

WHOI-91-02

Copy 2

**Woods Hole
Oceanographic
Institution**



**Development and Evaluation
of
Electromechanical Cables
for
Deep Sea Buoy Applications**

by

A. Bocconcelli

January 1991

Technical Report

Funding was provided by the Office of Naval Research under
Contract No. N00014-84-C-0134.

Approved for public release; distribution unlimited.

WHOI-91-02

**Development and Evaluation
of
Electromechanical Cables
for
Deep Sea Buoy Applications**

by

A. Bocconcelli

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

January 1991

Technical Report

Funding was provided by the Office of Naval Research under
Contract No. N00014-84-C-0134.

Reproduction in whole or in part is permitted for any purpose of the United States
Government. This report should be cited as Woods Hole Oceanog. Inst. Tech. Rept.,
WHOI-91-02

Approved for public release; distribution unlimited.

Approved for Distribution:



Albert J. Williams 3rd, Chairman
Department of Applied Ocean Physics
and Engineering



ACKNOWLEDGMENTS

The cables reviewed in this report have been designed, built, tested and used as essential components of complex, moored and free drifting buoy systems deployed at sea in the recent past. R.G. Walden, H.O. Berteaux, P. Clay, S. Kery, P. O'Malley and the author have all participated in one form or another, to the engineering and development of these cables and their terminations.

Also thanks are due to G. McPhee for her expert assistance with the writing and re-writing of this report and to R. Arthur and B. Pratt for the art work and CAD drawings.

Electromechanical cable data were provided by S. Whitehill, President of Whitehill Manufacturing and W. Tell, President of Consolidated Products Corporation.

Appreciation should also be given to Dr. S. Ramberg of the Office of Naval Research (ONR) for his continued personal interest and support. This work was performed under ONR Contract Number N00014-84-C-0134.

TABLE OF CONTENTS

	<u>Page</u>
Acknowledgments	2
Table of Contents	3
List of Figures	4
List of Tables	5
Abstract	6
1 Introduction	7
2 Cable Development	8
2.1 General Requirements	8
2.2 Specific Oceanographic Applications	9
2.2.1 Free Drifting Buoy Systems	9
2.2.2 Subsurface Moorings With No Permanent Surface Expression	16
2.2.3 Subsurface Moorings With Permanent Surface Expression	30
2.2.4 Surface Moorings	36
References	47

LIST OF FIGURES

	<u>Page</u>
1. RELAYS Buoy Systems	10
2. RELAYS E/M Cable	11
3. RELAYS Boot Termination	15
4. RTEAM Mooring Schematics	17
5. RTEAM Umbilical Cable	18
6. BIW E/M Cable	23
7. Consolidated Steel Double Armor E/M Cable	31
8. TETHERMOOR	32
9. MOIST	33
10. ABRUPT TOPOGRAPHY Mooring Schematics	34
11. STEM Mooring Schematics	37
12. 3x18 MacWhyte and 3x19 Consolidated E/M Cables	42
13. 3x18 - 7/16" E/M Cable	45
14. ESOM Mooring Schematics	46

LIST OF TABLES

- I Oceanographic electromechanical cable specifications for free drifting applications (RELAYS, Kevlar)
- II Tether E/M cable specifications (RTEAM, umbilical cable, Kevlar)
- III Oceanographic electromechanical cable specifications for subsurface applications (RTEAM, Kevlar)
- IV Oceanographic electromechanical cable specifications for subsurface applications (RTEAM, steel)
- V Oceanographic electromechanical cable specifications for subsurface applications (improved RTEAM, steel)
- VI 3x19 Oceanographic electromechanical cable specifications for surface applications (STEM)
- VII 3x18 Oceanographic electromechanical cable specifications for surface applications (ESOM)

1 INTRODUCTION

The need for real time data telemetry from oceanographic moorings has contributed to the development and proliferation of electromechanical (E/M) and/or electro-optical-mechanical (EO/M) cables. E/M cables constitute the main system component linking both sensors and the transmitting surface module. In a typical surface or sub-surface mooring the E/M cable fulfills two different tasks: it acts as the mooring strength member and also provides the electrical connection between sensors and surface buoy. E/M cable terminations are needed whenever a connection is made between sensors and instrument packages and/or sections of E/M cable.

This report describes certain E/M cables designed and developed at W.H.O.I. by the Ocean Systems and Moorings Lab in cooperation with private industry. Surface and sub-surface moorings are both covered. Electro-optical-mechanical cables (fiber optics) which have been successfully developed by the Deep Submergence Laboratory for R.O.V. tethers are not included in this report.

Eight E/M cables made by different U.S. manufacturers have been evaluated by the Ocean Systems and Mooring Lab in the past six years. Sea trials included shallow water deployment at the Buoy Farm and deep water deployment in several oceanographic moorings: MOIST, RELAYS, STEM, R-TEAM, TETHERMOOR, ESOM and ABRUPT TOPOGRAPHY. Post recovery analysis includes: tensile machine test, electrical tests and visual inspection for corrosion or jacket damage.

Three different E/M terminations have been developed to suit the construction of the cables presented in this report. Their design, construction and testing procedures will be covered in a following technical report.

2. CABLE DEVELOPMENT

2.1 General Requirements

The first requirement to be satisfied is that of mechanical strength: the mooring array must be kept in station and able to withstand drag and tension forces, cyclic stress caused by wave action and vibrations (strumming) and fishbite attacks. Therefore, the safe working load of the E/M cable must exceed the expected mooring load. Usually a safety factor of three for subsurface moorings and five for surface moorings is specified. To avoid damage to the conductors the cable modulus of elasticity must be high enough to minimize tension induced elongation. To ensure fishbite protection a jacket is extruded over the cable and/or the conductors are strategically placed in the cable structure (Reference 1). Slip-on plastic fairings may be used to lower the cable drag coefficient and reduce vibrations.

Corrosion and fatigue factors must also be taken into account in cable construction. The contrahelical, torque free, double armor construction is widely used. This design ensures good torque balance and reduced kinking danger during slack conditions or mooring deployment. Galvanized improved plough steel (GIPS) is the preferred armor material and once covered by a plastic jacket it offers good corrosion resistance.

Modern, hard wire telemetry uses low voltage, low power digital signal transmission. These requirements are easily satisfied with small gauge conductors, typically AWG #20 (.812 mm) or #22 (.644 mm). Conductor insulation, material and thickness must be specified not only to comply with the electrical requirements but also to ensure perfect and easy bonding at the termination ends and maximum protection from mechanical abuse.

2.2 Specific Oceanographic Applications

The following reviews, in chronological order, the buoy systems which, over the past few years, required the use of metallic and non metallic electromechanical cables. In each case, a description of the mooring type and purpose is first presented. Next the characteristics, mechanical and electrical, of the cables used are listed, together with appropriate comments as to design criteria and rationales. Finally a brief account is given of the cable deployment history and of its success or mode of failure at sea.

2.2.1 Free Drifting Buoy Systems

In 1982 the Ocean Structures and Moorings (OS&M) Laboratory together with the Advanced Engineering Laboratory (AEL), both from the Applied Ocean Physics and Engineering Department, Woods Hole Oceanographic Institution, undertook the development of a deep sea, free drifting Real-Time Link and Acquisition Yare System (RELAYS) (Reference #2). The purpose of the buoy system was to receive acoustic oceanic parameters from the surface down to the depth of the SOFAR sound channel. Data thus acquired were processed on board the buoy and transmitted via the ARGOS system. The main components of the system are shown in Figure #1.

Desirable features for the E/M cable connecting the surface buoy to the hydrophone array included: three electrical conductors, materials which would bond well to polyurethane, lightweight in water, 150 m of the total 1150 m to be positively buoyant, and adequate strength to account for cable degradation due to fatigue. Kevlar was chosen as strength member because of its light weight in water. The cable, shown in Figure #2, was jointly designed with Blake Wire and Cable Co., Torrance, CA. The floating portion of the cable acts as a compliance element which decouples and filters the wave action thus reducing tension variations and induced displacements of the sensors.

