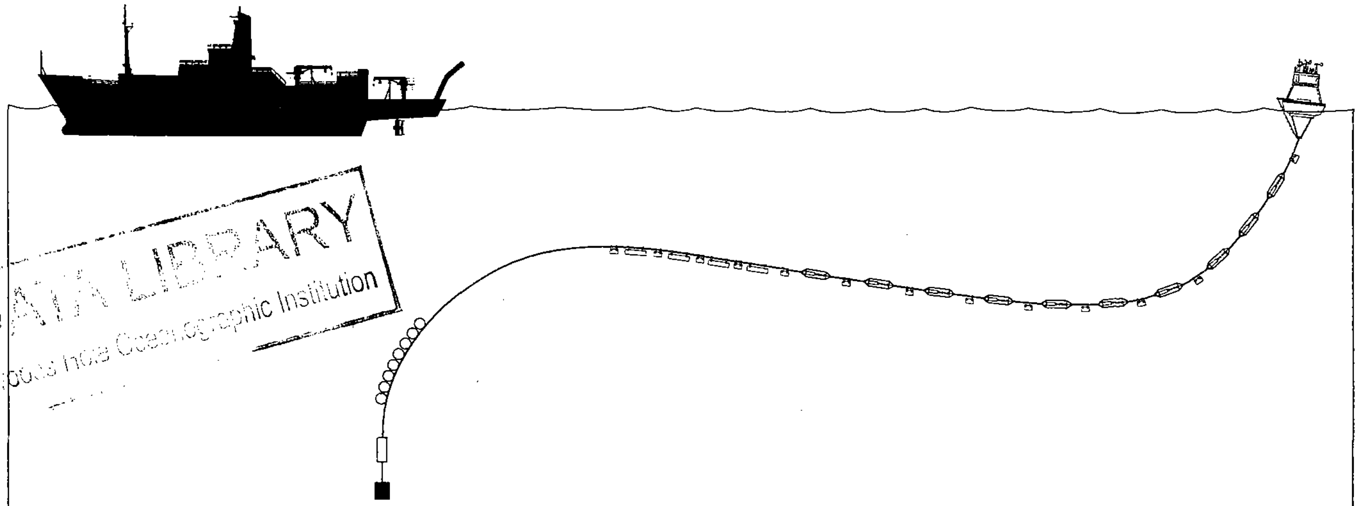

1996 ONR/MTS Buoy Workshop

March 26-27, 1996 • San Diego, CA

Summary, Abstracts, & Attendees

Office of Naval Research

Marine Technology Society

Compiled by Walter Paul
Woods Hole Oceanographic Institution, Woods Hole, MA
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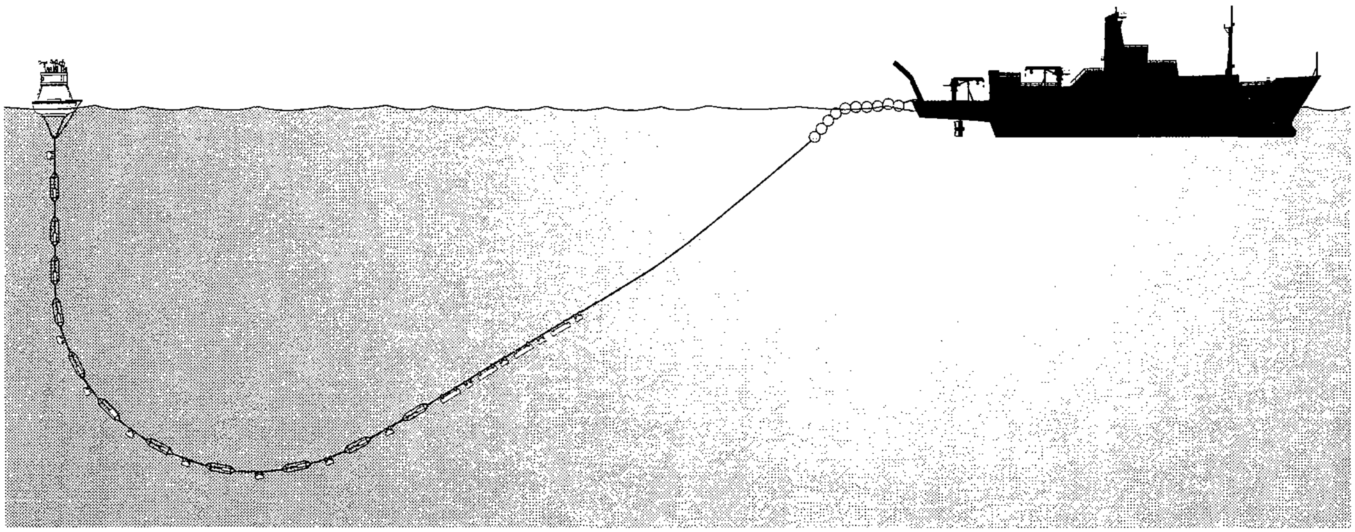

