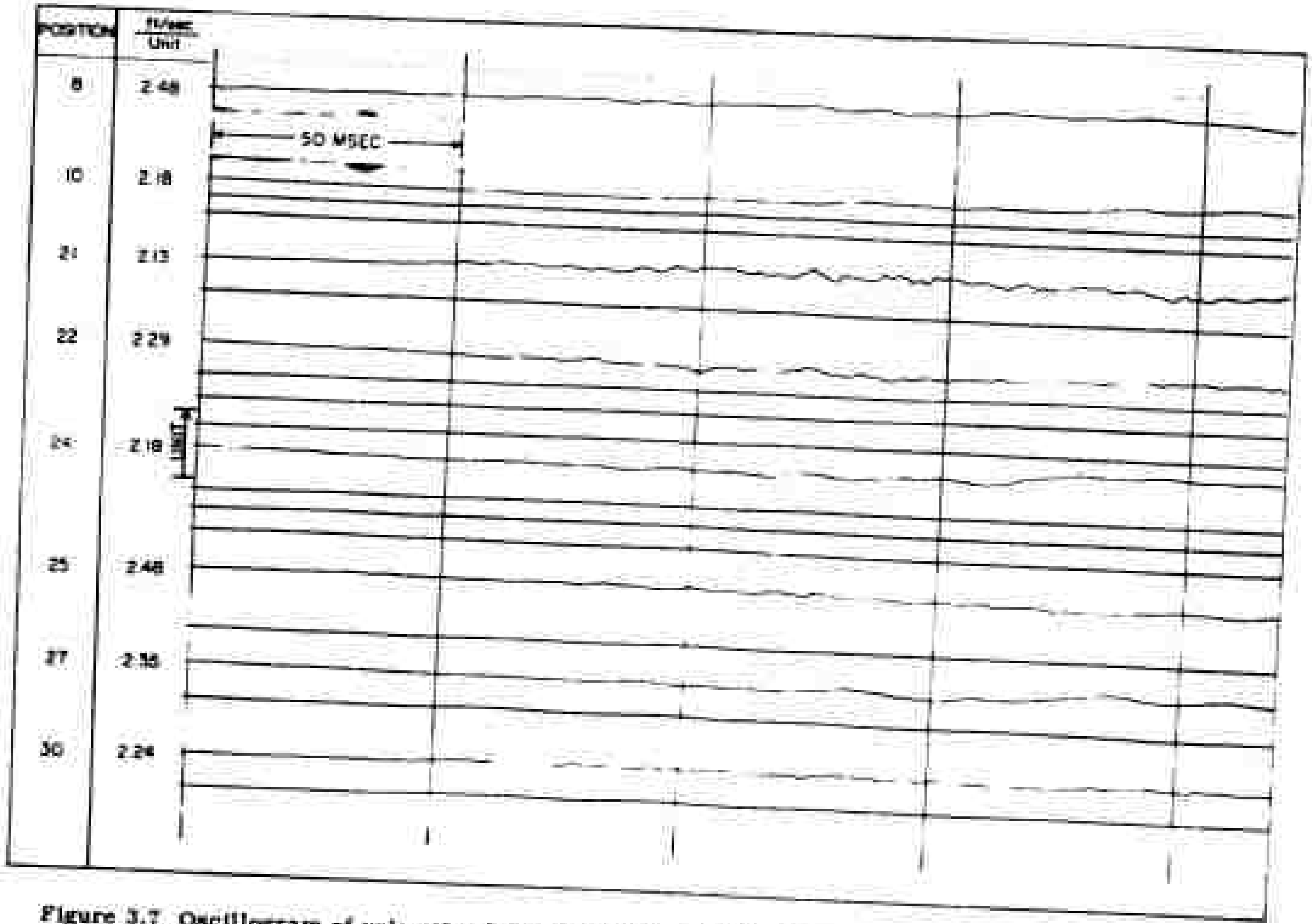

Figure 3.7 Oscillogram of velocities for Positions 8, 10, 21, 22, 24, 25, 27 and 30 on DD-845 from reflected shock wave.

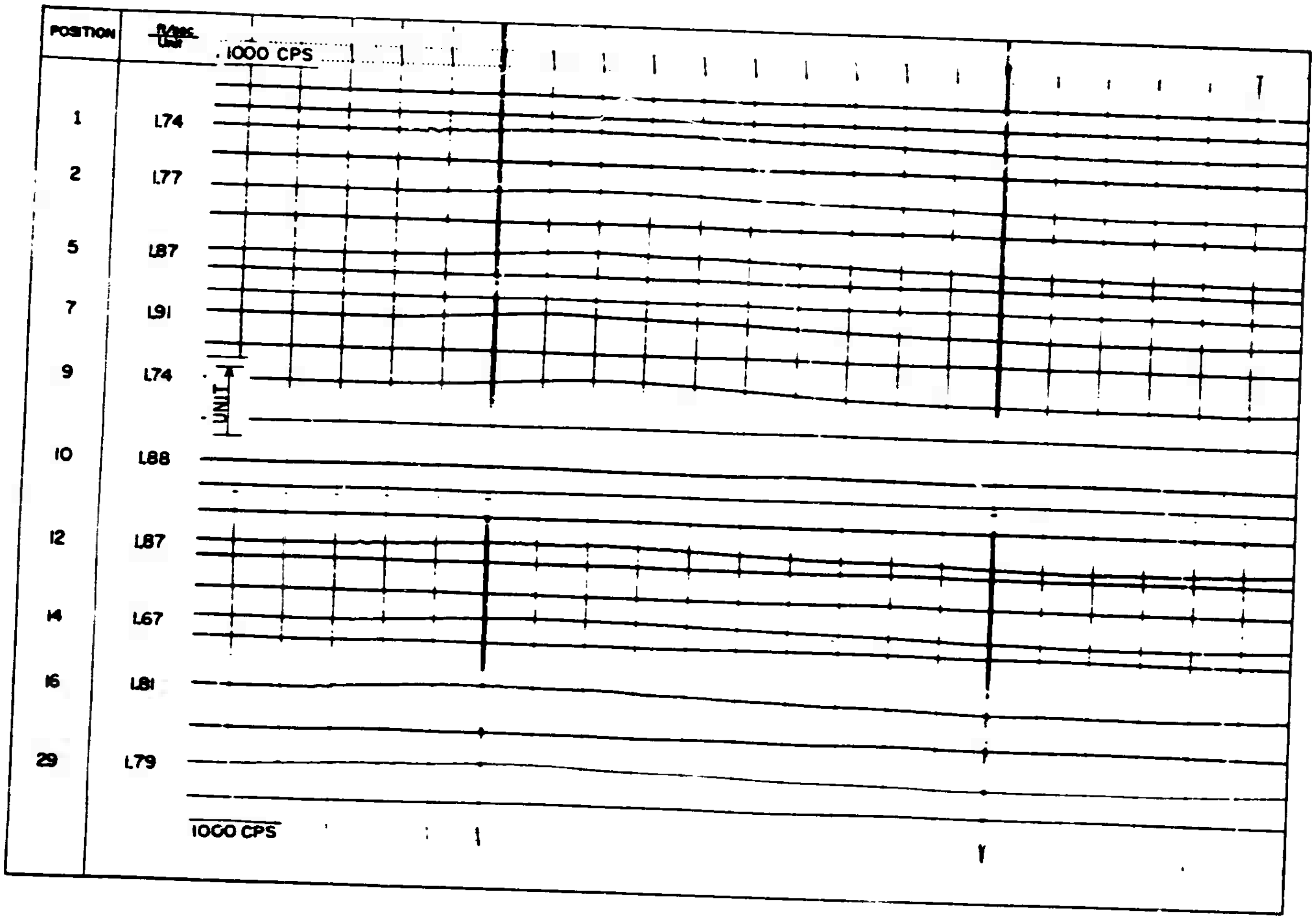

Figure 3.8 Oscillogram of velocities on DD-826 from direct shock wave.

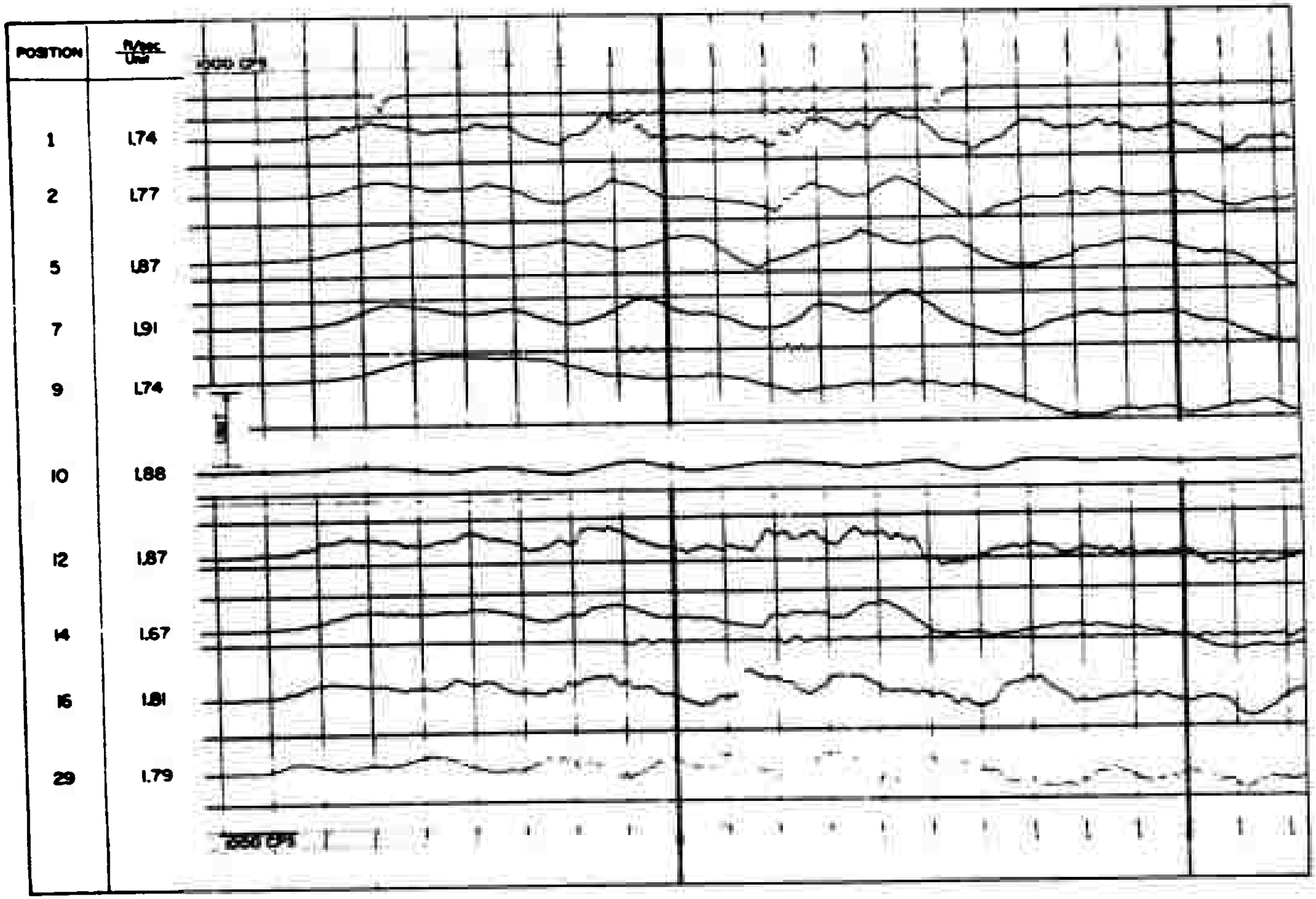

Figure 3.9 Oscillogram of velocities on DD-826 from reflected shock wave.

