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PERFORMANCE ANALYSIS OF WOODS HOLE TAUT MOORINGS

By

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ABSTRACT

The Woods Hole Oceanographic Institution has been using deep-sea moored buoys for acquiring serial observations of ocean currents, temperature and other data for over twelve years. A brief description of the deep-sea mooring program is given. The mooring statistics and performance are described. Mooring failures of 1970 and 1971 have been categorized and statistics on the modes and causes of failures are presented. The reliabilities of different types of moorings are computed and compared. The role of radio telemetry for the real-time measurement of mooring line tension and its use in checking the mooring status are discussed. Examples of potential design data like tension and currents recorded by moorings that failed are provided. Finally, recommendations for research and development needed to improve mooring reliability are given.

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1. Introduction

The moored array program at the Woods Hole Oceanographic Institution has set a total of 460 deep ocean moorings since 1960. These moorings have contained recording and telemetering instruments to measure current speed and direction, temperature, mooring tension, hydrostatic pressure (depth), acceleration in the horizontal and vertical planes, mooring inclination and rotation and certain meteorological parameters. Current speed and direction have been the parameters most frequently measured and recorded. This study considers in detail those moorings set or retrieved during the years 1970 and 1971 and attempts to categorize the causes of failures and to present statistics on individual component failures. In this two-year period 102 moorings were deployed, each engineered on an individual basis. Extensive documentation exists on their design, deployment and retrieval permitting a rational assessment of their performance. Through these statistics, reliability data have been obtained free from speculative and subjective inputs. The objective of the study was to provide information which can be used as a guide to define future engineering research and development efforts required to improve the reliability of the mooring types analyzed.

1.1 Data Base

Moorings set in the years 1970-1971 have been chosed to provide the data base for this study. The rationale behind this choice was based upon the establishment of an engineering program prior to these years to upgrade their performance and the introduction of a more complete documentation procedure of each mooring design, deployment and retrieval.

These years reflect the results of several basic engineering improvements such as the use of torque-balanced wire rope and improved hardware; see Berteaux and Walden (1) for details. A brief description of these moorings and their performance is given in tabular form in Appendix I.

Figures 1 and 2 show the geographical distribution by type of the moorings set in this period. Thirty-five (35) surface, 19 intermediate depth and 48 bottom moorings are shown. Most of the moorings were set in the North Atlantic Ocean on the 70th meridian West. However, 4 moorings were set in the Kuroshio Current off Japan, 5 near the Ryukyu Islands, 2 off South America and one (1) in the mid-North Atlantic.

1.2 Mooring Types

The moorings used at W.H.O.I. are single, series-connected taut structures composed of various materials and components. Three basic types of moorings are used, surface, sub-surface or intermediate, and bottom. Figure 3 shows schematically a typical surface mooring. The

