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Technical Report
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FDS-D WET-END SURVIVABILITY POST TEST ANALYSIS

by

David Warren, Kathy Kaska, Carl Stevens,
and David Wicklund

March 1995

Sponsored by
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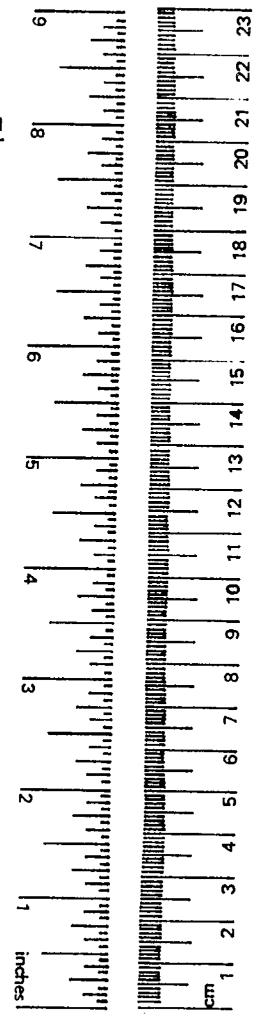
Arlington, VA 22245-5200

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

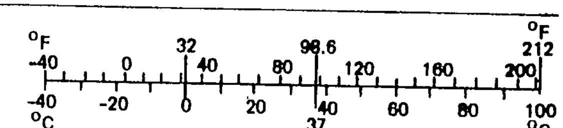
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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The Fixed Distributed System - Deployable (FDS-D) Underwater Segment (UWS) was deployed in the Mediterranean Sea between 5 May and 8 September 1994. UWS survivability was demonstrated in depths ranging from 370 feet to 11,500 feet over a length of 500 nautical miles. The FDS-D UWS was exposed to survivability threats from fishing and the harsh marine environment. Although faults occurred as a result of these threats, contingency plans allowed operations to continue, and FDS-D successfully gathered acoustic data throughout the planned operations. FDS-D demonstrated the viability of cabled systems for rapidly deployable undersea surveillance in high threat, shallow water, littoral zones. The experience gained from FDS-D has enhanced understanding of cable survivability. This experience will benefit both FDS and future cabled systems. This document addresses survivability of the FDS-D UWS.

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FDS-D WET-END SURVIVABILITY POST TEST ANALYSIS

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FDS-D WET-END SURVIVABILITY POST TEST ANALYSIS

1.0 INTRODUCTION

The Fixed Distributed System - Deployable (FDS-D) Underwater Segment (UWS) was deployed in the Mediterranean Sea between 5 May and 8 September 1994. UWS survivability was demonstrated in depths ranging from 370 feet to 11,500 feet over a length of 500 nautical miles. The FDS-D UWS was exposed to survivability threats from fishing and the harsh marine environment. Although faults occurred as a result of these threats, contingency plans allowed operations to continue, and FDS-D successfully gathered acoustic data throughout the planned operations.

FDS-D demonstrated the viability of cabled systems for rapidly deployable undersea surveillance in high threat, shallow water, littoral zones. The experience gained from FDS-D has enhanced our understanding of cable survivability. This experience will benefit both FDS and future cabled systems.

This document addresses survivability of the FDS-D UWS. It is constructed as a summary report with five appendixes. The summary report extracts the main points and conclusions from the appendixes. Each appendix addresses an aspect of FDS-D survivability. The appendixes are divided into the following subjects:

- Appendix A: Cable Autopsy report. The dissection, inspection, and analysis of cable fault samples recovered from the UWS.
- Appendix B: The Fishing Threat. Analysis of the local fishing threat around UWS.
- Appendix C: FDS-D CL106-107 Fault Analysis. Computer analysis of cable deployment dynamics at the fault location.
- Appendix D: FDS-D DWT Steel Tape Corrosion. Preliminary investigation into an accelerated corrosion rate found in FDS-D samples.
- Appendix E: FDS-D Recovery Quick Look Report. Highlights and log of events during FDS-D recovery.

2.0 DISCUSSION

Fault damage occurred to the UWS during all three phases of operations (installation, in-situ, and recovery). Only the installation and in-situ faults impacted system survivability. Recovery damage was a concern for FDS-D, but only relative to the refurbishment time and cost in the event the system had to be redeployed. Because there were no plans to redeploy the FDS-D system, recovery damage was not an issue.

The installation faults were quickly isolated and repaired and had only a minor impact on total deployment time and overall system survivability. Once the faults were cleared and the UWS was safely in situ on the seafloor, installation survivability was no longer an issue.

In situ faults had the greatest impact on survivability. Trawling activity was the leading cause of failure in the FDS-D UWS. While the UWS was exposed to many threats in the ocean environment, trawling damage was by far the most significant survivability problem.

During the FDS-D cable autopsy, a corrosion problem was identified in the deep water trunk (DWT) cable that leaves it vulnerable to cold flow and premature failure. The cause of the problem has not been determined. The status of the investigation into this problem is provided later in this report.

A fault contingency plan to relocate the tactical termination to an Alternate Termination Site (ATS) allowed FDS-D operations to continue after the UWS trunk had been damaged by trawlers. The FDS-D team was aware of the survivability threats prior to beginning FDS-D operations, and had practiced repair and relocation scenarios during sea trials on the termination ship (T-ship). The practice during sea trials, combined with a very capable T-ship, played a large part in the relocation success. Relocation enabled the T-ship to resume operations in less than 36 hours after failure (including a 16 hour transit).

2.1 UWS Fault Damage

The UWS was damaged during the installation, in situ, and recovery phases of the deployment. Three faults were induced during installation: one when the cable became fouled on a coral bed and two when the cable was inadvertantly laid on top of long-line fishing rigs (the faults occurred after the fishermen returned and attempted to recover their lines). Installation faults were quickly isolated and repaired by the deployment ship (D-ship).

The UWS was exposed to in-situ hazards such as fishing, currents, harsh seafloor, steep slopes, and biologics. A total of 17 in-situ faults were documented: 15 faults in the trunk section of the UWS, and 2 faults in the array field section. All 15 faults in the trunk were caused by trawling. Of the two in-situ faults in the array field, one was intermittent and could not be isolated, and the other resulted from a combination of abrasion, corrosion, and cold flow.

Recovery faults were induced when the UWS was picked up off the seafloor and the cable fouled on obstacles on the seafloor or long-line fishing rigs that were laid over the top of the cable. A large amount of damage was induced in UWS cable and cable-to-cable junctions (CCJ) during the recovery. This damage was to be expected due to the harsh seafloor conditions and the tight geometry of the field. We did <u>not</u> anticipate the number of long-line fishing rigs that were laid over top of the cable when we went to recover the UWS. A total of 23 long-line rigs were fouled in the cable during the recovery. Of the 23 long-line rigs encountered, fault damage resulted to the DWT cable three times. In each of these cases, the damage was the result of the fishing line sawing through the outer layers of the DWT cable. The long-line rigs were cut away from the UWS as it was recovered.

A summary of UWS fault damage is presented in Table 1.

Table 1. UWS Fault Damage

Deployment Phase	Cause	Quantity
Installation	Cable fouled on seafloor	1
	Long-lines	2
In-situ	Trawling	15
	Abrasion/corrosion /cold flow	1
	Unknown	1
Recovery	Cable fouled on seafloor	21
	Long-lines	3

2.2 In-Situ Faults.

Figure 1 identifies the locations of the in-situ faults.

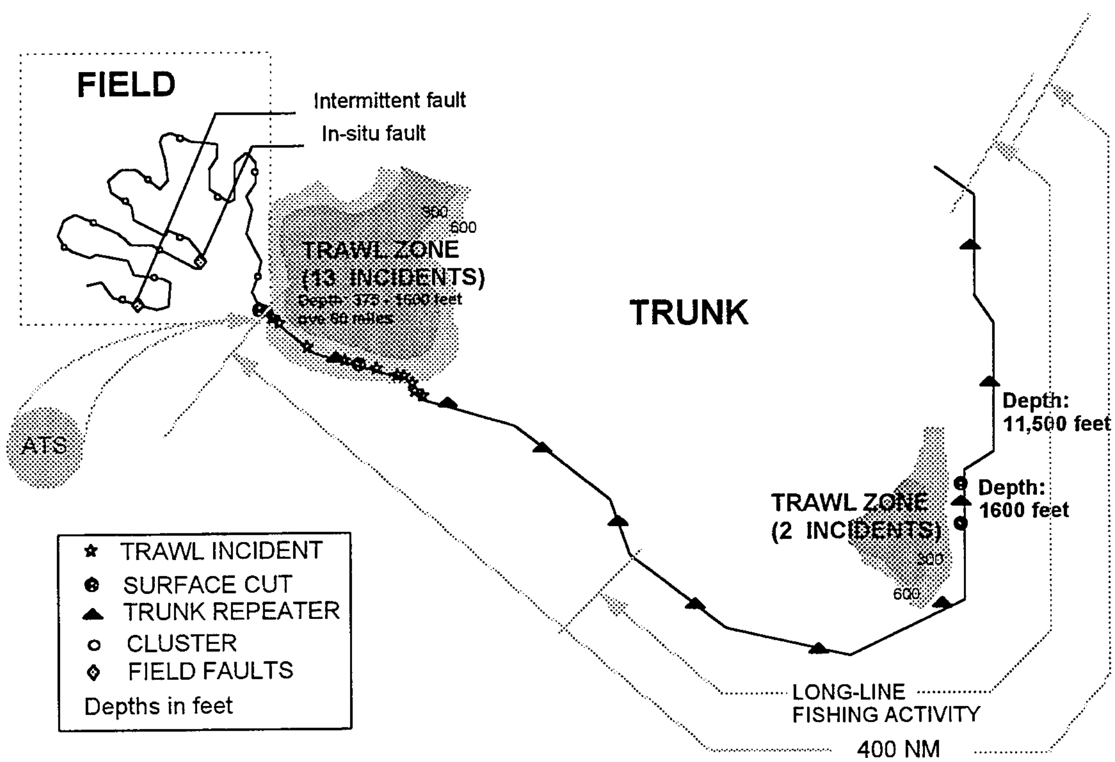


FIGURE 1. FDS-D UWS IN-SITU FAULTS

2.2.1 Trawling Faults. Trawling activity was the leading cause of failure in the FDS-D UWS. While the UWS was exposed to the many threats in the ocean environment, only trawling damage was a significant survivability problem. A total of 15 out of 17 in-situ faults were caused by trawling. All 15 trawling faults were in the trunk. Trawling damage was isolated to two heavily trawled areas covering 62 nautical miles out of 500 nautical miles along the UWS (12% of the total length). Trawl damage occurred in depths ranging from 380 to 1800 feet. Both areas were adjacent to shallow water banks. If the cable had been routed only a few miles over to one side of the existing route, the cable would have been in much deeper water and the trawling threat may have been avoided. Two reasons have been given for not routing the trunk in the adjacent deep water:

- The only way to route the cable in deeper water would have been to put it inside a 12-mile territorial limit of another country. That would have meant requesting permission from the country and explaining our presence.
- Routing the cable through the deeper water would have required making several crossings of existing seafloor cables. Repair operations on existing cables would have jeopardized the FDS-D cable.

Interaction with trawling gear resulted in severe mechanical damage to the cable. The trawler damage ranged from minor nicks and cuts on the cable jacket to major mechanical damage down to the conductor. In four separate incidents, the DWT cable was hooked by fishing gear and brought to the surface where it was cut away with bolt cutters. Additional armor on the DWT would have prevented some of the failures, but only burial would have prevented failures where the cable was hooked and brought to the surface. Rerouting the trunk cable, or relocating the tactical termination to the west or north versus the east may have avoided the trawling threat. The only way to confirm rerouting options would be to perform a detailed investigation of the trawling threat for proposed routings.

2.2.2 Cut and/or Abrasion Compounded with Corrosion and Cold Flow. One failure occurred in the field that was not trawling related -- the cable became entangled with a steel wire filter screen on the seafloor between CL106 and CL107. The failure appears to have been caused by an initial cut in the cable jacket from the filter screen, compounded with corrosion and cold flow. The failure resulted after a prolonged period of operation (81 days). The entanglement may have been initiated during installation. The evidence points to the cable being pulled through a turn during installation while the deployment ship was making a sharp course change. High surface current velocities of up to two knots were recorded near the fault position, which may be a contributing factor. No damage was observed on either side of the fault point, and no evidence supports that the cable was dragged at this point after deployment. Although site specific factors may be involved, **the scenario suggests that this failure mechanism could be a problem in future FDS deployments.**

No evidence was found to link this fault to trawling. The failure occurred in the middle of a 160-degree turn in the laydown track. The filter screen was bent or doubled over at a hard angle around the cable and a wear point developed where it made contact with the cable. The configuration of the filter screen on the cable and the cable location during recovery led to the hypothesis that the cable was inadvertantly pulled through the turn during deployment. Hence, this fault is theorized to have been caused by a combination of the following:

- Excessive tension in the cable.
- In situ hazard that resulted in a cut or abrasion to the jacket.
- Corrosion of the steel shield.
- Cold-flow of the dielectric and electrical failure of the cable.

Figure 2 illustrates this problem.

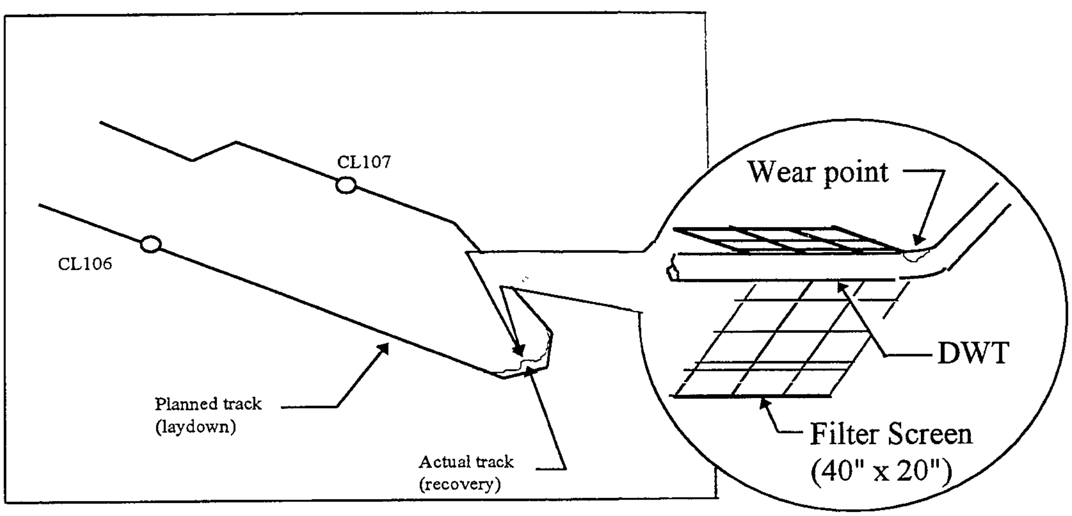


FIGURE 2. FAULT BETWEEN CL106 AND CL107

2.2.3 Intermittent Fault. An intermittent fault that was not isolated occurred just shoreward of CL101. This fault occurred on 8 July 1994 and was later masked by a fault between CL106 and CL107 that occurred on 25 July 1994. However, during recovery, after the fault between CL106 and CL107 was cleared, the system tested good through the sea ground -- in other words, the fault indication at CL101 was no longer present. The system continued to test good as it was recovered for the next 35 nautical miles until a fault indication suddenly appeared for no apparent reason at a point 2.078 nautical miles shoreward of cluster CL101. No visible signs of damage were present on the cable. The cable was retested 1 nautical mile shoreward of CL101 and the system then tested good to the sea ground. Therefore, the fault is presumed to be located in the section of cable between 1 nautical mile and 2.078 nautical miles shoreward of CL101.

The fault truncated only 1 out of 12 nodes in the field. The definition of a failure for FDS-D was the loss of more than 10% of the nodes, and therefore, this fault was not considered a system failure. The optical fiber tested good in the cable section. Electrical fault isolation equipment onboard the recovery vessel could not isolate the fault. The fault occurred 62 days after the UWS was installed, indicating a long-term failure mechanism. The fault was located in a rough seafloor area, but there were no obvious visible signs of cable damage in the suspect section. The fault may have been caused by a pinhole from interaction with the seafloor. **Another distinct possibility, and of greater concern, is the fault may be the result of a latent defect in the cable.**

2.3 Accelerated Corrosion Rate of the DWT Steel Tape

In many of the DWT autopsy samples, the steel tape between the outer high density polyethylene (HDPE) jacket and the medium density polyethylene (MDPE) dielectric completely corroded away where it came in direct contact with seawater. The corrosion process occurred quickly and very few corrosion products were found on the samples. In one sample the corrosion rate of the steel tape was three times as fast as the normal corrosion rate. This corrosion is not considered normal because of the rapidity of the attack and the lack of corrosion products. The accelerated corrosion problem is summarized as follows:

- The thickness of the steel tape is 7 mils.
- The corrosion rate of steel is approximately 8 mils per year.
- Assuming the corrosion attacks both sides of the tape, the shield should survive at least 160 days.
- The shield corroded away in less than 90 days (one cable sample in less than 50 days).
- Very small amounts of corrosion products were present in the samples--corrosion products normally occupy 4 to 8 times the volume of the steel that is corroded.

The purpose of the steel tape is to provide dielectric protection and cold flow protection. In a scenario where the outer jacket is cut and the tape is exposed, the tape will corrode away in approximately 6 months to 2 years. This does not present a problem in itself-- the cable can still function without the tape, **however, if what causes damage remains in contact with cable at the damaged point (i.e., a sharp rock is being pressed against unprotected dielectric) the cable becomes highly susceptible to cold flow of the dielectric and early failure.**

3.0 FDS-D WET-END AVAILABILITY

Availability during FDS-D operations can be approached in several ways. Operational times were as follows:

- FDS-D UWS was deployed a total of 125 days (5 May to 8 September 1994).
- FDS-D UWS was required a total of 92 days (5 May to 5 August).
- FDS-D operations were planned from 20 May to 5 August (76 days).
- FDS-D had a total of 30.5 days of planned tests.
- The total system was intact for 2.5 days from 4 June to 7 June.
- Mean time between failure (MTBF) was calculated at 6 days.
- Mean time to repair (MTTR) was 1.5 days.

Based on the previous data, availability can be calculated the following ways:

Full operational availability: $$A_o = \frac{\text{time full system was functional}}{\text{total test time}} = \frac{2.5}{76} = 0.033$$

Availability- Conservative Test: $$A_o = \frac{\text{time full data was obtained}}{\text{total time of planned test events}} = \frac{21.5}{30.5} = 0.7$$

Availability- Liberal Test: $$A_o = \frac{\text{time some data was obtained}}{\text{total time of planned test events}} = \frac{29}{30.5} = 0.95$$

Classic Availability: $$A_o = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} = \frac{6}{6+1.5} = 0.89$$

Sensor Field Availability: $$A_o = \frac{\text{time sensor field was fully operational}}{\text{total time sensor field was required}} = \frac{83}{92} = 0.90$$

Based on estimates of trawler activity along the trunk route, the estimated number of passes by trawl gear was between 0.167 and 0.333 passes per day per nautical mile, and the MTBF per nautical mile of cable was between 401 days and 802 days. Based on the number of nautical miles of cable laid through the trawled area, the MTBF due to trawling comes to 6.5 days. These data also suggest that, on the average, the cable survived 67 to 134 passes per system fault.

4.0 CONCLUSIONS

FDS-D successfully demonstrated a rapidly deployable undersea surveillance system in a high threat, shallow water, littoral zone. FDS-D gathered acoustic data for the planned 90-day operations. The trawling threat was a significant survivability problem in the trunk cable, but in spite of the cable faults, cableship repairs and contingency plans allowed operations to continue. The UWS sensor field demonstrated an availability of 0.90.

Trawling damage was isolated to areas around two shallow water banks. Interaction with trawlers often resulted in severe mechanical damage to the cable. In four separate incidents the DWT cable was hooked by fishing gear and brought to the surface where it was cut away with bolt cutters. Failure was unavoidable in these locations without burial. Alternate routing options were available that ran the trunk through deeper water in some places. An alternate route may have prevented trawling damage. However, the DWT was damaged in waters as deep as 1,800 feet, and a cable route completely avoiding this depth may have been too difficult or impossible to do.

For cable routed across the two fishing banks, the estimated number of passes by trawl gear is between 0.167 and 0.333 passes per day per nautical mile, and the cable survived between 67 to 134 passes for each fault. At that rate, the MTBF per nautical mile is between 401 days and 802 days. When a longer segment of cable is considered, the MTBF drops off very quickly. In the case of FDS-D, where 62 nautical miles was routed through a trawling hazard area, the MTBF is:

$$\frac{1}{MTBF} = \frac{1}{MTBF_1} + \frac{1}{MTBF_2} + \ldots \ldots \frac{1}{MTBF_{62}}; \qquad \text{MTBF = 6.5 DAYS}$$

A vulnerability in the FDS-D DWT was recognized in the fault between CL106 and CL107. The failure mechanism was a combination of a cut or abrasion to the jacket, corrosion of the steel tape, and cold flow through the dielectric. This fault was theorized to have been initiated by excessive tensions during the deployment. This fault also exhibited an accelerated corrosion problem characteristic in much of the fault damage. A corrosion problem combined with the potential for jacket damage and tension in the cable can result in premature failure in FDS.

The experience gained from FDS-D has enhanced our understanding of cable survivability. This experience will benefit both FDS and future cabled systems.

Appendix A

FDS-D DWT CABLE AUTOPSY REPORT

FDS-D DWT CABLE AUTOPSY REPORT

1.0 BACKGROUND

As part of the FDS-D demonstration test, the FDS-D Underwater Segment (UWS) was deployed in the Mediterranean Sea between 5 May and 7 September 1994. The UWS faulted several times during the demonstration. At the end of the demonstration, the UWS was recovered by a cableship and samples of damaged cable were shipped to the Naval Facilities Engineering Service Center (NFESC). These samples have been autopsied, and the results of the autopsies are enclosed in this report. The FDS-D cable was damaged during all three phases of the deployment: installation, in-situ, and recovery. This report is primarily interested in the in-situ faults.

2.0 DISCUSSION

The purpose of this autopsy was to determine what happened to the damaged cable sections. The primary goals were to determine the depth of damage to the cable, whether or not the damage resulted in electrical and/or fiber-optic failure, and if possible, what action caused the damage. The overall objective of this autopsy was to extract any information that will help improve survivability of FDS and future cable systems.

A total of eight samples were recovered and autopsied. The autopsy was performed by NFESC at the Fiber Optics Laboratory in Port Hueneme between 20-27 October 1994. Cable samples are numbered in the sequence in which they were recovered. Figure A-1 shows where the samples were recovered, and Table A-1 presents a summary of the fault samples.

3.0 ANALYSIS AND SUMMARY

Three key areas of vulnerability were highlighted by the autopsy results: trawling, abrasion compounded with corrosion and cold flow, and corrosion of the DWT steel shield.

3.1 Trawling

Trawling activity was the leading cause of failure in the FDS-D UWS trunk. Trawlers were observed during all phases of operation. As many as six trawlers at one time were observed making passes across and along the cable track. All of the observed trawlers were the bottom drag type.

Trawl damage ranged from singular trawl "hits" with the damaged length measured in inches, to extreme cutting and crushing over hundreds of feet of cable. Not all the trawl damage autopsied necessarily resulted in a failure. In two samples, the damage penetrated the outer layers and reduced the thickness of the dielectric, but did not create a direct path from the conductor to seawater. In three of the trawl incidents, the cable was cut with bolt cutters near the cable damage. In each of these incidents, it appears the cable was hooked on trawl gear and brought to the surface, where it was then cut away with bolt cutters. The various types of damage observed in the samples were:

- Small, localized nick
- Small, localized crush
- Long V-groove in jacket ending with gash to conductor
- Long cut exposing all cable components
- Cut with bolt cutters

Exactly what part of the trawl gear did the damage to the cable is unknown. The damage appears to have been done by a sharp or heavy object, or both sharp and heavy. This type of damage is likely to have been produced by an otterboard rather than sweep gear on the footrope.

Seven of the eight cable samples were damaged by trawlers. The cable was faulted electrically in six of the seven samples, and optically in one of the seven samples. Two of the seven samples were near where the cable had been cut with bolt cutters-- this indicates that the damage was associated with an entanglement with the trawl gear, and that the cable was brought to the surface where it was cut away by the fishing vessel personnel. Only burial would have prevented faults such as these.

Assuming all other factors equal, added external armor would have enhanced survivability in only four of the seven sample cases. Table A-2 provides a list of fault samples summarizing the cause of failure and the probable effect of added armor.

Table A-2.

Fault Sample	Electrical Failure?	Optical Failure?	Near Bitter End?	Improve with armor?
1	no	no	no	yes
2a	yes	no	no	yes
2b	yes	no	no	yes
2c	yes	no	no	yes
5a	yes	yes	***yes***	***no***
5b	yes	yes	***yes***	***no***
6	yes	yes	no	***no***

FIGURE A-1. FDS-D UWS

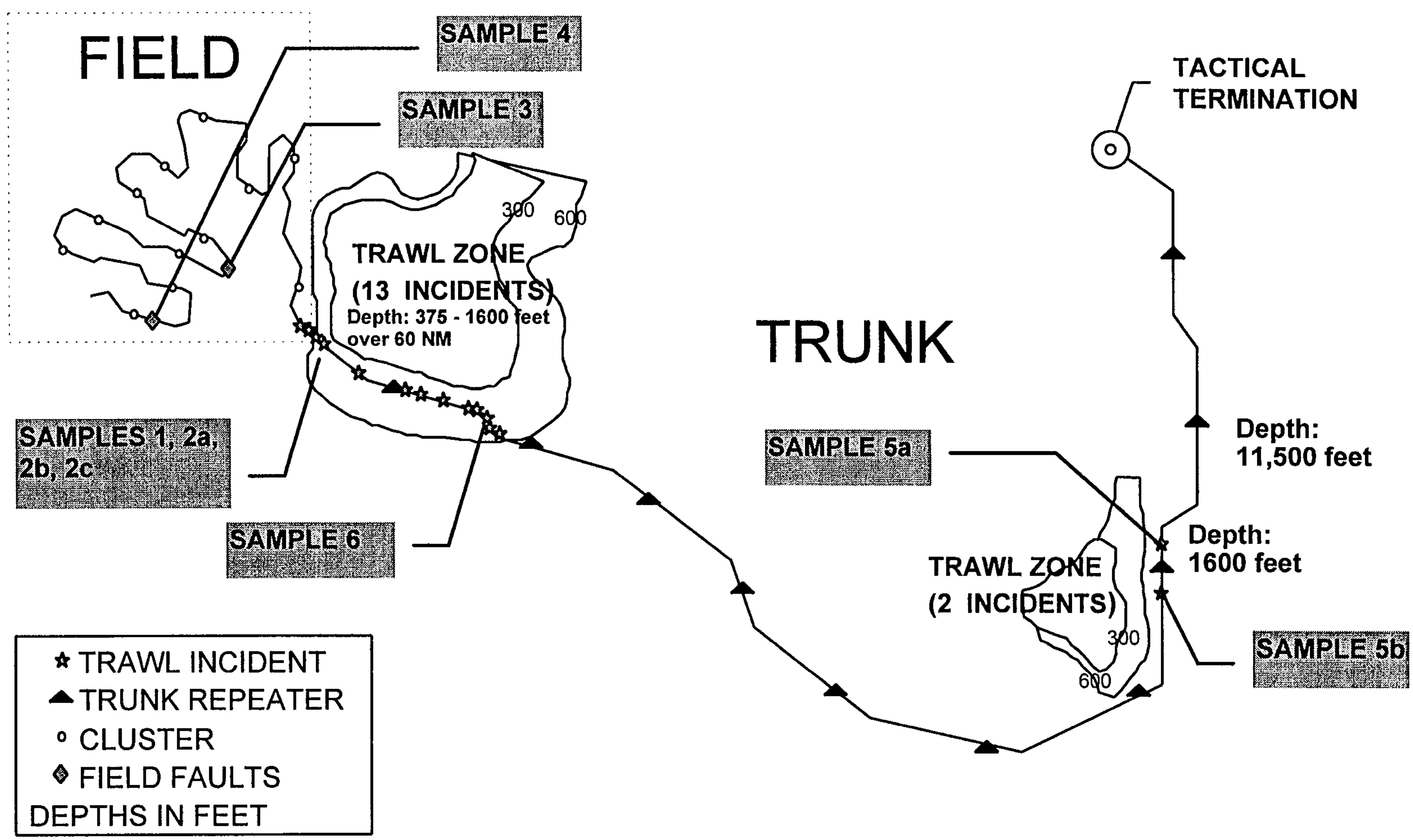


Table A-1. Cable Fault Sample Summary

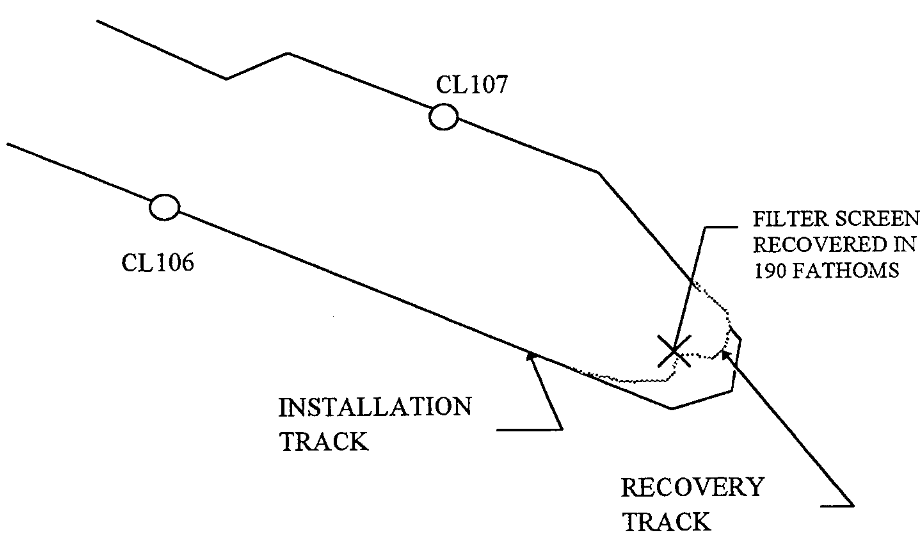
FAULT NO.	DATE RECOVERED/ LOCATION	DESCRIPTION
1	Recovered: 7/2/94 by T-ship Location: 1100' Depth, Appr. 5 nm shoreward of CL116.	Suspected trawl damage. Damage is a single cut in cable (0.6" x 0.4") down to steel tape. Minor groove in cable leading up to cut from one side. Green glue is visible on outside of tape. No sign of further penetration. Possible electrical failure.
2a,b,c	Recovered: 7/2/94 by T-ship Location: 1100' Depth, 4-5 nm seaward of CL116.	Suspected trawl damage. All three samples recovered within 4000' of each other with minor damage (nicks and grooves) between major damage. **(2a)** Deep gash down to strength member. **(2b)** Cut in outer jacket exposing tape. **(2c)** Deep groove along cable, long section where shield is exposed and green coating on outside of shield is present, one area where shield is penetrated and pushed open exposing the dielectric. Bottom: Along slope leading from bank (300-600') down to trench (1100-2000'). Electrical failure.
3	Recovered: 8/22/94 by R-ship Location: 1140' depth; 4.873 nm seaward of CL107.	Suspected cut/abrasion/corrosion/cold flow fault. Cable fault occurred 75 days into operations and resulted in the field being truncated. During recovery the cable came to the surface with a steel filter screen wrapped at a hard angle around it. The filter appeared to be a galley filter or fresh air intake filter. The fault occurred on the inside of a 160 degree bend in the laydown track. The power conductor and center strength member were exposed to sea water. A visual analysis of fault revealed the following: • Damage to the cable is approximately 1/2 " wide and 1" long. • Steel tape appears to have corroded away in the damage zone. Remnants of the blue-green coating on the tape are present. • The copper conductor is ruptured exposing strength wires. • The back side of the fault area has been worked and appears to have exceeded the elastic limit when bent, and buckled upon straightening. • Presence of cold flow and tearing to outer jacket. • The cable was bent at a 30° angle where it contacted filter screen when it came to the surface. Electrical failure.
4	Recovered: 8/24/94 by R-ship Location: 0-2 nm shoreward of CL101. **No sample available.**	Cause of fault is unknown. Fault indication first appeared 080115Z July. Fault was intermittent. The fault indication was **<u>not</u>** present on 8/22 after fault 3 was cleared--the system tested good all the way to the sea ground. The fault indication re-appeared on 8/24 at 2.078 nm seaward of CL101. No visible signs of damage to cable were observed. Electrical failure.
5a,b	Recovered: 8/30/94 by R-ship. Location: **(5a)** 0.6 nm shoreward of TR1004 in 1800' depth. **(5b)** 1.2 nm seaward of TR1004 in 1750' depth.	Suspected trawl damage. Both samples were recovered within 1.5 nm from each other. **(5a)** Crush, gash in cable jacket that appears to go down to the power conductor. The damaged area is approximately 6" long and looks like it was hit with a heavy, blunt object. The polyethylene jacket is deformed and separated from the core, possibly from cold flow. The steel tape green coating is visible. A very small hole appears to go down to the copper conductor. Bitter end located 1200' seaward of damage. **(5b)** Cable is bent sharply with severe abrasion damage 6" long. Cable was cut with bolt cutters one meter from damage, indicating this point was where the cable got hooked in trawl gear. Electrical failure.
6	Recovered: 9/7/94 by R-ship. Location: 6 nm seaward of TR1010	Suspected trawl damage. DWT splayed open exposing conductor and strength member. Damaged area over 100' long. Has appearance of being forced across sharp edge. Electrical and optical failure.

3.2 Cut/Abrasion Compounded with Corrosion and Cold Flow

One unique failure occurred in the field that was not trawling related -- a steel wire filter screen became wrapped around the cable on the seafloor. The entanglement presumably began during deployment. The failure appears to have been caused by an initial cut against the filter screen, compounded with corrosion and cold flow. The failure resulted after prolonged period of operation (81 days). The evidence points to the cable being over-tensioned during installation while the deployment ship was making a sharp course change. No damage was observed on either side of the fault point, and no evidence supports that the cable was dragged at this point after deployment. Although site specific factors may be involved, the scenario suggests that this failure mechanism could be a problem in future FDS deployments.

The failure was located between CL106 and CL107. The cause of the failure was discovered during the recovery when a steel wire filter screen was brought to the surface wrapped around the cable. The filter screen looked like it came from an air vent on a shipwreck or from a dump site. The filter screen was wrapped at a hard angle around the cable, indicating the cable was under tension while in contact with the filter screen on the seafloor. The cable jacket and dielectric had cold-flowed around the filter screen wire where it made contact with the cable. The failure occurred in the middle of a 160-degree turn in the field laydown track, which supports the theory that the cable was over-tensioned and pulled through the turn until it hooked onto the filter screen. Figure A-2 provides a drawing of the laydown and recovery track.

FIGURE 2. FAULT #3 INSTALLATION AND RECOVERY TRACK



During recovery, no damage was observed on either side of the fault point, and no evidence was found that the cable had been hit or dragged by trawl gear after the cable reached its in-situ location. The lack of evidence of external forces causing the damage, such as trawling, leads to the hypothesis that the cable fault was the result of an in-situ hazard condition combined with a cable design vulnerability. This scenario could also be further complicated by too little slack control at the deployment ship during installation. This cable fault is theorized to have been caused by a combination of cut and abrasion to the jacket, corrosion of the steel shield, cold-flow of the dielectric, and electrical failure. Although this would be the first known failure to have occurred this way, corrosion evidence gathered from autopsy samples support that a major vulnerability of FDS DWT may exist for this mechanism

3.3 Accelerated Corrosion Rate of the DWT Steel Tape

The DWT cable is constructed with a layer of steel tape between the outer HDPE jacket and the MDPE dielectric. The purpose of the steel tape is to provide protection against cold flow of the dielectric. In a majority of the cable fault samples, the steel tape completely corroded away where it came in direct contact with seawater. The corrosion process occurred very quickly--in one sample the corrosion rate of the steel tape was three times as fast as the normal corrosion rate.