1996 Joint ONR/MTS Buoy Workshop

Coordination: Walter Paul, Senior Engineer, Applied Ocean Physics & Engineering Department
Woods Hole Oceanographic Institution, Woods Hole, MA 02543 • 508-289-3506 • wpaul@whoi.edu

Design: Jim Canavan • Illustrations: Jayne Doucette
WHOI Graphic Services

1996 Joint ONR/MTS Buoy Workshop

Introduction

Oceanographic buoy technology is a diverse field loosely represented by the Buoy Technology Committee of the Marine Technology Society. Information on oceanographic buoy systems and related is often disseminated anecdotal while some results are communicated and published at various Ocean Technology conferences and in technical reports and journal articles. Every 4 to 6 years a Buoy Workshop has been organized to provide a forum for less formal and more open exchanges of successes and failures in the development of this challenging segment of technology. The Buoy Workshops have served the purpose of a focused exchange of state of the art technology in a single defined area. Buoy research and technology is performed by small groups in diverse locations. Frequently there is little interchange about ongoing work and lessons learned beyond the immediate research team. The 1996 Buoy Workshop was suggested and supported by the Office of Naval Research, in order to foster communication and exchange. The Buoy Workshop was organized to follow with a half day of overlap the 23rd Annual Undersea Cable and Connector Workshop of the Marine Technology Society. Both workshops were held at the end of March at the same hotel in San Diego under the auspices of the Marine Technology Society. About 80 people attended the two-day exchange about buoy technology successes and failures.

Speaker Program

The program consisted of 25 technical presentations and two entertaining lunch talks. The talks were grouped under general headings "**Buoy Systems**", "**Modeling of Buoy Performance**", "**Buoy Components and Measurements**", and "**Stretch Mooring Elements**", with an emphasis on coastal buoy mooring systems. The following is a brief summary of the talks. More information is provided in the abstracts of the presentations which form the Appendix of this report.

An up-to-date overview of the status of significant buoy programs was the focal point of most presentations in the **Buoy Systems** section. Scripps' Center for Coastal Studies has developed a standard shelf mooring for water depths between 20 and 500 meters. These shelf moorings with instruments have been deployed and retrieved over 300 times (Harvey, SIO). An overview of experiences with subsurface buoy systems for acoustic measurements in locations around the globe developed at the same research facility was the subject of another presentation. Of special interest was the inclusion of releasable Pop-Up Buoys from the subsurface buoyancy module. The small data spheres are individually commanded to ascend to the sea surface, each carrying a harddrive filled with data transported through a hardwired conductor path from the main instrument (Hardy, SIO). Two extremes of surface telemetry buoy moorings were described in the third paper. A small self-deploying and expendable shallow water buoy system with a limited sensor package is a low cost candidate designed for three month deployment in shallow waters. A deepwater mooring deployed as a test bed for a large number of instruments and for data telemetry is a more expensive multi-year system. Both systems use inductive coupling to transfer sensor data to the surface buoy and both aim to deliver telemetered sensor data at an affordable cost (Frye, WHOI). Large scale mooring operations are performed by NOAA's Pacific Marine Environmental Laboratory. Over 100 moorings are deployed annually, with the majority supporting an international climate study program spanning the equatorial Pacific from Asia to America. The experience of large numbers of similar moorings has led to significant increases in operational longevity (Milburn and Meinig, NOAA/PMEL). A different emphasis guides the deployment of vertical arrays in shelf depth waters to obtain high quality acoustic data for short duration deployments. High volume data storage or real time access through surface buoys with RF links is required, as is the reuse and easy reconfiguration and attachment of array cables containing a large number of conductors (von der Heydt, WHOI.)