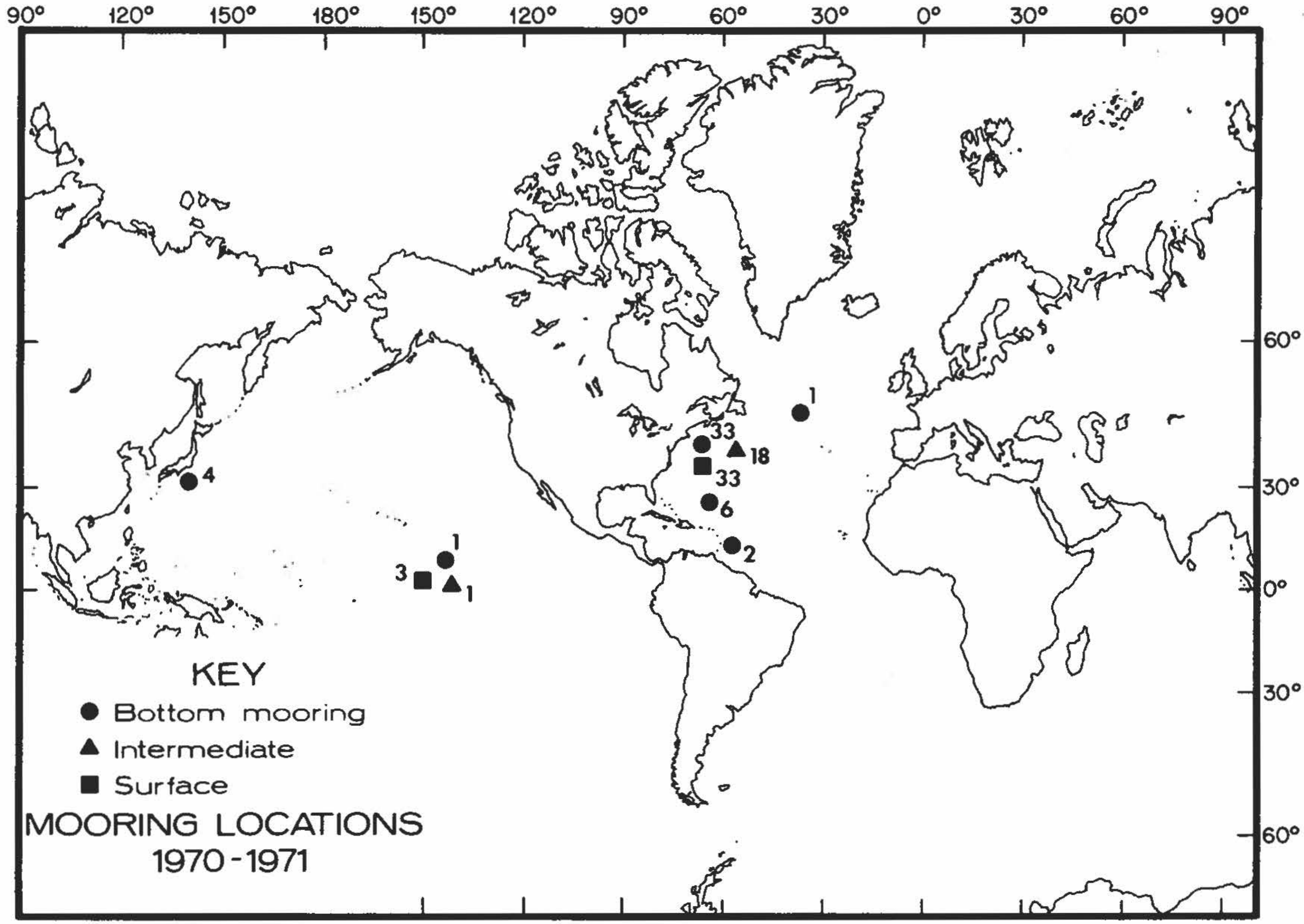

Figure 1. Mooring Locations

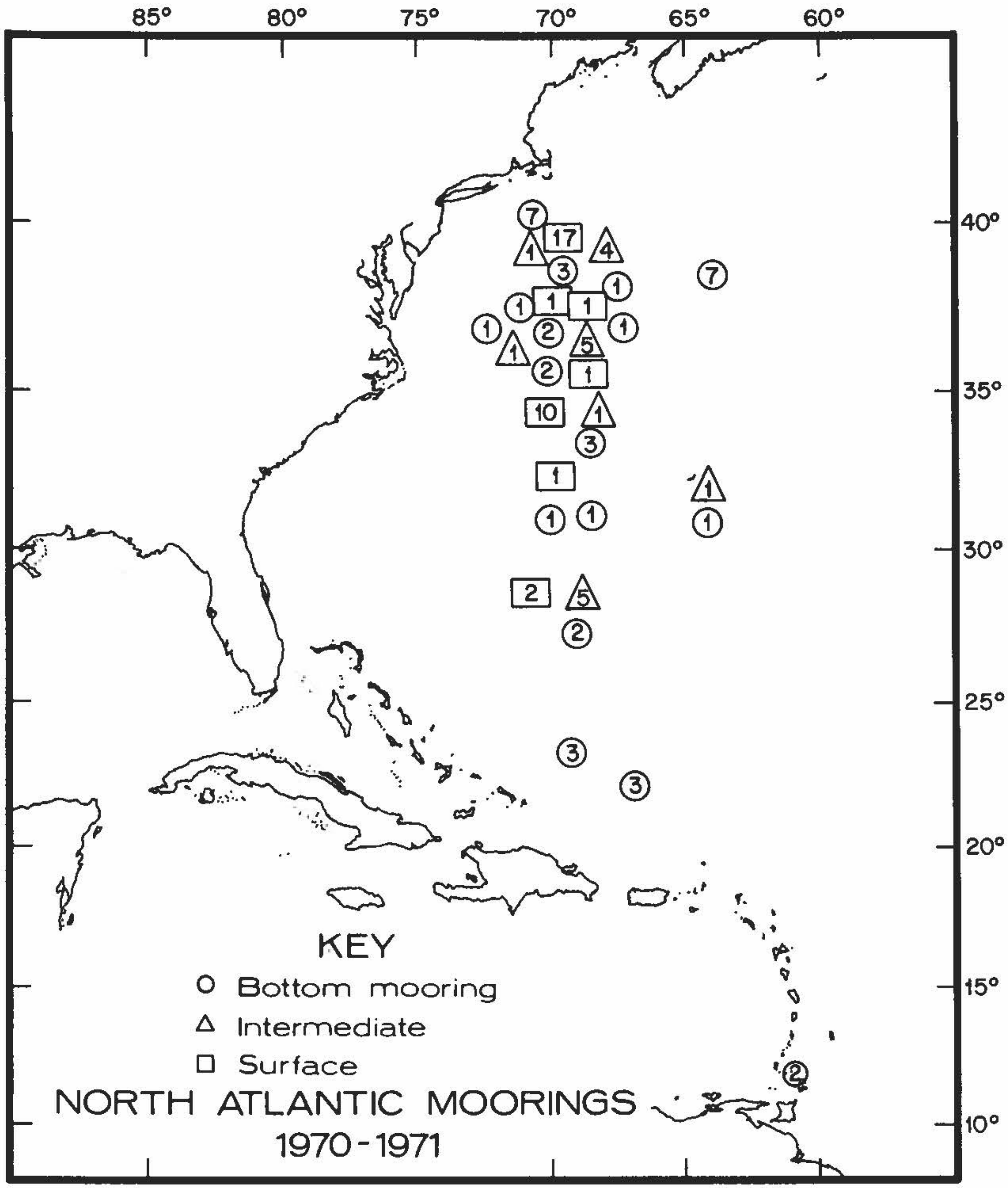

Figure 2. North Atlantic Moorings

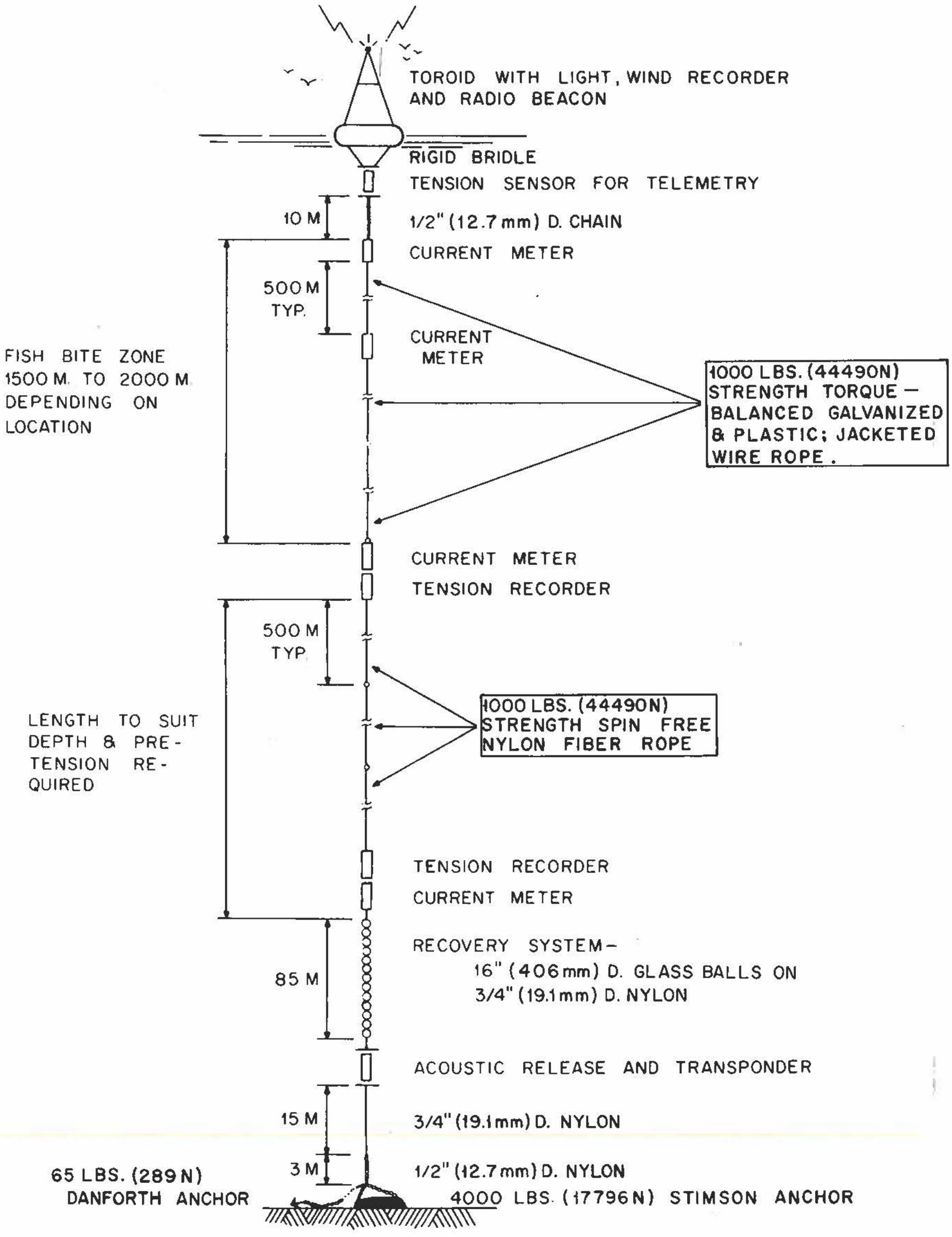

Figure 3. Typical Surface Buoy Mooring

mooring consists of a 2.5 meter toroidal shaped surface float having 22,200 newtons buoyancy. The float contains a navigation light, occasionally a windspeed and direction recorder and a beacon transmitter which is time code modulated by the output of a tension sensor located on the bottom of the rigid bridle. Attached to this tension sensor are 10 meters of chain and 2000 meters of torque-balanced wire rope to prevent damage from fishbite. The remainder of the mooring consists of non-rotating nylon rope. Recording instruments are connected into the mooring line at various depths. An acoustically operated anchor release is attached above the anchor to reduce the tension and loads during the recovery operation. A back-up recovery system, as described by Berteaux and Heinmiller (2) is attached to each mooring just above the acoustic release. It consists of a number of 40 cm. diameter hollow glass spheres attached to the mooring line to provide sufficient buoyancy to raise to the surface the remains of a failed mooring. Each sphere has a buoyancy of 212 newtons. The anchor is a specially designed iron clump which has relatively high holding power at large angles from the horizontal.

Figure 4 shows a typical intermediate type mooring. This type of mooring is used where measurements to the surface are not required and provides measurements free from the effects of mooring motions due to surface effects. A steel sphere is used as the flotation element where the top of the mooring is 200 meters or so below the surface. Where the upper end of the mooring is at greater depths glass spheres are used to obtain the required buoyancy. A radio and xenon strobe light, activated by decreased hydrostatic pressure upon surfacing, aid in the recovery of the mooring. Here again, torque-balanced wire rope is used to 2000 meters depth to provide fishbite protection. Dacron non-spinning rope is used below this depth. Recording instruments are connected into the line where required. Frequently the glass sphere buoyancy elements are distributed throughout the length of the mooring to reduce total mooring tension and also drag where the current is known to decrease with depth. The number of these flotation elements and their location ensures the recovery, at anchor release, of the remains of a failed mooring. The acoustic release permits retrieval of the mooring.

Figure 5 illustrates a typical bottom mooring configuration. A flotation module, made either from syntactic foam or a series of glass spheres contains a beacon radio and xenon strobe light. The typical buoyancy is 1560 newtons. Nylon or dacron line is used to connect the float to the anchor. Recording instruments are attached in the line. An acoustic anchor release is used to permit retrieval of the mooring. A dead-weight clump anchor is normally used in this mooring.

2. Recovery Statistics

Two hundred thirty (230) moorings have been set between the years 1965 and 1971. Figure 6 indicates the number set each year. Figure 7 shows the number of scientific sensors (usually current meters) set each year as opposed to those recovered. Certain engineering

