



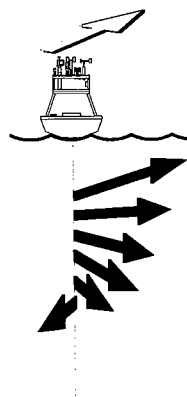
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# The Horizontal Mooring: A Two-Dimensional Array, Description of the Array, Components, Instrumentation, Deployment and Recovery Operations

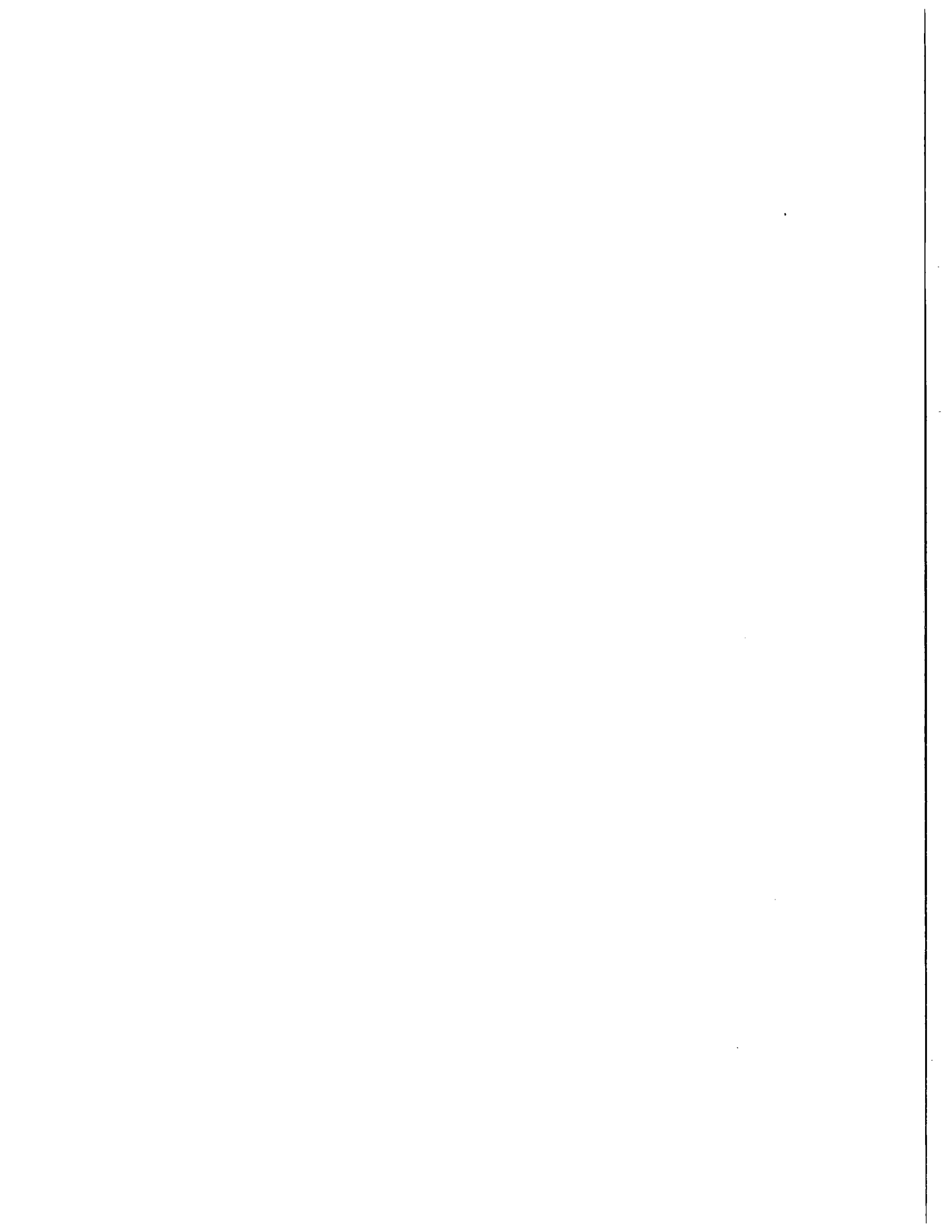
by

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September 1999



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Woods Hole Oceanographic Institution  
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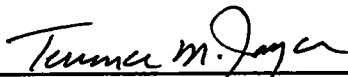
**Technical Report**