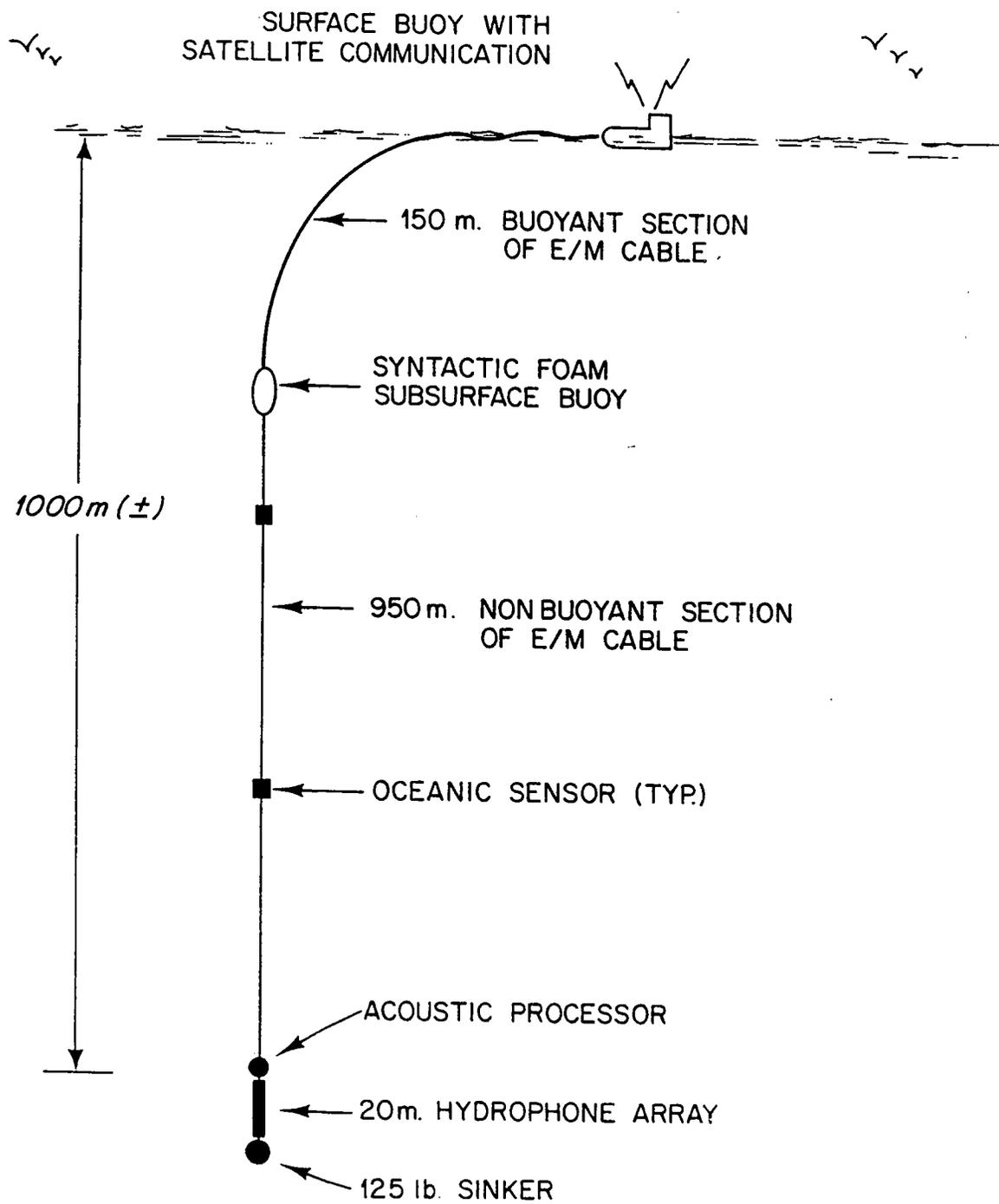
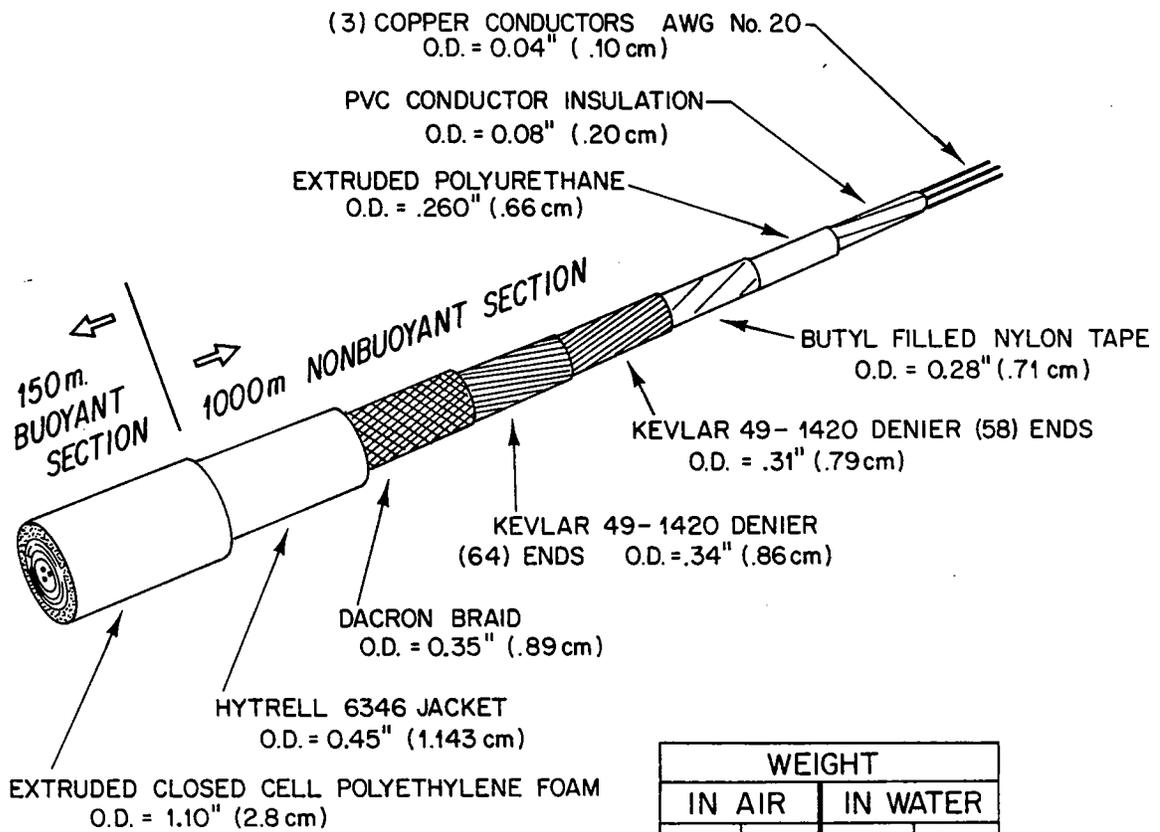


Figure 1: Relays Buoy Systems



	WEIGHT			
	IN AIR		IN WATER	
	lb/ft	kg/m	lb/ft	kg/m
BUOYANT	.303	.453	+.098	+.146
NONBUOYANT	.082	.122	-.011	-.016

NOTE : CABLE BREAKING STRENGTH = 6000 lbs (2725 kg)

Figure 2: Relays E/M Cable

A stress relief tapered polyurethane boot terminates the cable at the bow of the surface buoy. All the sensors are attached in line to the cable and terminated through smaller polyurethane boots. Cable main characteristics are shown in the following table:

TABLE I

**OCEANOGRAPHIC ELECTROMECHANICAL CABLE SPECIFICATIONS
FOR FREE DRIFTING APPLICATIONS (RELAYS, KEVLAR)**

Cable Denomination/Description

1/2" Kevlar Double Armor Cable with (3) #20 AWG conductors in the core, 1150m long

150 m foamed over at one end to a 1.1 O.D. Polyethylene foam with 0.31 specific gravity.

Manufacturer

Conductors & cable: Blake Wire and Cable, Torrance, CA

Conductors

Number of conductors and configuration: 3 twisted in central core

Gauge: AWG #20

Conductor Material: Tinned copper

O.D.: 0.04 in.

Insulation Material: PVC

O.D.: 0.08 in.

Electrical Specs:

Resistance: 11 OHMS/1000 ft.

Voltage: 600 Volts

Strength Member

Material: Kevlar 49-1420 Denier

Type of Construction: Double contrahelical armor

Braid: Dacron

Strength

Ultimate Breaking Strength: 6000 lbs. (nominal)

Cable Construction and Dimension

Core

Filler - 3 filler rods of Polypropylene

Wall Material: Polyurethane

Thickness: 0.09 in.

O.D.: 0.260 in.

Armor - O.D.: 0.31 in.

Jacket

1st Jacket

Material = Hytrel 6346 O.D. = 0.45 in.

2nd Jacket (Foamed section only)

Material = Polyethylene foam O.D. = 1.1 in.

Weight

In air = 0.303 lbs/ft (Buoyant); 0.82 lbs/ft (Non Buoyant)

In Water = +0.98 lbs/ft (Buoyant); -0.11 lbs/ft (Non Buoyant)

Bending Radius: 30 in.

Prior to final system deployment the following tests were performed on the E/M cable:

- Continuity and break test for non buoyant section. The sample failed at 3,150 lbs. pull at the spelter socket termination.
- Tensile test on E/M cable termination at hydrophone end. Termination failed at 2,600 lbs. pull.
- Tensile test on polyurethane boot, buoy to cable termination. Sample failed at 4,800 lbs. pull.
- Buoyancy test for foamed section of E/M cable. It was found to be: 0.122 lbs/ft.
- Deep water system test from the R/V FLORIDA (December 1982).

Following the first deployment at sea with three prototype RELAYS drifting system (1984) a mechanical failure mode was identified as wave induced flexing fatigue at the cable/buoy termination (Figure #3). The polyurethane boot appeared to fail at the base of the cone, where the boot base is bolted to the buoy forward bulkhead. Two different solutions were adopted and tested at the Buoy Farm in order to reduce the stress action and stress at the buoy termination: a long tapered boot (50 inch) and a foamed, buoyant section made of different materials (foamed P.E., polyurethane and TPR). The TPR sample offered the best performance over an extended deployment and was therefore chosen for the final experiment.

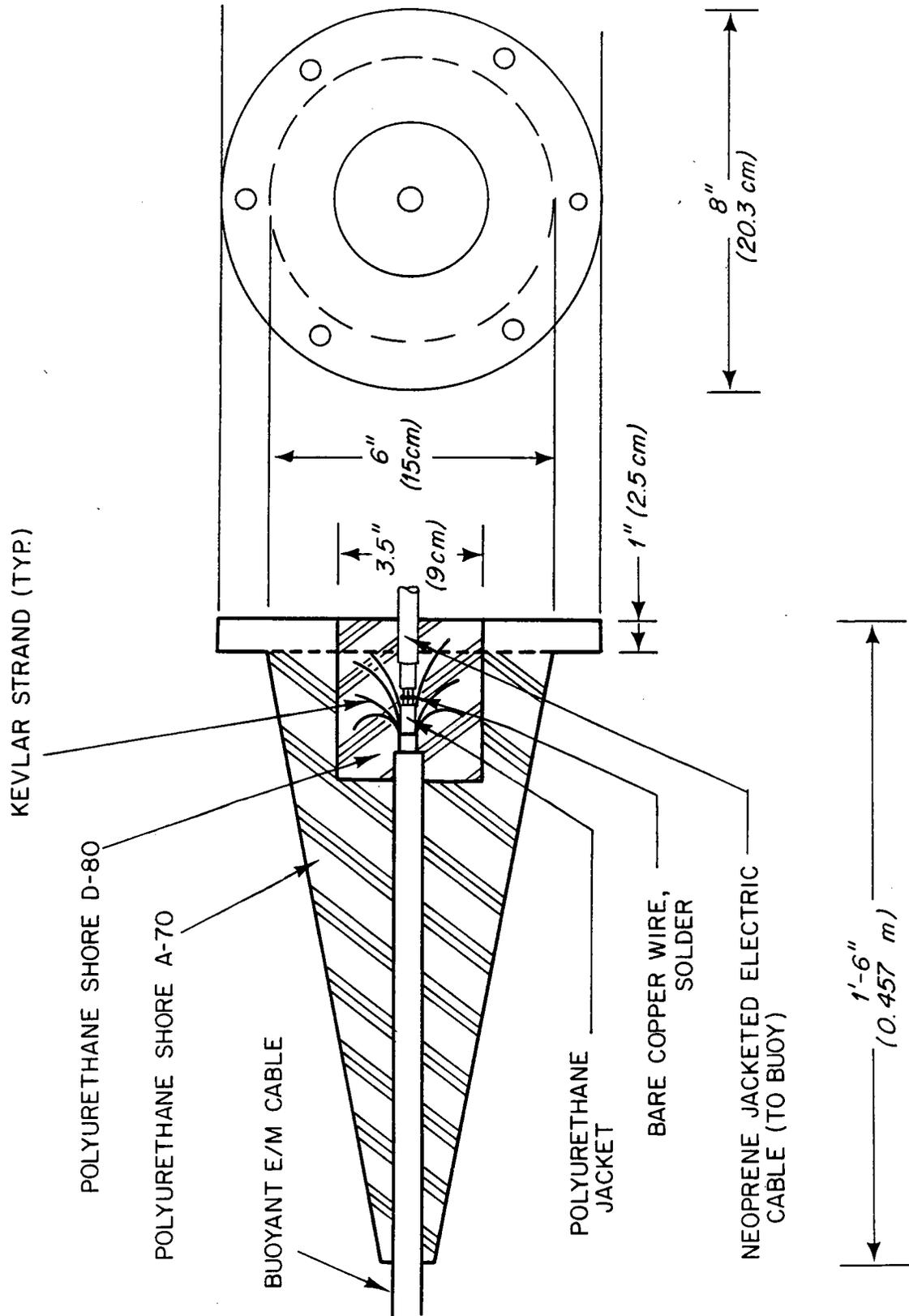


Figure 3: Relays Boot Termination

2.2.2 Subsurface Moorings with No Permanent Surface Expression

These moored systems are designed for collecting and recording oceanographic data in situ and occasionally relaying the data to shore with the help of a temporary surface expression (gas inflated or winch operated modules, free drifting capsules). A wide variety of sensors can be accommodated to collect data as a function of depth. Telemetry is achieved via satellite or direct radio relay to a nearby shore station. The system described in this section has two major components: a single point mooring with a shallow subsurface float and a variable ballast module that ascends from the subsurface float to the ocean surface on a prescribed schedule. Radio transmitters send the data either directly to shore or satellite.

