DEPARTMENT OF COMMERCE • NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL OCEAN SURVEY

SEA LANES TEST-OPERATIONS REPORT

National Data Buoy Systems
NDBCM W6222-1

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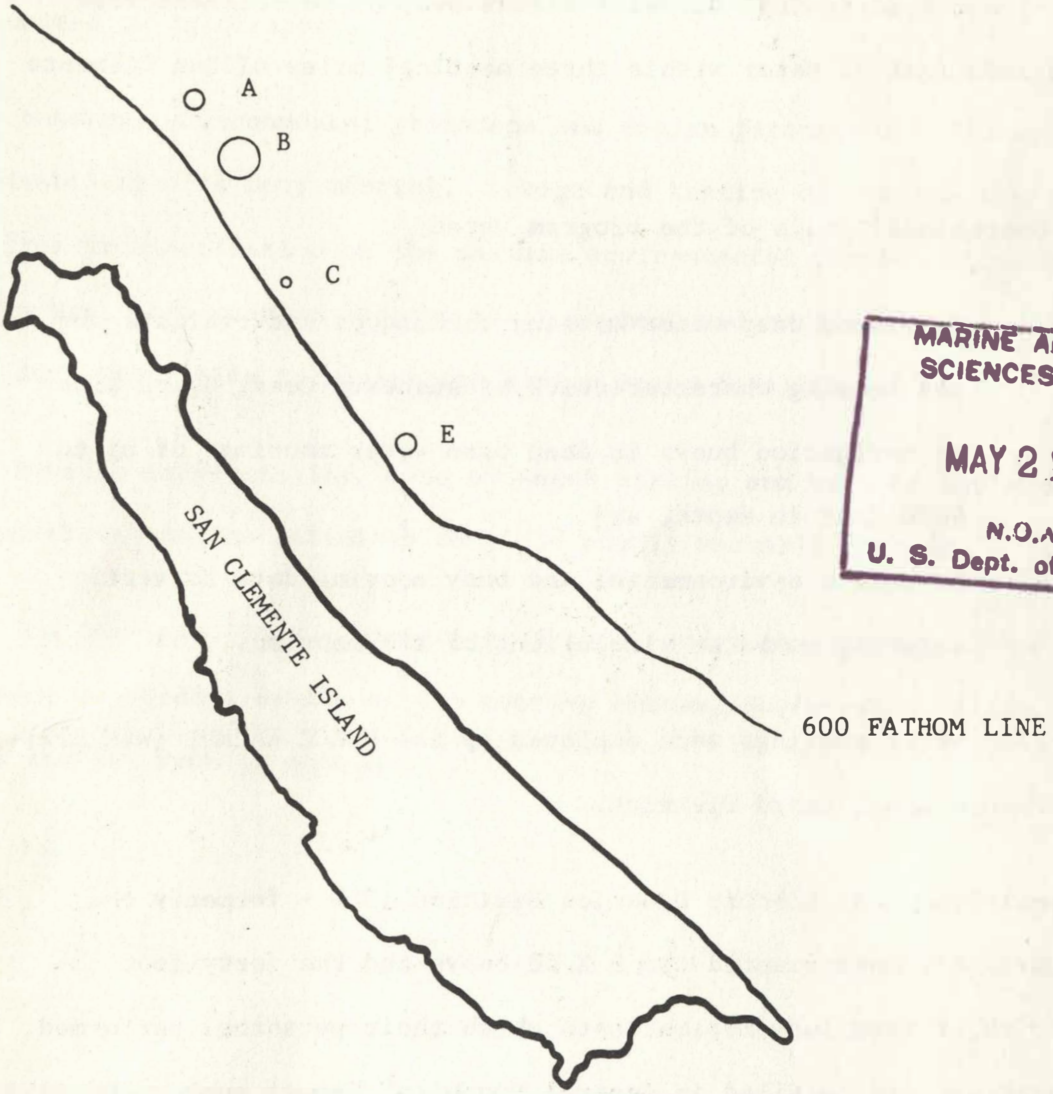
SEA LANES TEST - OPERATIONS REPORT



NATIONAL DATA BUOY CENTER
JULY 1971
MISSISSIPPI TEST FACILITY
BAY SAINT LOUIS, MISS. 39520

ABSTRACT

The Sea Lanes Buoy Project was an operational experiment performed northeast of San Clemente Island, California between November 1969 and September 1970. During this test, four aids to navigation buoys (9 X 38 LR) and a forty foot diameter discus buoy of ferrocement were moored in 3600 feet of water within three nautical miles of San Clemente Island.

The Operational Goals of the program were:

1. To extend deep water mooring techniques and evaluate the sea keeping characteristics of standard Coast Guard aids to navigation buoys in deep open water moorings of up to 4000 feet in depth, and
2. to obtain environmental and buoy mooring data to verify existing computer simulations of the moorings.

All deep water moorings were deployed by the USCGC WALNUT (WLM 252) of the Eleventh Coast Guard District.

General Dynamics' Electro Dynamics Division (EDD - formerly the Convair Division) instrumented two 9 X 38 buoys and the forty foot discus for short term buoy motion tests which their personnel performed. These operations are detailed in General Dynamics" Report number GDC-AAX70-020 entitled "Sea Lanes Test Program Final Report".[19*]

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*Numbers refer to references at the end of this report

Long term mooring line tension was recorded by self contained tensiometers. This data has been reduced by National Data Buoy Center personnel. Information obtained from the long term tension traces, buoy position plots, operational deployments and several tests of nylon line properties have been documented in this report.

Numerous environmental phenomena and design parameters influence the survivability of a buoy mooring. Design and testing of the Sea Lanes' moorings from estimation of the maximum environmental forces, calculation of the base line mooring length, to deployment and retrieval have shown this deep water aids to navigation system to be feasible.

Mooring survivability, size of watch circle, and ease of deployment and retrieval can be optimized to yield highly workable systems.

The Sea Lanes Test - Operations Report covers the origins of this Project, its goals, design of the mooring system, performance of the tests and the results obtained.

ACKNOWLEDGEMENTS

This report represents the culmination of two and one-half years of implementation and testing of deep water aids to navigation buoy systems on the Sea Lanes Buoy Project.

The Project was jointly sponsored by the United States Coast Guard Offices of Aids to Navigation (OAN) and Ocean Engineering (EOE), the National Plan for Navigation Project and the National Data Buoy Project (NDBP).

The author would like to thank these organizations, the Commander Eleventh Coast Guard District, the Officers and men of the USCGC WALNUT (WLM 252), the Commanding Officer, Naval Underwater Research and Development Center - San Clemente Island and the Commander, Naval Electronics Laboratory Center, San Diego for their contributions to this Program.

PATRICK J. HARTMAN

July 1971

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Section 1

INTRODUCTION

The Sea Lanes Buoy Project was an operational test jointly sponsored by the United States Coast Guard Offices of Aids to Navigation (OAN) and Ocean Engineering (EOE), the National Plan for Navigation Project (NNP) and the National Data Buoy Project (NDBP). NDBP personnel managed the Project from its inception in December 1968 until completion in October 1970.

This Report, the "Sea Lanes Test - Operations Report" deals primarily with the origins of the Project, its goals, operational performance and the conclusions which can be drawn from its findings.

1.1 ORIGINS OF THE PROJECT

During November and December of 1968, the Project Managers of the National Plan for Navigation (NNP) and the National Data Buoy Systems (NDBS) corresponded concerning the feasibility of implementing a deep water sea lanes buoy system as an alternate to area coverage electronic systems.[1,2]

From this correspondence and subsequent meetings, personnel and funds were committed to testing the state-of-the-art in deep ocean moorings. The Sea Lanes Buoy Program was conceived during this period and designed in detail during the following months.

1.2 OBJECTIVES OF PROJECT

Several aspects of the deployment of aids to navigations buoys in waters deeper than 300 feet deserve investigation. The Sea Lanes Buoy Project was initiated to examine the critical design and operational aspects of these moorings.

A reliable aid to navigation buoy is required to survive extreme environmental conditions and remain within a reasonable watch circle.

The design of such a buoy system must consider two "worst cases", one of maximum environment and one minimum sea action in which a long nylon mooring could drag and chafe on the bottom.

Information on these and many other aspects of deployment, operation, and retrieval of this deep water buoy system is available as a result of the Sea Lanes Project.

1.3 AREAS REPORTED ON

The Sea Lanes Test - Operations Report covers:

1. the origins of the Project,
2. its goals,
3. performance of the tests,
4. findings (listed by goal), and
5. conclusions drawn from this engineering experiment.

Section 2

PROGRAM GOALS

2.1 BASIC PROGRAM GOALS

Internal Coast Guard correspondence and discussions during November and December 1968 lead to detailed analysis of the problems of mooring buoys in deep water. Statement of basic test goals for the Sea Lanes Test Program and detailed design of the deep water mooring systems followed. During June and July of 1969, letters from the Manager of the National Data Buoy Project to the Coast Guard Chief of Staff and the Chief of the Office of Engineering detailed the basic program goals as follows:

1. to extend Coast Guard expertise in the area of operational deep sea moors,
2. establish liaison with Coast Guard operating units prior to the major NDBP test programs,
3. provide data for validation of a static mooring computer solution developed by EOE,
4. investigate mooring design factors associated with deep water moorings, and
5. provide data for validation and exercise of a dynamic numerical mooring simulation being developed by the Office of Naval Research (ONR) at Convair-General Dynamics.

2.2 FINALIZED PROGRAM GOALS

Procurement of the Sea Lanes Buoys and mooring equipment took place during July and August of 1969. In October, General Dynamics - Electro Dynamics Division (formerly Convair Division) was requested to propose methods of aiding the NDBP in the Sea Lanes Program. This aid was primarily in performing operational tests on Sea Lanes Buoys at San Clemente Island. The purpose of these tests was to obtain and analyze the dynamic data necessary for validation of the Office of Naval Research - Convair dynamic mooring simulation. The finalized program goals reflect this approach.

FINALIZED PROGRAM GOALS:

2.2.1 PRIMARY OBJECTIVES:

1. Evaluate the sea keeping characteristics of standard Coast Guard aids to navigation buoys in deep, open water moorings to 4000 feet in depth,
2. extend Coast Guard and NDBP operational experience with deep, open water mooring and testing techniques, and
3. obtain performance data on candidate mooring line materials.

2.2.2 SECONDARY OBJECTIVE:

Obtain data to validate the existing static models developed by the USCG and Convair for Hull/Mooring analysis.

2.2.3 TERTIARY OBJECTIVE:

Obtain data to validate the existing ONR-Convair dynamic models for Hull/Mooring analysis.

Section 3

PERFORMANCE OF THE SEA LANES PROJECT

Section three details the implementation of the Sea Lanes Project. The areas of interest covered are:

1. selection of the test site - San Clemente Island,
2. preparation for the buoy/mooring tests including detailed analysis of the mooring design,
3. deployment and retrieval operations, and
4. test procedures at San Clemente Island.

3.1 SELECTION OF TEST SITE

San Clemente Island is located approximately 60 miles off the Coast of California. It is nearly equidistant from Los Angeles and San Diego. Sailing time from Base Terminal Island at Long Beach, in the Eleventh Coast Guard District is six (6) hours. Flying time is one (1) hour by helicopter from the Coast Guard Air Station in San Diego. The U. S. Naval Under Sea Research and Development Center located on San Clemente Island (NUC SCI) provides food, lodging, ground and sea transportation, public works forces and technical assistance at San Clemente Island. A Government Contract airline provides round trip service from Long Beach Airport to San Clemente Island once daily on week days.

The San Clemente Island area has been the site of many previous Navy and Government-wide programs including the Sea Lab III and DSRV Projects.

Bottom contours, sediments, and ocean currents are well documented in reports such as the Naval Oceanographic Office's Bottom Environmental Survey Reports IR No. 67-77 and 68-20 (References 24 & 25) the Oceanographic Data Report - San Clemente Island Area October to December 1966 and July and August 1967.

The Island provided several unique environmental advantages to the Sea Lanes Project. Deep water is available within three nautical miles along the length of the Island. Near Wilson Cove, the primary location of Naval facilities, the bottom slopes away at nearly 18^o to the Santa Barbara Basin (650 fathoms) two and one-half nautical miles off shore. (See Figure 3.1-1).

The availability of Coast Guard Tender support at Base Terminal Island, San Clemente Island's environment and Naval facilities provided an advantageous combination.

3.2 PREPARATION FOR BUOY/MOORING TESTS

Liaison with the Offices of Ocean Engineering (EOE) and Aids to Navigation (OAN) provided operational support and portions of the funding on the Sea Lanes Project. The tests were jointly sponsored and funded by EOE, NDBP, NNP and OAN.

3.2.1 DESIGN OF THE MOORINGS

Many factors influence the design of a deep ocean mooring:

1. the environment - winds, waves, currents, marine fouling, and fish bite,

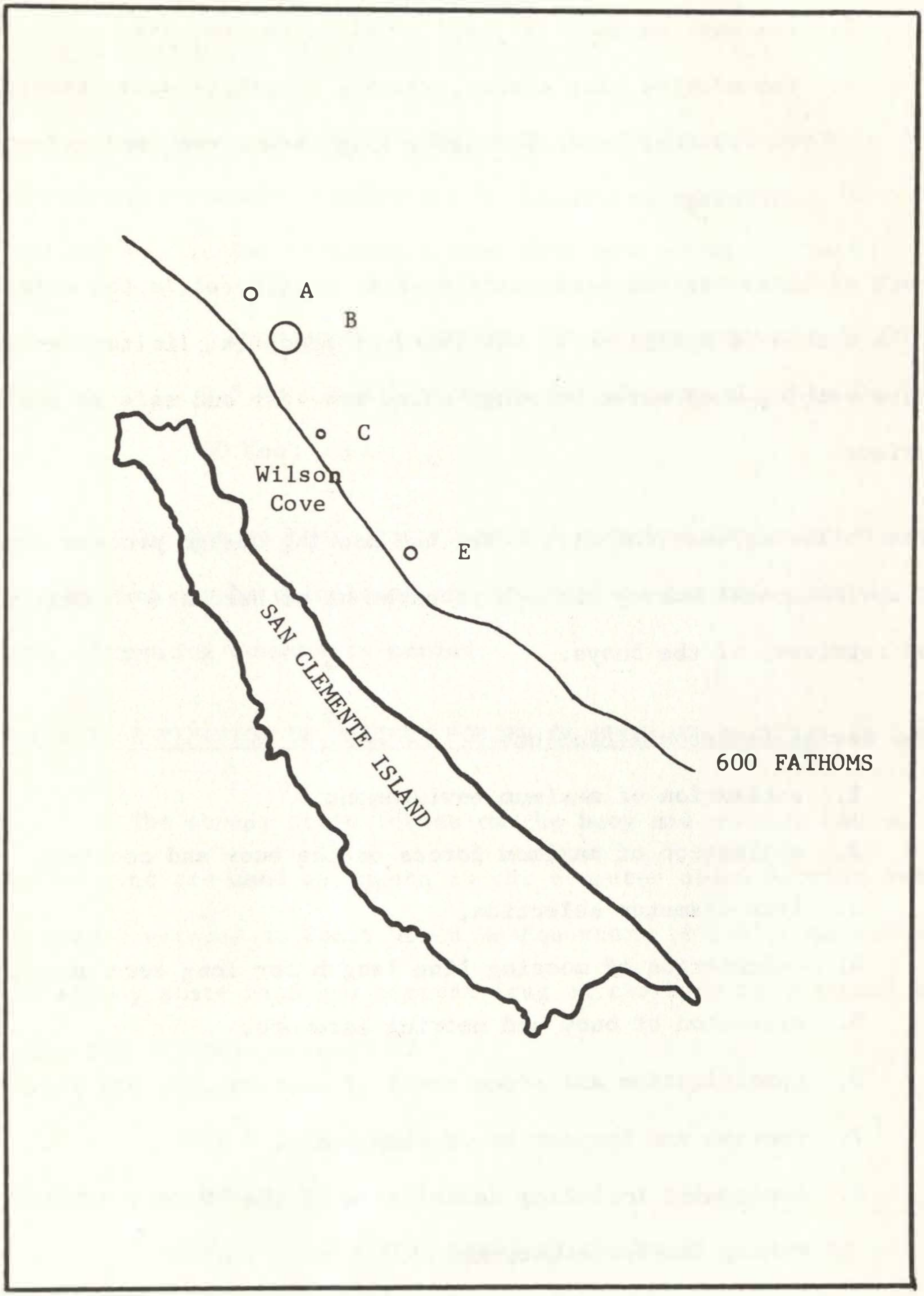


FIGURE 3.1-1 SAN CLEMENTE ISLAND LIGHTED TEST BUOYS

2. the mooring material used - nylon, dacron, and
3. the mooring line's size, weight, length (scope), stretch on loading, break strength, long term creep, and nylon shrinkage in water.

Each of these various parameters must be considered in the overall design. A system is optimized in the light of practical limitations to yield surviveable, deep water moorings which are easy and safe to deploy and retrieve.

The following sections will cover the mooring design process from the initial environmental survey through procurement of hardware to deployment and retrieval of the buoys.

The design report will follow:

1. estimation of maximum environment,
2. estimation of maximum forces on the buoy and mooring,
3. line diameter selection,
4. calculation of mooring line length for long term moors,
5. selection of buoy and mooring hardware,
6. specification and procurement of mooring line and hardware,
7. receipt and inspection of components,
8. deployment including description of the "WALNUT METHOD" Faking Box Technique, and
9. retrieval operations.

3.2.2 SIZING AND SELECTION OF MOORING COMPONENTS

3.2.2.1 ESTIMATION OF MAXIMUM ENVIRONMENT

Survival of a deep water buoy system depends largely on the maximum environmental conditions in the deployment area. The winds and currents at San Clemente Island have been shown to reach:[24, 25]

2 Knot surface current (depth approximately 0-100 feet)
0.5 Knot tidal currents (depth approximately 0-1200 feet)
60 Knot winds

The forces these environmental extremes impose on the buoy and mooring can be calculated and employed to determine the size and type of mooring components needed.

3.2.2.2 ESTIMATION OF MAXIMUM FORCES ON BUOY AND MOORING

The steady state forces on the buoy and mooring caused by wind and current are used as inputs in the computer aided mooring design program developed at Coast Guard Headquarters (EOE-3). An estimate of the steady state wind and current drag on the buoy is obtained by using the following equation:

$$F_D = \tfrac{1}{2}\, p\, C_D\, A\, V^2$$

Where:

F_D - is the drag force on the buoy (pounds)

p - is the density of the media

$$p \text{ for sea water} = \frac{64 \ \text{lb}_m/\text{ft}^3}{32.2 \ \text{ft/sec}^2 \cdot \text{lb}_f/\text{lb}_m}$$

$$p \text{ for air} = \frac{0.0808 \ \text{lb}_m/\text{ft}^3}{32.2 \ \text{ft/sec}^2 \cdot \text{lb}_f/\text{lb}_m}$$

C_D - is the drag coefficient

For the underwater portion of A, $C_D = 0.9$ to 1.05

(Determined in reference 21)

For a Synthetic mooring line, $C_D = 1.2$ to 1.9

A - is the projected area (square feet)

V - is the velocity (feet per second)

The Coast Guard computer simulation performs an engineering analysis of the static mooring system under "worst case" environmental conditions.[30] The computer needed inputs are:

1. Environmental:
   - Water Depth
   - Current Profile (2 - Dimensional)
   - Estimated Current and Wind Drag on Buoy
2. Mooring Parameters:
   - Distance below the surface of mooring point on the buoy
   - Number of Line Sections
   - Line Properties:
     - Length
     - Diameter
     - Cross Sectional Area
     - Modulus of Elasticity (linearized)
     - Weight Per Unit Length in Water
     - Rated Breaking Strength

3. Properties of Attached Objects:

    Position on Line

    Weight (or Buoyancy)

    Effective Projected Area

As the buoy mooring is modeled on the IBM 1130 at Coast Guard Headquarters, the following results are displayed and recorded:

1. Documentation of Input Data
2. Required Buoyancy of the Buoy
3. Tension and Line Angle at the Buoy
4. Tension and Line Angle at the Anchor
5. Buoy Excursion
6. Total Mooring Length Including Stretch
7. Location and Severity of the Weakest Link in Mooring
8. Curves Showing the Mooring Line and the Current Profiles

3.2.2.3 LINE SIZE SELECTION

The Nation's cordage manufacturers recommended normal working loads of less than 11 percent of a mooring line's rated breaking strength. Extreme loads of not more than 30 percent are allowed. Military specifications for double-braided, MIL-R-240505A (20 January 1967), and plaited nylon rope, MIL-R-24337 (ships) (17 June 1968), set the minimum breaking strengths at:

	Double-Braided	Plaited
1 inch diameter	25,000 pounds	25,000 pounds
1¼ inch diameter	40,000 pounds	38,000 pounds

The Sea Lanes Buoy Program tested double-braided nylon lines from Samson Cordage and Tubbs Great Western plus eight strand plaited nylon line from Columbian Rope Company. Handling and deployment tests yielded the following information:

1. No significant handling problems occurred with either type of line.
2. Plaited line is easier to grasp by hand because of its large, stranded construction.
3. Double-braided line can be made up in very long, continuous lengths.
4. If constructed with improper core and cover tensions, double-braided line can loose shape when working tension is applied and/or be very limp to handle under no load. (Not encountered on The Sea Lanes Test).
5. Nylon line is basically purchased by the pound. Eight strand plaited construction weighs less per foot for a given diameter than double-braided does. Line selection based on strength is recommended.

6. Double-braided and plaited construction have widely different load-elongation characteristics. The plaited construction stretches more under a given load.
7. Nylon line looses 15% of its strength in the sea due to water breaking down the molecular bonds in nylon.
8. Nylon may shrink up to 10% in water. This is a function of time, temperature and line tension.
9. Long term creep appears to be a purely material problem of nylon. (Reference 20). It amounts to approximately 2.5%.

3.2.2.4 SELECTION OF BUOY AND MOORING HARDWARE

BUOY SELECTION

As can be seen in Section 4.2.2, the maximum launch transient approaches the combined weight in water of the sinker, mooring line, chain and hardware. This deployment tension may exceed the reserve buoyancy of some buoys under consideration for traffic lanes, particularly the 8X26 LWR. (See Table 3.2.2-1). 9 x 38 LW's were used on the Sea Lanes Tests. These particular buoys had reserve buoyancies of approximately 12,000 pounds.

The mooring design employed must coordinate specification of mooring length, buoy handling and line deployment. This approach is needed to keep from exceeding 30% of the line's break strength or submerging the buoy.

Section 4.1 shows that the minimum line tensions of taut moored traffic lanes buoys fall well within the working load range of 8 x 26 LR's, LBR's and LGR's.

8X26 LWR

Working Load (1½ inch chain)

90 feet X 13.9 pounds per foot = 1250 pounds

Freeboard

12 inchex X 230 pounds per inch = 2760 pounds

Maximum Reserve Buoyancy: 4010 pounds

8X26 LR

Working Load (1½ inch chain)

360 feet X 13.9 pounds per foot = 5000 pounds

Freeboard

12 inches X 270 pounds per inch = 3240 pounds

Maximum Reserve Buoyancy: 8240 pounds

8X26 LBR and LGR

Working Load (1½ inch chain)

300 feet X 13.9 pounds per foot = 4170 pounds

Freeboard

12 inches X 270 pounds per inch = 3240 pounds

Maximum Reserve Buoyancy: 7410 pounds

TABLE 3.2.2-1 MAXIMUM RESERVE BUOYANCY OF 8X26 BUOYS

FROM CG-250-17D

HARDWARE SELECTION

Standard Coast Guard hardware can be used for deep water moorings. This includes split keyed shackles, swivels, chain and concrete sinkers as seen in Figures 4.2.1-1 to 4.2.1-7. The shackles used on the test buoys were sized to fit the line thimbles and insure proper bearing surfaces.

Material compatibility must be considered in selection of mooring line hardware. Mild steel shackles, swivels and chain are galvanically compatible in sea water. They deteriorate at a slow, constant rate. Rusting steel, however, is detrimental to nylon line. This precludes the use of galvanized thimbles for long term deployments.

Captive bronze thimbles were chosen for the Sea Lanes Project. The bronze and mild steel combination is compatible when the area of exposed bronze is small compared to that of the steel. "Deterioration of either material is normally within tolerable limits".* [29]

SINKER SELECTION

Selection of the proper sinker for a deep water mooring depends heavily upon the environmental forces which will be encountered and bottom conditions of the deployment area. Determining the holding power of a concrete sinker is difficult. The coefficient of friction between the sinker and the bottom varies widely from 0.5 to 2.5 or higher if "sanding in" occurs. A coefficient of friction of units is a good starting assumption. Holding power thus equals the weight in water of the sinker minus the vertical component of mooring line tension.

---

*International Nickel Company
Galvanic Corrosion Indicator for Materials in Sea Water at 40 - 80°F

DRY CONCRETE SINKER WEIGHT	WEIGHT IN WATER
5000 pounds	2920 pounds
8500 pounds	4900 pounds
10000 pounds	5830 pounds

The long term tension traces of buoy D during November and December 1969, along with data from Woods Hole Oceanographic Institution (WHOI) (Section 4.1.2) indicate that the anchors of taut mooring systems may drag under high loadings. It may be necessary to use a concrete sinker and a burial type of anchor (danforth) on each mooring because the large vertical component of the line tension reduces the sinker's horizontal holding power.

3.2.3 CALCULATION OF MOORING LINE LENGTH

Designing a deep water mooring is no easy task. Two environmental extremes must be considered. The maximum force environment has been studied in Sections 3.2.2.1 and 3.2.2.2

The second extreme, which affects mooring survivability, is the nearly calm sea state in which the nylon line might drag along the bottom.

This problem can be eliminated by a mooring designed to keep a number of feet of the bottom chain suspended at all times.