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## **Abstract**

A moored two-dimensional array with instrumentation distributed both horizontally and vertically was deployed for 27 days in August 1998 at an 85 meter deep site in Massachusetts Bay near Stellwagon basin. The horizontal mooring consisted of a 160-meter long horizontal element positioned at a depth of 20 meters between two subsurface moorings. Suspended below the horizontal member were five 25-meter long vertical strings. The vertical strings had a horizontal separation of 30 meters and each had instruments at depths of 20, 25, 30, 35, 40 and 45 meters. Instrumentation deployed on the two-dimensional array included acoustic current meters, temperature sensors, conductivity measuring instruments, pressure sensors and motion monitoring packages.

This report includes a detailed description of the two-dimensional array, the anchoring system and the instrumentation that were deployed. Also included is a description of the deployment and recovery techniques that were employed as well as an assessment of the performance of the array.



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## Section 1: Introduction

In 1997 preliminary work began toward developing a three-dimensional moored array for studying the upper ocean from the very near surface down through the permanent thermocline in shallow and deep water. As a first step in its development, a two-dimensional array with the capability of making measurements in the vertical along one horizontal axis was designed and tested. The design of such an array poses the same engineering challenges as the more complex three-dimensional array, and is, therefore, a necessary first step. This report documents the work completed to date (mid-1999) on the two-dimensional moored array project, with emphasis on the 1998 effort.

A numerical model of a subsurface horizontal mooring was developed in 1997 to aid in the evaluation of horizontal mooring designs. The numerical simulation and study of the performance of the horizontal mooring were performed using a general purpose numerical code, developed at WHOI, for calculating statistics and dynamic response of moored and towed oceanographic systems (Gobat *et al.*, 1997). The simulation is built around a mathematical model of cable dynamics that includes the effects of geometric nonlinearities, material nonlinearities, material bending stiffness, and material torsion. This permits accurate three-dimensional modeling of systems in which the cable goes slack. The nonlinear, one-sided boundary condition at the seabed is modeled as an elastic foundation for systems with cable lying on the bottom. The numerical implementation includes an adaptive time-stepping algorithm to speed the solution of problems with high nonlinearity.

The simulation was used to model the behavior of the subsurface horizontal mooring under sea-state and current forcing up to the worst hurricane scenario. Line tensions, tension fluctuations, motion of the corner buoys and component accelerations were so established. The results allow the detail mooring design to be within acceptable safe working load levels of all components.

On 19 August 1997, the first horizontal array was deployed off Provincetown, Massachusetts, in 100 meters of water. An instrumented horizontal element, 100 meters long, was tensioned between two subsurface moorings at 20 meters depth. Three current meters and five temperature/pressure recorders were deployed along the horizontal element recording data every one and two minutes respectively. In addition to these instruments, a motion-measuring package was deployed in one of the two subsurface mooring spheres. Three surface buoy guard moorings were deployed around the array to protect it from any damage due to fishing activities. One of the three surface buoys was deployed with an internally recording wind speed and direction sensor to monitor the surface forcing. A significant storm passed through the area two days after deployment, testing the holding power of the anchors and the integrity of the system under rough weather conditions. The array was successfully recovered on 27 August 1997. All instrumentation deployed along the horizontal element collected data for the entire deployment.

Experience gained from the first deployment led to the design of a new, modified, two-dimensional array, which had sensors distributed both horizontally and vertically. To evaluate the unique capability of this two-dimensional array, a joint engineering and scientific deployment was planned. The scientific focus was to explore the coherence at short horizontal and

temporal scales of the internal waves on the continental shelf, specifically targeting the effect of internal solitons on sediment transport. Working in conjunction with the United States Geological Survey (USGS), a site was selected in Massachusetts Bay near Stellwagon basin in 85 meters of water.