The area of tape that was corroded was often greater than the area of the jacket damage--the corrosion had undercut the jacket. There were very few corrosion products between the jacket and the dielectric. This corrosion is not considered normal because of the rapidity of the attack and the lack of corrosion products. The accelerated corrosion problem is summarized as follows:

- The thickness of the steel tape is 7 mils.
- The corrosion rate of steel is approximately 8 mils per year.
- Assuming the corrosion attacks both sides of the tape, the shield should survive at least 160 days.
- The shield corroded away in less than 90 days (one cable sample in less than 50 days).
- Very small amounts of corrosion products were present in the samples--corrosion products normally occupy 4 to 8 times the volume of the steel that is corroded.

The cause of the accelerated corrosion rate is under investigation. One possible explanation for the accelerated corrosion rate is the presence of an applied current. An applied current makes sense for some of the samples because current was applied to the conductor during the fault isolation process, and the cable damage created a path between the conductor and the shield. However, several examples exist where either a current was not intentionally applied to the conductor, or there was not a clear path from the conductor to the shield. **The evidence points to a stray current or a faulty current path on the shield.** Preliminary corrosion tests in the laboratory have confirmed that applied currents will accelerate the corrosion process and duplicate the corrosion found in the cable samples. NFESC and AT&T are investigating possible sources of the problem.

In general, corrosion of the steel tape is a serious cause for concern. Even without an applied current, once exposed to seawater the tape will corrode away within 2 years. This does not present a problem in itself-- the cable can still function without the tape. The concern is that if the object that caused the damage remains in contact with cable at the damaged point, i.e., a sharp rock pressed against unprotected dielectric, the cable is highly susceptible to cold flow of the dielectric and early failure. The contradiction with this problem is that the steel tape is intended to provide cold flow protection against hard, sharp objects, which are the objects most likely to cut the jacket and cause the steel tape to corrode away.

DWT fault repairs present another set of problems. As learned during FDS-D, the outer jacket is easily damaged during recovery operations. In repair operations, a segment of cable will be picked up off the seafloor and laid back down without being inspected at the ship. Assuming repairs are in a harsh seafloor area, the jacket can be cut and the tape exposed during recovery, and then the cable laid right back down on the hazard, with the cable now susceptible to corrosion and cold flow.

4.0 CONCLUSIONS

Trawling damage was isolated to areas around shallow water banks. Interaction with trawlers often resulted in severe mechanical damage to the cable. In four separate incidents the DWT cable was hooked by trawl gear and brought to the surface where it was cut away with bolt cutters. Failure was unavoidable in these locations without burial. Alternate routing options were available that ran the trunk through deeper water. Alternate routes were possible that may have prevented all trawling damage, but there is no way to determine this without further analysis of the trawling activity in those areas. The DWT was damaged in waters as deep as 1800 feet.

The fault between CL106 and CL107 was indirectly caused by tensions in the DWT on the seafloor. The fault occurred approximately 70 days after the UWS was installed indicating a long term failure mechanism. The failure mechanism was a combination of a cut or abrasion to the jacket from high tension, possibly magnified by currents and strumming, corrosion of the steel tape, and cold flow through the dielectric. If this fault was an indirect result of tension from deployment, one way to reduce the likelihood of it happening again is to modify installation procedures. Some recommendations are:

- Avoid sharp course changes.

- When sharp course changes are unavoidable, decrease ship speed and payout.
- Use a tension-controlled payout rather than a rate-controlled payout.

A corrosion problem with the DWT steel tape has been identified that may be a latent factor in cable failures. Accelerated corrosion may be the result of a stray current or faulty current path. The problem is being investigated.

5.0 WORKSHEET DATA

5.1 Fault Number 1 - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 7/2/94 Date Autopsied: 10/18/94
Autopsy Personnel: Dave Warren, Steve Smuck
Date of Failure: Between 150700Z Jun 94 and 021800Z Jul 94
Location: 5 NM shoreward of CL116
Depth: 200 fathoms
Seafloor: Assumed to be soft mud. No abrasion to cable observed during operations/recovery.

General Interest:

The outer jacket, steel tape, and dielectric were exposed to the seawater. Damage appears to have traveled along cable until the major damage portion. The steel tape had corroded to an oval shaped hole, smoother and larger than the damage area in the jacket. No evidence of electrical damage. No evidence of latent damage. No apparent difference due to different construction. Contact object appears to have been sharp enough to cut the jacket, but the major damage may have been due to a bashing or mashing action. Damage to outer jacket and steel tape and dielectric appear to have been done by a short term event with further longer term (corrosion) damage done to the steel tape. The dielectric was dented but not penetrated. There was no visible damage to the copper, and no assumed damage to the wires or fiber. Damage did not create a direct path from the conductor to seawater. However, damage may have reduced thickness of dielectric enough to arc. No signs of electrical arcing were present.

Special Interest:

Damage occurred along a slope leading from a bank (60 fathoms) down to a canyon (300 fathoms). Trawlers were observed operating on the bank adjacent to the fault location. The trawlers would drag across the bank and then turn around on the slope, right over the cable track. As many as six trawlers were observed operating in the immediate vicinity.

Description:

Condition of Jacket: A long cut leading up to the major damage point. A missing and sheared portion of the outer jacket approx. 0.63 in. long by 0.36 in. wide.

Condition of Steel Tape: An oval type hole in the steel tape, approx. 0.91 in. long by 0.58 in. wide. Scuff damage to the green glue under tape indicates amount of mechanical damage with the remaining corrosion damage.

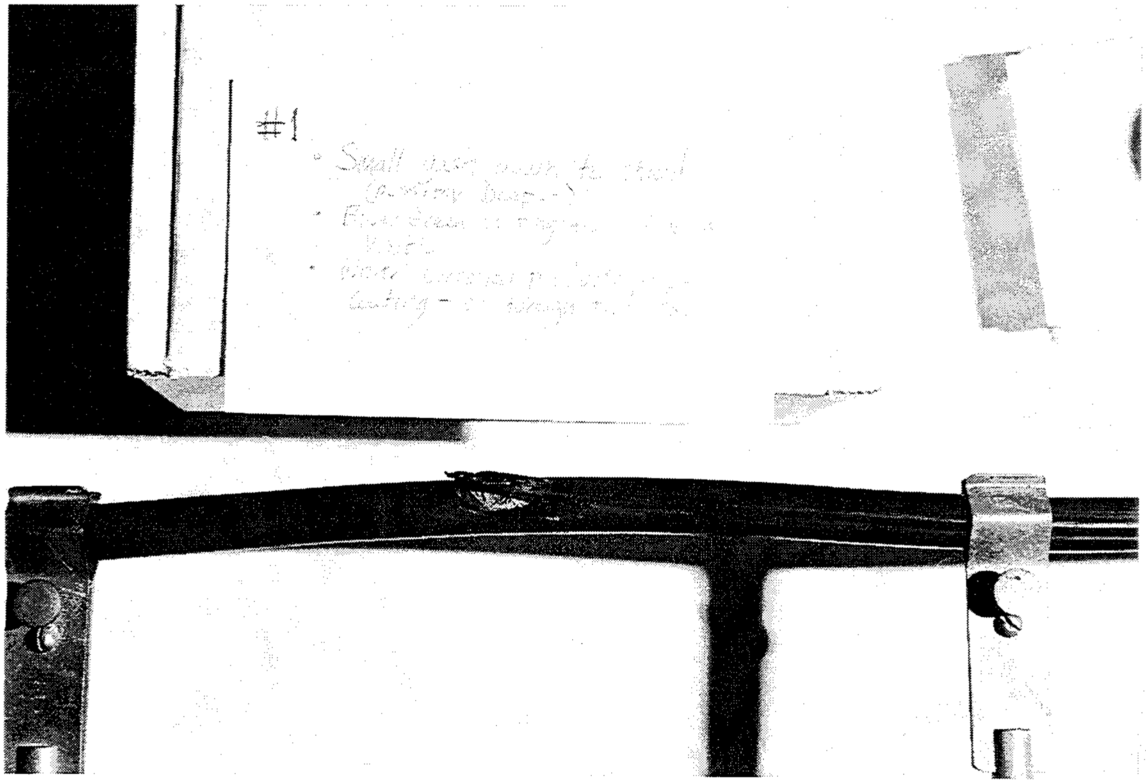
Condition of Dielectric: A dent approx. 0.03 deep. No visible evidence it broke through to the copper.

Condition of Copper Shield: No visible damage.

Condition of Steel Wires: Not inspected.

Condition of Optical Fiber Sheath: Not inspected.

Condition of Fiber: Not inspected.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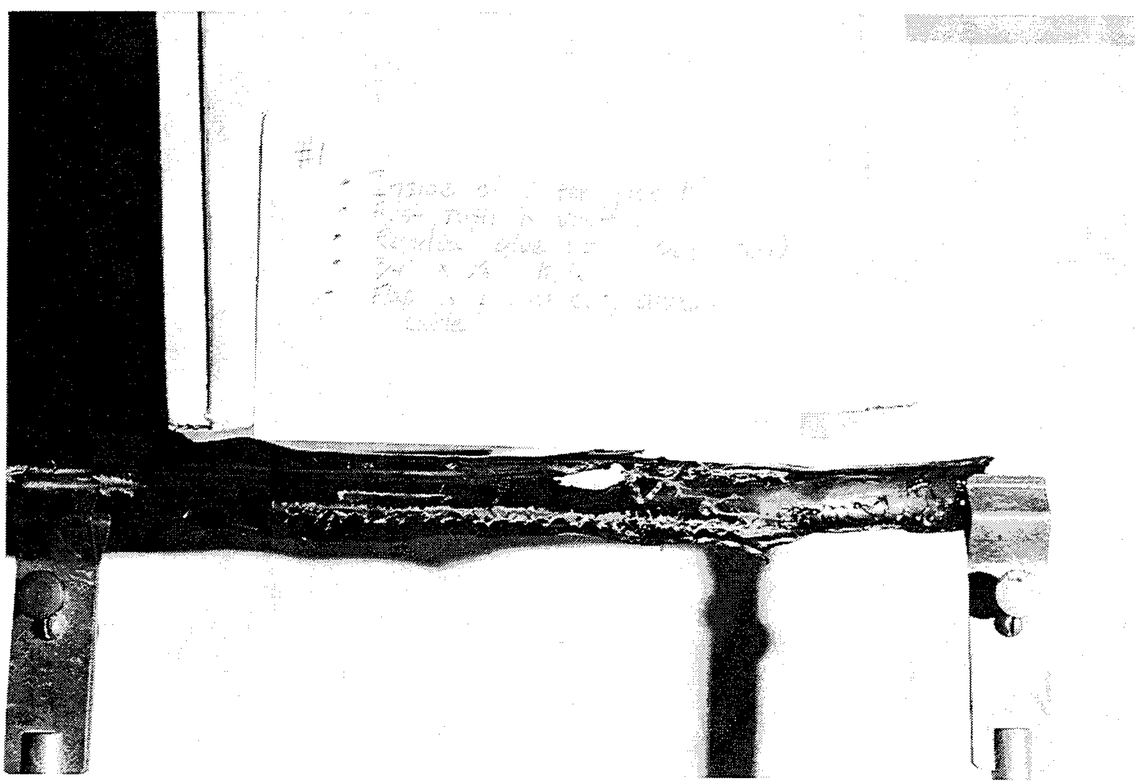
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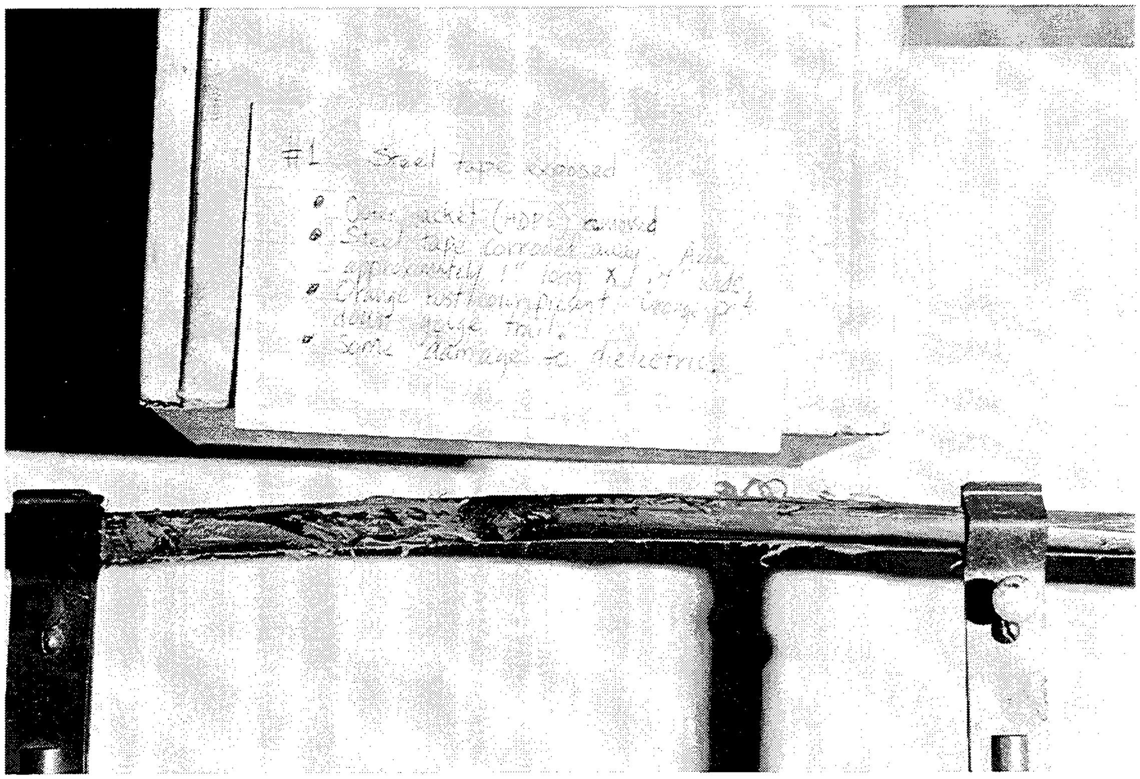
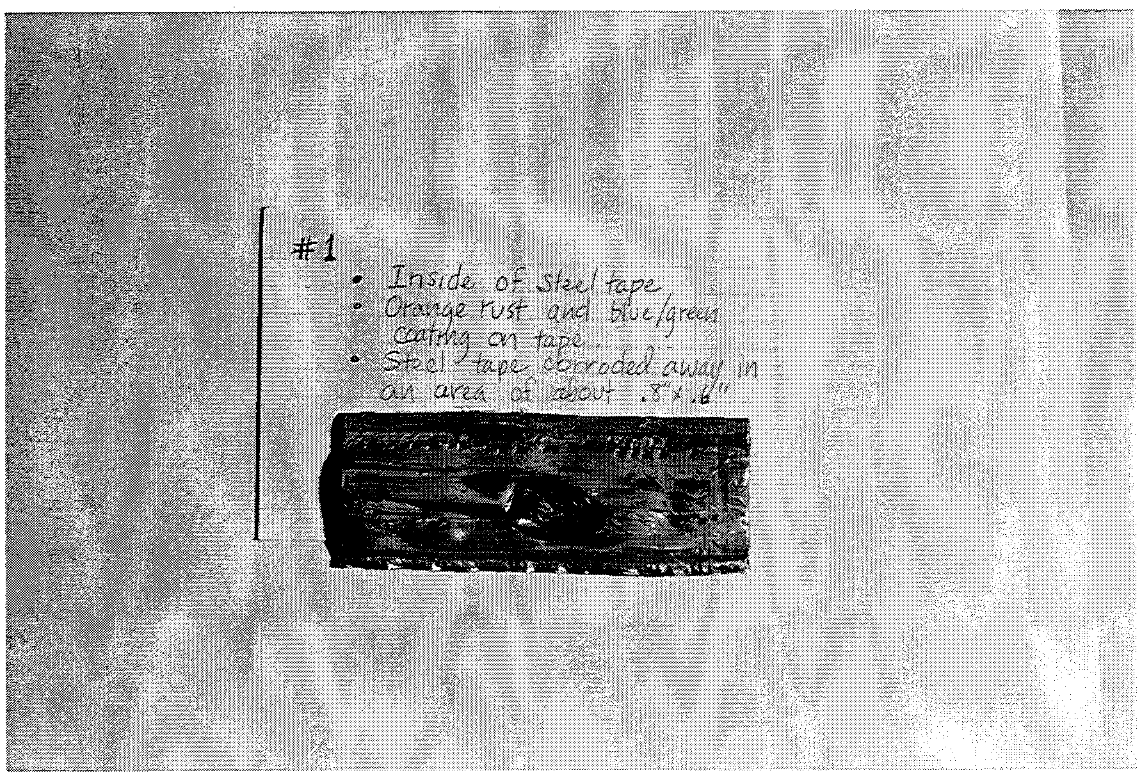
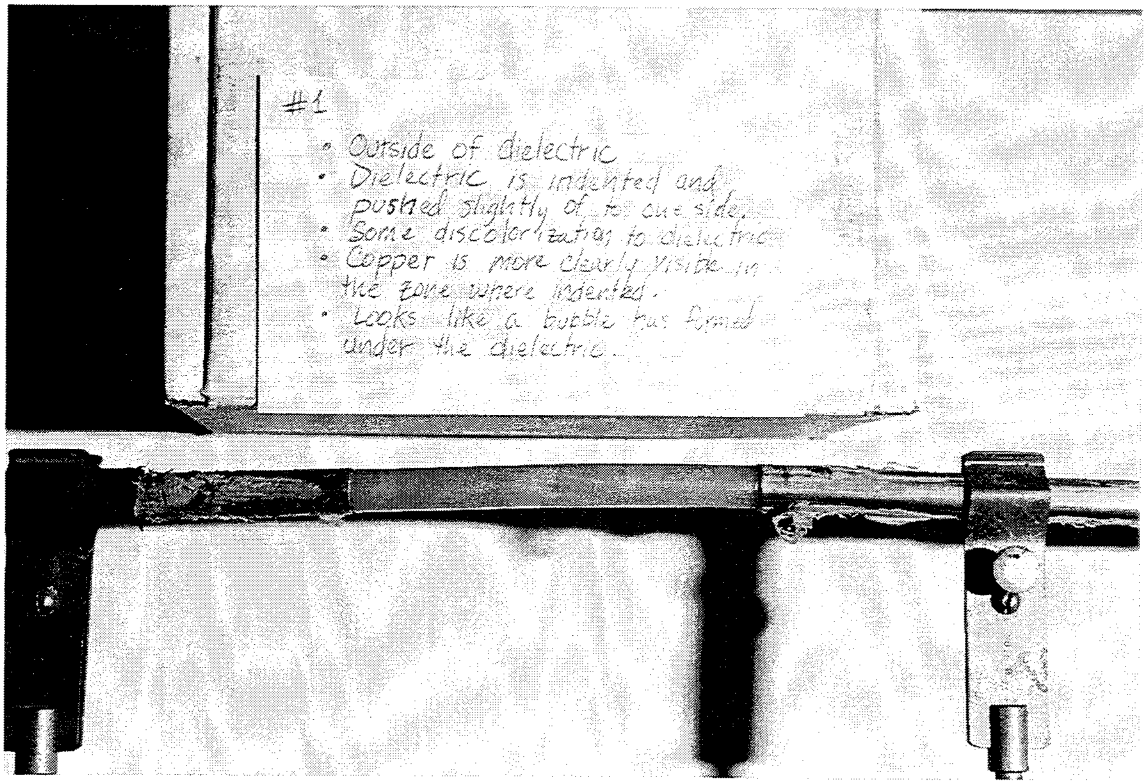
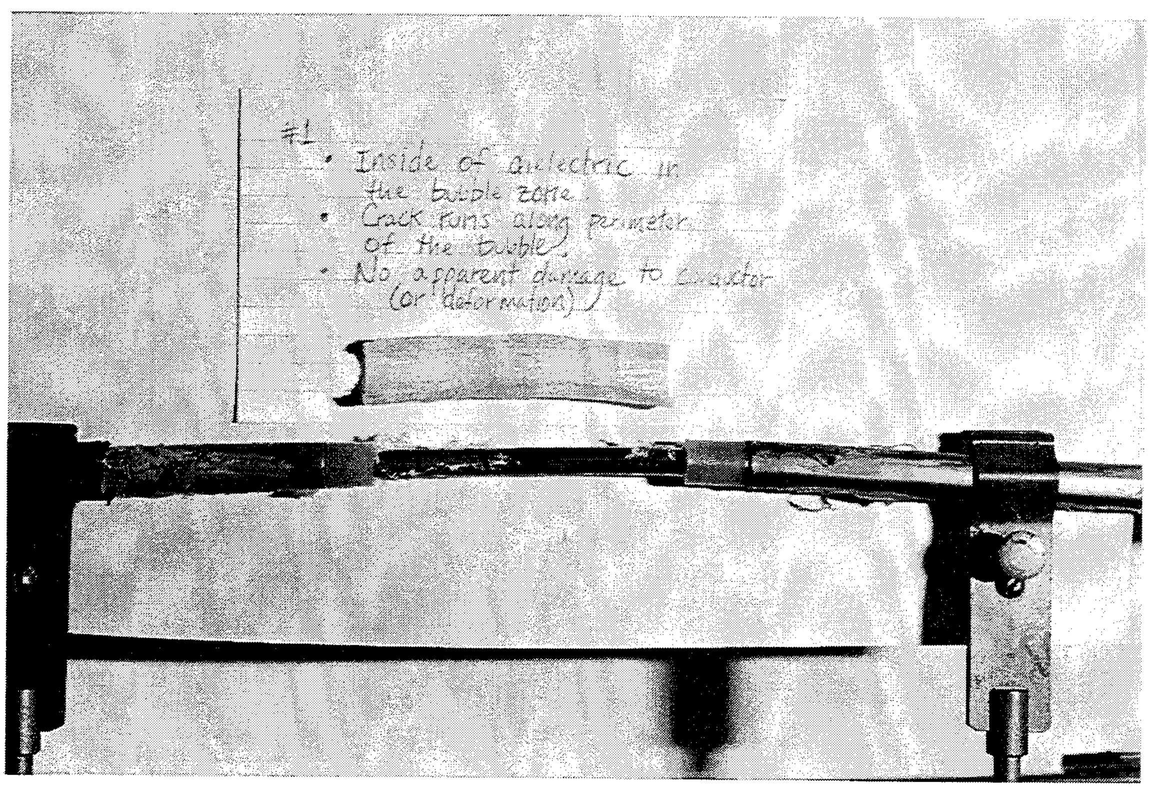

#1 Steel tape exposed
Steel tape corroded away
Some damage to dielectric.


#1
Inside of steel tape
Orange rust and blue/green coating on tape.
Steel tape corroded away in an area of about .8" x .6"


#1
• Outside of dielectric
• Dielectric is indented and pushed slightly of to one side.
• Some discolorization to dielectric
• Copper is more clearly visible in the zone where indented.
• Looks like a bubble has formed under the dielectric.


#1
• Inside of dielectric in the bubble zone.
• Crack runs along perimeter of the bubble.
• No apparent damage to conductor (or deformation)

5.2 Fault Number 2a - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 7/2/94 Date Autopsied: 10/19/94
Autopsy Personnel: Dave Warren, Steve Smuck
Date of Failure: Between 150700Z Jun 94 and 021800Z Jul 94
Location: 4 NM shoreward of CL116
Depth: 200 fathoms
Seafloor: Assumed to be soft mud. No abrasion to cable observed during recovery.

General Interest:

The shield, dielectric, and copper were exposed to seawater. Damage appears to have traveled along cable until the major damage portion. Most of damage to steel tape appears to be mechanical, not corrosion. No evidence of electrical damage. No latent damage apparent. No evidence of different construction. The type of object to make this damage appears to be identical to the damage in sample 1A. Damage to outer jacket and steel tape and dielectric appear to have been done by a short term event with further longer term (corrosion) damage done to the copper.

Special Interest:

Damage occurred along a slope leading from a bank (60 fathoms) down to a canyon (300 fathoms). Trawlers were observed operating on the bank adjacent to the fault location. The trawlers would drag across the bank and then turn around on the slope, right over the cable track. As many as six trawlers were observed operating in the immediate vicinity. The distance between 2a, 2b, and 2c was 4300 feet. The angle of the damage indicates a single pass by a trawler at a narrow angle with hits from both trawl doors.

Description:

Condition of Jacket: The sample was approx. 50 feet long. A long cut on one side leading up to the major damage point. A ridge and valley was created in the jacket. Ridge was higher on one side than the other. Jacket was not penetrated for approx. 13 feet out of 50 feet. Damage spiraled around cable. A missing and sheared portion of the outer jacket approx. 2.1 in. long by 0.32 in. wide.

Condition of Steel Tape: The majority of damage appears to be mechanical. The object tore the tape apart at its seam. Thus there is not a continuous damage area. The tape has two 0.25 inch tears in the radial direction where the object appears to have hit the tape. The outer jacket-tape bond glue appears to have sealed the tape and limited corrosion damage. There were some orange corrosion products on the inside of the tape.

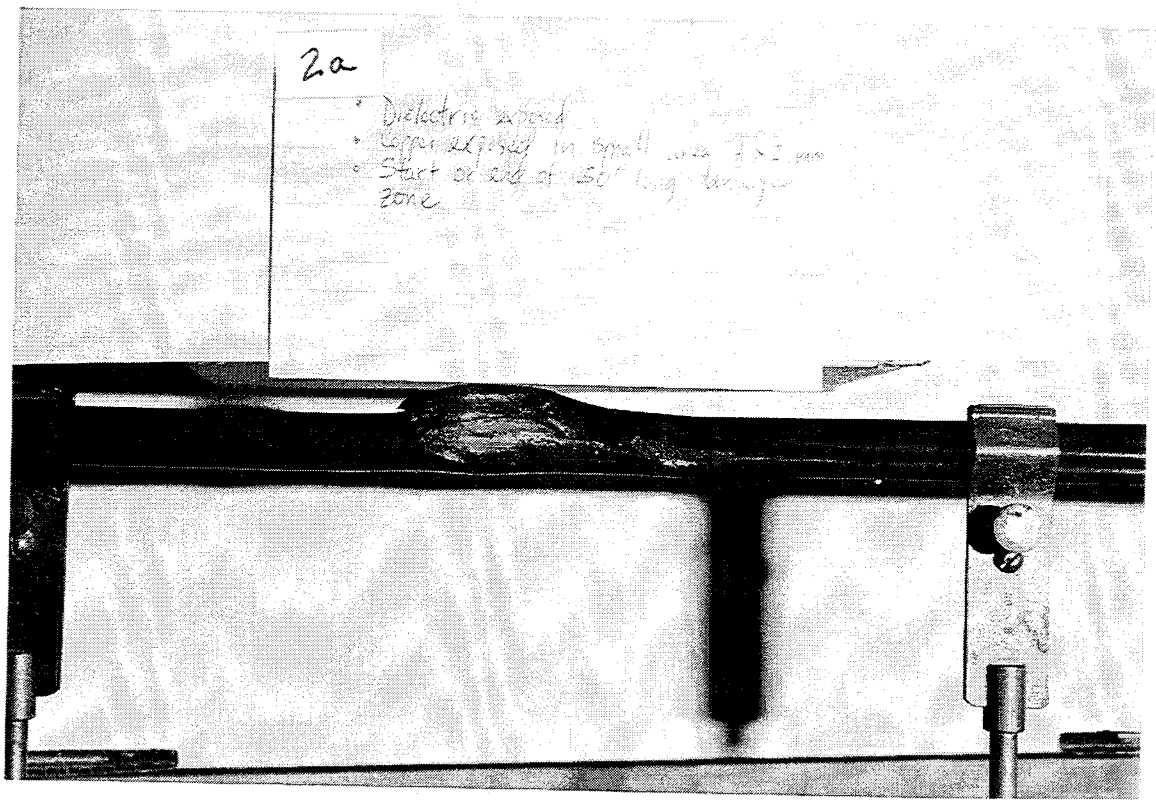
Condition of Dielectric: The damage done to the dielectric appears to be very similar in nature to the damage done to the outer jacket. The area of major damage is approx. 1 in. long by 0.06 in. wide. This area exposed the copper to seawater.

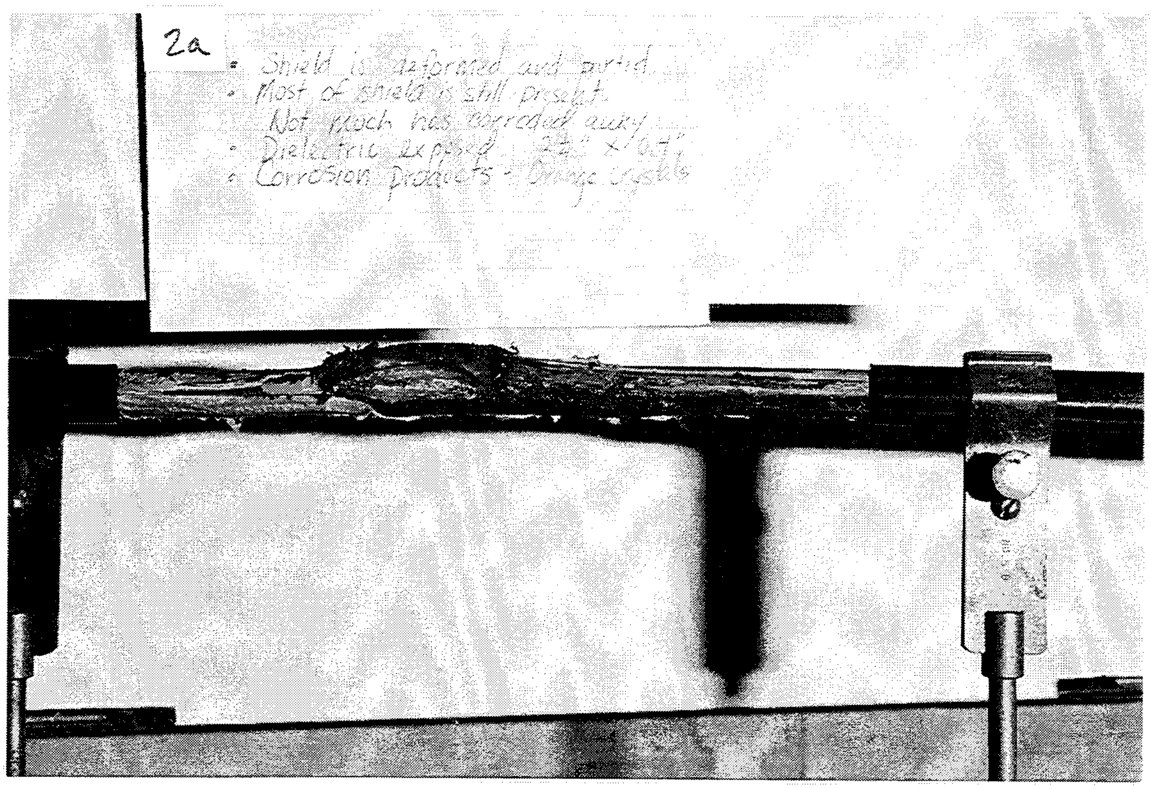
Condition of Copper Shield: Corrosion byproducts remain on the surface with some surface pitting apparent. A large percentage of area of exposed to seawater has a blackened appearance. No visible mechanical damage to the copper.

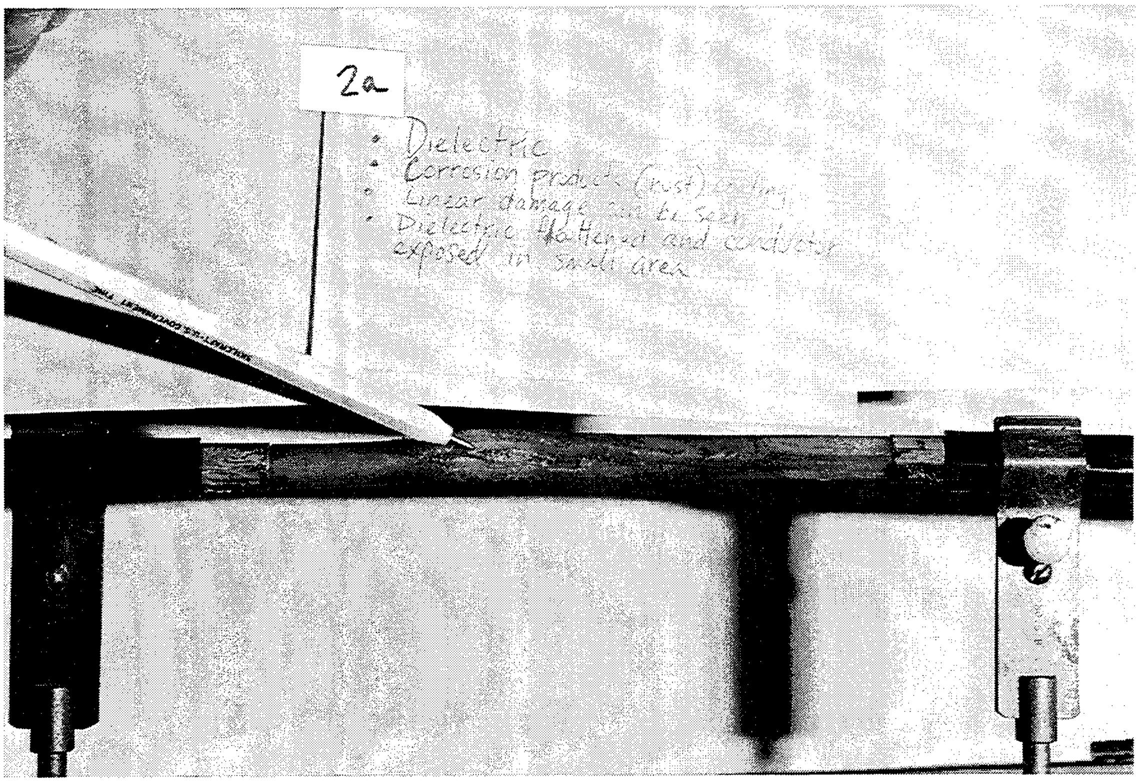
Condition of Steel Wires: Not inspected.

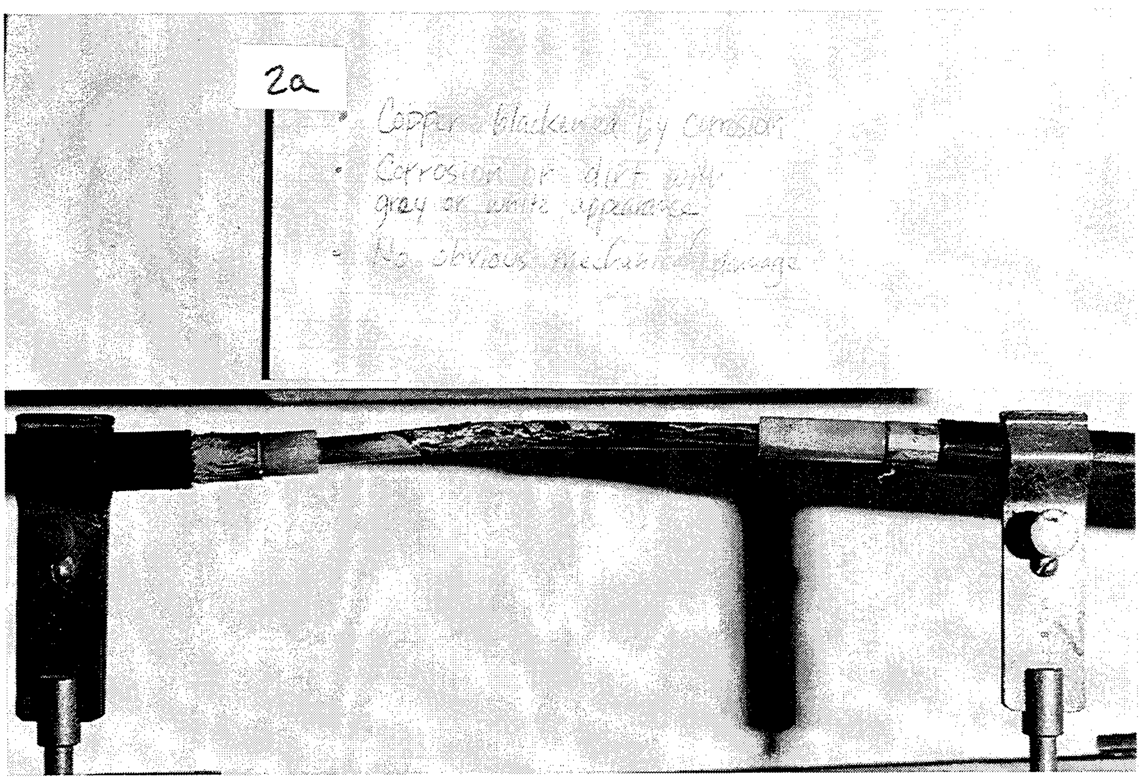
Condition of Optical Fiber Sheath: Not inspected.