3.2.3.1 SYNTHETIC LINE PROPERTIES IN WATER

The moorings employed in the Sea Lanes Project were constructed of nylon line. Nylon is nearly neutrally buoyant (specific gravity 1.14).

Several natural phenomena associated with nylon must be considered in calculation of the mooring length. These phenomena are discussed in the order in which they would occur during deployment.

SUNLIGHT AND RUST

Extended exposure to sunlight causes yellowing of the manufacturer's lubricant coatings on the nylon fibers. Exposure to the ultra violet portion of sunlight also breaks apart the molecular chains in nylon thereby reducing the strength of the affected fibers.

Dragging a nylon line over the rust on a buoy deck can cause a long term chemical reaction between rust and nylon. This yields a slight reduction in strength.

PERMANENT ELONGATION UPON LAUNCH

Launch transients appear to be the largest forces the mooring line encounters throughout its lifetime. (See Section 4.2.2)

During the Sea Lanes tests at San Clemente Island, launch tensions exceeded 5000 pounds (approximately 18% of rated break strength for a one inch diameter line). This tension caused an estimated permanent elongation of 4.5% for a double braided construction and 12% for an 8 strand plaited line. These figures are approximate. Both material and line construction affect permanent elongation.

Direct testing of a lines load-elongation properties will yield the data needed for precise calculation of a mooring's on-shore length. These tests should be done under the exact working conditions that the line will experience.

NYLON CREEP

Tests at the U. S. Coast Guard Academy have shown creep in nylon to be a time dependent material property. Creep is independent of load. After a number of days under load (3), dry 7/16 inch diameter nylon lines crept to approximately 2.5 to 3%. They remained at that length for the duration of the test.

STRENGTH REDUCTION IN WATER

Water molecules (acting as a solvent) break apart many of the molecular chains in nylon. This reduces the overall strength by 15%. When a line has dryed it regains the lost strength. This indicates just one more reason for testing mooring lines under conditions as close to actual deployment as possible.

PERMANENT ELONGATION DUE TO WORKING LOADS

As a line is repeatedly loaded in use, each strand and fiber works itself into a closer packed structure. Most of the permanent (at a given load) elongation occurs during the first few cycles (50).

NYLON SHRINKAGE

Mooring line shrinkage is a time and temperature dependent material phenomena. It occurs in nylon but not dacron. Shrinkage can be as much as 10% of the total length. It may increase tension in the line a corresponding 10%. In cold water shrinkage can take months. Line manufacturers "stabilize" nylon line by passing it through hot water or steam during manufacture.

LOAD ELONGATION TEST

To eliminate much of the confusion associated with synthetic line phenomena, the load-elongation test in Figure 3.2.3-1 has been devised. Each run of new line should be tested in water by the manufacturer for the following information:

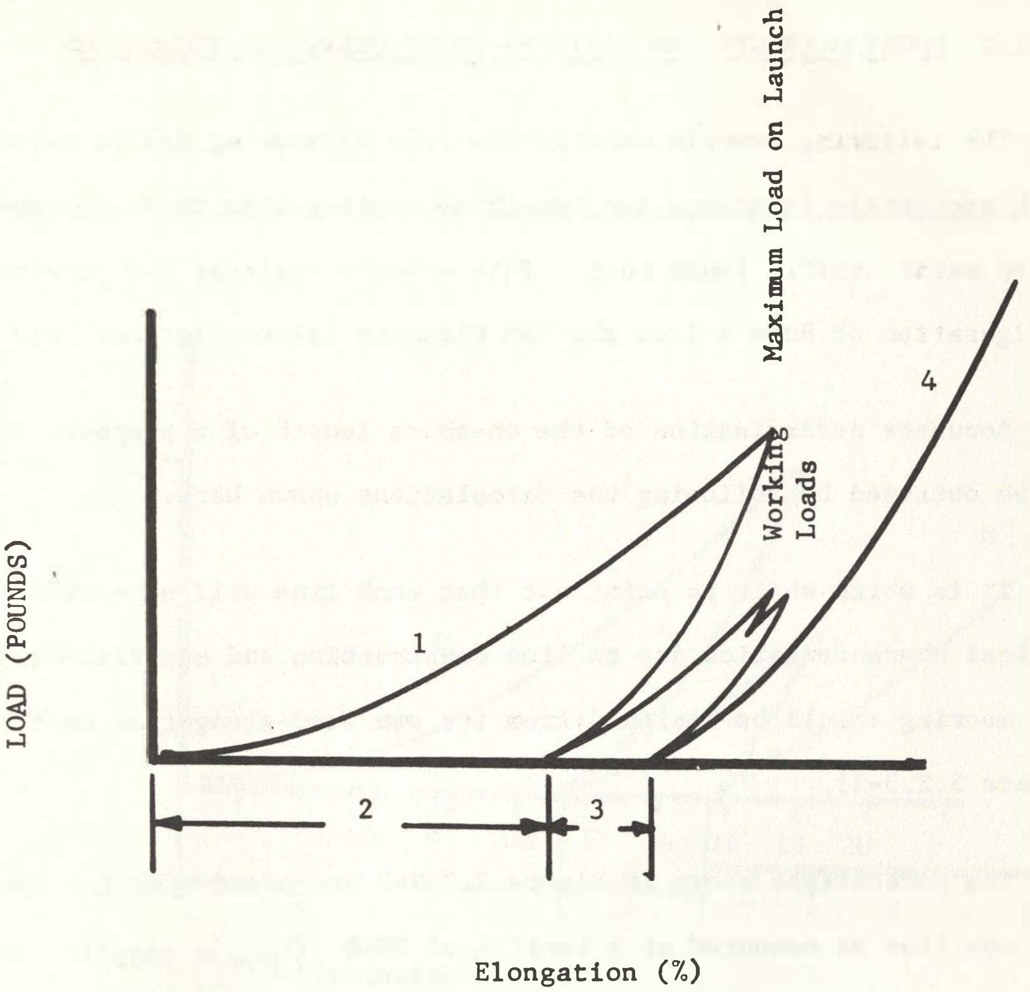
1. Load-elongation curve for new line in water.

2. Permament elongation caused by the launch transient.

3. Permanent elongation caused by working loads.

4. Load-elongation curve for the used line in water.

The information contained in this type of graph (Figure 3.2.3-1) is essential for accurate calculation of the mooring line length. The graphical technique documented below permits determination of both the on-shore line length and the maximum mooring elongation after months on station.



Legend
1. Load-elongation curve for new line in water.
2. Permanent elongation caused by the launch transient.
3. Permanent elongation caused by working loads.
4. Load-elongation curve for the used line in water.

FIGURE 3.2.3-1

LOAD ELONGATION TEST CURVE

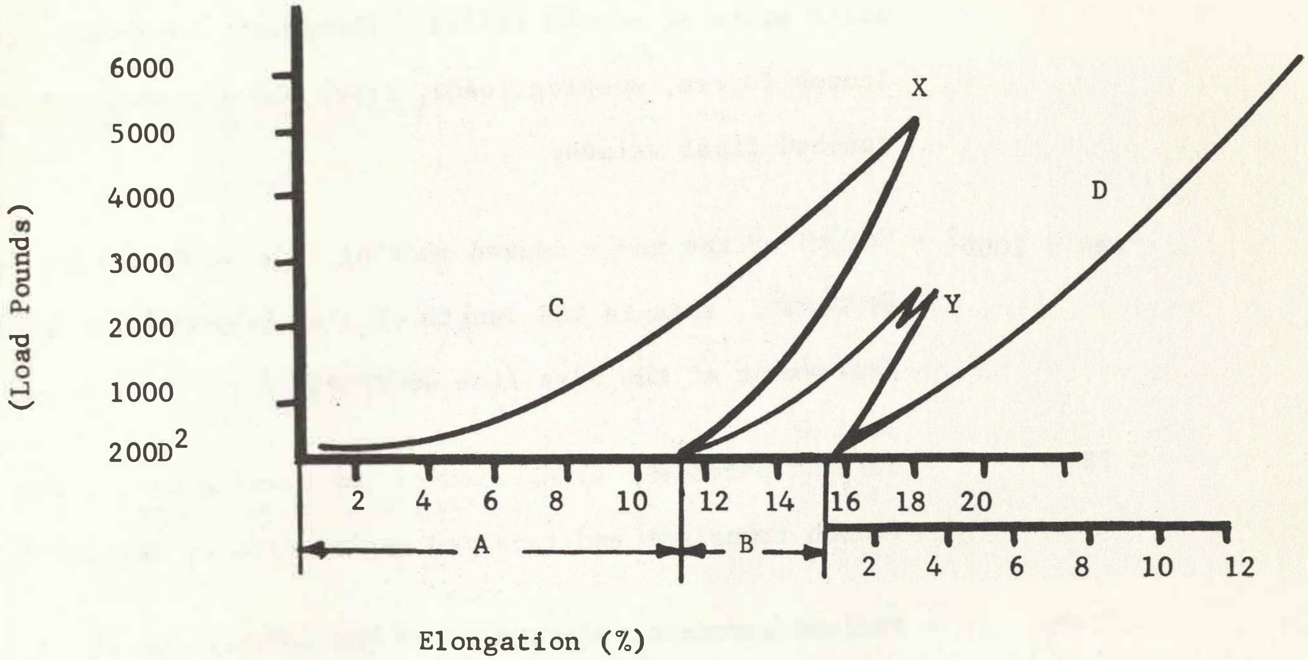
3.2.3.2 MOORING LENGTH CALCULATIONS USING GRAPHICAL TECHNIQUES

The following example details the type of mooring design calculations which accurately determine the length of mooring line to be deployed on a deep water traffic lanes buoy. This example analyzes the physical configuration of Buoy A from the San Clemente Island tests of July 1970.

Accurate determination of the on-shore length of a proposed mooring can be obtained by following the calculations shown here.

It is worth while to point out that each line will have different physical characteristics due to line construction and material variations. Each mooring should be designed from its own load-elongation test curve (Figure 3.2.3-2).

The percentages shown in Figure 3.2.3-2 are based upon the length of a new line as measured at a tension of 200D (L_{new} @ $200D^2$). Because of this, all calculations employing these percent changes must be applied to L_{new} @ $200D^2$.



Based on New Line Length at $200D^2$

LEGEND

A - Permanent elongation caused by launch.

B - Permanent elongation caused by working loads and creep.

C - Load-elongation curve for new line in water.

D - Load-elongation curve for used line in water.

X - Anticipated Launch Tension.

Y - Anticipated Average Working Load.

FIGURE 3.2.3-2

LOAD-ELONGATION CURVE OF NYLON LINE IN WATER

TERMS USED IN MOORING LENGTH CALCULATIONS

Water Depth - Design water depth of the mooring.

Fixed Length - Length of relatively inextensible members (ei. chain).

$L_{used\text{-}working}$ - Length of the mooring line under load (suspended chain) after weeks or months at sea. Permanent elongation due to launch forces, working loads, creep and shrinkage have reached final values.

$L_{new\ @\ 200D^2}$ - Length of the new - unused mooring line under a test tension of $200D^2$. This is the length of line measured and used for deployment at the base line water depth.

% PE - Percent permanent elongation of the mooring due to the launch transient and repeated application of working loads.

% Creep - Percent permanent elongation of the mooring due to Creep.

% Working - Percent elastic elongation of the mooring line due to the working load (suspended chain under still water conditions).

% Shrinkage - Percent reduction of mooring length due to nylon shrinkage.

MOORING LENGTH CALCULATIONS

BUOY SYSTEM

San Clemente Island Lighted Test Buoy A (See Figure 4.2.1-6).

ENVIRONMENT

Design water depth = 3780 feet.

FIXED LENGTHS IN MOORING

See Figure

Chain Bridle	26 Feet
Top Chain	15 Feet
Convair Tensiometer	2 Feet
Chain	5 Feet
Coast Guard Tensiometer	3 Feet
Chain	5 Feet
Coast Guard Tensiometer	3 Feet
Mooring Release	5 Feet
Fixed Lengths of Hardware	64 Feet

SUSPENDED CHAIN

For this example, we will consider 59 feet of the bottom chain to be suspended under still water conditions. The weight of 59 feet of 1½ inch chain is 1150 pounds. Any suitable length may be selected for specific designs. Greater lengths of suspended chain reduce the watch circle. This will be seen in Section 4.1.3.

TOTAL FIXED LENGTH CALCULATION

By combining the Fixed Lengths of the Hardware with the length of suspended chain, we obtain the Total Fixed Length of the mooring (See Equation 3.2.3 - 1).

Equation 3.2.3 - 1

Total Fixed Length = Fixed Length (Hardware) + Suspended Chain

= 64 feet + 59 feet

= 123 feet

CALCULATION OF $L_{\text{used-working}}$

Subtracting the Total Fixed Length from the Design Water Depth in Equation 3.2.3 - 2 yields the length of mooring line stretched between the buoy and the suspended bottom chain ($L_{\text{used-working}}$). This is the line length after the mooring has been at sea for weeks or months. Permanent elongation due to launch forces, working loads, creep and shrinkage have all reached their final values.

Equation 3.2.3 - 2

Design Water Depth - Total Fixed Length =

$L_{\text{used-working}}$ (59 feet of chain suspended)

3780 feet - 123 feet = 3657 feet

CALCULATION OF L_{new} @ $200D^2$

This final length ($L_{used\text{-}working}$ (59 feet of chain suspended) = 3657 feet) can be used to determine the on-shore length of the new line which will be deployed.

The manufacturer's load-elongation test of the new line in water (Section 3.2.3) provides the information needed to calculate this on-shore length (L_{new} @ $200D^2$). The test curves in Figure 3.2.3-2 show that the permanent elongation and creep total 15.7% of the new line length (L_{new} @ $200D^2$). The working elongation caused by 59 feet of suspended chain (1150 pounds) has been read from the used line section on the right side of Figure 3.2.3-2. The working elongation equals 4.5% of the new line length. Shrinkage has been estimated at 10% of L_{new} @ $200D^2$.

% PE + % Creep = 15.7%

% Working (59 feet of chain suspended) = 4.5%

% Shrinkage = 10%

Combining these line elongations as shown below yields a total length change of 10.2% (0.102 L_{new} @ $200D^2$).

(% PE + % Creep) + % Working - % Shrinkage = Total Length Change

15.7% + 4.5% -10% = 10.2%

Equations 3.2.3 - 3 and 3.2.3 - 4 use the information obtained above to solve for $L_{new\ @\ 200D^2}$.

Equation 3.2.3 - 3

$$L_{new\ @\ 200D^2}\ (1 + \%\ PE + \%\ Creep + \%\ Working - \%\ Shrinkage) = L_{used\text{-}working}\ (59\ \text{feet of chain suspended})$$

Equation 3.2.3 - 4

$$L_{new\ @\ 200D^2} = \frac{L_{used\text{-}working}\ (59\ \text{feet of chain suspended})}{1 + 0.102}$$

$$3310\ \text{feet} = \frac{3657\ \text{feet}}{1.102}$$

This (3310 feet) is the length of new line which will be measured for deployment in the Base Line (Design) water depth.

3.2.3.3 DESENSITIZING BUOY MOORING

Mooring line irregularities in elongation, shrinkage and water depth variability at the deployment site preclude a perfect match of line length to water depth. This problem can be overcome by "desensitizing" the buoy mooring through judicious choice of length and size of the bottom chain. The suspended chain and line elongation balance each other, thus adapting to great water depth variation.

Figure 3.2.3-3 plots still water mooring tension (pounds of suspended chain) versus water depth variation about the design depth for Buoy A. Determining the water depth range allowable for safe mooring deployment is important. The three most important points on the curve in Figure 3.2.3-3 can easily be calculated by hand.

These points are:

1. the design water depth,
2. the depth at which no chain is suspended,
3. and the depth at which all of the bottom chain is suspended.

The calculations below show how these points are obtained.

DESIGN WATER DEPTH

The point corresponding to the design water depth (3780 feet) was determined in the previous calculations of new line length. In this example, 59 feet of bottom chain are suspended by the mooring. The weight of this chain is 1150 pounds.

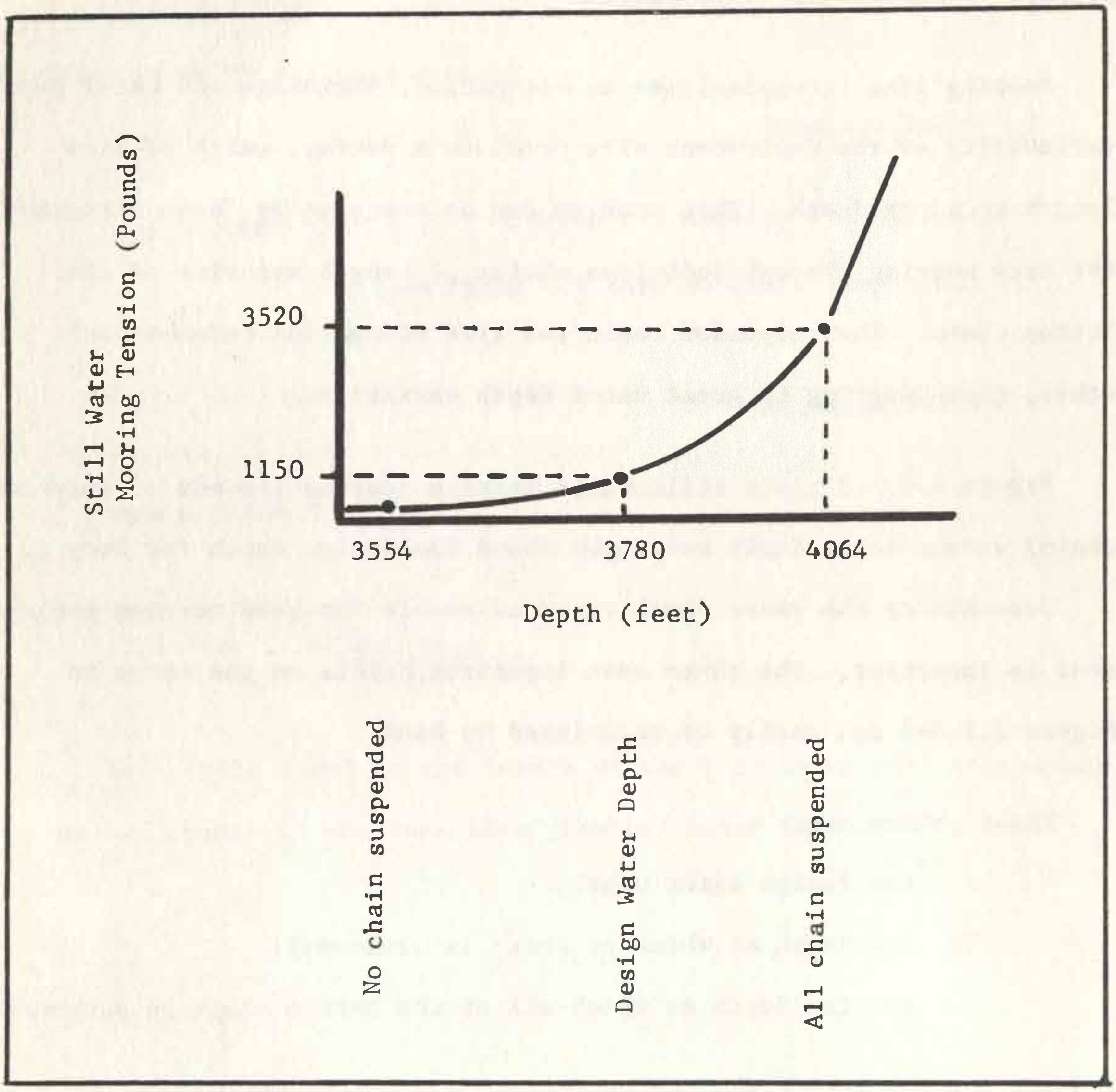


FIGURE 3.2.3-3

WATER DEPTH VARIABILITY CURVE - BUOY A

CALCULATION OF EXTREME POINTS

Two extreme points are present on the Water Depth Variability Curve in Figure 3.2.3-3. When the water is shallower than the design depth, there is a possibility that permanent elongation may result in sections of the line lying on the bottom during calm periods. This is a long term phenomena which may not occur for a number of months after deployment. Nevertheless, nylon chafing on the bottom during nearly calm sea conditions is very serious.

If a mooring is deployed in waters much deeper than the design depth, the line stretches to suspend more and more chain. There is a limit. After all of the chain has been suspended, any additional stretching of the nylon line increases the mooring tension rapidly.

The following example is included to aid in deriving the points on the graph in Figure 3.2.3-3.

NO CHAIN SUSPENDED

With no chain suspended, the mooring is effectively a used line tensioned at approximately $200D^2$. Equation 3.2.3 - 5 is used to calculate the length of the used line with no chain suspended (L_{used} @ $200D^2$).

Equation 3.2.3 - 5

$$L_{used\ @\ 200D^2} = L_{new\ @\ 200D^2}\ (1 + \%\ PE + \%\ Creep - \%\ Shrinkage)$$
$$= L_{new\ @\ 200D^2}\ (1 + 0.157 - 0.10)$$
$$= 3310\ feet\ (1.057)$$
$$= 3490\ feet$$

Adding the Fixed Length of Hardware (64 feet) to 3490 feet shows us the shallowest water in which the Base Line Mooring ($L_{new\ @\ 200D^2} = 3310$ feet) can be safely deployed is 3554 feet.

ALL CHAIN SUSPENDED

This second extreme differs from the No Chain Suspended Case by the increased elongation caused by the suspended chain. The maximum chain available in this example is 180 feet of 1½ inch chain. This chain weighs 3520 pounds. Looking at the used line load-elongation curve in Figure 3.2.3-2 we find that 3520 pounds yields 10% elongation of the new line ($L_{new\ @\ 200D^2}$).

Equation 3.2.3 - 6

$$L_{used\text{-}all\ chain\ suspended} =$$
$$L_{new\ @\ 200D^2}\ (1 + \%\ PE + \%\ Creep + \%\ Working\ (all\ chain) - \%\ Shrinkage)$$
$$= 3310\ feet\ (1 + 0.157 + 0.10 - 0.10)$$
$$= 3820\ feet$$

We add the Fixed Length of Hardware (64 feet) and the suspended chain (180 feet) to obtain 4064 feet as the deepest water in which the base line mooring may safely be deployed.

DEEPER DEPLOYMENTS

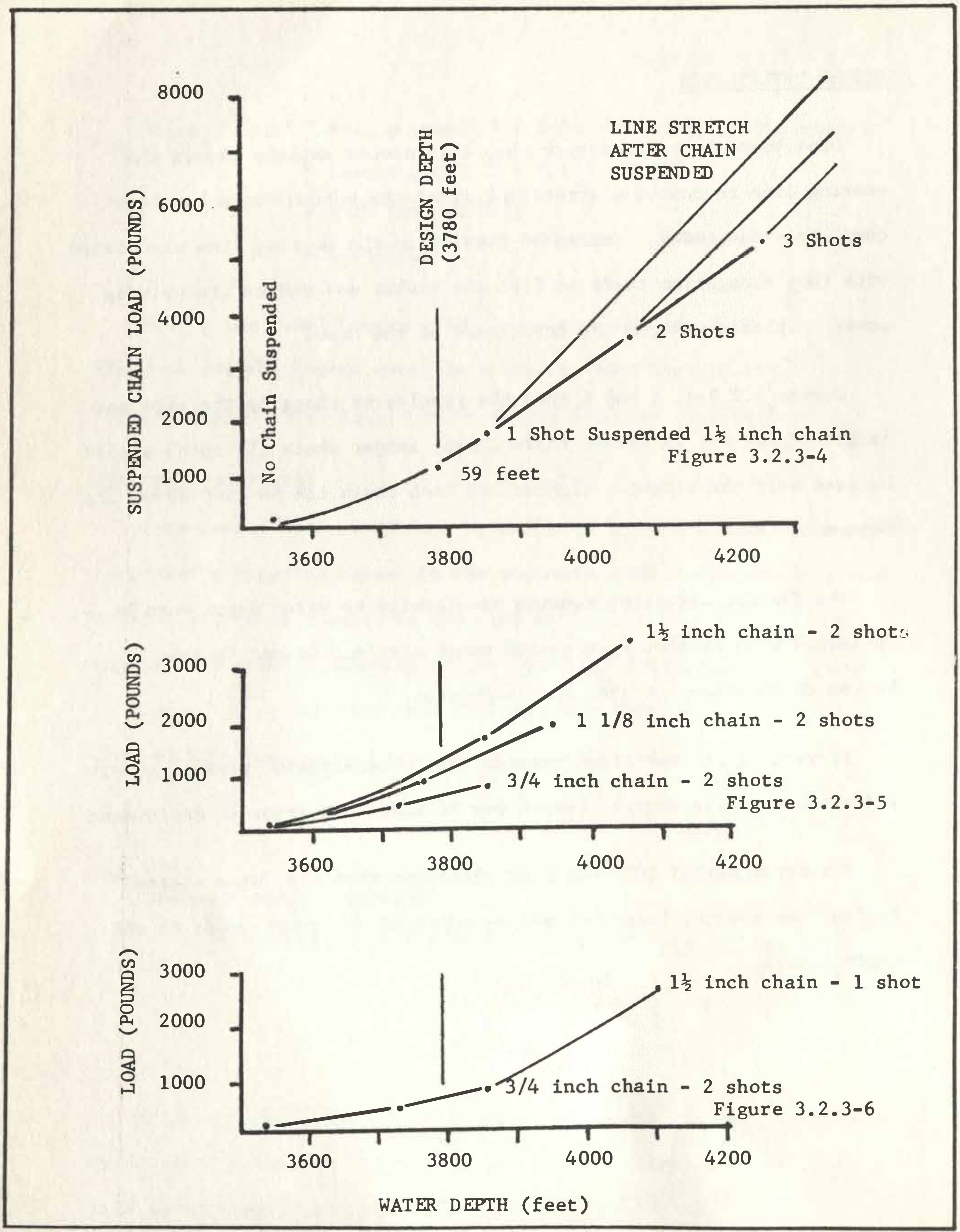
Deployment in water deeper than this second extreme causes the mooring line to continue stretching after the bottom chain has been completely suspended. Increased tension in the mooring line associated with this elongation tends to lift the sinker and reduce its holding power. It also reduces the free board of the buoy.