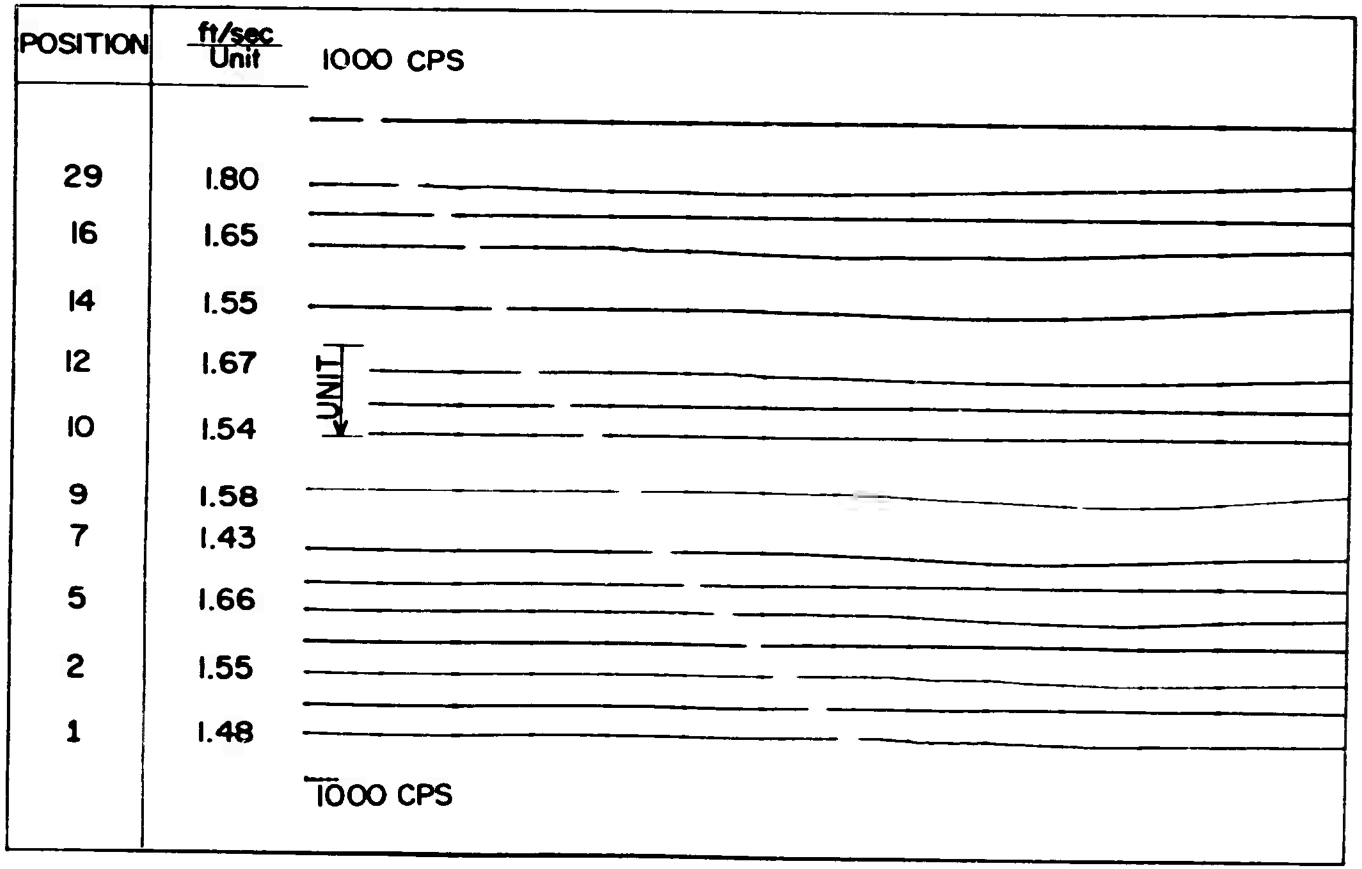

Figure 3.10 Oscillogram of velocities on DD-786 from direct shock wave.

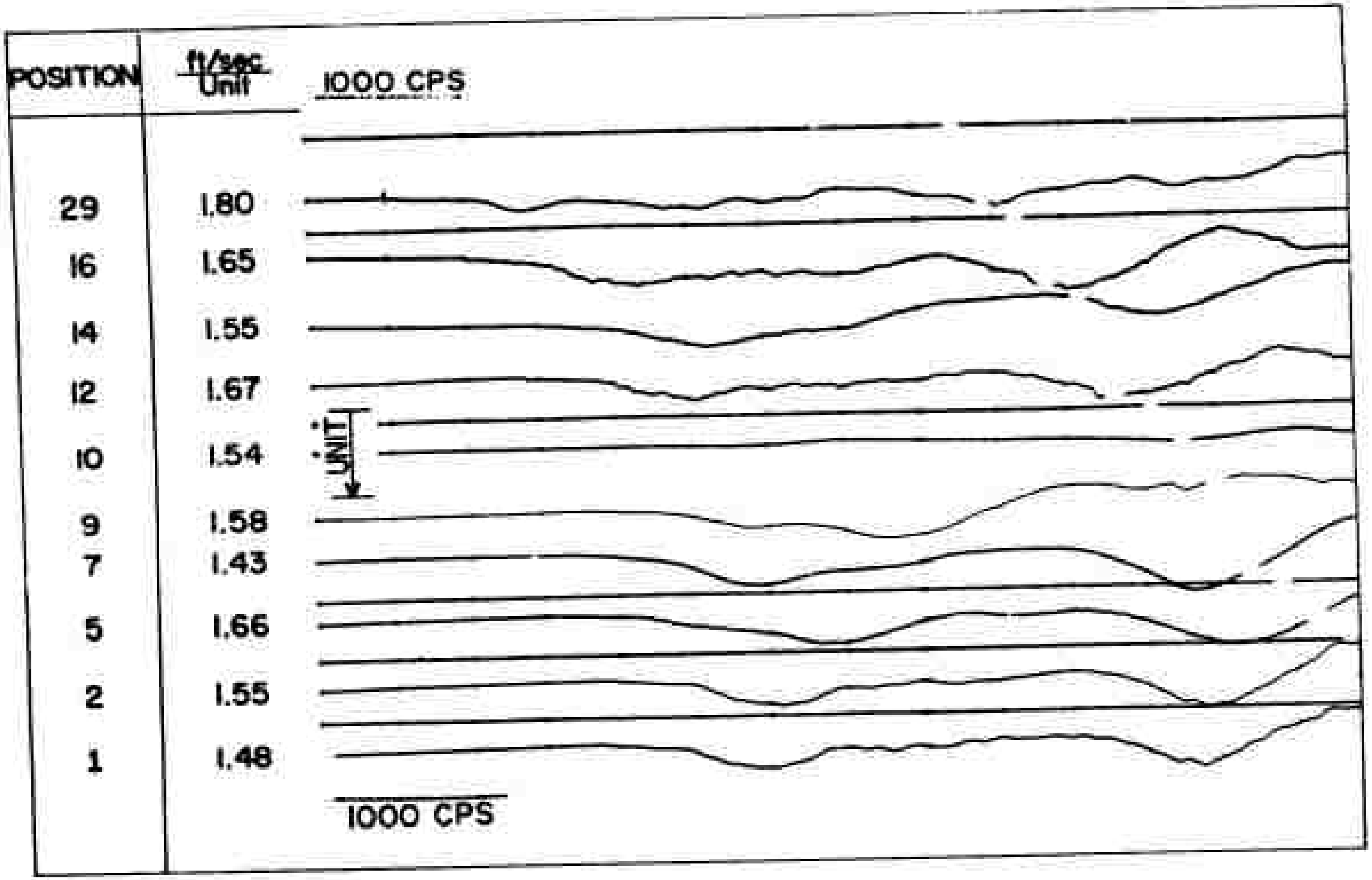

Figure 3.11 Oscillogram of velocities on DD-786 from reflected shock wave.

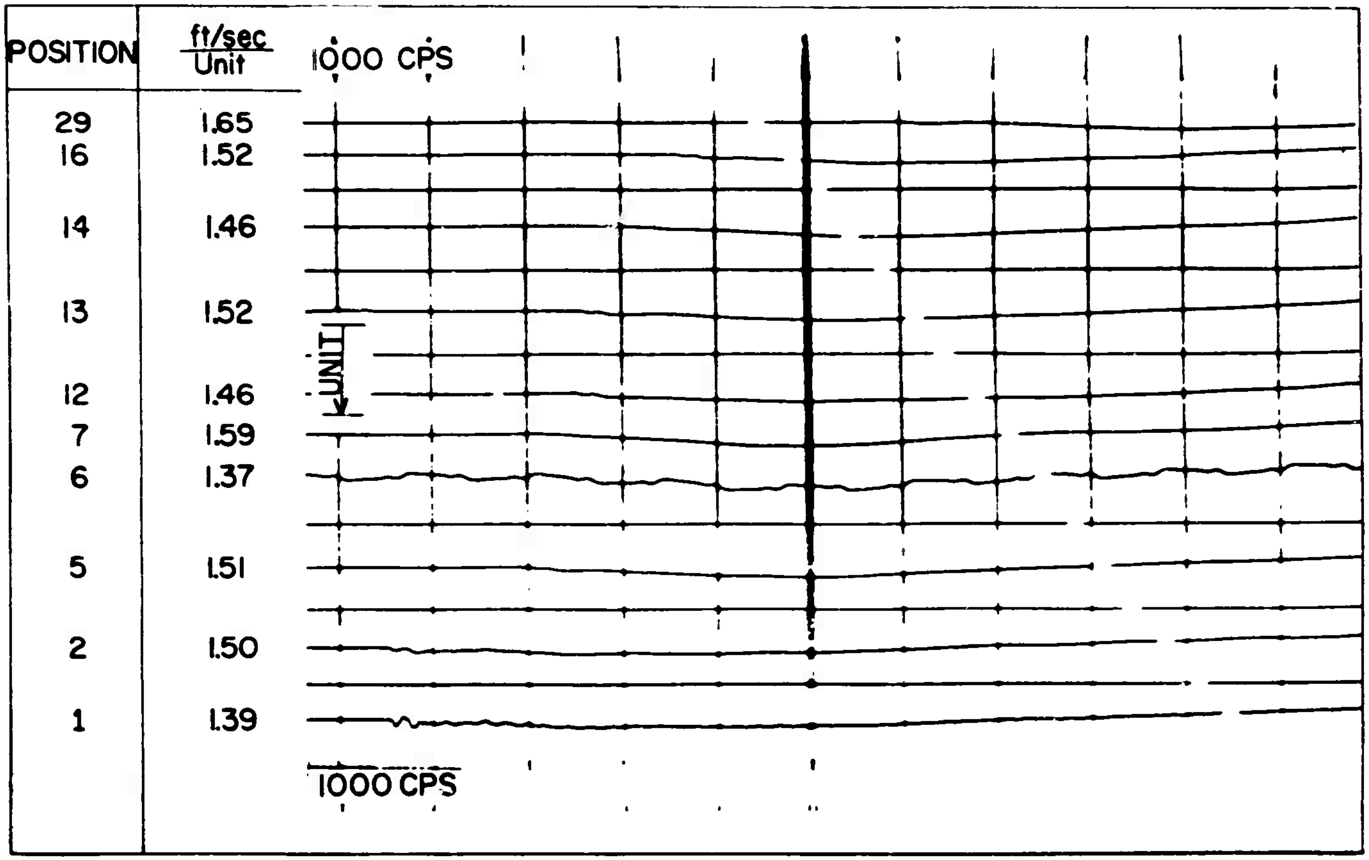

Figure 3.12 Oscillogram of velocities on DD-681 from direct shock wave.

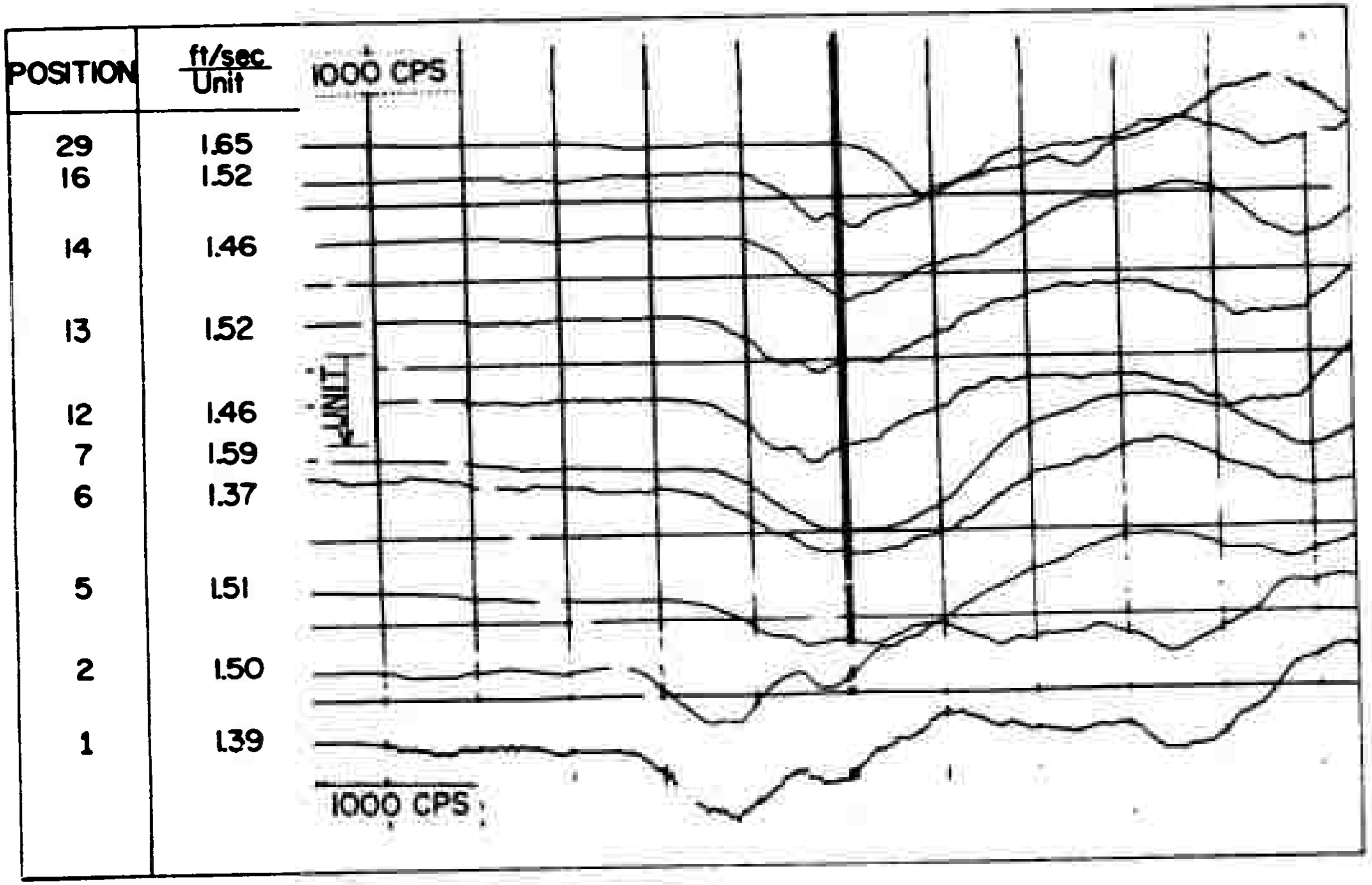

Figure 3.13 Oscillogram of velocities on DD-681 from reflected shock wave.