The Real Time Environmental Arctic Monitoring (RTEAM) is a prototype system of this kind (Reference 3). The RTEAM is specifically designed to collect oceanic environmental data in the Arctic region and to transmit these data to shore on a daily basis. To this end a variable buoyancy ascent module comes to the surface once a day and transmits directly to ARGOS (ice free surface) or indirectly through a relatively close by MF receiving station (ice covered surface) (Figure #4). When not transmitting the module remains in its rest position most of the time, well away from the surface, thus diminishing the risks of damage at the ice interface. The mooring is capable of deployment in depth of up to 4500 m and is able to operate in a maximum current speed of 2 knots at the surface. Design life for each deployment is one year.

The link between the subsurface buoy and the variable ballast ascent module is a critical component of the R-TEAM system. In order to provide a mechanical, electrical and pneumatic connection an electromechanical umbilical cable, 220 m. long, was designed. The Kevlar armored, buoyant umbilical cable with three conductors was then built by Consolidated Cable Corp. (Figure #5). The cable was terminated at WHOI with a polyurethane boot similar to the one used for the RELAYS project. The CO₂ gas used to

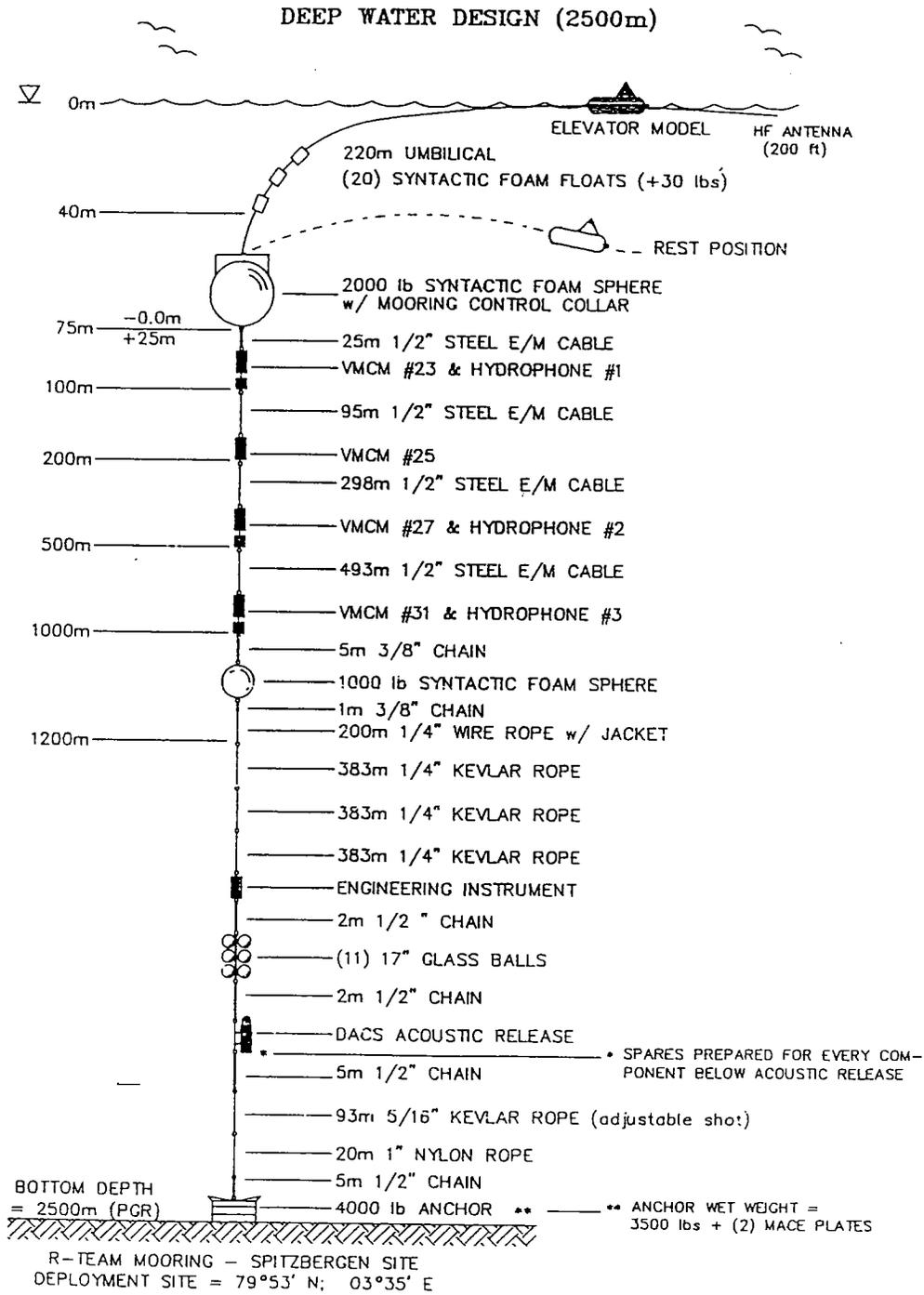


Figure 4: RTEAM Mooring Schematics

3-#20 AWG SINGLES:
 CONDUCTORS: 19 x .008" B/C.
 INSULATION: PVC

1-EA. HOSE:
 .188" I.D. x .422" O.D. MAX.
 SYNFLEX # 3130-03
 3000 PSI WORKING-PRESSURE
 12000 PSI MIN. BURST PRESSURE

19-EA. PLASTIC ROD FILLS

PVC-MYLAR TAPES

BLOCKING:
 ELASTOMERIC.
 ALL GROOVES.

STRENGTH MEMBER BRAD
 KEVLAR 29-1500-960
 .721" O.D.

JACKET:
 POLYURETHANE.
 BLACK.
 .0715" (NOM.) WALL.
 .695" (NOM.) O.D.

FLOTATION JACKET:
 FOAMED POLYETHYLENE
 BLACK.
 .1875" (NOM.) WALL
 1.350" (NOM.) O.D.

JACKET:
 NYLON.
 BLACK.
 .127" (NOM.) WALL.
 .975" (NOM.) O.D.

JACKET:
 NYLON.
 BLACK.
 .070" (NOM.) WALL
 1.490" (NOM.) O.D.

NOTES:

*1. CABLE WEIGHT PER 1000 FEET:
 650# IN AIR
 -124# IN SEA WATER.

*2. SPECIFIC GRAVITY: .84

**3. BREAK STRENGTH: 3200 # (NOM.)

**4. MAX. WORKING LOAD: 640 #

**5. MIN. BEND DIAMETER: 48"

* AT ZERO PSI EXTERNAL PRESSURE
 AND WITH EMPTY HOSE.

** WITH HOSE PRESSURIZED.

SOUTH					
BAY			CABLE DIVISION		
CONSOLIDATED PRODUCTS CORPORATION					
DRAWN	HUNT	1-12-87	APPROVAL	W.L.T.	1-13-87
CHECKED	H.M.T.H.	1-13-87	APPROVAL		
CABLE, E.M., SPECIAL PURPOSE				SB-37367	

Figure 5 : R TEAM Tether Umbilical Cable

displace water from the variable ballast module flows from the subsurface buoy tanks through a high pressure hose located at the core of the cable. The same umbilical cable has already been deployed four times and it is at sea at this moment for a year long experiment.

The RTEAM tether was designed to satisfy the following requirements:

- a) Minimum drag and maximum buoyancy for a given diameter;
- b) Strength to exceed 3000 lbs. which is much less than the strength of the rest of the mooring line, This would prevent total loss of the mooring in the event that the upper section was caught and dragged away;
- c) Fishbite and ice protection, achieved by covering the tether with a Zytel jacket and by placing the conductors with the air hose at the core of the cable;
- d) Three watertight conductors to carry signals to the elevator module;
- e) 3000 psi hose at the core of the tether.

The RTEAM tether specifications are summarized in Table II below.

TABLE II

**TETHER E/M CABLE SPECIFICATIONS
(RTEAM UMBILICAL CABLE, KEVLAR)**

Cable Denomination/Description

Umbilical cable with 3 conductors and air hose placed in the core.

Manufacturer

Consolidated Cable Corporation, Idyllwild, CA

Conductors

Number and configuration: 3 single conductor, twisted around core.

Gauge: #20 AWG

Material: Tinned copper

O.D.: 0.04 in.

Insulation Material: PVC

Thickness: 0.015" Wall

Core Material: Synflex #3130-03 air hose, 3000 psi maximum working pressure.

O.D.: .422"

Filler: 19 each plastic rods

Water block: Elastoremic

Electrical specs

Resistance: 10 OMS per 1000 feet

Voltage: 500 volts

Strength Member

Type: Braid

Material: Kevlar 29-1500-960

O.D.: 0.721"

U.B.S. = 3,200 lbs.

Yield Strength = 2000 lbs.

Umbilical Cable Construction and Dimensions

Core: Synflex air hose #3130-03

I.D.: 0.188"

O.D.: 0.0422"

Armor: O.D. = .721"

Jacket:

1st Jacket

Material = Black polyurethane

O.D. = 0.695"

2nd Jacket

Material = Black nylon

O.D. = 0.975"

3rd Jacket

Material = Black foamed polyurethane

O.D. = 1.350"

4th Jacket

Material = Black nylon

O.D. = 1.490"

Overall Outside Diameter: 1.490"

Weight

In Air = 650 lbs/1000 ft.