Curves 3.2.3-4, 5 and 6 show the results of changing the size and length of chain. In severe chafe zones, larger chain (1½ inch) should be used near the sinker. Lighter 3/4 inch chain can be used above the bottom.

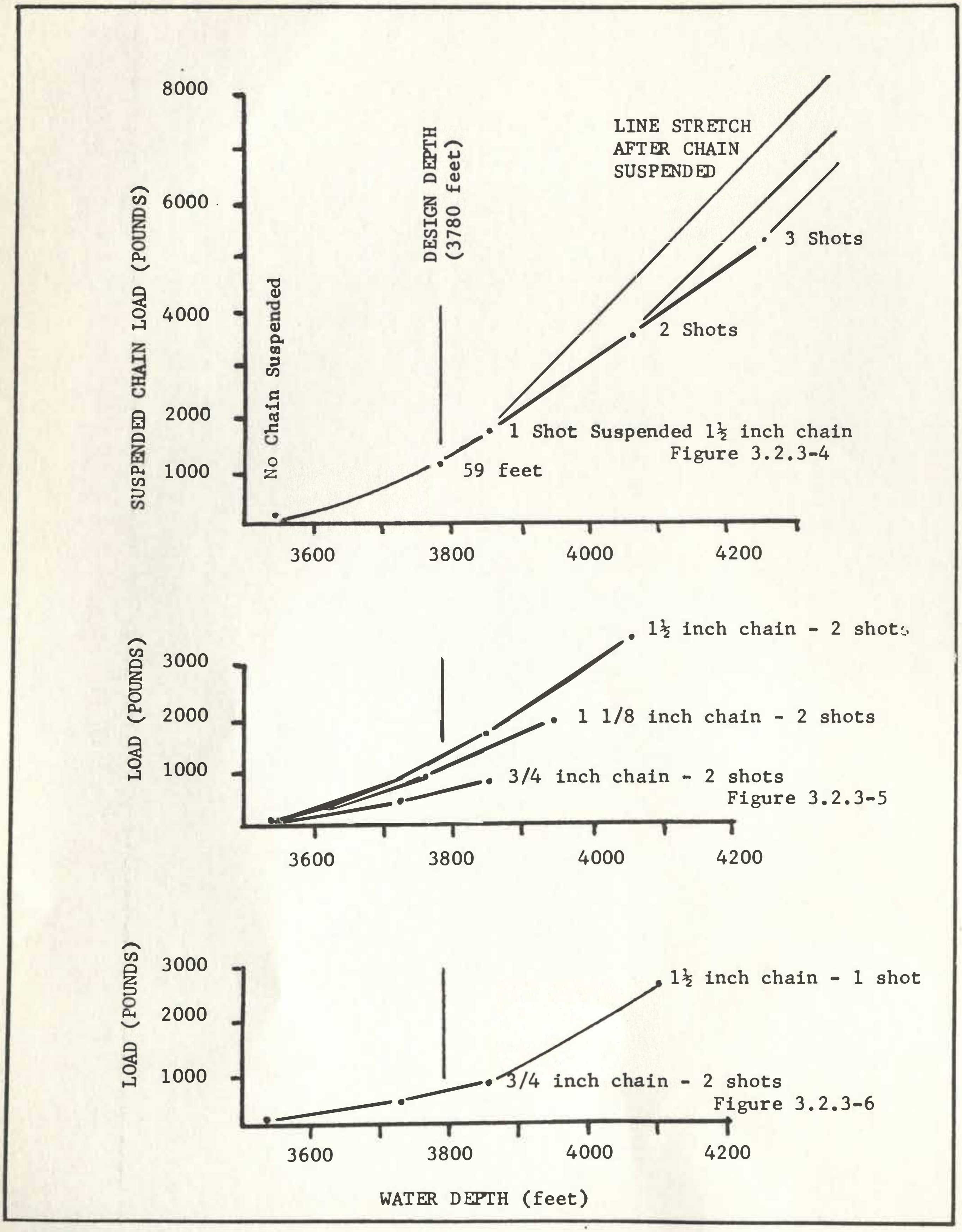
The factors affecting mooring sensitivity to water depth must be optimized with respect to required watch circle. Longer lengths of bottom chain allow greater buoy excursion.

If water depth variation exceeds the "desensitized" region, on site adjustments to the mooring length may be made just prior to deployment.

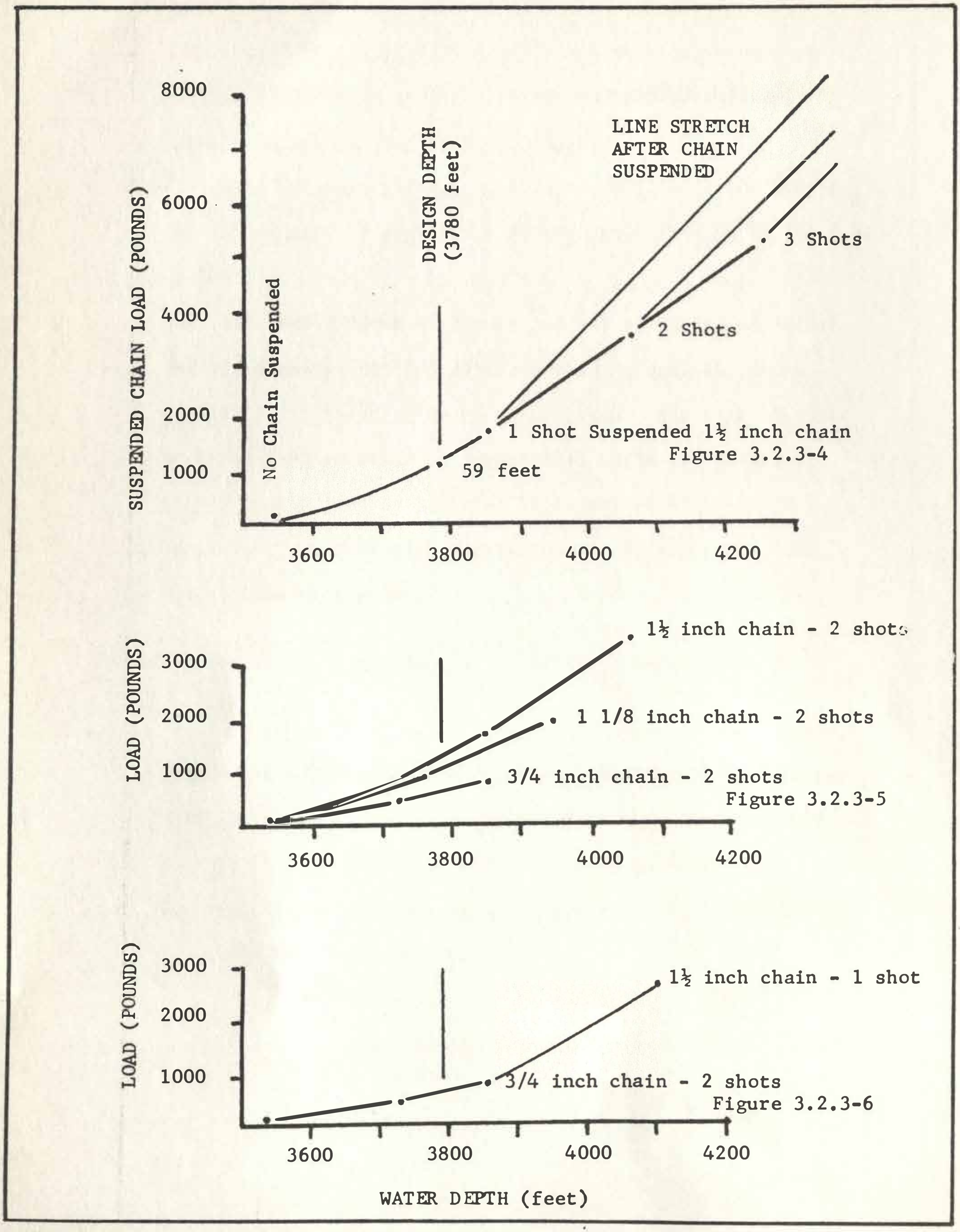
For water depths 10% deeper or shallower than the "desensitized" region, the mooring length should be adjusted an amount equal to the depth change.



FIGURES 3.2.3-4, 5 and 6
A VARIETY OF CHAINS SUSPENDED BY THE MOORING OF BUOY ALPHA VS WATER DEPTH



FIGURES 3.2.3-4, 5 and 6
A VARIETY OF CHAINS SUSPENDED BY THE MOORING OF BUOY ALPHA VS WATER DEPTH



FIGURES 3.2.3-4, 5 and 6
A VARIETY OF CHAINS SUSPENDED BY THE MOORING OF BUOY ALPHA VS WATER DEPTH

3.2.4 PROCUREMENT AND ASSEMBLY OF MOORING

The Sea Lanes Buoy Project has provided detailed information on specification and procurement of nylon line for deep water buoy moorings. This section covers:

1. Hardware specification and procurement.
2. Receipt and inspection of components.
3. Assembly of mooring and check of component compatibility.
4. Cutting mooring line to length.

3.2.4.1 HARDWARE SPECIFICATION AND PROCUREMENT

The basic Sea Lanes mooring consisted of nylon line and standard Coast Guard hardware. Several line manufacturers produce double braided or 8 strand plaited nylon lines suitable for deployment in a deep water traffic lanes situation. During procurement, the most recent Military Specification for double braided or plaited nylon rope should be imposed. For example, MIL-R-24050A, 20 January 1967, on double braided and MIL-R-24337 (ships), 17 June 1968, for plaited line.

It is recommended that the following additional specifications be included in procurement of nylon line:

1. That maximum and minimum lengths of line be specified.
2. That the line manufacturer weigh a sample length (tensioned to $200D^2$) of each line delivered to an accuracy of ±0.5%.

This weight per foot is to be marked on the reel. (This number will be invaluable in measuring the length of each mooring line. Line length is best measured by weighing out the amount of line to be deployed.)

3. To insure ultimate strength and survivability of the mooring, the line should be continuous with no hand splices in the body of the line.
4. The line sample curve in Figure 3.2.3-2 is needed to obtain the permanent elongation data and load-elongation curves necessary for calculating mooring length. The line manufacturer must be required to supply this curve for a typical sample of the line he proposes to supply at the time of quotation. He must also supply curves obtained from each lot of line he supplies.

The curve specified in recommendation number 4 above shall be obtained as follows:

1. Take a new unstretched sample of rope having eye splices and thimbles in each end (as per applicable MIL Specification),
2. Soak it in cold water (40 - 60°F) for 10 minutes,
3. Test the sample and automatically graph the load elongation curve for the following sequence:

a. Load the sample from an initial tension of $200D^2$ to X pounds at a rate of 20% of RBS* per minute (X being the anticipated launch tension.).

b. Reduce the tension to $200D^2$ thus graphing the permanent elongation anticipated during the launch.

c. Load the sample from $200D^2$ to 200 pounds above Y, (Y being the anticipated average working load.).

d. Cycle the sample from 200 pounds above Y to 200 pounds below Y until the master hysteresis loop is evident (10 - 20 cycles).

e. Reduce the tension to $200D^2$ thus graphing the permanent elongation caused by the working loads.

f. Load the sample to its ultimate break strength at a rate of 8% of RBS per minute. This yields the wet, used line load elongation curve which is used in mooring length calculation.

After completion of the test, the resulting curve should be scaled and titled as shown in Figure 3.2.3-2.

Eye splices and captive bronze nylon thimbles were specified at each end of the mooring lines used on the Sea Lanes Test Buoys. These thimbles are covered by MIL-T-23326 (ships) dated 2 July 1963.

Table 3.2.3-1 lists standard Coast Guard hardware used along with their stock numbers as listed in CG-250-17D.

---

*RBS - Rated Break Strength

SHACKLES:**	STOCK NUMBER:*
2 inch	CG 4030 236 8403 SK
1 3/4 inch	CG 4030 236 8402 SK
1 1/2 inch	CG 4030 236 8401 SK
1 inch	CG 4030 236 8400 SK
SWIVELS:**	
2 inch	CG 4030 729 6089
1 1/4 inch	CG 4030 729 6094
CHAIN:	
1 1/2 inch	CG 4010 729 5921
3/4 inch	CG 4010 729 5924
BRIDLE:	
1 1/2 inch X 26 feet	
SINKERS:	
10,000 pound concrete	

*Reference Coast Guard Civil Engineering Report No. 17D
CG-250-17D Mooring Components

**Reference Drawing No. BU-45-01 Swivels and Shackels

TABLE 3.2.3-1

MOORING COMPONENTS

3.2.4.2 RECEIPT AND INSPECTION OF COMPONENTS

Upon receipt of the mooring lines, they should be checked for supplier error, damage during shipment, enclosure of all specified data and load-elongation curves and the correct type of thimbles.

Nylon line is susceptible to damage from direct exposure to sunlight, rodents, and chemical contamination including contact with large amounts of rust.

3.2.4.3 ASSEMBLY OF MOORING AND CHECK OF COMPONENT COMPATIBILITY

A dockside compatibility test of each mooring component should be performed to insure smooth operation of the system during deployment. This is especially important when non-standard items such as test instruments are used in the mooring line.

3.2.4.4 CUTTING MOORING LINE TO LENGTH

After calculating the length of line needed, (see Section 3.2.3.2), the mooring may be measured and cut. The most satisfactory method of measuring synthetic line utilizes the weight per foot measurement supplied by the manufacturer. The amount of line equal to the length of the mooring (L_{new} @ $200D^2$) is weighed out on a scale and marked.

It is recommended that an extra 10% be weighed out in excess of the calculated mooring length before the cut is made. This additional 10% may be needed for the on-site adjustment detailed in Section 3.2.3.3.

Once a buoy station becomes well known, this excess can be reduced or eliminated.

3.3 DEPLOYMENT AND RETRIEVAL OPERATIONS

3.3.1 DEPLOYMENT OF THE SAN CLEMENTE ISLAND LIGHTED TEST BUOYS

Seven separate buoy deployments off San Clemente Island were successfully accomplished by the U. S. Coast Guard Cutter WALNUT (WLM 252) between 5 November 1969 and 8 April 1970. San Clemente Island Lighted Test Buoys D and B were deployed using the buoy first anchor last, "tow-away" technique. In this type of deployment, all of the mooring line was stretched out in the water before the sinker was dropped.[6,12] Buoy D was deployed on 5 November 1969. It was retrieved, inspected and re-deployed on 24 March 1970.

Between 25 March and 8 April 1970, the WALNUT deployed buoys E, C, A and B (a 40 foot diameter composite buoy) using the "faking box" technique. This technique was developed by the ship's personnel and subsequently christened the "WALNUT Technique".[13]

3.3.1.1 DEPLOYMENT AREA

The San Clemente Island area features deep water very close to shore. In the Wilson Cove section northeast of the Island, the bottom slopes away at 18 to 20 degrees. Because of this, water 600 fathoms deep lies within 2 nautical miles of the Island.

The WALNUT ran bottom contour surveys prior to deployment (days or weeks in advance as convenient) using the ship's fathometer. Final adjustments were made to the mooring line length based upon these bottom surveys. (See Section 3.2.4.4)

3.3.1.2 DEPLOYMENT TECHNIQUES

Two deployment techniques were employed on the Sea Lanes Project, the "tow-away" technique and the "WALNUT Method".

The "tow-away" technique used on D and B is described below by the Commanding Officer of the WALNUT in his report of operations.[12]

"TOW-AWAY TECHNIQUE"

"During the three successful deployments and the one attempt which was aborted because of a discrepancy in line length, I employed different maneuvering techniques to determine which is best. The following procedures are the ones I have found to be most satisfactory:

a. Determine the set and drift of the ship dead in the water. Estimate the time necessary to make all preparations to drop the sinker and position the ship up-current a distance equal to the drift times the preparation time. Current in this case, is defined as the resultant of all factors which cause the ship to move over the ground when engines are stopped.

b. Launch the buoy on the up-current side and have the boat tow it up-current as the line is payed out. If any of the current is due to wind, this ship - and ships with similar characteristics - will drift faster than a 9 X 38 buoy. Thus, the ship will always be drifting away from the buoy and the line will tend away from the ship.

c. Maintain a careful plot of the ship's position and maneuver to keep a steady bearing on the drop position. If depth is a critical factor, also plot the buoy and have the boat maneuver (so) that the buoy is on the same isobathic line as the ship at drop time.

d. Just before the ship arrives at the drop position, lower the bottom instruments over the side so they will be well clear of the sinker and chain as they go. We had them aft of the buoy port and tried to insure that the main nylon tended aft of the beam at this point. Cast off stoppers and make a final check to insure that all gear will run free. When ship is on position, let her go.

This method of deployment has two major disadvantages:

a. The long line stretched between the ship and the buoy severely restricts maneuverability and the danger of entangling the line in the screw or rudder always exists. This danger was my main concern throughout this program.

b. The sinker does not go straight down so the drop position must be computed and adjusted. Unfortunately, we were never able to definitely determine to what degree the sinker was affected during the drop. We knew our own position with reasonable accuracy when the sinker was dropped, but could not accurately determine the sinker position when it was on the bottom. From a study of the information we did obtain, my best estimate is that the sinker moves horizontally about 250-350 yards in the direction in which the line tends, providing the line tends straight away. If the line lays in an arc through the water, as was the case during the first deployment of Buoy D, then I believe that the sinker descends in a spiral pattern, generally following the direction of the line. Similarly, the buoy will move in the direction the line tends from it. These opinions are supported by the behavior of Buoy D, the sinker of which apparently ended up fairly close to the sinker drop position. On the deployments during which the lines tended straight away, or nearly so, the sinkers apparently came to rest in a direction toward the buoy."[12]

"Position checks may be made at any time, of course, but, to be on the safe side, the buoy should not be considered stabilized until an hour after drop."[6]

"WALNUT METHOD"

Buoys E, C, A and B were deployed using the "WALNUT METHOD". The technique is described below:

"In the planning phase of this Test Project, WALNUT was charged with the task of developing and testing methods of deploying the test buoys. Three buoys were set using the "tow-away" method described in references (a) and (b). (References 6 and 12 in this paper.)

Reasoning that a deployment method which was as closely related to proven methods used in regular buoy work would be an area worth investigating, we started exploration in that direction. The essential difference between these test buoys and aids-to-navigation buoys is, of course, the long piece of nylon line in the mooring. After consultation with representatives of Samson Cordage Works, Tubbs Cordage Company and Columbia Rope Company, I decided that it might be feasible to deploy the line from the deck using a faking box similar to that used with line throwing guns with beach rescue apparatus.

Using formula supplied by the Samson representative, ship's personnel designed a box which was built by Base, Terminal Island. It was made of 3/4" plywood. Inside dimensions are 6' long x 4' wide x 4' deep and it will hold about 5500 feet of 1 1/2" diameter line or about 12000 feet of 1" diameter. One of the long edges of the open end was capped with a piece of oak to provide a smooth surface over which the line could run. The box was built with legs that caused it to tilt at a 45^{o} angle. This tilt proved impractical because the line slid to the low side, so the legs were removed to allow the box to lay flat on deck. After the first deployment, the box was further modified by mounting on it a 3" pipe rub rail to keep the line running over the outboard edge and to provide a smoother running surface.

The first deployment using the faking box was San Clemente Island Test LB E on 25 March 1970.

The 1" diameter Samson double braided nylon line was faked in the box before departure from home port. Fakes were made with the line in each layer laid 90^{o} from the line in the layer above and below. As the last fake of a layer was made, the next layer was started at the corner diagonally opposite from the corner at which the previous layer ended. The looped ends of each layer were held down with a piece of marline secured at holes drilled in the sides and ends of the box. The top end of the line was faked in first and about 200' was left out to provide working slack to the buoy. It was led up the after-outboard corner of the box and lightly secured with small stuff.

The 25' MSB was lowered and the buoy was put in the water. The nylon was not attached to the buoy at this point, but the lower end of the 15' section of chain was stopped off on a fitting on the buoy body. When final assembling was completed on the ship, the boat took the end of the nylon to the buoy, shackled it to the chain and released the stopper. The ship then commenced the final approach to the drop position as the boat kept the buoy abeam. Because of the excellent weather conditions (Wind - calm, no sea, slight swell from the northwest, overcast, visibility - 5 miles in haze. The drift of the ship was less than 0.1 knots.), maneuvering was easy. At 1030, the drop position was reached, the boat cast loose and the sinker was let go.

The chain (three shots of 3/4 inch chain) was off the deck in 30 seconds and the line commenced to run from the faking box. The action of the line as it ran was surprisingly gentle. There was no "whipping" or "rise" above the edge of the box at all. Because of the space taken up on the buoy deck by the chain, the box had been placed in the buoy port so that the line ran over one of the plywood ends instead of over the hardwood cap as intended. This was no problem, however, because of the ease with which it ran. At one point it shifted direction so that it ran out over the forward edge of the box instead of the outboard end and a man was able to guide it back to the end with a boat hook handle. This experience caused us to add the 3" pipe rub rail mentioned earlier. When the last of the line was out, it took about 3 - 4 seconds to part the marline which secured the top end to the box.

About 100' of the slack was looped over the bulwark and it, too, ran easily. The total time for the chain and line to run off deck was 4m 33s.

At 4m 55s after sinker drop, the buoy draft had increased about 3 inches. At 5 minutes 15 seconds it started moving very slowly toward the ship and appeared to move about 50 feet until movement could no longer be detected from wake.

The second deployment was San Clemente Island Test LB C on 31 March. In this case I placed the ship up-current from the drop position and launched the buoy, with the nylon attached on the weather side. Weather was: Wind - 300°T, 12 knots, slight chop, swell - 290°T, 4 feet, visibility - 8 miles. The ship drifted faster than the buoy, so the working slack in the nylon was stretched out between the ship and the buoy. A steady bearing was maintained on the drop position by going ahead or back handsomely and the boat just kept the buoy abeam. Just before drop position was reached, and all was ready on deck, the acoustic release was hung over the side and suspended below the water with a piece of small stuff so that it would be clear of all running gear. For this and subsequent deployments, the faking box was positioned aft of the buoy port so that the line ran over the buoy deck bulwark. This allowed for more room on deck inboard of the buoy port and permitted us to position the box with the long axis fore and aft so that the line ran over the pipe rub-rail. Also, on this and subsequent deployments, the line was faked in the box with no tie-downs, i.e., it was not tied down with marline as was the line of buoy E. The two ends were tied off at the corners of the box just to keep them out of the way. When the desired position was reached at 1529, the sinker was let go. (See Figure 3.3.1-1)

Of the methods we have used to deploy these test buoys, the faking box is far superior. The primary advantage, when compared to the "tow away" method, is the absence of the line in the water. As mentioned in previous reports, the possibility of entangling the line in the screw was my main worry throughout the program.

The faking box method is also faster than the other, is more closely related to regular A to N buoy work and, except for the box itself, requires no special equipment. I believe that the box could also be used to deploy lines with instruments such as current meters attached. I also believe that the procedure could eventually be refined to the point that a buoy could be laid in the same way we lay A to N buoys; that is, the buoy is hung over the side, the ship maneuveres to position, the sinker is dropped and the hook is taken out of the buoy after the sinker is on the bottom. This, of course, would be better and faster because the ship could maneuver at will without the problem of the buoy and boat nearby." [13]

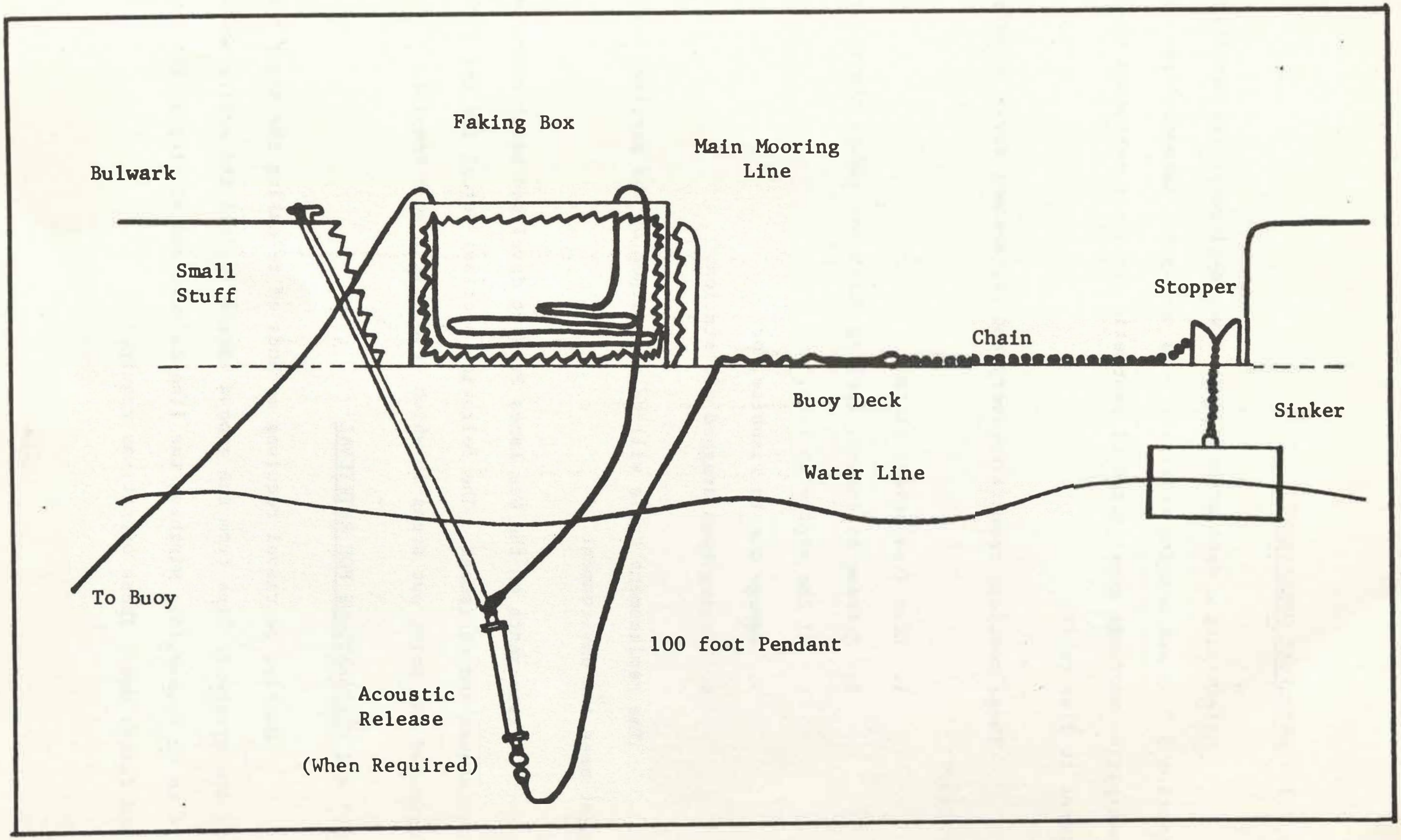


FIGURE 3.3.1-1 DECK ARRANGEMENT FOR "WALNUT METHOD" FAKING BOX DEPLOYMENT

3.3.2 RETRIEVAL OPERATIONS

Maintaining a deep water aid involves deployment (as detailed in Section 3.3.1) and mooring retrieval. As necessary, European aids to navigation moorings constructed of synthetic lines are retrieved every three to five years.