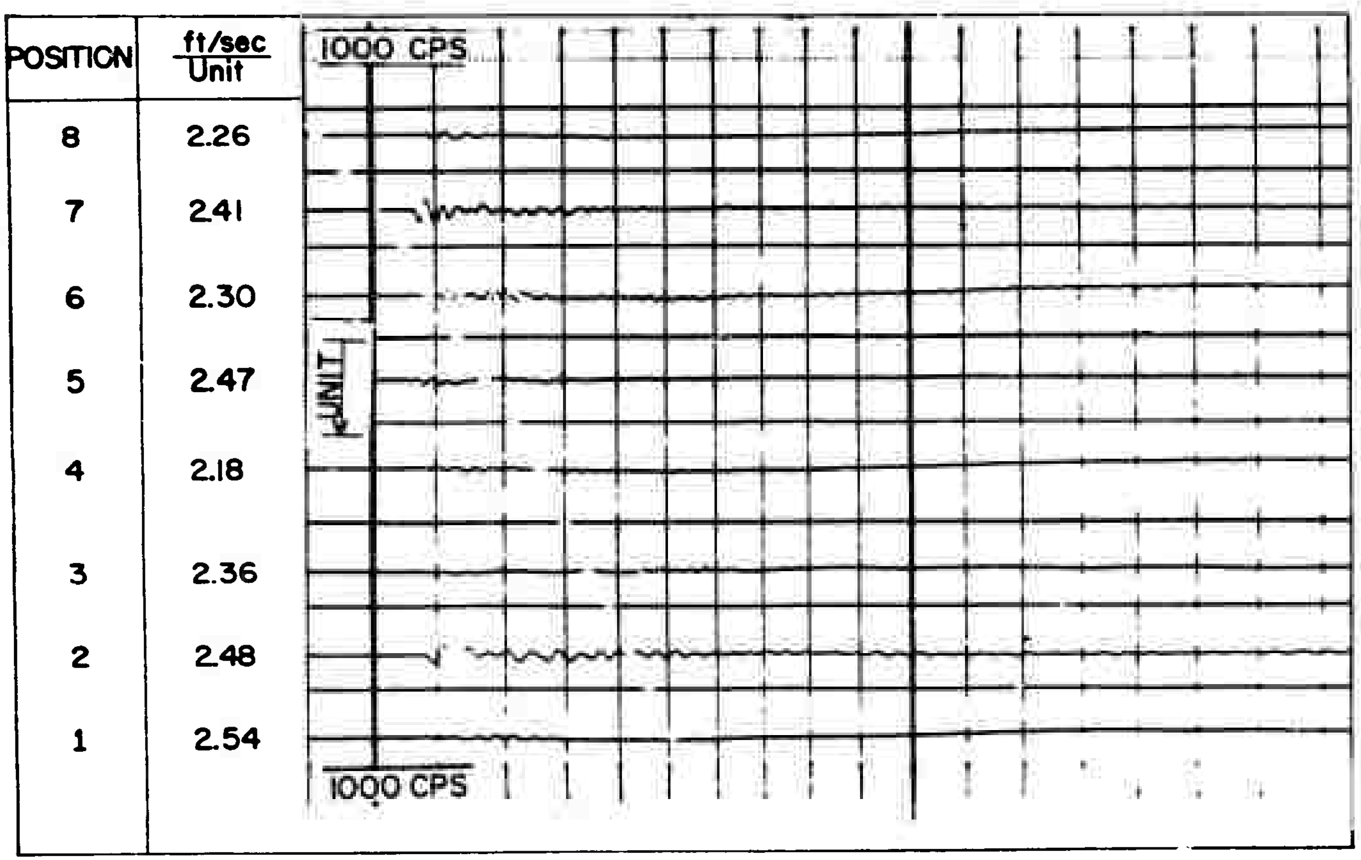

Figure 3.14 Oscillogram of velocities on SS-394 from direct shock wave.

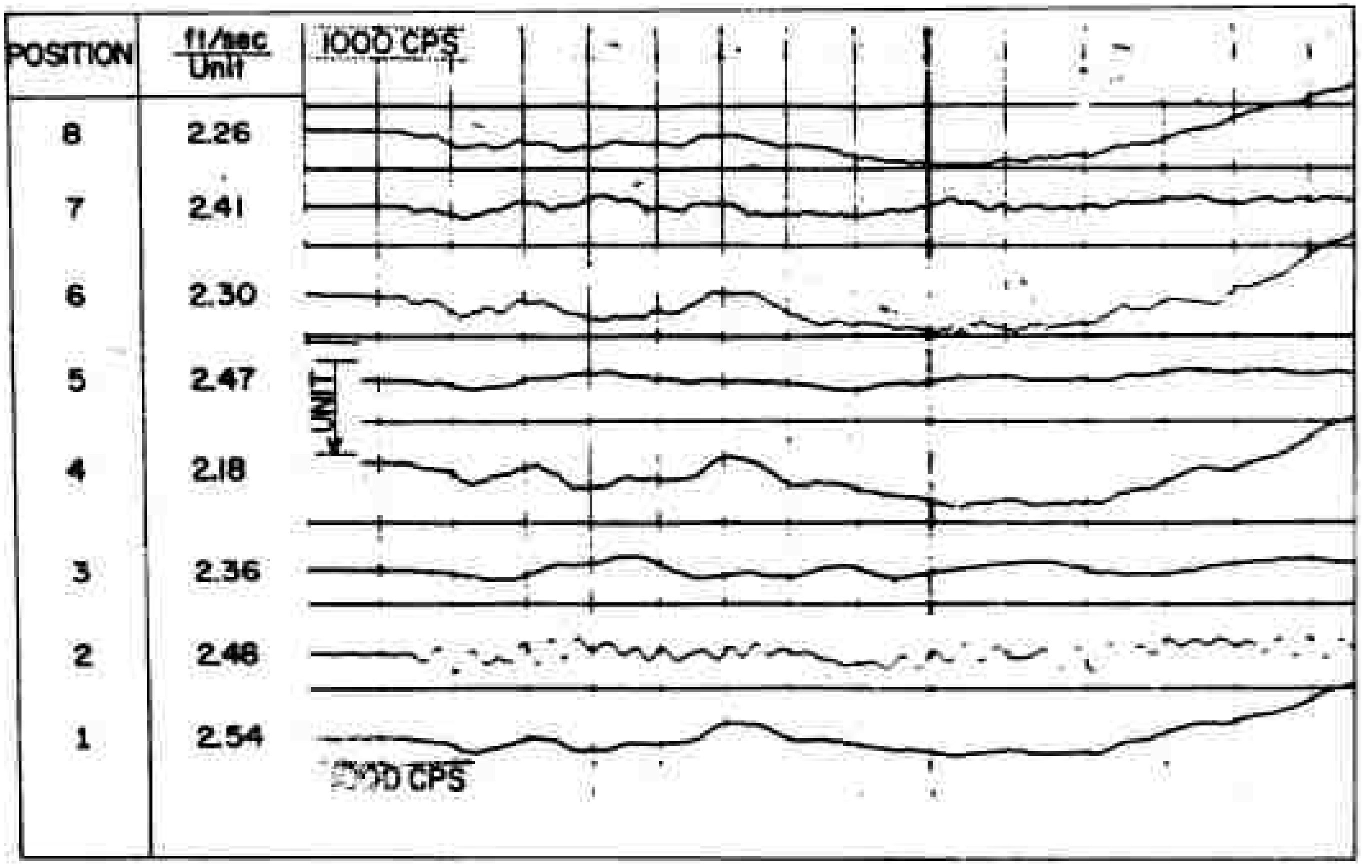

Figure 3.15 Oscillogram of velocities on SS-394 from reflected shock wave.

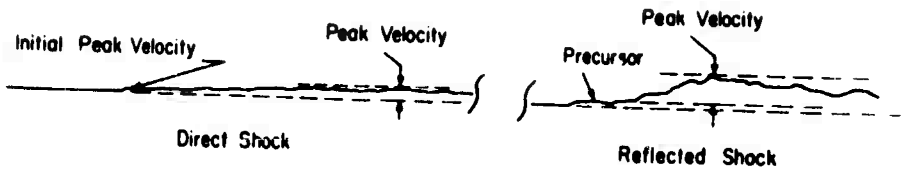

Figure 3.16 Tracing of a velocity-time record showing the method of reading peak velocities.

The record was obtained from Position 16 on DD-826, and shows the motions resulting from the direct and reflected waves during Shot Sword Fish. Both portions of the record are to the same velocity and time scales. The zero line for measuring the velocity from the direct shock was extended from the portion of the record just preceding the arrival of the shock wave. The zero line for the reflected shock is drawn from the point of arrival of the shock wave parallel to the portion of the record just preceding the arrival of the precursor.

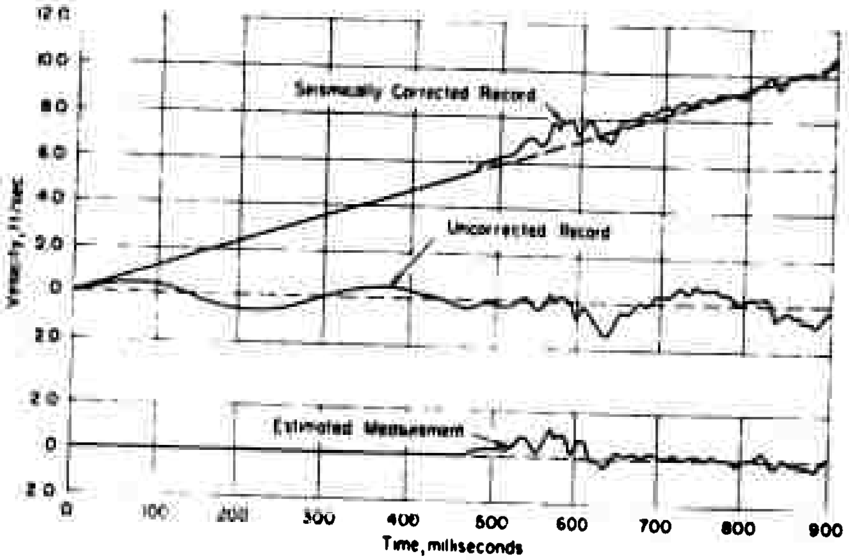

Figure 3.17 Procedure for determining reflected wave response on DD-845. Record is that for Position 2. The upper figure shows the uncorrected record as obtained, with the reflected shock motion superposed on residual spring motion. The seismic correction removed the spring component; however cumulative errors in integration due to drift or errors in the zero value caused a linear drift of the corrected record with time. The lower figure shows the estimated corrected record in which the cumulative drift has been subtracted from the original seismically corrected record.

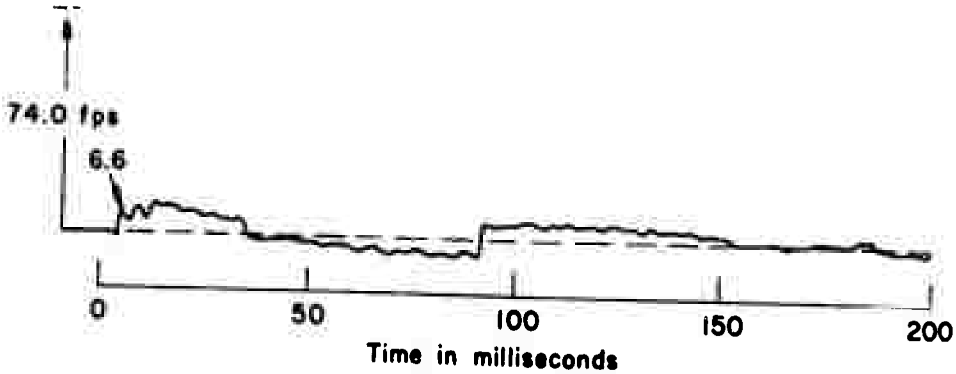

Figure 3.18 Velocity record obtained from Platform P-2. The calibration amplitude is indicated at the left.