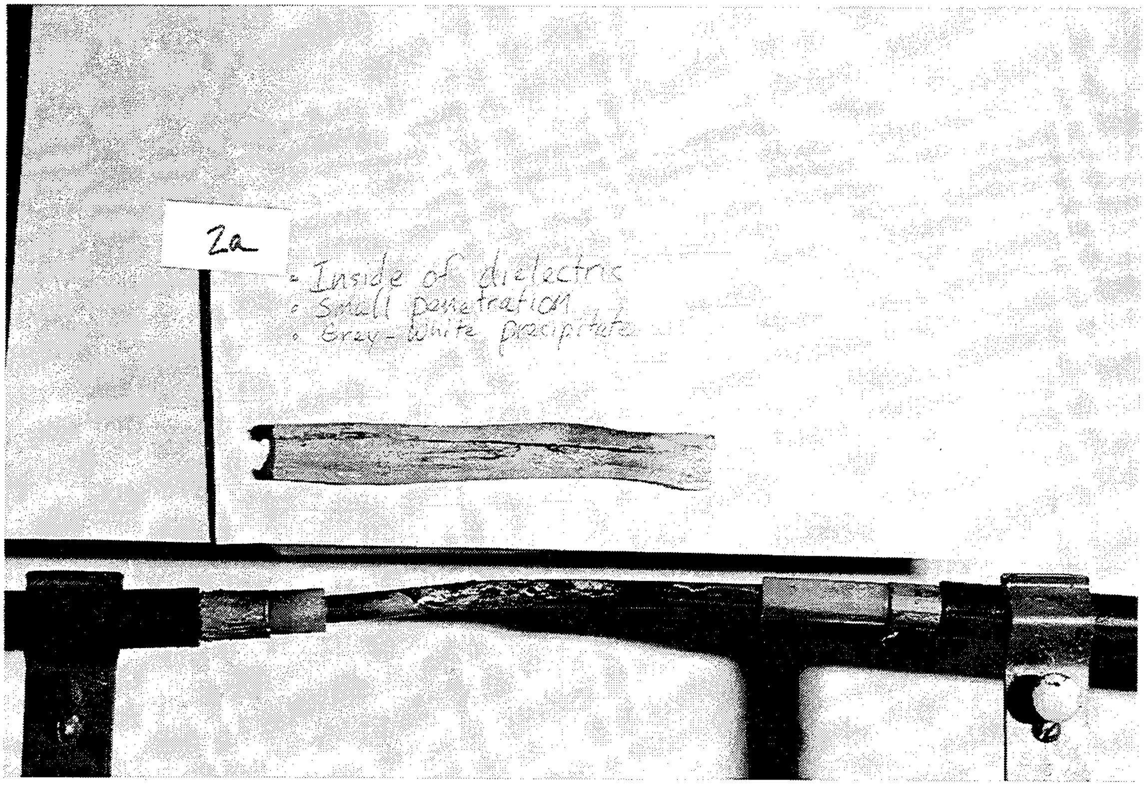
Condition of Fiber: Not inspected.

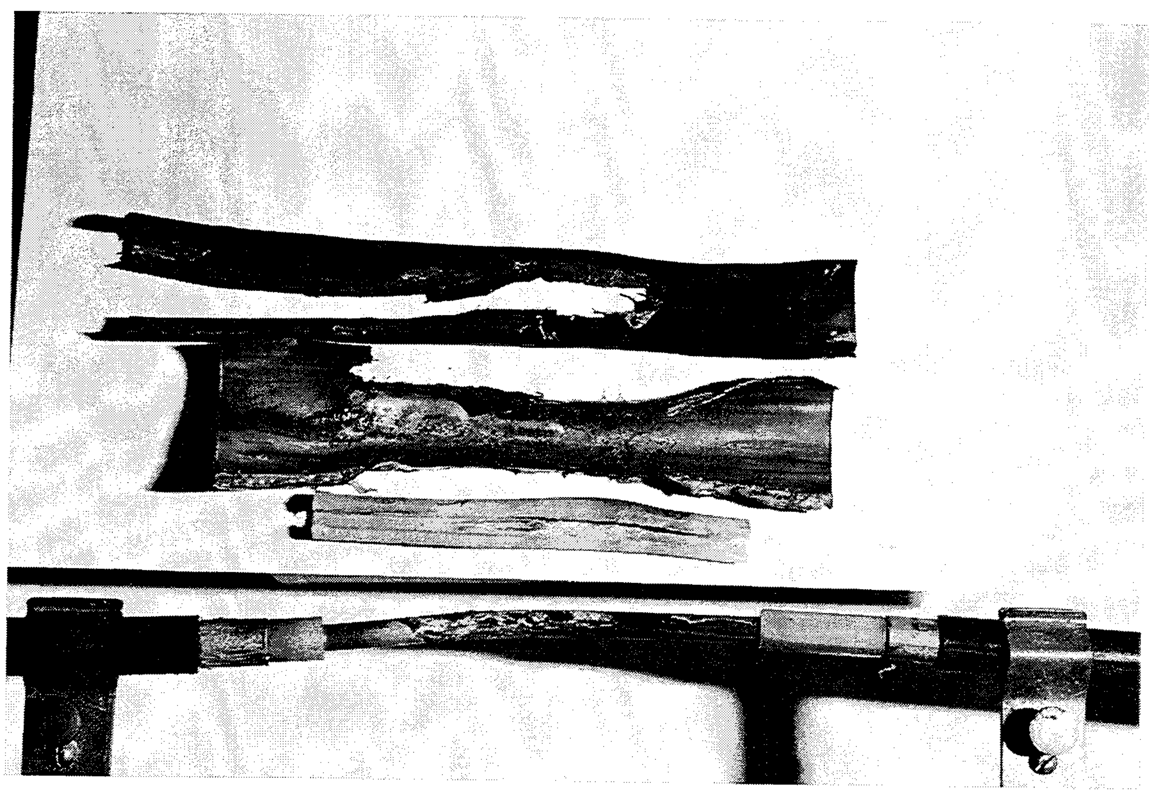

2a
• Dielectric exposed
• Copper exposed in small area
• Start or end of
zone


2a
• Shield is deformed and pitted
• Most of shield is still present.
Not much has corroded away
• Dielectric exposed
• Corrosion products - Orange crystals


2a
Dielectric
Corrosion product (rust) coating
Linear damage can be seen
Dielectric flattened and conductor
exposed in small area


2a
Copper blackened by corrosion
Corrosion or dirt with
gray or white appearance
No obvious mechanical damage


2a
• Inside of dielectric
• Small penetration
• Grey-White precipitate



5.3 Fault Number 2b - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 7/2/94 Date Autopsied: 10/20/94
Autopsy Personnel: Carl Stevens, Steve Smuck
Date of Failure: Between 150700Z Jun 94 and 021800Z Jul 94
Location: 4 NM shoreward of CL116
Depth: 200 fathoms
Seafloor: Assumed to be soft mud. No abrasion to cable observed during recovery.

General Interest:

The outer jacket, steel tape, and dielectric were exposed to the seawater. The object damage appears to have occurred in the same fashion as the previous samples. The majority of the damage appears to have been caused by a short term event, with some corrosion to the steel tape. There is no evidence of electrical damage. There is no evidence of damage elsewhere due to this damage. There is no apparent difference due to different construction. Nor are there any appearances of latent defects. The marks and damage appears to have been from a fairly sharp object.

Special Interest:

Damage occurred along a slope leading from a bank (60 fathoms) down to a canyon (300 fathoms). Trawlers were observed operating on the bank adjacent to the fault location. The trawlers would drag across the bank and then turn around on the slope, right over the cable track. As many as six trawlers were observed operating in the immediate vicinity. The distance between 2a, 2b, and 2c was 4300 feet. The angle of the damage indicates a single pass by a trawler at a narrow angle with hits from both trawl doors.

Description:

Condition of Jacket: 4 feet of the jacket was scored. The mark on the jacket is rippled (as if the object were imprinting a tread), ending or starting with a cut down to the steel tape. There is some dirt, possibly corrosion in the cut. The cut is approx. 0.7 in. long by 0.15 in. wide.

Condition of Steel Tape: The green glue on the outer side of the steel tape appears to be intact. There is however a nick in the tape approx. 0.2 in. long by 0.1 in. wide. This area shows some corrosion byproducts. Dirt and/or silt and/or corrosion products have migrated back under the jacket (between the jacket and the green glue) in about a 0.4-inch circular area. Glue seems to have prevented additional corrosion of the steel tape. Steel tape is also dented at the point of the nick.

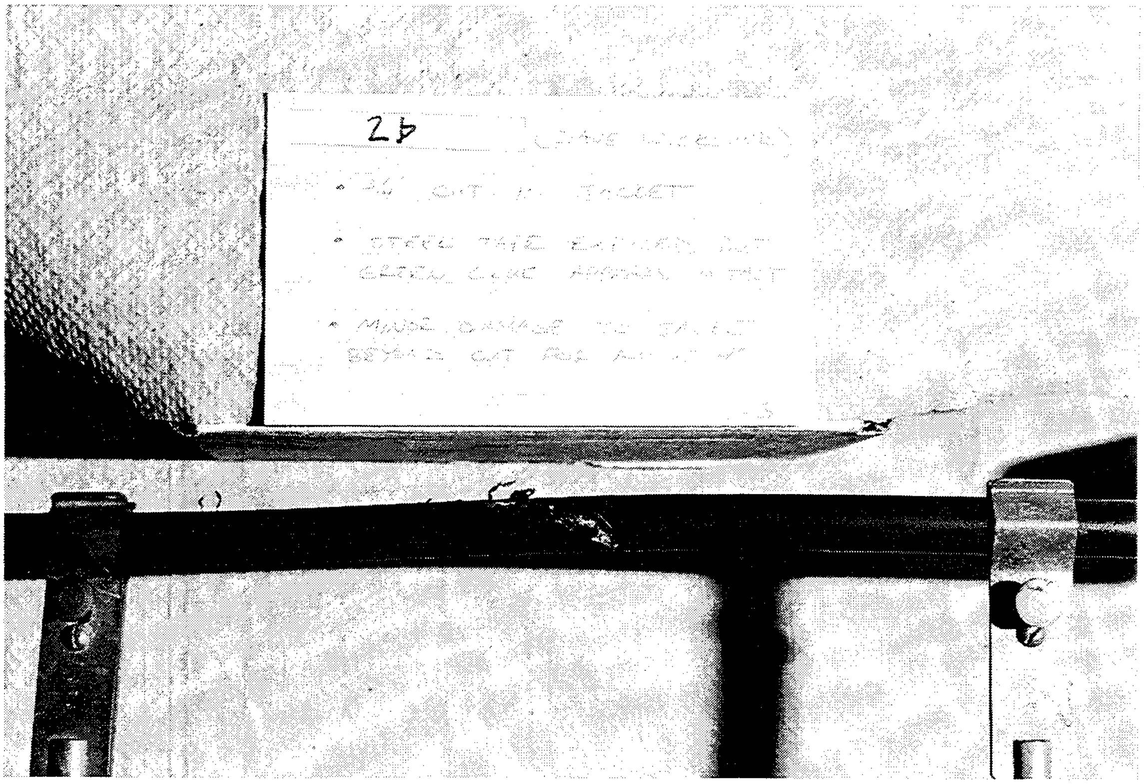
Condition of Dielectric: Under the nick in the steel tape the dielectric appears unaffected. There is quite a bit of corrosion from the steel tape - water flooded under the tape and it looks like the seam is corroding. Possibly at the edges of the tape.

Condition of Copper Shield: Not visibly affected.

Condition of Steel Wires: Not inspected.

Condition of Optical Fiber Sheath: Not inspected.

Condition of Fiber: Not inspected.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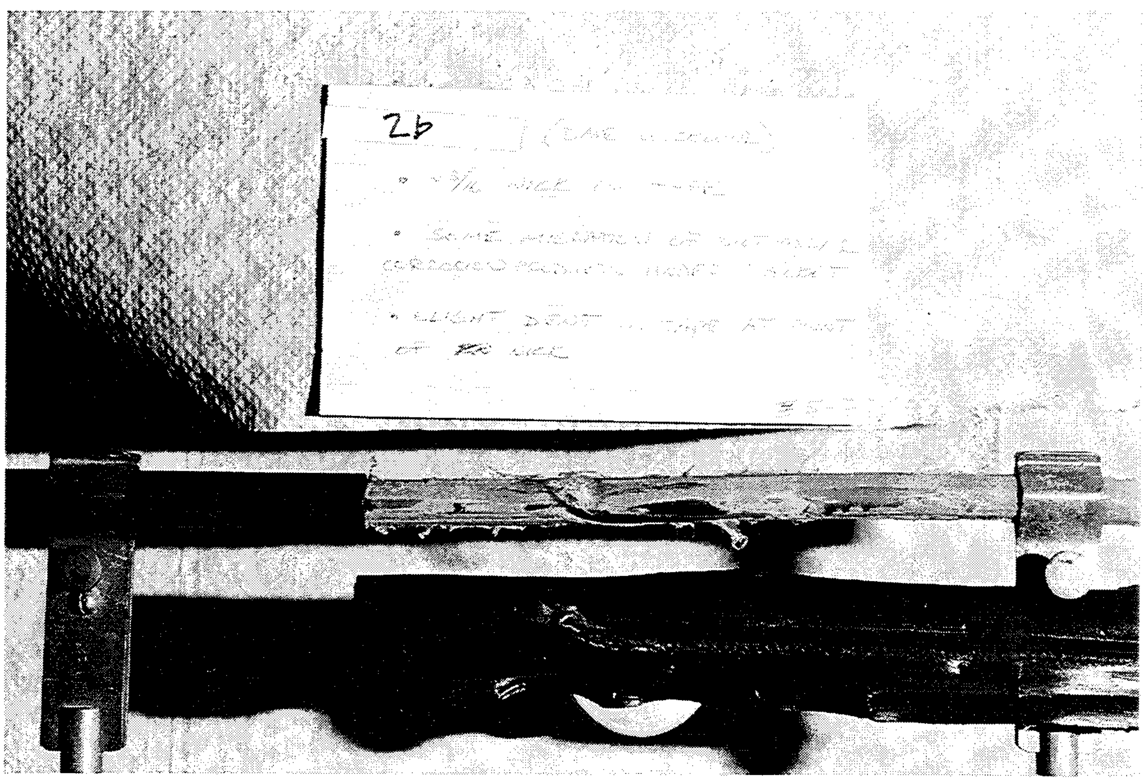
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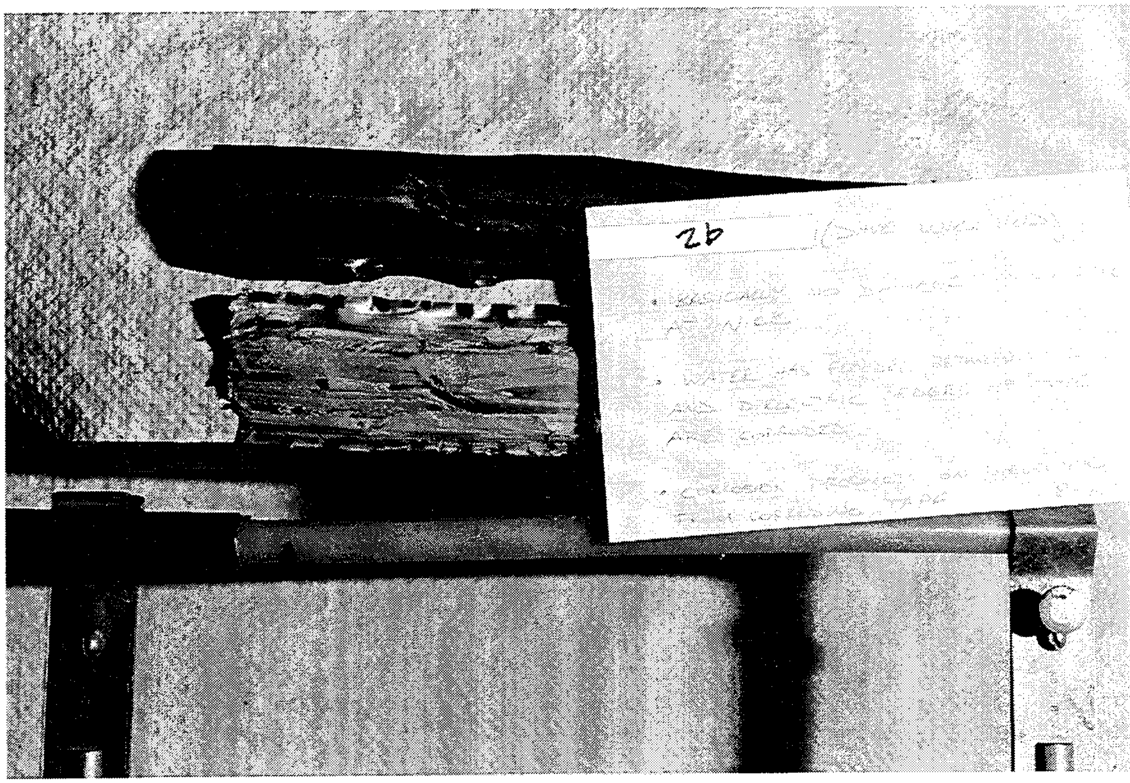
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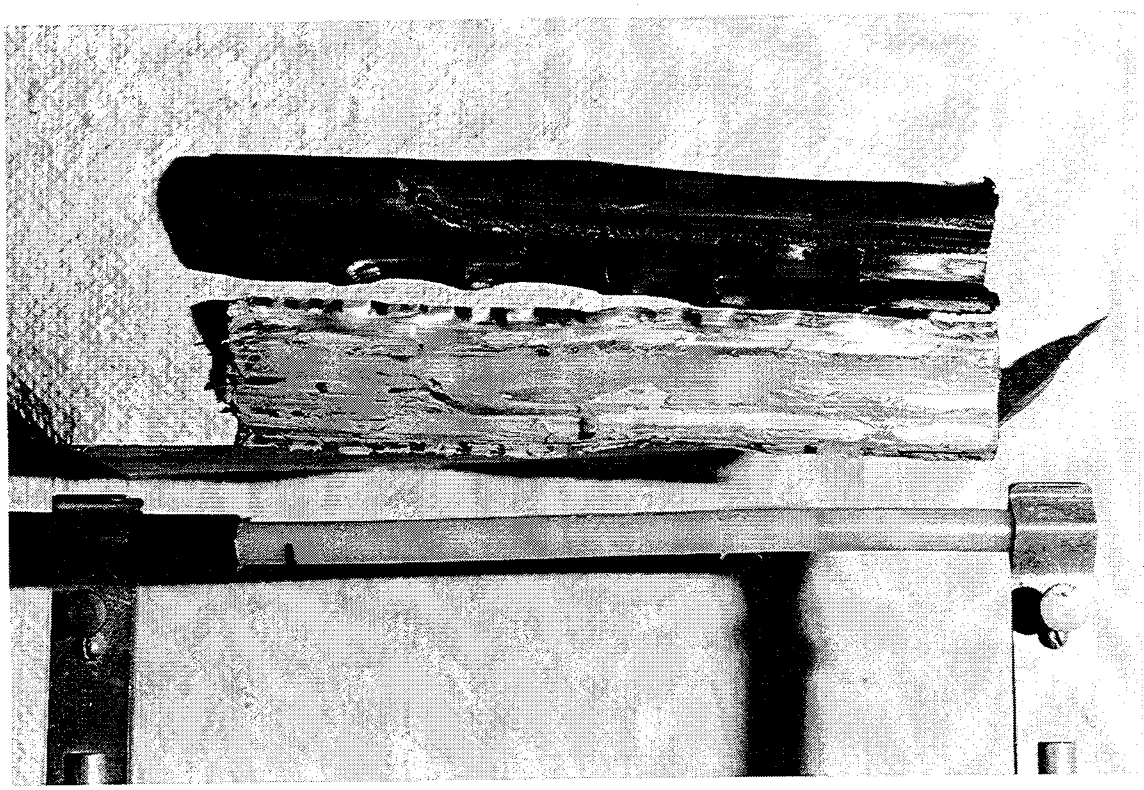


5.4 Fault Number 2c - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 7/2/94 Date Autopsied: 10/20/94
Autopsy Personnel: Carl Stevens, Steve Smuck
Date of Failure: Between 150700Z Jun 94 and 021800Z Jul 94
Location: 4 NM shoreward of CL116
Depth: 200 fathoms
Seafloor: Assumed to be soft mud. No abrasion to cable observed during recovery.

General Interest:

All layers of the cable were exposed to seawater. The damage appears to have started or ended at the point of heaviest damage. Most likely the running board rode on and spiraled the cable and tensioning it. Once breakaway forces were reached the board gashed the cable and released it. Just an assumption. There is mechanical and corrosion damage. There doesn't appear to be electrical damage. There doesn't appear to be any difference due to construction, nor any manufacturer defects. Hard to tell if the object was sharp or blunt. There may have been some high loads which caused the jacket to tear as opposed to having been cut.

Special Interest:

Damage occurred along a slope leading from a bank (60 fathoms) down to a canyon (300 fathoms). Trawlers were observed operating on the bank adjacent to the fault location. The trawlers would drag across the bank and then turn around on the slope, right over the cable track. As many as six trawlers were observed operating in the immediate vicinity. The distance between 2a, 2b, and 2c was 4300 feet. The angle of the damage indicates a single pass by a trawler at a narrow angle with hits from both trawl doors.

Description:

Condition of Jacket: Spiraling damage along the 8 feet of cable. 6 feet of the damaged area has had the jacket split open but the tape and glue is intact and undamaged. There is corrosion at the tape seam. In some areas the tape has buckled, but is difficult to say if that is due to the original damage or due to handling and shipping. The jacket has been splayed open in one spot, the rest of the jacket seems to be good condition. At the point of greatest damage, the cable has been opened down to the strength wires. An approx. 2.5 in. opening in the tape and dielectric. Opening in copper, but difficult to say how big.

Condition of Steel Tape: The steel tape has torn open for 2.5 to 3 in. through dielectric for 2 to 2.5 in. Glue is missing and corrosion has started there and at the edges of the tape. Corrosion products and/or silt on the tape and under the tape. The cross section is no longer round, a flattened edge spirals around the cable length and matches the damage to the cable jacket.

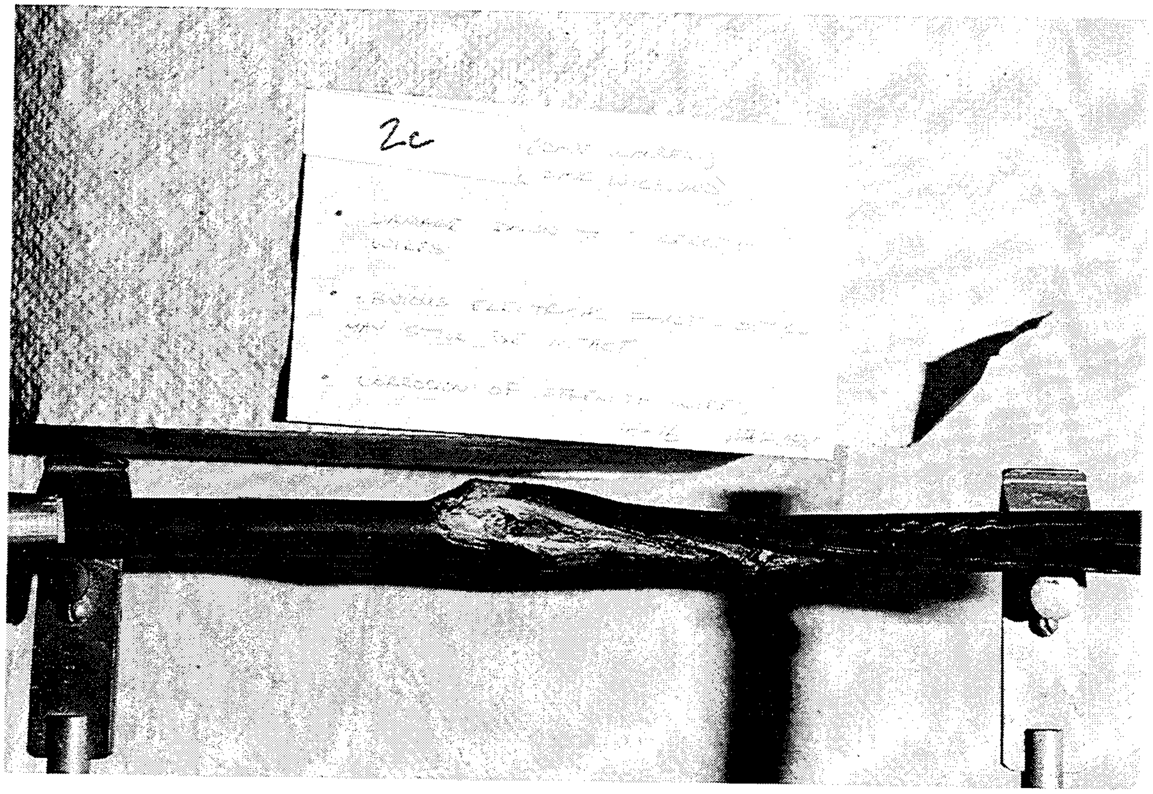
Condition of Dielectric: The dielectric has been torn open, but the opening changes to look more like a cut. The dielectric is covered with what looks like silt and or corrosion. The dielectric has whiter appearance in some places - where it has separated from the copper.

Condition of Copper Shield: The copper has cracked open at the point of heaviest damage. The split extends almost all the way around the cable. The split also extends up and down the cable for about 0.5 in. The copper is corroded - black, green, and orange deposits are present. The core seems to have lost its round shape.

Condition of Steel Wires: All wires are intact, but all are corroded. Heavier corrosion at the largest opening of the copper. Water has wicked in and corrosion is also present on other wires. The wire bundle is deformed, flattened, at the point of heaviest damage.

Condition of Optical Fiber Sheath: The sheath is intact but has been crushed by the strength wires. The nylon jacket and buffer have cold-flowed when crushed by the inner layer of wires.

Condition of Fiber: By a visual inspection the fiber appears intact. Power meter tests were not possible.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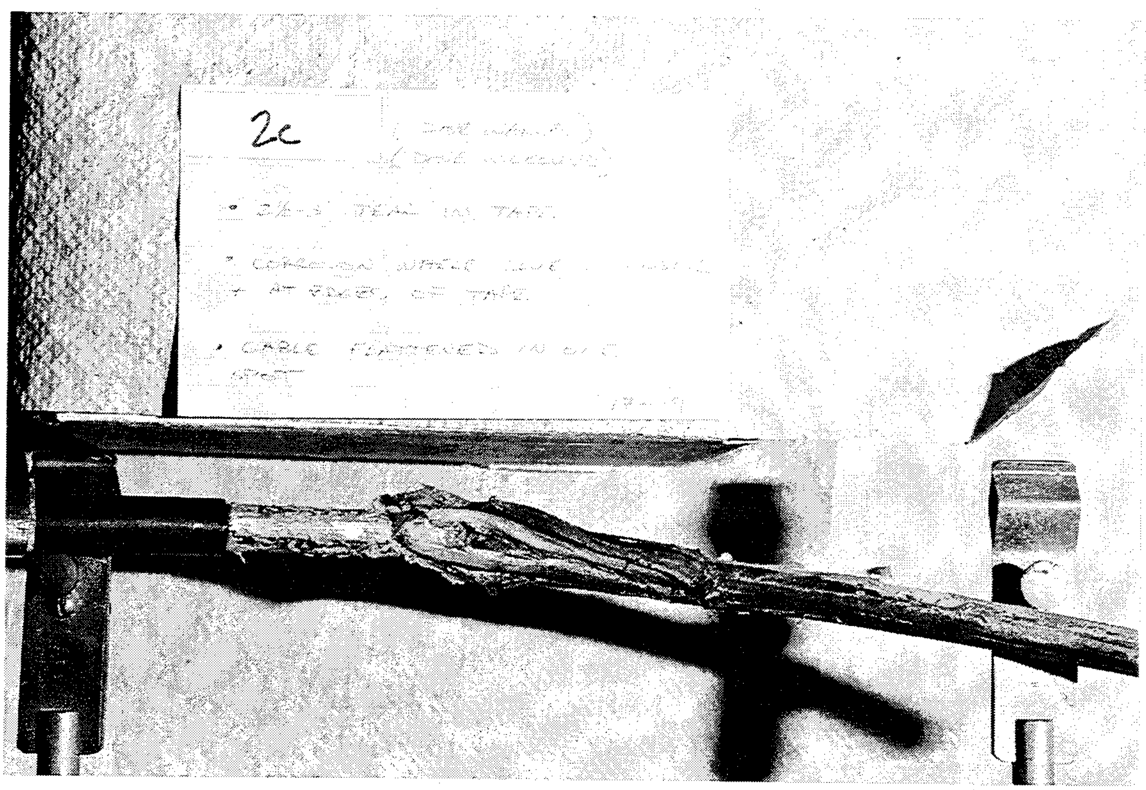
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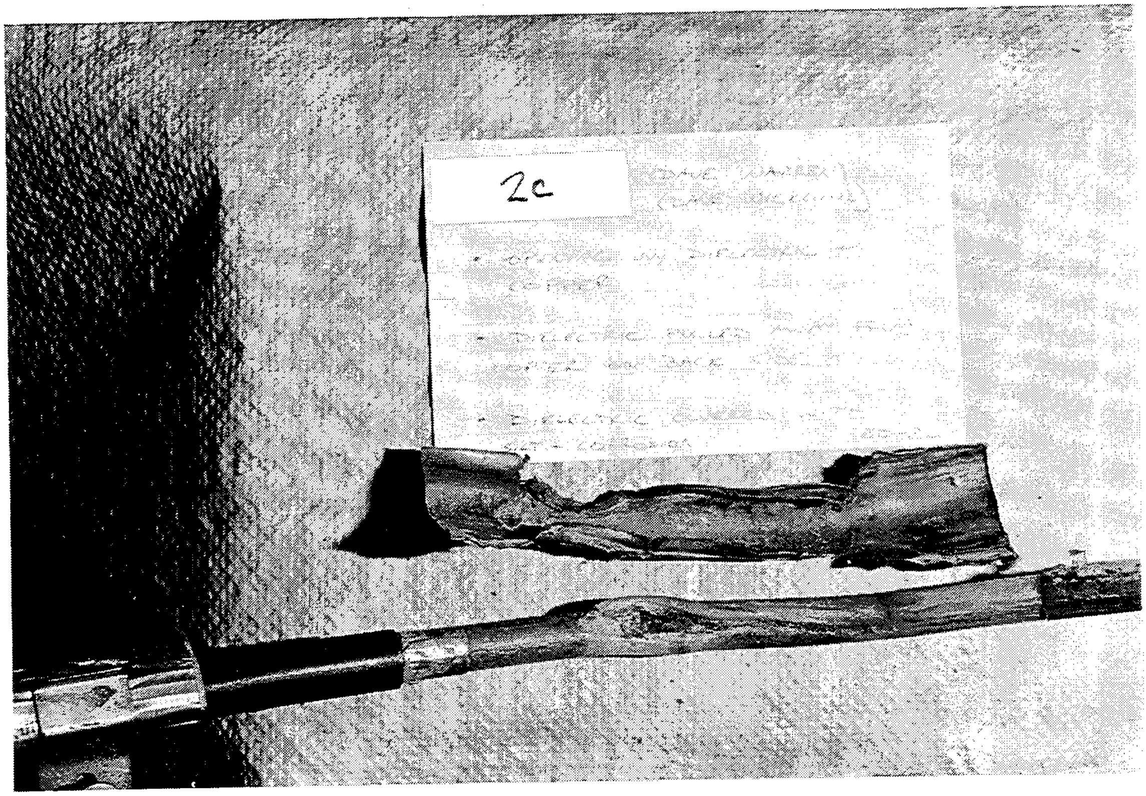
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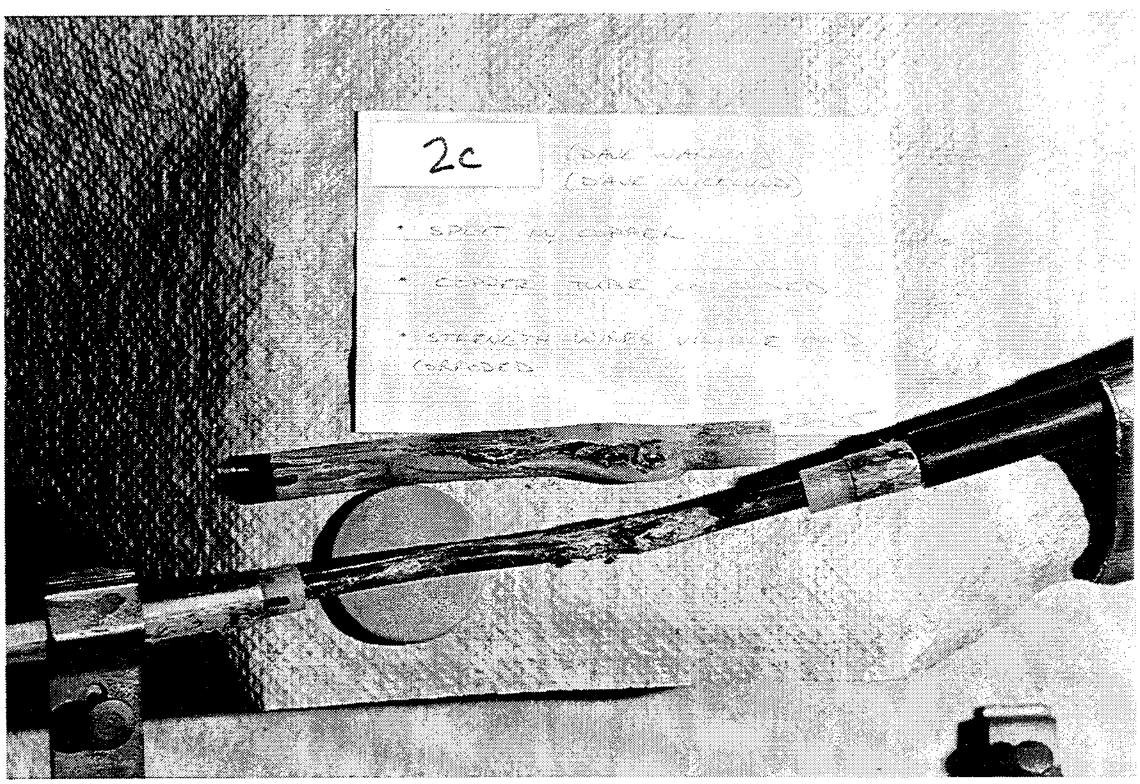
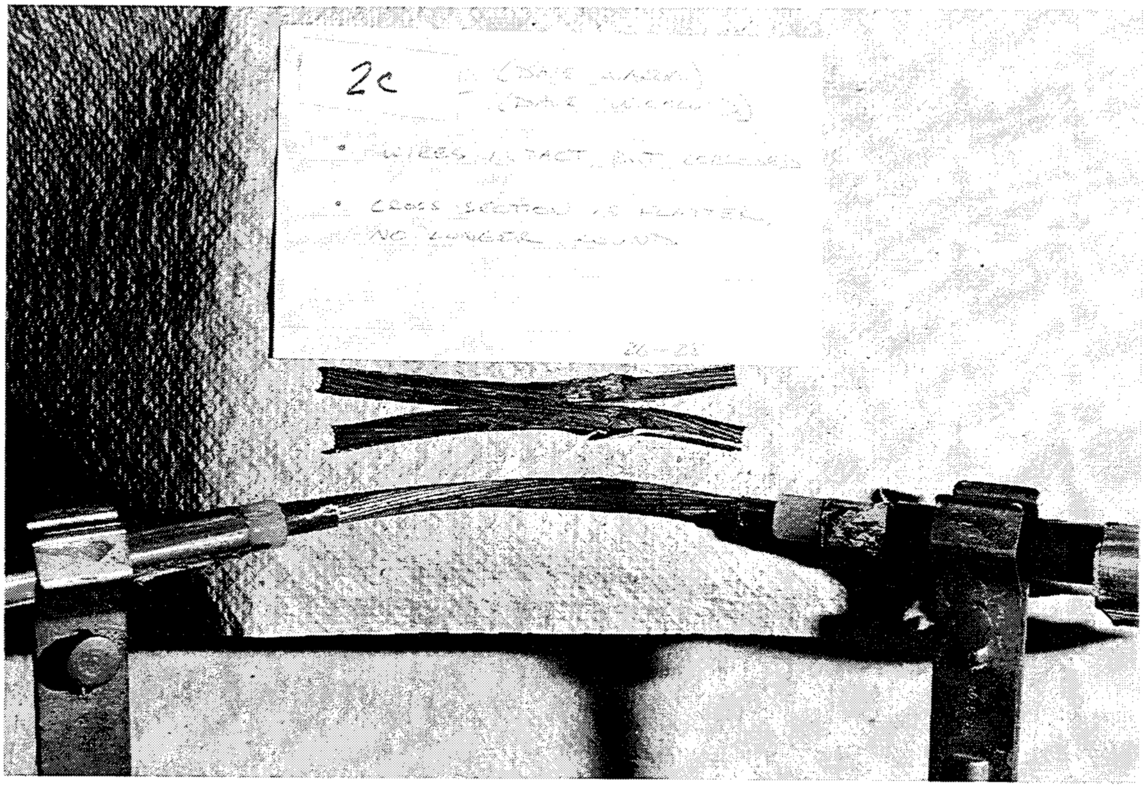
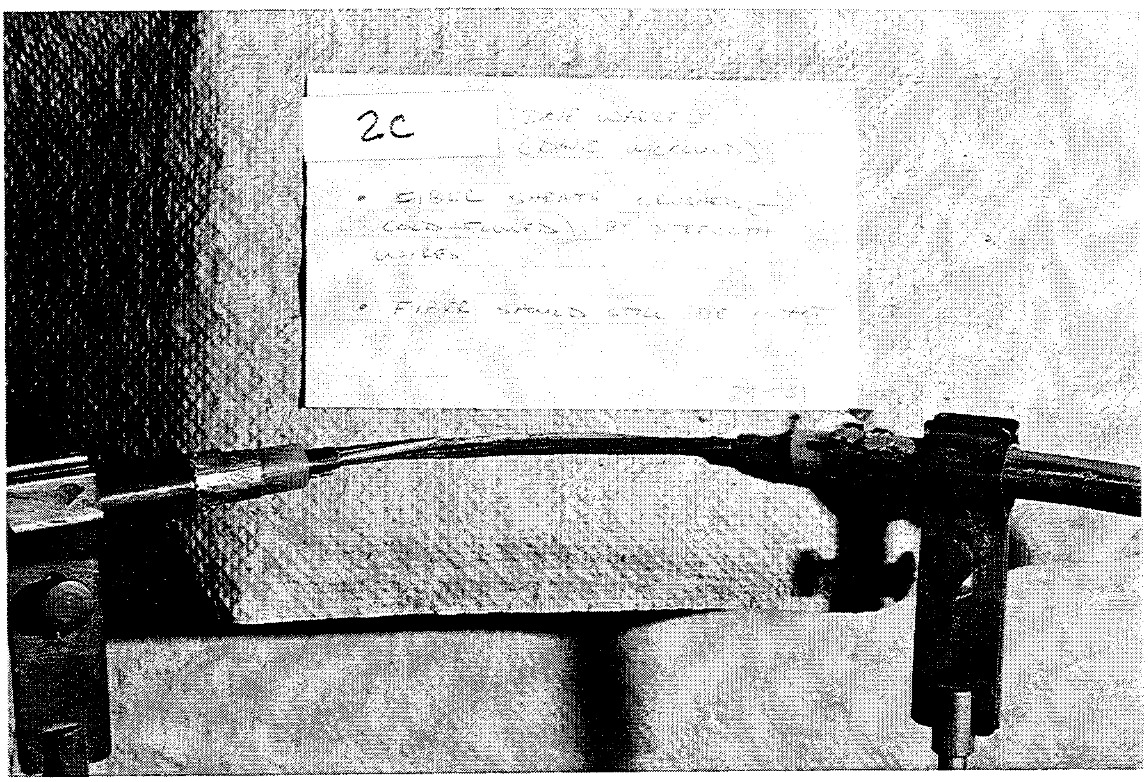