The **Buoy Systems** section also addressed new buoy configuration developments. The considerations for component selection and integration to produce application-specific data telemetry buoys were illustrated by following the development of remote ocean data gathering buoys from design to deployment (Pearlman, InterOcean Systems Inc.). Highlights of the design process of for advanced communications spar buoy system with a significant sensor suite showed the complexity and versatility of a configuration which operates mostly submerged, but periodically surfaces to transmit or receive data. A fiber-optic link with a tether management system forms the communications path between buoy and submerged sensors. Variable ballast controls the vertical spar buoy position in the water column (Macha and Rogers, NCCOSC; Brown, SAIC). A off-shore single point buoy mooring system for large tankers was the focal point of a non-oceanographic yet relevant presentation. The mooring consists of a multi-leg chain catenary configuration with inline suspended dead weights. Such a configuration provides increased compliance and lower tension peaks than regular chain catenary moorings, and may be of use for some coastal oceanographic or navigational buoy moorings (Flory, TTI).

Four talks were presented during the **Modeling of Buoy System Performance** Session. The advanced Dynamic Response Simulation Program (DRSP) computes 3-dimensional moored buoy motions in regular and random seas, showing improved agreement with wave tank tests compared to earlier modeling programs (Karnoski and Chiou, NFESC). Numerical modeling of a drifting buoy system was used to determine configurations with greatly reduced vertical velocities under sea state forcing. This effort was undertaken after sea trial results established a strong correlation between sea state generated vertical velocities and flow noise at the suspended acoustic array (Gobat, WHOI/MIT). The third presentation covered the current modelling and test efforts in the area of buoy/mooring dynamics at the National Data Buoy Center. A number of new programs and updating of older programs was highlighted, with a strong trend towards time-domain modeling. NDBC is also conducting a field experiment with two heavily instrumented 3 meter discus buoys and mooring systems to provide feedback data for the modeling process (Teng, NDBC). The fourth presentation described the development of static and dynamic analysis for instrumented surface buoy moorings in combination with laboratory strength and fatigue tests. Together with sea state and wind input data at a deployment site the life expectancy of each mooring component is computed allowing the identification and elimination of weak links (Grosenbaugh, WHOI).

Talks included in the **Buoy Components and Measurements** section described miniaturization of TZ-cables (thermistor chains) and connector design and fabrication for sonobuoys (Lindberg, RELTEC, and Selsor NRL Stennis), rare cases of hull plate corrosion in T5086 aluminum used in discus buoys (Newman, NDBC), and surface tether improvements of the established Seatex data buoy (Tupper, WHOI). Description of a low cost acoustic release for low tension applications in shallow water (Catalano, Benthos Inc.), and the volume recovery of the ionomer foam flotation used in a surface buoy after its accidental submergence and subsequent recovery was also presented (Greider, Gilman Corporation). In addition, a serious problem with U.S Navy cable and connector failures at hull and pressure case penetrations was summarized (Roush, NUWC NL).