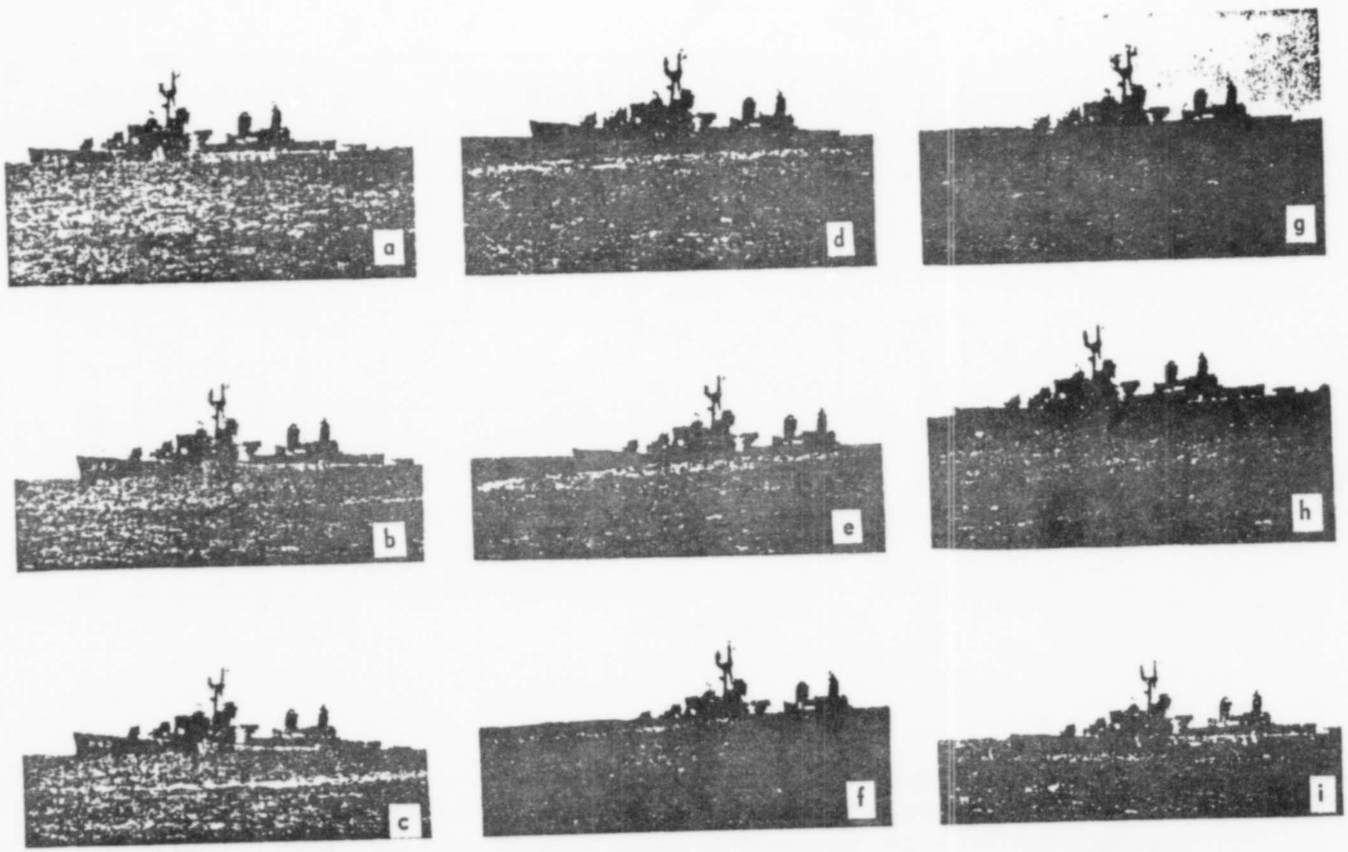

Figure 3.19 Frames from film at DD-826 showing displacement of DD-845 relative to surface waves. Time between frames is approximately 2.1 seconds. Time of frame in sequence of waves is indicated in Figure 3.20. (DTMB photos)

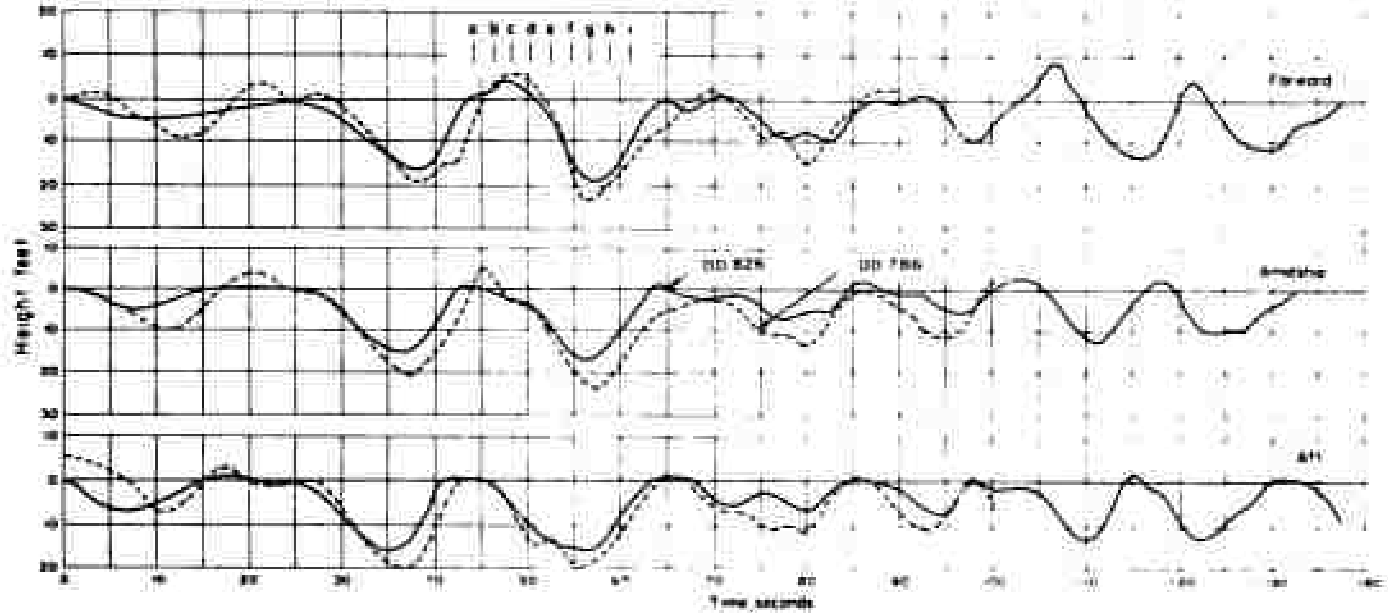

Figure 3.20 Plots of data on motion of DD-845 in response to surface waves. The solid lines show measurements made from film from cameras on DD-826; dashed lines are from DD-786 films. The plots show the motion at three locations on DD-845 relative to the water surface between the ship and viewing cameras. Zero displacement corresponds to measurement with ship in flat sea or ship on crest of passing wave. Approximate times of frames reproduced in Figure 3.19 are indicated at top of figure.

Chapter 4

DISCUSSION

4.1 PRELIMINARY REMARKS

The discussion which follows is directed toward the establishment of a relation between the Sword Fish conditions (charge size, ship range and orientation, etc.) and the recorded shock velocities and damage.

The total yield of the weapon, the depth of burst, and time of burst were calculated by Project 1.1 and reported in Reference 27. These data are used in the following discussion.

The ranges and orientations of ships in the test array were determined by combining data of Projects 1.1 and 1.2 with the shock-wave-arrival times at the ships as determined by Project 3.1. Common time measurements of shock-wave-arrival time were based on fiducial timing signals transmitted by Project 9.2 and recorded independently by Projects 1.1 and 3.1.

The damage data were collected by Project 9.1 for both the HE explosion tests and Sword Fish. These data are reported in detail in Reference 26.

Other data on geographical, operational, and atmospheric conditions related to Shot Sword Fish are included in the report of the Scientific Director, Reference 28.

4.2 RANGES AND ORIENTATIONS OF TARGET SHIPS

Target ship locations relative to the detonation point were determined using shock-wave-arrival times at the ships, the detonation time as determined by Project 1.1 (Reference 27), and an average acoustic velocity for the water between the surface and the depth of burst. The direct shock-wave-arrival times are indicated in Table 2.1 for the various target ships. Times are indicated relative to a zero time, which was the time at which a wire across the back of the firing cell of the ASROC launcher opened. This time was considered zero time and was transmitted and recorded by Project 9.2 (EG&G).

Detonation as determined by Project 1.1 occurred at 39.810 ± 0.005 seconds after zero time. Ranges to the ships were determined by using differences between the shock-wave-arrival times of Table 3.1 and the detonation time, and an average acoustic velocity of 4,940 ft/sec.

This average velocity was determined from data provided by Project 1.1. The value was weighted toward the velocity near the surface, since, with refraction, the major portion of the path of an acoustic ray would be in upper water layers.

Ranges obtained in this manner were published in the POIR for Project 3.1 (POIR 2005) and are reproduced here in Table 4.1. The ranges obtained with actual arrival time data were compared with ranges and transit times computed using the Sword Fish velocity gradient. A correlation equal to that used in Reference 4 to compensate for the higher shock-wave velocities near the charge was also applied to the calculated transit time data. The resulting computed ranges agreed closely with the ranges obtained using the average velocity.

Orientations of the target ships relative to the direction of propagation of the direct wave were determined from the relative arrival times of the shock wave at different positions along the length of the ships. Orientations are indicated in Table 4.1, for each of the surface ships. Orientation of SS-394 could not be determined from shock-wave-arrival data, since all of the shock measurements were made in a limited section of the ship's length.

4.3 VARIATION OF VERTICAL VELOCITIES OF TARGET SHIPS WITH RANGE

The vertical bodily velocity of the surface targets for Sword Fish was expected to depend on the peak pressure in the shock wave and the angle of incidence of the shock wave with the ocean surface. Refraction caused by variations in temperature and density of the water through which the shock wave was transmitted had an appreciable effect on both the value of the peak pressure and on the direction of travel of the shock wave for Sword Fish, and consequently on the bodily velocity of surface ships.

Previous tests had indicated that the initial vertical bodily velocity of surface ships was approximately equal to the peak water-particle velocity. Peak water-particle velocity V is defined as:

$$V = \frac{2P_o}{\rho c} \cos \theta \qquad (4.1)$$

Where:

P_o = peak pressure at the water surface

θ = the angle of incidence of the shock wave at the water surface

ρ = density of water

c = velocity of sound in water

In the absence of refraction effects P_o can be computed from standard TNT formulas for a charge of W pounds of TNT at depth d in feet and slant range R from the surface in feet. The equation for particle velocity of the water then becomes

$$V = \frac{620\ dW^{0.377}}{R^{2.13}}\ \text{ft/sec} \qquad (4.2)$$

In accordance with previous results, the TNT equivalent was taken as percent of the calculated RC yield. For this report a total (RC) yield value of ___ and a depth of burst of 670 feet as determined by Project 1.1 (Reference 27) were used for calculating water-particle velocity.

In Figure 4.1, computed vertical-particle velocity for isovelocity conditions is plotted as a function of horizontal range for Sword Fish weapon size and geometry. Initial vertical velocities recorded at bulkheads at the bottom of each ship were averaged and the results are indicated in Figure 4.1. The velocity obtained on Platform P-2 is also indicated.

The effects of refraction on the surface water-particle velocity at various ranges were determined using an IBM 7090 computer. The calculations were based on the sound-velocity structure reported by Project 1.1 in Reference 28. It was assumed in the calculations that the high-frequency components of the shock wave traveled outward from the burst in directions parallel to the acoustic ray paths. The pressure at the shock front was calculated from the lengths of the rays and from spreading effects as measured by the distances between adjacent rays. The results of the calculation are also plotted in Figure 4.1.

As may be seen in the figure, the measured initial bulkhead velocities were close to the values computed for the refraction condition. For all except the closest ships, this value of velocity was less than 0.1 ft/sec. For these ships, the measured initial peak velocity was less than one-tenth the value computed for isovelocity conditions. At DD-845, the effects of refraction were considerably less, although the measured bulkhead velocity was still about half the value expected under isovelocity conditions.

Refraction affected the shape of the velocity-time records as well as the initial magnitude at each of the surface ships.

The shock motions recorded at two of the bulkheads in machinery spaces on DD-845 are shown in Figure 4.2. The motions at these positions were considered to be representative of the bodily motion of the ship. They are shown along with a curve representing the computed motion of surface water at DD-845. The water motion was computed without refraction effects being considered. The motion of a surface target is compared with the motion of the surface water in Reference 3. The water velocity as a function of time is computed to be

$$V_w = \frac{2P}{\rho c} (\cos \theta) e^{-t/\tau} \quad (4.3)$$

for the case in which the cutoff time at the ship's bottom is very short compared to the time constant. Cutoff at keel depth of DD-845 would occur in 0.5 msec, while the time constant of the charge τ was reported by Project 1.1 as 29 msec.

The initial peak velocity for the unrefracted case was determined from Figure 4.1 as 1.7 ft/sec and the exponential function $e^{-t/29}$ was used to define the decay with time t in msec.