These moorings require recovery and replacement for a variety of reasons:

1. Loss from severe storms,
2. Extreme biological fouling which may reduce the strength of the synthetic line,
3. Damage due to fishbite, or
4. Having been dragged off station.

The replacement cycle will be determined by the particular deployment area and environment.

Experiments on the Sea Lanes Project developed basic retrieval techniques and equipment. The following sections detail the principles involved and point out areas in which development work remains.

3.3.2.1 PREPARATIONS FOR RETRIEVAL

Mooring retrieval requires methods of releasing the major portion of the synthetic line from the ground tackle (unless the entire mooring is to be recovered), winching the line on deck and storing it for examination and future use. These operations require:

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1. a release mechanism,
2. a winching capability, and
3. a line storage technique.

The San Clemente Island Lighted Test Buoys were all equipped with acoustic releases immediately above the ground tackle. Buoy E is the only exception. This mooring contains no acoustic release. Buoy E is scheduled for recovery in April 1972, with the use of an external, ship deployed, release mechanism.

Development is currently under way at the National Data Buoy Project to perfect a pressure actuated explosive release which can be slid down the mooring line. The explosive device being tested is the Underwater Sound Signal (SUS), MK 59-0a.

The USCGC WALNUT was equipped with a hydraulic motor and gear box compatible with the ship's hydraulic system. The motor and gear box were obtained from an oceanographic winch. A capstan head was mounted on it and the entire unit was permanently installed to the port side of the ship's boom under SHIPALT 175-X-52.

One of the retrieved mooring lines was faked on the 02 deck as a result of Samson Cordage Representatives' strong advice against spooling nylon line directly onto a drum or reel under tension. Nylon lines creep under sustained load. After this load has been released, delayed recovery from this creep elongation takes place. Large tensions can build up in the line as recovery takes place when the line is wound tightly on a reel.

It is possible to spool this line loosely on a reel after it has been winched aboard. This was done on several San Clemente Island moorings.

3.3.2.2 ENERGY STORED IN MOORING

A synthetic mooring acts much like a large rubber band when stretched. It stores a great deal of energy within its structure.

If one attempts to retrieve the mooring with sinker and ground tackle attached, this stored energy may be catastrophically released by line failure.

The following exert from "Review of Synthetic Fiber Ropes"[26] by Dr. Walter Paul, defines the energy in a mooring line.

> "Potential energy is defined as load times the displacement along which this load is working. Moorings which stretch under load therefore absorb mechanical energy which is equal to the work done by the external loads on the mooring. Since $E_{pot} = \int L \, dx$, the absorbed energy can be expressed by the area under of mooring load elongation curve.
>
> The actual length which the rope elongates is important, a rope that is twice as long will stretch twice the distance under the same load and thus will absorb twice the energy.
>
> The energy absorbed by the mooring can thus be expressed by the area under the load elongation curve.

$$E_{pot} = C_e \times L \times l \times s$$

Where:

E absorbed energy in (ft x lbs-wt, kilogram-wt x meter)

C_e shape factor of the curve. For a straight line, (Hooke's) as in wire ropes, $C_e = 1/2$. For fiber ropes C_e is approximately 1/3.

L load of the mooring (lbs-wt,kilogram-wt)

l initial length of the mooring (ft, meters)

s strain under load = $\Delta l/l$

A large amount of energy is stored in long lengths of ropes and in highly stretching ropes. If by overstressing ropes break, the stored potential energy is converted into kinetic energy which causes the dangerous snapback. The broken rope parts accelerate to high speeds. The potential energy of a mooring at break is

$$E_{pot} = C_e \; BS \; l \; s_b$$

where BS is the breaking strength and s_b the strain at break. This potential energy is converted to the kinetic energy of the broken rope."

The mooring on buoy E consists of 3360 feet of 1 inch diameter Samson 2 in 1 double braided nylon line. This line has an elongation at break strength (strain at break) of 17%. Its break strength is 28,500 pounds.

The combined weight in water of the three shots of 3/4 inch chain and the 10,000 pound sinker is 7300 pounds. The line elongation at this load is 9%.

On 21 July 1970, buoy A was lifted from the water for servicing. The peak load measured during this operation was 2500 pounds. This corresponds to a line elongation of 5%.

If this mooring line reaches its full break strength while dislodging a sanded in anchor, the energy released will be $5.4 X 10^6$ foot-pounds.

When this line breaks, the energy released in each section of the line is proportional to its length. Thus, if the mooring parts just above the ground tackle all of the potential energy available will go toward accelerating the end of the line in the direction of the ship. Hydrodynamic drag will dissipate most of this energy very quickly.

A line breaking near the ship or on deck can be very hazardous.

Loads of 2,500 and 7,300 pounds shown above yield potential energies of $1.4 X 10^5$ foot-pounds and $7.35 X 10^5$ foot-pounds respectively.

3.3.2.3 BREAKOUT OF SINKER

If the sinker and ground tackle are to be retrieved, the sinker should be broken out before any line winching operations begin.

This breakout can be accomplished by securing the buoy to the ship with a length of chain and backing on the mooring.

3.3.2.4 RETRIEVAL OF BUOY AND MOORING

Retrieval of the San Clemente Island buoys was performed as follows:

Buoy D 24 March 1970

"At 0750U with the short piece of chain just above the nylon in the chain stopper, the command unit was triggered to fire the acoustic release. There were no immediately perceptible indications of release, although the nylon did slack off a bit in time.

The chain was lifted from the stopper and the nylon was led through a snatch block on the hook, through a fairlead snatch block on deck and taken to the temporarily installed hydraulic winch. Two or three men were able to pull in the line very slowly by hand. The weight of one man hanging on the line inboard of the first snatch block would cause it to come along slowly.

The line was taken around the capstan head at the hydraulic winch, winched in and faked on the 02 deck. On the first 30 feet of the line there was light mussel growth. The line was discolored by what appeared to be a very light mossy marine growth down to about 200 feet. Below that the nylon had the appearance of new line. All line and the acoustic release were aboard at 0849U."[12]

Buoy B 5 February 1970

"At 1305U, 5 February 1970, while working aids in San Diego, WALNUT was informed by CCGD ELEVEN message that Test Buoy B was missing from station. The buoy was located by a Coast Guard helicopter from San Diego Air Station at 1400U in position 33-00N 118-29W. WALNUT departed San Diego at 1515U and was alongside the drifting buoy at 2100U at position 32-59.5N 118-27.7W in about

550 fathoms. The buoy and all appendages above the acoustical release were taken aboard using the temporarily installed hydraulic winch to pull in the nylon. Total time to hoist the buoy and all gear aboard was about 40 minutes.

A preliminary inspection of the acoustical release showed that the releasing piston was withdrawn indicating that the squib had been fired, releasing the mooring."[9]

Buoys A, B, and C 15 September 1970

"The buoys were recovered on 15 September 1970, and returned to Base, Terminal Island. The recoveries were without significant incident. Acoustic releases worked as they should and all five recording tensiometers were operating. All equipment was in good condition.

Buoy A was hoisted aboard at 0808T (PDT) and the command to trigger the release was sent at 0820T. There were no immediately noticeable indications of release. When we started to heave around on the line; however, it was apparent that it was loose. The line came in easily and it took 42 minutes to recover it.

Buoy C was hoisted aboard at 1030T and the release command was sent at approximately 1100T. Again, there was no instant indications of release, although slackness of the line could easily be seen after a few minutes observation. Time to recover line was 31 minutes.

A party was placed on buoy B in the early afternoon using the ZEEBIRD rubber boat. EOD divers from a local Navy command shackled one end of a nylon pendant into the mooring at a point just above the thimble of the nylon mooring line. On the deck of the buoy, two two-fold purchases were secured to the tower of the buoy and hooked into eyes spliced in the nylon pendant about 12 feet. By hauling it on the tackles alternately, the bottom of the upper mooring assembly was drawn up to the buoy deck. The strain became greater as the gear was hauled in; however, and the last few feet had to be hauled in by using the tackles two-fold purchase upon two-fold purchase. The release command was sent in hopes that the drifting buoy would relieve some of the tension. Eventually the line end was on deck and stopped off, the upper end of the nylon was passed to the ship by messenger, the buoy was east adrift and the mooring line was winched in. This time, we were not certain that the release had worked until a few hundred feet of line was hauled in. Tension remained fairly heavy throughout the recovery and the line tended away from the vertical as if it might be attached to something. Change in ship's position indicated movement, but I did not evaluate it as conclusive evidence of drift. Time to recover the line was 41 minutes. The LDB was taken in tow and towed to port at 8 knots."[14]

3.3.2.5 EXAMINATION OF COMPONENTS

Each mooring component (shackles, captive thimbles, synthetic line and chain) should be examined for wear or damage.

A cursory inspection can be made as the mooring elements are winched aboard. Marine fouling may be removed with a fire hose when desired, but close examination of these organisms is recommended during the development of deep sea moors and when establishing new stations.

Fish bite may well be the most damaging problem facing a deep moor in several areas of the oceans. Woodshole Oceanographic Institution suffered several buoy losses north and east of the Gulf Stream until they began deploying plastic jacketed 3 X 19 torque balanced wire rope for the top 1500 meters of each mooring.

Fish bite damage is sometimes difficult to detect. An innocent looking set of neatly clipped fibers in a short three inch section of line may be the external markings of a bite that cuts 25% to 50% of the line strands.

Strength reduction in a synthetic line is not directly proportional to the cut number of fibers. It is more severe due to resultant line imbalance and stress concentration.

3.3.2.6 REDEPLOYMENT OF BUOY AND MOORING

Once the buoy and mooring is recovered, another must be set if the station is to be maintained.

To reset the old mooring would require the ship to perform a tow away deployment as outlined in Section 3.3.1.2.

Several problems should be mentioned here:

1. The tow away technique is more time consuming, less accurate, and more difficult than the WALNUT faking box method.
2. It is difficult to examine every foot of mooring line for damage. This is better done on shore where weak sections can be cut out and the mooring respliced.

A replacement mooring packed in a faking box could be easily brought along and used during redeployment.

3.4 TESTS AT SAN CLEMENTE ISLAND

Environmental and buoy motion data was taken on San Clemente Island Lighted Test Buoys A, B and C from April to July 1970. Data acquisition, reduction and analysis have been documented in detail in the Sea Lanes Test Program Final Report of October 1970, General Dynamics Report No. GDC-AAX70-020.

3.4.1 ENVIRONMENTAL AND BUOY MOTION DATA

The test periods at San Clemente Island lasted approximately one week per month. During the tests, wind speed was recorded on the large discus buoy (B) and current profiles were taken to 450 feet in the vicinity of the buoys. A special comparison test was conducted during July using Naval Ship Research and Development Center (NSRDC) wave measuring buoys (Splashnik). Splashniks were deployed near Buoy B to transmit wave data back to the test van on the Island. These wave measurements were later processed to determine wave spectra.

Sea spectra derived from Buoy B for the same test period was then compared to the Splashnik data. NSRDC personnel have determined that the double integrated accelerometer data recorded on B provided sea spectrum within 10 - 20% of the actual value.

Both short term (30 minutes) and long term buoy motion data (3 months) were recorded during the Sea Lanes Project.

Short term data consisted of tension measurements on A, B and C's moorings, telephoto motion pictures of the buoys and buoy position on the Fleet Operational Readiness Accuracy Check Sites (FORACS) Range at San Clemente Island.

Long term tension data was recorded at the top and bottom of the buoy moorings as seen below:

Buoy	Tensiometer Location
A	Top and Bottom
B	Top and Bottom
C	Top Only

This data from the buoys has been examined and reduced by National Data Buoy Project personnel. Observations and conclusions drawn from this data are contained in Sections 4.1 and 5 of this report.

3.4.2 REDUCTION OF DATA FOR ANALYSIS

Personnel of General Dynamics Electro-Dynamics Division performed the data reduction for the dynamic test portion of the Sea Lanes Project. Manual techniques were used to retrieve the raw data from the motion picture films and Rustrak paper traces. The process consisted of manually following the tension traces and buoy motion with OSCAR and BOSCAR semi-automatic data processors. These machines yielded IBM punch carded data which was further reduced, scaled and displayed as shown in Figure 3.4.2-1.

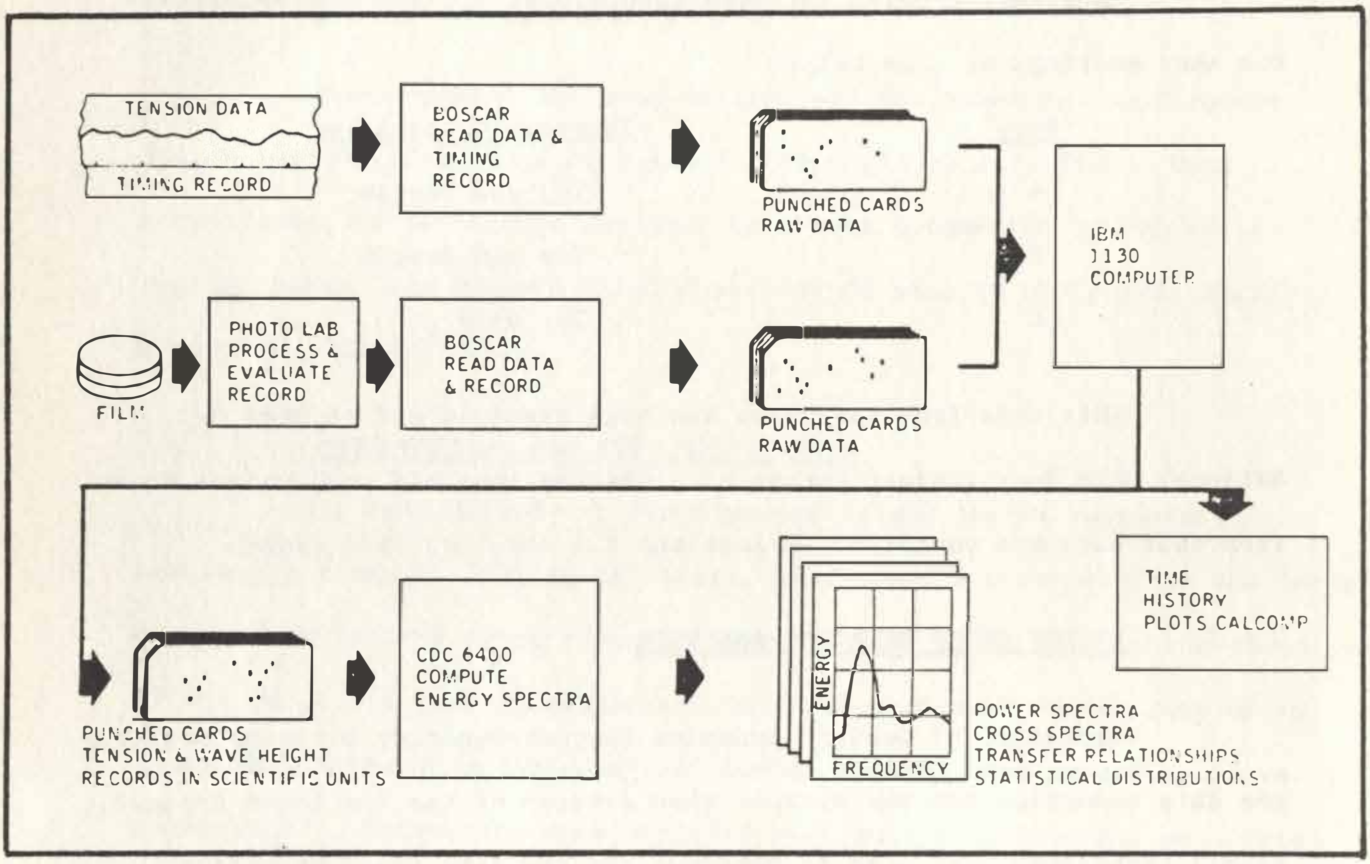


FIGURE 3.4.2-1 DATA PROCESSING FLOW DIAGRAM

Section 4

PROGRAM FINDINGS DOCUMENTED BY GOAL

4.1 PRIMARY OBJECTIVE - EVALUATE SEA-KEEPING CHARACTERISTICS OF A TO N BUOYS IN DEEP WATER

The sea-keeping characteristics of a buoy system are dependent upon the mooring components, the buoy and the overall system design. Tests were performed at San Clemente Island to determine buoy motion in response to the in-situ sea spectrum.

Sea spectra was measured using a hull mounted accelerometer on the large discus buoy located between buoys A and C.

Motion of the A to N buoys was derived from reduction of the motion picture data.

Comparison of the sea-spectra and buoy motion has met with some success, but instrumentation and analysis techniques require refinement before reliable derivations of the response amplitude operator between sea energy spectra and buoy motion can be made.

Long term mooring line tension records were recorded on the test buoys. These tension records and the FORACS position plots represent useful examinations of buoy system reaction to the surrounding environment. This data can be used to refine future systems and estimate their responses.

4.1.1 SEA SPECTRA

Much has been learned which will be of future use in developing techniques for obtaining and analyzing sea spectra and buoy motion.

At this time instruments and systems are not readily available which will yield sea spectra information to tolerances closer than 10 to 20% of the actual value. This includes large floating platforms and small styrofoam blocks like plashnik.

The simple hull mounted accelerometer employed on the Sea Lanes test is susceptible to data aliasing as the buoy pitches and rolls in the seaway. More sophisticated, and costly, systems of vertical gyro referenced accelerometers are being developed along with the computer programs required to reduce and analyze the data. The National Data Buoy Center's Engineering Experimental Phase (EEP) is examining hull motion and sea spectra.

4.1.2 LONG TERM TENSION RECORDS

During this Project, long term line tension traces were recorded by self-contained under water tensiometers located at the tops and bottoms of the San Clemente Island Lighted Test Buoys (Figures 4.2.1-2, 4.2.1-3, 4.2.1-5, 4.2.1-6 and 4.2.1-7).

These tension traces have been time correlated and analyzed by National Data Buoy Center personnel.

Tension extremes and excursions are documented for Buoys A, B and C in Tables 4.1.2-1, 4.1.2-2 and 4.1.2-3. (See also Tables 4.2.1-1 to 4.2.1-7)

These values have been compiled to provide a means of comparing the effects of different scopes and line sizes for the A to N buoys. Comparison of the Large Discus Buoy to the A to N's is also possible.

OBSERVATION	VALUE	DAY
Deployed		2 April 1970
Retrieved		15 September 1970
Time on Station	166 days	
Top Tensiometer:		
Peak Tension	3850#	2 September 1970
Max. Ave. Tension	3700#	2 September 1970
Max. Dynamic Tension	±650#	27 June 1970
Min. Ave. Tension**	1000#	19 June 1970
Min. Dynamic Tension	±50#	Numerous
Buoy Lifted ol Deck	3800#	21 July 1970
Bottom Tensiometer:		
Peak Tension	2500#	21 July 1970
Max. Ave. Tension	2500#	21 July 1970
Max. Dynamic Tension	±200#	27 April 1970
Buoy Lifted on Deck	2500#	21 July 1970
Max. Excursion*	715 ft.	28 April 1970
Max. Excursion*	730 ft.	21 May 1970

*Derived from FORACS Position Plots
**Due to suspended line and chain

TENSION AND EXCURSION EXTREMES FOR BUOY A

TABLE 4.1.2-1

OBSERVER	VALUE	DAY
Deployed		8 April 1970
Retrieved		15 September 1970
Time on Station	160 days	
Top Tensiometer:		
Peak Tension	5750#	27 April 1970
Max. Ave. Tension	4250#	27 April 1970
Max. Dynamic Tension	±1200#	27 April 1970
Min. Ave. Tension**	2500#	Numerous
Bottom Tensiometer:		
Peak Tension	2500#	27 April 1970
Max. Ave. Tension	2000#	27 April 1970
Max. Dynamic Tension	±250#	27 April 1970
Max. Excursion*	2200 ft.	28 April 1970
Max. Excursion*	2250 ft.	21 May 1970

*Derived from FORACS Position Plots

**Due to suspended line and chain

TENSION AND EXCURSION EXTREMES FOR BUOY B (LDB)

TABLE 4.1.2-2

OBSERVATION	VALUE	DAY
Deployed		31 March 1970
Retrieved		15 September 1970
Time on Station	169 days	
Top Tensiometer:		
Peak Tension	3750#	29 August 1970
Max. Ave. Tension	3700#	29 August 1970
Max. Dynamic Tension	±200#	28 June 1970
Min. Tension**	2050#	Before Buoy on Deck (21 July)
Min. Tension**	1950#	After Buoy on Deck (21 July)
Min. Dynamic Tension	±25#	Numerous
Buoy Lifted on Deck	5000#+	21 July 1970
Max. Excursion*	360 ft.	28 April 1970
Max. Excursion*	375 ft.	20 May 1970

* Derived from FORACS Position Plots

** Due to suspended line and chain

TENSION AND EXCURSION EXTREMES FOR BUOY C

TABLE 4.1.2-3

Tension traces for Buoy D from November to January 1969, show tension drops and rises very similar to those in Figure 4.1.2-1. This figure represents data from a Woods Hole Oceanographic Institution (WHOI) taut mooring in which the anchor was suspected of dragging as the environmental conditions built up. At a certain sea state the line tension appears to have exceeded the holding power of the anchor thereby pulling it along the bottom. When breakout occurred the line tension dropped abruptly, the anchor settled back in and the tension began to rise again until it reached breakout tension once more.

This slip, grap, slip cycle on the WHOI mooring took approximately one (1) hour. Buoy D experienced several cycles similar in duration and shape as these. (Figure 4.1.2-2).

The major difference marking the tension traces from the WHOI buoy and those of San Clemente Island Lighted Test Buoy D was the dynamic tension at the time of possible anchor drag.

The WHOI tension drops occurred during a period when the seas were increasing the line tension from a mean value of 2700 pounds to 3250 pounds. The dynamic tension range peaked at ±250 pounds as compared to ±50 pounds before and after the storm. Buoy D exhibited slip and grap motion exclusively at times of low dynamic tensions (but possibly high currents). Low in this case means ±250 pounds compared with maximum dynamic tensions of ±750 pounds during storms.

As indicated in Section 3.2.2.4, it may be necessary to employ a burial type of anchor (danforth) along with the dead weight concrete sinker to eliminate the problem of anchor dragging.

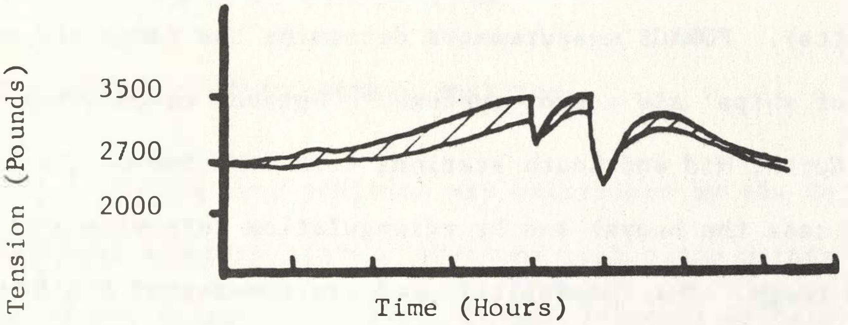


FIGURE 4.1.2-1 MOORING TENSION TRACE FROM WOODS HOLE OCEANOGRAPHIC INSTITUTION

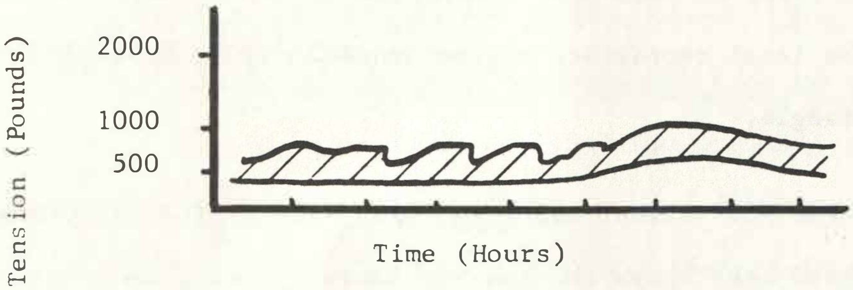


FIGURE 4.1.2-2 MOORING TENSION BUOY D 8 JANUARY 1970

4.1.3 FORACS WATCH CIRCLE DATA

4.1.3.1 REDUCTION OF DATA

San Clemente Island is the location of one of the four Fleet Operational Readiness Accuracy Check Sites (FORACS) located in the Atlantic and Pacific Oceans. The remaining three locations are Guantanmo Bay (Cuba), Nanakuli (Hiwaii), and Cape Cod (Massachusetts). FORACS measurements determine the range and bearing accuracies of ships' ASW sensor systems. "Optical theodolites located at North, Mid and South stations track the bow of the ship (or in this case the buoys) and by triangulation determine its location on range. The theodolites used are two-second K & E Models IE. Accuracy of location in mid range is well within one foot. However, at extreme ends of the range or if the target is difficult to track, the closure triangle may be very large."[11] This inaccuracy has been attributed to wind shear and thermal gradients causing refraction over these along optical lengths. "The size of the closure triangle, delta east and delta north, are displayed for each mark (sequence number) so that the probable accuracy of each measurement can be evaluated. The location X and Y on the local coordinate system is taken from the centroid of the closure triangle." [11]

Over 700 optical sightings were made on the San Clemente Island Lighted Test Buoys for the Sea Lanes Project, from April through July by the FORACS Facility on a not to interfere basis. These sightings resulted in approximately 50 position points for each buoy. Each point consists of three sightings by each of the tracking stations.