2c
(DAVE WICKLUND)
• SPLIT IN COPPER
• COPPER TUBE CORRODED
• STRENGTH WIRES VISIBLE AND
CORRODED


2C


2C

5.5 Fault Number 3 - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 8/22/94 Date Autopsied: 10/20 & 25/94
Autopsy Personnel: Carl Stevens, Steve Smuck
Date of Failure: Between 220700Z Jul 94 and 251800Z Jul 94
Location: 4.867 NM seaward of CL107 - in center of 160-degree turn
Depth: 190 fathoms
Seafloor Conditions: Possible shipwreck or dump site.

General Interest:

All cable layers were exposed to seawater. There is no apparent indication of the directionality of the object. There is no indication of electrical damage. Much of the involved metallic parts have both mechanical and corrosion damage. There don't appear to be any differences from construction. No apparent manufacturing defects. The object in this case is known. The wire frame came to the surface with the filter material attached.

Special Interest:

The cable is bent at about a 30-degree angle. This is the cable section that was recovered with a piece of filter panel wrapped around it with the corroded steel wire frame. It looks as though the wire in the panel cold-flowed and abraded its way through the various layers. The gash appears clean except for some white corrosion/deposits on the strength wires.

Description:

Condition of Jacket: The damage is localized to a 1.1-in. gash in the cable. The gash angle is approx. 20 deg. to the axis. The gash cuts through the jacket, steel tape, dielectric, and copper.

Condition of Steel Tape: The steel tape has corroded away from the gash in the cable. The area is approx. 1.33 in. by 0.63. The tape is broken all the way around the cable - looks like it stretched, failed, and then buckled when the two edges hit each other again. Brown and black silt and/or corrosion products are present. The green glue is obviously providing some corrosion protection, except for in the cross-sectional view. This appears to be the corrosion propagation path - between the two layers of glue.

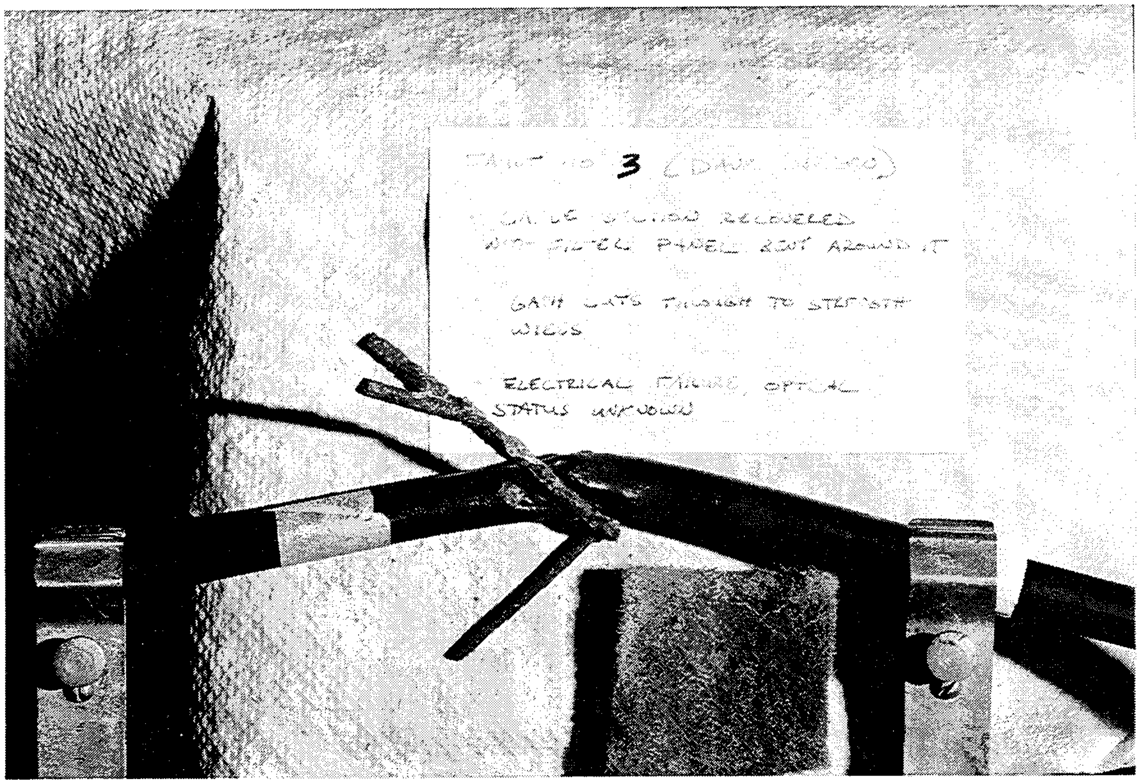
Condition of Dielectric: The damage is limited to one side of the dielectric. The dielectric has been opened up down to the copper in an area approx. 0.52 in. by 0.15 in. It is not apparent if this gash was from a single event or if the dielectric cold flowed. Before dissection there appears to be an air gap between the dielectric and the copper in an area surrounding the gash.

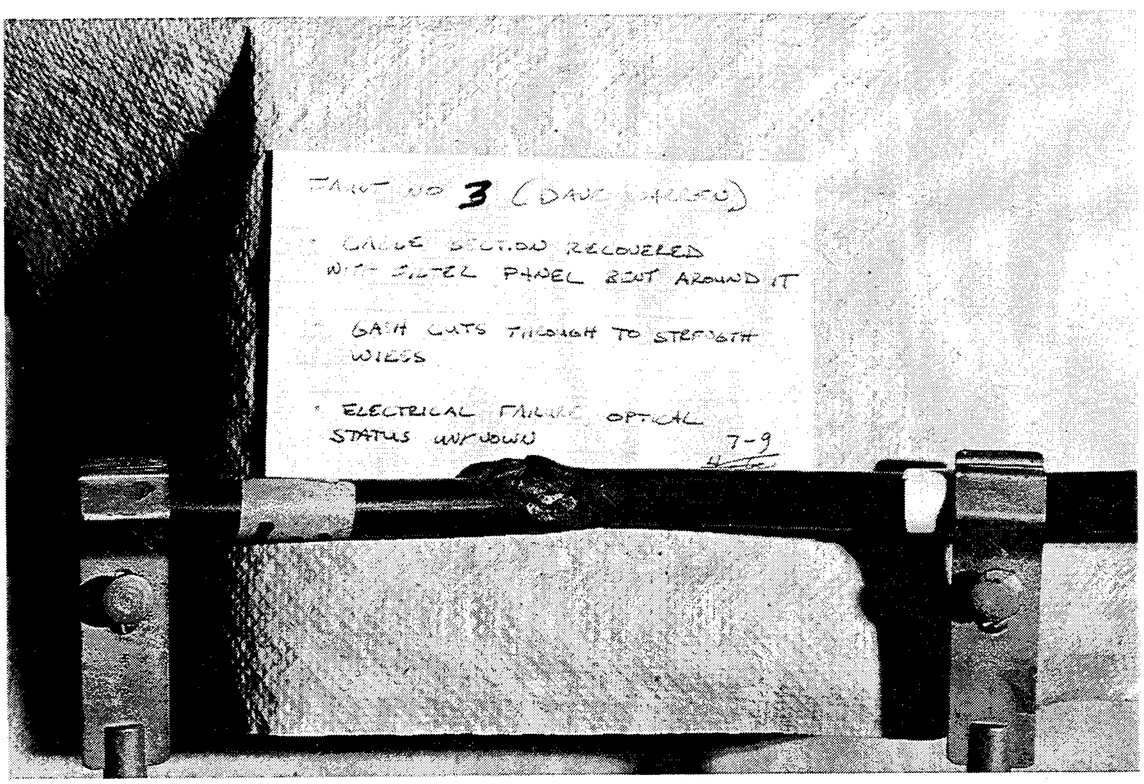
Condition of Copper Shield: The copper tube has opened up to expose the steel strength members. A 0.23-in. gap has opened up with some fracturing of the copper in a radial direction, approx. 0.17 in. on each side. It looks like the cable bent over tight and then bent open again tearing the copper in the process. This would have opened the fracturing of the copper on both sides of the opening. White and blue corrosion is present and the copper tube is discolored, apparently by presence of water. The outer surface is a shiny gun metal black finish.

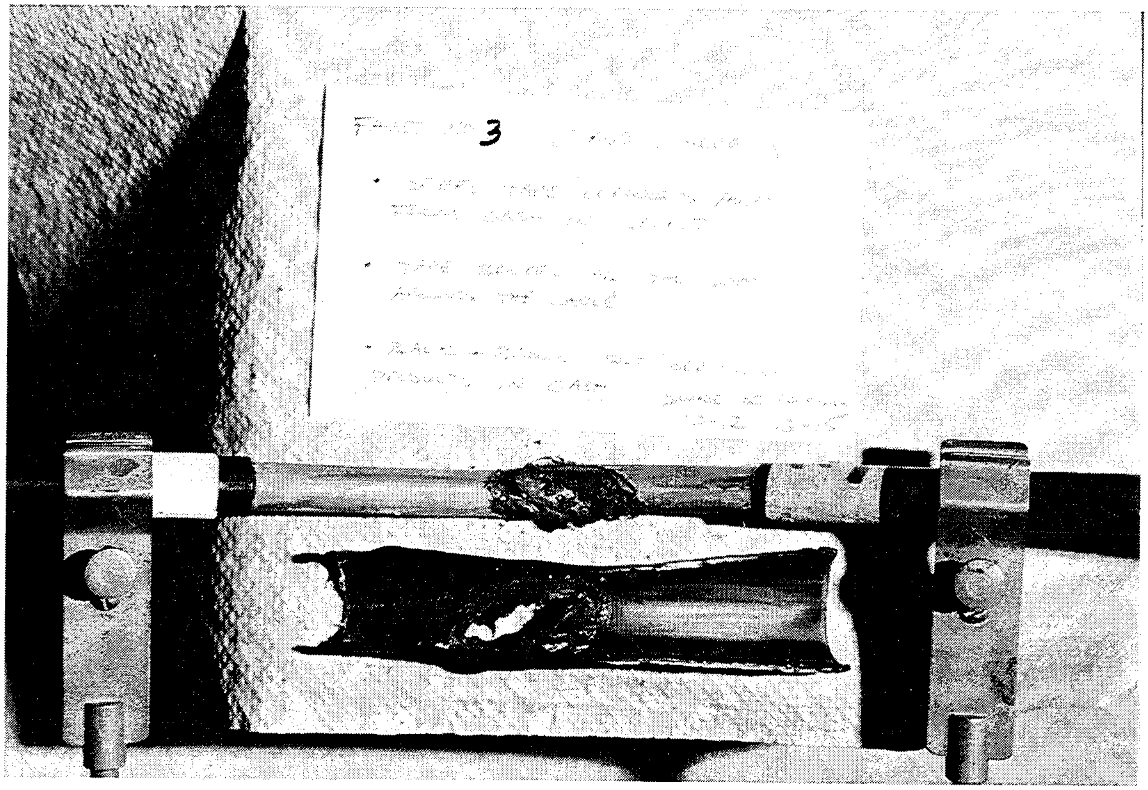
Condition of Steel Wires: There is a white corrosion byproduct present - heavy in exposed area of the gash, and lighter in the interstices. Red corrosion also present. The wires are bent at a 30-degree angle. In the plane of the bend the cable is deformed and has been left with a slight "S" shape. Cross section of cable has been changed from round to oval. There are slight separations in between wires in the gash area.

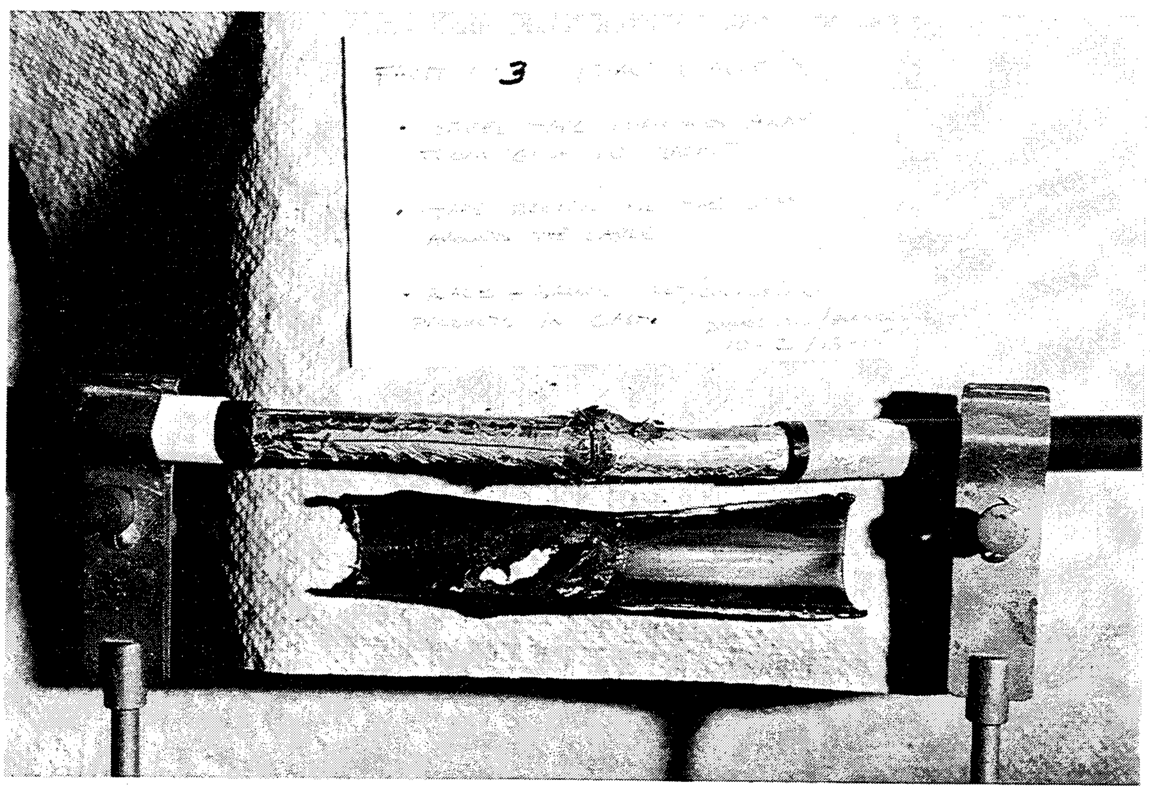
Condition of Optical Fiber Sheath: The sheath has cold flowed into spaces between inner layer of strength wires. Sheath is discolored (yellow/mustard) corrosion from wires stuck on the sheath.

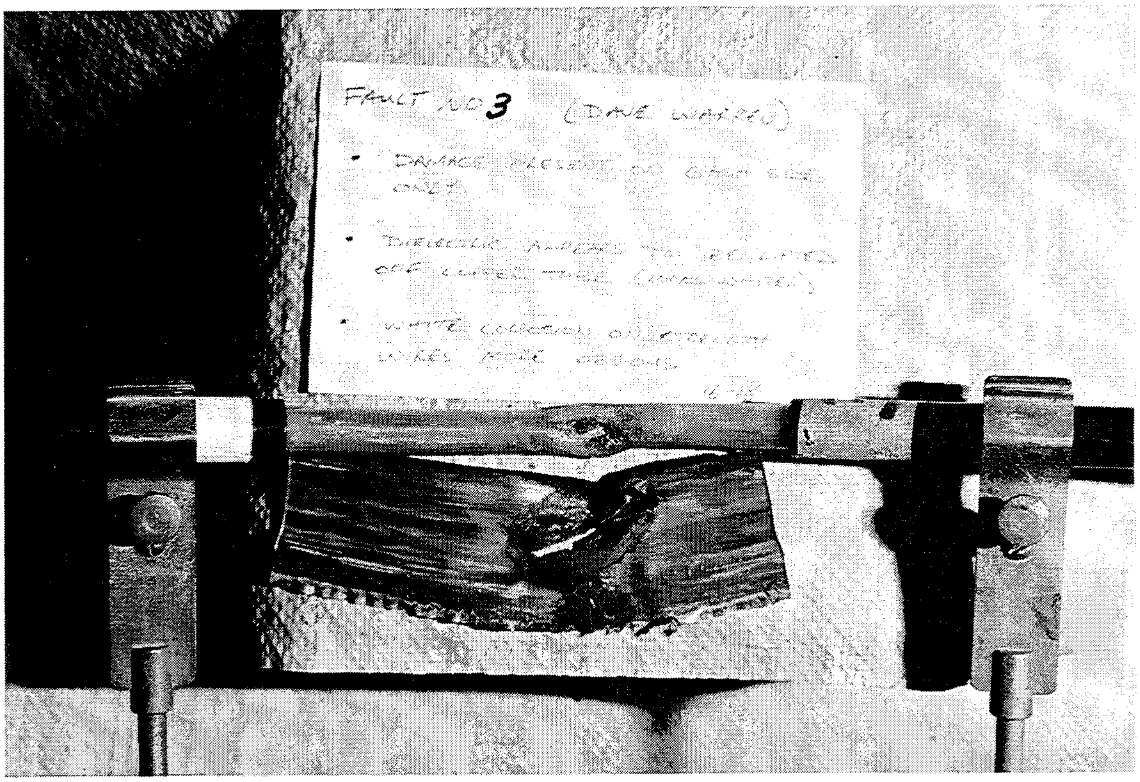
Condition of Fiber: Unknown. Attempted to check with a bare fiber adapter - unsuccessfully, but can't say that the fiber is bad. Fiber may be broken at the point where the pigtail emerges from the end of the sample.

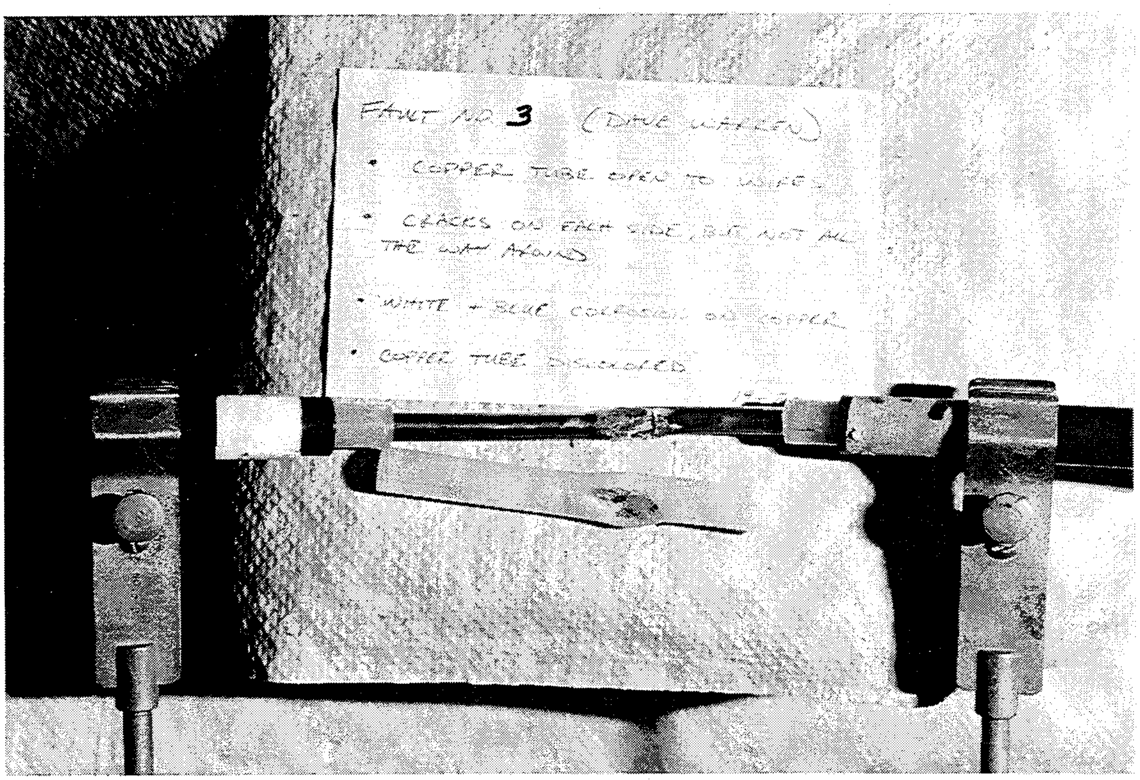

3
PANEL AROUND IT
CUTS THROUGH TO
ELECTRICAL FAILURE, OPTICAL
STATUS UNKNOWN

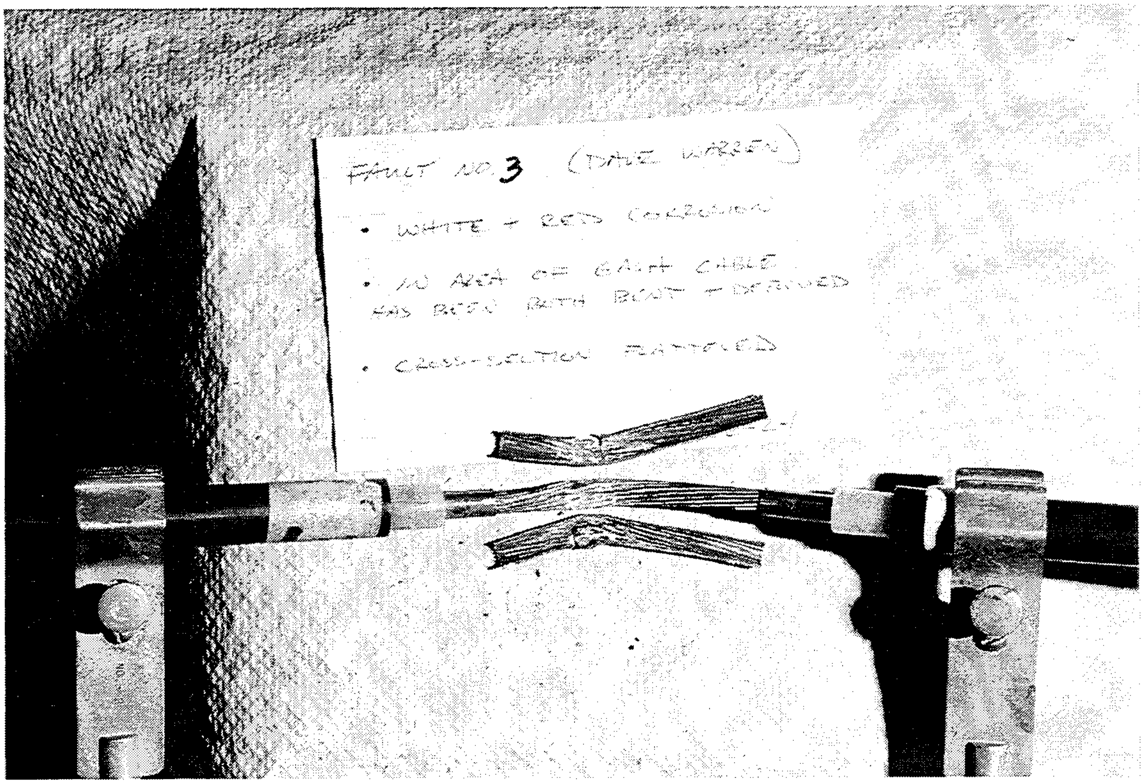

FAULT NO 3
CABLE SECTION RECOVERED
WITH FILTER PANEL BENT AROUND IT
GASH CUTS THROUGH TO STRENGTH
WIRES
ELECTRICAL FAILURE, OPTICAL
STATUS UNKNOWN
7-9

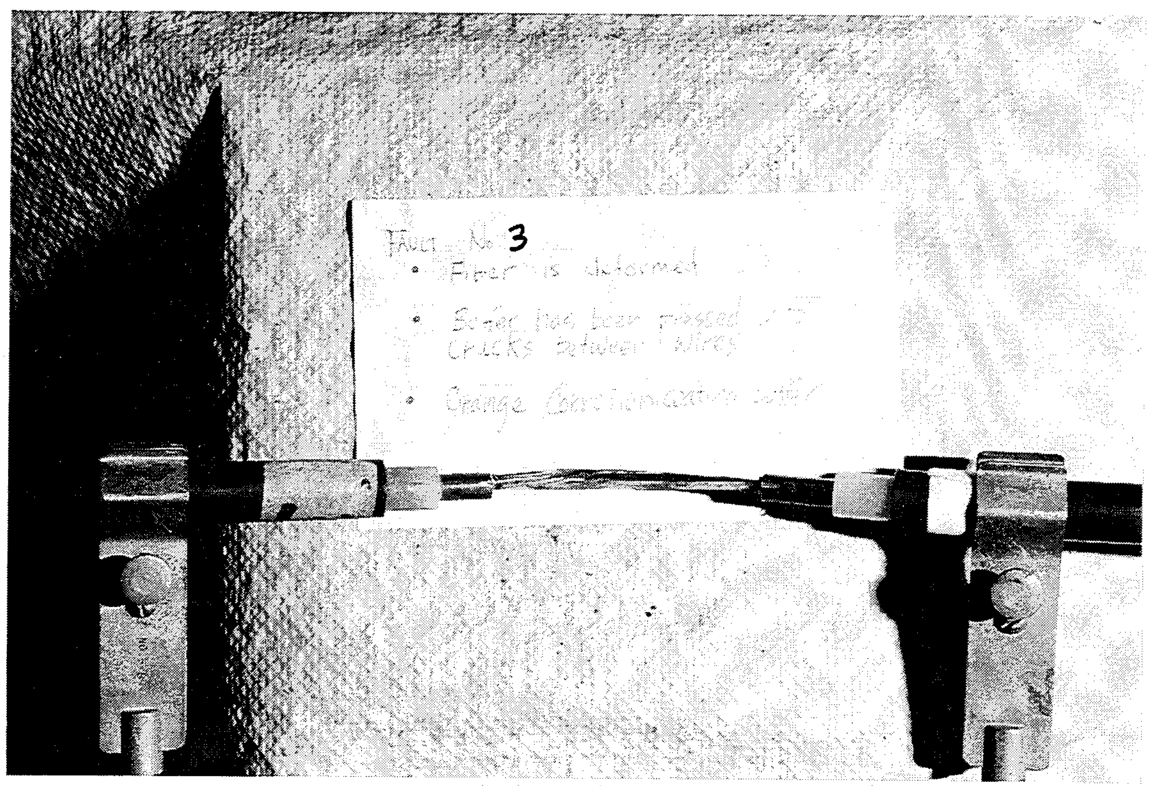





FAULT NO 3 (DAVE WARREN)
DIELECTRIC APPEARS TO BE LIFTED OFF COPPER TUBE (CHALKY WHITE)
WHITE CORROSION ON STRENGTH WIRES MORE OBVIOUS


FAULT NO 3 (DAVE WARREN)
COPPER TUBE OPEN TO WIRES
CRACKS ON EACH SIDE, BUT NOT ALL THE WAY AROUND
WHITE + BLUE CORROSION ON COPPER
COPPER TUBE DISCOLORED


FAULT NO. 3
• WHITE + RED CORROSION
• CROSS-SECTION FLATTENED


FAULT No 3
• Fiber is deformed
cracks between wires
• Orange

5.6 Fault Number 5a - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 8/30/94 Date Autopsied: 10/20/94
Autopsy Personnel: Steve Smuck
Date of Failure: Between 271200Z Jun 94 and 071400Z Aug 94
Location: 0.6 NM shoreward of TR1004
Depth: 328 fathoms
Seafloor: Soft mud came up on the grapnel hooks.

General Interest:

The outer jacket and steel tape were exposed to seawater. It appears that the contact object hit the cable from the side or at least on some kind of angle. The outer jacket has been sheared from one side and pushed up on the other. This is the data supporting the assumption. There is evidence of prolonged corrosion of the steel tape. There does not appear to be any differences between different construction. There is a "V" shaped groove in the dielectric (see below for details). It appears the contact object was fairly blunt. The outer jacket has been deformed at the impact site and along the cable as well. The jacket was not cut in any great length, but it definitely was deformed. There is no apparent evidence of fatigue or abrasion indicating a long term event.

Special Interest:

The dielectric was only slightly indented. The cable would most likely have remained functional at this location had it not been for it being cut with bolt cutters approximately 90 fathoms from this point. It is assumed that a trawler working in the area passed across the cable and hit the cable with one otter board and hooked it with the other. The cable was probably then recovered to the surface and cut with bolt cutters.

Description:

Condition of Jacket: The overall length of the damaged area is approx. 6 in. The outer jacket has been separated from the tape and exhibits a 1.25 in. long and 0.1 in. wide hole in the jacket. This exposed the steel tape to seawater. The jacket is deformed from the exposed area extending to the end of the 6 in. There appears to be rust in the exposed area and sand or silt in the other damaged areas.

Condition of Steel Tape: There has been extensive corrosion to an oval area approx. 1.5 in. by 0.75 in. There were small holes in the jacket but water obviously had easy access. It appears as if the steel tape was initially nicked due to the remaining green glue on the backside of the HDPE and steel tape. There doesn't appear to be much mechanical damage other than a slight flattening in the damaged area. There is a scoring from the large damaged area running the length of the damaged area. There is a small deposit of HDPE in the steel tape from this scoring. There is some corrosion under the glue under the steel tape.