Figure 4.2 indicates the resulting motion and shows that the high-frequency components of the measured shock motion were the ones most affected by refraction, as indicated by the initial history. At the destroyers at greater ranges, the high-frequency components of the shock motion were even further attenuated as may be seen in Figures 3.8, 3.10, and 3.12.

At these ships, the initial peak was achieved in about 1 millisecond, but a much larger (the maximum) velocity from the direct shock was attained in about 40 milliseconds. The velocity associated with this later peak was three to seven times the initial peak at individual ships. The values as plotted in Figure 4.1 more nearly correspond to the expected velocity for isovelocity water conditions. Since these peaks occur at such late times with respect to the arrival of the shock wave, calculation of their magnitude on the basis of initial peak pressure is not possible. Shock effects of these velocities are extremely limited because of the long time duration. While the magnitude of these velocities is greater than for the initial peak, the associated accelerations are appreciably lower than those for the initial peak. Integration of the velocity-time curve for large time ranges would be a comparatively inaccurate process. Visual inspection of the records suggests that maximum vertical displacements are less affected by refraction than are initial velocities.

4.4 VARIATION OF SHOCK MOTION WITH LOCATION IN SHIP

The main structural motions of the surface ships were obtained for positions along the length of the keel and for positions at increasing heights in the ship along main structural bulkheads. The direct shock produced significant motions only on DD-845. This discussion is, therefore, limited to measurements on that ship.

4.4.1 Longitudinal Distribution of Shock Loading. DD-845 was oriented stern-on to the burst. Figure 4.3 shows the vertical shock velocities recorded at various locations along the bottom of the ship. Arrival times at various locations are shown relative to the arrival of the shock wave at the aft-most location, Position 29.

The shock motions recorded at the three locations which were at the same elevation on main structural bulkheads agree well in both amplitude and shape. In contrast, the velocity record at Position 29 is considerably attenuated in the early stages, possibly due to some effect associated with shallow draft and ransom-stern location, and is included mainly to show the variation in shock-wave-arrival times.

The agreement in the three records at similar locations indicates a uniform loading over the length of the ship. Had the ship been oriented differently, e.g., broadside, the shock levels at the bottom of the ship also would not have been different. Only minor differences in relative shock-wave-arrival times would have existed.

4.4.2 Variation of Motion with Height in Ships. The shock velocity amplitudes at the different deck levels of DD-845 did not vary greatly. Where measurements were made on continuous vertical structures through the ship, the most significant differences in the records were in the slopes of the initial portion of the record and consequently in the acceleration amplitudes.

In Figure 4.4, shock motions at three levels of DD-845 are shown. The measurements at Positions 16 and 23 were made at the keel and main deck levels, respectively, at the main bulkhead at the forward end of the aft engineroom. The measurement at Position 26 was made at the superstructure level slightly forward of the same bulkhead.

As may be seen in the figure, the peak velocity was not greatly different at the three locations. The initial accelerations as determined from the slopes of the records for ascending levels in the ship, however, were 90, 20, and 5 g respectively.

The shock displacements determined from integration of the velocity records agree well over relatively long periods of time as is shown in the figure. No significant relative displacements occur in the early portions of the records. The relative displacements at the end of the records are not reliable because of cumulative errors in correcting the records for motions of the seismic elements of the velocity meters.

At several locations in the ship, higher peak velocities were recorded than those at main structural bulkheads. This was true at the various levels of the ship. At the lower deck levels, these larger peaks resulted from the high-frequency components of motion associated with local structure. These motions, in some cases, excited high-frequency meter resonances. At the upper deck levels, the greater amplitude resulted from the low-frequency deck response to the motion imparted by the bulkhead. The dynamic response of deck plating, in which the damping is low, would be expected to exceed the input for the type motions which were recorded.

4.5 ATHWARTSHIP AND LONGITUDINAL SHOCK MOTIONS

On DD-845, which was oriented with its stern toward the explosion, shock motions were recorded in three orthogonal directions at two locations in the ship. At the keel level, the vertical shock velocity from the direct shock wave was twice the longitudinal and three times the athwartship. At the main deck level, the vertical component was five times as great as the others.

At the range of DD-845, the displacements associated with these horizontal components of the shock motion were of even less relative magnitude.

In all of the surface ships, the shock motions measured in the horizontal plane were considerably lower in amplitude than those in vertical.

4.6 SHOCK MOTIONS ON THE SUBMARINE SS-394

SS-394 was located at a range comparable to that of the manned destroyers and was at periscope depth, starboard side to the explosion. The initial peak vertical velocities on the submarine from the direct shock were about the same as those on the destroyers. In the submarine, however, the corresponding peak athwartship velocities were two to four times as great as the vertical. As expected, displacements associated with these velocities were small for all components of the motion.

4.7 SHOCK MOTIONS CAUSED BY SHOCK WAVE REFLECTED FROM THE OCEAN BOTTOM

Shock velocities were recorded on each of the ships from shock waves which appeared to originate on the ocean bottom. The resulting motions included the effects of a bottom-transmitted precursor, a direct reflection from the bottom surface and subsequent reflections fr deeper bottom layers.

In Figure 4.5, the calculated arrival time at the surface of the direct shock and the shock reflected directly from the bottom are plott as a function of horizontal range. The computation of reflected wave arrival time was based on a flat bottom at a depth of 13,300 feet. Th Sword Fish gradient reported by Project 1.1 (Reference 27) was employed in the calculations. The measured arrival times are also plotted and indicate a reasonable agreement between the computed and experimental results. As expected, at increasing ranges, the arrival time for the reflected wave approaches the arrival time of the direct shock wave.

At the range of each of the manned ships, the magnitude of the velocity as a result of the reflected shock wave was greater than that as a result of the direct shock. Figure 4.6 indicates the magnitude of the resulting shock motion at the different ships. Also shown is a curve of expected peak velocity with a perfectly reflecting bottom, i.e one in which all of the pressure is reflected from the surface and in which the shape of the pressure-time curve is preserved. Since the reflected pressure wave retains neither its magnitude nor its shape up reflection from a bottom of the type which existed, the resulting ship velocities are lower than suggested by the computed curve. Other curv are shown in the figure and labeled "reflection ratio". In this report the reflection ratio is the ratio of the measured velocity to the parti velocity computed for a direct path length equal to that of the reflec- tion path, and an angle of incidence equal to that between the actual reflection path and the water surface.

The plotted points are averages for the motions at bulkheads at th bottom of each ship. The values for the manned ships were readily obtained from the data as shown in Figure 3.16. Those for DD-845 could not be as readily determined, as shown in Figure 3.17. Since the cumulative effect of corrections of the records at DD-845 was several times the amplitude of the record being extracted, the range of values of the reflected shock velocity is shown in Figure 4.6 rather than an average value.

In any case, there was a considerable spread in the velocity magni tudes for ships at nearly the same range. The bottom-reflected veloci on DD-681 were almost twice those on DD-786 and DD-826. Unfortunately no pressure measurements were made in the water near DD-681 and the nature of the differences in the reflected pressures at this ship rela- tive to other ships cannot be ascertained. It appears that the resul may be related to some local focusing effect in the path from the char to DD-681 via the bottom.

Bottom-reflected wave-shock motions differed appreciably from direct shock-wave motions. Whereas peak velocities at the keel of DD-845 for the direct shock were reached in 1 millisecond or less, peaks for the reflected shock at identical locations on the manned destroyers were attained in 12 to 15 milliseconds. The change in the character of the response is presumably due to the change in the character of the pressure pulse during reflection.

4.8 COMPARISON OF MOTIONS WITH THOSE OF HE TESTS

Prior to the actual Sword Fish event, each of the Sword Fish ships in the test array was subjected to a single shock test employing a 1,200-pound high-explosive charge. Each test was conducted in the manner described in Reference 24. The test severity was about one-half that to which ships are scheduled to be tested routinely (Reference 9).

The tests served to detect weaknesses in the shock resistance of these ships in order that corrective action could be taken before Sword Fish. During two of the tests, those on Agerholm (DD-826) and Razorback (SS-394), shock measurements were made as a part of Sword Fish. Peak velocities for these tests are reported in Tables 3.3 and 3.6 respectively.

A direct comparison of motions recorded at two positions on DD-826 for the HE tests, Sword Fish direct shock, and Sword Fish reflected shock, is made in Figure 4.7. As may be seen, the HE test produced peak velocities greater,by a factor of four or more,than the larger of the two Sword Fish velocities. High-frequency accelerations associated with the initial slope of the HE test records a factor of fifty or more greater than the accelerations associated with the Sword Fish records.

The effects of these three shock motions on undamped single-degree-of-freedom systems is illustrated in Figure 4.8. Again, the largest responses resulted from the HE shock. With increasing frequency, the ratio of the HE test response to the Sword Fish response increased.

In Figure 4.9, shock spectra for the HE test of DD-826 are compared with the Sword Fish results for DD-845 at the same locations in the respective ships. Even for this, the closest of the Sword Fish ships' response was lower than for the HE tests. At the positions compared, the peak velocities for the HE test were more than twice as great as on DD-845 for the direct shock. There is indication that, at the low-frequency end of the spectra, the DD-845 motion resulted in a response closer to that for the HE tests. This increase in the relative response at low frequencies would be expected for DD-845 in view of the predominantly low-frequency type of motion recorded at these locations in Sword Fish (see Figure 4.3).

On Razorback, the results with respect to the measurements were similar to those reported for DD-826. The vertical velocity peaks for the HE test were higher by about a factor of three than those for the reflected shock in Sword Fish. The athwartship reflected velocities on structure were greater by about a factor of six.

4.9 DAMAGE TO SHIPBOARD EQUIPMENT

While the extent of damage resulting from the ASROC burst was relatively minor compared to the HE tests, each of the target ships had damage which resulted in weapon-delivery impairment. None of the ships suffered hull damage or were immobilized. The degree of weapon-delivery impairment was no greater on the closest ship than on destroyers at a nominal 12,000-foot range.

The shock velocities which were measured as a result of the Sword Fish burst were comparable to or less than those experienced in the least severe of the routine shock tests reported in References 10 through 19. They were also lower than those experienced in the pre-ASROC shock test on the target ships themselves, as was shown earlier. While the character of the shock motion differed between the two types of tests, generally the HE test would be expected to be the more damaging. In the HE test, the accelerations and decelerations were appreciably greater than those experienced from the ASROC shock. Consequently, the loads on equipment, particularly in the lower levels of the ship, were greater for the HE tests.

Although the displacements were greater for the ASROC test, they were not damaging of themselves. Even the low-frequency, suspended, master gyrocompass which failed on Hardtack and Crossroads targets did not show appreciable deflection relative to the ship. Damage related to displacement generally occurs when mounts yield due to large relative excursions, or components collide as a result of the relative deflections. The high-speed motion pictures taken inside DD-845 dramatize the lack of significant motion. A coffee cup resting on a shelf in one of the scenes is not visibly disturbed as a result of either the direct or reflected shock motions at this ship.

The ships which were shock tested prior to the ASROC shot showed a marked decrease in the number of damaged items. The destroyer USS Preston (DD-795) which was at a greater range than the target destroyers, but was not shock tested prior to Sword Fish, received considerably more damage than the shock-hardened target ships. Equipment similar to that damaged on Preston was not damaged on Hopewell (DD-681), one of the target ships. Had the target ships not been previously shock tested and refitted, considerably more damage would probably have occurred.

The damage which resulted in different ships was of a similar type but occurred rather randomly with respect to a particular console or a particular component of a system. ASROC systems on two of the ships, for example, were disabled by blown fuses, one in a fire-control-group switchboard, and the other in the SQS-23 sonar.

In machinery areas, the shock levels were lower on each of the ships than those which might normally be expected to result in machinery damage. In character, however, equipment response to the Sword Fish shock was similar to the response of similar heavy machinery to other higher level shocks. An example of such response was the motion of the low-pressure turbine on DD-845.

The response of low-pressure turbines had been studied during Hardtack. The magnitude of the motions during Sword Fish, however, was roughly one-third that which resulted in damage from Shot Umbrella of Operation Hardtack. During Hardtack, the loads in the supporting structures for the propulsion turbines caused deformation of the supports of sufficient amplitude to seriously misalign the propulsion system.

The input to the low-pressure turbine and the response of the turbine girder on DD-474 during the Umbrella test of Hardtack are shown in Figure 4.10. In this test, the motion from the direct shock was preceded by the shock transmitted through the bottom of the lagoon. The significant response, however, was to the direct shock.

On DD-845, the turbine mounting arrangement was like that on DD-474. The response on DD-845 was also similar. Figure 4.11 shows the motions recorded at the supporting structure and on the low-pressure turbine girder in the aft engineroom of DD-845. The motions of the bulkhead at the keel level, of the shelf plate (which joins the bulkhead-attached structure to the flexure plate) and of the turbine girder are shown.

The girder motion oscillates about the keel motion. The shelf plate initially tends to follow the keel but as the girder motion overshoots the keel motion, the plate follows the turbine with lower oscillatory amplitude. From this time, the plate appears to move as though it were a point on a spring connecting the turbine to the bulkhead structure, indicating that a portion of the flexibility of the system lies in structure on the bulkhead side of the flexure plate.