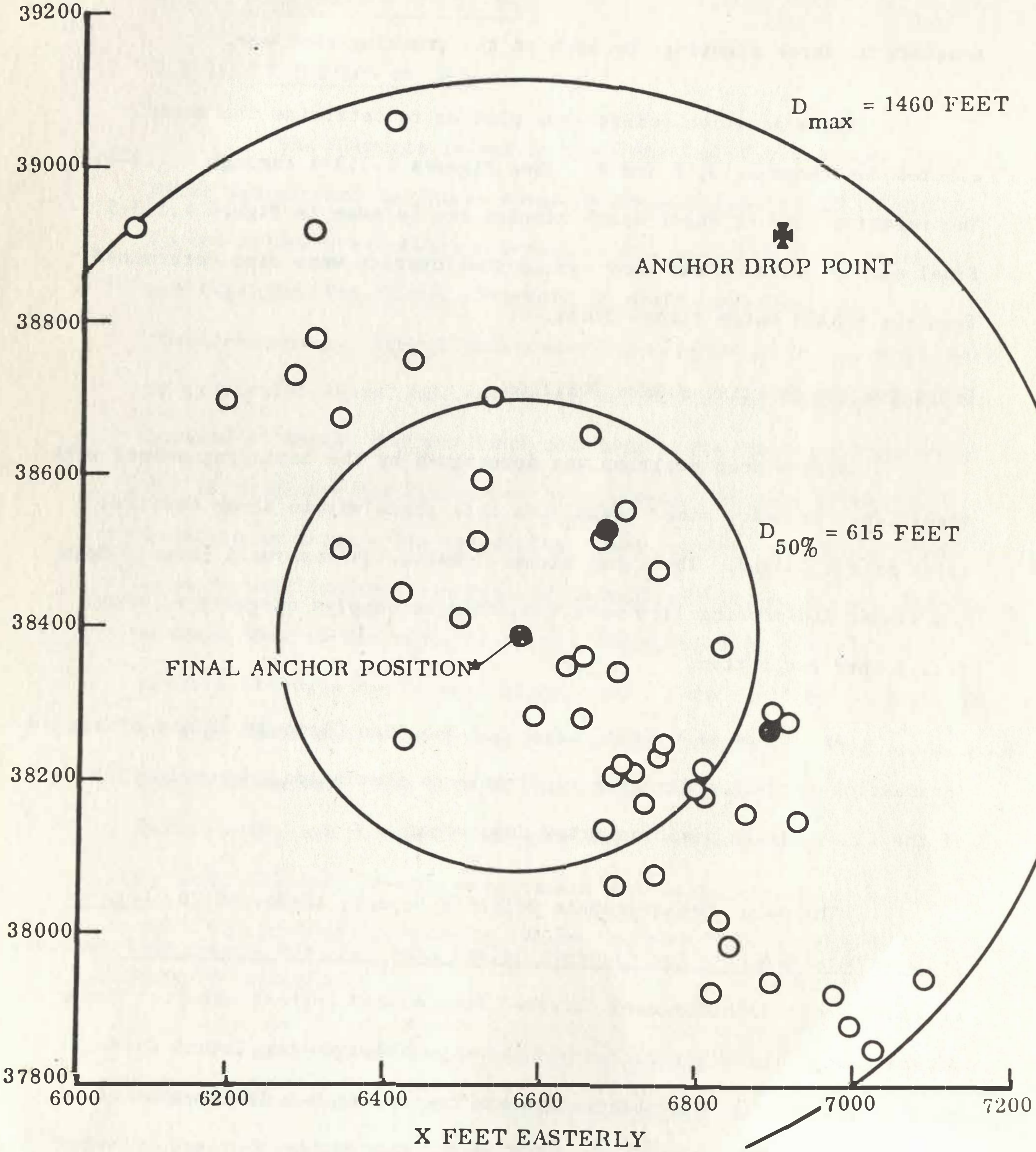
These position points were plotted to determine the watch circles for buoys A, B, C and E. (See Figures 4.1.3-1 through 4.1.3-4). The relative size of their watch circles can be seen in Figure 4.1.3-5. Final anchor position and buoy system stationarity were also determined from the FORACS Watch Circle Plots.

DETERMINATION OF FINAL SINKEN POSITION

Sinken drop position was determined by the deploying vessel with significant accuracy since operations took place within three nautical miles of the Island. The final sinker location is less well known. Both the sinker and mooring line were subjected to complex currents as they fell toward the bottom.

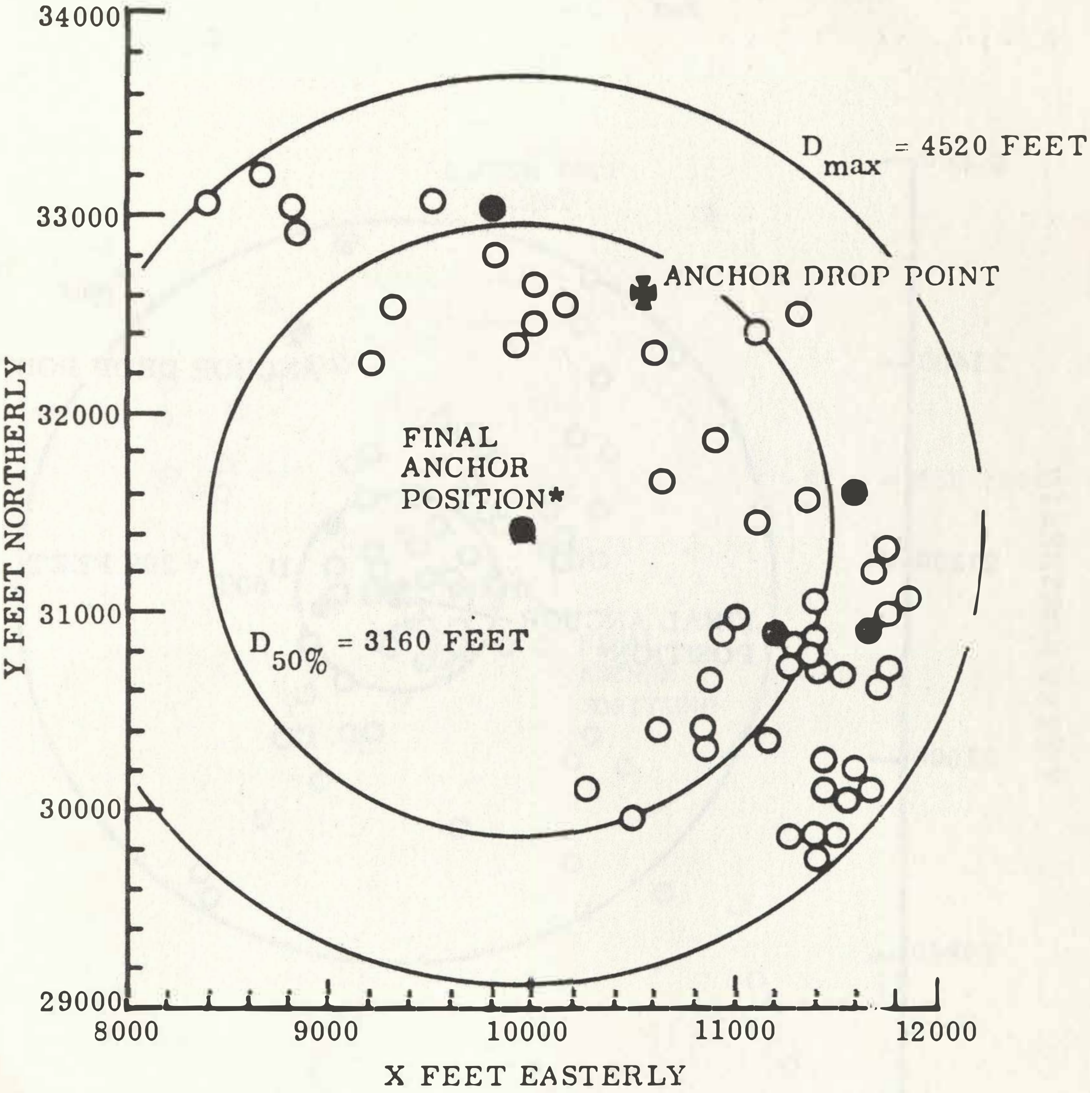
As can be seen from Figure 4.1.3-5, San Clemente Island offers an interesting situation directly applicable to statistical determination of the final sinken position after deployment.

The Naval Oceanographic Office's Report, IR-No. 68-20, Oceanographic Data Report - San Clemente Island Area July and August 1967 includes current direction histograms obtained from moored current meters. These diagrams show the major currents flowing parallel to the Island during much of the year. This observation has been borne out in a series of current profile casts taken from CGC WALNUT during November and December 1969, and by the Watch Circle Position Plots of the Sea Lanes Buoys for April through July 1970.



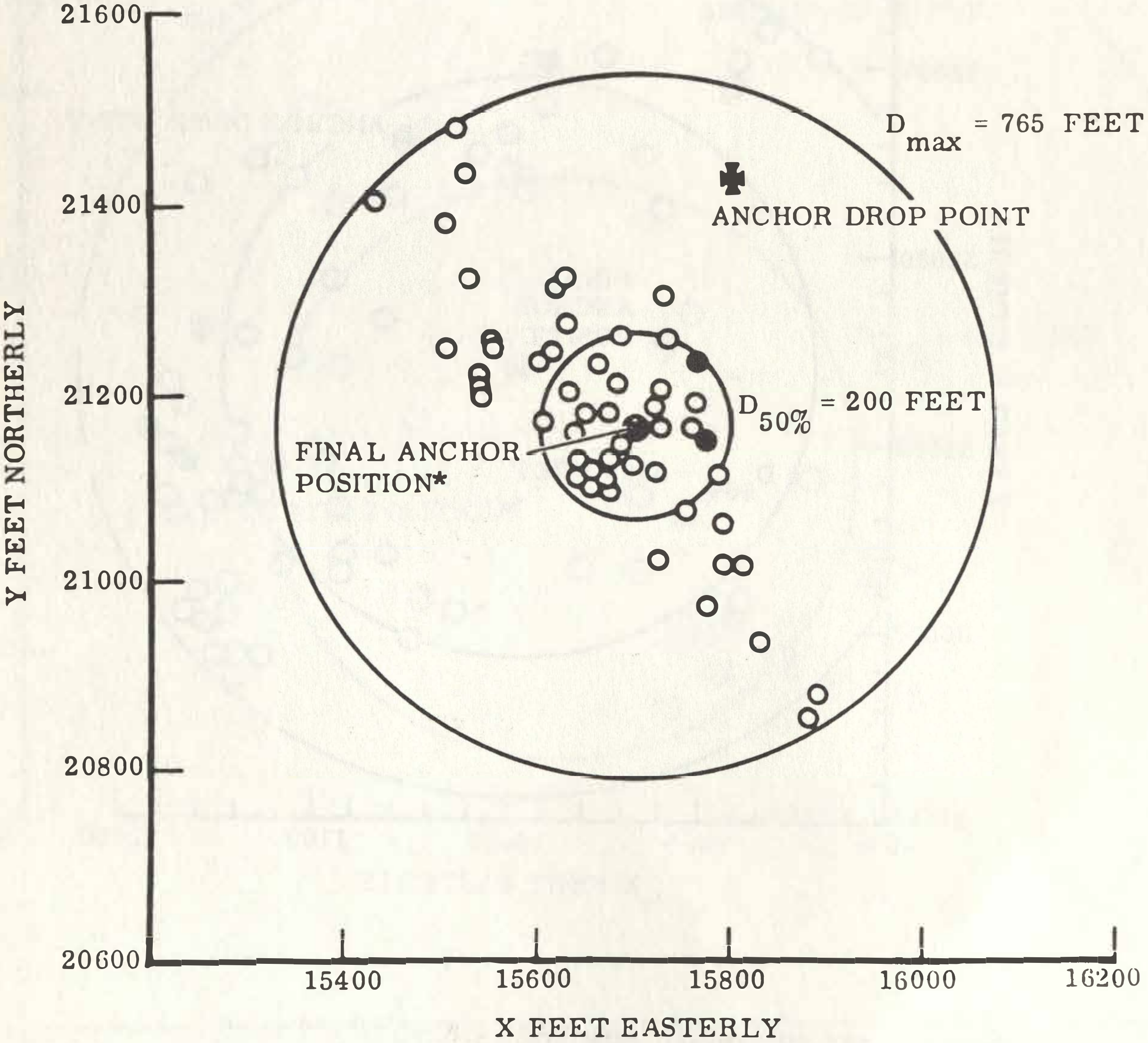
*AS DETERMINED FROM FORACS DATA

FIGURE 4.1.3-1. BUOY A LOCATIONS FROM FORACS DATA



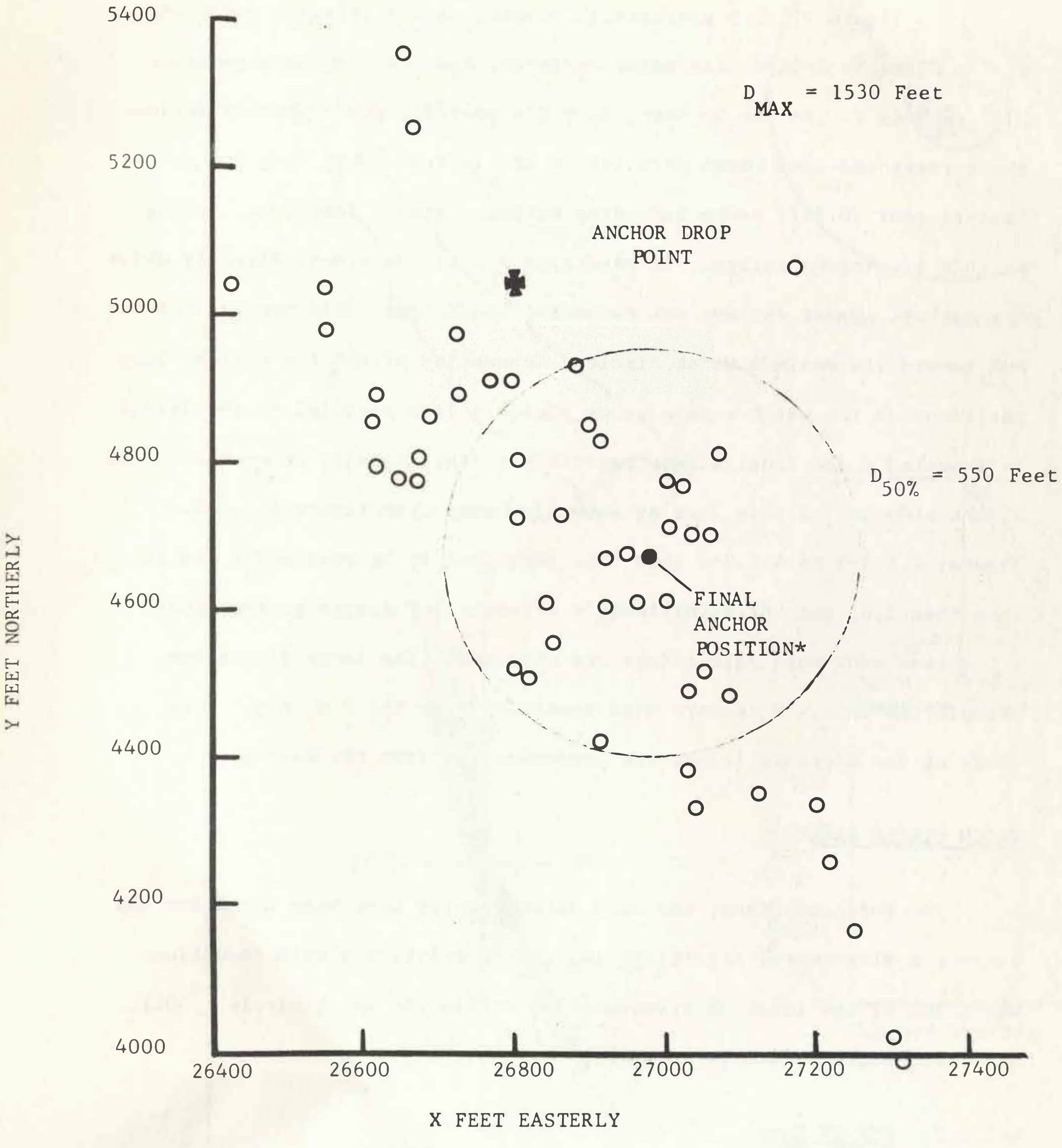
*AS DETERMINED FROM FORACS DATA

FIGURE 4.1.3-2. BUOY B LOCATIONS FROM FORACS DATA



*AS DETERMINED FROM FORACS DATA

FIGURE 4.1.3-3. BUOY C LOCATIONS FROM FORACS DATA



*AS DETERMINED FROM FORACS DATA

FIGURE 4.1.3-4 BUOY E LOCATIONS FROM FORACS DATA

Figure 4.1.3-5 graphically summarizes the relative positions of San Clemente Island, its major currents, and the long term position plot of Buoy C. As can be seen, Buoy C's position predominately follows the current and thus moves parallel to the Island. This buoy has the tautest moor (0.87/1 scope including bottom chain). Therefore, during periods of minimum current, it maintains a position almost directly above its anchor. Under extreme environmental conditions, this mooring reaches out toward its maximum watch circle. Connection of the two extreme buoy positions on the watch circle plots yields a line parallel to the Island as expected. The final sinker position is statistically determined to be at the midpoint of this line as shown for Buoy C in Figure 4.1.3-5. Figures 4.1.3-1 to 4.1.3-4 show this technique to be reasonable for scopes less than 1.0, but not significantly accurate for scopes greater than 1.0 unless many more data points are obtained. The large discus buoy exemplifies this. B is more wind sensitive than the 9 x 38's. (The winds at San Clemente Island are predominantly from the West.)

WATCH CIRCLE DATA

For comparison, the buoy watch circles have been drawn for the extreme environmental conditions (D_{MAX}) and relatively calm conditions where 50% of the total observations lie within the watch circle ($D_{50\%}$). This watch circle data is documented in table 4.1.3-1.

4.1.3.2 USE OF DATA

The watch circle data obtained on the Sea Lanes Program can

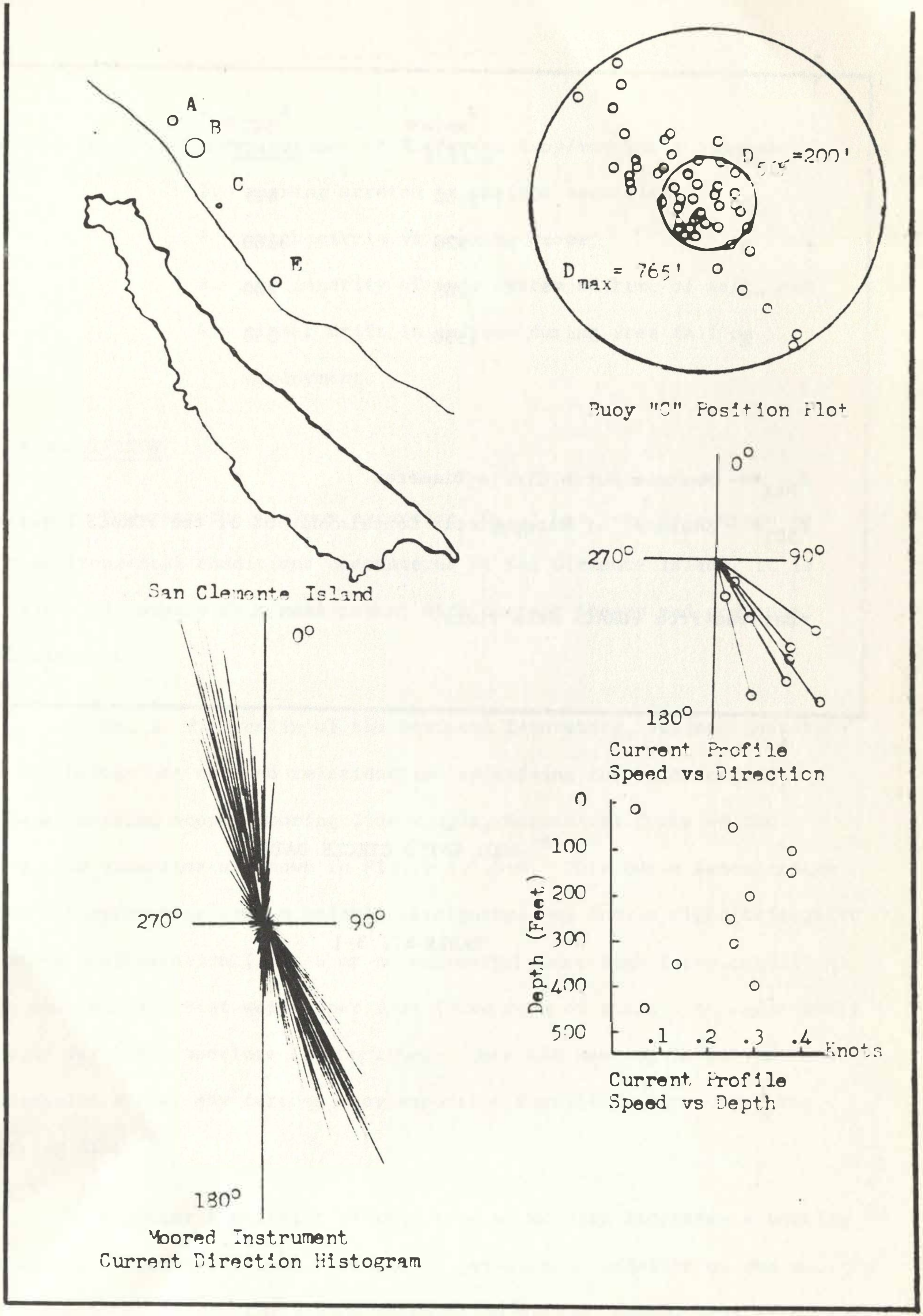


FIGURE 4.1.3-5
BUOY C POSITION VS PREDOMINANT CURRENT DIRECTION

BUOY	D_{MAX}** (FEET)	$D_{50\%}$* (FEET)
A	1460	615
B	4520	3160
C	765	200
E	1530	550

D_{MAX}**- Maximum Watch Circle Diameter

$D_{50\%}$* - Diameter of Watch Circle Containing 50% of the FORACS Observations.

*Derived From FORACS Data Plots.

BUOY WATCH CIRCLE DATA

TABLE 4.1.3-1

be used to investigate a number of different buoy/mooring phenomena:

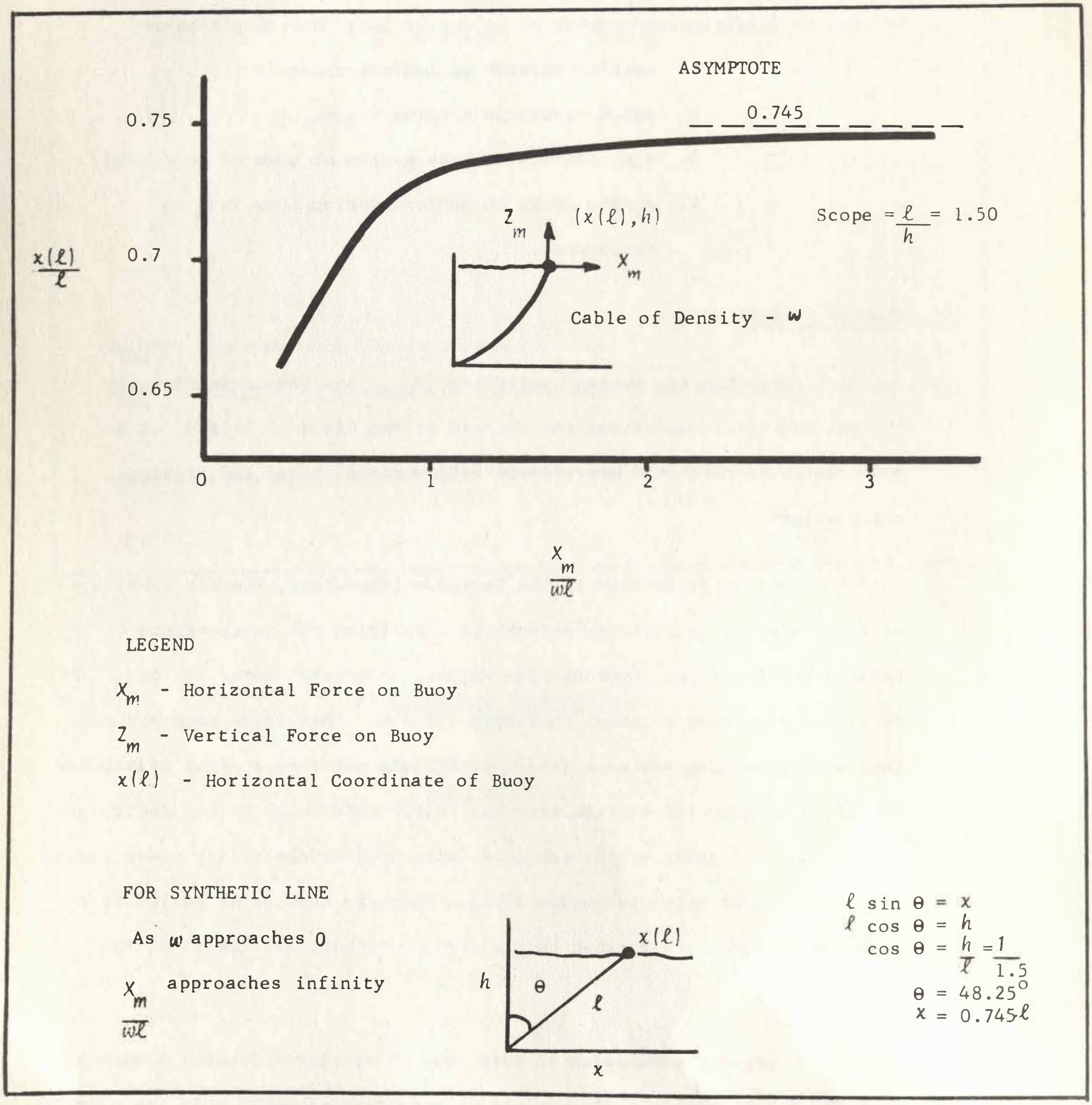
1. mooring stretch at maximum excursion,
2. watch circle vs mooring scope,
3. stationarity of buoy system at time of test, and
4. sinker drift in current during free fall on deployment.