A two-dimensional mooring was deployed on 6 August 1998 from the R/V *Argo Maine*. The horizontal mooring consisted of a 160-meter long horizontal element positioned at a depth of 20 meters between two subsurface moorings. Suspended below the horizontal member were five, 25-meter long vertical strings. The vertical strings had a horizontal separation of 30 meters and each had instruments at depth of 20, 25, 30, 35, 40 and 45 meters. The central vertical string was instrumented with an acoustic current meter, five temperature- and conductivity-measuring instruments, and one acceleration-sensing package. The other four vertical strings were each instrumented with six temperature recorders. The instruments at the bottom of the vertical strings also measured pressure. Two additional acoustic current meters were deployed along the horizontal member. Pressure sensors and motion monitoring packages were deployed at the ends of the horizontal member. The two-dimensional array was successfully recovered on 1 September 1998 after 27 days on station.

This report will include a detailed description of the two-dimensional moored array, the instrumentation that was deployed, the technique used to deploy and recover the array, as well as an assessment of its performance.

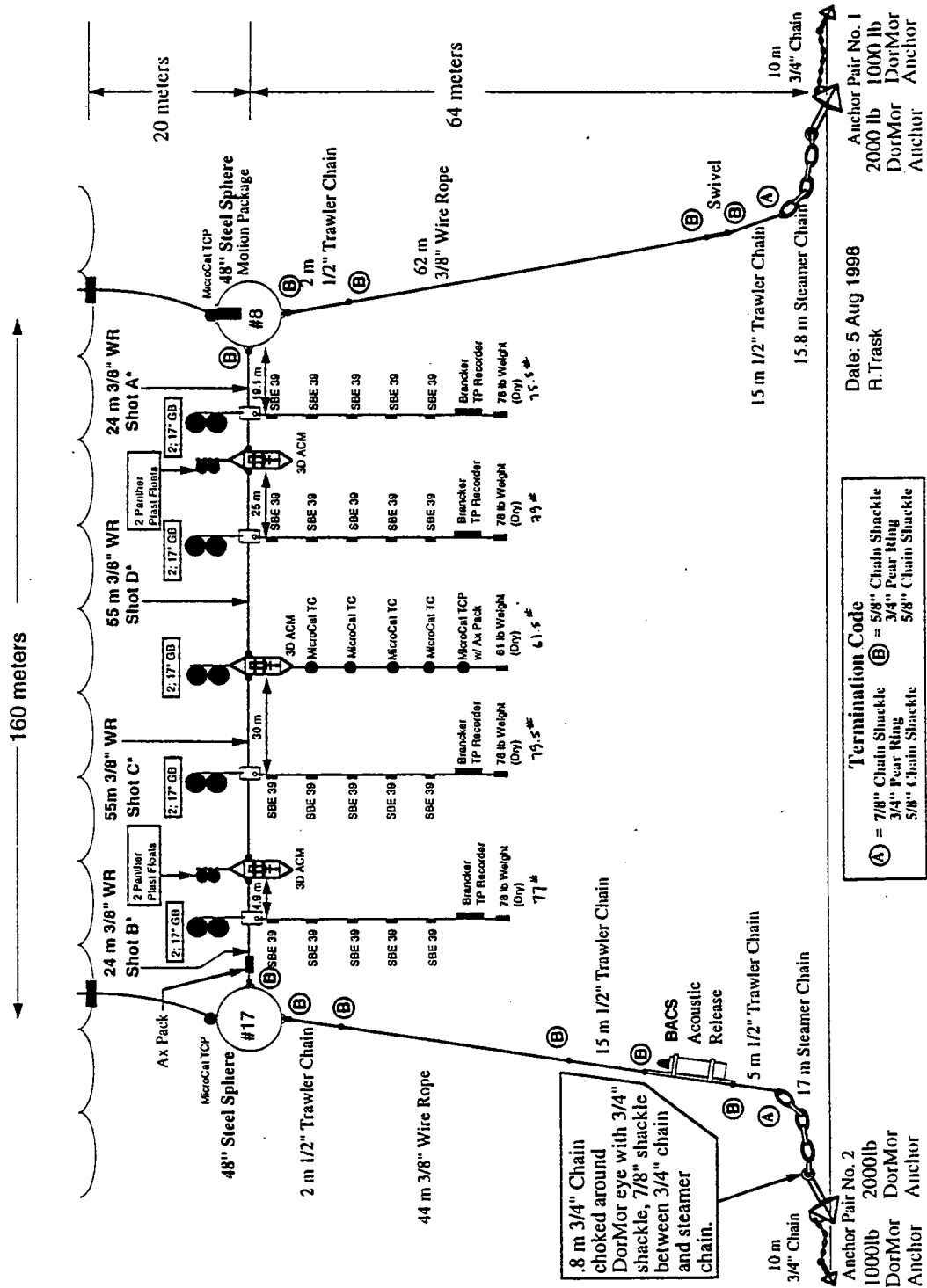
## **Section 2: Description of the Array**

### **A. Mooring Description**

The two-dimensional array consisted of two subsurface moorings with a taut horizontal member stretched between them (Figure 1a). Figure 1b shows the details of the ground line that was deployed as a means of properly tensioning the array. A description of the subsurface moorings will be followed by a detailed description of the horizontal member with its associated vertical strings.