In water = -124 lbs/1000 ft.

Bending Radius: 24"

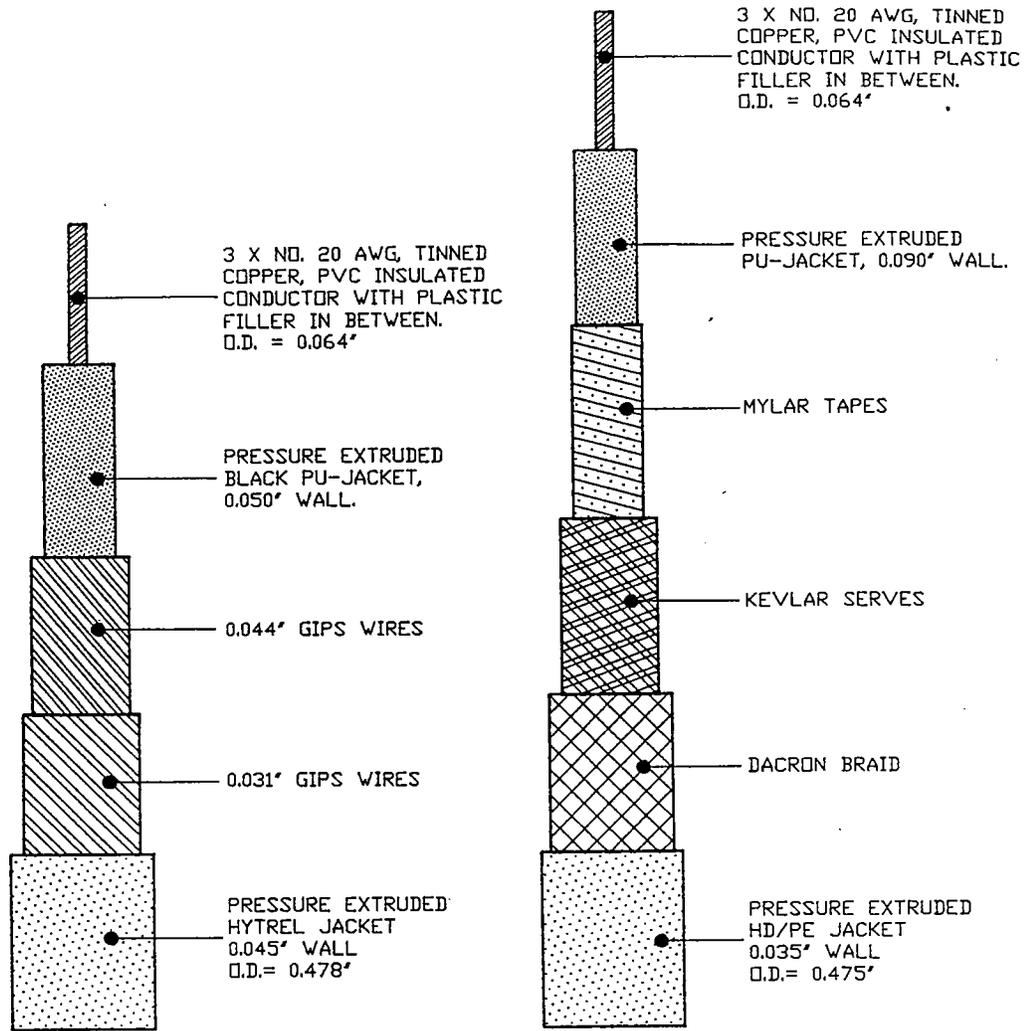
The tether cable was tested before and after termination for electrical and pneumatic integrity. A sample was pull tested with the tensile machine and broke at 2,800 lbs. The site "D" prototype test and two deployments in the Arctic prove the validity of this cable design and its construction. The tether has been retrieved in August 1990 at the end of a one year deployment in the Arctic region.

Two E/M cables were purchased from B.I.W. Corp., Boston, MA for the RTEAM prototype deployment at Site "D" during the summer of 1987. Both cables had a double armor, torque balanced construction. One cable was made of steel whilst the other was made of Kevlar. Electrical characteristics

were the same for both versions. The double armor design satisfies the RTEAM mooring requirements: long term deployment, limited fishbite danger (in the Arctic), three electrical conductors for the SFK Sail cable/sensors circuit. Since the mooring is operating as a subsurface system the wave induced stress and bending cable fatigue is minimal. This allows for the use of a more rigid double armor cable vs. a more flexible 3 x 19 design.

Cable samples were pull tested at WHOI prior to shallow water deployment at the buoy farm (Figure #6). The steel cable broke at 10,650 lbs. whilst the Kevlar sample failed at 4,800 lbs. Several tests were performed on the Kevlar cable, with different termination designs, without achieving a higher breaking strength. Due to the test results and the difficulty of terminating the cable, Kevlar was not used for the deep sea deployment.

A steel cable length was then terminated by D.G. O'Brien, Inc., Seabrook, NH and successfully pressure tested at 3000 psi. An endurance test was subsequently performed at the Buoy Farm with a subsurface mooring arrangement in which a continuity meter monitored the E/M cable electrical functioning. The test assembly was on station for over three months without failures of any kind. As the cable passed all the preliminary tests five E/M assemblies were prepared and terminated by D.G. O'Brien for the deep water RTEAM prototype mooring.



STEEL ARMOR (BIW)

STRENGTH = 10,300 LBS
WEIGHT = 257 LBS/1000'

KEVLAR ARMOR (BIW)

STRENGTH = 8,300 LBS
WEIGHT = 94.1 LBS/1000'

E/M CABLES FOR SUBSURFACE
MOORING APPLICATIONS

Figure 6: BIW E/M Cable

The Kevlar and steel E/M cable specifications are as follows:

TABLE III
OCEANOGRAPHIC ELECTROMECHANICAL CABLE SPECIFICATIONS
FOR SUBSURFACE APPLICATIONS (RTEAM, KEVLAR)

Cable Denomination/Description

Kevlar armored cable, 0.475" O.D. with (3) #20 AWG Conductors
in the core

Manufacturer

Cable: Boston Insulated Wire Cable Systems Inc., Plymouth, MA

Conductors

Number of conductors and configuration: (3) conductors twisted
in central core with plastic filler in between

Gauge: AWG #20

Conductor Material: Tinned copper

O.D.: 0.064

Insulation Material: PVC

Thickness: 0.013"

Core Material: Pressure extruded polyurethane jacket,
0.090" wall

Electrical specs:

Resistance: 11.2 OHMS/1000 ft.

Voltage: 600 volts

Strength Member

Material: Kevlar

Type of construction: Contrahelical serves

Braid: Dacron

UBS = 8,300 lbs. (rated)

Yield strength = 7,400 lbs. (rated)

Cable Construction and Dimensions**Core**

Filler: Plastic filler between conductors

Wall material: Pressure extruded polyurethane jacket wrapped
with mylar tapes

Thickness: 0.013"

O.D.: 0.090"

Armor

O.D. = 0.405"

Jacket

Material: Pressure extruded high density polyurethane jacket

Thickness: 0.035"

O.D.: 0.475"

Overall Outside Diameter = 0.475"

Weight

In air = 94.1 lbs/1000 ft.

In water = 15.3 lbs/1000 feet

Bending Radius = 18"

TABLE IV

**OCEANOGRAPHIC ELECTROMECHANICAL CABLE SPECIFICATIONS
FOR SUBSURFACE APPLICATIONS (RTEAM, STEEL)**

Cable Denomination/Description

Torque balanced, double armor steel cable with (3) #20 conductors in the core; 0.478" O.D.

Manufacturer

Cable: Boston Insulated Wire Cable Systems, Inc., Plymouth, MA

Conductors

Number of conductors and configuration: (3) conductors twisted in central core with plastic filler in between

Gauge: AWG #20

Conductor Material: Tinned copper

O.D.: 0.064"

Insulation Material: PVC

Thickness: 0.013"

Core Material: Pressure extruded black polyurethane jacket, 0.050" wall

Electrical specs:

Resistance: 11.2 OHMS/1000 feet

Voltage: 600 volts

Strength Member

Construction: Double contrahelical armor

Material: Galvanized improved plow steel (GIPS)

Armor Dimensions: 0.388" O.D.

1st Layer: Number of Wires = 19

Wire Size = 0.044"

O.D. = 0.326"

2nd Layer: Number of Wires = 40

Wire Size = 0.031"

O.D. = 0.388"

Cable Construction and Dimension

Core

Filler: Plastic filler in between conductors

Wall Material: Pressure extruded black polyurethane jacket

Thickness: 0.050"

O.D.: 0.238"

Armor

O.D.: 0.388"

Jacket

Material: Pressure extruded Hytrel

Thickness: 0.045"

O.D.: 0.478"

Overall Outside Diameter = 0.478"

Strength

UBS = 10,300 lbs.

Yield strength = 9,400 lbs.

Weight

In air = 257 lbs/1000 feet

In water = 177 lbs/1000 feet

Bending Radius = 18"

Following the Site "D" test of summer 1987 a new, less expensive, electromechanical cable was developed with the cooperation of Consolidated Cable Products. The new design is an improved version of the original double armor construction (Figure #7). Each RTEAM cable assembly was terminated by D.G. O'Brien using the same hardware deployed in the prototype mooring. The performance of this cable has been excellent and the same assemblies have been redeployed twice in the Arctic Sea. The same cable design was also used for the Tethermoor mooring off Bermuda and the Abrupt Topography mooring off Northern California.

Cable samples were tested at WHOI for rotation, break and continuity. The breaking load for several samples was above 11,400 lbs. and electrical continuity was maintained throughout the tensile test until mechanical failure occurred. Each terminated assembly was pressure tested at 3000 psi. This cable main features are as follows:

TABLE V

OCEANOGRAPHIC ELECTROMECHANICAL CABLE SPECIFICATIONS FOR SUBSURFACE APPLICATIONS (IMPROVED RTEAM, STEEL)

Cable Denomination/Description

Torque balanced, double armor steel cable with (3) #20 AWG conductors in the core;
O.D. = 0.480"

Manufacturer

Cable: Consolidated Cable Products Corp., Idyllwild, CA

Conductors

Number of conductors and configuration: (3) conductors twisted
in central core with plastic filler in between

Gauge: AWG #20

Conductor Material: Tinned copper

O.D.: 0.064"

Insulation Material: PVC

Thickness: 0.013"

Core Material: Black, polyurethane jacket

Wall thickness: 0.051"

Electrical specs.