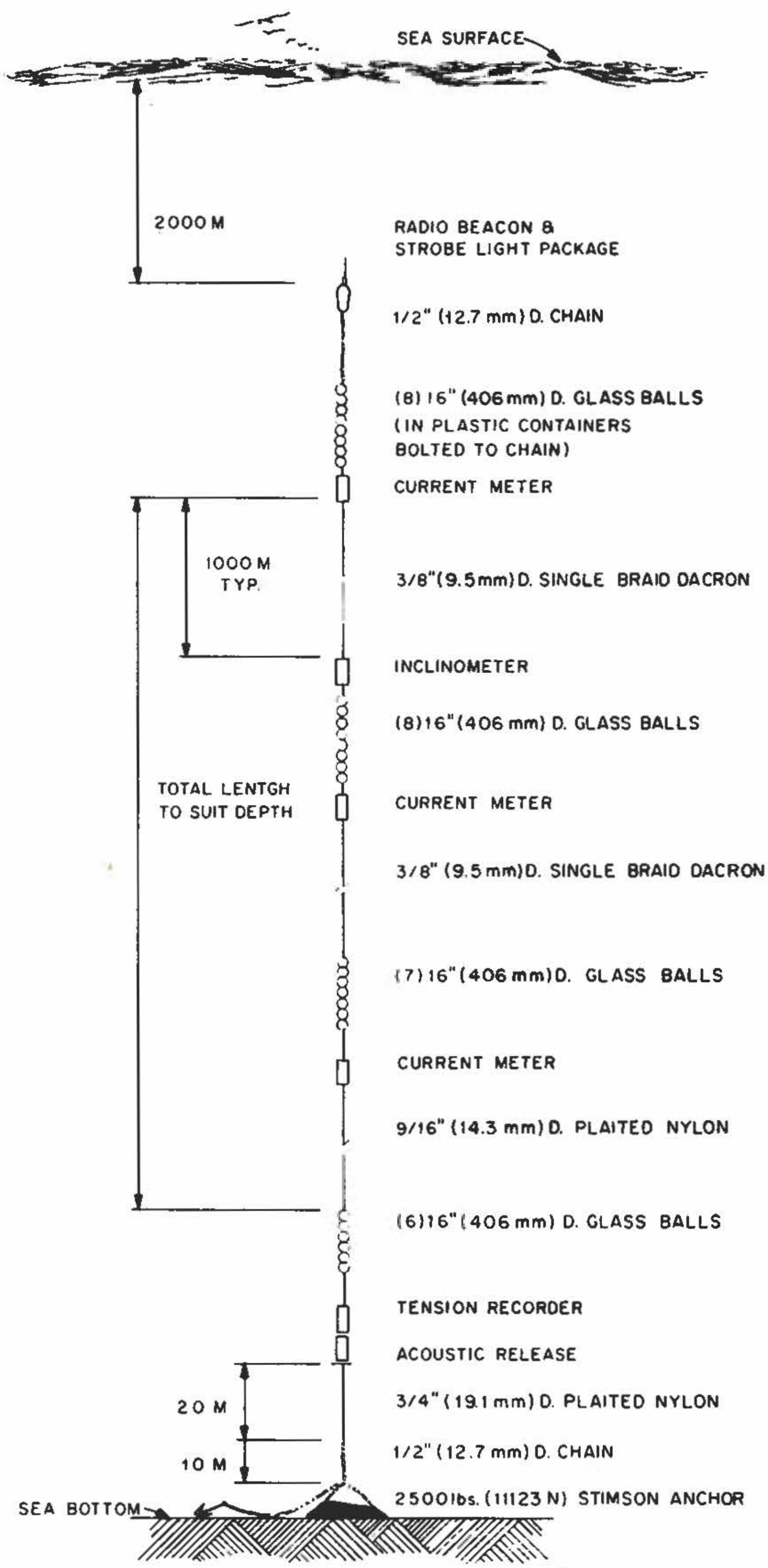

Figure 4. Typical Intermediate Buoy Mooring

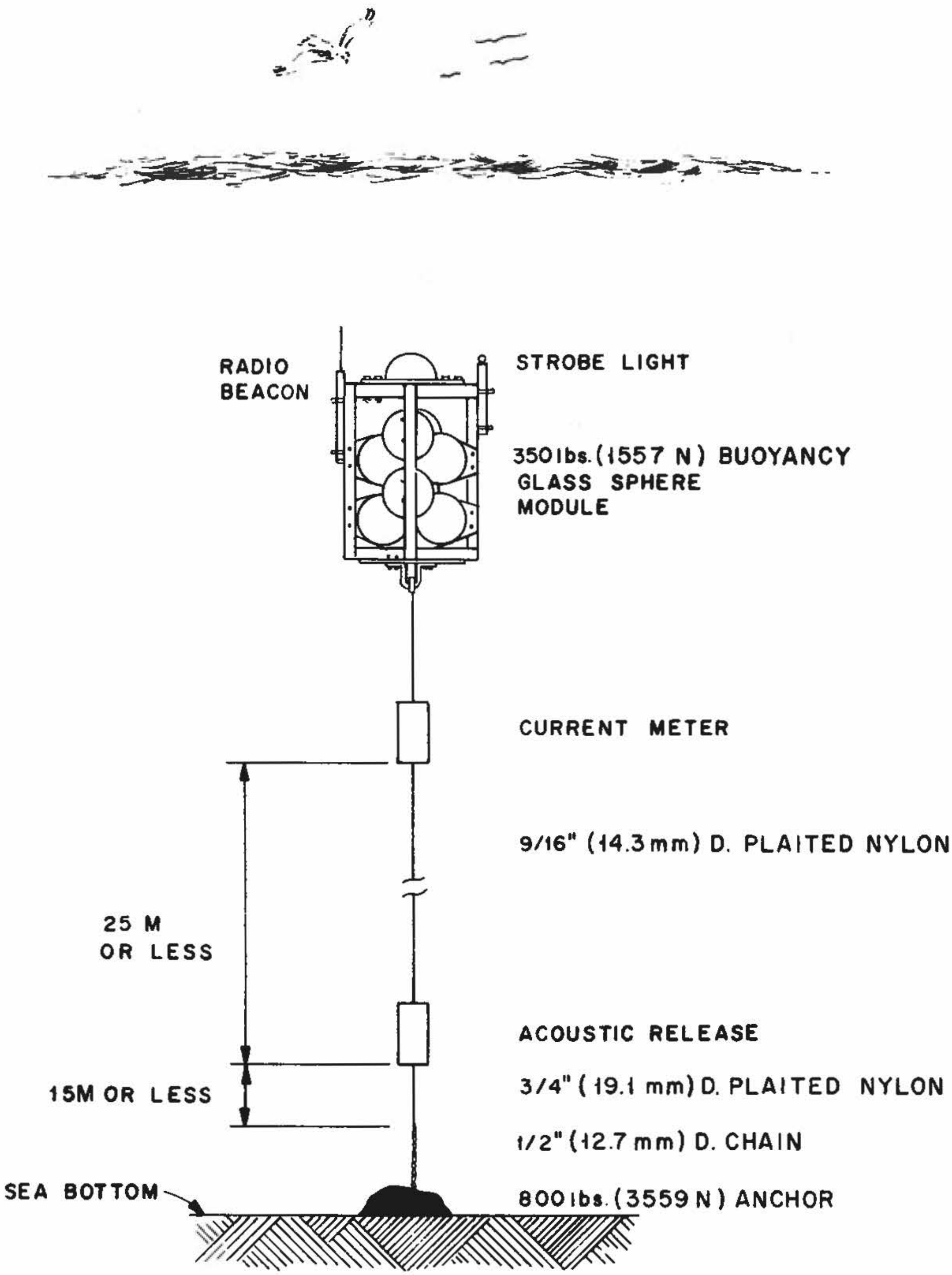

Figure 5. Typical Bottom Buoy Mooring

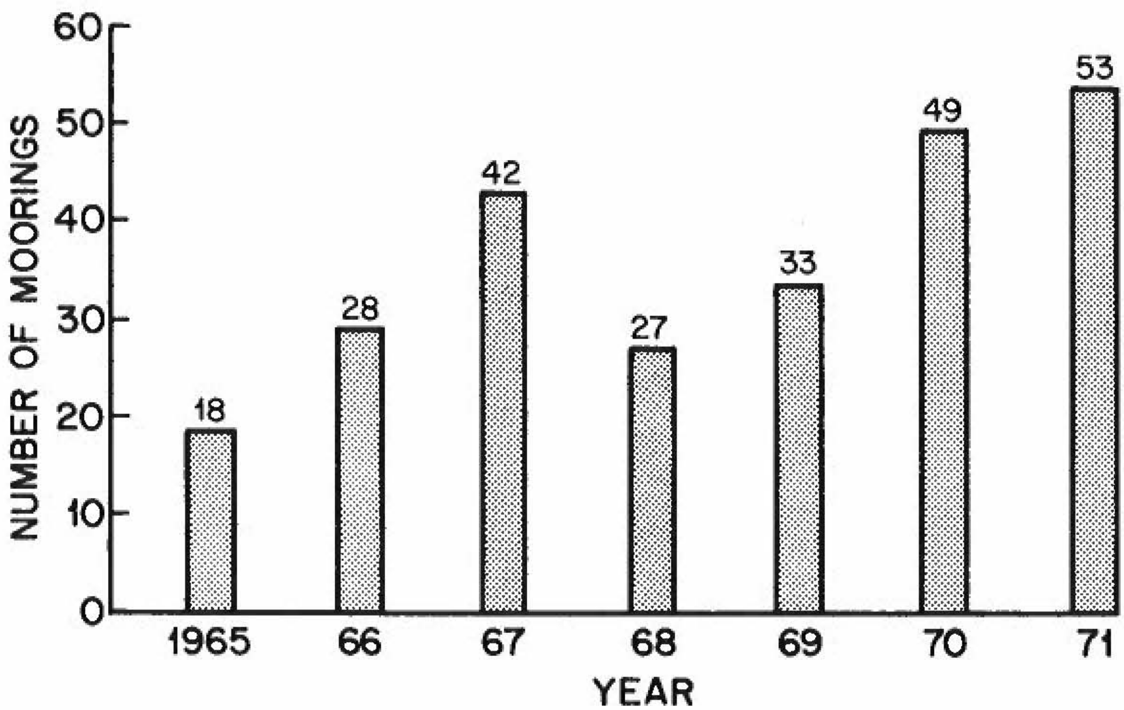

Figure 6. Moorings/Year

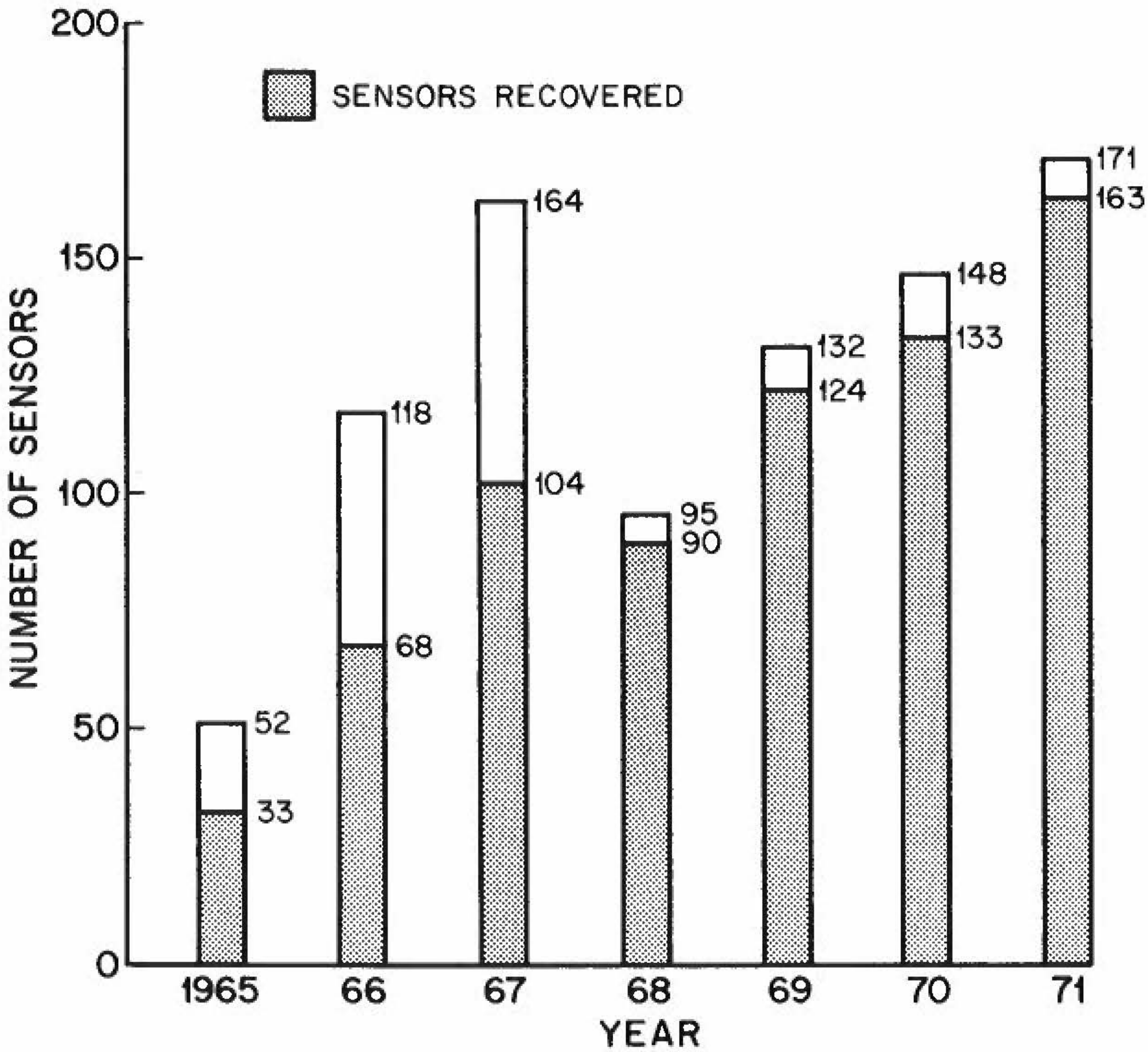

Figure 7. Sensor Exposure - Recovery Data

instruments such as tension, acceleration and depth recorders are included in the sensors shown for 1970-1971. The following analysis will be limited to the data from the years 1970 and 1971 under the rationale previously discussed.

Figure 8 and Table 1 show the duration of different types of W.H.O.I. moorings. It gives the number of days on station as a cululative percentage of the total moorings deployed by type. This graph indicates that bottom moorings were set on station for a longer duration than intermediate moorings and that surface moorings were of the shortest duration. Considering all the three types of moorings together, the mean life of W.H.O.I. moorings was found to be 83 days and 90% of them were on station for less than 150 days.

The numbers of deployments, losses and partial losses by mooring type are shown in Figure 9. The back-up recovery system has permitted many partial recoveries of failed moorings providing valuable evidence of the failure cause.

For this analysis a mooring is deemed to have failed if it is lost entirely or partly or in cases of complete retrieval, if it has failed to operate as a functional mooring because of a structural failure. As indicated, a mooring consists of many individual components connected in series. A mechanical failure of any one of these components will very likely lead to failure of the complete mooring. Component failures which have been directly responsible for a mooring failure (partial or complete) are shown in Figure 10.

The primary purpose of these moorings was the measurement of ocean currents. In 1970 W.H.O.I. deployed 80 current meters of which 59% returned good data, 16% was partially good and the rest was either bad or lost. In 1971 only 75 current meters were set in the moorings of which 49% provided good data, 16% partial data, and the rest was either bad or lost (3). The above statistics include both the mooring failure and the malfunctioning of the recording instrument. However, the analysis in this paper will be limited only to mooring failures.

During the beginning years of the deep-sea mooring program Woods Hole Oceanographic Institution used to lose on the average of about 40% of its moorings (4). As the primary causes like fishbite were identified and guarded against, the failure rate dropped considerably. Out of 102 moorings set in 1970-1971, a total of 23 failed, amounting to a failure rate of only 22.5%. Of these 13% failed during deployment and a like percentage due to damage during retrieval.

The mooring failure data of W.H.O.I. have some serious limitations that would not permit generalizations for use in other situations. Each of the 102 moorings set in 1970-71 by W.H.O.I. are different from each other not only in location and time of deployment, but also in the physical configuration. Each is designed separately for a given purpose and location. Even within the same type of mooring the characteristics differ very much. One of the requirements of a statistical analysis and probabilistic prediction is to have a large