MOORING STRETCH

Now that the maximum excursion (D_{MAX}) has been determined by the environmental conditions encountered at San Clemente Island, it is possible to compare this measurement with current theory and previous calculations.

Dr. J. P. Breslin of the Davidson Laboratory, Stevens Institute of Technology has derived relationships specifying the interactions between mooring scope, mooring line weight, horizontal force on the buoy, and excursion as shown in Figure 4.1.3-6.[16] This curve demonstrates that a buoy/mooring system quickly straightens out into a right triangular mooring configuration (little or no catenary) under high force conditions for moorings of great weight per foot (wire rope or chain), or under small forces for light moorings (nylon line). Once the mooring is pulled to a triangular shape, any further buoy excursion results in stretch of the mooring line.

Computer simulation of this type of mooring indicates a working stretch of approximately 5%. Values of permanent elongation of the mooring line due to the transient forces encountered during launch, long term creep and line shrinkage must also be considered in the final mooring design as demonstrated in 3.2.1.



LEGEND

X_m - Horizontal Force on Buoy

Z_m - Vertical Force on Buoy

$x(\ell)$ - Horizontal Coordinate of Buoy

FOR SYNTHETIC LINE

As w approaches 0

$\frac{X_m}{w\ell}$ approaches infinity

$\ell \sin \theta = x$

$\ell \cos \theta = h$

$\cos \theta = \frac{h}{\ell} = \frac{1}{1.5}$

$\theta = 48.25^{\circ}$

$x = 0.745\ell$

FIGURE 4.1.3-6 INTERACTIONS BETWEEN MOORING SCOPE, MOORING LINE DENSITY, HORIZONTAL FORCE ON THE BUOY AND EXCURSION

WATCH CIRCLE VERSUS SCOPE

The graph of buoy watch circle versus scope (Figure 4.1.3-7) bears out calculations that smaller scopes result in greater tensions in the mooring line and tighter watch circles as a result of the greater horizontal restoring forces of very taut moors.

Each of the San Clemente Island Lighted Test Buoys was designed with a different mooring as shown below:

A 1¼ inch diameter - Columbian Line
B 1½ inch diameter - Columbian Line
C 1 inch diameter - Columbian Line
E 1 inch diameter - Samson Line

Detailed drawings and lists of mooring components can be found in Figures 4.2.1-1 to 4.2.1-7.

BUOY SYSTEM STATIONARITY

To achieve accurate buoy/mooring data for validation of the static and dynamic mooring simulations, the buoy system tested must be in steady state equilibrium with its environment at the time of data acquisition. The buoy must be at the furthest point of the watch circle defined by the current and winds acting at that time. FORACS position data which contains buoy location and time can be of help in determining system stationarity. A fine example of a buoy system in motion was captured

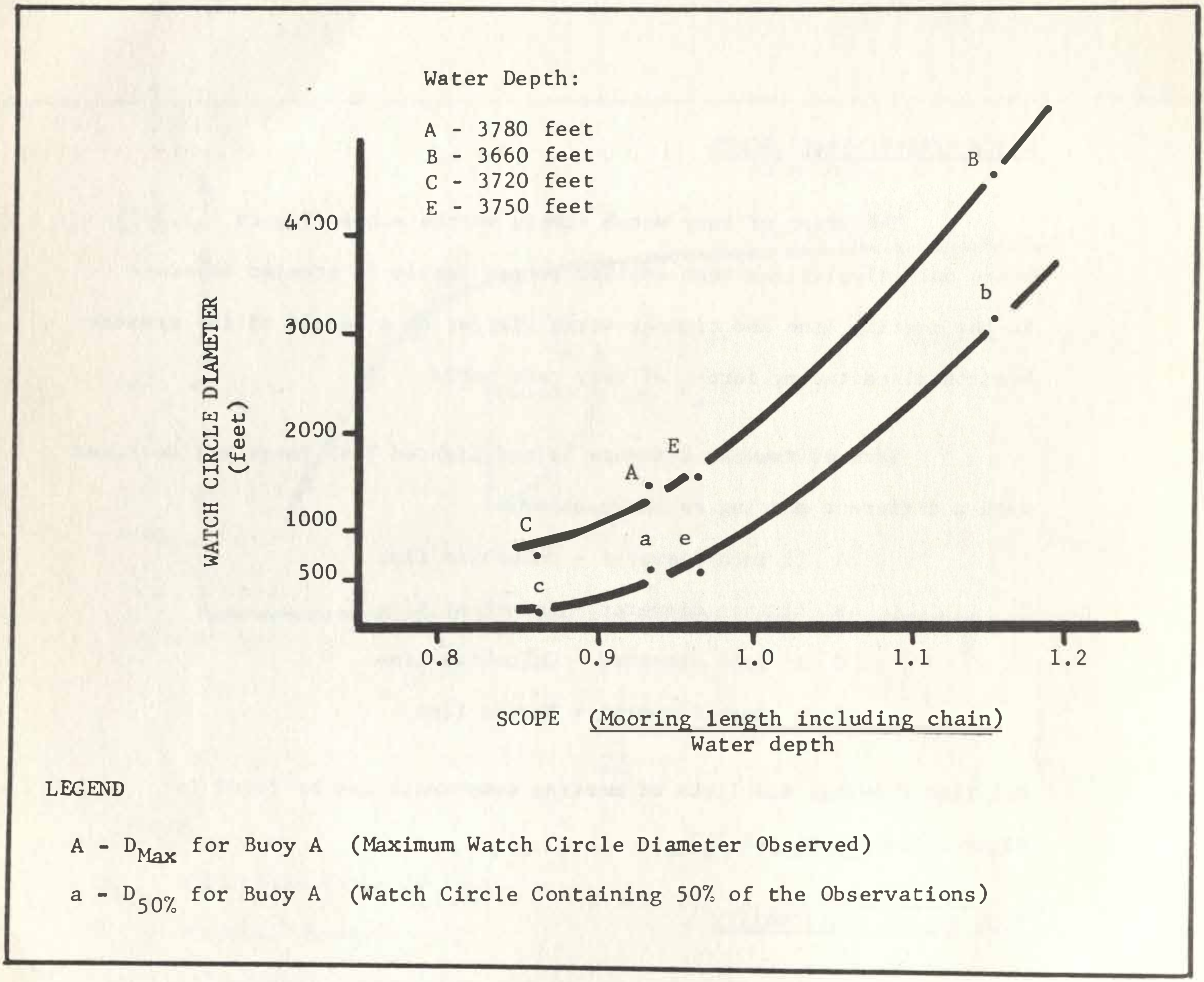


FIGURE 4.1.3-7. BUOY WATCH CIRCLE VERSUS SCOPE

on 15 April 1970. The Large Discus Buoy B, responding to winds and currents off San Clemente Island, moved approximately 1200 feet in 473 minutes (between 0743 and 1536) for an average speed of 0.025 knots. At the start of its movement, the buoy drifted at 0.044 knots.

The EOE and ONR-Convair mooring simulations being investigated on this program are two dimension models. All forces are assumed to lie in the same vertical plane as the buoy, mooring, and anchor. By knowing the final sinker position and buoy position during a static or dynamic test run, it is possible to determine whether the environmental forces (wind and currents) are coplanar with the buoy and anchor or if they are moving the buoy back around its anchor and out of equilibrium.

SINKER DRIFT ON DEPLOYMENT

During the Sea Lanes program, the sinker deployment point was determined by the Coast Guard Cutter WALNUT. The final anchor location was derived by statistical analysis of the FORACS data. This data is summarized in Table 4.1.3-2.

Separate calculations which assume a uniform current acting on the sinker from the time it enters the water to impact on the bottom,

BUOY STATION	SINKER DROP POSITION*				FINAL SINKER POSITION**				DISTANCE BETWEEN DROP POINT AND FINAL SINKER POSITION (FEET)**
			FORACS RANGE COORDINATES				FORACS RANGE COORDINATES		
	LATITUDE	LONGITUDE	X (FEET)	Y (FEET)	LATITUDE	LONGITUDE	X (FEET)	Y (FEET)	
A	33°04'27"N	118°32'53"W	6898	38912	33°04'32.2"N	118°32'42.8"W	6558	38390	625
B	33°03'26"N	118°32'06"W	10600	32620	33°03'32.6"N	118°31'55.5"W	9880	31400	1400
C	33°01'42"N	118°30'59"W	15794	21425	33°01'42.99"N	118°30'56.08"W	15700	21165	280
E	32°59'01"N	118°28'46"W	26800	5040	32°59'1.88"N	118°28'39.96"W	26973	4678	410

* Visual Sighting Upon Deployment

** Derived from FORACS Data Plots

FORACS SINKER POSITION DATA

TABLE 4.1.3-2

show that large currents would be necessary to produce the movement exhibit between the drop point and final sinker position.

A	1.38 knots
B	3.22 knots
C	0.59 knots
E	0.88 knots

Surface currents in the San Clemente Island deployment area were less than 0.4 knots during the deployments.

These results point to the need for further investigation of the problems affecting accurate buoy location before and after deployment. Several phenomena might be responsible for the observed distances between sinker drop point and final sinker position.

Buoys A and E are at extreme ends of the test range at San Clemente Island. The same environmental problems would affect visual position location from the deployment vessel as encountered by the FORACS facility, namely wind shear, thermal gradients and small triangulation angles.

Inaccuracy of sinker drop position plotting may occur when converting from longitude and latitude measurements to X, Y coordinates on the FORACS range.

Predominant winds or currents may have biased the buoy position plots.

An interesting concept requiring further investigation for deep water mooring is the "sailing sinker" effect. Hydrodynamic model tests have indicated that a sinker dropped into deep waters may sometimes deviate significantly from a vertical path. Full scale tests on the Sea Lanes Project have shown this deviation (due to current and sailing) to be less than the radius of the buoy watch circle.

For Buoy B, whose large scope dictates a large watch circle, the final sinker location can not be statistically defined with the amount of data obtained.

4.2 EXPAND CG/NDBP OPERATIONAL EXPERIENCE WITH DEEP OPEN WATER MOORINGS AND TESTING TECHNIQUES

The second primary objective of the Sea Lanes Program was to expand Coast Guard and NDBC operational experience in deep open water mooring and testing techniques. This objective has been accomplished in several areas:

1. design of survivable deep water A to N mooring system,
2. development of ship handling and deployment techniques for these mooring systems,
3. experience with instrumentation and testing techniques.

4.2.1 DESIGN OF SURVIVABLE DEEP WATER A TO N SYSTEM

As pointed out in Section 3.2.1, deep water A to N moorings have specialized functions to fulfill and their design requirements reflect them:

1. small well defined watch circles,
2. high reliability and survivability of the buoy and mooring system, and
3. ease and safety of deployment and tending.

These requirements dictated development of the mooring designs seen in Figures 4.2.1-1 to 4.2.1-7. Further examination of the performance of these moorings, as shown in Tables 4.2.1-1 to 4.2.1-7 and throughout this report has been performed in light of these requirements. The buoy systems employed on the Sea Lanes Project were developmental in nature. Their results point to reliable operational deep water A to N moorings constructed of nylon line

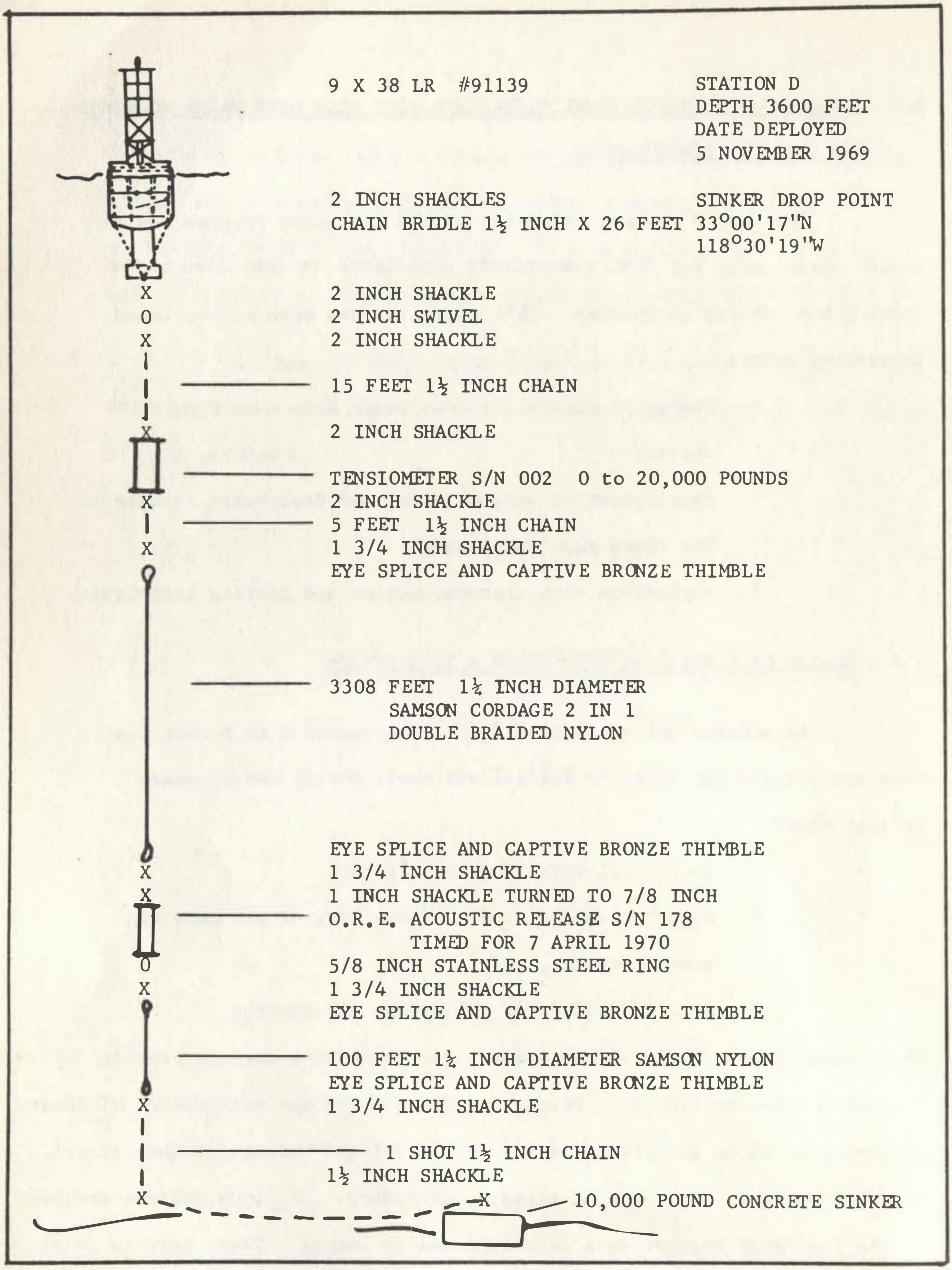


FIGURE 4.2.1-1 BUOY D MOORING CONFIGURATION

BUOY STATION	D
BUOY BODY	9 X 38 LR
MOORING DIAGRAM	FIGURE
LINE MANUFACTURER	SAMSON CORDAGE
LINE TYPE	2 IN 1 DOUBLE BRAIDED NYLON
LINE DIAMETER	1¼ INCH DIAMETER
LINE LENGTH*	3308 FEET
PENDANT 100 FT. 1¼" DIA.	SAMSON CORDAGE
BOTTOM CHAIN DIA.	1½ INCH DIAMETER
CHAIN LENGTH	90 FEET
SINKER	10,000 POUND CONCRETE
WATER DEPTH	3600 FEET
SCOPE (LINE ONLY)	0.946/1
SCOPE (LINE AND CHAIN)	0.97/1
DATE DEPLOYED	5 NOVEMBER 1969
DATE RETRIEVED	24 MARCH 1970
DAYS ON STATION	143 DAYS
DEPLOYMENT TECHNIQUE	TOW AWAY
SINKER DROP RATE	8 MINUTES TOTAL DROP TIME
MAX. LOAD ON DEPLOYMENT	5000 POUNDS
MIN. LOAD ON STATION	700 POUNDS

*MEASURED AT 200D^2

TABLE 4.2.1-1 BUOY D DEPLOYMENT DATA

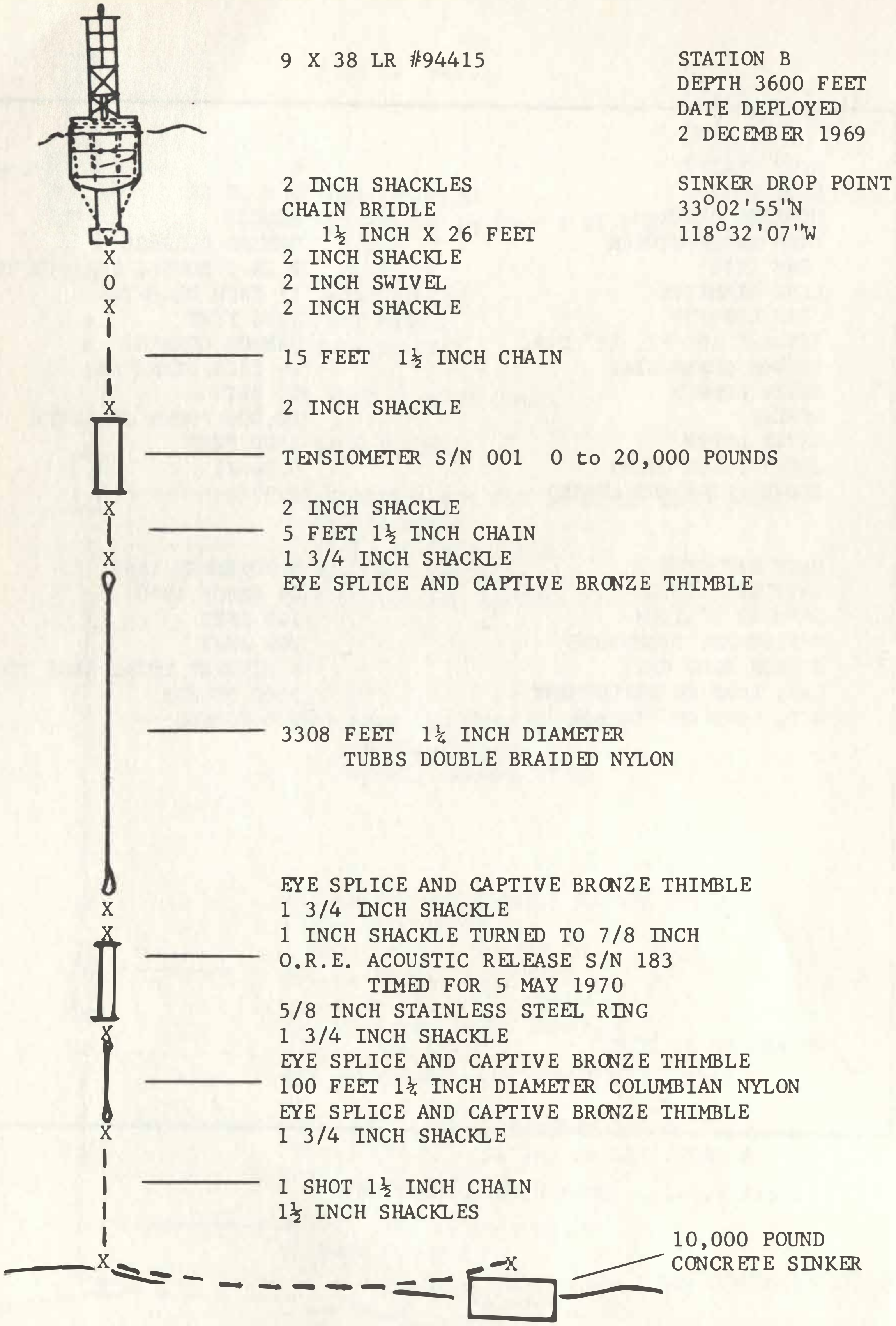


FIGURE 4.2.1-2 BUOY B MOORING CONFIGURATION

BUOY STATION	B
BUOY BODY	9 X 38 LR #94415
MOORING DIAGRAM	FIGURE
LINE MANUFACTURER	TUBBS GREAT WESTERN
LINE TYPE	DOUBLE BRAIDED NYLON
LINE DIAMETER	1¼ INCH DIAMETER
LINE LENGTH*	3308 FEET
PENDANT 100 FT. 1¼ INCH DIA.	COLUMBIAN
BOTTOM CHAIN DIA.	1½ INCH DIAMETER
CHAIN LENGTH	90 FEET
SINKER	10,000 POUND CONCRETE
WATER DEPTH	3600 FEET
SCOPE (LINE ONLY)	0.946/1
SCOPE (LINE AND CHAIN)	0.97/1
DATE DEPLOYED	2 DECEMBER 1969
DATA RETRIEVED	5 FEBRUARY 1970
DAYS ON STATION	65 DAYS ACOUSTIC RELEASE FAILED #183**
DEPLOYMENT TECHNIQUE	TOW AWAY
SINKER DROP RATE	9½ MINUTES TOTAL DROP TIME
MAX. LOAD ON DEPLOYMENT	4500 POUNDS
MIN. LOAD ON STATION	NEGLIGIBLE

*MEASURED AT 200D^2

**O.R.E. ACOUSTIC RELEASE S/N 183 ALSO FIRED PREMATURELY WHILE STORED IN THE MACHINE SHOP OF CGC WALNUT IN THE ARMED CONDITION. STORAGE PERIOD 23 DAYS.