#### **1. End Buoys (Steel Spheres)**

Each of the two subsurface moorings had a 48-inch diameter steel sphere as their primary buoyancy. The spheres were modified with new bales to accommodate the two points of attachment required for the array (Figure 2). These same spheres had been used during the first horizontal mooring deployment in 1997. Analysis of the pressure data collected from that mooring revealed that there was a persistent slope along the array with one side approximately six meters deeper than the other. Both spheres were assumed to be identical, and the manufacturer's buoyancy specifications were used in the design process. The numerical model suggested that one way for the observed slope to persist throughout all the variable tidal current forcing was to have one of the subsurface spheres with 20% less buoyancy than the other.



Date: 5 Aug 1998  
 R. Trask  
 Anchor Pair No. 1  
 2000 lb DorMor Anchor

**Termination Code**  
 (A) = 7/8" Chain Shackle  
 (B) = 5/8" Chain Shackle  
 3/4" Pear Ring  
 5/8" Chain Shackle

Anchor Pair No. 2  
 1000 lb DorMor Anchor

Figure 1: (a) Side view of the horizontal mooring.

# Ground Line Detail

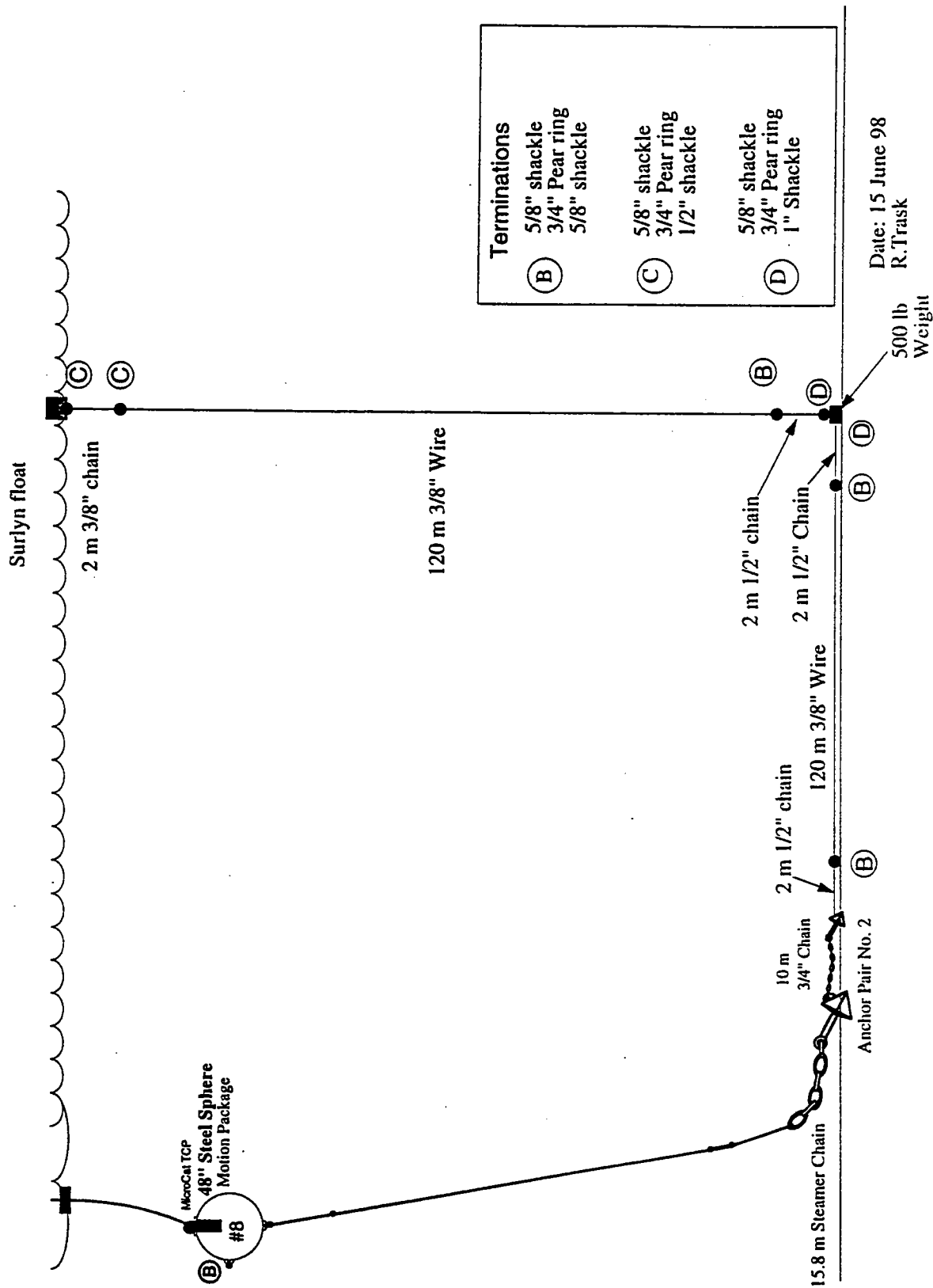
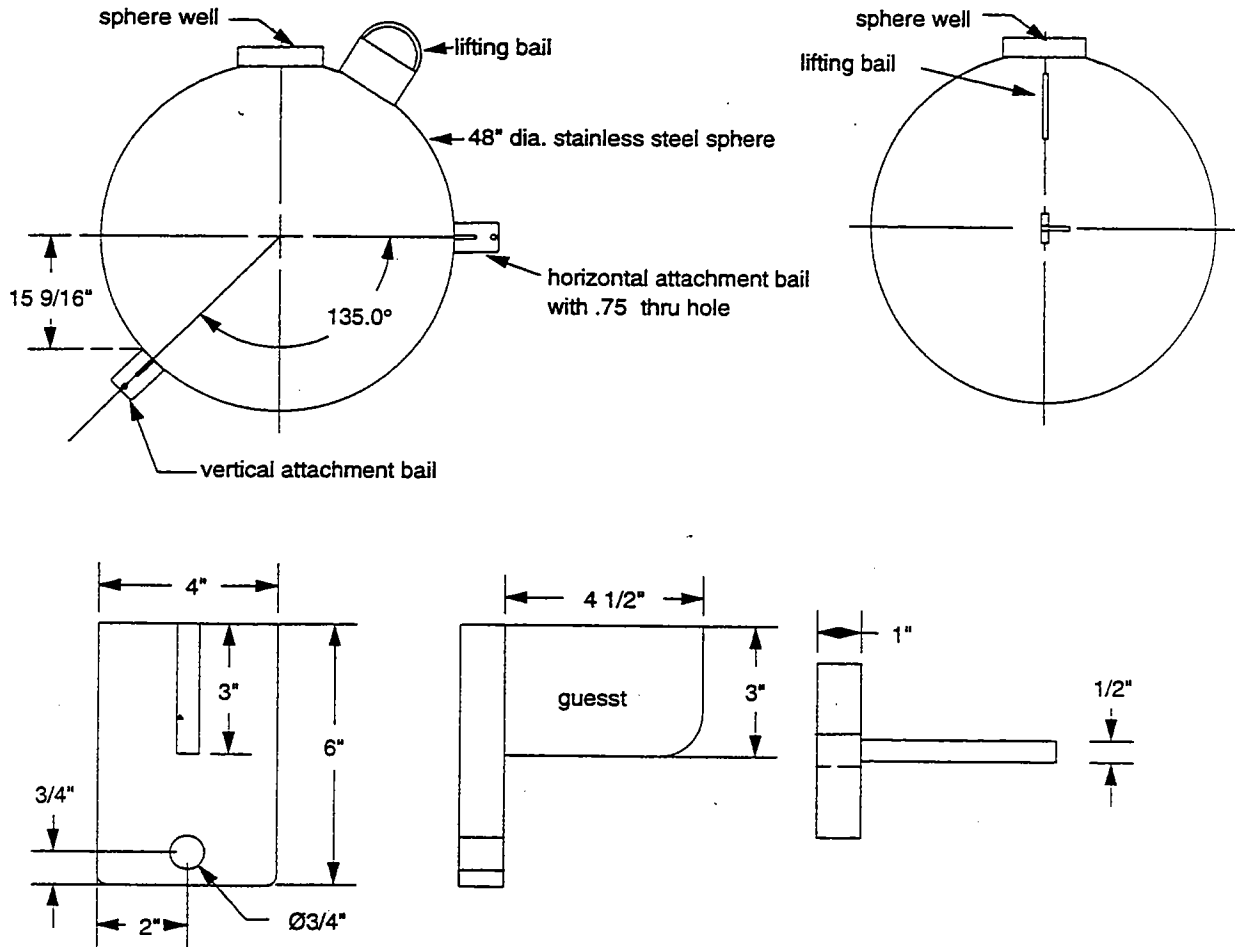