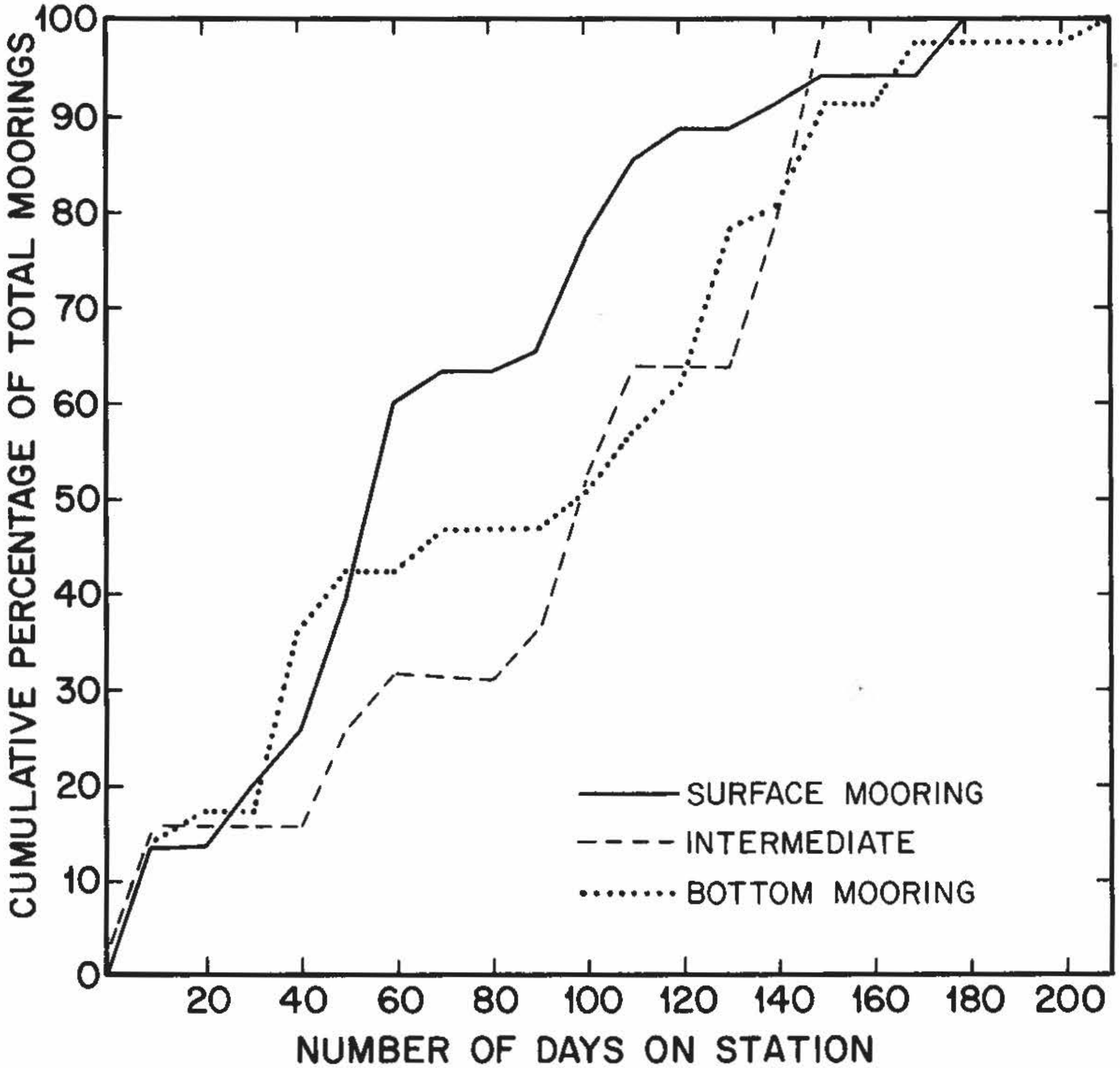

Figure 8. Duration of Different Types of W.H.O.I. Moorings

Days less than	Surface Moorings No. of moorings	% of total	Intermediate Moorings No. of Moorings	% of total	Bottom Moorings No. of Moorings	% of total
10	5	14.3	7	14.9	3	15.8
20	5	14.3	8	17.0	3	15.8
30	7	20.0	8	17.0	3	15.8
40	9	25.7	17	36.2	3	15.8
50	14	40.0	20	42.5	5	26.3
60	21	60.0	20	42.5	6	31.6
70	22	62.9	22	46.8	6	31.6
80	22	62.9	22	46.8	6	31.6
90	23	65.7	22	46.8	7	36.9
100	27	77.1	24	51.1	10	52.6
110	30	85.7	27	57.4	13	68.5
120	31	88.5	29	61.6	13	68.5
130	31	88.5	37	78.6	13	68.5
140	32	91.5	38	80.7	15	79.0
150	33	94.2	43	91.5	19	100.0
160	33	94.2	43	91.5		
170	33	94.2	46	97.9		
180	35	100.0	46	97.9		
190			46	97.9		
200			46	97.9		
210			47	100.0		

Table 1. Cumulative number of days on station of WHOI moorings

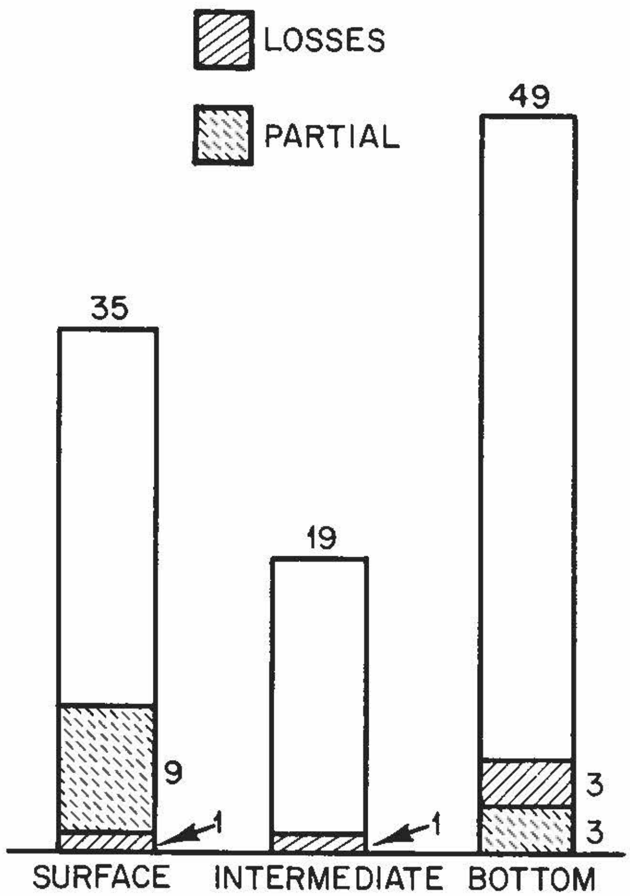

Figure 9. Deployments, Partial Losses and Losses by Mooring Types

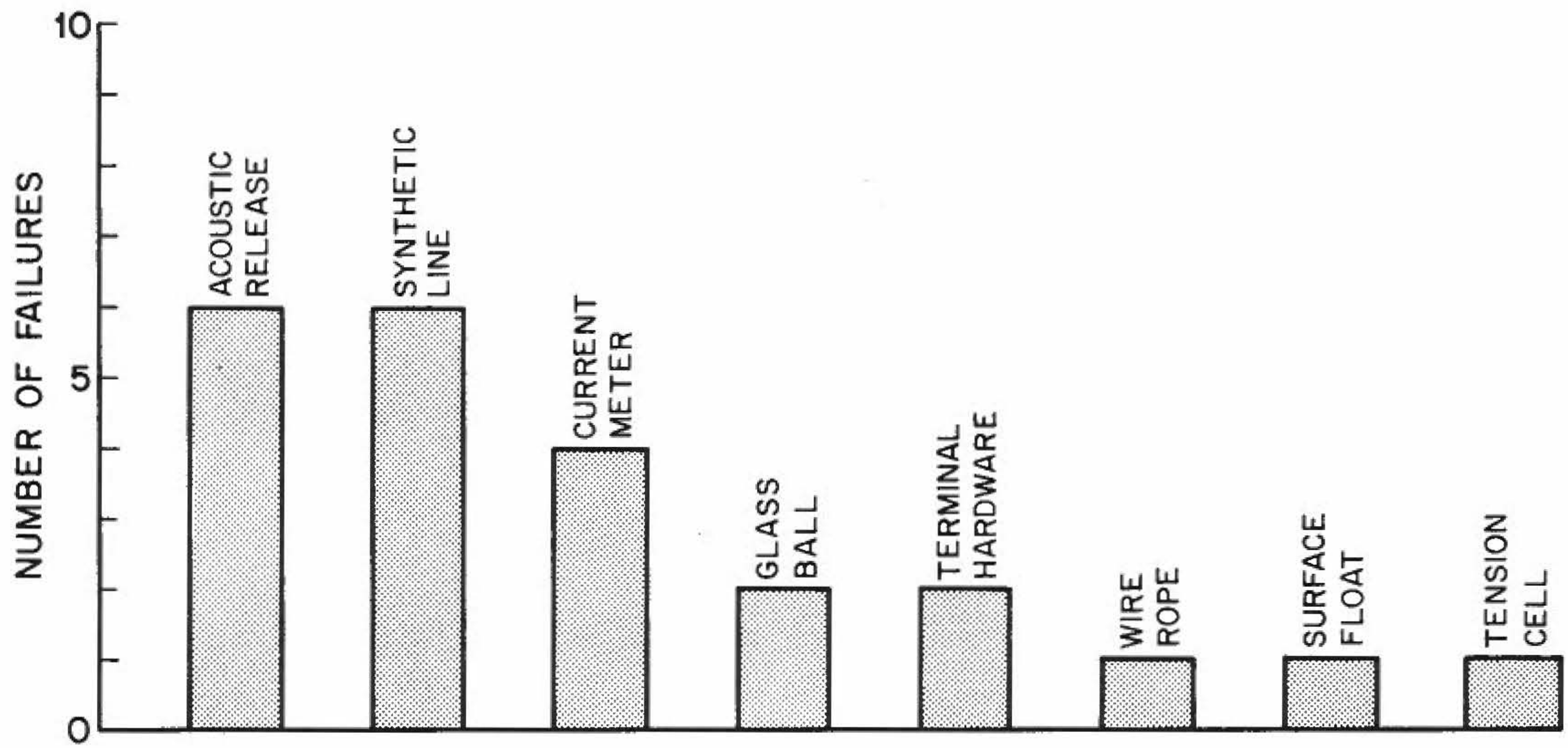

Figure 10. Component Failures

number of samples from an identical population. Therefore, it appears that the data at hand does not lend itself to such an analysis. The number of moorings set and the number of failures have been such that the requirements of homogeneity and stationarity are lacking from any statistical population that could be meaningfully grouped for study. The process under study is remarkably nonstationary because of abrupt changes in techniques and technology of taut-line mooring. These improvements in technology were usually made as an attempt to prevent types of failures just previously observed. This feedback relationship brings in an element of deterministic dependence, usually negative, in the process. Geography, seasonal effects, type of mooring and technology affect the process very distinctly. For a meaningful prediction using the theory of probability, one needs samples from a population describing an identifiable process; a prediction based on a tabulation of single events may not be physically meaningful even if pedagogically tolerated. Therefore, rigorous statistical analysis and probabilistic prediction are not attempted in this study.

3. Causes of Mooring Failures

The causes of failures for a particular type of mooring are shown in Figure 11. Seven mooring failures which were definitely associated with high currents were found to occur on surface moorings. The two authenticated fishbite failures of bottom moorings occurred in the Gulf Stream while the mooring was on the surface in the process of being deployed. The deployments took place at night and sharks were observed in the vicinity, probably attracted to the area by the ship's lights.

Figure 12 shows the percentage of all types of mooring failures due to various causes. The major cause of failures has been due to high mooring stresses caused by the incursion of high currents into the area. While the reliability of operation of our acoustic anchor release has improved markedly, it can be seen that at least during those two years, problems involving this critical component existed. Failures due to hardware were found, only in surface moorings, where excitation from surface waves caused shackled connections in the wire rope portion of the mooring to foul or cock resulting in bending moments of the swaged fittings with resulting failure.

The largest single cause of mooring failure during this two-year period can be seen in Figure 12 as the occurrence of strong ocean currents. High currents caused about 30% of all the mooring failures. The current meters on these failed moorings recorded currents as high as 1.5 meters per second. In one such record (Mooring #402), a current speed of greater than a meter per second persisted for about 2 days and the mooring failed 3 days later. The cage of one of the current meters parted and the surface float was picked up 110 kilometers away from the place where it was set. The excessive tensile stress developed on the current meter cage because of the high drag on the surface float, the mooring line and other