Resistance: 10.47 OHMS per 1000 feet

Voltage: 1500 volts

Insulation breakdown: +100 Megaohms at 500 volts DC

Strength Member

Double Contrahelical Armor

Material: Galvanized improved plow steel (GIPS)

Armor dimensions: 0.384" O.D.

1st layer: Number of wires = 16

Wire Size = 0.047"

O.D. = 0.324"

2nd Layer: Number of wires = 33

Wire Size = 0.030"

O.D. = 0.384"

Strength

UBS = 10,000 lbs.

Yield strength = 9,000 lbs.

Peak load = 2,500 lbs.

Cable Construction and Dimensions

Core

Filler = plastic filler between twisted conductors

Wall Material = Black polyurethane jacket

Thickness = 0.051"

O.D. = 0.138"

Armor

O.D. = 0.384"

Jacket

Black HDPE jacket; Thickness: 0.048"

O.D. = 0.478"

Overall Outside Diameter: 0.478"

Weight

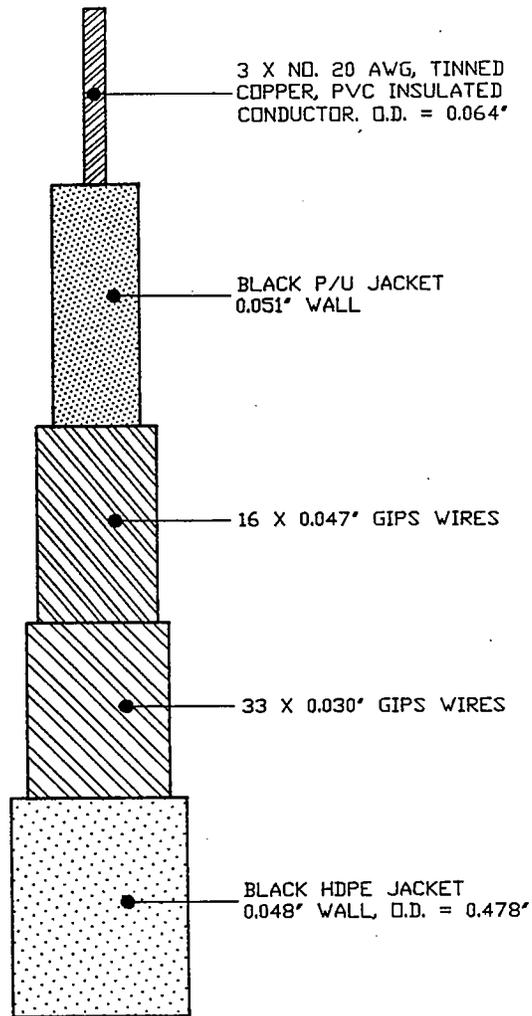
In Air = 247 lbs. per 1,000 feet

In water = 167 lbs. per 1,000 feet

Minimum Bending Radius: 18"

2.2.3 Subsurface Moorings with Permanent Surface Expression

A typical mooring system of this kind includes a small, low drag surface buoy with telemetry unit connected to a subsurface mooring by an electromechanical tether. This particular configuration decouples the waves action from the subsurface section of the mooring and insures more accurate oceanographic measurements and longer components life. This approach has been followed for the MOIST, TETHERMOOR and ABRUPT TOPOGRAPHY projects (Figures #8, #9, #10).



E/M CABLE FOR SUBSURFACE
MOORING APPLICATIONS

Figure 7: Consolidated Steel Double Armor E/M Cable

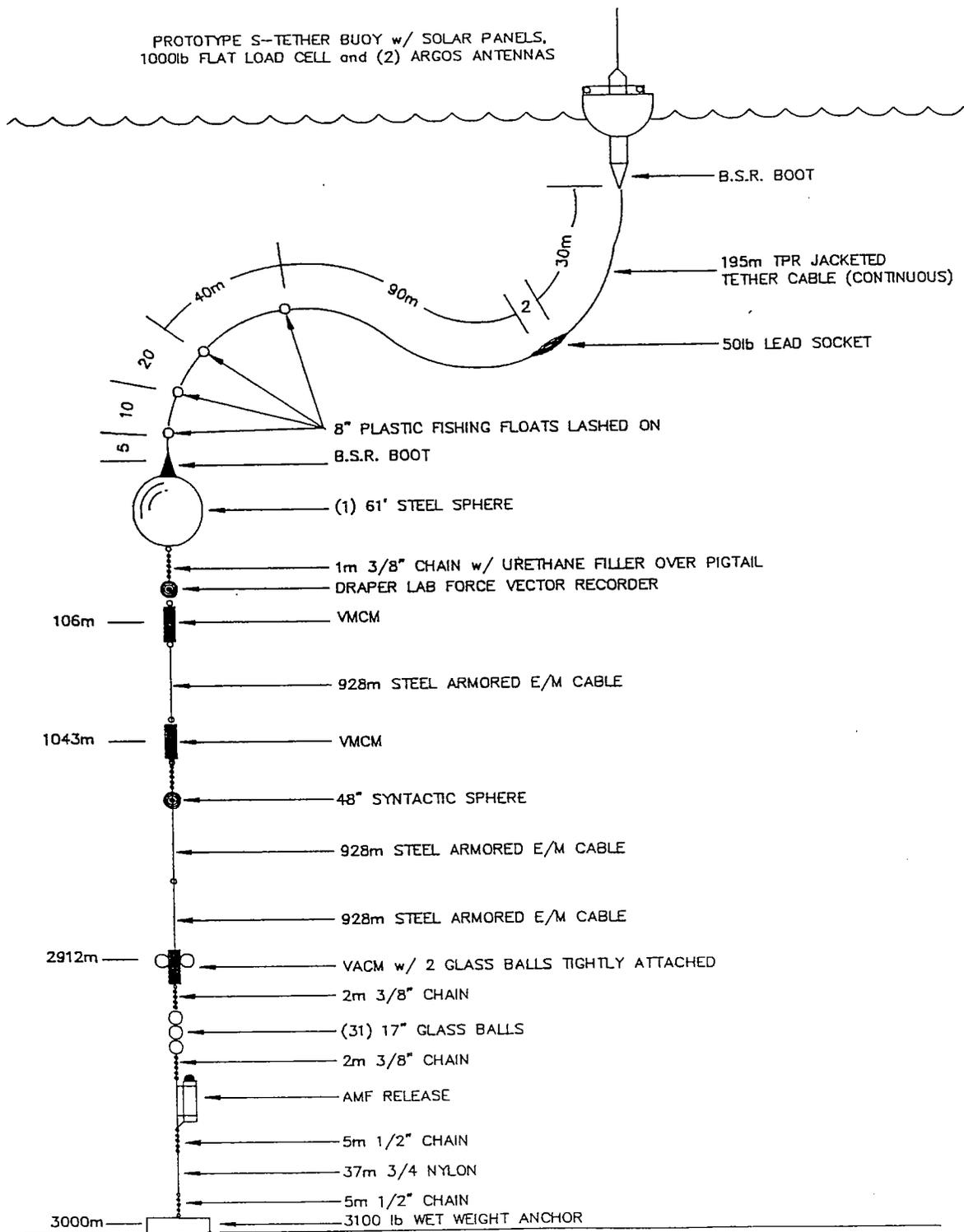


Figure 8: TETHERMOOR Mooring Schematics

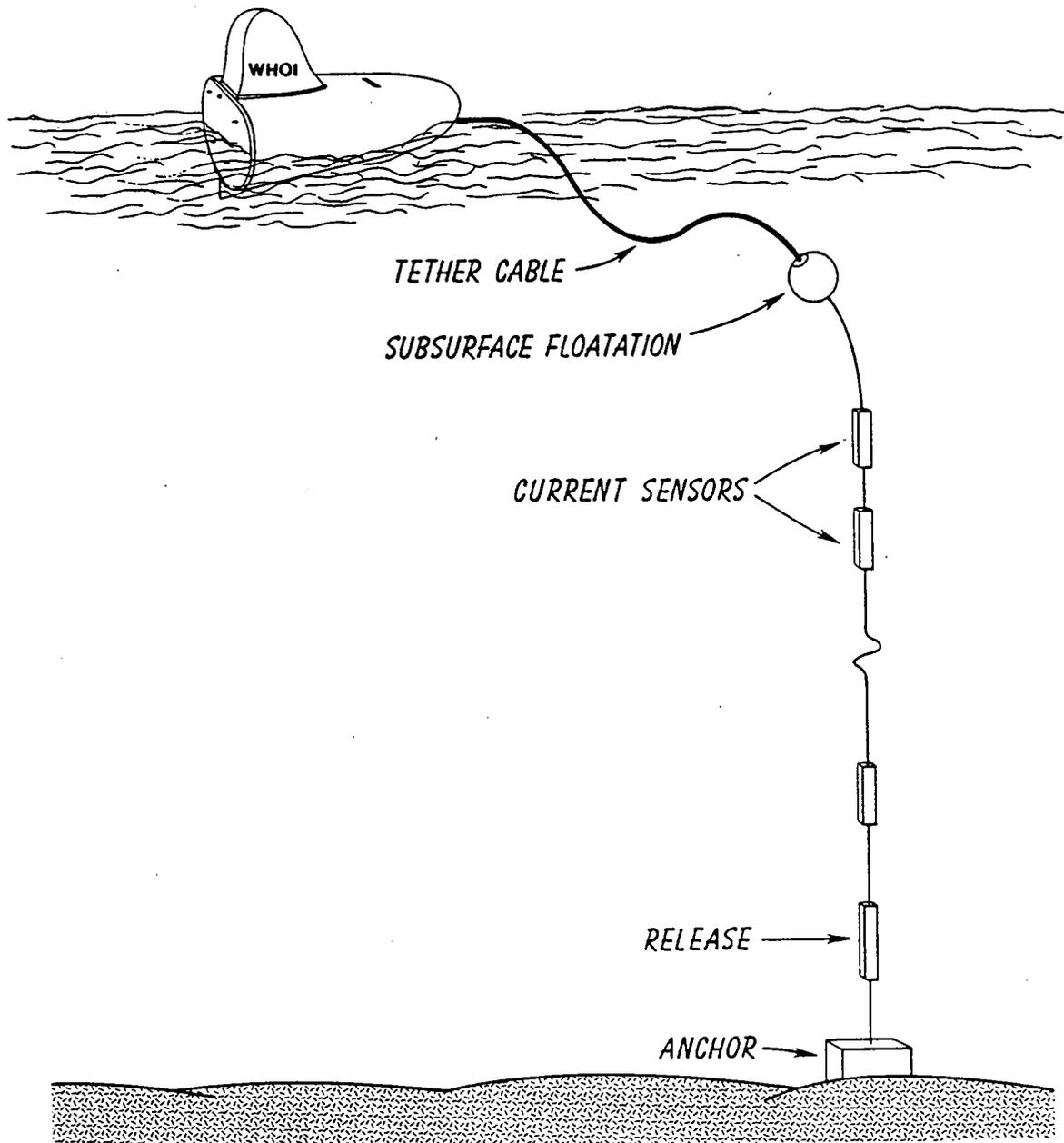


Figure 9: MOIST - Conceptual configuration of the proposed satellite-linked, moored oceanographic instrument system.