Figure 1: (b) Schematic of the horizontal mooring ground line deployed with the two-dimensional array.



Woods Hole Oceanographic Institution Upper Ocean Processes		
<b>Title:</b>	Horizontal mooring sphere bail design and location	
<b>By:</b> W. Ostrom	<b>Date:</b> 7/28/97	<b>Scale:</b> 1" 4"
<b>Material:</b> steel		
<b>Drawing #:</b>	<b>Version :</b> 1	<b>Checked</b>
<b>Note:</b> 1. 1/4" weld all around 2. align bails along same axis as lifing bail		

Figure 2: Horizontal mooring sphere modifications.

The buoyancy of the two spheres was determined experimentally at the WHOI dock. An anchor of known weight in water was attached below each sphere, and the spheres were lowered into the water with a crane until the spheres were completely submerged. The weight in water of the sphere-anchor assembly was measured using a load cell. The results of the buoyancy tests appear in Table 1.

**Table 1: Sphere buoyancy test results**

Test date: 17 March 1998 Anchor Wet Weight: 2050 pounds		
<u>Sphere #</u>	<u>Weight in water with anchor</u>	<u>Net buoyancy</u>
17	570 pounds	1480 pounds
8	880 pounds	1170 pounds

Although the spheres appeared identical, there was considerable difference in their available buoyancy. These buoyancy differences were taken into consideration in the design of the two-dimensional array deployed in 1998.

## 2. End Buoy Mooring Details

A two-meter shot of 1/2-inch trawler chain was attached directly below the sphere for ease in handling during deployment and recovery. Below the two-meter shot of chain was 3/8-inch diameter 3x19 jacketed wire rope. The length of each wire rope was adapted to lead to a horizontal long-line positioning despite the differences in buoyancy of the two corner buoys.

One of the two subsurface moorings had an acoustic release as a means of back-up recovery. Above and below the acoustic release were two lengths of 1/2-inch trawler chain. The longer length (15 meters) above the release was intended as an adjustable shot had there been a discrepancy between the design water depth and the actual depth. Since there was no acoustic release on the other subsurface mooring, a single 15-meter length of 1/2-inch trawler chain was deployed below the 3/8-inch diameter wire rope with a 5-ton swivel between the two.

Below the 1/2-inch chain on each mooring was a length of 1.25-inch steamer chain. The steamer chain weighed, on average, 46 pounds (21kg) per meter. It was included in the design to reduce the angle between the bottom and the direction of the force exerted on the anchor. A pair of DorMor® inverted pyramid-shaped mooring anchors were used to secure each subsurface mooring leg. According to the manufacturer, the DorMor® style anchor has the greatest holding capacity when used in conjunction with large scope moorings. The steamer chain was used to replicate the low angle of pull characteristic of a large (3:1) scope mooring. The horizontal mooring anchor system consisted of a 2000-pound and a 1000-pound Dor-Mor® anchor connected by a 10-meter length of 3/4-inch chain. The primary anchor was the

larger of the two. The smaller anchor was added due to uncertainties about the holding capacity of the DorMor® anchors in the expected bottom conditions and in this particular application. The DorMor® anchor was chosen after testing several anchor types. The results of those tests are described in Section 2C.

The DorMor® anchors were modified with additional bales so that two anchors could be used in series as shown in Figure 1, as well as tensioned during the deployment operations as described in Section 4 of this report.