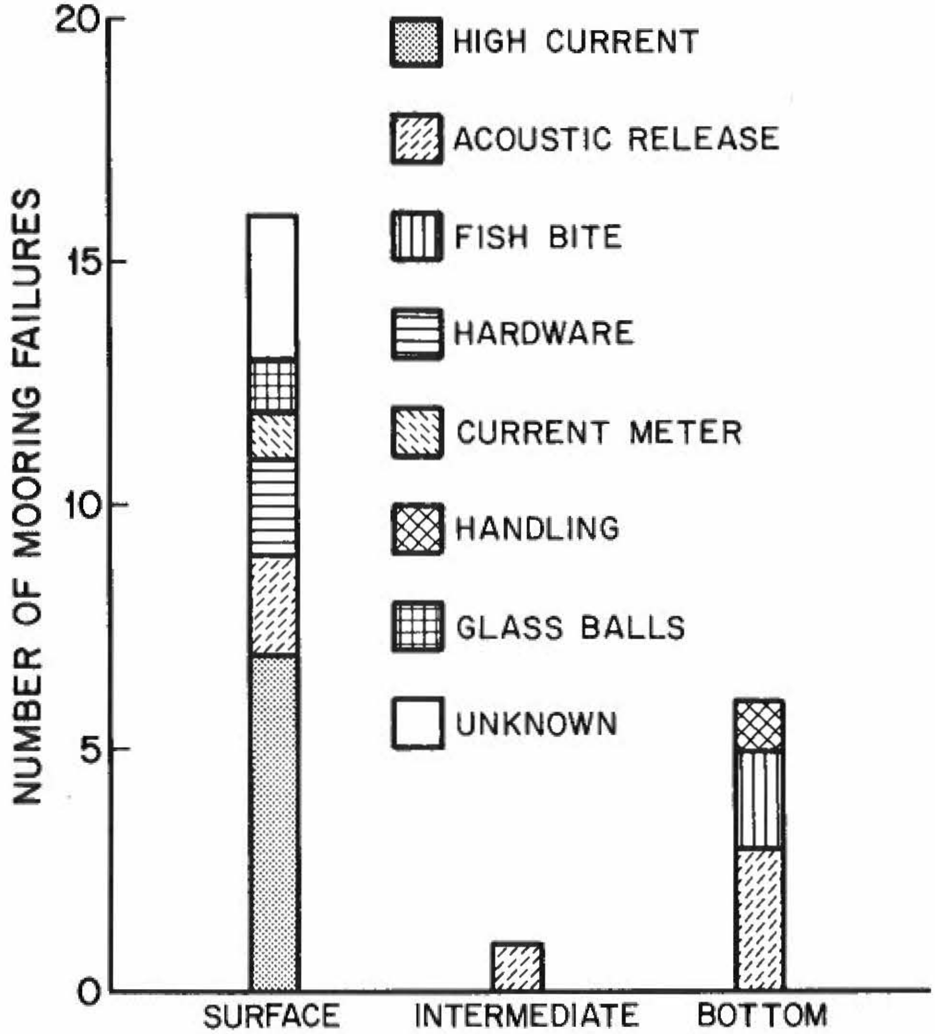

Figure 11. Causes of Mooring Failures

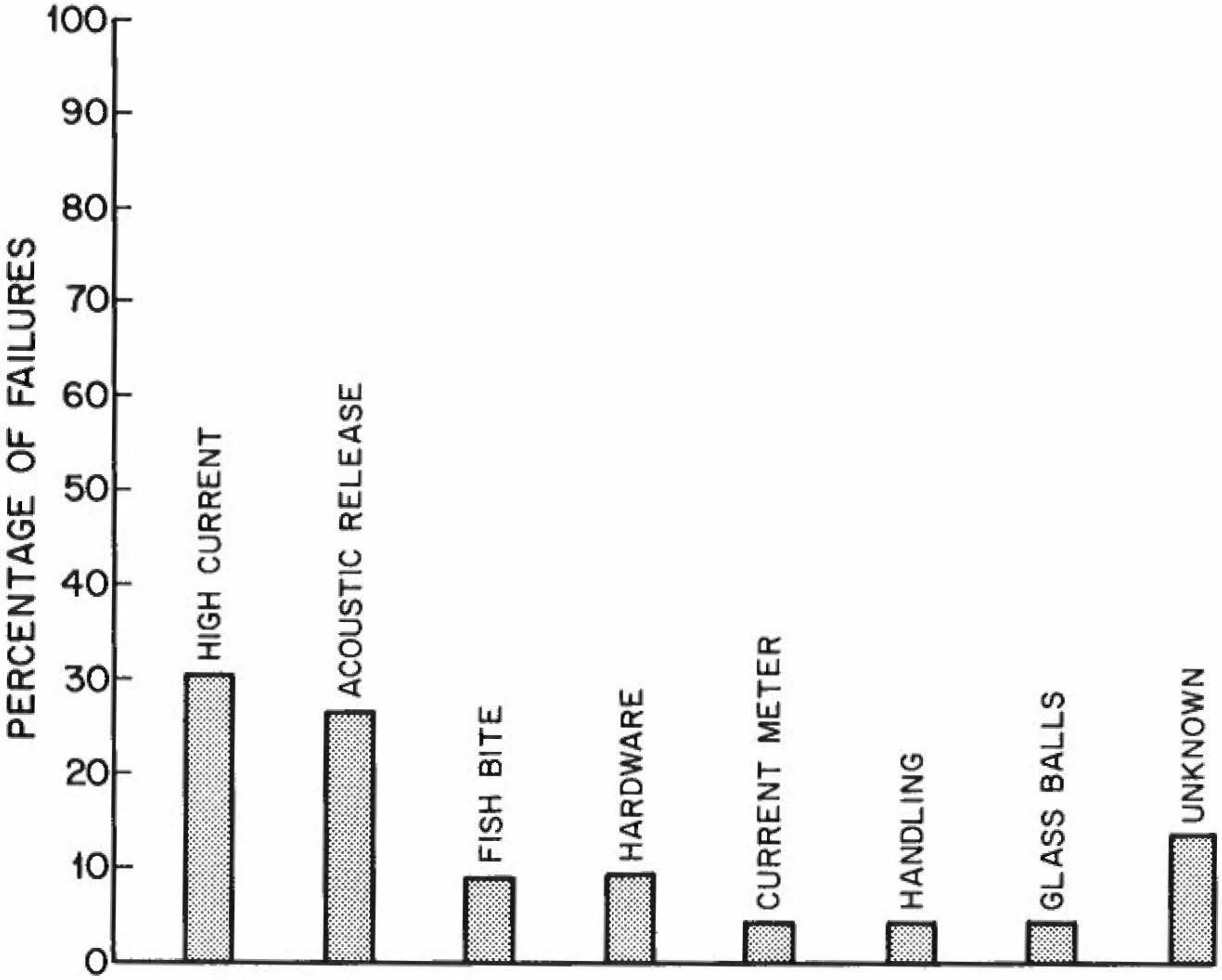

Figure 12. Breakdown of Mooring Failure Causes

components, was believed to be the mechanism of failure. Table 2 gives values of peak current speeds obtained from three surface moorings that failed on account of strong currents. Figure 13 shows the tension history on one of these moorings. Intermediate moorings do not normally experience such extremes of hydrodynamic forces. This may be seen for example in Figure 14 where the tension record and inclinometer record from an intermediate mooring are shown.

In line with the above facts, W.H.O.I. has a high success rate with subsurface moorings, but with surface moorings at high current areas the success rate has been low. The reliabilities of the three types of moorings are compared in Figure 15. Reliability here was computed as a ratio of the number of successful moorings to the total number of moorings of the same type for 1970-71. Intermediate moorings had a reliability of 94.7% and bottom moorings 87.1%. With a reliability of 54.3%, the surface moorings were found to be the least reliable of the three. It was also found that there is a greater likelihood of failure of components near the surface than at great depths. An analysis shows that 20.8% of all failures occured at the surface and another 12.5% at depths less than 10 meters below the surface. As a matter of fact, 45.8% of all failures occurred at components at depths less than 35 meters. This may be due to the prevalence of high currents near the surface. Current meter records from three different depths obtained from a typical mooring are shown in Figure 16. It may also be seen from Figure 17 that both the deployment and retrieval times are the highest for the surface mooring suggesting a greater chance of failure for surface moorings during deployment and retrieval also.

4. Telemetry

The present scientific program at Woods Hole does not require real-time data such as might be provided by radio telemetry from surface buoys. In fact the amount of data collected from a typical surface mooring would probably be prohibitive in quantity for anything but satellite relay. In addition many of our moorings have no surface expression, their sensors and flotation located many hundreds of meters below the surface. However, H. F. telemetry is routinely used on each surface mooring to monitor the mooring tension at the buoy. A small transmitter, also used as a radio beacon for locating the float for retrieval, is time-code modulated by a tension cell to which is attached to the mooring line and components. Through the use of this technique it is possible to determine, at the laboratory in Woods Hole, the mooring status. For instance, a normal tension reading of ¢. 7000 newtons indicates that the mooring is intact and probably on station; variations around this mean over a short time interval reflect the state of the sea; high readings are associated with increased mooring drag due to high currents or wind; and obviously little or no tension indicates a parted mooring. Figure 18 shows the variations in tensions received by telemetry over 2 months for a mooring which eventually parted due to the incursion

Mooring #	Location	Depth of current meter from sea surface, m	Peak current, cm/sec 2 hour average	5 sec. average
402	Site D (39N-70W)	10	115.1	143.5
396	Site D	10	118.1	134.0
399	Site D	11	113.1	125.5
399	Site D	1013	42.7	50.0

Table 2. Values of peak current speeds from moorings that failed on account of high current

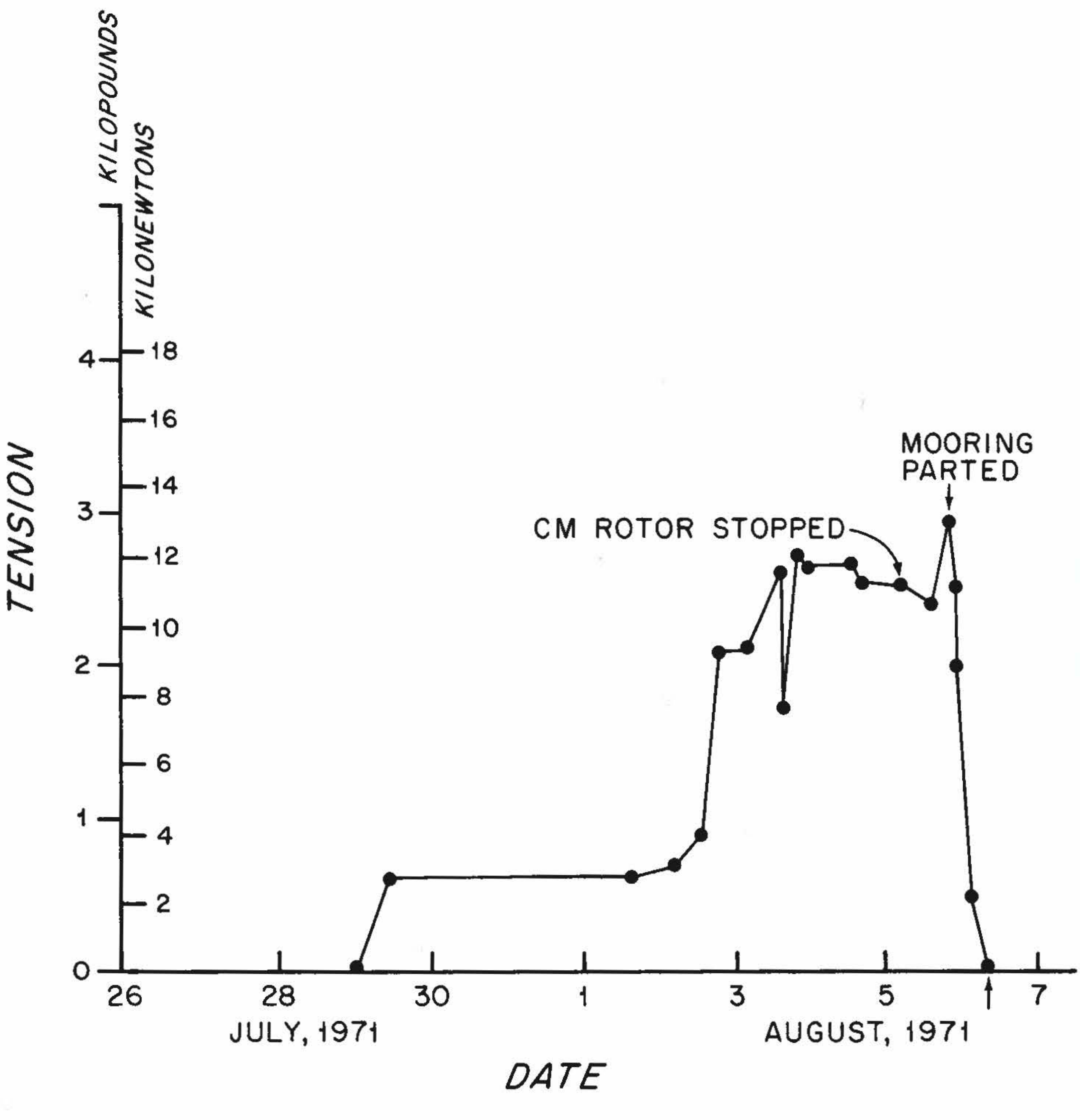

Figure 13. Tension Record from Site D Surface Mooring #399 that failed due to high current