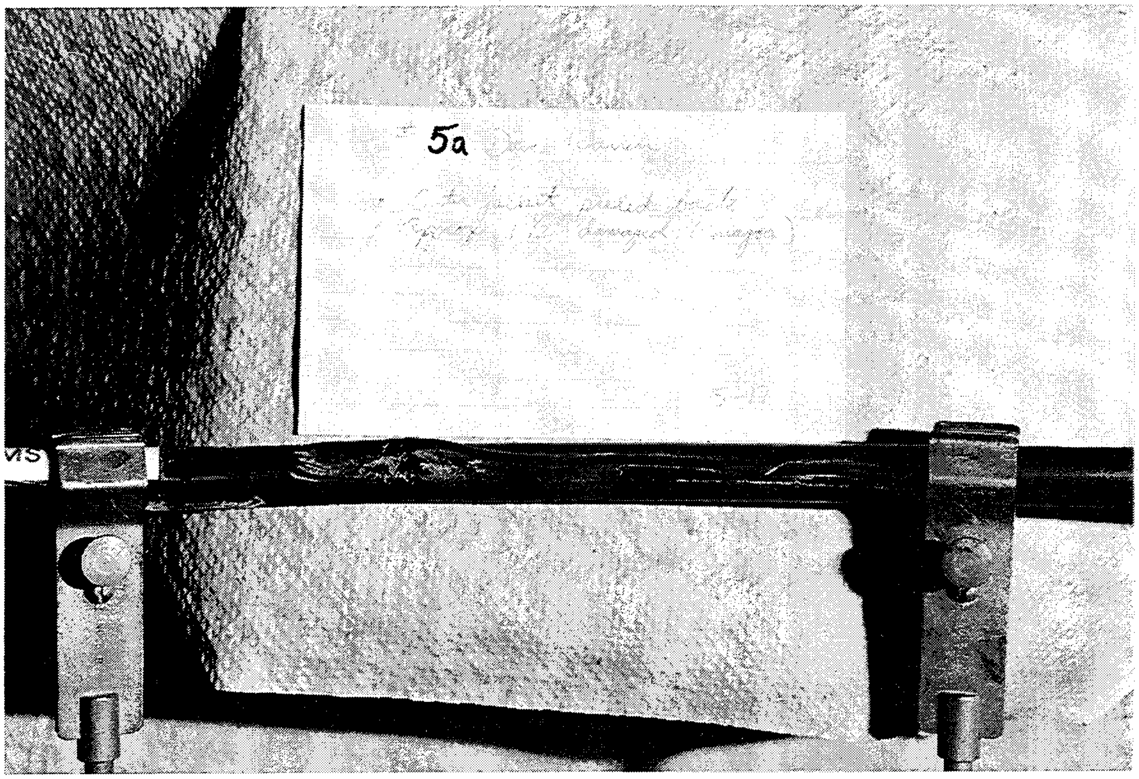
Condition of Dielectric: There is a slight mechanical deformation in the dielectric. There is no appearance of any abrasions or cuts into the dielectric. There is the same "V" groove in sample 5B. This "V" groove runs the entire length of the sample (not just the damaged area) and it doesn't appear to have any connection to the damage. The groove is approx. 0.025 in. wide at the top and approx. 0.010 in. deep. It is so regular and uniform it appears to be from the manufacturing process. The dielectric didn't appear to have been compromised in any way. It had very good adhesive properties to the copper.

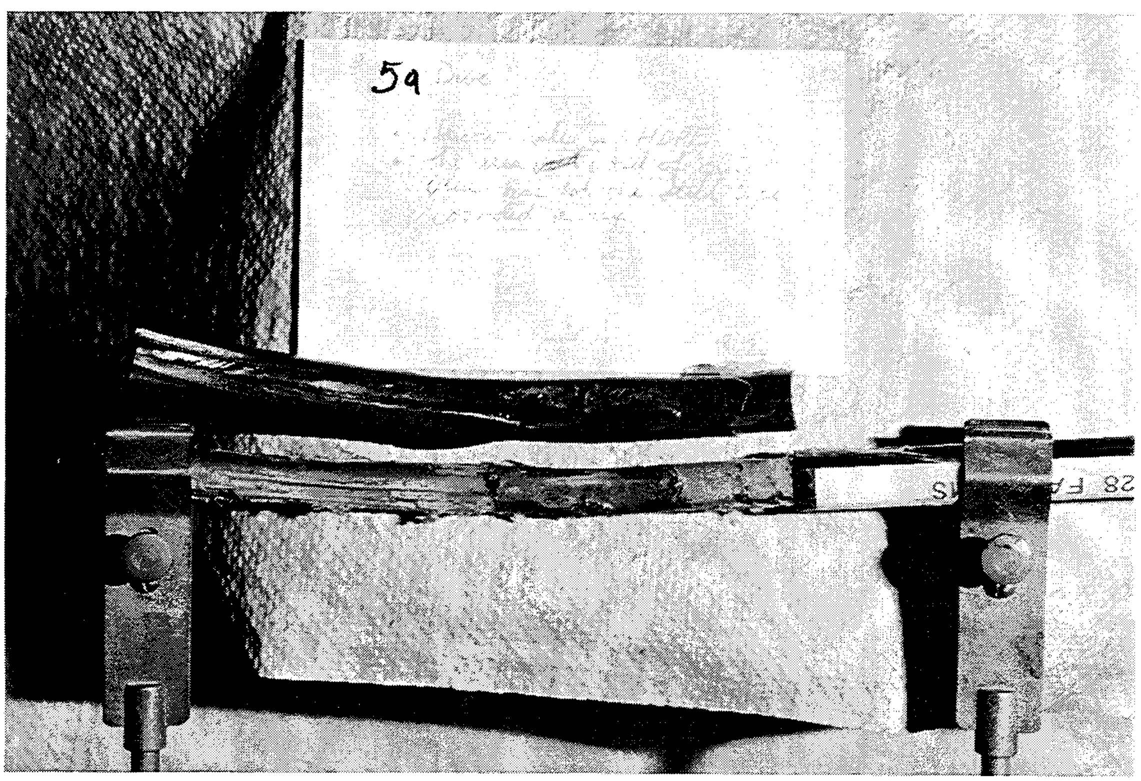
Condition of Copper Shield: There was no visible damage to the copper. Any marks on the copper can be traced to the autopsy.

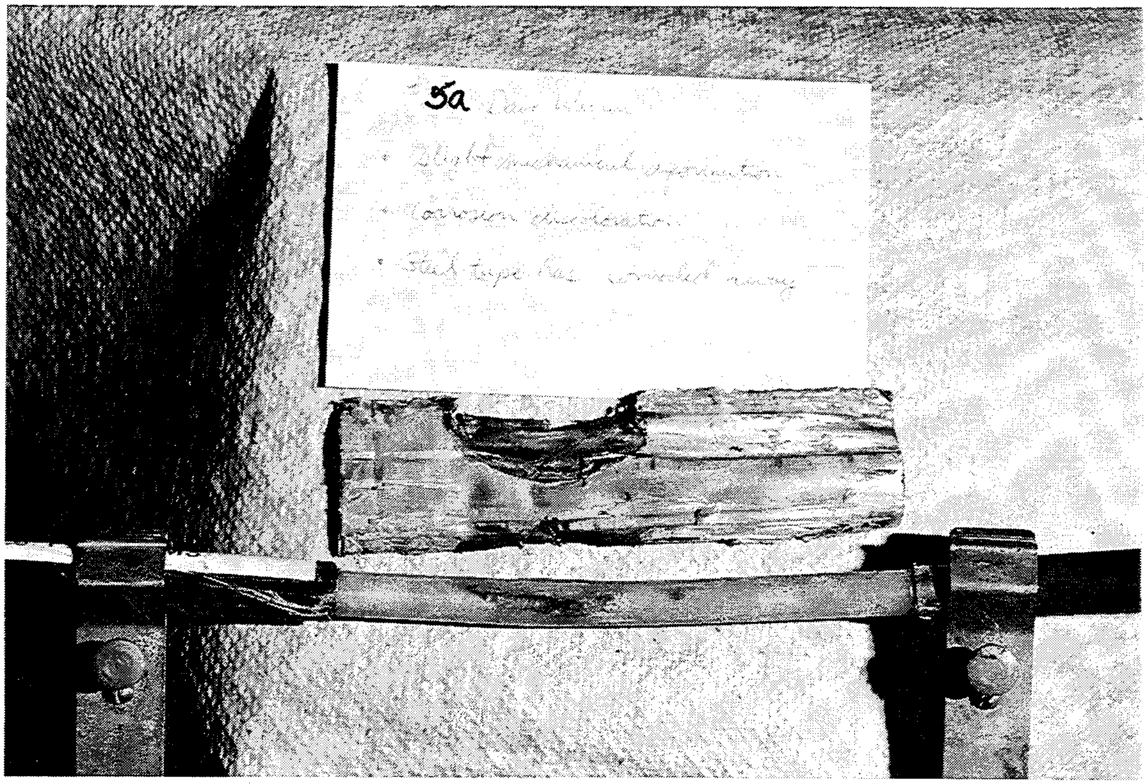
Condition of Steel Wires: Not inspected.

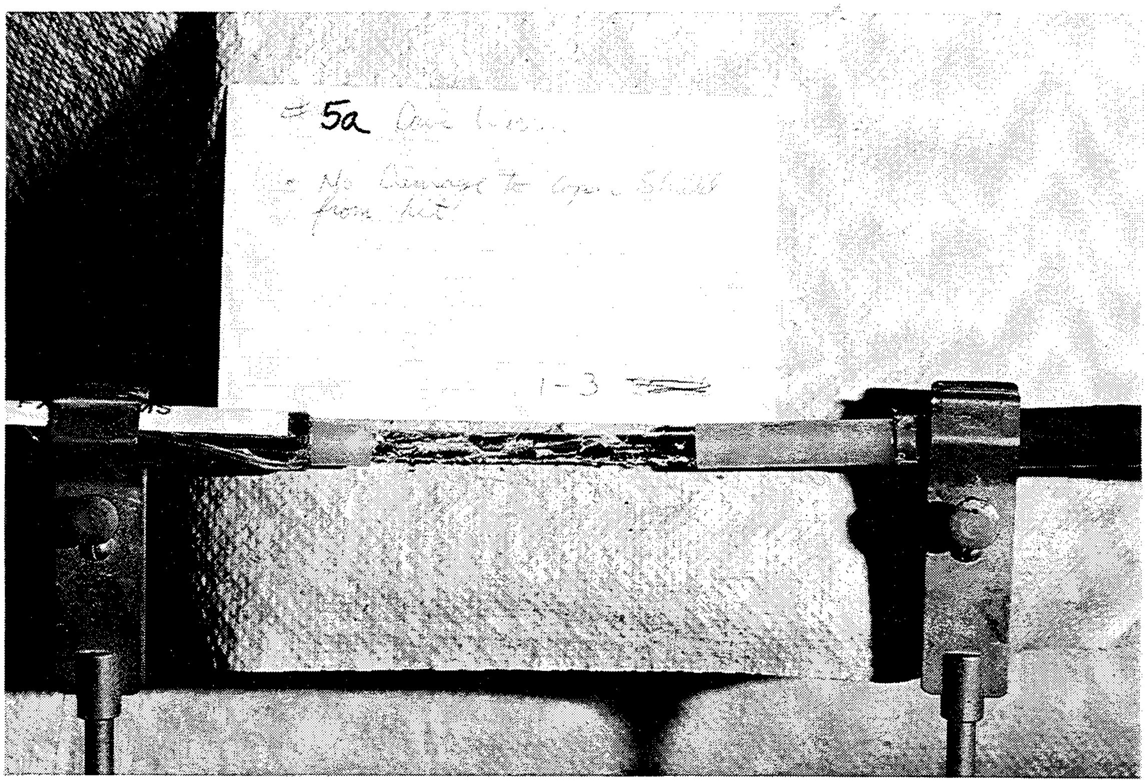
Condition of Optical Fiber Sheath: Not inspected.

Condition of Fiber: Performed a power meter check with one splice and one pare fiber adapter. The fiber checked out good.


5a


5a


5a


5a
1-3

5.7 Fault Number 5b - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 8/ /94 Date Autopsied: 10/20/94
Autopsy Personnel: Carl Stevens, Steve Smuck
Date of Failure: Between 271200Z Jun 94 and 071400Z Aug 94
Location: 1.2 NM seaward of TR1004
Depth: 290 fathoms
Seafloor: Soft mud.

General Interest:

Initially the steel tape and later the dielectric were exposed to seawater. The cable appears to have been hit from the side by an object. There are shear lines on one side of the cable and the other side has the displaced jacket. The damage area is localized in a 5-in. area. There is no evidence of latent damage elsewhere in the cable. The only construction related data may be the "v" groove. The mechanical damage appears to have been from a short term event, with the corrosion occurring later. There is no evidence of fatigue or long term abrasion. One end of the sample was cut with bolt cutters of some type. Corrosion products in and around the cut.

Special Interest:

This sample was 12 inches from a bitter end. The bitter end had obviously been made with bolt cutters. The assumption can be made that the cable was hooked on trawl gear at this location and brought to the surface where it was cut away with bolt cutters.

Description:

Condition of Jacket: Damage over a length of approx. 4.5 in. Heaviest damage over a length of approx. 2.5 in. The jacket was scuffed off down to the steel tape. Difficult to tell if the tape is also damaged. Silt and/or corrosion is evident in the scuff.

Condition of Steel Tape: The tape has completely corroded from the damaged area over a length of 3.5 in. and nearly all the way around the cable. Distinct line of corrosion shows the edge of the remaining tape. Glue is still in place - makes it look like the steel tape may still be there, but its not. The lack of any damage to the underlying glue indicates the mechanical damage was limited to the outer surface of the steel tape and didn't penetrate to the dielectric.

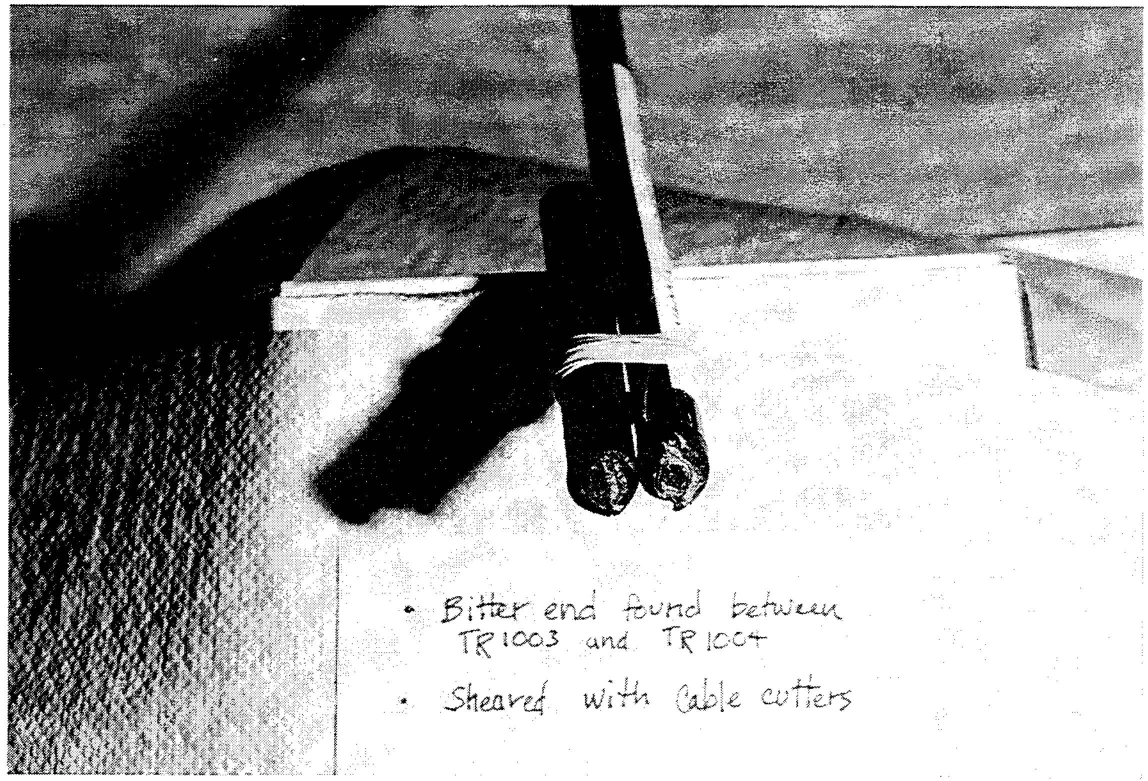
Condition of Dielectric: There is a small depression (approx. 0.25 in. dia.) area of damage. There are no scratches or abrasions on the dielectric. There is an unusual groove (shaped like a "V"). See sample 5A. There is rust discoloration in the groove.

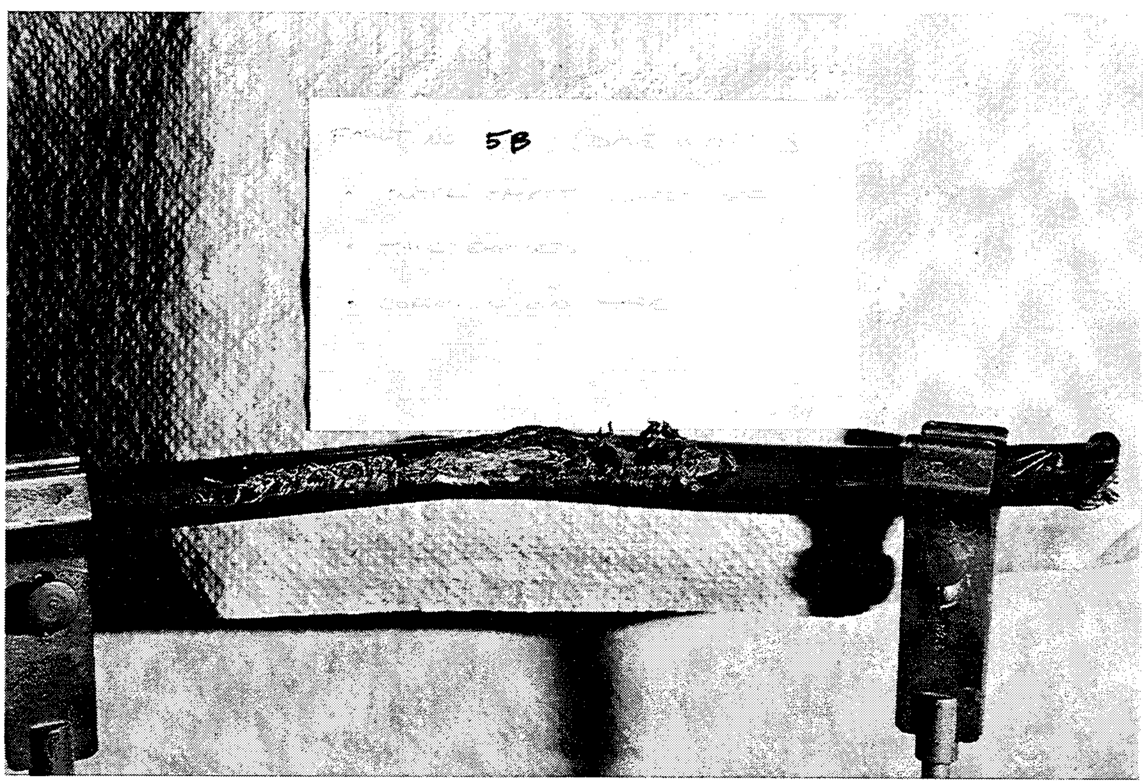
Condition of Copper Conductor: There is no apparent damage to the conductor. There is a slight discoloration of the copper to a bronze-ish color.

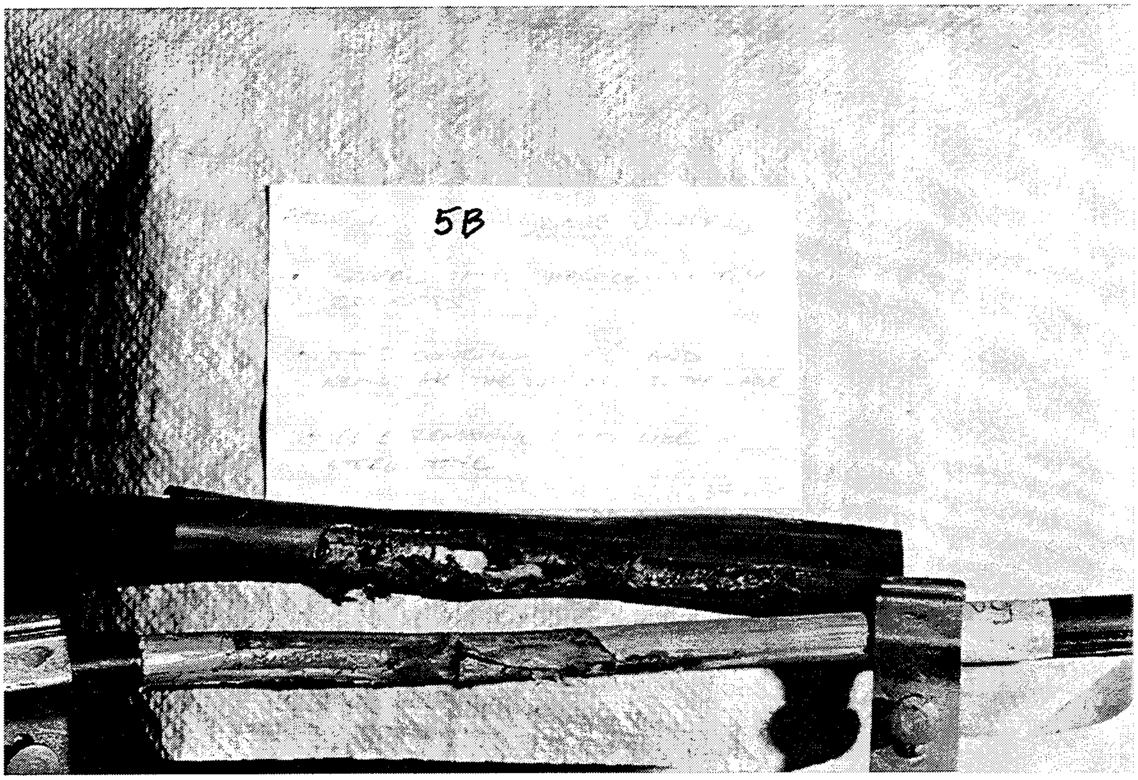
Condition of Steel Wires: Not inspected.

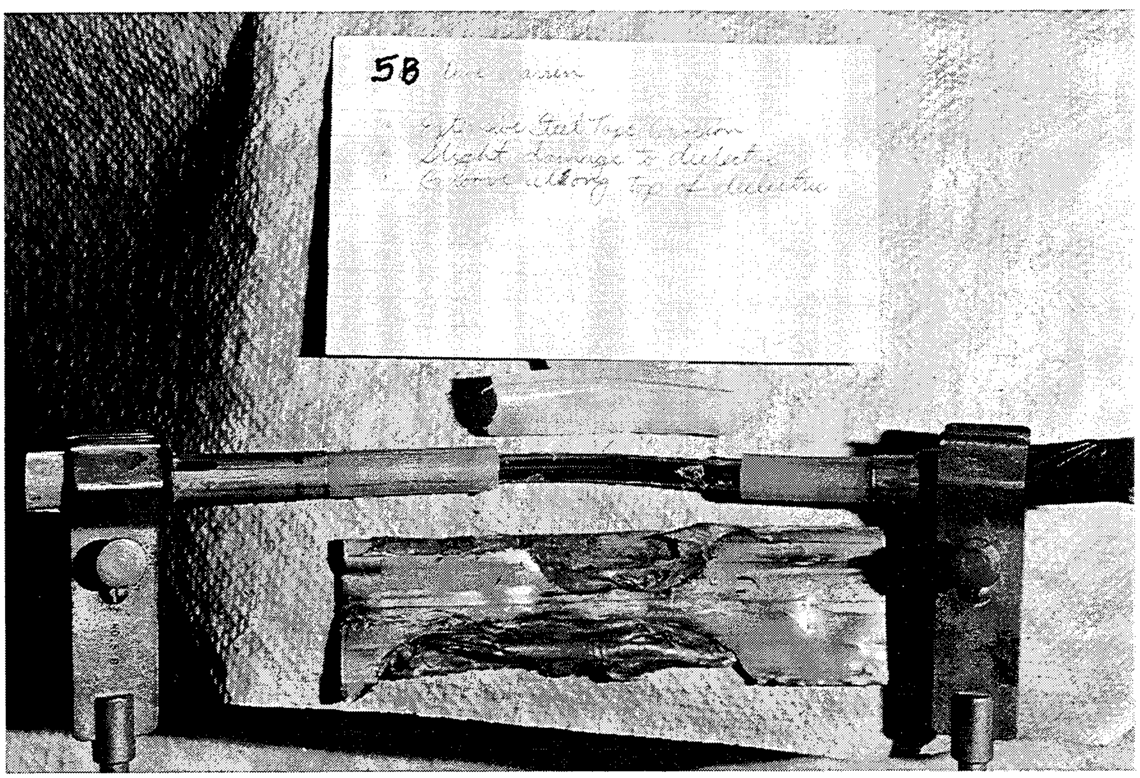
Condition of Optical Fiber Sheath: Not inspected.

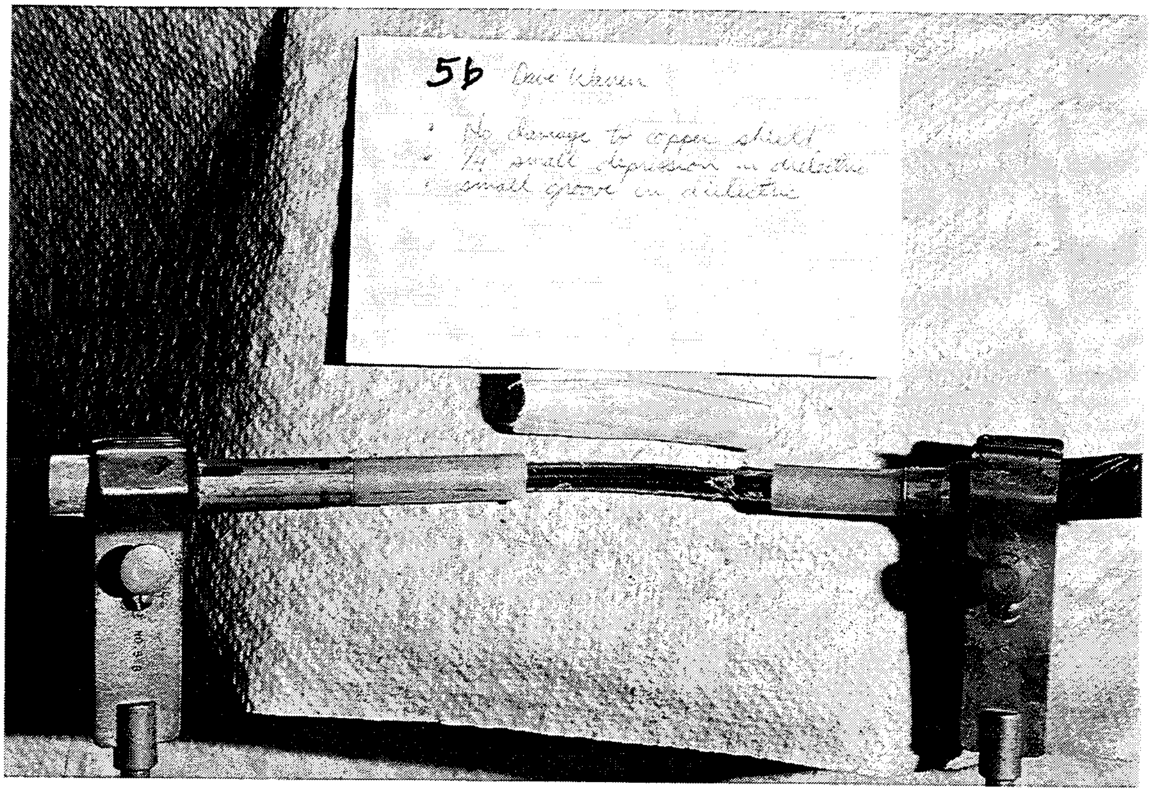
Condition of Fiber: Not inspected.


• Bitter end found between TR1003 and TR1004
• Sheared with cable cutters


5B


5B


5B


5b Dave Warren
• No damage to copper shield
• 1/4 small depression in dielectric
• small groove in dielectric

5.8 Fault Number 6 - FDS-D CABLE AUTOPSY WORKSHEET

Date Recovered: 9/7/94 Date Autopsied: 10/28/94
Autopsy Personnel: Dave Warren
Date of Failure: 071000Z Jun 94
Location: 6.1 NM seaward of TR1010
Depth: 270 fathoms
Seafloor: Unknown

General Interest:

All cable components were exposed to seawater by the damage. The direction of the damage was obvious. Although the sample is now heavily corroded, when it came to the surface during recovery it was only lightly corroded. Damage appears to have been caused by a sharp object. Damage occurred very quickly, probably as a result of being dragged around the edge of a fishing trawler otter board. Damage resulted in both an electrical and optical failure. Total damage length was approximately 120 feet.

Special Interest:

Cable damage was similar to damage evidenced during laboratory drag tests of DWT where the cable was dragged around a sharp edge under various loads.

Description:

Condition of Jacket: The jacket was splayed open along with the rest of the components in the cable package. Periodic tendrils curled off the two edges of the jacket pointing in the opposite direction of the cutting force. The back side of the jacket had ridges (humps) periodically (spaced 0.5 in apart) that may have been the result of the shield below deforming plastically and then relaxing some, causing the shield to buckle.

Condition of Steel Tape: The steel tape shield is ripped open and spread apart along with the jacket, dielectric. Blue green glue is visible. Edges of the tape are rough and corroded.

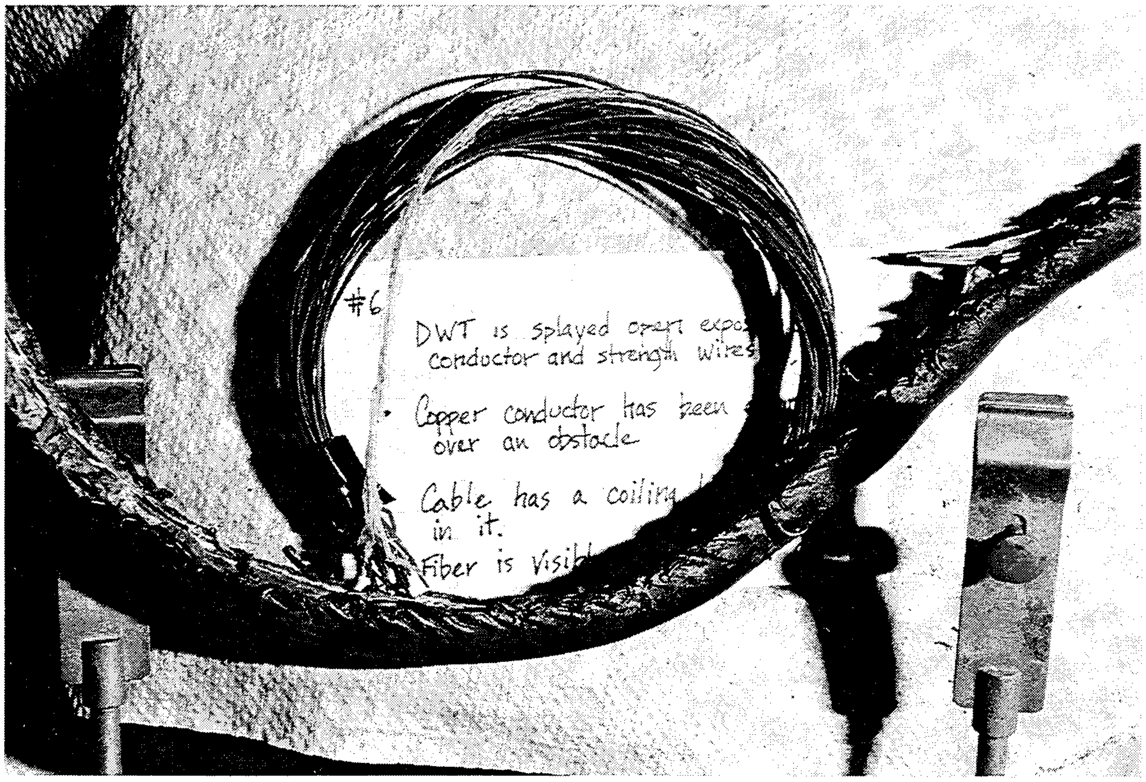
Condition of Dielectric: Spread open, cold flowed, torn.

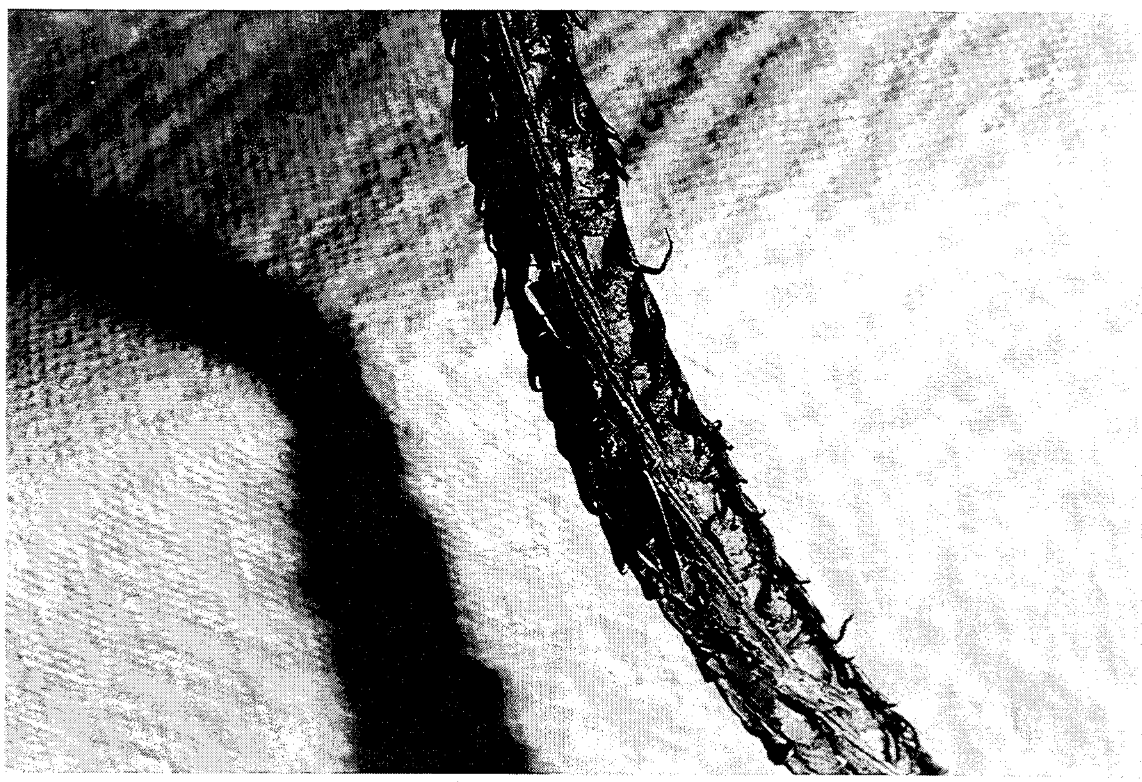
Condition of Copper Shield: The copper appears to have been extruded over a sharp object. Repetitive fractures approx. 0.75 in. apart. Corrosion present - moderate. Very little volume loss from corrosion.

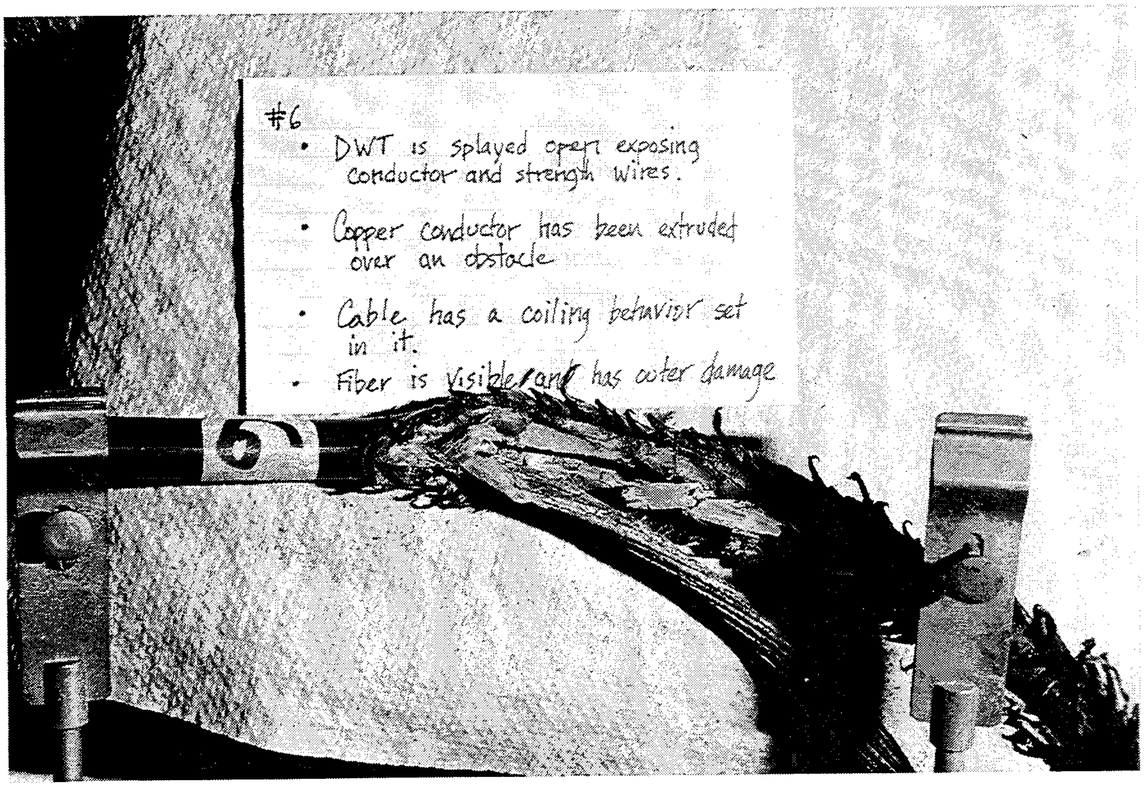
Condition of Steel Wires: The wires are intact - none have broken in this sample. All corroded over 100% of the area. There was residual torque set in the cable. This caused it to coil up once the tension was relieved.