### 3. Horizontal Mooring Member

Stretched between the two 48-inch diameter spheres was a horizontal member consisting of four lengths of 3/8-inch diameter 3x19 jacketed wire rope. The details of the wire shots are shown in Figure 3(a) and (b). Instrumentation was either clamped to the horizontal wire or placed in line with the wire. Three Falmouth Scientific, Inc. (FSI), 3D acoustic current meters (3D-ACM) were deployed in line with the horizontal wire. The FSI 3D-ACM cages were modified with additional bales so that the current meter could be deployed in-line with the horizontal wire and still maintain the vertical orientation required for proper operation of the compass (Figure 4).

Every effort was made to reduce the loading along the horizontal member. Typical wire rope terminations consist of a closed swage socket and a strain relief boot. To connect instrumentation in-line, the normal complement of mooring hardware consists of a shackle-link-shackle combination. To reduce the localized loading, the horizontal mooring wire shots were terminated with an open swage socket. The open socket was placed over an instrument bale and connected by means of a single bolt. The open swage sockets used in this application were Crosby S-501 sockets for 7/16-inch or 1/2-inch diameter wire rope.

This configuration reduced the loading; however, because links were not used, there was no readily available place where the mooring could be stopped off either during deployment or recovery. A light-weight solution to this problem was the addition of Yale grips® to the wire at selected locations. The Yale grip® works on the same principle as a Chinese finger. It has an eye with four long tails of Kevlar flat braid that are spirally wrapped around the wire. The Yale grip® provides an eye at which the mooring can be stopped off. As tension is applied to the eye the spiraled Kevlar material tightens around the wire. The ends of the wire shots that were connected to the two 48-inch diameter spheres had conventional closed swage sockets and strain relief boots. The common hardware complement of shackle-link-shackle was used.

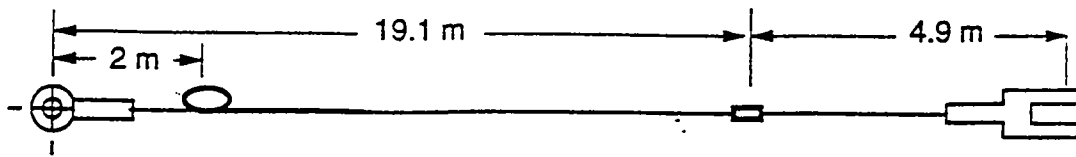
### 4. Instrumentation Attachment to Horizontal Member

Instrumentation that was not placed in line with the horizontal member was clamped to the wire. Four of the five vertical strings shown in Figure 1 were clamped to the horizontal member by means of a pair of PVC plates. Figure 5 is a photograph of the upper part of a



Closed swage socket w/ boot

Open swage socket w/boot



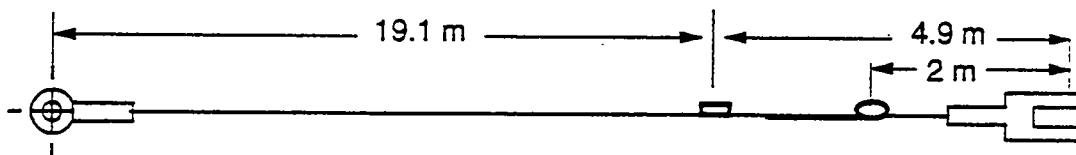
Shot A Quantity Required: 1

24 meter long shot of 3/8" diameter 3x19 TB Wire Rope

Marked 19.1 meters from the closed eye with Duct tape indicating "Temperature String". End with closed eye should be labelled "Marked 19.1 m from this end".

Other end should be labelled "Marked 4.9 m from this end".

Yale Grip eye located 2 meters from closed swage socket, oriented as shown



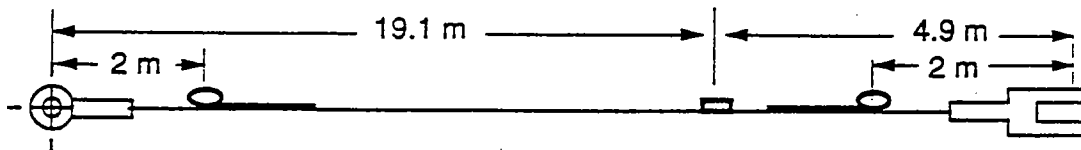
Shot B Quantity Required: 1

24 meter long shot of 3/8" diameter 3x19 TB Wire Rope

Marked 19.1 meters from the closed eye with Duct tape indicating "Temperature String". End with closed eye should be labelled "Marked 19.1 m from this end".