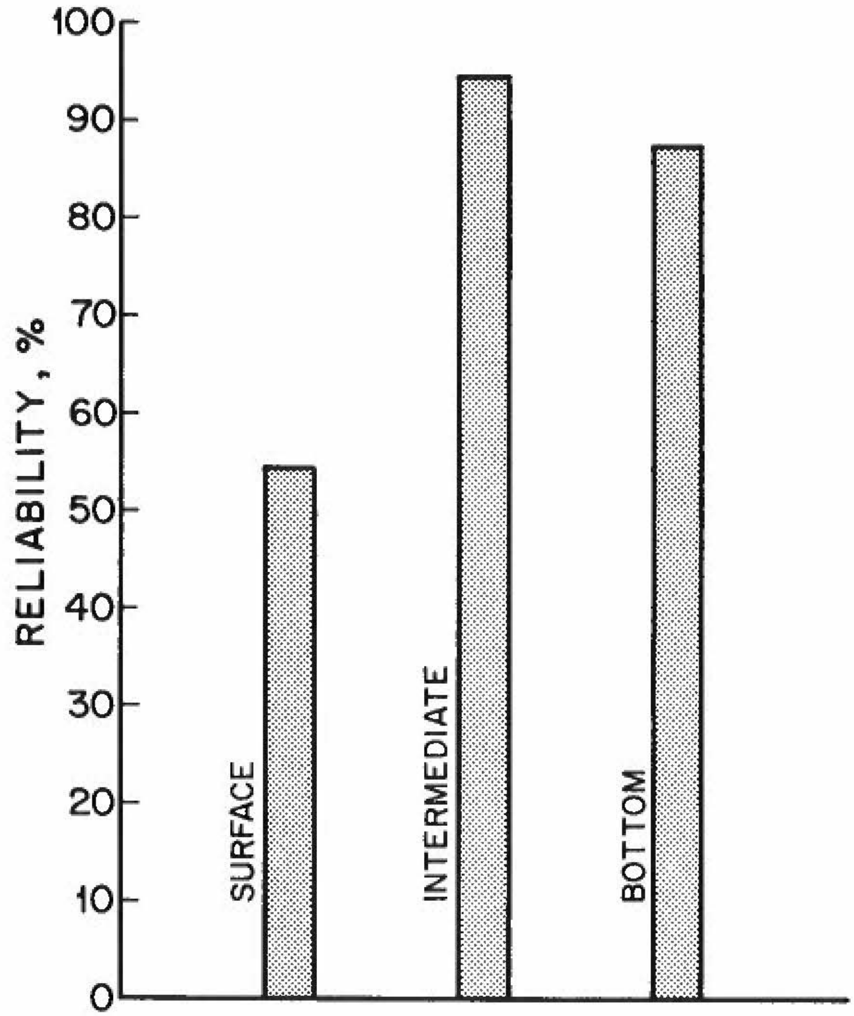

Figure 15. Reliability of W.H.O.I. Moorings 1970-71

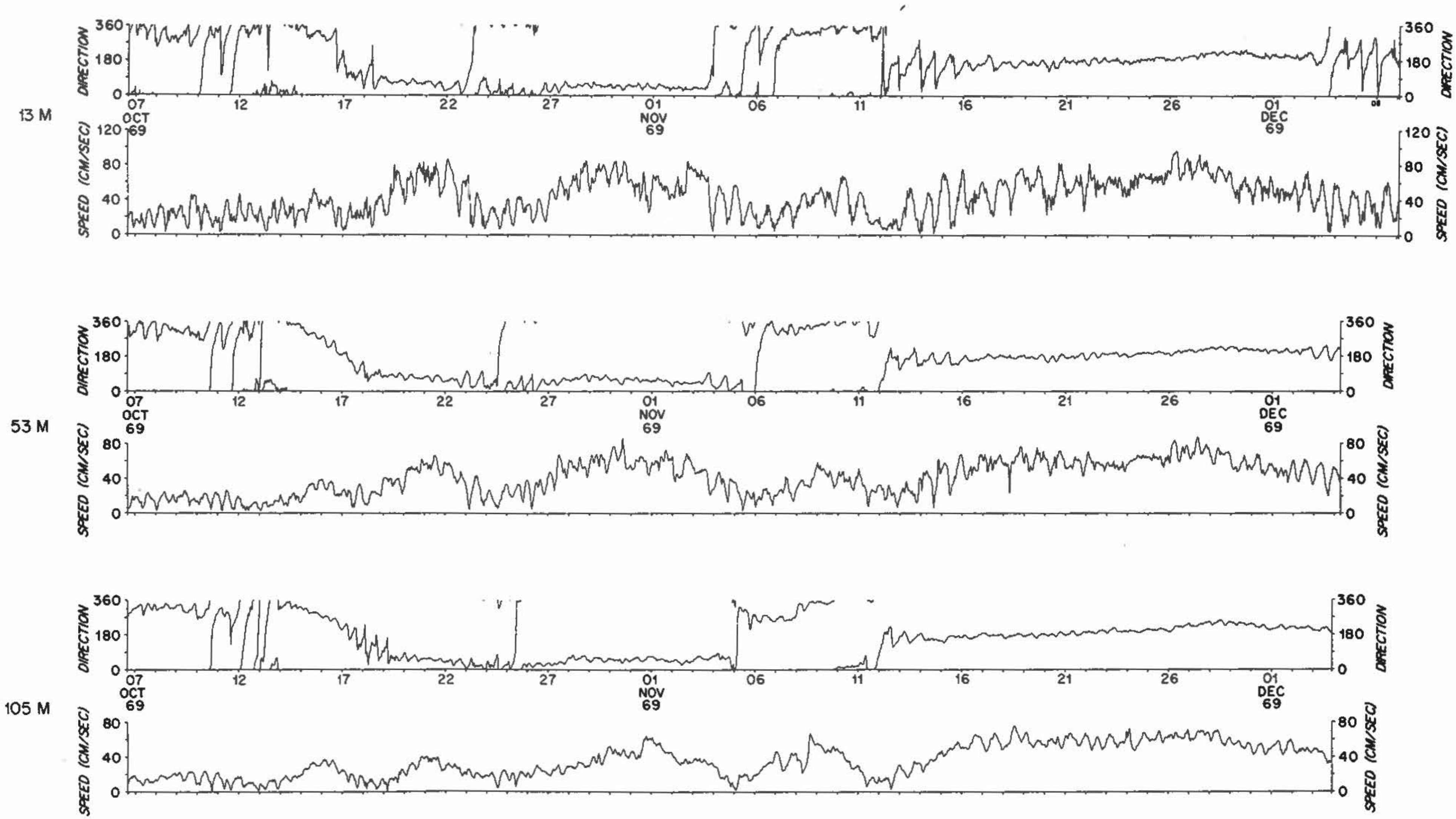

Figure 16. Current Meter Record from Site D Surface Mooring #317 from depths of 13m, 53m, and 105m

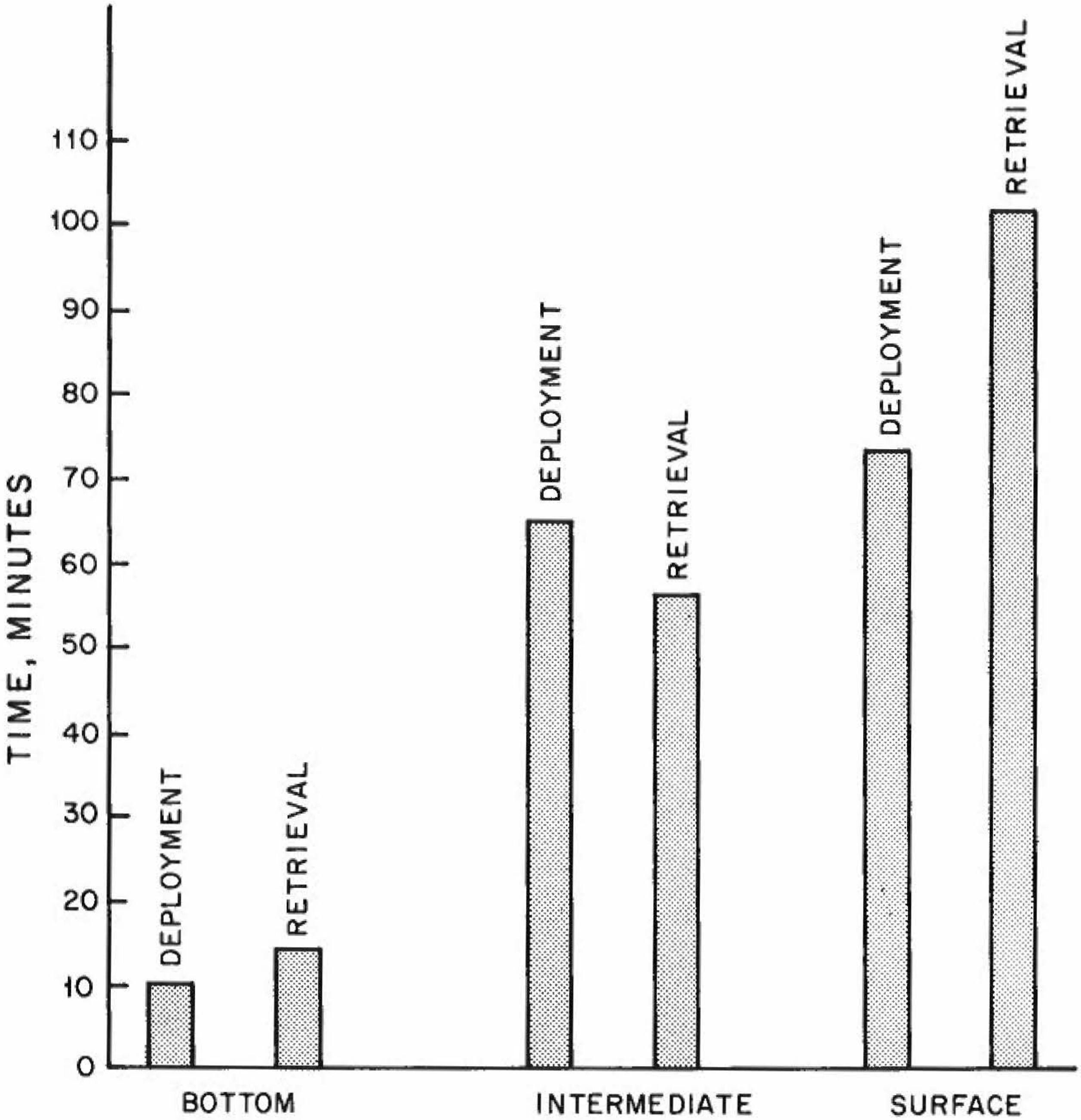

Figure 17. Typical Lengths of Time for Deployment and Retrieval of W.H.O.I. Moorings at Site D