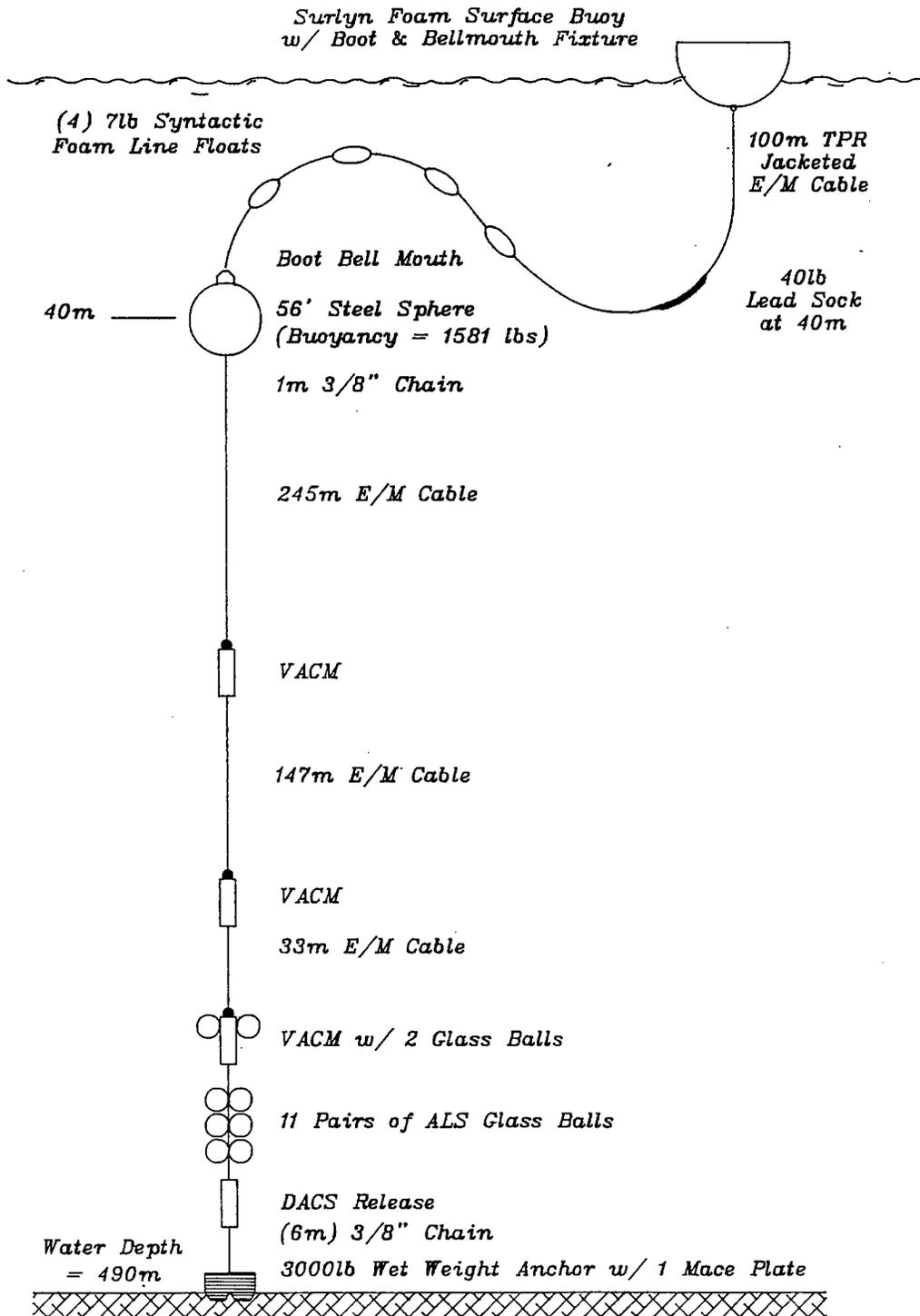


Figure 10 : Abrupt Topography Mooring Schematics

The tether shape follows two different approaches:

1. Concave upward floating tether connected to a surface buoy (MOIST project).
2. S shaped tether connected to a surface buoy as in the TETHERMOOR and ABRUPT TOPOGRAPHY Project.

In general the surface buoy is of small dimensions in order to achieve a low drag profile to current and wind. A real time telemetry transmitter, solar cells, antennae and a light marker are part of the buoy equipment. The tether cable design varies from mooring to mooring but in general includes an armored section as strength member made of Kevlar or steel with electrical conductors placed in the core. A plastic buoyant jacket is extruded over the strength member to provide fishbite protection and the needed buoyancy. The tether "S" shaping is accomplished by placing ballast weights and extra floats in different section of the tether. This weight distribution along the tether prevents tangling during slack current conditions. The main cable used for the subsurface mooring in the TETHERMOOR and ABRUPT TOPOGRAPHY projects is the double armor contrahelical design model manufactured by Consolidated Cable Products (See RTEAM Section 2.2.2, Page 28).

The tether deployed for the TETHERMOOR and ABRUPT TOPOGRAPHY project was built by simply extruding a thermoplastic rubber (TPR) jacket over the main E/M cable made by Consolidated and already described in Section 2.2.2, Page 28. Final features of the tether are:

- overall O.D.: 1.4"
- specific gravity: 1.18

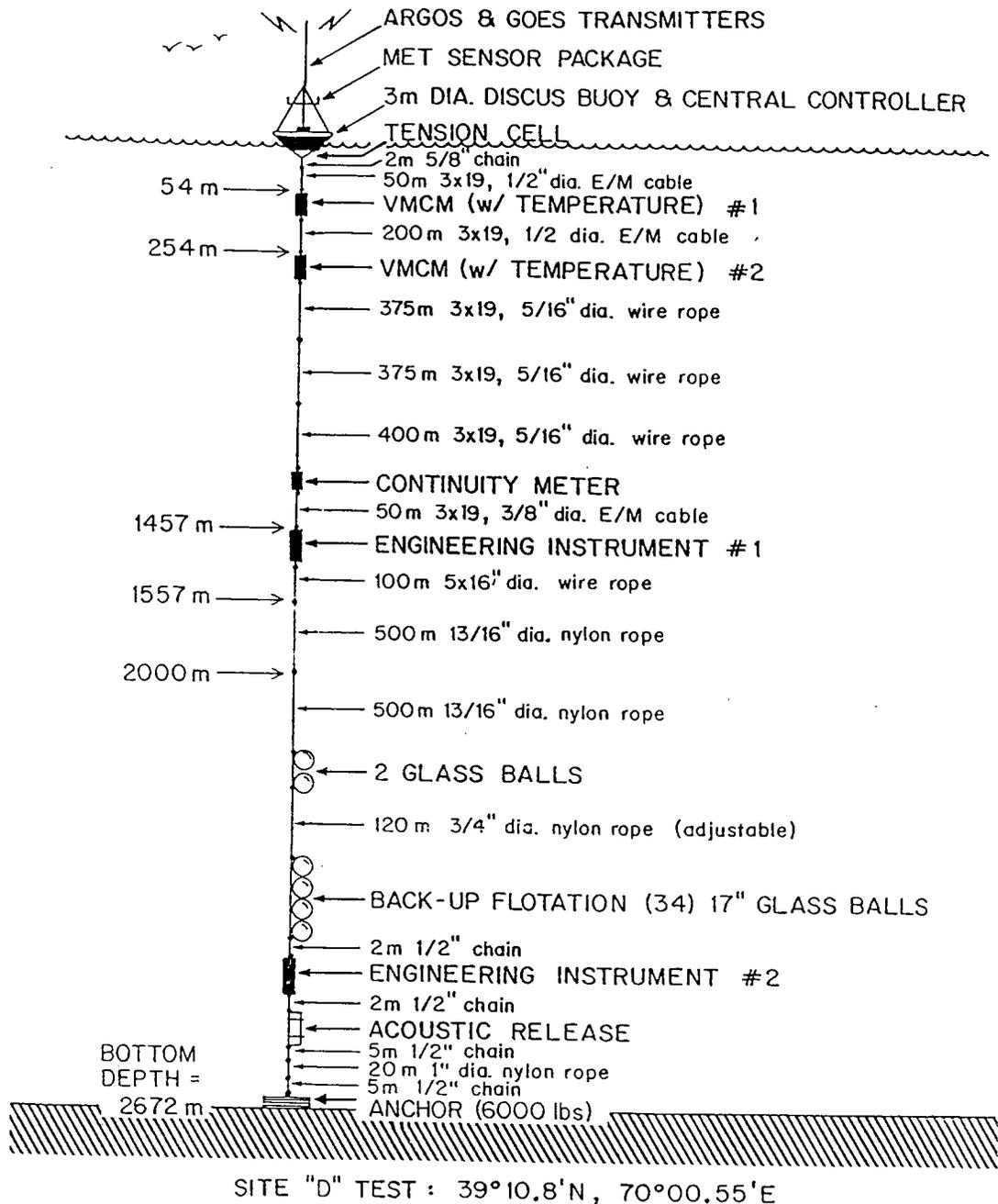
The TPR jacketed tether was selected after several tests performed at the Buoy Farm. At the same time the proper distribution of buoyancy and ballast along the cable was found. The final assembly is terminated at each end with bending strain relief boots made of polyurethane similar to these used for the RTEAM project. The addition of floats at the lower end of the tether and weights at the upper end gives the characteristic S shape.

2.2.4 Surface Moorings

Oceanographic surface moorings are deployed all over the world to collect atmospheric data together with current, temperature and other parameters in the water column. Recently surface moorings have undergone design modifications to permit real time data telemetry transmissions. Such operation can be achieved by hardwiring all the surface and subsurface sensors with E/M cables. Data are then collected by a controller usually located in the surface module and transmitted to shore via satellite links (Argos, Goes, etc.). This satellite linkage also allows for constant monitoring of the surface buoy should it drift away from the known position. The OS&M Lab at WHOI has deployed the Surface Telemetering Mooring (STEM-1987) and the Engineering Surface Mooring (ESOM-1989). Both are representative of a new generation of surface telemetry moorings.