Other end should be labelled "Marked 4.9 m from this end".

Yale Grip eye located 2 meters from open swage socket, oriented as shown



Spare Shot for A or B Quantity Required: 1

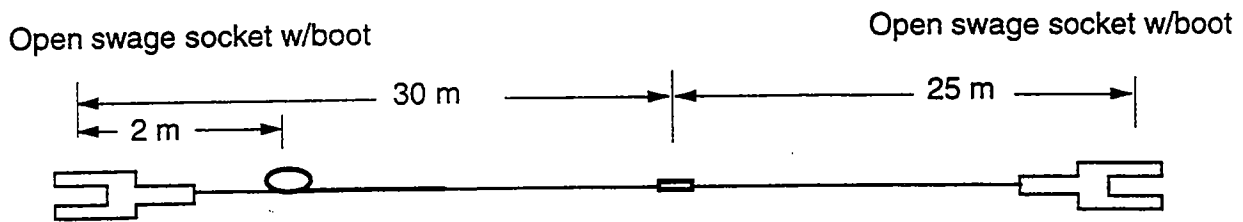
24 meter long shot of 3/8" diameter 3x19 TB Wire Rope

Marked 19.1 meters from the closed eye with Duct tape indicating "Temperature String". End with closed eye should be labelled "Marked 19.1 m from this end".

Other end should be labelled "Marked 4.9 m from this end".

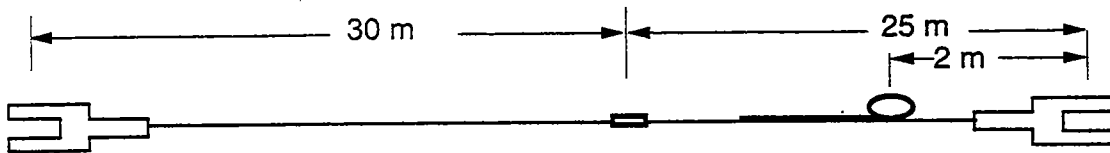
Two Yale Grips with eyes located 2 meters from each end, oriented as shown

Figure 3: (a) Schematics of the horizontal mooring wire rope.



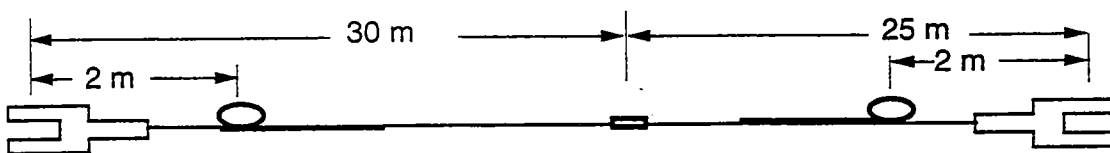
Shot C Quantity Required: 1

55 meter long shot of 3/8" diameter 3x19 TB Wire Rope  
 Marked 25 meters in from one end with Duct tape indicating "Temperature String". End from which measurement is made should be labelled "Marked 25 m from this end".  
 Other end should be labelled "Marked 30 m from this end".  
 Yale grip eye located 2 meters in on 30 m segment oriented as shown.



Shot D Quantity Required: 1

55 meter long shot of 3/8" diameter 3x19 TB Wire Rope  
 Marked 25 meters in from one end with Duct tape indicating "Temperature String". End from which measurement is made should be labelled "Marked 25 m from this end".  
 Other end should be labelled "Marked 30 m from this end".  
 Yale grip eye located 2 meters in on 25 m segment oriented as shown.



Spare for Shot C or D Quantity Required: 1

55 meter long shot of 3/8" diameter 3x19 TB Wire Rope  
 Marked 25 meters in from one end with Duct tape indicating "Temperature String". End from which measurement is made should be labelled "Marked 25 m from this end".  
 Other end should be labelled "Marked 30 m from this end".  
 Two Yale grip eyes located 2 meters from each end, oriented as shown.

Figure 3: (b) Schematics of the horizontal mooring wire rope elements.