Additional presentations in the **Buoy Components and Measurements** section included a talk describing transient tension peaks during mooring deployments (Hamilton, BIO). Results of a long series of cyclic tension fatigue testing on mooring hardware like shackles, end links, wire rope, and instrument cages were reported. These tests simulate at 3-5 Hz frequency the rapid load changes in deep sea surface buoy moorings (Trask, WHOI). The development of a wave powered moored profiler was described, which can make daily profiles to 2,000 meter depth (Fowler and Hamilton, BIO). A new streamlined current meter package was presented by the same researchers in a second talk. The streamlined packaging eliminates errors associated with in-line rotor-vane and electromagnetic type current meters due to strumming oscillation (Hamilton and Fowler, BIO).

Three speakers addressed **Stretch Mooring Elements** as important components for shallow water moorings. Rubber "rodes" reinforced with PVA braids are stressed up to 100 percent working elongation and are in wide use as pontoon moorings in semi-protected waters with over ten years service life (Brandt, Ancro Marine, Sweden). Elastomeric moorings for oceanographic buoys have shown remarkable survivability on exposed shallow water sites with up to 14 meter wave height. They allow taut buoy moorings to stay on station over one year with estimated severe weather stretch up to 200 percent. Conventional chain moorings failed at the same site after three summer months. Rubber moorings are however vulnerable to cutting by fishing gear (Wyman, Buoy Technology, Inc.). A compliant, rugged rubber stretch hose with embedded nylon tire cord reinforcement allows up to 35 percent working elongation, and has demonstrated protection against fishbite and fishing gear cutting through incorporated layers of Kevlar cords. The hose, attached to the bottom of surface buoys, is also the conduit for electrical conductors, forming a compliant, stress-free electrical path to submerged sensors. Five sea deployments as part of drifting and moored buoy systems have survived up to 11 months with scars from fishing gear contact and shark bite (Paul, WHOI).

Lunch Talks portrayed buoy engineering from the lighter side. Henri Berteaux compiled a slide show of 25 years of mooring surprises from his career at the Woods Hole Oceanographic Institution. The showed the frustrations and excitement of work at sea with kinked cables, broken hardware, entangled mooring lines, mixed with scenes of ultimate relaxation on board the research vessels after successful deployments or retrievals at sea.

The lunch talk by Bill Hagey from Pisces Design combined serious development work of underwater illumination towers with professional show-business. The towers were used to film AUV adventures around the wreck of the Titanic for a commercial TV production, using a spacious Russian oceanographic vessel as mothership for the autonomous vehicles. The title "Russian Hollywood Buoys in Canada" was the cover for well made video-coverage of this effort with a catching theme song for the work. Hollywood could do wonders to popularize ocean research and engineering.

Conclusion

The 1996 Buoy Workshop gave a comprehensive but not complete overview of the major oceanographic buoy systems currently in operation or under design, and informed attendees of the challenges and progress in systems and components development. The Workshop delivered the state of the art of oceanographic buoy technology as represented by the speakers and participants. The attendees expressed their will to hold a Buoy Workshop every other year; the prior 4 to 6 year intervals were considered too long to keep the community informed and connected. The lively exchange of experiences, successes, and failures could be taken as proof for the need of a focused Buoy Workshop, which provides the essential communication to avoid parallel developments due to the lack of information.

Acknowledgements

The Buoy Workshop was made possible through funding by a grant from the Office of Naval Research, which also provided the original initiative to organize the Workshop. The significant help in preparation of the Workshop of the Chairman of the Undersea Cable & Connector Committee, Mr. Albert Berian, is gratefully acknowledged, as is the help during the Workshop of Mr. Martin Finerty, Executive Director of the Marine Technology Society. The secretarial support of Mrs. Judy White and Mrs. Anita Norton at the Woods Hole Oceanographic Society is appreciated. Thanks to all speakers who made the Workshop possible, and to all participants at the Workshop for contributing to a lively and stimulating event.