The turbine response at its forward end was like that of an undamped single-degree-of-freedom system with a frequency of 16 cps to the motion recorded at the keel. The velocity response computed for such a system is compared with the recorded equipment response in Figure 4.12. The relative displacement of the point on the turbine girder with respect to the point on the keel is shown in Figure 4.13. The relative displacement of a 16-cps system to the keel motion is also shown. The indicated peak deflection of the turbine girder relative to the keel was on the order of 0.1 inches.

While this relative deflection apparently did not damage the turbines at the shock levels encountered in Sword Fish, the data illustrate that the conditions (equipment type, turbine support design, and response) which resulted in mobility damage to destroyers in Hardtack also exist in FRAM ships. As a result, ships of this type can be expected to suffer immobilizing damage like that experienced in Hardtack at shock-velocity levels on the order of three to four times those encountered by DD-845 in Sword Fish. Using data from Figure 4.1, the range at which such damage would occur is 3,500 to 4,000 feet; considerably less than that at which ships were positioned in Sword Fish.

The submarine in the array saw less damage than did most of the destroyers. It appears that a submarine of this type could be appreciably closer to the burst under Sword Fish conditions without experiencing serious shock damage.

TABLE 4.1 RANGES AND ORIENTATIONS OF INSTRUMENTED SHIPS, SHOT SWORD FISH

Ranges and orientations were obtained from arrival times of the direct shock wave at instrument positions on each target. Orientations are relative to the direction of approach of the shock wave at each target.

Ship	Horizontal Range from Surface Zero	Reference Point for Range	Angle with Shock Wave	Reference Line for Angle	Attitude of Ship
	(feet)		(deg)		
DD-845	6,486	Keel, Fr. 92-1/2	180 ± 10	Longitudinal Centerline	Stern toward burst
DD-826	12,940	Keel, Fr. 92-1/2	114 ± 2	Longitudinal Centerline	Starboard quarter toward burst
DD-786	12,703	Keel, Fr. 92-1/2	155 ± 5	Longitudinal Centerline	Starboard quarter toward burst
DD-681	11,880	Keel, Fr. 92-1/2	0 ± 5	Longitudinal Centerline	Bow toward burst
SS-394	13,420	2 feet above bottom of hull, Fr. 47-1/2	*	—	—

* No adequate reference line for determining angle of ship with burst.

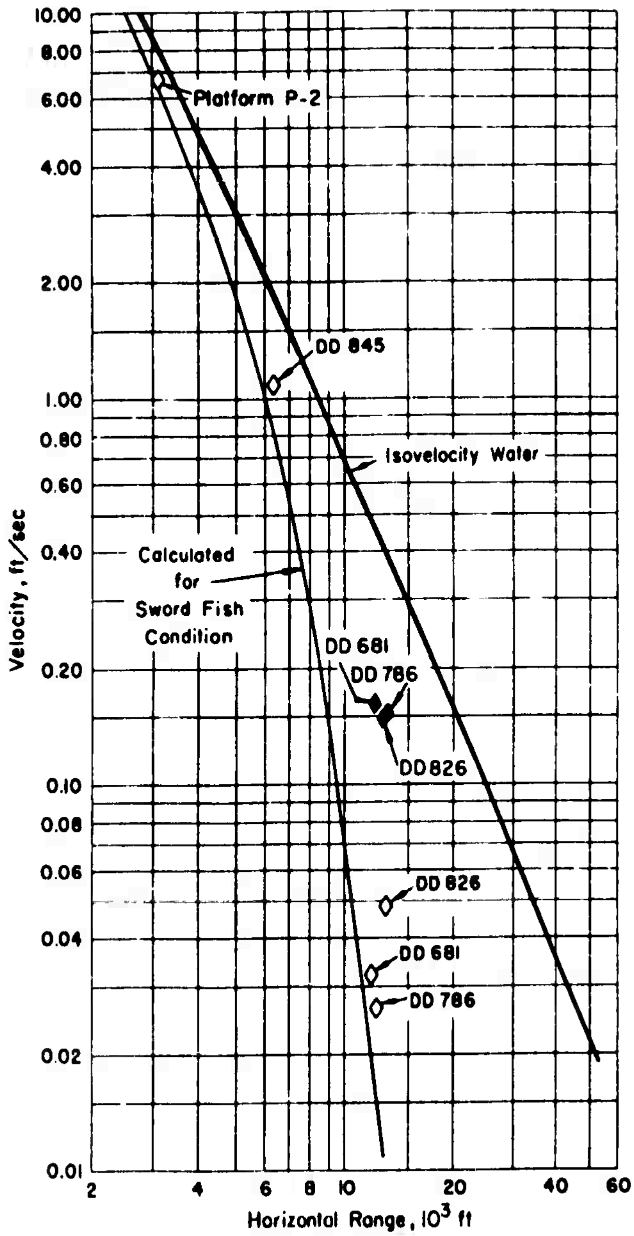

Figure 4.1 Peak vertical velocity of surface water for direct shock wave. The heavy curve was calculated for isovelocity water and the light curve was calculated for Sword Fish refraction conditions. The labeled points are measured velocities of the keel at bulkheads. Open symbols represent initial peak velocities. Closed symbols show maximum velocity.

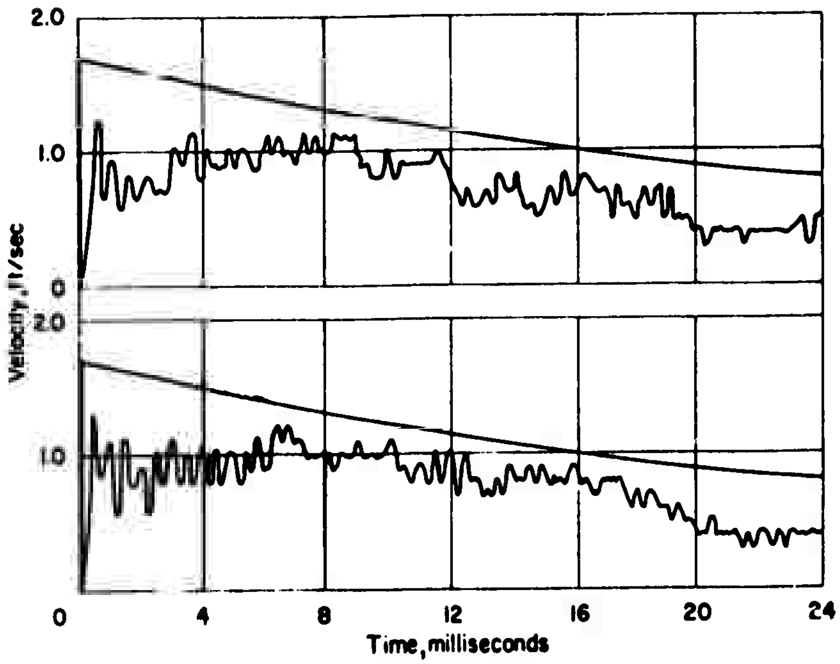

Figure 4.2 Shock motions at bulkheads at keel level on DD-845. The motions at Position 12 (upper curve) and Position 16 (lower curve) are compared with computed motions in response to an exponentially decaying pressure pulse.

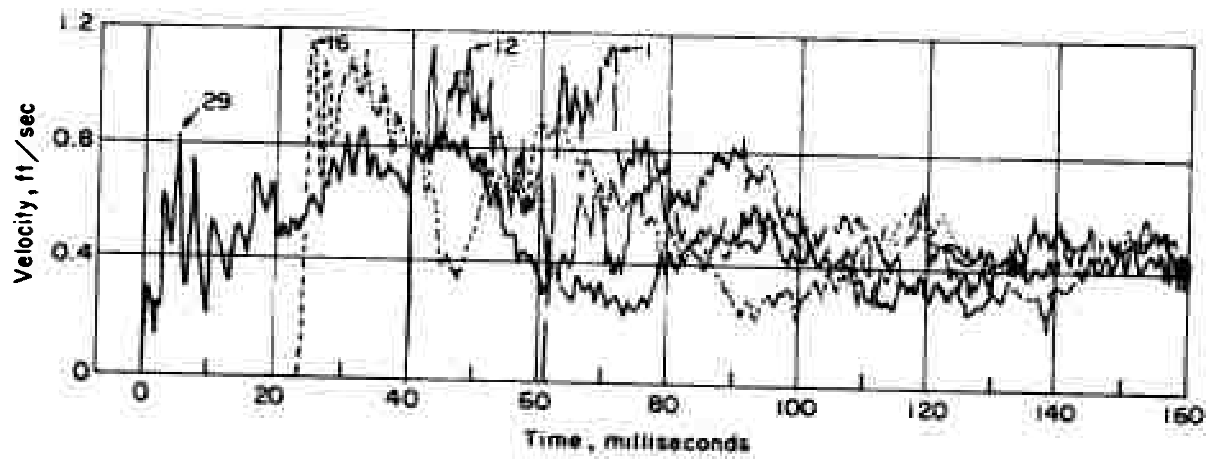

Figure 4.3 Shock motions at lower levels of DD-845 in response to direct shock. The zero time in the figure is the time of arrival at Position 29, the position closest to the burst point. Position numbers indicated for each trace correspond to those in Table 2.1.

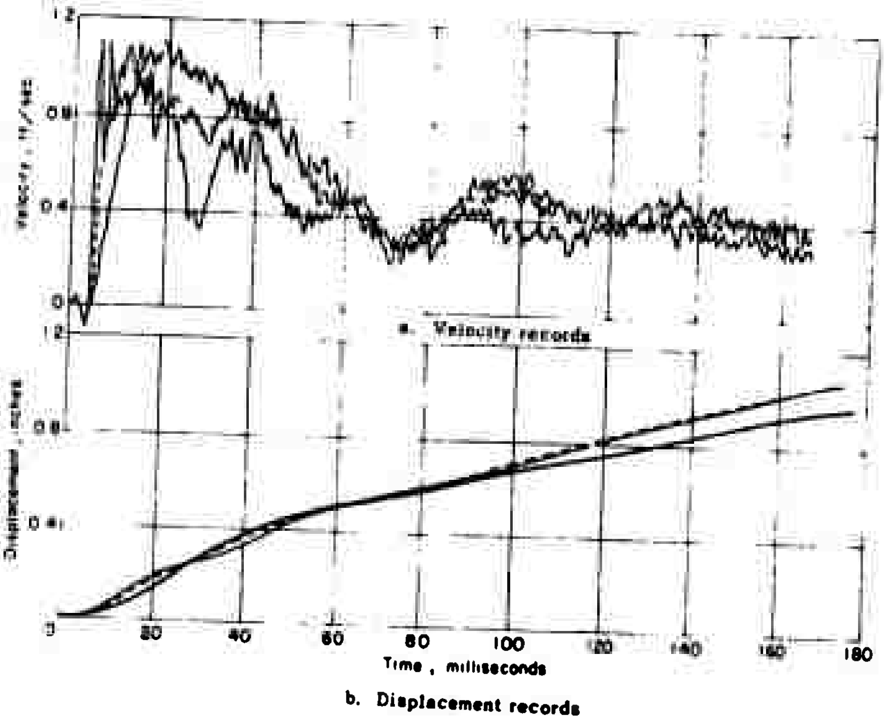

Figure 4.4 Vertical velocity and displacement at different levels on DD-845. The light solid line is the keel motion (Position 16), the dashed line the main deck (Position 23), and the heavy line the superstructure (Position 26).

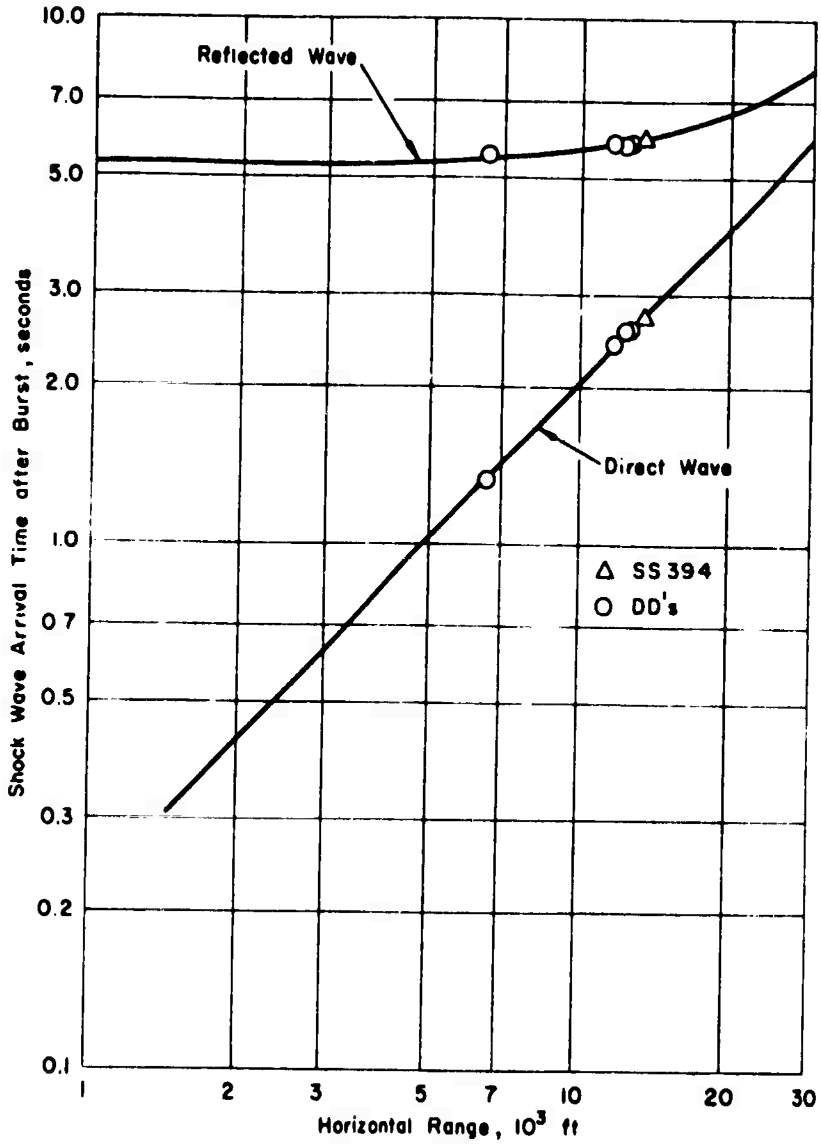

Figure 4.5 Arrival time of direct and reflected waves as a function of horizontal range.