The purpose of the STEM project was to demonstrate the feasibility of collecting and transmitting oceanographic and meteorological data via satellite from a moored surface platform deployed in harsh environment for a long period of time (Reference #4). To this end a taut surface mooring equipped with an array of sensors collecting current, temperature and engineering data was deployed in deep water off the North Atlantic coast (Figure #11). The deployment lasted six months through the worst expected environmental conditions at the site (Winter/Spring).

A special E/M cable, cable to sensor connections and terminations were designed and built for this specific application. The well known 3x19



SURFACE TELEMETRY MOORING (STEM)

NOVEMBER 21, 1987 - MAY 2, 1988

Figure 11: STEM Mooring Schematics

oceanographic wire rope design was chosen as strength member for the E/M cable. Its advantages can be summarized as follows:

- High reliability, as proven by hundreds of deep water mooring deployments;
- Tolerance to wave induced stress, necessary for a surface mooring;
- Ability of being easily interfaced with electrical conductors which can be either placed in the center of the strand or in the valleys between strands.

A high degree of mechanical and fishbite protection is achieved by placing the conductors in the center of the strands. However, this design presents some difficulties at the manufacturing level. In fact, great care must be taken when stranding the cable in order to avoid pinching the central conductors. To avoid this, a thicker and tougher conductor insulation is strongly recommended. The manufacturing of E/M cable with conductors placed in the valleys is less complicated even though some extra protection must be added since the conductors are now located on the outside diameter of the cable. To this purpose a plastic braid or a steel tape can be inserted between the cable and the outside jacket.

A 3x19 E/M cable was built by Consolidated Products Inc. (CA) by inserting 3 conductors in the valleys of a 3/8" 3x19 MacWhyte torque balanced wire rope (Figure 12). The cable specifications are as follows:

TABLE VI

3x19 OCEANOGRAPHIC ELECTROMECHANICAL CABLE SPECIFICATIONS FOR SURFACE APPLICATIONS (STEM)

Cable Denomination/Description

3/8", 3x19 GIPS wire rope construction with (3) #20 conductors
in valleys

Manufacturer

Conductors: Consolidated Products Inc., CA
Wire Rope: MacWhyte Wire Rope Co., Wis.
Cable: Consolidated Products Inc., CA

Conductors

Number of conductors and configuration: (3) conductors, each
one nested in valley between strands.

Gauge: AWG #20

Conductor Material: Stranded copper

Insulation Material: PVC

Thickness: 0.015" wall

Insulation Material: Nylon

Thickness: 0.010" Wall

Electrical specs.

Resistance: 10.47 OHMS/1000 ft.

Voltage: 600 volts

Insulation breakdown: 100 Megaohms/1000 ft. at 500 volts DC

Strength Member

Wire rope construction:

Type: 3x19

Material: GIPS

Number of strands: 3

Strand construction:

Number of Wires: 9

Size: .026" Dia. (Inner layer)

Number of Wires: 9

Size: 0.43" (Outer layer)

Strength

UBS = 14,800 lbs.

Yield strength = 10,500 lbs.

Cable Construction and Dimension

Core: 3x19 3/8" wire rope torque balanced

O.D.: 3/8" Nominal

Armor

O.D.:

Jacket

1st Jacket

Material = Black polyurethane

Thickness = 0.051" (Non Wall)

O.D. = .500"

2nd Jacket

Material = Two layers of steel tape

Thickness = 0.008"

O.D. = .516"

3rd Jacket

Material = High density polyethylene

Thickness = 0.047" wall

O.D. = 0.610"

Overall Outside Diameter: 0.610" (Nom.)

Weight

In air = 360 lbs/1000 ft.

In water = 230 lbs/1000 ft.

Bending Radius: 18"

Cable samples underwent strength and rotation tests, conductor resistance measurements and pressure tests after termination. Following mooring recovery the cable assemblies were carefully inspected and tested for shorts, opens and residual strength. No sign of conductor damage or rope deterioration was found.

A 3x18 E/M cable with conductors placed in the center of the core was also developed. By replacing the king wires with the three conductors fishbite protection is achieved without adding extra protective jackets. The final cable has therefore a smaller diameter and lower drag. The first 3x18 cable prototype (3/8" dia.) did not function properly because one of the conductors had been damaged during wire stranding (Fig. 12). Subsequently the size of the wires was increased leading to the final design with an outer diameter of 7/16" (Fig. 13). 3x18 cable samples with different kinds of termination were electrically and mechanically tested at WHOI and then successfully deployed on the Engineering Surface Oceanographic Mooring (ESOM) project (Ref. 5). The ESOM project was conceived to assess the long term, on site evaluation of new mooring components performed at an open ocean, deep water location (Fig. 14).

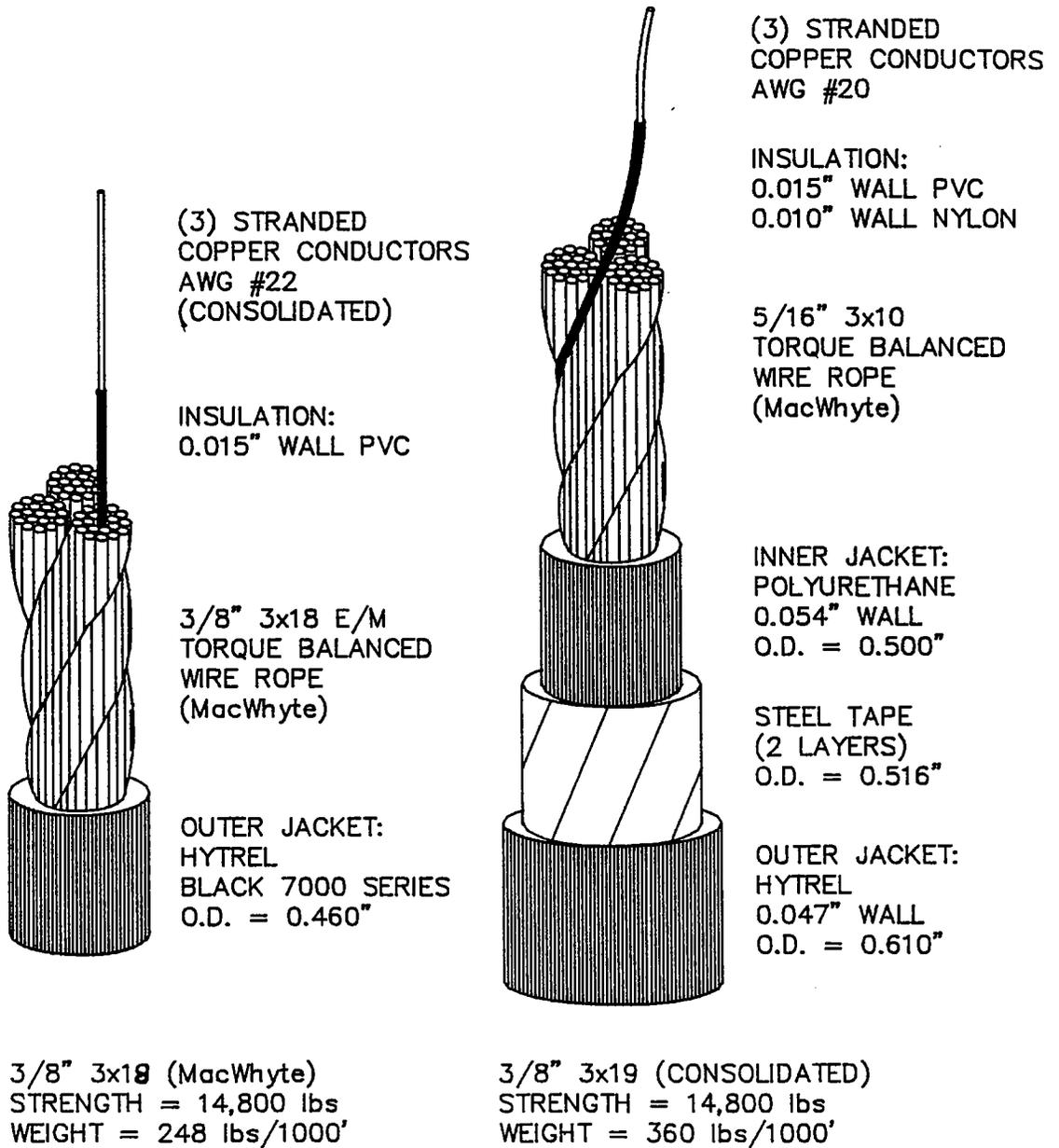


Figure 12: 3 x 18 MacWhyte and 3 x 19 Consolidated E/M Cables

Cable characteristics are as follows:

TABLE VII

**3x18 OCEANOGRAPHIC ELECTROMECHANICAL CABLE SPECIFICATIONS
FOR SURFACE APPLICATIONS (ESOM)**

Cable Denomination/Description

7/16", 3x18 GIPS wire rope construction, with (3) #22 AWG conductors in the center of each strand, covered with extruded HYTREL to 0.518" OD.

Manufacturer

Conductors: Consolidated Products Inc., CA
Wire Rope: ManWhyte Wire Rope Co., Wis.
Cable: Consolidated Products Inc., CA

Conductors

Number of conductors and configuration: (3) conductors, one each in center of rope strand.
Gauge: AWG #22
Conductor Material: Stranded copper
Insulation Material: PVC
Thickness: 0.015" Wall
Max. O.D.: 0.071"
Electrical specs.
Resistance: 16 OHMS/1000 ft.
Voltage: 600 volts
Insulation breakdown: 100 Megaohms/1000 ft. at 500 volts DC

Strength Member

Size: 7x16" (nominal)
Type: 3x19 Wire Rope Construction

Material: Galvanized improved plow steel

Number of strands: 3

Strand Construction: (9) 0.51" dia. wires over (9) .030" dia.
wires

Strength

Ultimate Breaking Strength: 20,000 lbs.

Yield strength: 17,500 lbs.