Condition of Optical Fiber Sheath: The sheath is shredded exposing the buffer. Indentations from where the strength wires deformed the buffer.

Condition of Fiber: There appear to be kinks and bends in the core. Obvious catastrophic failure.


#6
DWT is splayed open expo
conductor and strength wires
Copper conductor has been
over an obstacle
Cable has a coiling
in it.
Fiber is visib




#6
• DWT is splayed open exposing conductor and strength wires.
• Copper conductor has been extruded over an obstacle
• Cable has a coiling behavior set in it.
• Fiber is visible and has outer damage
5

Appendix B

FDS-D FISHING THREAT

16 December 1994

FDS-D FISHING THREAT

1.0 INTRODUCTION

The FDS-D Underwater Segment (UWS) was deployed in the Mediterranean Sea between 10 May and 7 September 1994. The total length of the UWS was 500 NM and it was deployed in a depth ranging from 370 feet to 11,500 feet. The UWS was exposed to in situ hazards such as fishing, currents, harsh seafloor, steep slopes, and biologics. The UWS trunk survived all the in situ hazards except for damage caused by fishing trawlers. Long-line fishing caused damage during cable installation and recovery, but once the cable was in situ, the threat from long-lines diminished. A total of 15 in situ cable failures occurred as a result of trawling activity.

The UWS was damaged by trawling activity in two geographic locations. The damage was spread over a length of 60 NM (12% of total length). Both geographic locations were near shallow water banks that are heavily fished. The UWS survived the hazards over the remaining 88% of the length.

Initially, the cable faults were repaired by a cableship that was standing by, however, the cableship left the area to meet other commitments. The faults continued after the cableship left and the termination ship (T-ship) was forced to use a contingency plan and move to an alternate termination site (ATS) beyond the faults.

Two other faults occurred during the demonstration that were not trawling related. Both of these failures occurred in the array field. One failure occurred as a result of the cable becoming entangled with a steel wire filter screen on the seafloor — this failure is attributed to excessive tensions in the cable during installation that resulted in dragging the cable through a turn on the seafloor. The other field fault was an intermittent fault that was located in a section of cable approximately 2 NM long. The cable was visually inspected during recovery, but no specific damage could be identified and the cause of the fault was never isolated.

2.0 DISCUSSION

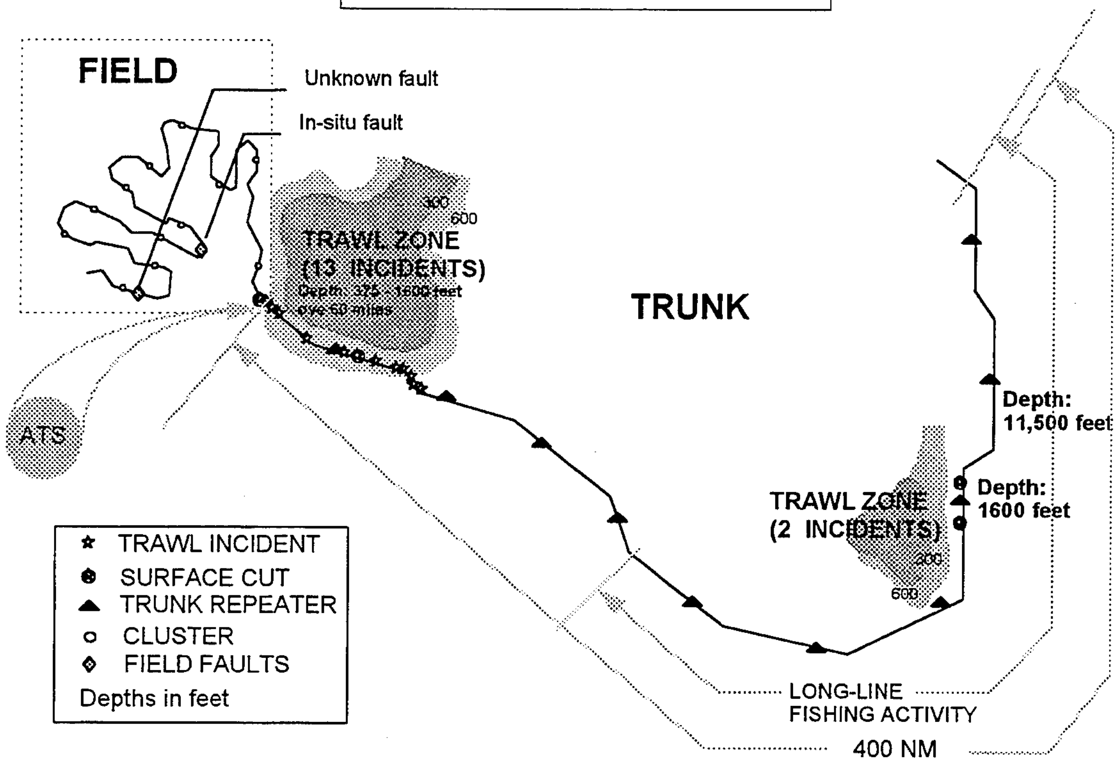
Trawling activity was the leading cause of failure in the FDS-D UWS trunk. The trawling damage was isolated to two geographic locations along the 400-NM trunk section. Both locations were on or near shallow water banks where trawling was prevalent. There is no way to infer from marks on the cable how many passes were made by trawlers across the cable track. Tests have shown that that trawl gear crossing a cable can result in:

- no marks on the cable
- small, inconclusive marks on the cable

- significant mechanical damage resulting in failure

A trawl failure is definitive. Fifteen incidents of trawler-induced damage were documented in the UWS. A trawl failure incident is characterized by damage that results from one pass across the cable track by a trawler otterboard. It is possible a single trawler may have produced damage in more than one incident, but did so on separate passes. Failure locations are identified in Figure 1.

FIGURE B-1. FDS-D UWS



Trawlers were observed during all phases of operations over a period of 4 months (May through September). As many as six trawlers at one time were observed making passes across and along the cable track. All of the observed trawlers were the basic bottom trawl type. Figures B-2 through B-7 provide pictures of a trawler and trawl gear photographed near the site.

Trawl damage ranged from singular trawl “hits” with the damaged length measured in inches, to extreme cutting and crushing over hundreds of feet of cable. Not all the trawl damage necessarily resulted in immediate failure. In two cases the damage penetrated the outer layers and reduced the thickness of the dielectric, but did not create a direct path from the conductor to seawater.

In four of the trawl incidents, the cable was cut with bolt cutters near the cable damage. In each incident it appears the cable was hooked by fishing gear

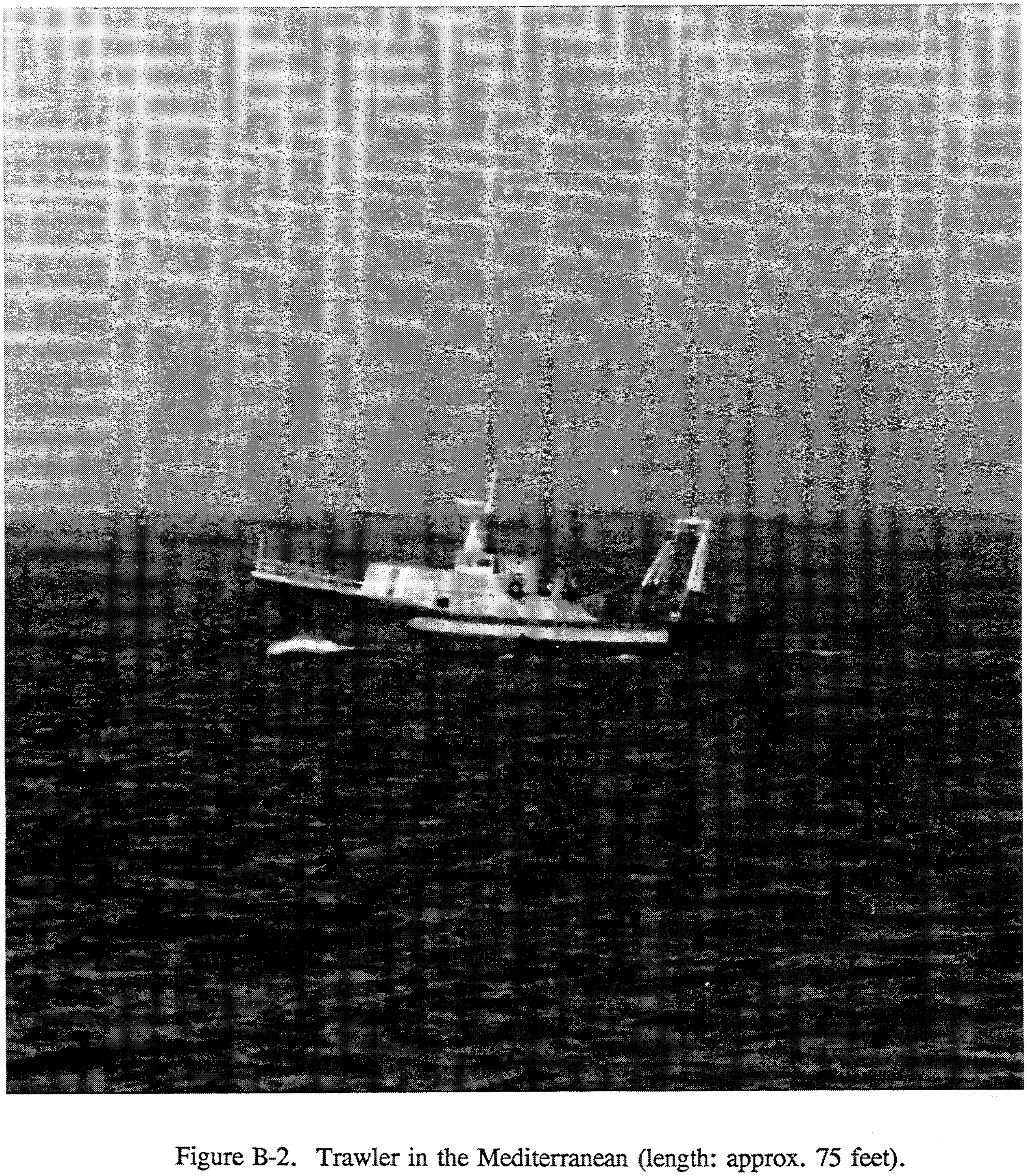


Figure B-2. Trawler in the Mediterranean (length: approx. 75 feet).

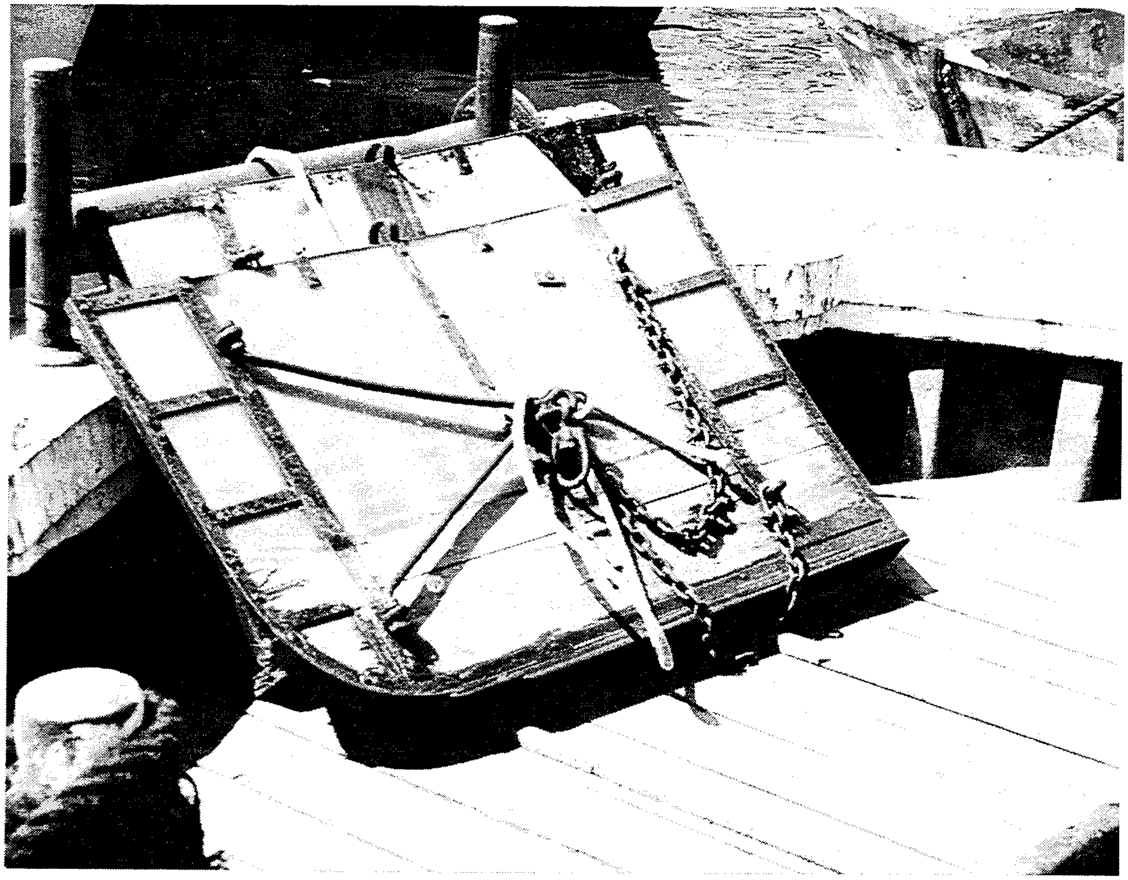


Figure B-3. Wood, fiberglass, and steel trawl door.

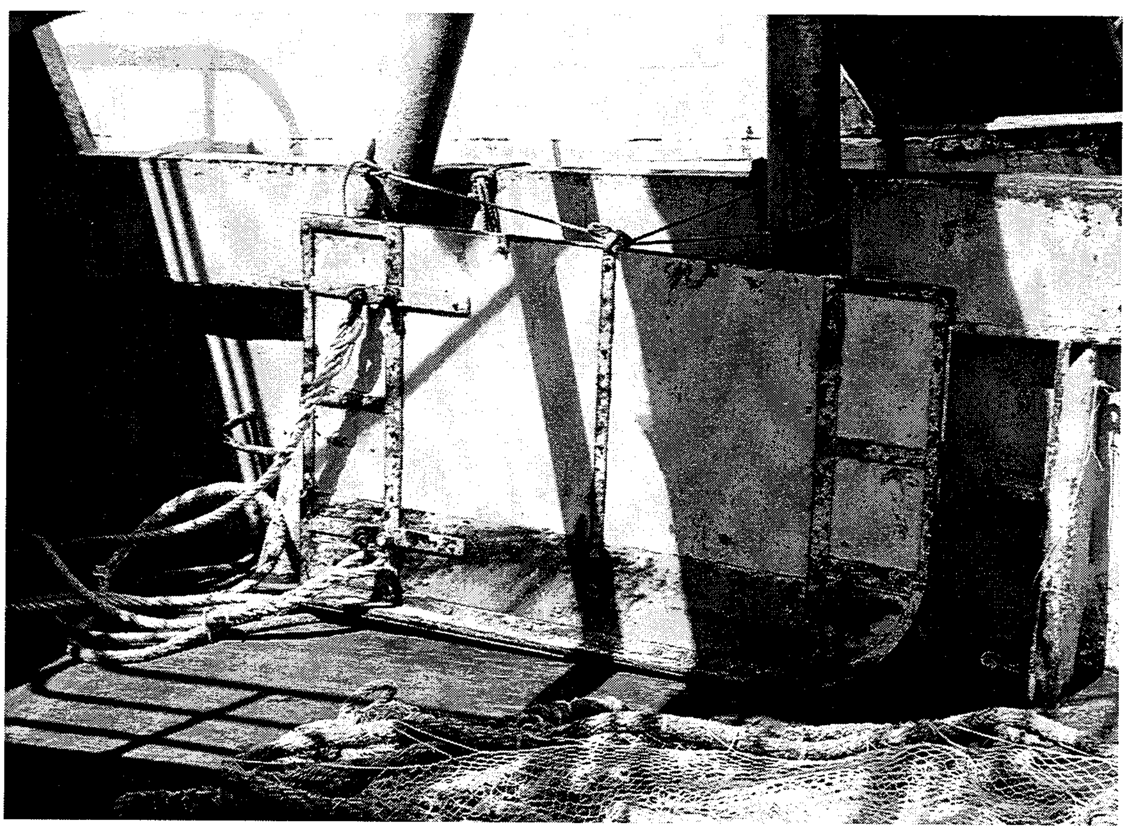


Figure B-4. Steel trawl door.

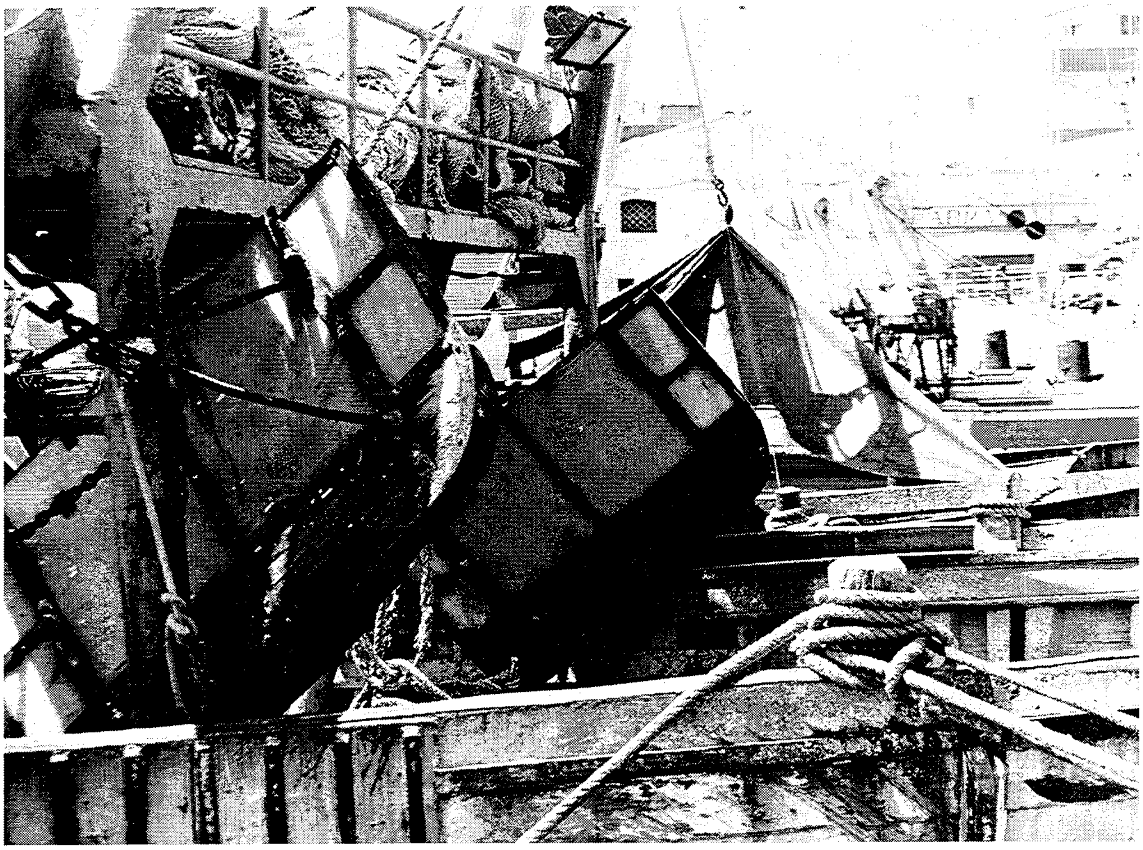


Figure B-5. Wood, fiberglass, and steel trawl doors.

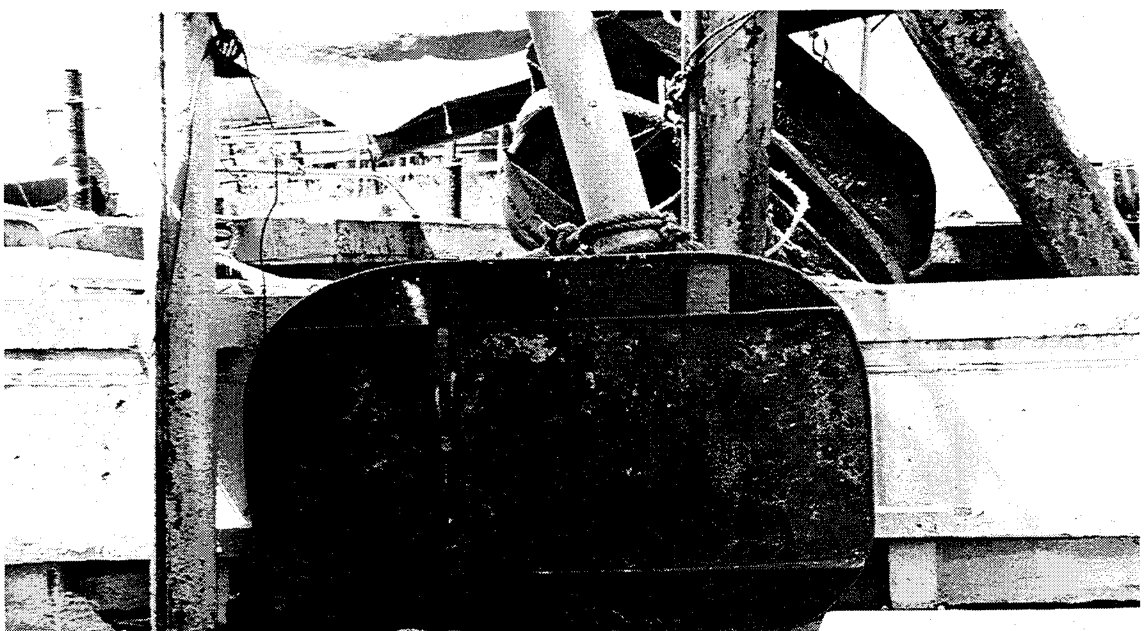


Figure B-6. Oval trawl door.

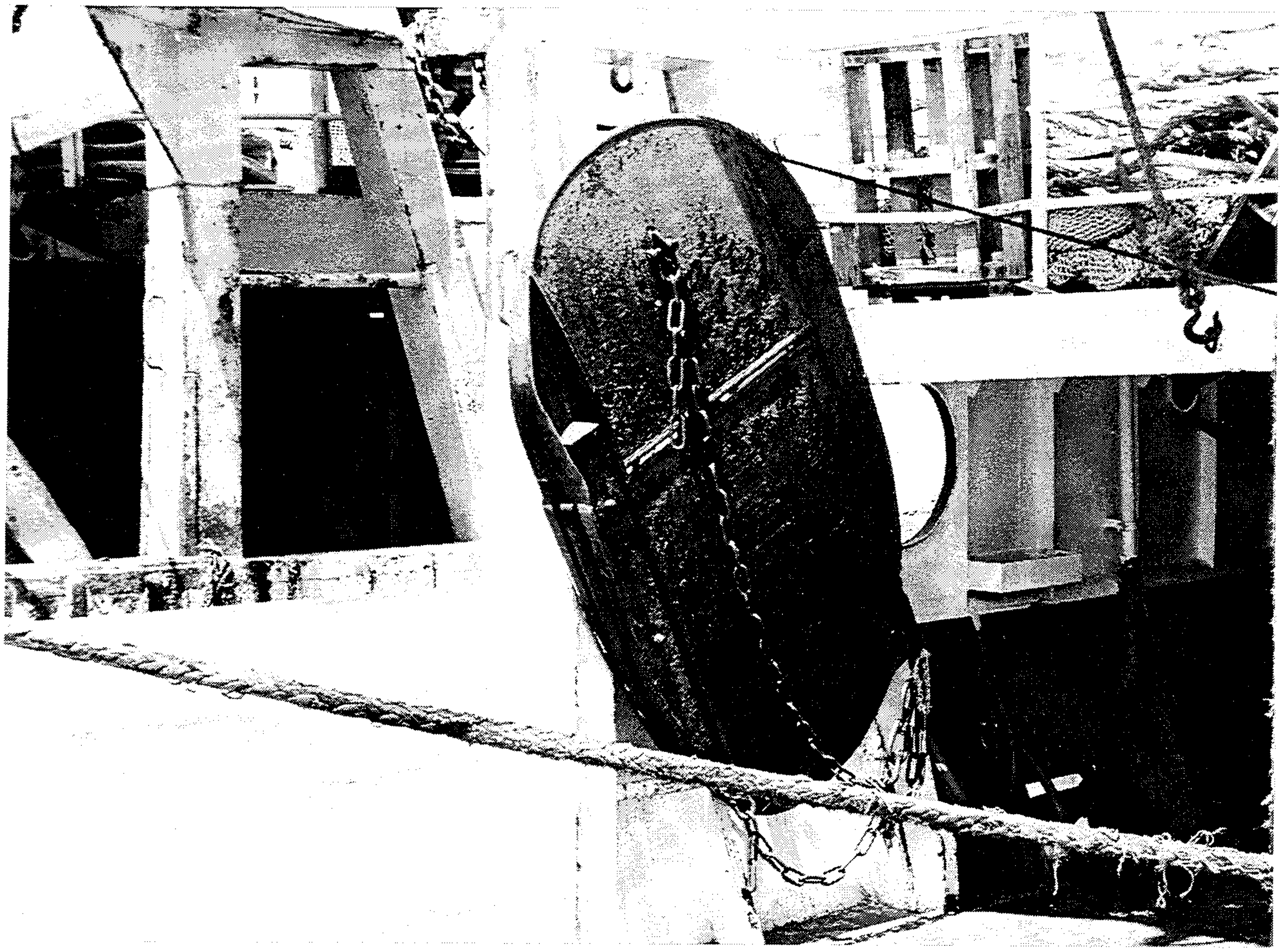


Figure B-7. Oval trawl door.

and brought to the surface, where it was then cut away with bolt cutters. There is no evidence that trawl gear parted the DWT.

2.1 Failure Analysis

A total of 15 trawl incidents were counted during the FDS-D demonstration. Interaction with trawl gear often resulted in severe mechanical damage to the cable. The following types of damage were observed in the samples:

- small, localized nick (1 to 2 inches long)
- small, localized crush (6 to 12 inches long)
- long V-groove in jacket ending with gash to conductor (> 100 feet)
- long cut exposing all cable components (> 100 feet)
- cut with bolt cutters by fishing vessel

It is unknown exactly what part of the trawl gear damaged the cable. The damage appears to have been done by a sharp or heavy object, or both sharp and heavy. This type of damage is more likely to have been produced by an otterboard rather than sweep gear on the footrope. Figure B-8 provides a sketch of typical bottom trawlers observed in the Mediterranean.

Of the 15 trawling-related failures, the cable was faulted electrically in 14 cases and optically in 5 cases. An electrical failure without an optical failure is an indication that the cable was hit and mechanically damaged from the outside in, but not deep enough to fault the fiber. With additional armor, the cable may not have faulted at these exact locations. However, four fault cases were near where the cable had been cut with bolt cutters — this indicates that the damage was associated with an entanglement with the trawl gear, and that the cable was brought to the surface where it was cut away by the fishing vessel. Only burial would have prevented faults such as these. If the cable had been armored, it would have survived at most only 10 of the 15 incidents. Table B-1 provides a summary of the failures.

Table 2. Trawling Fault Summary.

Total Trawling Fault Incidents	Electrical Failure?	Optical Failure?	Near Bitter End?	Survive with additional armor?
15	14	5	4	≤ 10

Most of the cable failures (13 out of 15) occurred on the southern edge of a large, 3,000-square mile, shallow water bank. The cable track was along the edge of the bank over a length of 60 NM. The depth in this area ranges from 300 to 1650 feet, the seafloor composition is mostly mud, and the slope ranges between 0% and 10%. The cable faults were spread out over the entire 60-NM length. Approximately 40 NM of the cable track was on a flat area of the bank in a depth between 300 feet and 600 feet. The remaining 20 NM was on the slope of the bank where the depth ranged between 600 and 1800 feet. Of

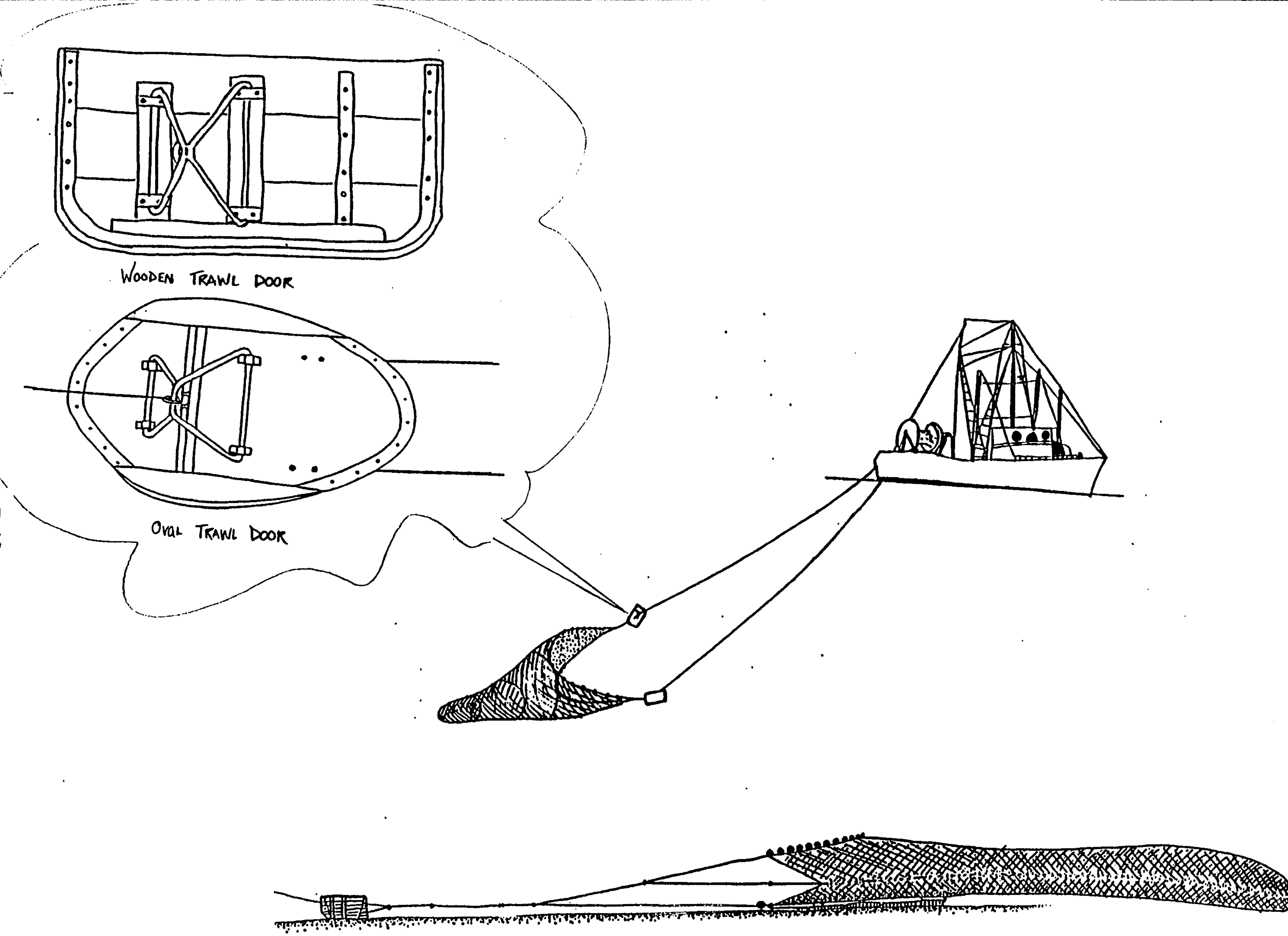


FIGURE B-8. TYPICAL TRAWLING RIG IN THE MEDITERRANEAN the 13 cable failure incidents, nine occurred on the slopes on either side of the bank in the depths between 600 and 1800 feet. The failure incident density versus depth was one incident per 2.22 NM between 600 and 1,800 feet deep, and one incident per 9.5 NM between 300 and 600 feet deep. Figure B-9 provides a graph of UWS trunk length versus depth.

Trawl hits were more concentrated on the slopes on either side of the bank. Along slopes trawlers tend to follow the contour lines to stay in a constant depth and avoid having to adjust trawling gear. In flat areas, the trawling pattern is assumed to be random. A cable laid up a slope is perpindicular or askew to the contour and more likely to be crossed by a trawler than in a flat area. Three theories for the higher fault density between 600 and 1,800 feet deep are:

1) the slope is more heavily fished
2) a greater probability of cable suspensions occur on a slope
3) trawl patterns along a slope tend to follow contours, and thus a cable laid up a slope (perpendicular to contours) is more likely to be crossed than a cable in a flat area.

2.2 Trawler Observations

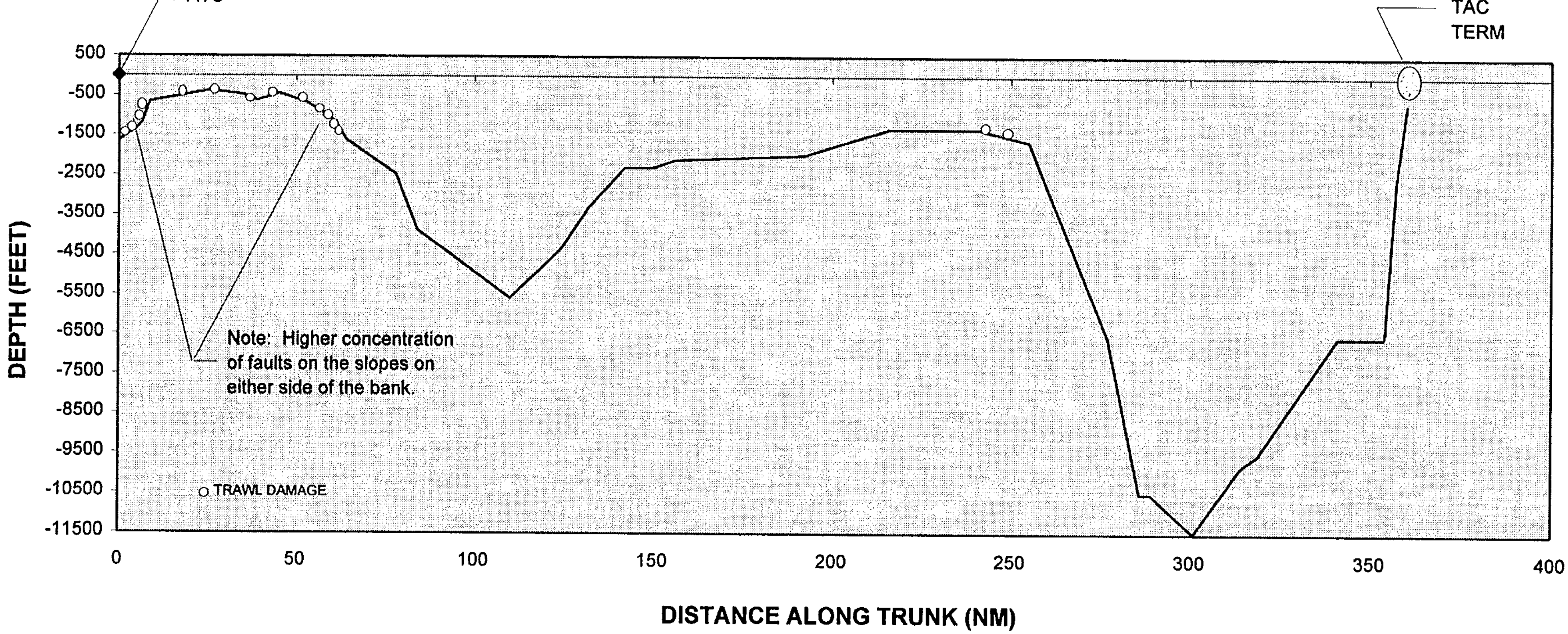
Trawlers were observed working near the cable track during all phases of the exercise — installation, operations, and recovery. A total of 35 trawlers were documented operating near the cable track over a period of 43 days of operations along the bank. Documented observations were recorded on message traffic, ship's logs, project personnel logs and notes. Table B-2 provides a summary of trawler observations.