TABLE 4.2.1-2 BUOY B DEPLOYMENT DATA

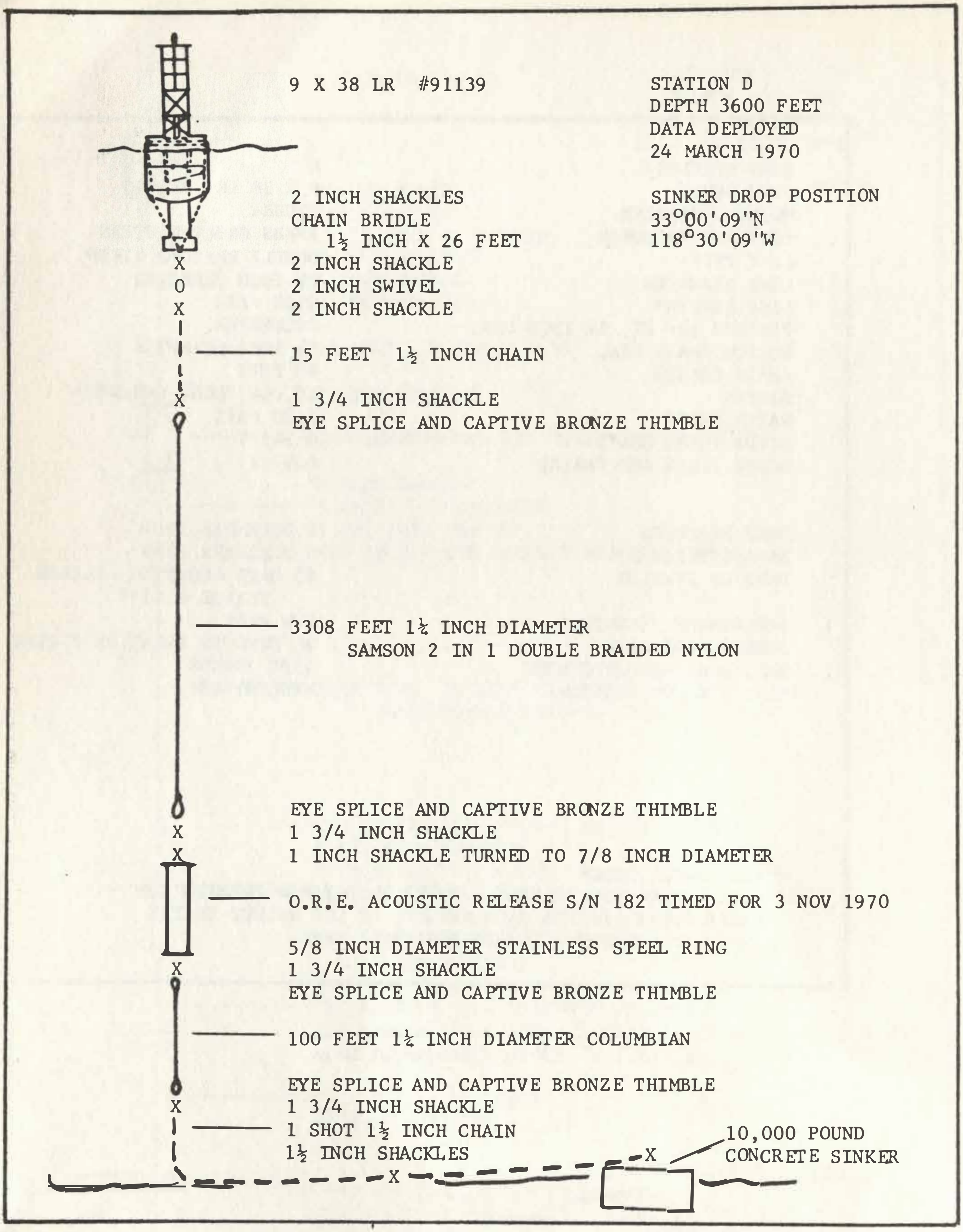


Figure 4.2.1-3 BUOY D MOORING CONFIGURATION

BUOY STATION	D
BUOY BODY	9 X 38 LR #91139
MOORING DIAGRAM	FIGURE
LINE MANUFACTURER	SAMSON CORDAGE
LINE TYPE	2 IN 1 DOUBLE BRAIDED NYLON
LINE DIAMETER	1¼ INCH DIAMETER
LINE LENGTH*	3308 FEET
PENDANT 100 FT. 1¼" DIA.	COLUMBIAN
BOTTOM CHAIN DIA.	1½ INCH DIAMETER
CHAIN LENGTH	90 FEET
SINKER	10,000 POUND CONCRETE
WATER DEPTH	3600 FEET
SCOPE (LINE ONLY)	0.946/1
SCOPE (LINE AND CHAIN)	0.97/1
DATE DEPLOYED	24 MARCH 1970
DATE RETRIEVED	7 MAY 1970 ACOUSTIC RELEASE FAILED #182
DAYS ON STATION	45 DAYS
DEPLOYMENT TECHNIQUE	TOW AWAY
SINKER DROP RATE	9 MINUTES TOTAL DROP TIME

* MEASURED AT $200D^2$

TABLE 4.2.1-3 BUOY D DEPLOYMENT DATA

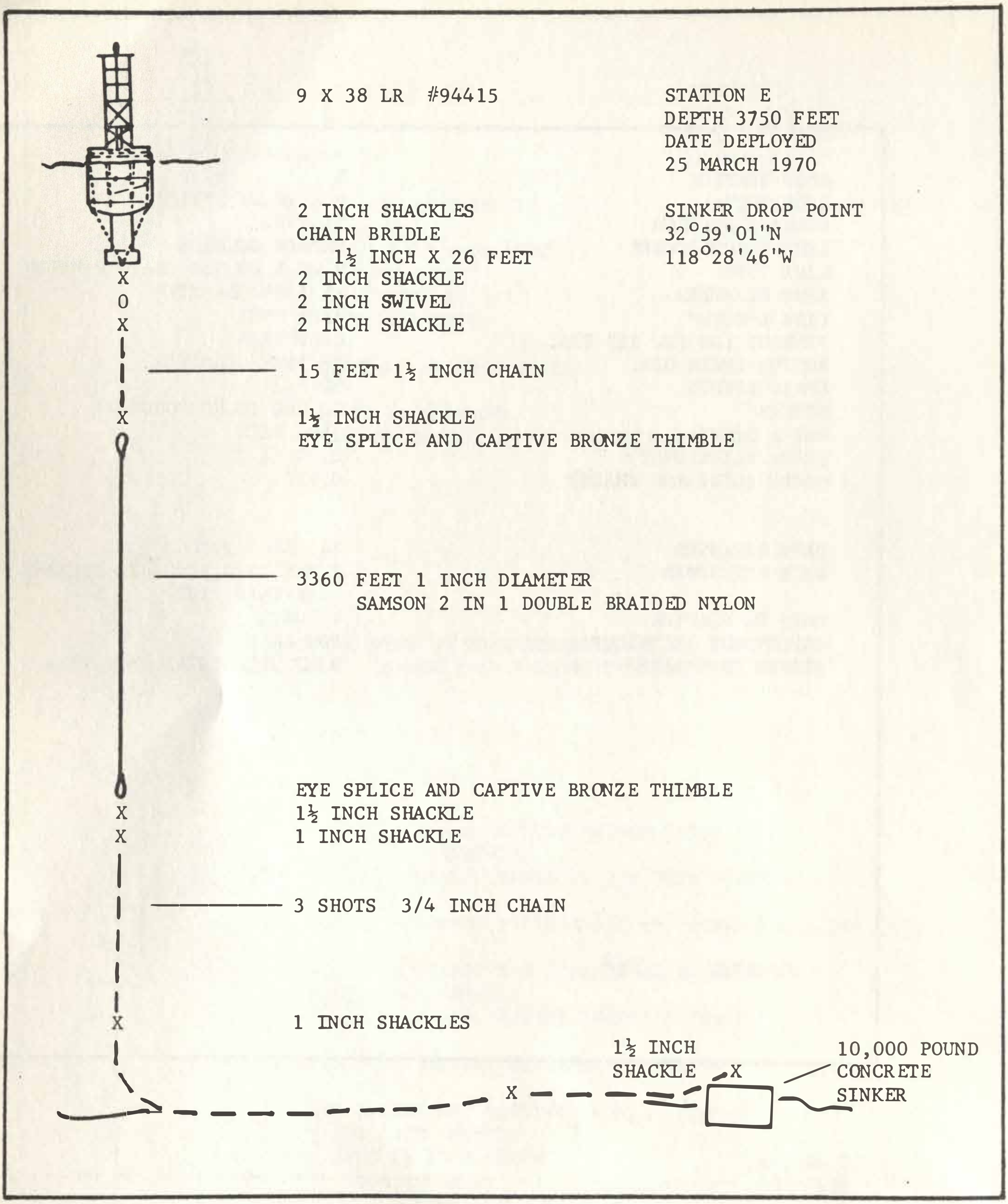


FIGURE 4.2.1-4 BUOY E MOORING CONFIGURATION

BUOY STATION	E
BUOY BODY	9 X 38 LR #94415
MOORING DIAGRAM	FIGURE
LINE MANUFACTURER	SAMSON CORDAGE
LINE TYPE	2 IN 1 DOUBLE BRAIDED NYLON
LINE DIAMETER	1 INCH DIAMETER
LINE LENGTH*	3360 FEET
PENDANT 100 FT. 1½" DIA.	NONE
BOTTOM CHAIN DIA.	3/4 INCH DIAMETER
CHAIN LENGTH	270 FEET
SINKER	10,000 POUND CONCRETE
WATER DEPTH	3750 FEET
SCOPE (LINE ONLY)	0.895/1
SCOPE (LINE AND CHAIN)	0.97/1
DATE DEPLOYED	25 MARCH 1970
DATE RETRIEVED	ON STATION - TO BE RETRIEVED IN APRIL 1972
DAYS ON STATION	
DEPLOYMENT TECHNIQUE	FAKING BOX
SINKER DROP RATE	13.6 FEET PER SECOND
MAX. LOAD ON DEPLOYMENT	NO TENSION MEASURING DEVICES ON BUOY
MAX. CHAIN SUSPENDED	UNKNOWN
MIN. LOAD ON STATION	UNKNOWN
MIN. CHAIN SUSPENDED	UNKNOWN
FINAL SINER POSITION**	32°59'01.88"N 118°28'39.9"W
MAX. WIND	30 MPH
MAX. CURRENT	0.2 to 0.8 KNOTS SURFACE CURRENT
D_{MAX} WATCH CIRCLE	1530 FEET
$D_{50\%}$ WATCH CIRCLE	550 FEET

*MEASURED AT $200D^2$

**DERIVED FROM FORACS DATA

TABLE 4.2.1-4 BUOY E DEPLOYMENT DATA

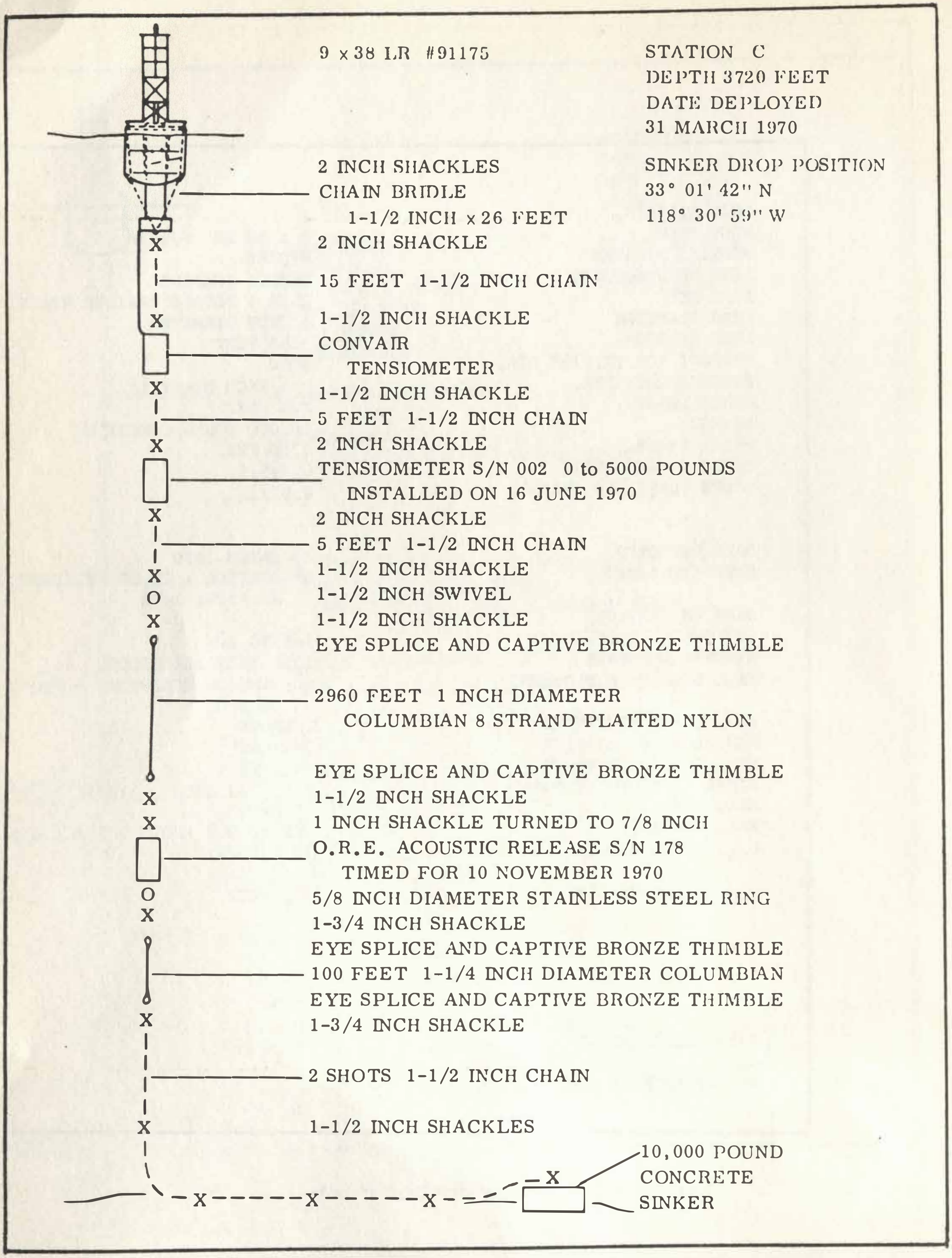


FIGURE 4.2.1-5 BUOY C MOORING CONFIGURATION

BUOY STATION	C
BUOY BODY	9 x 38LR #91175
MOORING DIAGRAM	Figure 3-5
LINE MANUFACTURER	Columbian Rope Company
LINE TYPE	8 Strand Plaited Nylon
LINE DIAMETER	1 Inch
LINE LENGTH*	2960 Feet
PENDANT 100 Ft. 1 1/4" Dia.	Columbian
BOTTOM CHAIN DIAMETER	1 1/2 Inch
CHAIN LENGTH	180 Feet
SINKER	10,000 Pound Concrete
WATER DEPTH	3720 Feet
SCOPE (LINE ONLY)	0.823/1
SCOPE (LINE AND CHAIN)	0.87/1
DATE DEPLOYED	31 March 1970
DATE RETRIEVED	15 September 1970
DAYS ON STATION	169 Days
DEPLOYMENT TECHNIQUE	Faking Box
SINKER DROP RATE	13.2 Feet Per Second
MAX. LOAD ON DEPLOYMENT	5120 Pounds
MAX. CHAIN SUSPENDED	180 Feet Plus Stretch of Line
MIN. LOAD ON STATION ***	1950 Pounds
MIN. CHAIN SUSPENDED	91 Feet
FINAL SINKER POSITION**	33°01'42.9"N 118°30'56"W
MAX. WIND	30 MPH
MAX. CURRENT	0.2 to 0.8 Knots Surface Current
D_{MAX} WATCH CIRCLE	765 Feet
$D_{50\%}$ WATCH CIRCLE	200 Feet

*Measured at $200D^2$

**Derived from FORACS Data

***Measured at Tensiometer S/N 002

TABLE 5.2.1-5 BUOY C DEPLOYMENT DATA

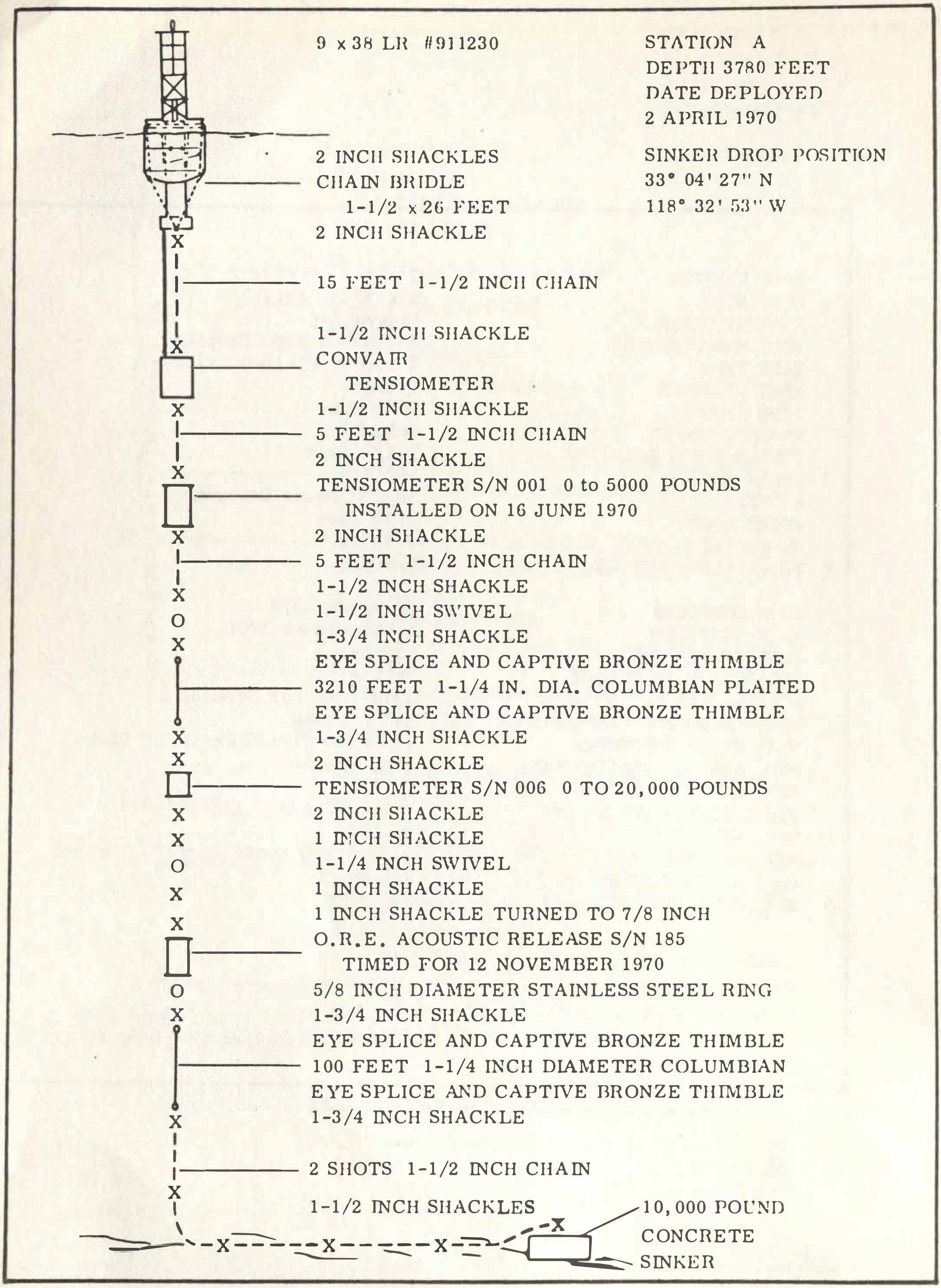


FIGURE 4.2.1-6 BUOY A MOORING CONFIGURATION

BUOY STATION	A
BUOY BODY	9 x 38 LR #911230
MOORING DIAGRAM	Figure 3-4
LINE MANUFACTURER	Columbian Rope Co.
LINE TYPE	8 Strand Plaited Nylon
LINE DIAMETER	1 1/4 inch
LINE LENGTH*	3210 Feet
PENDANT 100 FT. 1 1/4" dia.	Columbian
BOTTOM CHAIN DIAMETER	1 1/2 inch
CHAIN LENGTH	180 Feet
SINKER	10,000 Pound Concrete
WATER DEPTH	3780 Feet
SCOPE (LINE ONLY)	0.875/1
SCOPE (LINE AND CHAIN)	0.94/1
DATE DEPLOYED	2 April 1970
DATE RETRIEVED	15 September 1970
DAYS ON STATION	166 days
DEPLOYMENT TECHNIQUE	Faking Box
SINKER DROP RATE	13.9 Feet per Second
MAX. LOAD ON DEPLOYMENT	3252 Pounds
MAX. CHAIN SUSPENDED	166 Feet
MIN. LOAD ON STATION***	1000 Pounds
MIN. CHAIN SUSPENDED	42 Feet
FINAL SINKER POSITION**	33°04' 32.2"N 118°32' 42.8"W
MAX. WIND	30 MPH
MAX. CURRENT	0.2 to 0.8 Knots Surface Current
D_{MAX} WATCH CIRCLE	1460 Feet
$D_{50\%}$ WATCH CIRCLE	615 Feet

*Measured at $200D^2$

**Derived from FORACS Data

***Measured at Tensiometer S/N 001

TABLE 4.2.1-6 BUOY A DEPLOYMENT DATA

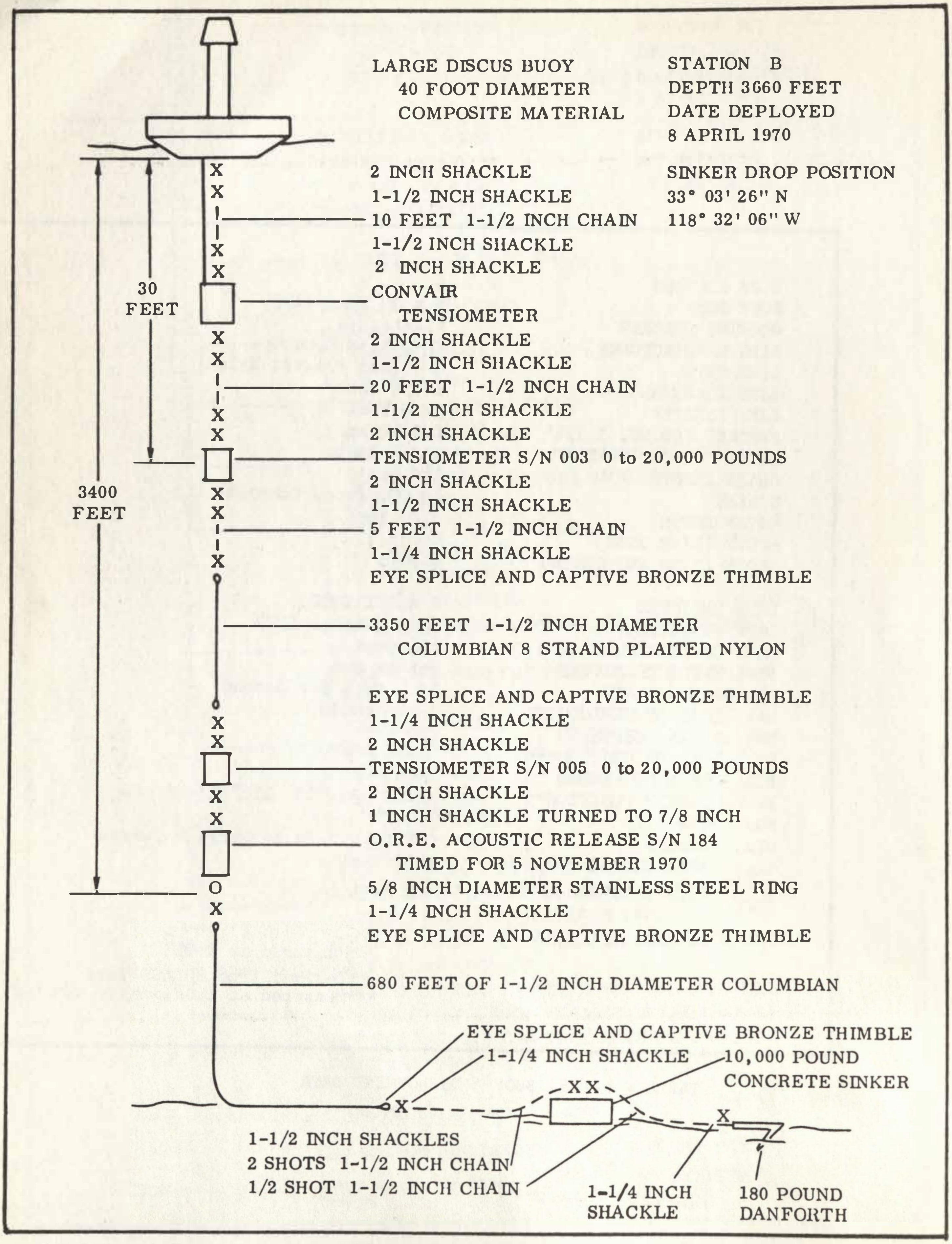


FIGURE 4.2.1-7 BUOY B MOORING CONFIGURATION

BUOY STATION	B
BUOY BODY	40 Foot Diameter Composite LDB
MOORING DIAGRAM	Figure 3-10
LINE MANUFACTURER	Columbian Rope Co.
LINE TYPE	8 Strand Plaited Nylon
LINE DIAMETER	1 1/2 Inch
LINE LENGTH*	3350 Feet
PENDANT 100Ft. 1 1/4" Dia.	680 Feet 1 1/2" Diameter Columbian
BOTTOM CHAIN DIAMETER	1 1/2 Inch
CHAIN LENGTH	180 Feet
SINKER	10,000 Pound Concrete + 180# Danforth
WATER DEPTH	3660 Feet
SCOPE (LINE ONLY)	1.1/1
SCOPE (LINE AND CHAIN)	1.16/1
DATE DEPLOYED	8 April 1970
DATE RETRIEVED	15 September 1970
DAYS ON STATION	160 Days
DEPLOYMENT TECHNIQUE	Faking Box
SINKER DROP RATE	14.1 Feet per Second
MAX. LOAD ON DEPLOYMENT	1000 to 1500 Pounds
MAX. CHAIN SUSPENDED	Unknown
MIN. LOAD ON STATION	Negligible
MIN. CHAIN SUSPENDED	Zero
FINAL SINKER POSITION**	33°03'32.6"N 118°31'55.5"W
MAX. WIND	30 MPH
MAX. CURRENT	0.2 to 0.8 Knots Surface Current
D_{MAX} WATCH CIRCLE	4520 Feet
$D_{50\%}$ WATCH CIRCLE	3160 Feet

*Measured at $200D^2$

**Derived from FORACS Data

TABLE 4.2.1-7 BUOY B DEPLOYMENT DATA

having scopes between 0.85/1 to 0.9/1 which suspend approximately one shot of chain above the bottom during relatively calm periods. Smaller watch circles can be obtained by utilizing moorings with shorter scopes. By their nature, smaller scopes yield greater tensions.

Two "worst cases" exist for the A to N synthetic mooring. The first is the extremely rough environmental condition where winds and currents build up to such a level that the mooring is susceptible to line failure. The second case which must be considered for long term reliability and survivability is the nearly calm condition during which the mooring line may lie on the bottom and become chaffed. Permanent elongation and long term creep in the synthetic line can lead to this second case.

It can now be seen that the A to N mooring is a system which must be optimized with respect to size of watch circle, both extreme environmental conditions and the material properties of the mooring itself.

4.2.2 MOORING DEPLOYMENT PHENOMENA

The operational aspects of a deep water mooring system must be smooth, easy, and safe. The Sea Lanes Project has been able to explore this area in depth through the efforts of the officers and crew of USCGC, WALNUT (WLM 252). Their ideas, criticisms, and aid on the Sea Lanes deployments have advanced the state-of-the-art in operational techniques applicable to deep water moors. Documentation of each mooring deployment is contained in the deployment reports (reference numbers 6,7,8,9,12,13 & 14) available at COMDT (O), (OAN), (OMS), (EOE), and Comwest area. Many of the important points of these reports can be found in Section 3.3.1.2.