Abbreviations Not Explained in Text

BIO	Bedford Institute of Oceanography, Dartmouth, NS, Canada
NDBC	National Data Buoy Center, Stennis Space Center, MS
NCCOSC	Naval Command, Control and Ocean Surveillance Center, San Diego, CA
NFESC	Naval Facilities Engineering Service Center, Port Hueneme, CA
NOAA/PMEL	National Oceanic and Atmospheric Administration/Pacific Marine and Environmental Laboratory, Seattle, WA
MTS	Marine Technology Society, Washington D.C.
NUWC NL	Naval Underwater Warfare Center, New London, CT
SAIC	Science Applications International Corporation, San Diego, CA
TTI	Tension Technology International, Weston, MA
WHOI	Woods Hole Oceanographic Institution, Woods Hole, MA

Shelf Moorings Used at the Center for Coastal Studies

Paul J. Harvey, Scripps Institution of Oceanography

The standard shelf mooring used at the Center for Coastal Studies has been successfully deployed and recovered over 300 times. It has been used in waters 20 to 500 meters deep as both an instrumented mooring and as a guard mooring for subsurface board arrays. The engineering aspects of design and component selection are presented along with environmental and public relations aspects that we consider to successfully perform moored observations in coastal waters.

Recent Experience with Subsurface Disk Buoy Moorings at Scripps

Kevin Hardy, Scripps Institution of Oceanography

Recent experiences with subsurface buoys for scientific moorings set for UCSD/Scripps Institution of Oceanography's Acoustic Oceanography Group will be discussed. Moorings deployed included a short coupled acoustic projector in 1Km water off Bermuda, three transceiver moorings in 100m in Canada's Knight Inlet, four moorings in 200m water in the Strait of Gibraltar, 6 transceiver moorings set to winter over under ice in the Greenland Sea, and several deployed in deep waters of the Pacific and Atlantic Oceans. Experiences in using steel spheres and syntactic composite materials will be discussed, including design goals, shapes (sphere, flat disk, and elliptical), composite densities, buoy frames and material acceptance testing. Recent adaptations to the flat disk buoys create an instrument platform which extend the usefulness of the bulk buoyancy module, including releasable Pop-Up Buoys (PUB), small data spheres which are individually commanded to release and float to the surface carrying a 2Gb harddrive of data, hardwire transmitted from the main instrument below.

Surface Telemetry Moorings —Two Extremes

Daniel E. Frye, Woods Hole Oceanographic Institution

Ocean researchers are being pushed by opposing forces to develop measurement strategies that are both more capable and lower cost than conventional technologies. While advances in electronics and satellite communication offer some means to achieve these divergent goals, similar advances in the mechanical realm are more elusive. The two-sided nature of this challenge is illustrated by two projects at WHOI involving surface moorings with real time data telemetry from a number of subsurface sensors.

Case 1 is a deep water mooring deployed offshore Bermuda as an instrumentation and data telemetry testbed. It uses conventional mooring technology combined with inductive telemetry, satellite and short range RF telemetry, and supports an extensive suite of physical, optical, and chemical instrumentation. It has been operating for several years with scheduled turnarounds every 4 months. It survived the passage of several hurricanes this summer, but recently experienced a failure in an instrument cage that resulted in the buoy going adrift and most of the instrumentation falling to the bottom where some instruments were crushed. Case 1 maintenance and field operations require an experienced crew and a large, well-equipped ship to keep it operating.

Cases 2 is at the other extreme. This case is a shallow water surface mooring that combines satellite and short range radio telemetry, inductively-coupled sensors distributed throughout the water column and three month deployments. Rather than use conventional mooring technology, Case 2 is self-deploying and expendable (inexpensive). Its sensor load is more limited than Case 1, but still includes 2-11 channel thermistor strings, several full function CTD's, and a few meterological sensors.

The presentation will discuss the design and operation of these two mooring systems focussing on their similar functionality and their dissimilar design approaches. It will illustrate the quandary of the ocean engineer in trying to meet the rigors of th ocean environment while minimizing the cost of monitoring the environment.