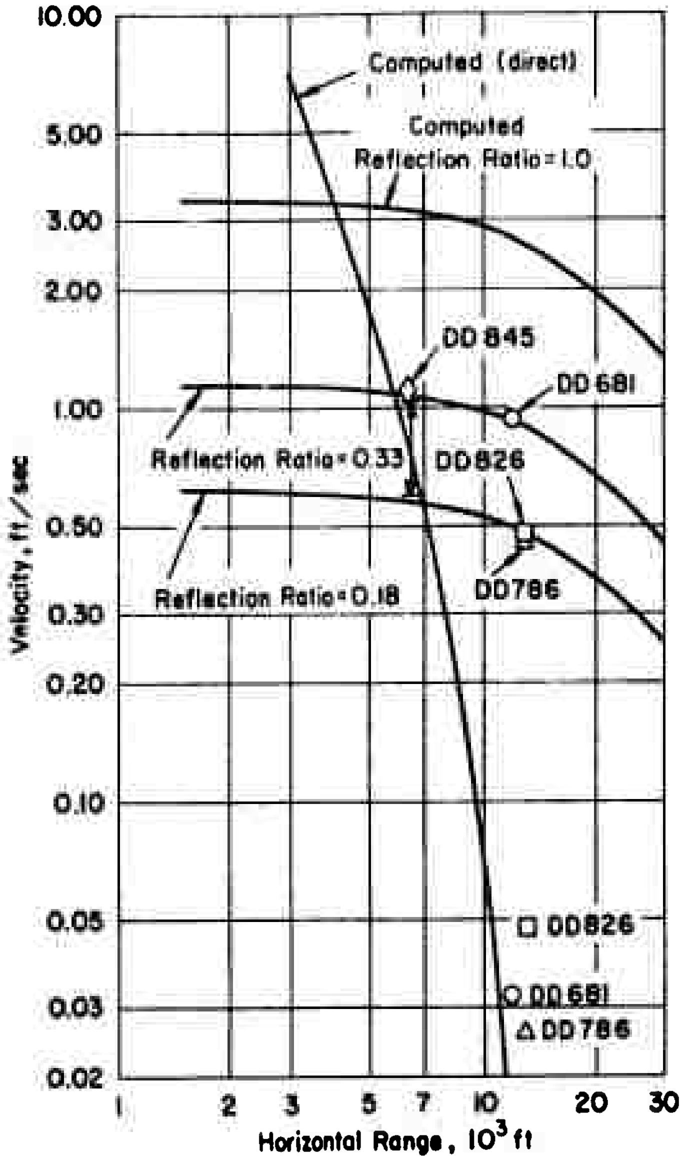

Figure 4.6 Peak vertical velocity of surface water for direct and reflected shock waves of Sword Fish. I Indicates range of measured velocities on DD-845 in response to reflected shock.

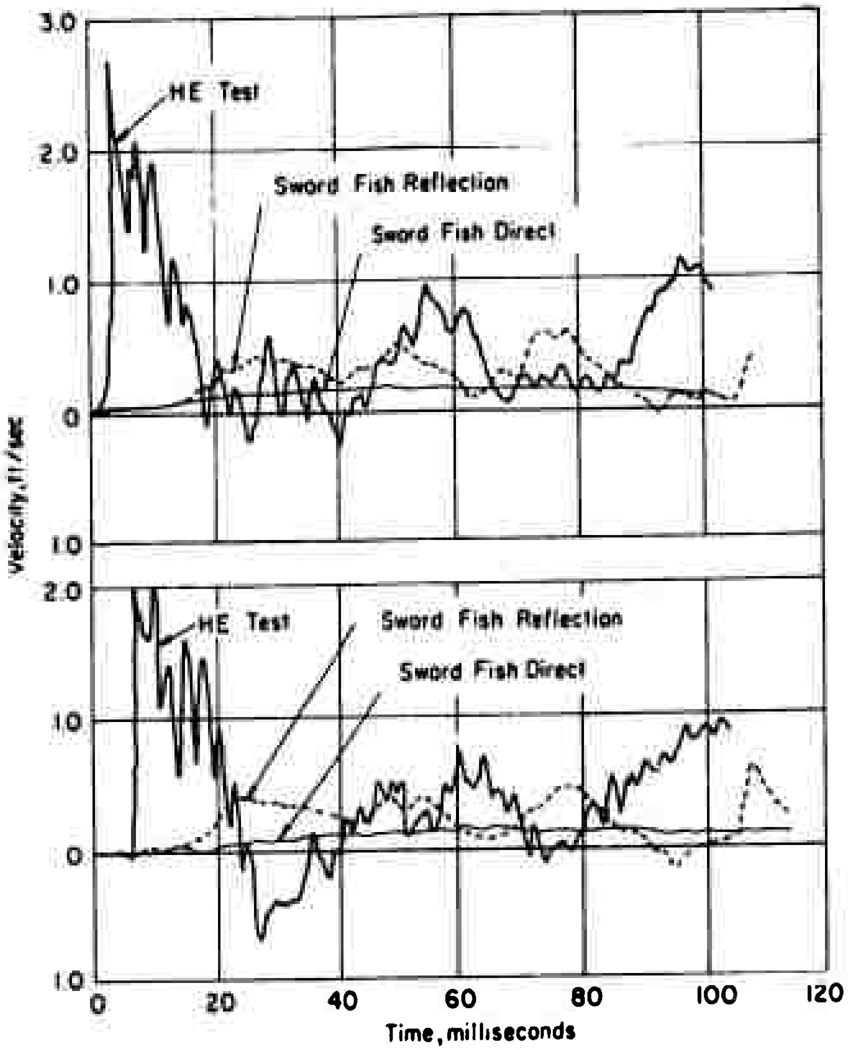

Figure 4.7 Shock motions on DD-826 in response to three shock waves. The upper curves show motions at Position 12 and the lower curves show motions at Position 16.

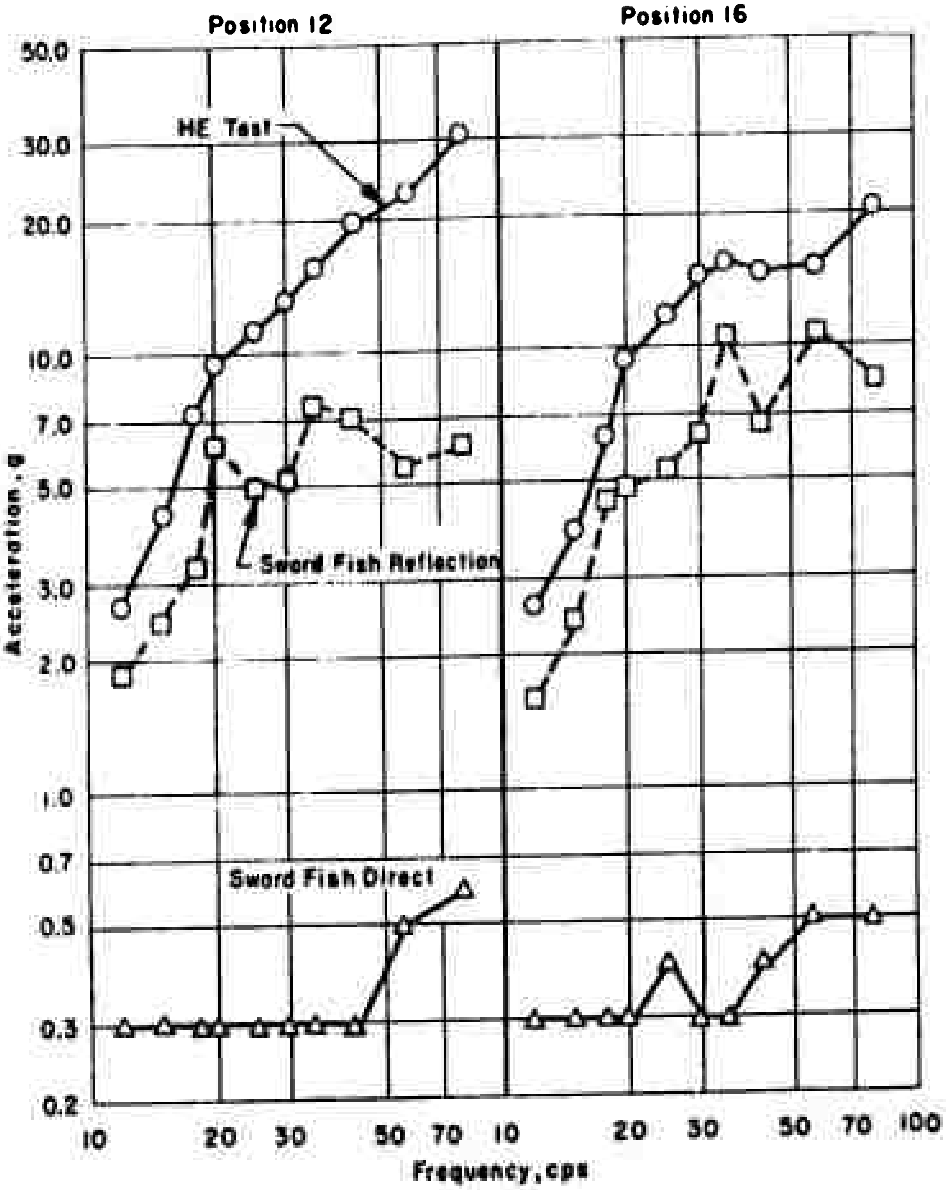

Figure 4.8 Shock spectra computed for shock motions shown in Figure 4.7.

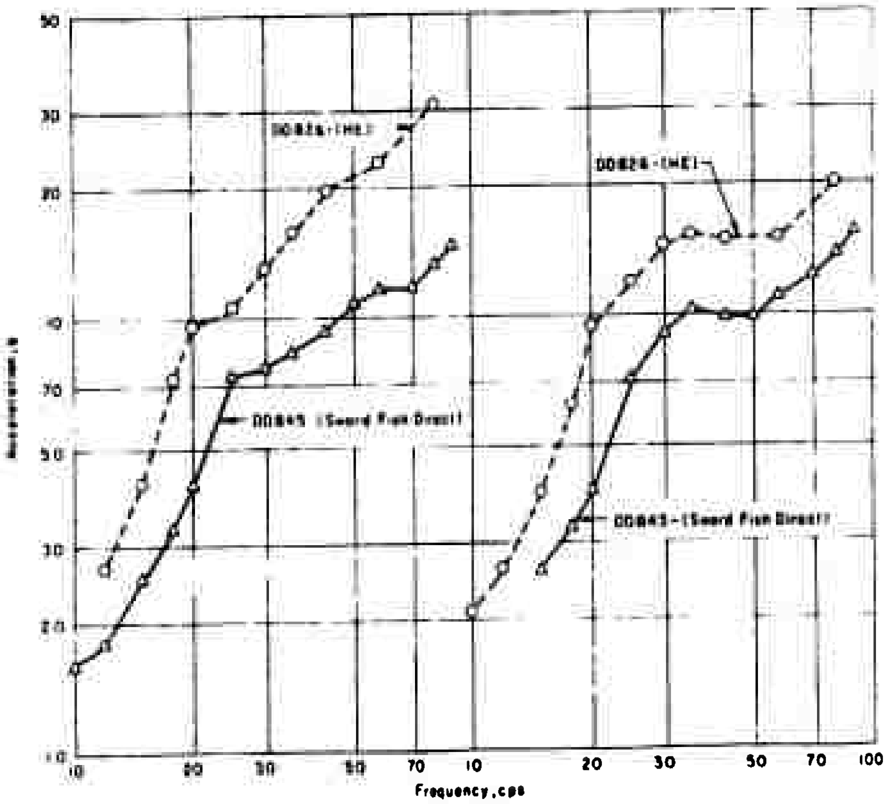

Figure 4.9 Shock spectra comparison for HE test and Sword Fish. The data are for HE test of DD-826 and Sword Fish direct shock at DD-845. Data are for Position 12 (left) and Position 16 (right) on each ship.