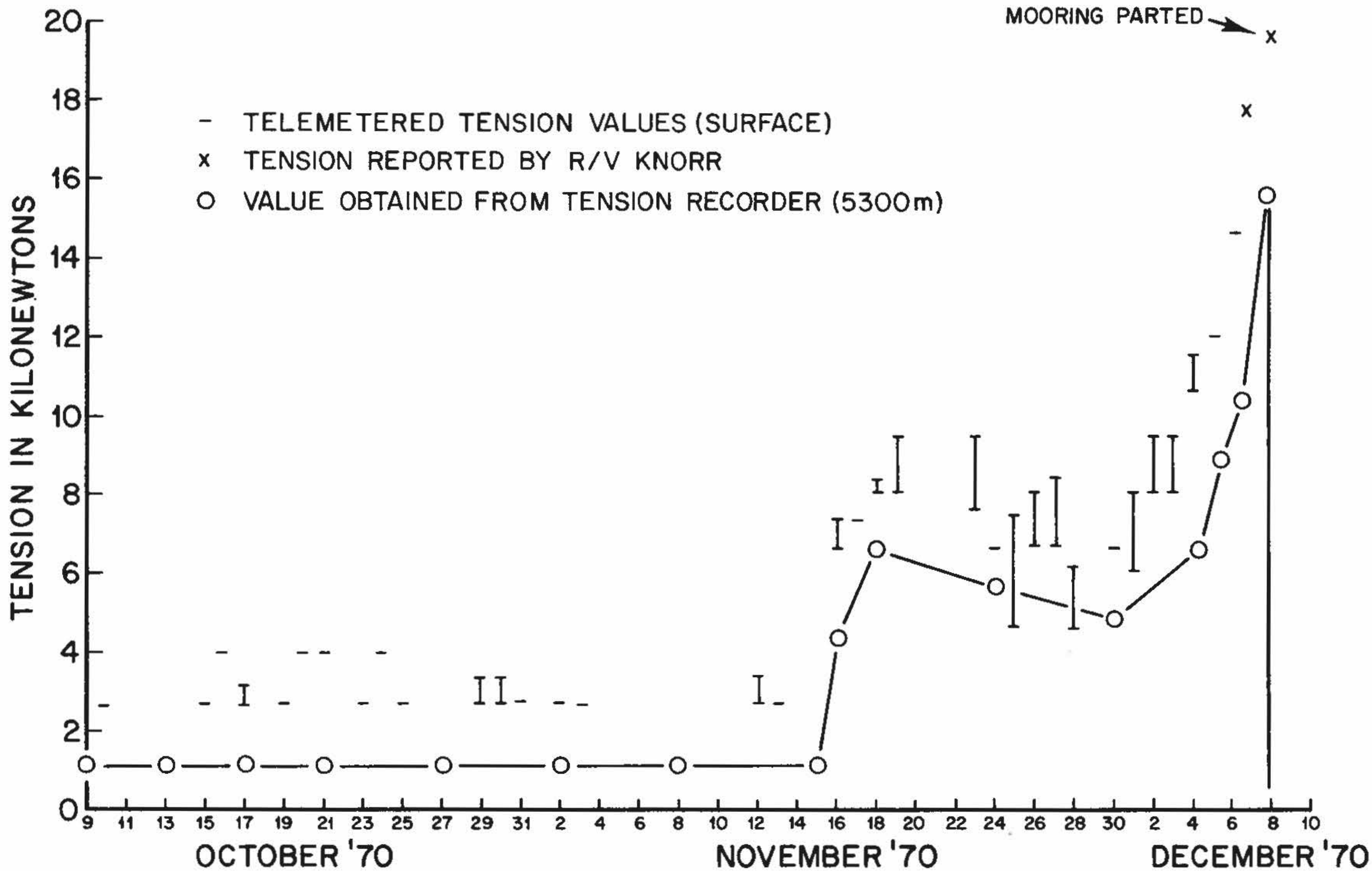

Figure 18. Tension Measured on Mooring #355 at Site L

failures. The causes of 13.1% of the failures could not be identified, because the moorings or failed components were lost.

During the first several years of the deep-sea mooring program of the Woods Hole Oceanographic Institution the loss rate of moorings averaged about 40%. As the primary causes like fishbite were identified and eliminated at least partly, the failure rate decreased. For the two-year period of 1970 and 1971 the failure rate dropped to 23 out of 102 or about 22.5%. More recently there has been a dramatic improvement in the reliability of acoustic releases, a primary cause of failure in 1970 and 1971. Therefore the failure rate is expected to drop considerably hereon.

As the oceanographic data collected by W.H.O.I. are usually from deep below the surface and the amount of data is prohibitively large, telemetry is not normally resorted to especially because real-time availability of oceanographic data is not crucial for the current scientific programs. However, real-time measurement of mooring line tension is done on each surface mooring, which allows continuous monitoring of the mooring status.

5.2 Recommendations for Research and Development

The study has shown that insofar as surface moorings are concerned, high currents contributed to the largest number of failures. Increases in mooring stress values due to large hydrodynamic loadings caused tensile and fatigue failures in certain of the mooring components. The combination of strong current and high sea state create a particularly unfavorable condition of large dynamic stresses superimposed upon high static stresses. In most instances we conclude that sufficient data on worst-case or peak current conditions are not available to the design engineer. Not only are surface wind, wave and current data required but a reasonable estimate of a worst-case currents as a function of depth is also necessary for the design. Given this data, the mooring design engineer can determine the resulting mooring response and provide the required component safety factors. Criteria for both operational and survival conditions, based upon more realistic environmental inputs, can avoid the expense of overdesign and yet minimize the chances of catastrophic structural failures. We urge the cataloging and archiving of this worst-case data by an organization such as the NODC.

The need to determine the actual static and dynamic response of moorings to such conditions remains obvious. This should involve a mutually interacting process of computer simulation and actual measurements. Through a process of progressive iteration of analysis procedures and matching of input and response data, improvements in mooring design and prediction may be arrived at.

The vulnerability to environmental forces and unsuitability for sensor location of our present surface following buoys suggests alternate arrangements of buoyancy providing better sensor stability. Efforts should be pursued to develop buoy forms and mooring configurations to meet the requirements of structural integrity and dynamic stability.

We continue to experience incidents of fishbite attack on our moorings. While the use of wire rope in the upper 2000 meters has prevented mooring loss from this cause, damage to the jacket and to instruments (current meter rotors) has been noted. Forthermore the synthetic portions of a mooring have proven to be vulnerable in two cases where nylon line was bitten through during the launch process while still on the surface. Experiments and testing of suitable armoring materials should continue to be pursued.

Failure of acoustic anchor releases to function accounted for a significant number of failures on all types of moorings. Recent improvements in our check-out procedures, preventive maintenance and instrument documentation records has dramatically decreased malfunctions of this critical component. In addition each release is lowered from the ship in deep water and acoustically checked out prior to deployment on a mooring. For these reasons no additional development work is recommended at this time on this component.

Failures of hardware such as terminations, shackles and instrument bales occurred mostly on surface moorings. Fatigue, sometimes associated with corrosion was the most common cause. Shackles which could cock in their terminations created a severe enough bending moment at times to part the wire rope termination. Such failures have been corrected through the choice of more suitable materials, sacrificial anodes and modifications of terminations and connections. However, our experience indicates that these areas require constant vigilance through inspection and testing procedures.

Deployment and retrieval of moorings still remain potential sources of problems. Efforts should therefore be put into the development of alternative methods of deployment and retrieval for better efficiency and reliability. Perhaps permanent or longer-term moorings where the data may be retrieved without the necessity of mooring recovery may be worthy of further effort.

In summary, this study has identified problem areas including specific components used in the Woods Hole taut-moorings, surface, intermediate and bottom, for the years 1970 and 1971. Recommendations for improved performance have been made.

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Appendix I

Tabular Description of the Moorings and Performance

Mooring No.	310	316	317	318	320	322
Mooring Type	Subsurface	Surface	Surface	Surface	Surface	Surface
Location	39N - 70W D	39N - 70W D	39N - 70W D	39N - 70W D	34N - 70W L	39N - 70W D
Water Depth, m	2683	2692	2681	2545	5370	2690
Float Depth, m	70	0	0	0	0	0
Deployment Date	8/11/69	10/4/69	10/6/69	10/6/69	10/10/69	1/4/70
Retrieval Date	1/4/70	1/4/70	1/5/70	1/6/70	3/3/70	2/28/70
Days on Station	147	93	92	93	145	55
Mooring Material	Nylon-Dacron	Wire-Nylon	Nylon	Nylon	Wire-Nylon	Wire-Nylon
Flotation Type	D.R.E. Sphere	Jumbo	Toroid	Toroid	Toroid	Toroid
Retrieval Status	Complete	Complete	Complete	Partial	Partial	Partial
Depth of Failure, m	n.a.	n.a.	n.a.	548	<1000	19
Cause of Failure	n.a.	n.a.	n.a.	Acoustic Release, Nylon Parted	Unknown	High Current (2 knots - 1 m/sec)
Fishbite Evidence	Many	Moderate	Severe	Severe	No	
Acoustic Release Operation	OK	OK	OK	No	OK	No
Current Meters	4	1 Rotor Loose	5	5 1 vane gone	1 Lost	4 3 lost
Telemetering Tensiometer		yes			yes, lost	yes
Other Instruments		1 Tensio- meter			2 Tensio- meters	
Light Status	Not working	Not known	Not known	Not known		
Radio Status	Antenna gone	OK	OK to 11/17 /69			OK
Hardware	Some corro- sion					CM Bale parted (303)
Remarks		Mooring moved 118 m		Hauled with anchor	Mooring parted 11/ 21/69	Toroid & top CM only re- covered

Mooring No.	344	345	346	347	348	349
Mooring Type	Surface	Intermediate	Bottom	Bottom	Bottom	Bottom
Location	34N - 70W L	39N - 70W D	39.5N - 71W	40N - 70.5W	40N - 71W	40N - 71W
Water Depth, m	5365	2527	2263	876	977	943
Float Depth, m	0	1492	2155	766	964	843
Deployment Date	8/14/70	8/18/70	8/18/70	8/19/70	8/19/70	8/19/70
Retrieval Date	10/9/70	10/6/70	12/11/70	10/4/70	10/6/70	10/6/70
Days on Station	56	49	116	46	48	48
Mooring Material	Wire-Nylon	Dacron - Nylon	Nylon	Nylon	Nylon	Nylon
Flotation Type	Toroid	Glass Balls	Syntactic Foam	Syntactic Foam	Glass Balls	Glass Balls
Retrieval Status	Complete	Complete	Complete	Complete	Complete	Complete
Depth of Failure, m	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cause of Failure	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fishbite Evidence	Severe					
Acoustic Release Operation	OK	OK	OK	OK	OK	OK
Current Meters	1	2 & Dummy	1	1	2	3
Telemetering Tensiometer	Yes Plug Broken					
Other Instruments	2 Tension Rec.	1 Depth Rec. 1 Inclino-meter 1 Tension Rec.				
Light Status	OK	Not known	None	Not working	OK	OK
Radio Status	OK	OK	Unknown	OK	OK	OK
Hardware	Toroid leaked		Release Shackle Corroded	Release thimble corroded		
Remarks						

Mooring No.	350	351	352	353	354	355
Mooring Type	Bottom	Bottom	Bottom	Bottom	Bottom	Surface
Location	40N - 71W	39.5N - 71W	39N - 71W	36N - 70.5W	34N - 70W L	34N - 70W L
Water Depth, m	993	2150	2509	4436	5368	5361
Float Depth, m	885	2049	2377	4108	5281	0
Deployment Date	8/19/70	8/19/70	10/6/70	10/8/70	10/9/70	10/9/70
Retrieval Date	12/4/70	12/11/70	12/11/70	12/9/70	5/4/71	12/8/70
Days on Station	108	115	67	63	208	61
Mooring Material	Nylon	Nylon	Nylon	Nylon	Nylon	Dacron PVC Armor
Flotation Type	Glass Balls	Glass Balls	Glass Balls	Syntactic foam	Glass Balls	Conical
Retrieval Status	Complete	Complete	Complete	Complete	Complete	Complete in 2 Sections
Depth of Failure, m	n.a.	n.a.	n.a.	n.a.	n.a.	5200
Cause of Failure	n.a.	n.a.	n.a.	n.a.	n.a.	High Current
Fishbite Evidence						Moderate
Acoustic Release Operation	OK	OK	OK	OK	OK	OK
Current Meters	2	1	2	1	1 (Flooded) & 1 Dummy	0
Telemetering Tensiometer						yes
Other Instruments					1 Tension Rec. Dummy	1 Tension Rec.
Light Status	OK	OK	OK		OK	Not known
Radio Status	OK	OK	OK	Not working	OK	OK
Hardware		Release Shackle Corroded				Nylon parted high tension
Remarks						Parted before picking up

Mooring No.	356	357	358	359	360	361
Mooring Type	Surface	Intermediate	Inter-mediate	Bottom	Inter-mediate	Bottom
Location	34N - 70W L	34N - 70W L	39N - 70W D	37N - 72W	36.5N - 71W	38N - 69.5W
Water Depth, m	5374	4425	2680	3528	4230	3950
Float Depth, m	0	2044	1454	3310	3668	3737
Deployment Date	12/8/70	12/9/70	12/11/70	12/12/70	12/13/70	12/14/70
Retrieval Date	n.a.	5/6/71	4/27/71	4/30/71	5/3/71	12/14/71
Days on Station	n.a.	148	137	139	141	Less than 1
Mooring Material	Wire-Nylon	Dacron-Nylon	Dacron - Nylon	Nylon	Dacron	Nylon
Flotation Type	Toroid	Glass Balls	Glass Balls	Syntactic Foam	Glass Balls	Syntactic Foam
Retrieval Status	Lost	Complete	Complete	Complete	Complete	Partial
Depth of Failure, m	Unknown	n.a.	n.a.	n.a.	n.a.	0
Cause of Failure	Unknown	n.a.	n.a.	n.a.	n.a.	Fishbite
Fishbite Evidence						Catastrophic
Acoustic Release Operation	Not known	OK	OK	OK	OK	Unknown Lost
Current Meters	1 Lost	3	3 & 1 Dummy	1	2	1
Telemetering Tensiometer	yes					
Other Instruments	2 Tension Rec.	1 Depth Rec 1 Inclino-meter 1 Tension Rec.	1 Depth Rec. 1 Inclino-meter 1 Tension Rec.			
Light Status		None	None	None	None	OK
Radio Status	Worked 21 Days	OK	Not known	Not working	Not working	OK
Hardware						
Remarks	High tension after launch					Release lost when line bitten