PMEL Mooring Operations

Hugh B. Milburn and Christian Meinig, NOAA/Pacific Marine Environmental Laboratory

Research at NOAA's Pacific Marine Environmental Laboratory is supported with the deployment of over 100 oceanographic moorings every year. This includes an array of >65 surface moorings maintained in the TAO array in the equatorial Pacific in an international climate study program. Also, surface and subsurface moorings are deployed in support of the FOCI (Fisheries Oceanography Combined Investigations) program in Alaskan waters, and subsurface and bottom moored instrumentation for hydrothermal VENT and tsunami research deployed in the Pacific. These moorings encompass shallow to deep environments and primarily incorporate traditional mooring technology with an emphasis on standardization and attention to details.

Although the mooring program has been very successful, a great deal of knowledge has been gained from the many modes of failures encountered, including vandalism, trawl damage, material failures, and deployment errors. An overview of the mooring operations with a focus on experience gained in countering these problems will be given.

Experiences with Surface Telemetry Buoys Connected to Vertical Acoustic Arrays in Shallow Water

Keith von der Heydt, Woods Hole Oceanographic Institution

In recent years, we have used vertical hydrophone arrays in shelf depth waters for short duration deployments of a few weeks or less where the objective is a high quality snapshot of the acoustic environment. Coincident experimental components have imposed the combined requirements of realtime access to acoustic data as well as large amounts of autonomous data storage accompanying these arrays when no means of data retrieval is present. As one might expect, among the objectives of such projects is a high probability of recovering the desired data, the need to reconfigure costly array cables for future use, and of course modest system cost. This has led us to explore new telemetry methods, various array designs, include large amounts of disk space aboard an attached surface buoy and to use easily relocated means of attaching buoys and mooring components to array cables containing many electrical conductors.

The focus of this talk will be the U-shaped mooring and buoy configurations that we have used (and not used), some of the successes and perhaps more importantly, a discussion of some areas where improvements are required particularly in the attachment of such cables to surface buoys.

Remote Ocean Data Buoys — From Concept Through Design

Stephen M. Pearlman, InterOcean Systems, Inc.

Remote data collection from oceanographic buoy platforms is always application-specific and involves choosing and implementing the correct combination of components required to achieve the specific task. The implementation of data telemetry from a remove buoy involves even further considerations and complexity of design. When planning and selecting a remote data buoy system, the system user may have a choice of using an available pre-designed general purpose buoy system and thereby modifying his experiment to comply with the capabilities of the buoy system, or face the daunting task of carefully considering and specifying each element of an appropriate buoy system for design and production in exact accordance with the specific application requirements for which it will be used. The presentation simplifies the specification and design parameters for a remote data telemetry buoy by outlining the consideerations necessary for the proper selection and integration of components for an application-specific remote oceanographic data collection buoy.

Submersible RF Communication Buoy System

William R. Macha and Kenneth E. Rogers,
Naval Command, Control and Ocean Surveillance Center
Jay A. Brown, Science Applications International Corporation (SAIC), San Diego, CA

Buoy geometries for ocean applications are as varied and diverse as the programs that give rise to their needs. NRaD is designing for ONR an autonomous, battery-powered, pop-up buoy system to provide RF communications between the sea surface and a remote ship or shore terminus, or an airborne or spaceborne repeater. This buoy system will act as a communication relay, sending and receiving data over an RF link, and shuttling that information, via fiber-optic link, to and from a sensor system on the ocean floor. Unique design features include an inherently positive, variable-displacement spar; a variable-ballast chamber to regulate surface exposure; and a self-compensating tether-management/counterbalance system. Four micro-controllers distributed throughout the system will control all buoy functions. An innovative antenna configuration combines several transmit and receive antennas in a single smooth mast, which will reduce drag and snagging. Onboard engineering sensors will collect and store voltages, currents, pitch, roll, temperature, and other buoy performance data on a regular basis while the spar is submerged, and will send that information to the user when RF communication is established. Safety features include backup acoustic commands to the buoy and a GPS locator/beacon that will detect and report the spar's position should it break away from its mooring.