Cable Construction and Dimension

Core: 3x19 - 7/16" wire rope torque balanced

O.D.: 7/16" (Nominal)

Jacket:

1st Jacket

Material = Black Hytrel

7000 series

Thickness = 0.040" wall

O.D. = 0.518"

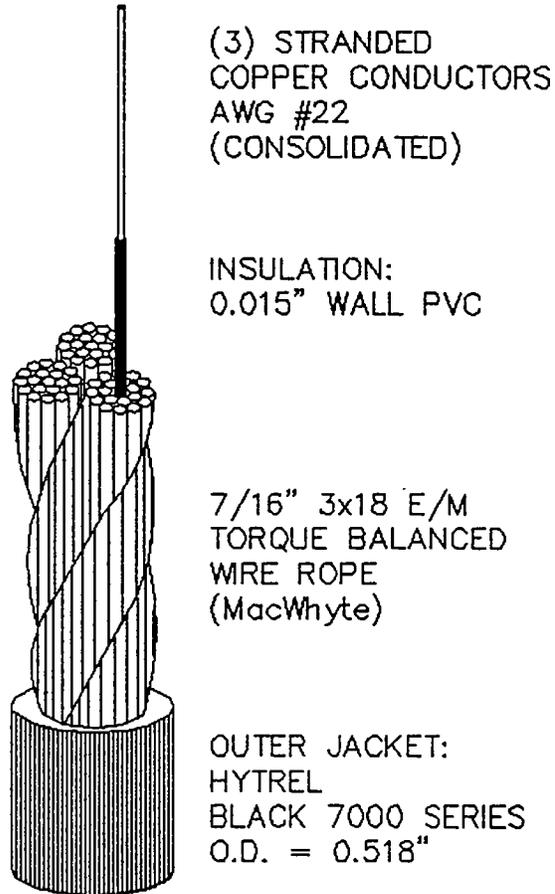
Overall Outside Diameter: 0.518"

Weight

In air = 346 lbs/1000 ft.

In water = 250 lbs/1000 ft.

Samples of 3x18 and 3x19 cables were deployed on ESOM I and ESOM II moorings. Both types performed well on the one year ESOM I mooring (Ref. 6). One 3x18 sample placed on ESOM II failed in what appeared to be corrosion fatigue, after 18 months of exposure, at a cable termination. Detailed results from the ESOM test mooring are being compiled and soon will be available (Ref. 7).



7/16" 3x18 (MacWhyte)
STRENGTH = 20,000lbs
WEIGHT IN AIR = 346lbs/1000'
WEIGHT IN WATER = 250lbs/1000'

Figure 13: 3x18 - 7/16" E/M Cable

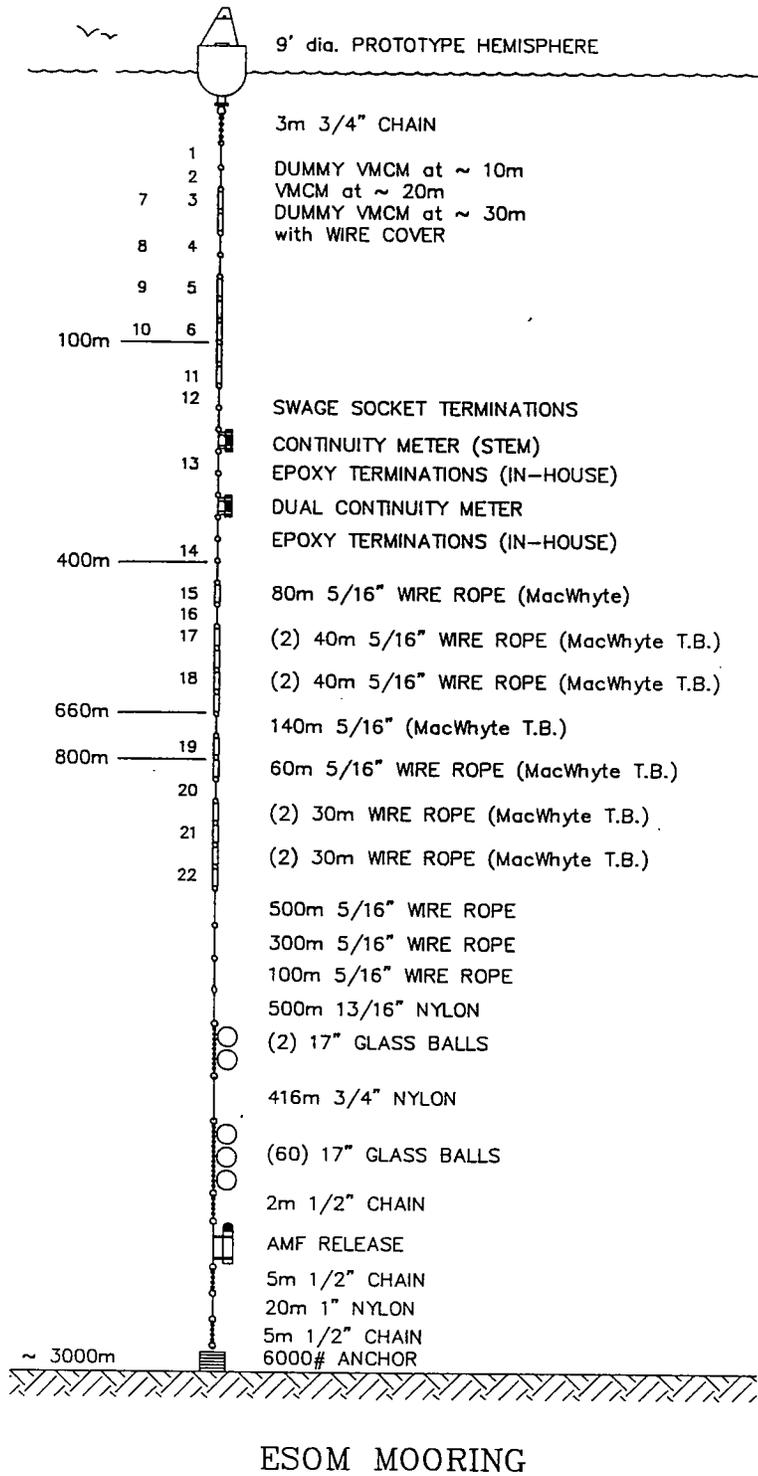


Figure 14: ESOM Mooring Schematics

REFERENCES

1. Berteaux, H.O., Prindle, B., "Deep Sea Moorings Fishbite Handbook," Woods Hole Oceanographic Institution Tech. Report, WHOI-87-8.
2. Walden, R.G., Berteaux, H.O., "Free Drifting Relays Buoy Systems," presented at Buoy Technology Symposium, 1983, New Orleans.
3. Bocconcelli, A., Editor. 1987. "Real Time Environmental Arctic Monitoring (RTEAM)," Woods Hole Oceanographic Institution Tech. Report, WHOI-87-50.
4. Berteaux, H.O., Frye, D.E., Clay, P.R., Mellinger, E.C., "Surface Telemetry Engineering Mooring (STEM)," presented at IEEE Oceans '88, September 1988.
5. Bocconcelli, A., "Engineering Surface Oceanographic Mooring (ESOM)," presented at IEEE Oceans '89, September 1989.
6. Berteaux, H.O., Prindle, B., Putnam, S., "Monitoring Fishbite Activities and Protecting Synthetic Fiber Ropes Used in Deep Sea Moorings," presented at MTS '90, September 1990.
7. Berteaux, H.O., Bocconcelli, A., Prindle, B., "ESOM I and ESOM II Results," Woods Hole Oceanographic Institution Tech. Report, WHOI-91- (in preparation).

DOCUMENT LIBRARY

January 17, 1990

Distribution List for Technical Report Exchange

Attn: Stella Sanchez-Wade
Documents Section
Scripps Institution of Oceanography
Library, Mail Code C-075C
La Jolla, CA 92093

Hancock Library of Biology &
Oceanography
Alan Hancock Laboratory
University of Southern California
University Park
Los Angeles, CA 90089-0371

Gifts & Exchanges
Library
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS, B2Y 4A2, CANADA

Office of the International
Ice Patrol
c/o Coast Guard R & D Center
Avery Point
Groton, CT 06340

NOAA/EDIS Miami Library Center
4301 Rickenbacker Causeway
Miami, FL 33149

Library
Skidaway Institute of Oceanography
P.O. Box 13687
Savannah, GA 31416

Institute of Geophysics
University of Hawaii
Library Room 252
2525 Correa Road
Honolulu, HI 96822

Marine Resources Information Center
Building E38-320
MIT
Cambridge, MA 02139

Library
Lamont-Doherty Geological
Observatory
Columbia University
Palisades, NY 10964

Library
Serials Department
Oregon State University
Corvallis, OR 97331

Pell Marine Science Library
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882

Working Collection
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Library
Virginia Institute of Marine Science
Gloucester Point, VA 23062

Fisheries-Oceanography Library
151 Oceanography Teaching Bldg.
University of Washington
Seattle, WA 98195

Library
R.S.M.A.S.
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Maury Oceanographic Library
Naval Oceanographic Office
Bay St. Louis
NSTL, MS 39522-5001

Marine Sciences Collection
Mayaguez Campus Library
University of Puerto Rico
Mayaguez, Puerto Rico 00708

Library
Institute of Oceanographic Sciences
Deacon Laboratory
Wormley, Godalming
Surrey GU8 5UB
UNITED KINGDOM

The Librarian
CSIRO Marine Laboratories
G.P.O. Box 1538
Hobart, Tasmania
AUSTRALIA 7001

Library
Proudman Oceanographic Laboratory
Bidston Observatory
Birkenhead
Merseyside L43 7 RA
UNITED KINGDOM

REPORT DOCUMENTATION PAGE	1. REPORT NO. WHOI-91-02	2.	3. Recipient's Accession No.
4. Title and Subtitle Development and Evaluation of Electromechanical Cables for Deep Sea Buoy Applications			5. Report Date January 1991
7. Author(s) A. Bocconcelli			6.
9. Performing Organization Name and Address Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543			8. Performing Organization Rept. No. WHOI-91-02
12. Sponsoring Organization Name and Address Office of Naval Research			10. Project/Task/Work Unit No.
			11. Contract(C) or Grant(G) No. (C) N00014-84-C-0134 (G)
15. Supplementary Notes This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept., WHOI-91-02.			13. Type of Report & Period Covered Technical Report
16. Abstract (Limit: 200 words) Electromechanical (E/M) cables have been developed in order to satisfy the growing need for real time data telemetry from oceanographic moorings. Several E/M cable designs have been implemented with the cooperation of private industry in order to accommodate E/M cable requirements for different mooring experiments. Surface and subsurface E/M cable applications are discussed with reference to WHOI Projects (ESOM, STEM, RTEAM). Floating tether and their special designs (concave up, S-tether) are also illustrated together with an evaluation of their performance at sea (RTEAM, MOIST, TETHERMOOR, ABRUPT TOPOGRAPHY). Data from material tests performed by the OS&M Laboratory are reported in seven separate tables.			14.
17. Document Analysis			
a. Descriptors electromechanical cable mooring			
b. Identifiers/Open-Ended Terms			
c. COSATI Field/Group			
18. Availability Statement Approved for public release; distribution unlimited.	19. Security Class (This Report)		21. No. of Pages 47
	20. Security Class (This Page)		22. Price