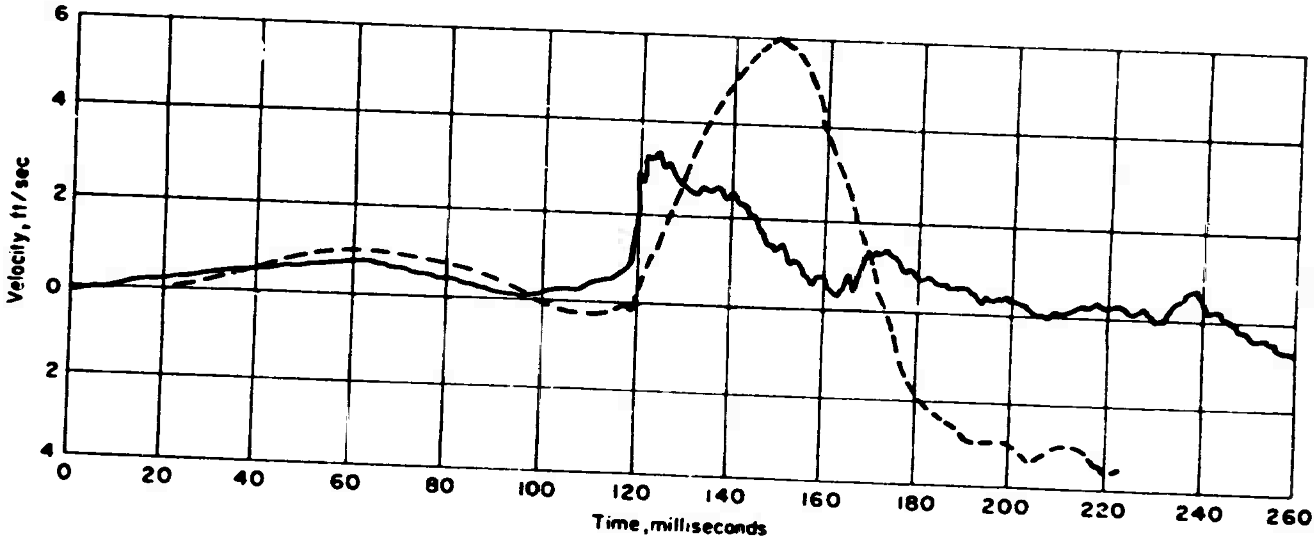

Figure 4.10 Input to and response of turbine girder in DD-474 for Shot Umbrella of Operation Hardtack. Solid line is motion at forward support point for low-pressure turbine girder. Dashed line is motion on girder.

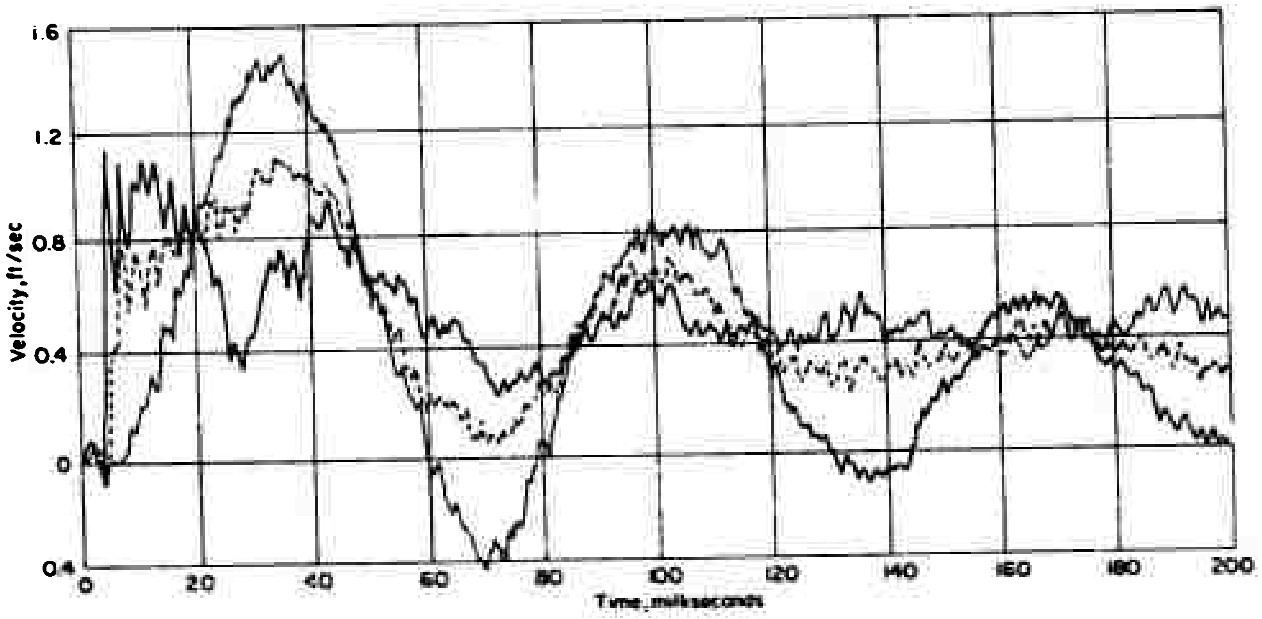

Figure 4.11 Shock motions at forward end of aft engineroom of DD-845. The heavy line shows the velocity at the keel at the bulkhead which supports the main propulsion turbine. The dashed line shows the motion of the box girder which supports the forward end of the turbine by a flexure plate. The box girder is attached to the bulkhead. The light solid line shows the motion at the forward end of the low-pressure turbine girder.

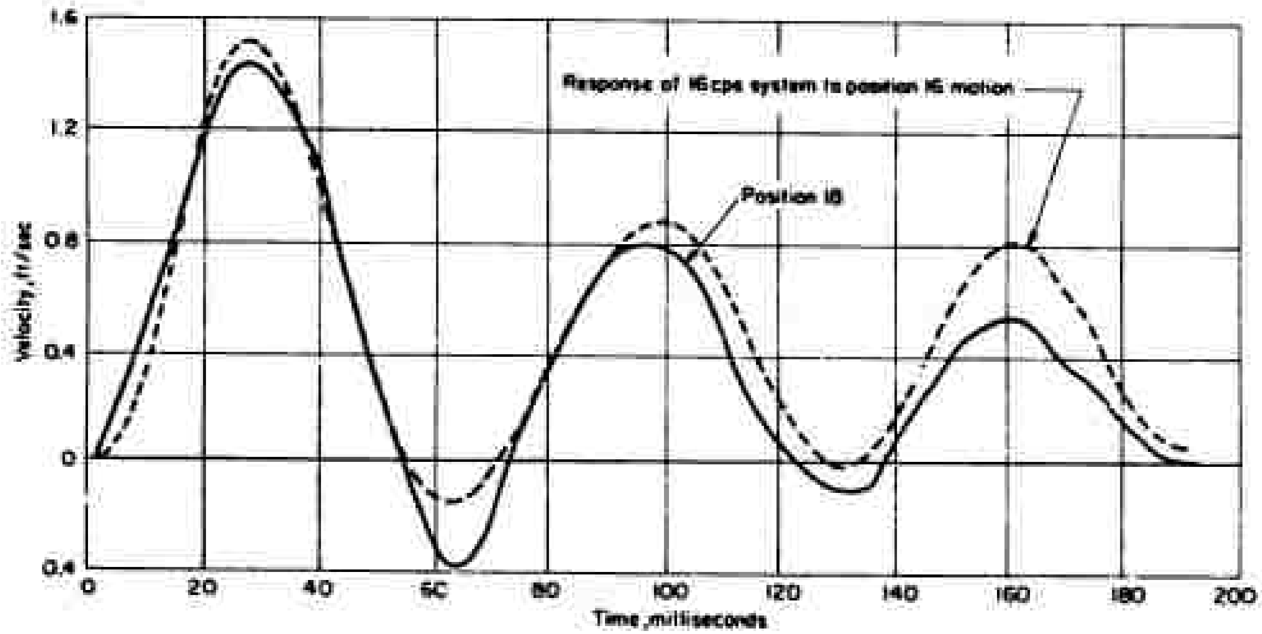

Figure 4.12 Comparison of motion of turbine girder on DD-845 with computed response of 16-cps system to keel motion.

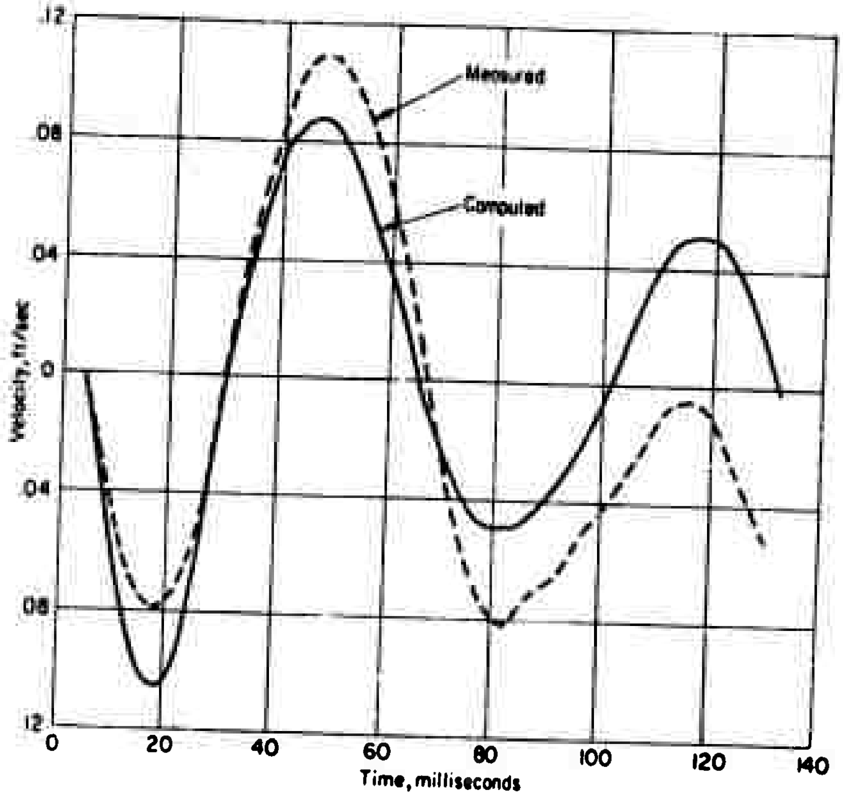

Figure 4.13 Comparison of computed and measured relative displacement of turbine girder with respect to keel.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The conclusions in this chapter refer to underwater nuclear bursts and are specifically concerned with Shot Sword Fish conditions. The term "Shot Sword Fish conditions" includes yield, shot geometry, bottom reflections, thermal gradient characteristics and target ship types.

The shock motions on ships in the vicinity of the Sword Fish burst were documented. The vertical shock velocities on all ships were very low (less than 2 ft/sec).

The vertical shock velocities on the closest destroyer, at 6,500 feet from the burst, were about the same in magnitude for the direct and reflected shock, while at 12,000 feet, vertical shock velocities resulting from the reflected shock wave were two to ten times as great as the direct velocity.

Thermal gradients in the water refracted the direct shock wave and caused considerable diminuation of the shock motions produced in the surface ships with respect to those that would have been produced in isovelocity water. At 6,500-foot range, measured shock velocities were one-half, and at a nominal 12,000-foot range, one-fifteenth to one-eighth those which would be expected for isothermal conditions.

Ship orientation to the burst played no significant role,under Sword Fish conditions, for vertical shock motions.

In spite of the low shock severity in Sword Fish, varying degrees of weapon-delivery impairment on all of the target ships resulted. Disability ranged from complete loss of ASW and AA capability to minor impairment. No mobility impairment resulted.

The extent of impairment of ships at 12,000 feet from the burst was as great as that of the ship at 6,500 feet. Damage on the ships at 12,000 feet resulted from the reflected shock.

On all ships, the shock velocities were lower than those experienced in the mild HE test preceding Sword Fish.

On the surface ships and the submarine, the shock damage from the Sword Fish test was less than for the HE test. This is due both to the lower shock levels in Sword Fish and to the fact that remedial action taken as a result of the HE test improved the shock hardness of the tested ships.

Response measurements on a low pressure turbine on DD-845 were similar in character to those obtained on destroyers in Hardtack. Conditions which contributed to mobility damage during Hardtack exist on FRAM destroyers. Impairment of propulsion similar to that reported for Hardtack would probably occur at ranges of 3,500 to 4,000 feet under Sword Fish conditions.

Motions of DD-845, in response to surface waves resulting from the Sword Fish burst were documented. The maximum measured ship displacement relative to the water as a result of the wave action was 17 feet.

5.2 RECOMMENDATIONS

Sword Fish demonstrated that for comparable conditions, ships which have been shock tested and subjected to even limited shock hardening perform better under the nuclear shock environment than do ships of a similar type which have not been tested. The need for continuation of the program of shock testing and shock hardening fleet units has again been demonstrated. It is recommended that this program of shock testing ships be pursued with vigor and that the lessons learned from tests of specific ships be applied to all ships of the same class, and of other classes which are similarly equipped. Special attention should be paid to weapon systems.