LAUNCH TRANSIENTS

Two different deployment techniques were used on the Sea Lanes Project. The first used was the towaway technique. This is a buoy first anchor last deployment, examined in Woods Hole Oceanographic Institutions' May 1969 report on Analysis & Experimental Evaluation of Single Point Mooring Buoy Systems.

In a towaway deployment, the buoy is placed in the water, the mooring line is then payed out and the anchor released at the drop point.

The second type of deployment is the original technique devised (with the aid of Samson Cordage representatives), developed and operated by the CGC WALNUT personnel. The "WALNUT Technique" (see Section 3.3 for details) is an operation as much akin to standard Coast Guard buoy tending practice as possible.

In this technique the sinker is hung in the chain stopper, and the drop point is approached. The buoy is then hung over the side. (The buoy is not released to float away from the ship.) The ship maneuvers into position and the sinker is released from the chain stopper at the drop point. The mooring line runs freely from a faking box position at the ship's rail, the buoy is released after the sinker is on the bottom.

In this type of deployment, the sinker and mooring fall almost straight for the bottom (affected mainly by subsurface currents and hydrodynamic drift. See Section 4.1.3). In the towaway technique, the anchor and mooring execute a complex arc through the water.

Of the two, the "WALNUT Method" should yield more accurate sinker positioning. It is also faster and less complicated. No small boat is needed to tow the buoy away from the ship to keep the line out of the ship's screws during maneuvers.

Figure 4.2.2-1 shows the launch transients encountered on three different deployments Buoys D, C, and A. Alpha and Charlie deployed using the "WALNUT Technique" and the third (D), the towaway technique. Each system used comparable moorings as can be seen in Figures 4.2.1-1, 4.2.1-5 and 4.2.1-6. They each had 10,000 pound sinkers and 1½ inch diameter chain for ground tackle.

The launch transient began to build immediately after sinker drop with the towaway technique. The tension continued to increase until it approached the weight in water of the sinker and bottom chain (5000 pounds recorded) shortly before the sinker impacted the bottom.[15] The tension then dropped off toward the steady state value (nearly zero for Buoy "D" which had a scope of 0.97/1).

With the WALNUT Faking Box Technique, no tension build up was encountered until all the line had run from the faking box. At

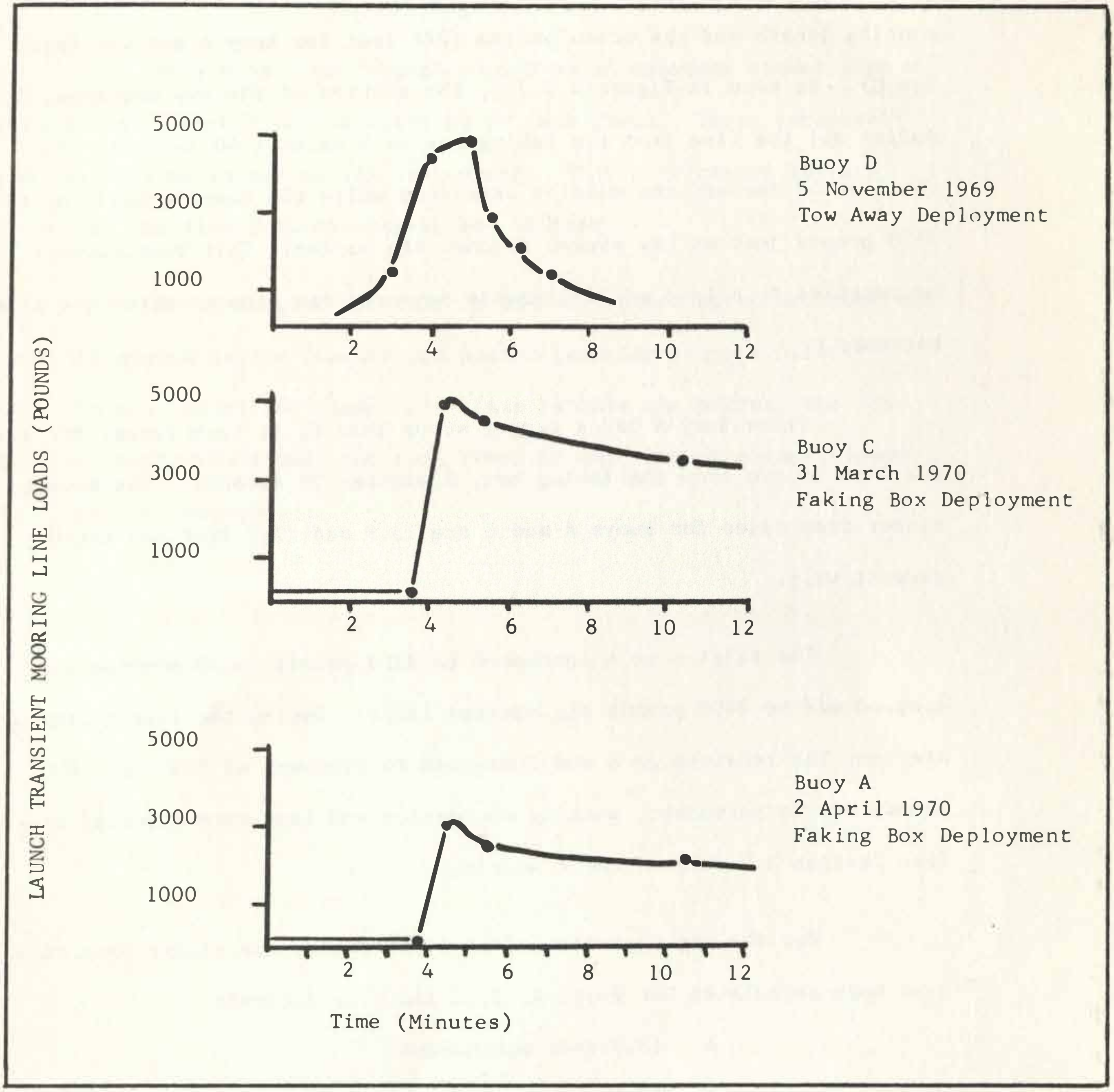


FIGURE 4.2.2-1 LAUNCH TRANSIENTS FOR TOW AWAY AND FAKING BOX DEPLOYMENTS

that time the mooring stretched out to close the gap between deployed mooring length and the ocean bottom (226 feet for Buoy A and 419 feet for C). As seen in Figure 4.2.2-1, the shorter of the two moorings, C, pulled all the line from the faking box in 3 minutes 40 seconds. For the next 48 seconds the mooring stretched while the tension built up to 5120 pounds just as the sinker touched the bottom. This tension then began to decrease to a load of 3630 pounds measured six minutes after the sinker bottomed.

Since Buoy A had a larger scope than C, it took longer for all the line to run from the faking box, 3 minutes 53 seconds. The average sinker drop rates for Buoys A and C are 13.9 and 13.2 feet per second respectively.

The tension on A increased to 3250 pounds in 33 seconds and dropped off to 2400 pounds six minutes later. During the four months on station, the tensions on A and C dropped to minimums of 1000 and 1950 pounds due to permanent, working elongation and long term material creep (See Section 3.2.3.1) of their moorings.

For the San Clemente Island deployments, the sinker drop rates have been calculated for Buoys A, B, C and E as follows:

A 13.9 feet per second
B 14.1 feet per second,
C 13.2 feet per second,
E 13.6 feet per second.

The calculation of this data was based on the time needed for the sinker and ground tackle to pull the nylon mooring line from the faking box.

Buoy B had the typical 10,000 pound concrete sinker plus a 180 pound danforth anchor and 2½ shots of 1½ inch chain. These components acted as the driving forces during deployment. This combination appears to have pulled the line from the faking box fastest.

A significant decrease in the deployment speed was observed on B when the ground tackle reached the bottom (mooring scope - 1.16/1 including chain). After the sinker and chain reached the bottom, the line in the water continued to pull the rest from the box, but at a much slower rate (2.7 feet per second).

4.2.3 TEST INSTRUMENTS AND TECHNIQUES USED

Ruggedness, accuracy and reliability are the greatest assets at sea instrumentation can possess. During this project profiling current meters, tensiometers and acoustic releases were employed and tested. Tables 4.2.3.1 to 4.2.3-4 document the successes and failures encountered.

Sound programs covering predeployment tests and calibration of equipment are essential. Confidence in the data obtained is dependent upon both the original and final check calibrations.

Optical techniques were employed to determine each buoy's response to the sea. A telephoto motion picture camera was located at the test site command station (Figure 4.2.3-1). This camera recorded buoy motion at each mooring during the thirty minute period in which dynamic line tension data was being recorded. These motion pictures were then reduced and analyzed as indicated in Section 3.4.2, Figure 3.4.2-1.

This technique suffered from lack of contrast and definition when black and white film was used.

During the morning hours, the sun was behind the buoys and photographic recording of the motion was impaired.

The current profile unit suffered most from its lack of ruggedness. Failure of underwater connectors became a continuing problem during the tests when deployed from a small boat.

INSTRUMENT	LOCATION	DATE DEPLOYED	RESULTS
Marine Advisors Current Profile Meter, Model B-1a/5b with S-13a readout	WALNUT	5 November 1969	Satisfactory operation.
	WALNUT	2 December 1969	Satisfactory operation.
	WALNUT	25 March 1970 31 March 1970	Satisfactory operation.
	San Clemente Island	April-July 1970	Numerous instrument failures due to at-sea operation in small boat. Predominant failure: leakage and breakage of underwater connectors and bearing failure on Savonius rotor. Refurbishment performed September 1970

CURRENT PROFILE INSTRUMENT DEPLOYMENT

TABLE 4.2.3-1

INSTRUMENT	LOCATION	DATE DEPLOYED	DATE RETRIEVED	DAYS ON STATION	RESULTS
EDD tensiometer 0-6000#	C Top	31 Mar 1970	16 June 1970	-	Operating on deployment; bridge b failing from salt water leak on 15 Apr 1970; failure noted on tape on 25 May 1970.
EDD tensiometer 0-6000#	A Top	2 Apr 1970	16 June 1970	-	Operating on deployment; confirmed salt water leakage 8 June 1970.
Refurbished tensiometer	C Top	21 July 1970	15 Sept 1970	57	Satisfactory operation.
Refurbished tensiometer	A Top	21 July 1970	15 Sept 1970	57	Satisfactory operation.
EDD tensiometer 0-6000#	B Top	8 Apr 1970	15 Sept 1970	160	Satisfactory operation.

EDD TENSIOMETER DEPLOYMENT

TABLE 4.2.3-2

INSTRUMENT	LOCATION	DATE DEPLOYED	DATE RETRIEVED	DAYS ON STATION	RESULTS
Wm. F. Swift Co. 0-20,000 lb. Tensiometer S/N 002	D top	5 November 1969	17 February 1970	74	6v. battery drained (acid droplets inside case). Trace shows time of battery failure.
0-20,000 lb. S/N 001	B top	2 December 1969	5 February 1970	65	No indication of tension after deployment. Instrument did not register strain when tested.
0-20,000 lb. S/N 006	D top	17 February 1970	24 March 1970	24	No indication of tension - mechanical linkage flipped backwards.
0-20,000 lb. S/N 006	A bottom	2 April 1970	15 September 1970	166	Refurbished. Satisfactory operation. Stopped while being opened. Battery dead. Positive pressure inside case. Dry inside.
0-20,000 lb. S/N 005	B bottom	8 April 1970	15 September 1970	160	Satisfactory operation; running when opened. 6v. battery read 3/4 volts. Dry inside but some water had passed first "O" ring.
0-20,000 lb. S/N 003	B top	8 April 1970	15 September 1970	160	Satisfactory operation. Running normally when opened, but out of paper. Dry inside. Battery voltages good.
0-5,000 lb. S/N 001	A top	16 June 1970	15 September 1970	91	Refurbished; satisfactory operation. Operating normally when opened. Dry inside. Battery voltages good.
0-5,000 lb. S/N 002	C top	16 June 1970	15 September 1970	91	Refurbished; satisfactory operation. Operating normally when opened. Dry inside. Battery voltages good.

SELF-RECORDING TENSIOMETER DEPLOYMENT

TABLE 4.2.3-3

INSTRUMENTATION	LOCATION	DATE DEPLOYED	DATE RETRIEVED	DAYS ON STATION	RESULTS
O. R. E. Acoustic Release S/N 183	WALNUT			0	Fired prematurely during 23 day storage in ship's machine shop.
S/N 178	D	24 Nov 1969	24 Mar 1970	143	Satisfactory operation.
S/N 183	B	2 Dec 1969	5 Feb 1970	65	Fired prematurely allowing buoy to drift.
S/N 182	D	24 Mar 1970	7 May 1970	45	Fired prematurely allowing buoy to drift.
S/N 178	C	31 Mar 1970	15 Sept 1970	169	Satisfactory operation.
S/N 185	A	2 April 1970	15 Sept 1970	166	Satisfactory operation.
S/N 184	B	8 April 1970	15 Sept 1970	160	Satisfactory operation.

O. R. E. ACOUSTIC RELEASE DEPLOYMENT

TABLE 4.2.3-4

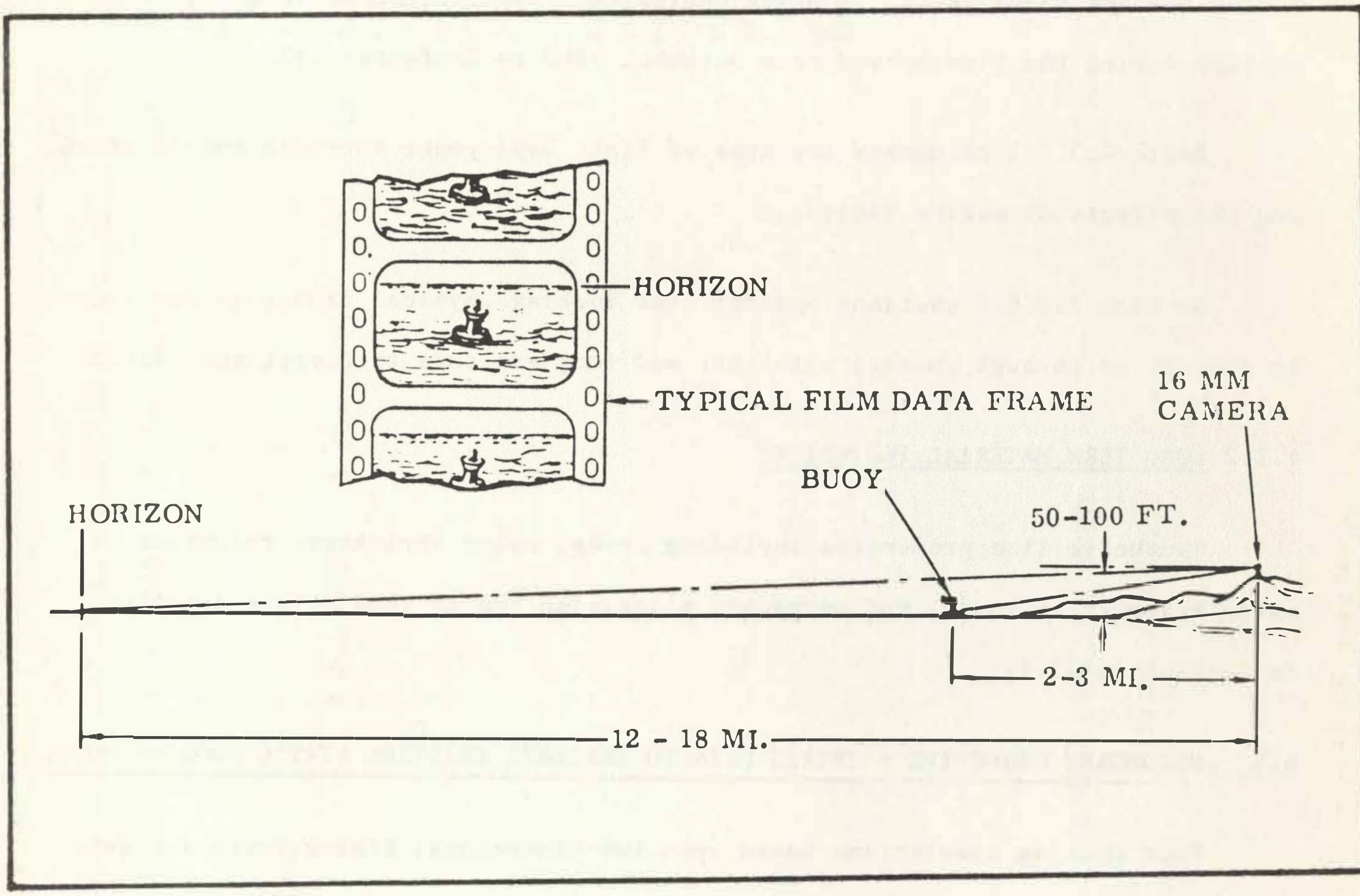


FIGURE 4.2.3-1 OPTICAL TEST SETUP

4.3 OBTAIN PERFORMANCE DATA FOR CANDIDATE MOORING LINE MATERIALS

4.3.1 ENVIRONMENTAL EFFECTS

Both 8 stand plaited and 2-in-1 double braided nylon lines were deployed during the Sea Lanes Tests. Mooring deployments lasted from 45 to 169 days on station during the time period from November 1969 to September 1970.

Table 4.3.1-1 documents the type of line, deployment location and duration, and the effects of marine fouling.

Section 3.2.4.2 cautions against over looking physical damage to new line by rodents or through contact with rust and long exposure to direct sun light.

4.3.2 LONG TERM MATERIAL PROPERTIES

Synthetic line properties including creep, nylon shrinkage, reduction of nylon strength in water, and permanent elongation due to loading are detailed in Section 3.2.3.1.

4.4 SECONDARY OBJECTIVE - OBTAIN DATA TO VALIDATE EXISTING STATIC MOORING MODELS

Four mooring simulations based upon two-dimensional static force analysis have been exercised to compare their predicted results with actual test data obtained during this program.

The outcome has been encouraging. Tensions and excursions of the buoys can now be predicted to within 10 - 20% of the actual values.

LINE	LOCATION	DATE DEPLOYED	DATE RETRIEVED	DAYS ON STATION	RESULTS
1¼ inch diameter Samson 2 in 1 double braided nylon (line redeployed on "D" on 24 March 1970)	D	5 Nov 1969	24 Mar 1970	143	First 30 feet light mussel growth. Very light mossy marine growth down to 200 feet. 200 feet to end like new.
Tubbs Great Western 1¼ inch diameter double braided nylon	B	2 Dec 1969	5 Feb 1970	65	Acoustic release packed with heavy brown mud. Bottom thimble sand polished. One of captive straps torn loose. Outer jacket of lower 850 feet of line lightly frayed as if it had been dragged in sand. Several heavy abrasions in line between 80 and 825 feet from the bottom of line. (Worst at 400 feet above lower end of line). Honeycombed, coral like organisms entangled in the frayed fibers.

MOORING LINE DEPLOYMENT

TABLE 4.3.1-1

LINE	LOCATION	DATE DEPLOYED	DATE RETRIEVED	DAYS ON STATION	RESULTS
1¼ inch diameter Samson 2 in 1 double braided nylon	D	24 Mar 1970	7 May 1970	45	Slightly discolored down to 200 feet. Light mussel growth near the top. Discoloration and growth were not as heavy as on 24 March 1970.
1 inch diameter Samson 2 in 1 double braided nylon	E	25 Mar 1970	On Station		Satisfactory operation. Retrieval scheduled for April 1972.
1¼ inch diameter Columbian 8 strand plaited nylon	A	2 Apr 1970	15 Sept 1970	166	All three of these lines showed discoloration down to about 130 feet. Barnacle growth was much lighter than that previously observed on other nylon lines in the area. The predominant life form was a grasslike growth which was identified as HYDROID. On the lines of buoys A and C, the nylon was approximately 10% fowled with the growth. The line on B was about 35% covered. The HYDROID colonies were about 18" long and grew all around the circumference of the line. Also present were a slug-like animal called NUDI-BRANCHE and a worm (polycheata annelidia) which lives in the hydroid. Only one or two acorn barnacles were present. Below the 130 foot mark, the lines were like new.
1½ inch diameter Columbian 8 strand plaited nylon	B	8 Apr 1970	15 Sept 1970	160	
1 inch diameter Columbian 8 strand plaited nylon	C	31 Mar 1970	15 Sept 1970	169	

MOORING LINE DEPLOYMENT (continued)

TABLE 4.3.1-1

Several difficulties block direct validation of these two-dimensional models. The three-dimensional sea with complex subsurface current profiles and waves does not lend itself to description in coplanar terms.

It is premature to state that any computer simulation is truly validated over the entire range of probable mooring configurations and sea states.

Further parametric study such as C.E. Sibre's "Force Magnitude and System Sensitivity Analysis of Deep Sea Buoy Mooring Systems"[27] is required to determine critical elements to be simulated and tested at sea for each mooring type.

Sibre worked with the two-dimensional mooring simulation prepared by U. S. Coast Guard Headquarter's Office of Ocean Engineering.[30]

He separated the system into various parameters for detailed study.

These parameters are:

1. Reaction Parameter - a parameter that measures the system reaction to the static forces or defines the steady state configuration.

   Tension at Buoy
   Tension at Anchor
   Buoy Excursion
   Percent Stretch

2. Comparison Parameters - the parameters defining the environmental conditions (water depth and current velocity profile) and the principle design tool, the system scope.

3. Engineering Parameters - the parameters defining the system

Normal Drag Coefficient
Tangential Drag Coefficient
Cable Diameter
Cable Cross-Section Area
Cable Modulus of Elasticity
Cable Saturated Weight
Horizontal Buoy Drag

This work has shown that "The sensitivity of the system Reaction Parameter to variation in an Engineering Parameter is determined by the magnitude of the force controlled by the Engineering Parameter".

The Reaction Parameters of a single point mooring of synthetic material are most sensitive to mooring scope, specifically in the taut region (scopes of less than 1.0). This sensitivity results from the static tension caused when the line stretches to reach the bottom.

This phenomena can be graphically demonstrated by examining the force needed to stretch different moorings when under their deployed tensions.

Buoy C	1 inch diameter Columbian	$10\ \frac{\text{lb}}{\text{ft}}$
Buoy A	1¼ inch diameter Columbian	$48\ \frac{\text{lb}}{\text{ft}}$

Compare this with the weight per foot of different chains.

3/4 inch diameter chain	$4.9\ \frac{\text{lb}}{\text{ft}}$
1½ inch diameter chain	$19.6\ \frac{\text{lb}}{\text{ft}}$

Differential forces such as those shown above may be utilized to develop desensitized moorings as noted in Section 3.2.3.3 and Figures 3.2.3-4, 5 and 6.

The Engineering Parameters which may be varied when designing a taut A to N Traffic Lanes Mooring are diameter, modulus of elasticity and weight of the mooring line, and horizontal buoy drag.

Examining a deep water A to N system with a given water depth and scope shows the following:

1. Tension at the buoy is affected most by weight and modulus of elasticity of the line,
2. tension at the anchor increases with the diameter of the line, and
3. buoy excursion is influenced by horizontal buoy drag and line diameter.

4.5 TERTIARY OBJECTIVE - OBTAIN DATA TO VALIDATE EXISTING DYNAMIC MODELS FOR HULL/MOORING ANALYSIS

Comparison of existing computer aided simulations of dynamic mooring response to waves has met with partial success. It has been possible to determine that the models can be made to simulate the buoy/mooring response with a fair degree of accuracy. True validation is still distant.

Dynamic simulation of lines and short moorings should be carried out in laboratories and tow tanks to gain confidence with and determine the limitations of the computer models before realistic validation can be successful in full scale tests.

The dynamic moors are based upon static calculations of the mooring equlib state. Therefore, the same strengths and weaknesses apply as in Section 4.1.

In addition to the previous comments, dynamic internal damping of the line becomes a very necessary parameter in mooring analysis. As seen in Section 3.3.2.2, a deep sea mooring of synthetic line can store a great deal of energy. Some of this energy is lost due to internal damping in a dynamic system.

Long synthetic moorings are believed to be super critically dampended. The term for internal damping must be included in mathematical mooring simulations to preclude invalid discoveries of resonances or standing waves in the mooring.

Certain parameters have shown themselves to be important to the dynamic simulation of deep sea moorings of synthetic line.

A representation of internal line damping which can be varied between the under damped through over damped appears essential.

Stress-strain relationships and modulus of elasticity have been shown to be very important especially for the taut moored systems.

Tests of dynamic mooring simulation are detailed in General Dynamics' Report Number GDC-AAX70-020 entitled "Sea Lanes Test Program Final Report".[19]

Section 5

CONCLUSIONS

1. Deep water aids to navigation can be maintained using standard Coast Guard equipment in conjunction with a synthetic mooring line, hydraulic deck winch, release device and plywood taking box for mooring deployment.
2. A 9 x 38 LR moored with one inch diameter nylon line and two shots of 1½ inch bottom chain (initial mooring scope for line and chain equaling 0.87/1) in 3700 feet of water will maintain a maximum watch circle of approximately 760 feet under a 0.4 knot surface current, 30 MPH winds and 8-10 foot seas.
3. When deployed using the WALNUT faking box technique, this mooring would experience a transient launching load of approximately 5000 pounds. The minimum load on station would approach 2000 pounds.
4. The synthetic (nylon) mooring lines were not seriously affected by marine fouling during their two to six month deployments on the Sea Lanes Tests. Below the light zone, these lines were as clean as new.
5. Fish bite is reported to present one of the greatest hazards to synthetic lines. This is an area (location) dependent problem. None of the moorings located off San Clemente Island have suffered fish bite to date even though sharks, pilot whales, and seals inhabit the area.

6. The U.S. Coast Guard computer aided mooring simulation has been modified slightly by the National Data Buoy Center as a result of findings from the Sea Lanes Project. The Program was found to be a reasonable simulation of a buoy system in the actual ocean environment.
7. This Computer Program can be used in conjunction with the mooring length calculations in Section 3.2.3 to determine the new on-shore length of a proposed deep water mooring.

Section 6

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