Table B-2. Trawler Observations (documented)

Operations Phase	No. of Observations
Installation/repair	12 trawler-days in 10 days on-site
ATS1	9 trawler-days in 8 days on-site
ATS2	4 trawler-days in 9 days on-site
ATS3	5 trawler-days in 13 days on-site
Recovery	5 trawler days in 3 day period on-site

Trawlers ranged in length from 50 to 100 feet. The trawlers were identified visually by the bridge watch or project personnel using binoculars. Trawlers could be identified out to a range of about 5 NM. Beyond that range it was difficult to positively identify a vessel of that size. Although a variety of headings were noted, the predominant course of observed trawlers was perpendicular to the cable track with headings between 0 to 50 degrees, and 180 to 230 degrees. The speed of the trawlers ranged between 2.5 and 4 knots. Figure B-10 provides a chart showing fault locations and trawler headings.

FIGURE B-9. DISTANCE ALONG TRUNK VERSUS DEPTH



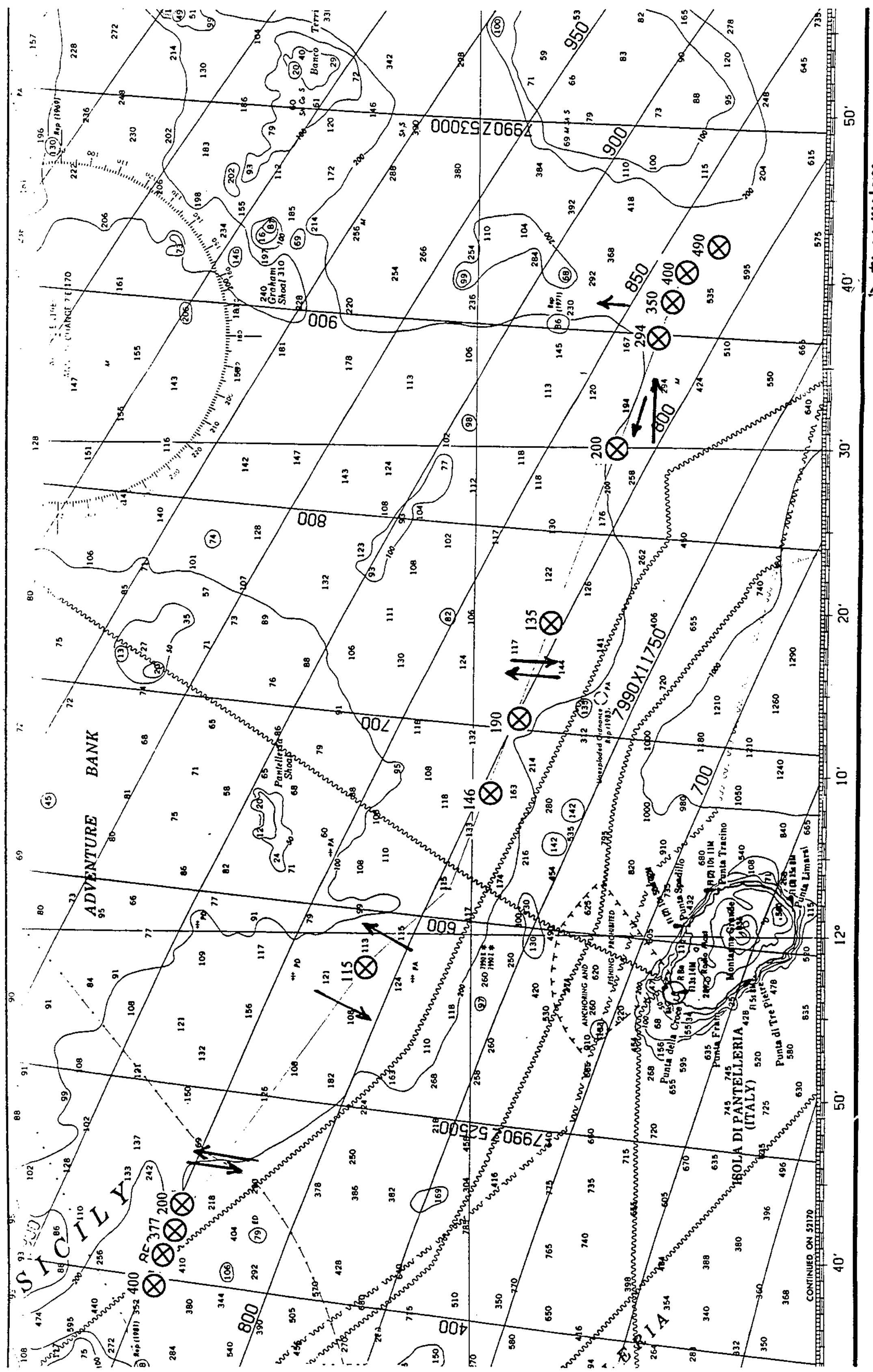


FIGURE B-10. TRAWLING FAULT LOCATIONS

At the end of operations, NFESC visited a small local port located 40 NM from the bank edge. An estimated 500 to 1,000 bottom trawlers were in-port on that day similar to the ones observed at sea. A local fisherman reported that approximately 10% of the fishing fleet from the port worked the bank (50 to 100 fishing boats). Of course there are other fishing ports within range of the bank. The conclusion is that the area is very heavily fished.

Total trawler activity along the entire 60-NM length of the cable track across the bank can be estimated using two different approaches:

1) Visual observations of trawlers while at the site
2) Based on the survey taken at a nearby fishing port

2.3 Estimated Trawling Activity Based on Visual Observations

Visual observations of trawling activity were used as a basis for estimating total trawling activity on the banks. From visual observations, the trawler frequency along any given 10-NM cable length can be averaged at 1 trawler every 1.25 days. For a 60-NM section of cable there are 4.8 trawlers per day operating near the cable track. If half the trawlers ride parallel to the cable and never cross it, and the other half run perpendicular and make 4 passes per day, the cable is passed 9.6 times per day by trawl gear (that is 9.6/60 passes per NM per day, or an average of 1 pass every 6.25 days on every NM of cable). Over a 90-day period, the cable was crossed by trawl gear an estimated 864 times.

2.4 Estimated Trawling Activity Based on Local Survey

Based on the survey from the fishing port, an estimated 50 to 100 trawlers work the bank on a regular basis. If trawl speed averages 3.25 knots, and the distance between successive passes is 0.25 NM, a typical trawler can cover an area of 20 square miles in a 24-hour period. Fifty to one hundred trawlers cover an area of 1,000 to 2,000 square miles per day. A 3,000-square mile bank can be covered in 1.5 to 3 days. Subtracting time to off-load fish, transits to and from port, and down time, it is assumed the average trawler only works three 24-hour days per week. Based on that figure, the bank is completely fished 1 to 2 times per week. If the bank is blocked into 20-square mile plots, the cable track will pass through approximately 15 plots. Depending on the trawl pattern with respect to the orientation of the cable lay, the cable track will be crossed between 1 and 8 times per plot. If it is assumed that half the trawlers run parallel with the cable and the other half run perpendicular, the cable will be crossed, on the average, 4.5 times per plot along the cable track. If the plots are fished 1 to 2 times per week, and there are 15 plots covering the cable, the cable will be crossed by trawl gear an estimated 870 to 1,740 times in a 90-day period. The estimates based on the survey are remarkably close to estimates based on visual observations.

Thirteen cable failures occurred over 90 days in one 60 NM stretch. The MTBF in this area was 6.9 days. The total number of passes made by trawl gear was estimated between 870 and 1740. On the average, the cable faulted every 1/67 passes to 1/134 passes along this bank (67 to 134 trawl passes per fault).

3.0 CONCLUSION

Trawling damage was isolated to areas around shallow water banks. Interaction with trawlers resulted in severe mechanical damage to the cable. In four separate incidents the DWT cable was hooked by fishing gear and brought to the surface where it was cut away with bolt cutters. Failure was unavoidable in these locations without burial. Alternate routing options were available that could have routed the trunk through deeper water. An alternate route may have prevented trawling damage. However, the DWT was damaged by trawlers in waters as deep as 1,900 feet, and completely avoiding depths of less than that was not possible without relocating the field. Segments of the FDS-D field were in depths less than 1,900 feet, but were not affected by trawling.

For cable routed across this bank, the estimated number of passes by trawl gear is between 0.167 to 0.333 passes per day per NM, and the MTBF per NM is between 401 days and 802 days. When a longer segment of cable is considered, the MTBF drops off very quickly. In the case of FDS-D, where 60 NM was routed through a trawling hazard area, the MTBF is:

$$\frac{1}{MTBF} = \frac{1}{MTBF_1} + \frac{1}{MTBF_2} + \ldots \ldots \frac{1}{MTBF_{60}}; \qquad \text{MTBF} = 6.7 \text{ DAYS}$$

Appendix C

FDS-D CL 106-107 FAULT ANALYSIS

FDS-D1 CL106-107 Fault Analysis

S. Kelly

Ocean Engineering Division
NFESC

02 December 1994

ABSTRACT

FOCAL-P was used to analyze a cable deployment that resulted in a cable failure after the deployment. FOCAL-P is a computer program that uses a lumped parameter method to analyze the deployment of small diameter cables in the ocean environment. A number of analyses were conducted: a baseline case with a steady-state deployment, a case with current, and a case with a varying ship speed while maintaining a constant payout rate. Although the model was unable to replicate what may have happened during the deployment, it provided insight as to potential mechanisms that may have caused the cable failure. Adverse currents and/or a large change in ship speed versus payout rate may have improperly deployed the cable and contributed to its failure. Environmental conditions must be well understood and monitored. This must be coupled with careful monitoring of deployment mechanisms to insure installed slack is maintained in the cable.

TABLE OF CONTENTS

<u>LISTS OF TABLES AND FIGURES</u>

1.0 INTRODUCTION.

The Ocean Engineering Division was asked to assist in analyzing a cable failure on the seafloor, particularly, how the deployment may have contributed to the failure. The cable deployment project is entitled Fixed Distributed Systems-Deployable 1 (FDS-D1) and consists of a deployed cable making a series of s-turns approximately 120 miles long (Figure 1). The cable failed in the midst of one of the s-turns; therefore, the analysis was focused on that particular s-turn, consisting of approximately 14 miles of cable (Figure 2). This section of the deployment had a cable-to-cable junction (CCJ) that was included in the analysis.

FOCAL-P, a software package that models cable deployment in the ocean, was used to conduct the analysis. FOCAL-P is a computer program that uses a lumped parameter method to analyze the deployment of small diameter cables in the ocean environment. FOCAL-P was developed by PMB Engineering, Incorporated under the Tether Development Project at the Naval Facilities Engineering Service Center. A verification of FOCAL-P was conducted to gain confidence in the results being obtained from FOCAL-P executions. Comparisons between FOCAL-P and SEADYN (another cable deployment model that has been validated) and FOCAL-P and field data demonstrated that FOCAL-P provides correct quantitative results, such as cable tensions.

FOCAL-P's capabilities include explicit and implicit numerical solution techniques, several possible initial conditions for deployed cables, time-varying three-dimensional currents, bottom topography consisting of a three-dimensional seafloor or a single sloping planar seafloor, the deployment of point masses attached to a cable, and both time-varying tension and time-varying rate controlled cable payout.

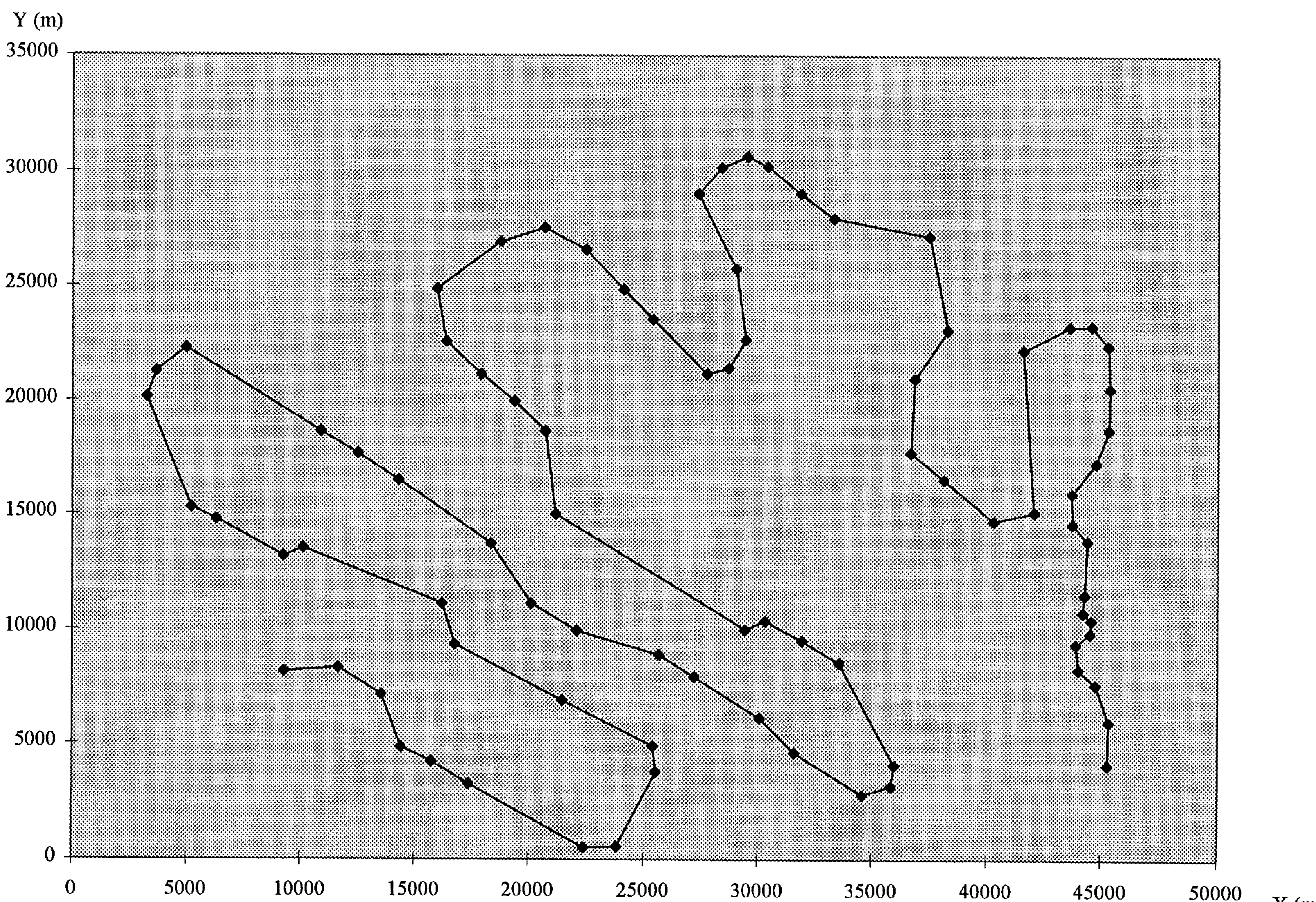
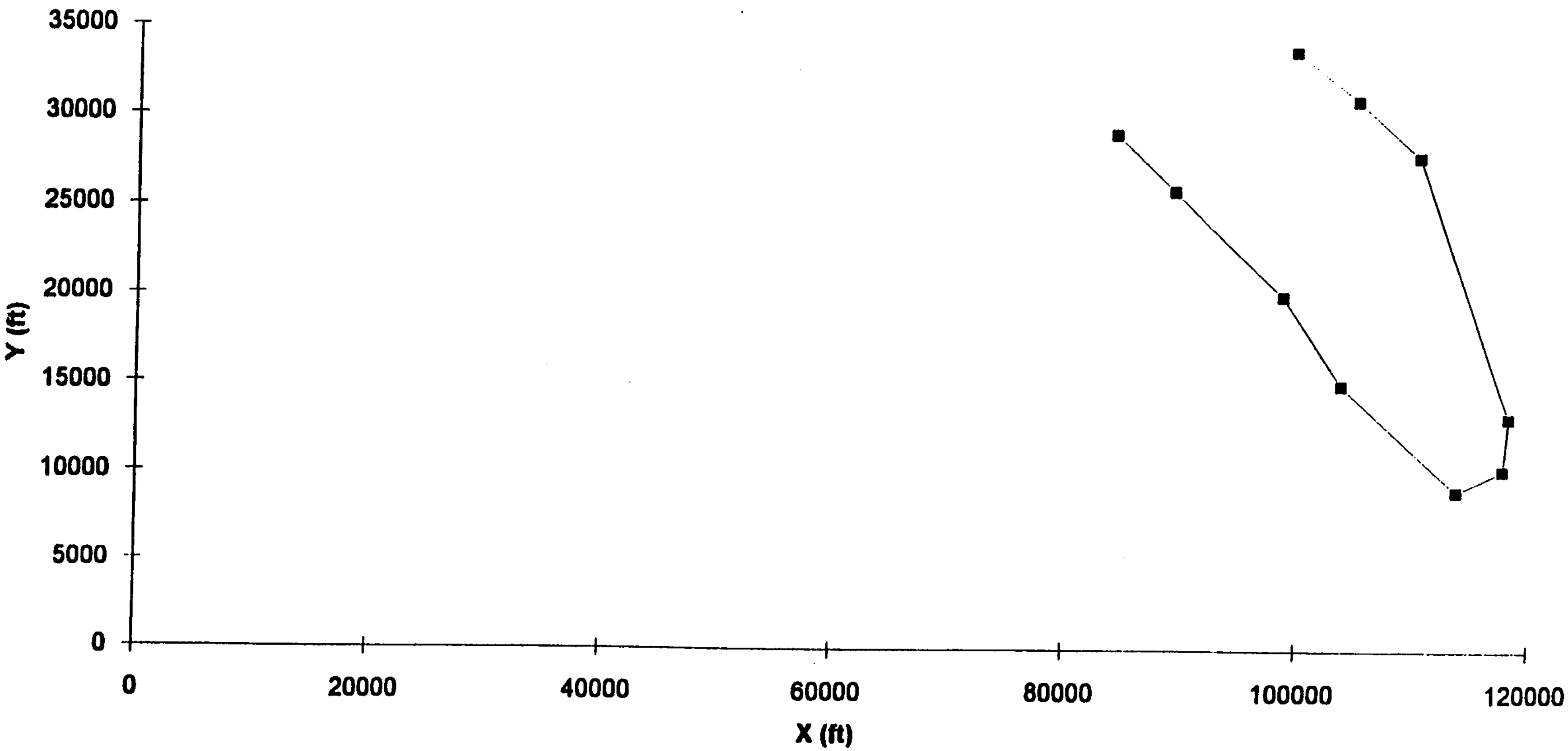


FIGURE 1. FDS-D DWT CABLE TRACK

Figure 2. Modeled Portion of FDS DWT Track



2.0 MODELING AND RESULTS.

2.1 Model Input. The modeled portion of the deployment consists of a 14 mile section of cable that passes through a 180 degree turn. Four different scenarios were examined for this cable track. Table 1 summarizes the analyses conducted.

TABLE 1. Analyses Conducted.

Analysis	Characteristics
1	3.5 knot ship speed, 2% slack payout rate
2	3.5 knot ship speed, 10% slack payout rate
3	3.5 knot ship speed, 2% slack payout rate ship speed increasing to 4 knots after turn with no increase in payout rate
4	3.5 knot ship speed, 2% slack payout rate nominal current: 1 knot @ surface, 1/4 knot at seafloor, 315 degrees

The other characteristics of the model that remained constant for the different analyses were as follows:

TABLE 2. Model Input Parameters

Model Input Parameter	Value
analysis duration	12140 s
analysis time step	0.01
initial number of elements	20
spare nodes	5
cable diameter	0.525 in
cable specific gravity	2.63
Young's Modulus	2.1 x 10^6 psi
No. of strength members	1
strength member diameter	0.525
water depth	1140 ft
attached mass (CCJ) @ 32553 ft along cable	

2.2 Input Parameters Discussed. The Young's Modulus was a nominal value that was selected based on the fact that it was appropriate for other small diameter cables. Ideally, a modulus is obtained from the manufacturer; the modulus, however, was unavailable for this cable. The cable is described in the model as being comprised of one strength member for simplicity and to account for the jacketing surrounding the fiber optic cable and the strength members. The analysis duration is the time that is necessary to complete the model's track at a ship speed of 3.5 knots. The time step is a calculated value. Spare nodes refers to the number of nodes on the seafloor that the user wants to keep in the analysis. These nodes are kept in the analysis to confirm if any cable is lifted off the seafloor after having already touched down. The other model parameters are self explanatory. Consult Reference 1 for more information on any of the model input parameters.

2.3 Results. Analyses 1 and 2 were similar to each other; more slack was payed-out in analysis 2. Both analyses exhibited normal behavior. Analysis 1 had cable tensions linearly decreasing from approximately 150 lbs at the surface to 0 lbs at the seafloor. The second-to-last element at the seafloor end of the cable carried approximately 7 lbs of tension. The CCJ deployment did not affect the results. Analysis 2 did not offer any new information.

In analysis 3, an effort was made to simulate the ship traveling with a tidal current after making the turn. Tidal currents are known to exist in the deployment area although no data is available on the tides or current during the deployment. The ship velocity was increased to 4 knots after making the turn, and the payout rate was left unchanged. This would simulate the deployment crew not responding quickly to a change in the environment.

The deployed slack in the model went negative, reaching a steady-state of approximately -10%. The tensions built in the cable, the touchdown point stopped advancing, the length of cable in the water column increased, and, eventually, 2 elements were picked-up from the seafloor. The deployed cable did not remain underneath the ship's track; rather it took a straight line path on the inside of the turns. FOCAL-P does not have a seafloor interaction model, therefore cable is not allowed to drag across the seafloor and this was not displayed in the results. Nevertheless, a safe assumption would be that the cable would get pulled across the seafloor under tensions of this magnitude; in this case, pulled towards the inside of the turn. The benefit of this type of model is that it simulates the cable being snagged (after already being dragged) and the subsequent build-up of tensions that would jeopardize the cable's integrity.

In analysis 4, an arbitrary current was selected. The current was 1 knot at the surface, decreasing linearly to 1/4 knot at the seafloor. The direction was 315 degrees. Note that although the previous analysis was intended to imitate the ship riding on a current, it differs from this analysis because the deployed slack was maintained in this analysis. Looking at a plan view of the plotted deployment shows the cable being pushed in the direction of the current as it falls to the seafloor, as would be expected. No adverse tensions occur in the cable. Figures 3, 4, and 5 provide snapshots of FOCAL-P simulations for analysis 1 and 3.

3.0 CONCLUSION.

The model's results are only as accurate as the input. The input was most likely oversimplified in relation to the real world. If the cable deployment had been conducted as modeled in analyses 1 and 2, the cable would have fallen to the seafloor underneath the ship's track with no installed tension. If a current existed that was not accounted for in the deployment plan or accommodated for during deployment, then some unforeseen and unknown occurrence may have jeopardized the cable. Furthermore, if an operator error occurred and went uncorrected for some time, the cable may have also been jeopardized. A combination of these events would only potentially magnify the problem. The analysis will not match the real results unless we know what unwanted events occurred. However, with the model we can attempt to approximate a real event that may have occurred to provide us with insight.

4.0 RECOMMENDATIONS.

More attention should be given to the currents in a potential deployment area during the planning stages of the deployment. Deployment parameters and environmental conditions should be carefully monitored during deployment.

5.0 REFERENCES.

1. PMB Engineering, 1990, "TRAC - Time Domain Response Analysis of Cables (FOCAL-P) User's Manual," San Francisco, CA.

2. Anderson, G. and Anderson, P., 1986, "The UNIX C Shell Field Guide," Prentice-Hall, Englewood Cliffs, NJ.

3. O'Reilly & Associates, Inc., 1990, "UNIX for FORTRAN Programmers," Sebastopol, CA.

FIGURE 3. **Plan View of Analysis 1. Snaphots of Deployed Cable at 500 sec Increments.**

Plot times: 0.0 sec. through 12126.0 sec. at 500.0 sec. increments
Analysis Name: /home/conan2/skell/FDS/fds2.pst

TRAC-III Postprocessor
Thu Dec 22 09:47:44 1994

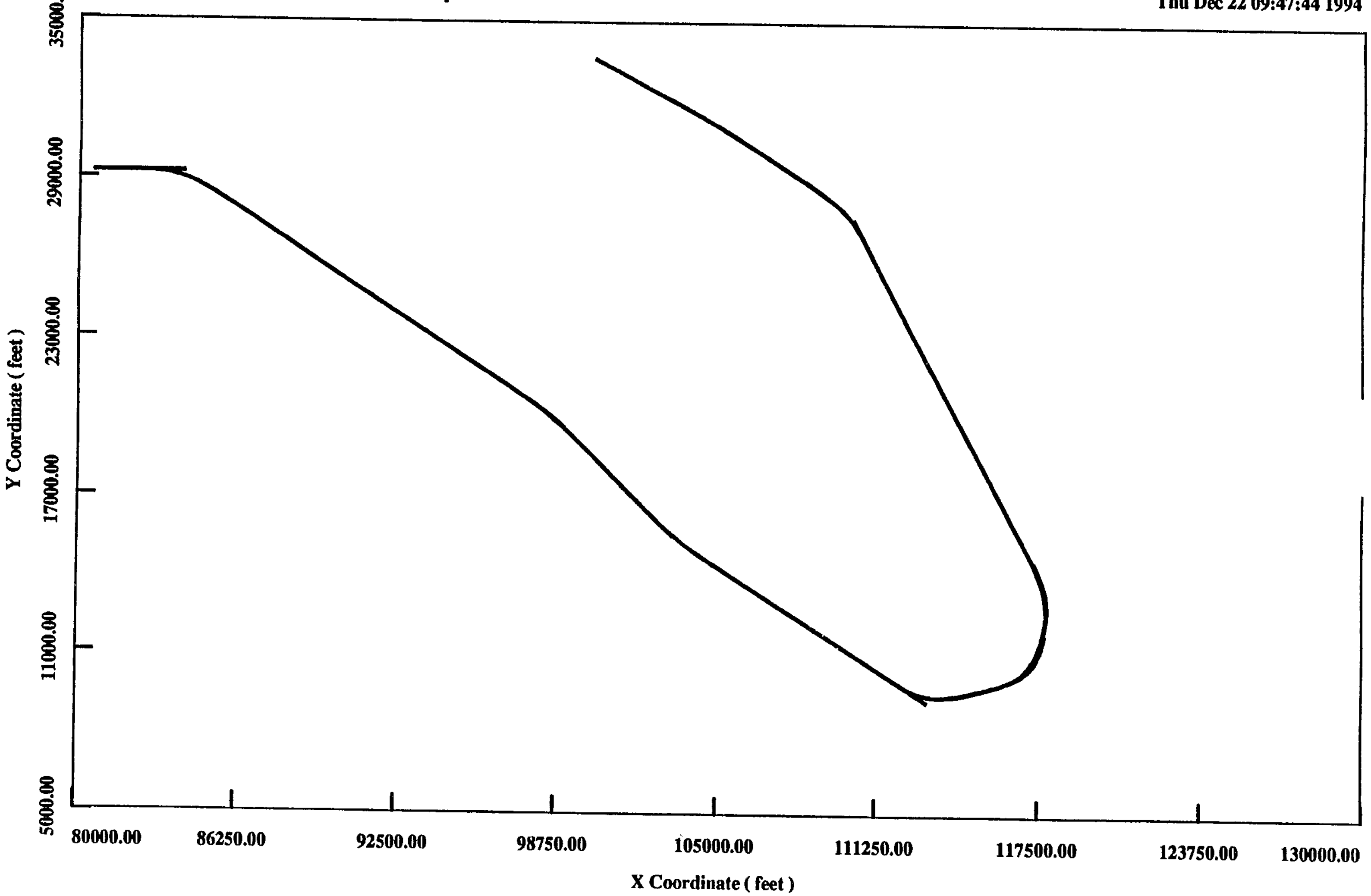


FIGURE 4. **Elevation View of Analysis 1. Snaphots of Deployed Cable at 200 sec Increments.**

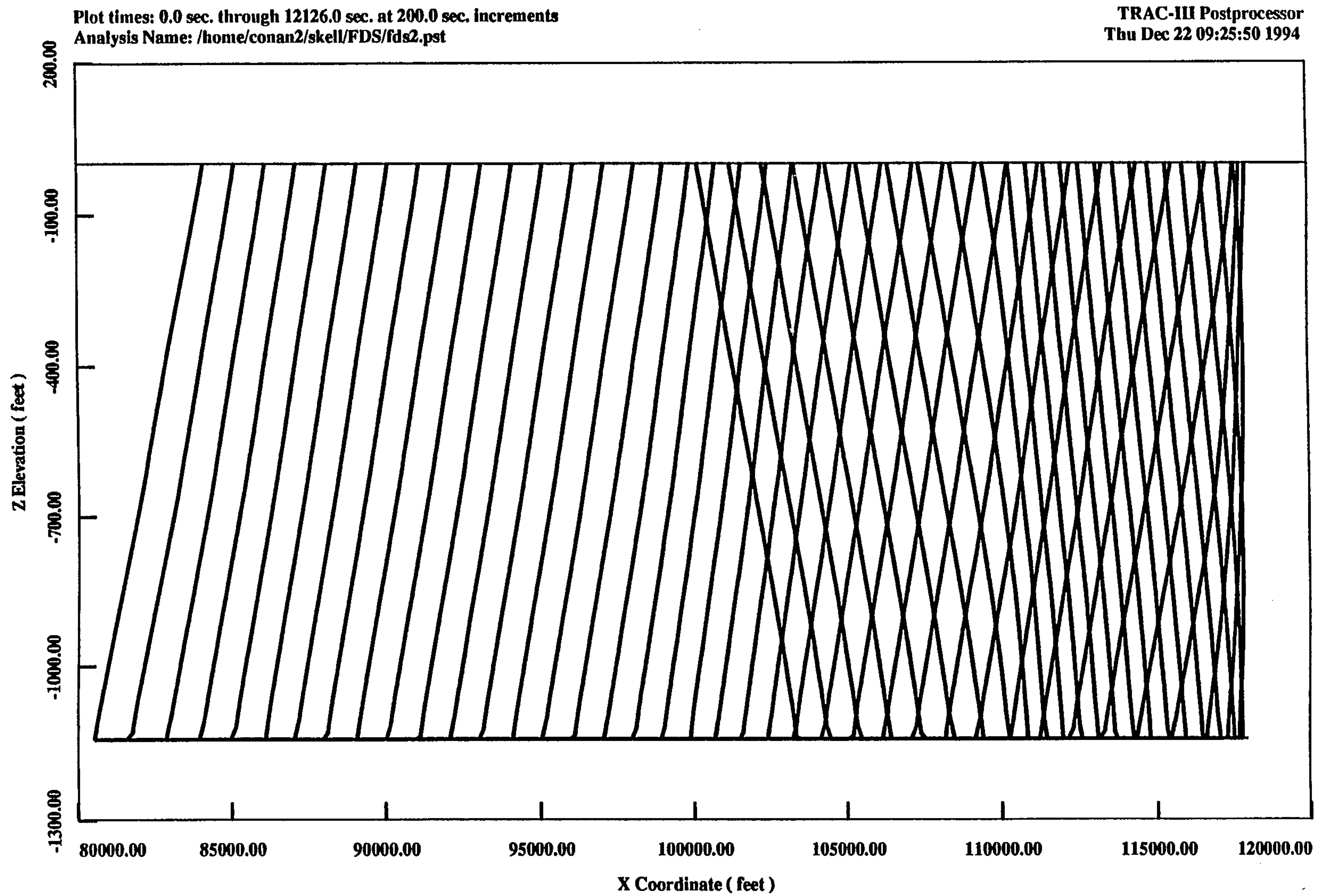
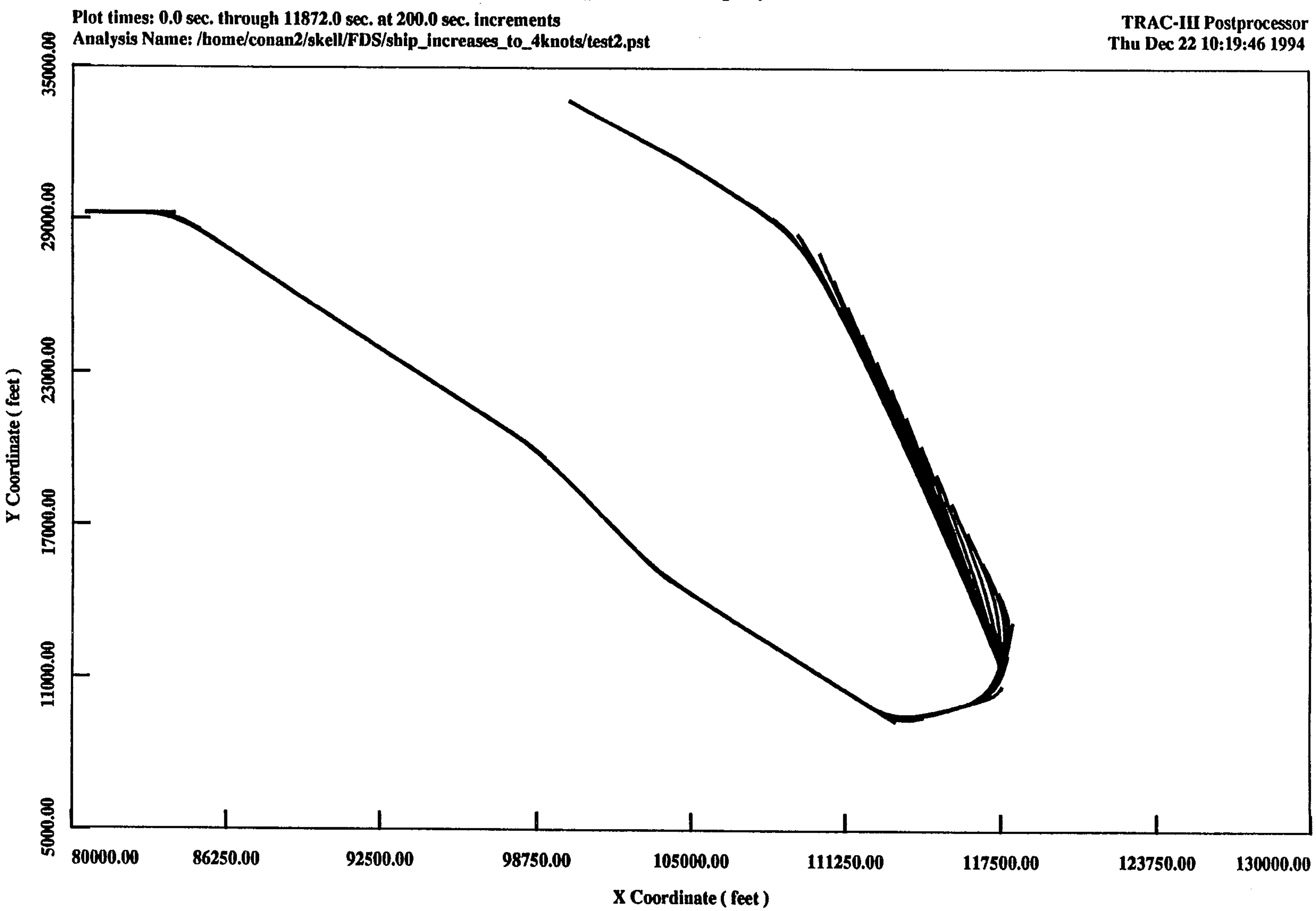


FIGURE 5. **Plan View of Analysis 3. Snapshots of Deployed Cable at 200 sec Increments.**



Appendix D

FDS-D DWT STEEL TAPE CORROSION

11/22/94

MEMORANDUM

FROM: C52/Jenkins
TO: C52/Warren

SUBJ: FDS DWT STEEL TAPE CORROSION

1. In many of the autopsies performed on FDS Deepwater Trunk (DWT) cable, the steel tape was significantly corroded at areas of damage to the outer jacket of the cable. The area of tape that was corroded (often several square centimeters) was greater than the area of jacket damage - the corrosion had undercut the jacket. There were few, if any steel corrosion products present between the jacket and the dielectric. This corrosion was not considered normal because of (1) the rapidity of attack - a 0.007" steel tape should last a minimum of six months before perforation even if freely exposed to seawater on both sides - and (2) if freely corroding, there should be copious amounts of corrosion products trapped between the dielectric and shield - corrosion products normally occupy 4 to 8 times the volume of the steel that is corroded..