Mooring No.	368	369	370	371	372	373
Mooring Type	Bottom	Bottom	Bottom	Bottom	Bottom	Surface
Location	38N - 69.5W	23N - 66.5W	22N - 67W	21N - 68W	00 - 160W	01N - 160W
Water Depth, m	3955	5817	5402	5325	183	4441
Float Depth, m	3735	5601	5186	5294	132	0
Deployment Date	12/16/70	1/21/71	1/22/71	1/24/71	4/8/71	4/13/71
Retrieval Date	5/8/71	5/23/71	5/23/71	5/22/71	Lost	9/22/71
Days on Station	143	122	121	128	n.a.	182
Mooring Material	Nylon	Nylon	Nylon	Nylon	Nylon	Wire-Nylon
Flotation Type	Glass Balls	Glass Balls	Glass Balls	Glass Balls	Glass Balls	Toroid Lost
Retrieval Status	Complete	Complete	Complete	Complete	Lost	Partial
Depth of Failure, m	n.a.	n.a.	n.a.	n.a.	181	10
Cause of Failure	n.a.	n.a.	n.a.	n.a.	Acoustic Release	Lower bale on top CM parted
Fishbite Evidence						
Acoustic Release Operation	OK	OK	OK	OK	No	OK
Current Meters	1	2 1 flooded	2	1	1 Lost	3 1 Lost
Telemetering Tensiometer						
Other Instruments						
Light Status	OK	OK	Unknown	OK	None	Lost
Radio Status	OK	OK	OK	OK	None	None
Hardware		Corroded Shackles	Corroded Shackle at buoy bale	Slightly Corroded		CM bale broken
Remarks		CM rotor fouled				

Mooring No.	374	375	376	377	378	379
Mooring Type	Surface	Surface	Inter-mediate	Surface	Surface	Surface
Location	00 - 150W	01S - 150W	01N - 150W	39N - 70W D	39N - 70W D	39N - 70W D
Water Depth, m	4451	4657	4431	2665	2665	2662
Float Depth, m	0	0	3666	0	0	0
Deployment Date	4/16/71	4/18/71	4/25/71	4/27/71	4/27/71	4/28/71
Retrieval Date	4/23/71	9/20/71	Lost	5/24/71	5/24/71	7/28/71
Days on Station	7	155	n.a.	27	27	91
Mooring Material	Wire-Nylon	Wire-Nylon	Nylon	Wire-Nylon	Wire-Nylon	Wire-Nylon
Flotation Type	Toroid Lost	Toroid	Glass Balls	Toroid	Toroid	Toroid
Retrieval Status	Partial	Complete	Lost	Complete	Complete	Complete
Depth of Failure, m	1000	n.a.	4430	n.a.	n.a.	n.a.
Cause of Failure	Wire rope		Acoustic Release			
Fishbite Evidence		Severe at 500 m				
Acoustic Release Operation	OK	OK	No	OK	OK	OK
Current Meters	4 3 lost	2	1 Lost	4	3	5 1 Dummy
Telemetering Tensiometer				yes	yes	yes
Other Instruments				1 Wave Rec. 1 Temp. Rec.	1 Temp. Rec.	
Light Status	Lost	Unknown	None	Unknown	Unknown	OK
Radio Status	None	None	None	OK	Not working	Not working
Hardware	Wire parted near termination					2 bands broken on toroid
Remarks						

Mooring No.	380	381	382	383	384	385
Mooring Type	Surface	Surface	Inter- mediate	Bottom	Bottom	Bottom
Location	37N - 70W	34N - 70W L	36N - 70W J	40N - 40.5W	33N - 137E	33N - 135E
Water Depth, m	4160	5375	4445	4803	3578	1211
Float Depth, m	0	0	2059	4516	3395	1031
Deployment Date	4/30/71	5/4/71	5/6/71	5/9/71	6/18/71	6/19/71
Retrieval Date	5/2/71	11/4/71	8/1/71	8/8/71	10/4/71	10/3/71
Days on Station	2	184	87	91	108	106
Mooring Material	Wire - Nylon	Wire-Nylon	Dacron- Nylon	Nylon	Nylon	Nylon
Flotation Type	3 m disc	Toroid	Glass Balls	Glass Balls	Glass Balls	Glass Balls
Retrieval Status	Complete	Complete	Complete	Complete	Complete	Complete
Depth of Failure, m	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cause of Failure	n.a.	n.a.	n.a.,	n.a.	n.a.	n.a.
Fishbite Evidence	Minor					
Acoustic Release Operation	OK	OK	OK	OK	OK	OK
Current Meters	3	1 & Dummy Rotor broke	3	1	1	1
Telemetering Tensiometer	yes	yes				
Other Instruments	3 Tension Rec., 3 Tensacs, 2 Inclino-meters, 2 Depth Rec.	2 Tension Rec.	1 Depth Rec. 1 Inclino-meter			
Light Status	Unknown	Not working	None	OK	OK	OK
Radio Status	Not working	Not working	OK	OK	OK	OK
Hardware	CM damaged at launch. Rotor broken					1 GB broken
Remarks	Wire damaged at block	Swordfish attack on CM				

Mooring No.	386	387	388	389	390	391
Mooring Type	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom
Location	33N - 134E	31.5N-132E	38N - 64.5W	38N - 64.5W	38N - 65W	38N - 65W
Water Depth, m	1058	2236	5005	4996	5000	4931
Float Depth, m	880	2058	4775	4766	4770	4701
Deployment Date	6/26/71	6/27/71	6/29/71	6/29/71	6/29/71	6/29/71
Retrieval Date	Lost	10/2/71	7/31/71	7/31/71	7/30/71	7/30/71
Days on Station	n.a.	97	32	32	31	31
Mooring Material	Nylon	Nylon	Nylon	Nylon	Nylon	Nylon
Flotation Type	Glass Balls	Glass Balls	Syntactic Foam	Syntactic Foam	Glass Balls	Glass Balls
Retrieval Status	Lost	Complete	Complete	Complete	Complete	Complete
Depth of Failure, m	1057	n.a.	n.a.	n.a.	n.a.	n.a.
Cause of Failure	Acoustic Release (no release)	n.a.	n.a.	n.a.	n.a.	n.a.
Fishbite Evidence		None				
Acoustic Release Operation	No	OK	OK	OK	OK	OK
Current Meters	1 Lost	1	1	1	1	1
Telemetering Tensiometer						
Other Instruments						
Light Status	Lost	OK	OK	OK	OK	OK
Radio Status	Lost	OK	OK	Not working	OK	OK
Hardware						
Remarks						XBT wire tangled on line

Mooring No.	392	393	394	395	396	397
Mooring Type	Bottom	Bottom	Bottom	Surface	Surface	Surface
Location	39N - 65W	39N - 65W	39N-65.5W	39N - 70W D	39N - 70W D	39N - 70W D
Water Depth, m	4870	4810	4780	2428	2738	2655
Float Depth, m	4640	4580	4550	0	0	0
Deployment Date	6/29/71	6/29/71	6/30/71	7/27/71	7/27/71	7/28/71
Retrieval Date	7/30/71	7/30/71	7/30/71	9/10/71	9/11/71 & 11/6/71	9/11/71
Days on Station	31	31	30	45	46/102	45
Mooring Material	Nylon	Nylon	Nylon	Wire-Nylon	Wire-Nylon	Wire-Nylon
Flotation Type	Glass Balls	Glass Balls	Glass Balls	Toroid	Toroid	Toroid
Retrieval Status	Complete	Complete	Complete	Complete	Complete in 2 sections	Complete
Depth of Failure,m	n.a.	n.a.	n.a.	n.a.	525	n.a.
Cause of Failure	n.a.	n.a.	n.a.	n.a.	High Current	n.a.
Fishbite Evidence				Some	Some	Little at 30 m
Acoustic Release Operation	OK	OK	OK	OK	OK	OK
Current Meters	1	1	1	2	1	3
Telemetering Tensiometer						
Other Instruments				1 Temp. Rec. 1 Tension Rec. (flooded), 1 Wind Rec.	1 Temp. Rec. 1 Wave Rec. 1 Wind Rec.	1 Temp. Rec 1 Radiation Rec.
Light Status	OK	OK	OK	Unknown	OK	OK
Radio Status	OK	OK	OK	OK	OK Antenna broken	OK
Hardware				Acoustic Release End Cap Corroded	Swaged fitting failed	Long-line fishing gear fouling
Remarks				Recovered 3 miles from position	Bent shackle High Current	Moved 5.5 mi. (8.8 km)

Mooring No.	410	411	412	413	414	415
Mooring Type	Inter-mediate	Inter-mediate	Inter-mediate	Bottom	Bottom	Bottom
Location	28.5N-69.5W	28N - 70W MODE	28N - 70W MODE	28N - 70W MODE	28N - 70W MODE	23N - 69W
Water Depth, m	5460	5427	5455	5460	5460	5454
Float Depth, m	1484	1456	1482	5422	5400	5325
Deployment Date	10/31/71	10/31/71	10/31/71	10/31/71	10/31/71	11/20/71
Retrieval Date	2/9/72	2/7/72	2/7/72	11/2/71	11/2/71	5/4/72
Days on Station	102	100	100	2	2	166
Mooring Material	Wire-Dacron	Wire-Dacron	Wire-Dacron	Nylon	Nylon	Nylon
Flotation Type	Glass Balls	Glass Balls	Glass Balls	Glass Balls	Glass Balls	Glass Balls
Retrieval Status	Complete	Complete	Complete	Complete	Complete	Complete
Depth of Failure, m	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cause of Failure	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fishbite Evidence	none	slight	none			
Acoustic Release Operation	OK	OK	OK	OK	OK	OK
Current Meters	2	2	2			1
Telemetering Tensiometer						
Other Instruments		1 Inclino-meter	1 Depth Rec. 1 Inclino-meter			
Light Status	OK	OK	OK	Unknown	Unknown	OK
Radio Status	OK	OK on side	OK	None	None	OK
Hardware		Corrosion on release hardware				Some corrosion on acoustic re-lease - no grease
Remarks						

Mooring No.	416	417	418	419	420	421
Mooring Type	Bottom	Bottom	Inter-mediate	Inter-mediate	Surface	Inter-mediate
Location	23N - 69W	23N - 69W	39N - 70W D	39N - 70W D	39N - 70W D	36N - 70W J
Water Depth, m	5392	5378	2660	2654	2654	4440
Float Depth, m	5261	5249	488	477	0	1289
Deployment Date	10/20/71	11/21/71	12/10/71	12/11/71	12/12/71	12/13/71
Retrieval Date	5/4/72	5/4/72	12/20/71	12/20/71	3/13/72	3/14/72
Days on Station	166	165	10	9	32	91
Mooring Material	Nylon	Nylon	Wire-Nylon	Wire-Nylon	Wire-Nylon	Dacron-Nylon
Flotation Type	Glass Balls	Glass Balls	Glass Balls	Glass Balls	Toroid	Glass Balls
Retrieval Status	Complete	Complete	Complete	Complete	Complete	Complete
Depth of Failure, m	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Cause of Failure	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Fishbite Evidence					slight	
Acoustic Release Operation	OK	OK	OK	OK	OK	OK
Current Meters	1	1	3	3	5	2
Telemetering Tensiometer					yes	
Other Instruments			2 Temp. Rec. 1 Depth Rec.	2 Temp. Rec.	1 Tension Rec.	
Light Status	OK	Unknown	OK	OK	Not working	OK
Radio Status	OK	OK	OK	OK	Not working	OK
Hardware						
Remarks	No corrosion AR grease OK	CM rotor stuck (corrosion)	Extra acoustic release at top	Extra Acoustic Release at top	Rotor out of top CM	

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2. Buoys
3. Reliability

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13. ABSTRACT

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