2. It was suspected that the corrosion of the steel tape had been accelerated by an applied electrical current. It was calculated that the steel tape should be lost at a rate of 7.5 square centimeters for each ampere-hour of current flow assuming that the entire current flow was through the corrosion of the steel tape according to the reaction $Fe - Fe^{++} + 2e^{-}$. In addition, it was calculated that the resistance to seawater of the tape exposed at a 1 MM square hole should be about 100 ohms, but that this resistance should increase to about 1500 ohms as the corrosion of the tape began to undercut the jacket. In order to validate this suspected mechanism, a test sample was prepared and exposed to seawater under conditions that were felt to represent the conditions that caused the actual corrosion of the FDS-D cables that were autopsied.

3. The sample was prepared by intentionally damaging the jacket of a 3' long sample of FDS DWT cable. The damage exposed approximately 1 square mm of steel tape. The sample was then exposed to fresh flowing seawater in a laboratory tank. A copper cathode was placed in the tank and a connection was made to an exposed portion of the steel tape that was not immersed in the seawater. A DC power supply was used to apply a potential between the copper cathode and the steel tape.

4. Initially, a voltage of 15 V was applied resulting in a current flow of approximately 100 MA. This corresponds roughly with the calculated resistance of the boldly exposed steel tape (100 ohms calculated Vs 150 ohms measured). Gassing was noted at the surface of the steel tape immediately following the application of the current. After approximately 2 hours, the boldly exposed steel tape had been corroded away and the

circuit resistance increased causing the current to fall off with a constant applied voltage. The applied voltage was increased to 50 V resulting in an initial current flow of 15 MA. At an applied voltage of 50V, the current fluctuated between 10 MA and 3 MA. The equivalent circuit resistance was, therefore, between 500 and 1667 ohms which compares favorably with the calculated resistance of 1500 ohms for undercut shield. Over a period of 6 days, a total of approximately 1.25 Ampere-hours of current flowed in the circuit.

5. At the end of 6 days of exposure with a total current flow of 1.25 AH, the sample was removed from the seawater tank and autopsied. There was only a light staining of rust on the outer surface of the jacket adjacent to the point of damage. The steel tape was not visible at the point of damage. There was a very noticeable odor of chlorine at the point of jacket damage The jacket was removed revealing an elliptical area where the steel tape had corroded away, but there were only traces of yellow corrosion products under the jacket. The area of damage was approximately 3 cm X 1.25 cm (area equal to 2.95 square cm). This is substantially less than the calculated area of 11.25 square cm based upon 7.5 square cm per ampere hour. The difference between the calculated area based upon the entire current being used to oxidize the iron tape and the actual area corroded can be attributed to current being used to complete other electrochemical reactions such as the oxidation of chloride ion to form chlorine gas and the oxidation of hydroxyl ions to form oxygen gas and hydrogen ions.

6. This test reproduced the salient features of the corrosion that occurred on the autopsied samples from the FDS-D test, namely greatly accelerated tape corrosion, undercutting the jacket and lack of corrosion products between the jacket and dielectric. Thus, the corrosion of the steel tape experienced during the FDS-D tests can be attributed to an electrical current flow (positive charge flow) from the tape to the seawater.

7. A blackening was noted on the dielectric at the point of initial jacket damage and discoloration of the copper conductor covering the strength member in the general vicinity of tape corrosion was noted. The dielectric was removed and the stain on the copper was confirmed. A strong odor of chlorine was noted upon removal of the dielectric. Polyethylene is known to be susceptible to deterioration by chlorine. It is likely that damage by chlorine generated during electrolysis of seawater will damage the dielectric significantly if cable faults resulting in tape corrosion occur.

8. Several possible causes of the current flow that can cause tape corrosion have been proposed by Ted Louzon of AT&T. In all of these proposed cases, damage to the cable exposing the powered center conductor is required to cause the damage. In all of these cases, calcareous deposits should have been formed on other system components such as the cable-cable junction housings. Inspection of these housings may be required to verify these causes of tape corrosion in the FDS-D tests.

9. Several laboratory tests have been proposed to validate the possible causes of the steel tape corrosion proposed by Ted Louzon.

10. Please let me know if I can initiate these laboratory tests and if it is possible to inspect the hardware from the FDS-D test to validate or refute the several possible scenarios for the application of current to the tape.

James F. Jenkins

Appendix E

FDS-D RECOVERY QUICK LOOK REPORT

9/27/94

MEMORANDUM

From: NFESC/Warren
To: File

Subject: FDS-D RECOVERY QUICK LOOK REPORT

Encl: (1) NFESC Daily Log

1. NFESC was tasked by SPAWAR to ride the FDS-D recovery ship as an observer and document the recovery. The primary purpose was to document failures resulting from damage caused by fishing trawlers. The task description was as follows:

- Keep a log of events, particularly hardware faults and damage. Report highlights to the Program Manager via normal daily SitReps.
- Take photographs of damaged sections. Indicate time and location and probable cause on the photograph.
- Cut out samples of damaged sections of cable and hand-carry to NFESC for autopsy.
- Document environmental conditions at site (depth, slope, bottom conditions, current, wind, etc..)
- Interview cable engineers to ascertain if trawling damage was primary or secondary cause of failure, or if damage was induced some other way (i.e., during recovery).

2. The UWS was successfully recovered after being on the seafloor for 120 days. The recovery operation began on 17 August and was completed 8 September 1994. All major UWS components and 500 NM of DWT were recovered. A small quantity of DWT was not recoverable either because of close proximity to active commercial cables or due to time constraints on the recovery ship.

3. Faults that were encountered during the recovery have been put in two categories: in situ faults and recovery induced faults. In situ faults are faults that occurred after the system was in place on the seafloor, either from trawling or some other threat. Recovery induced faults are faults where the cable was damaged as it was recovered from the seafloor, either by snagging on seafloor obstacles (rock or coral) or entanglement with long-line fishing gear.

The UWS field had two in situ faults at the start of the recovery. One fault occurred between CL106 and CL107. This fault appears to have been caused by abrasion/corrosion/cold flow with debris on the seafloor. The other fault was an intermittent fault of unknown origin between CL101 and CL102 that was not isolated. The field did not get damaged by trawlers. The trunk was damaged by fishing trawlers in 15 separate incidents. Six in situ fault samples will be autopsied by NFESC.

The DWT cable was damaged 16 times during recovery operations when it hung up on seafloor rock or coral. In addition, the cable was also damaged five times during recovery when it became entangled with long-line fishing gear. A total of 23 long-line rigs were encountered.

Fault Summary:

	FAULT AREA	
FAULT TYPE	FIELD	TRUNK
IN SITU		
OTHER IN SITU	2	0
TRAWLING	0	15
RECOVERY INDUCED		
ABRASION	13	3
LONG-LINE	0	5

4. The recovery speed averaged 1.1 knots and the maximum recovery speed was 1.5 knots. Weather conditions were very good for the majority of the recovery and ranged from calm to sea state 3/4.

5. The AT&T Cable Operations Team and ship's crew did an outstanding job on the FDS-D UWS recovery.

NFESC Daily Log

8/16 Tuesday

- A pre-cruise meeting was held in-port at Augusta. The EIC discussed the recovery method. The field will be recovered first and the trunk last. Both the field and trunk will be recovered starting from the shoreward end. Damaged sections will be bighted out. The top and bottom of each cable section will be numbered and color coded. All splice work will be done later. Most of the splicing equipment has been removed from the ship.
- 1400h The ship departed for the field site.

8/17 Wednesday

- 1030h Ship arrived at the start of the field and began recovery of temporary mooring left by T-ship.
- 1805h Cable grappled (DG1) and onboard ship. Depth 186 fathoms. Haul in junk cable left by T-ship for grappling- total of 0.5 NM. Going to next CCJ prior to testing appr. 3.2 NM shoreward of CL116.
- 2135h CCJ onboard. This CCJ was the final splice from fault 5 made on 4 June. Cable came up tangled and wrapped in tight knots. Cable was probably not in this condition on the seafloor and should be faulted due to tight radius bends. The knots were probably set as a result of recovery tension.
- 2400h Cable cut and tested good to CL107. 120V, 253 mA.
- Wind 190/8 kt; Sea 190/2'; Swell 180/3'

8/18 Thursday

- 0330h Cable faulted during recovery. Tension spikes up to 4.5K recorded.
- 0646h Voltage arc in cable tank. Crew reported smoke (steam?).
- 0707h Cable hung up and parted 1.851 NM seaward of CCJ1013-1. Fault corresponds with tension spike of 4500 lbs.
- 1300h Grappling run DG2 completed and cable onboard. Depth of 232 fathoms. DG2 Grappling operation took 5 hours. Continued delays will force us to alter plans. The EIC has suggested only going for the clusters if we run out of time.
- Heavy localized damage to conductor due to abrasion with seafloor.
- 1820h Cable parted a second time. Grapple drive (DG3) on cable 1 mile up the track. Grapnel got hung up on seafloor, but was eventually freed and brought to surface, but did not hook the cable. Cable eventually recovered at 0130 on 8/19 on DG4 in a depth of 240 fathoms.
- Wind 310/25 kt; Sea340/4'; Swell 285/6'

8/19 Friday

- Continuing to experience hostile seafloor. Grappled cable after first break at 0.052 NM seaward of CCJ 1013-2. Parted cable for second time during recovery at 0.754 NM seaward of CCJ 1013-2. Grappled cable seaward of CCJ 1013-3. Cable/system tested good seaward to CL107. Recovered CS1013-3 and CL115 in good condition. 0.807 NM seaward of CCJ 1014-1 began experiencing tension spikes and abrasion damage exposing the power conductor. Experienced repeated damage over the next two NM.
- Delays have resulted following cable faults because of time to cut and prepare cable end and retest seaward, only to find next cable fault a short distance away. Due to schedule constraints, we intend to concentrate on recovery of clusters. Will salvage as much good DWT seaward of each cluster as possible.
- Hydrophone spacing was measured as requested. CL115 hydrophone distances:
- 2010h Pink coral imbedded in jacket.
- 2153h Cable parted for 3rd time. Fault corresponds to tension spike of 6 Klb. Came to the end of cable and the cable jammed on the fleeting drum. Cable grappled (DG5), brought on board, and the tag end was cut away. Depth was 312 fathoms.
- Wind 320/16 kt; Sea 320/4'; Swell 280/6'

<u>8/20 Saturday</u>

- CL114/CL113 and CL112/CL111 recovered in good condition. CL112 H10 housing slightly damaged during recovery (hydrophone cover split open). CL112 Mux/repeater outer jacket punctured to strength bypass in two places. Three cable faults have occurred in last 24 hours: Cable was parted once and hung on coral twice. A big chunk of coral came to the surface hooked on cable.
- Cable/system testing good to CL107. Prior to recovery of CL112/111, power supply voltage fluctuated between 76 volts and 84 volts and intermittently jumped to 138 volts. Cause of voltage fluctuations is unknown. Fluctuations possibly caused by unstable seawater ground at fault between CL107 and CL106.
- 1430h Tenion spikes up to 6.5 Klb were recorded but cable did not part. Damaged cable section came to surface with red coral imbedded in it.
- Total 44 NM of DWT recovered with 28.5 NM in good condition.
- Wind 15/3 kt; Sea calm ; Swell 270/3'

<u>8/21 Sunday</u>

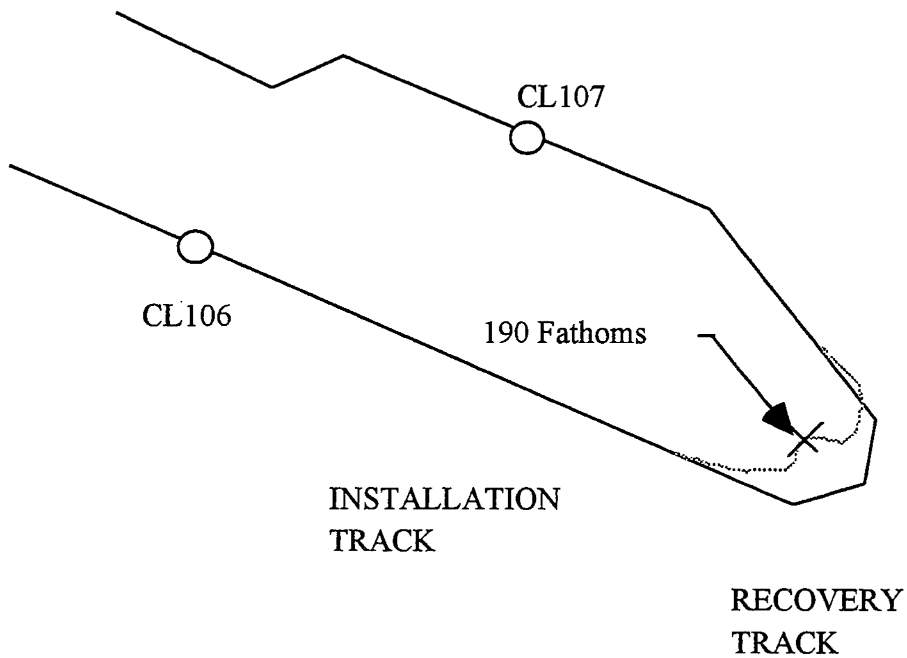
- CL110 and CL109 recovered in good condition. Cable/system testing good to CL107.
- Two cable faults have occurred in last 24 hours. Both faults were caused when cable was snagged by obstacles on seafloor. Tension spikes up to 3000 lb were recorded at fault locations. Faults were caused by cuts and

abrasion exposing the power conductor. First fault occurred 2.8 NM seaward of CL109 while making a turn along cable track. Second fault occurred 4.8 NM seaward of CL109.

- Total of 54 NM of DWT recovered with 38 NM in good condition.
- Recovered 23 NM in last 24 hour period. 60 NM to go in field.
- While working with Homer L. in the test room, we noticed a tone picked up by CL109. Several different frequencies were noticed. Hydrographic survey ship approximately 30 deg. off port bow distance of 2 miles, isosceles triangle to cluster.
- While observing cable operations in the control room, cable was hung on obstacles three times. Twice the cable was faulted but did not part. Once the cable engineer was able to free the cable without faulting it by maneuvering the ship around the obstacle. This was done by first stopping haul in, then moving the ship starboard or port of the track and slowly picking up until the cable popped free.
- Requested one additional day water clearance due to delays.
- Noticed that phones were coming up with half of the BeCu housing shiny and half tarnished, indicating the phones were settling in the seafloor. Mud was inside hardware tapped holes.
- 1658h Cable faulted with a tension spike of 3300 lbs. Ship was making a course change at the time.
- 1942h Cable faulted after tension spikes of 2400 lbs. Long section of bare copper came up at 2100h.
- Wind 135/11 kt; Sea 135/2'; Swell none

<u>8/22 Monday</u>

- CL108, CL107, CL106, and CL105 recovered in good condition. Total of 25 NM of DWT has been recovered in the last 24 hour period and there are 36 NM remaining at this location.
- Hydrophone spacing measurements: CL107 hydrophone H15 to H14 spacing is ___; H14 to H13 spacing is _____.
- Fault between CL107 and CL106, present since 25 July, was discovered to be a cut in the cable caused by a piece of scrap steel. The scrap steel appears to be the remnants of a filter screen from a ship (dimensions: 40"x20"x1"). The filter screen came to the surface wrapped at a hard angle around the cable. Power conductor and strength member were exposed. Fault location is 4.873 NM seaward of CL107/108 and on the inside of a 180 degree turn made during the cable deployment. Depth is approximately 190 fathoms.

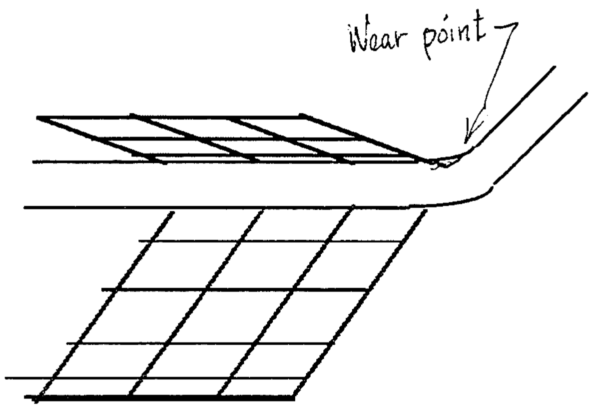


Testing on the seaward side of the fault indicates remaining clusters CL101 through CL105 are operational.

- One fault occurred in the last 24 hours. Fault location 4.554 NM seaward of CL105/106. Tension spike of 3600 lbs was recorded at time of fault. Fault caused by cuts through to power conductor. Fragments of shell or coral were imbedded in cable at fault location.
- CL107/108 recovered. T-2501208 list 3 Fault Location Test Set (Bakerhead) used to isolate fault. Wheatstone bridge applies current to steel tape and ground to ship's hull. When the fault comes out of the water, the circuit should open.
- Received a Hydrolant message indicating the French cable ship Vercors will be conducting underwater cable ops at our location. Coordinates given in the message conform to commercial cable identified as "Ariane". The area where the they will be working crosses our track.
- 1311h A kink in the cable came onboard. Cable inspector believes this kink is one waivered for reel damage. 2-5" radius bends in "s" shape.
- 1703h Tension spiked to 1600 lbs. Only jacket damage.
- 1732h Tension spike to 2000 lbs faulted cable.
- Wind 125/5 kt; Sea 125/2' ; Swell 190/3'

8/23 Tuesday

- CL104, CL103, and CL102 were recovered in good condition. The system tests good to the sea ground. A total of 22 NM of DWT has been recovered in the last 24 hour period and 14 NM remains to be recovered at this location.
- The French cableship Vercors arrived in the area at 1000Z to perform cable operations at coordinates coinciding with "Ariane" commercial cable system. Ariane crosses under the FDS-D cable track at N E. The Vercors arrived at these coordinates simultaneously with us. The bridge watch made contact with Vercors via VHF radio requesting that Vercors give 1/2 mile clearance from the stern. DWT was recovered from this location at **1130Z** just prior to Vercors commencing cable operations.
- One fault occurred in the last 24 hours. The cable became entangled with unknown object(s) that resulted in an extended series of tension spikes exceeding 3000 lbs. The fault location was 3.107 NM seaward of CL103. The tension spikes continued for 3.027 NM until the decision was made to cut the cable and grapple further down the track. The cable was grappled (DG6) 1 NM shoreward of CL102 in 200 fathoms depth. Approximately 3 NM of cable was abandoned. EIC suggested that same source that faulted Ariane possibly fouled our cable.
- There has been no evidence of fishing trawlers or trawling damage to the field area.
- Test room reported CL103 H16 was making an unusual noise. Possible problem.
- Visual analysis of fault between CL107 and CL106:
  - Damage to cable is approximately 1/2 " wide and 1" long.
  - Strength members are exposed.
  - No sign of steel tape. Appears tape has corroded away. Remnants of blue-green coating are present.
  - Copper conductor is ruptured exposing strength wires.
  - Back side of fault area has been worked. Appears to have exceeded elastic limit when bent and buckled upon straightening.
  - Cold flow and tearing to outer jacket.
  - Cable bent at a 30° angle where it contacted filter screen.



- 0720h Kinks in cable came onboard. Cable inspector thinks kinks may be from holding station during repair 1 or installed during recovery when loops in the cable were pulled tight
- Wind 175/15 kt; Sea 175/2' ; Swell 190/3'

8/24 Wednesday

- CL101, UCA, and the sea ground were recovered in good condition. All remaining DWT has been recovered. Operations at this site are complete and we are currently in transit to N E to begin recovering the trunk. Trunk recovery operations will begin 260400Z.
- Three faults occurred while recovering the remaining 14 NM of DWT. Two of the faults were caused by snagging objects on the seafloor. Both of these faults followed tension spikes exceeding 3000 lbs.
- A third fault appeared when CL101 became truncated for no apparent reason. The fault indication occurred at a point 2.078 NM shoreward of the cluster. A damaged section of cable came up 71 fathoms after the fault indication, but the damage looked like it had been done previously during deployment by the wheels on the hauler. This section was cut out and the cable was re-tested, but the fault was still present. No evidence of physical damage was noticed upon further inspection of the cable. The cable was cut again 1 NM shoreward of CL101 and retested, and this time CL101 tested good. The evidence points to failure in the cable section between 1 and 2 NM shoreward of CL101, however there is no observed physical damage to support this. CL101 reportedly became truncated during FDS-D ops in between 2-11 July, but CL101 tested good after 22 August when the fault between CL107 and CL106 was cleared. As a precaution, CL101 should be inspected closely and tested upon return to the U.S.
- 0230h Cable faulted but did not part after tension spikes of 6K.
- Wind light; Sea calm ; Swell 190/2'

8/25 Thursday

Field Recovery Summary:

- Recovery of the FDS-D cluster field was completed at 241500Z. Recovery took 168 hours. Maximum recovery speed was 1.3 knots and average recovery speed was 0.7 knots. Speed was limited by how fast the crew could stow cable in the tanks.
- Total cable recovered in FDS-D field is 111.445 NM.
- Total cable abandoned is 4.004 NM.
- Of the total recovered, 90.577 NM is considered in good condition. 16.864 NM is considered scrap and not reusable.
- All 16 clusters are in tank 1 outer with twenty ends up on deck. The shortest tail on a cluster is 76 fathoms.
- CL101 or the DWT may have an intermittent fault. This cluster is on top of the tank 1 outer stow.
- Tank 1 inner is scrap cable. Tank 2 has no FDS-D cable. Tank 3 has 35.185 NM of good DWT with 12 ends up on deck. Intend to recover trunk cable in tank 3.
- Fault summary (Field): A total of 15 cable faults were detected with the STTS during recovery of the field. 13 of 15 faults were induced by the recovery. 2 of the 15 faults were present prior to the start of recovery. None of the faults were caused by trawling. There were no fishing trawlers in the field area and there was no evidence of trawling damage to the field. Most of the induced recovery faults can be correlated with course changes made during deployment of the system.
- General Observations:
  - At the beginning of the recovery ops, cable faults were induced in succession due to a combination of a harsh seafloor, rough weather, and ship control.
  - The ship's DPS was not suited for following the cable track, and hence control of the ship was done manually. This is apparently a recovery problem, not a deployment problem.
  - Two underwater video cameras on the hull designed to provide cable lead angle information to the cable layers were not beneficial because they were fouled with marine life. A sonar system designed to track the cable lead angle was not usable.
  - The main fleeting drum has a design flaw where the cable can get pinched in the side wall.
  - The cable linear hauler software control does not maintain constant tension on the DWT cable. The correction for this is to manually control the hauler speed up to the point just before the tires begin to slip on the cable.
  - One of two underwater lights in the center well burned out reducing the ability to monitor the lead of the cable, and there was no way to replace the bulb without using a diver (which we could not do).

- At first, the cable layers tried to monitor cable lead angle from the control room by viewing the video monitors, with no feedback from someone standing next to the centerwell. Viewing the cable lead by camera from the control room seemed difficult and limited. Eventually a cable spotter was positioned next to the main sheave to provide inputs to the control room via sound powered phone.
- The control station in the control room was not particularly well laid out. A single person has to control the ship and monitor lead angle, tension, and depth, as well as make log entries. The tension meters are not in a good spot for the cable laying specialist to monitor. The tension meters should be alarmed to warn the specialist when tension begins to rise.
- No detailed bathymetry was available for the field laydown area. This was a hostile seafloor area with many depth changes. A detailed bathymetry chart could have provided information to aid maneuvering the ship to avoid some of the cable damage induced by recovery.
- For depths less than 400 fathoms, cable faults occurred when tensions at the surface were as low as 2000 lbs.
- In depths less than 400 fathoms, the cable consistently faulted at tensions of 3000 lbs or more. These faults are obviously not strictly from tension generated by the catenary -- these tensions are the result of the cable wrapping and holding on a seafloor object. The average tension as measured by the dynamometer in 250 fathoms was 800 lbs.

- Wind 255/14 kt; Sea 355/3' ; Swell 235/4'

8/26 Friday

- FDS-D trunk recovery commenced at 260400Z (DG7). 1.39 NM of LAT, 10 NM of DWT, and one Nautronix transponder have been recovered.
- Test of the trunk indicates a fault between TR1003 and TR1004. Voltage measured 81.2 volts at 253 ma at a position 22.392 NM shoreward from TR1002. This voltage corresponds with the position where deployment faults 2 and 3 occurred on 12 May and 19 May.
- Another fault occurred during recovery when the trunk cable became entangled with long line fishing gear that had been layed over top of it. The fault was located 17 NM shoreward of TR1002. The long-line gear was cut away and recovery has resumed.
- Maverick fish spotted. Long, narrow fish approximately 12' with whiskers that swims upright .
- 2230h A small launch (30-40') approached the ship to within 20' and illuminated the side with a search light, and then departed a few minutes later. There was no communication or ID of the boat, but the boat supposedly had the look of being on official business.
- Wind 025/13 kt; Sea 025/3' ; Swell 010/4'

8/27 Saturday

- The cable continues to get entangled with long-line fishing gear. Since starting trunk recovery, 6 long-line rigs have been cut away at the ship. Others may have been entangled that we did not see. The damage induced by these rigs is minor, but they are an interference and have reduced recovery speed.
- Wind 240/10 kt; Sea 240/2' ; Swell 250/3'

8/28 Sunday

- Continue to encounter long-line fishing gear.
- While recovering trunk cable, the test room got a fault indication that was localized approximately 1 NM shoreward of TR1003. The power was turned off and the cable was recovered to a position 3 NM shoreward of TR1003 and retested. The fault was no longer present, indicating that the fault was in the previous section, and was probably a high resistance fault.
- Wind light; Sea calm ; Swell 045/4'

8/29 Monday

- Trunk cable has incurred damage to power conductor in three places. Damage is the result of fishing line causing a rope burn through to the power conductor. The first fault indication occurred just before CCJ1003-1. This fault indication was intermittent, and went away briefly and returned. Decision was made from a safety aspect to power down and continue hauling in cable until the predicted location came aboard. Inspection was done visually only. No damage was observed. The cable was cut just before TR1003 and tested and there was no fault indication. The fault was probably a high resistance fault around CCJ1003-1. This cable section is in question! Some of this section may be salvaged but the tank will have to be turned to get to it.
- Average speed for recovery of trunk so far is about 1 knot. If recovery continues at this pace we will be completed on 9/10.
- Recovered 23 NM of DWT in last 24 hours with 290 NM to go. Presently 17.5 shoreward of TR1004R.
- 1800h Cable faulted. Tension rose to 5000 lbs. Depth is 1850 fathoms. Average tension is 4K.
- Wind light; Sea calm ; Swell 020/4'

8/30 Tuesday

- During recovery of trunk cable section CS1004R-2 we came to a bitter end 0.3 NM shoreward of TR1004, which appears to be the cause of the fault indication discovered on 7 August when the trunk was tested from the mooring site. A close examination of the bitter end indicates that the cable was cut with bolt cutters. Just prior to the bitter end, the cable had damage that appeared to be trawler hits. DWT cable may have become entangled in trawl gear, brought to the surface, and cut away. Depth at fault location was 328 fathoms. This fault was in an area that is heavily fished by long-line fisherman.

- The cable was grappled (DG8) 0.5 NM seaward of TR1004. Depth was 291 fathoms. TR1004 was recovered from the seaward side and tests good.
- We continued recovering cable seaward and came to a second bitter end 1.2 NM seaward of TR1004. Again the bitter end appears to have been made with bolt cutters. We are now in the process of grappling (DG9) for the trunk.
- Completed DG9 (245 fathoms) and recovered cable 4 NM seaward of TR 1004. Abandoned 2.5 NM due to close proximity to commercial cable. Cable tests good to TR1010.
- Recovered 20 NM of DWT in last 24 hours and abandoned 2.5 NM. 267.5 NM to go.
- Wind 330/4 kt; Sea 330/1' ; Swell 350/3'

<u>8/31 Wednesday</u>

- Recovered 30 NM of DWT in last 24 hours and 267.5 NM remain to be recovered.
- Continue to encounter long-line fishing rigs
- At 2200, we are 0.3 NM shoreward of TR1005.
- 0145h stopped pick-up to repair torn cushion in tank 3 on upper walls and on cone. The torn cushions cause the cable to hang up and put several minor kinks in the cable.
- Wind light; Sea calm ; Swell none

<u>9/1 Thursday</u>

- Recovered 31.5 NM in last 24 hours and 206 NM remain to be recovered.
- System tests good to TR1010. TR 1005 recovered in good condition and presently 5 NM shoreward of TR1006.
- Wind light; Sea calm ; Swell none

<u>9/2 Friday</u>

- Recovered 33 NM in last 24 hours and 173 NM remain to be recovered.
- System tests good to TR1010. TR1006 recovered in good condition.
- Approached and illuminated by small patrol boat. Contact made by radio and we informed him we were performing hydrographic survey operations. At the time we were 178/24.5 NM from SE point of island.
- Wind light; Sea calm ; Swell none

<u>9/3 Saturday</u>

- Recovered 31 NM in last 24 hours and 142 NM remain to be recovered.
- System tests good to TR1010. TR1007 recovered in good condition.

- CCJ 1008-1 had extensive jacket distortion -- it was collapsed inward and had ripples in the jacket.
- Cable Faulted when it fouled on the bottom 2.6 NM seaward of CCJ1008-1. (330 Fathoms) Tension spikes to 4K. Cut out damaged section 75 fathoms long and resumed recovery.
- Wind 315/28 kt; Sea 315/5' ; Swell 310/8'

<u>9/4 Sunday</u>

- Recovered 30 NM in last 24 hours and 112 NM remain to be recovered.
- System tests good to TR1010. TR 1008 recovered in good condition.
- Wind 345/12 kt; Sea 345/3' ; Swell 305/8'

<u>9/5 Monday</u>

- Recovered 31 NM in last 24 hours and 81 NM remain to be recovered.
- System tests good to TR1010. TR 1009 recovered in good condition.
- No long-line fishing rigs were encountered after a point 18 NM shoreward of TR1009.
- Logreq sent out
- Wind 340/12 kt; Sea 340/2' ; Swell confused/3'

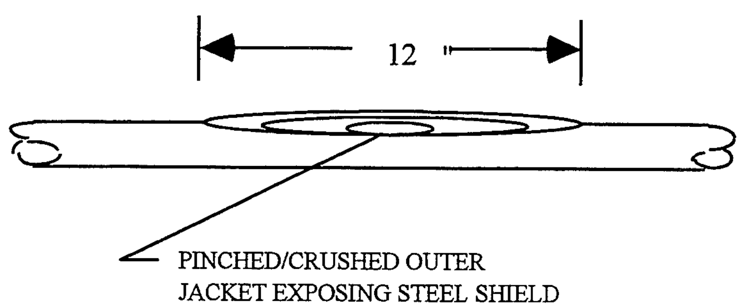
<u>9/6 Tuesday</u>

- Recovered 29 NM in last 24 hours and 50.5 NM remain to be recovered. Abandoned approximately 1.5 NM.
- TR1010 recovered in good condition.
- The first operational fault occurred in the section between TR1010 and TR1011 on 4 June. We began troubleshooting to localize the fault in this section by cutting and testing 1 NM seaward of TR1010 . The fault was isolated to a point 6.1 NM seaward of TR 1010. Prior to reaching the faulted point, the cable fouled on the seafloor and parted. Tension was recorded at 6.2 klbs. Recovered cable during DG10 and resumed pick-up.
- Wind 125/5 kt; Sea 125/2' ; Swell 190/3'

<u>9/7 Wednesday</u>

- The trunk cable was heavily damaged in the area from 6 to 15 NM seaward of TR1010. Five separate faults were encountered in this area and all appear to have been the result of trawling. All faults were electrical and optical faults. The cable did not part in any of the faults.
- As many as five trawlers have been working in the immediate vicinity. One trawler crossed the stern with a CPA of less than 400 meters.
- Fault summary:
    - Fault 1 - 6 NM seaward of TR1010. Depth 270 fathoms. Cable is 150 fathoms off track. DWT flayed open down to strength wires. Damaged section 120 feet long.
    - Fault 2 - 11.8 NM seaward of TR1010. Depth 161 fathoms.

- Damaged section 500 fathoms long. Short 100' section of cable stripped back to dielectric, conductor and strength wires, followed by 500 fathom section of kinked, deformed cable. Jacket remained intact for most of the distance, but steel tape was buckled and deformed underneath.
- Fault 3 - 17.4 NM seaward of TR1010. Depth 110 fathoms. DWT was highly stressed. One side of the cable was flattened out, and crew had extreme difficulty getting it to lay in tanks. Cable was cut away and recovered 4 NM further up the track. The cable fault was never actually brought onboard.
- Fault 4 - Cable was cut with bolt cutters 4 NM shoreward of TR1011. Depth 105 fathoms. I assume a trawler did this after getting its gear entangled with the cable. The cable was recovered further up the track and the trawl damage was never recovered.
- Fault 5 - 2 meters shoreward of TR1011. Depth 80 fathoms. Fault was located near TR1011. Cable had been hit leaving a section 12" long peeled back exposing the shield. There was no obvious sign of damage past the shield. However, testing of TR1011 failed bit error rate tests. The test engineer believes the fault has a high resistance current leak to ground. There is no way of knowing if this is an optical fault because it is too close to the repeater.



- Recovered 21.5 NM, abandoned 4 NM, and 25 NM remaining.
- 1950h CCJ 1011-2 came onboard with large piece of orange coral attached.
- Wind 130/8 kt; Sea 130/3' ; Swell none

<u>9/8 Thursday</u>

- Last 21 miles of cable being brought onboard. Testing indicates cable is good out to the spot the T-ship first cut in on 8 June.
- Some damage was induced during recovery of last 21 NM. Tension spike of 6Klb. Depth ranges from 80 to 280 fathoms in the section.
- No sign of trawlers in the area. They must move around in groups and stay near fish processors.

- 2341h Bitter end onboard. Recovery complete. Average recovery speed was 1.1 knots and maximum recovery speed was 1.5 knots.

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