CASALM (Catenary and Single Anchor Leg Mooring) Single Point Mooring

John F. Flory, Tension Technology International

The Catenary and Single Anchor Leg Mooring (CASALM) consists of a buoy on the sea surface, a riser extending down from the buoy to a weighted junction suspended above the sea floor, and catenary legs extending from the junction to anchors on the sea floor.

In the CASALM, weight is preferably concentrated at the junction instead being distributing as sinkers on individual anchor legs. When concentrated at the junction this weight is more effective in producing restoring force, no matter in which direction the mooring force is applied. The force-deflection characteristics of the CASALM can be altered by changing the weight at the junction, by changing the length of the riser leg (thus changing junction elevation), and by adjusting the catenary leg pretensions. Thus the design parameters of a CASALM can usually be tailored to produce more linear force-deflection characteristics than those obtainable with a single catenary, a catenary anchor leg mooring (CASALM), or a single anchor leg mooring (SALM).And because the force-deflection characteristics are more linear, the peak mooring forces experienced by a vessel moored at a CASALM will generally be less than those at the other alternative moorings.

This talk will describe the CASALM and compares its characteristics with those of the catenary anchor leg mooring (CALM).

Dynamic Response Simulation Program for 3-Dimensional Moored Buoy Motion Prediction: An Update on Enhancements

Stephen R. Karnoski and Ray Chiou,
Naval Facilities Engineering Service Center

The task of developing a dynamic 3-dimensional simulation program for moored buoys has resulted in recent improvements and enhancements to the Dynamic Response Simulation Program (DRSP). DRSP, developed with funding from the U.S. Navy, U.S. Coast Guard, and the National Data Buoy Center, computes the 6 degree of freedom motions of a moored buoy in regular and random seas. Discussion includes the recent improvements which include the development and implementation of large angle rotation algorithms, the addition of multidirectional seas to the excitation environment, and cable/seafloor interaction. Results of comparisons with laboratory tank test data demonstrate the improved prediction of buoy motions particularly pitch response in regular and random waves using the new large angle algorithms over the previously applied algorithms whichused the small angle assumption.

Modeling Noise Reduction in the Surface Suspended Acoustic Receiver

Jason I. Gobat, Woods Hole Oceanographic Institution

The Surface Suspended Acoustic Receiver (SSAR) is a free drifting acoustic tomography reception system. Early prototypes of the SSAR exhibited very poor signal-to-noise ratios in the frequency band of the hydrophones. A series of sea trials was conducted with instrumented systems to determine the source of the noise and a numerical model was developed to explore possible design solutions. Accelerometer data from the sea trials indicated a correlation between the vertical velocity of the acoustic array and the noise level in the hydrophones; unacceptable levels of noise were only observed for velocities greater than approximately one meter per second. The numerical model was used to find design solutions which resulted in reduced velocities at the array. By combining model results with the empirical relationship between velocity and noise we were able to develop simple design modifications which would lower the noise level by ten dB.

Buoy/Mooring Dynamics: Modeling and T esting Activities at NDBC

Chung-Chu Teng, National Data Buoy Center

There are three tools to analyze and study buoy/mooring dynamics: mathematical and numerical modeling, physical model testing, and prototype and field testing (Teng and Timpe, 1994). These three tools have their own pros and cons and should be used complimentarily. For example, field or model testing data can be used to validate mathematical/numerical models and to verify/correct some coefficients used by these models.

Mathematical and numerical modeling can be conducted in either time domain or frequency domain. Time domain models become more and more preferable due to their ability to better handle nonlinearity and fast progress of computing and computer capability in recent years. In addition to several time domain models developed for the National Data Buoy Center (NDBC) (e.g., BDRIFT, SFEROID), NDBC is working with researchers at the Naval Research Laboratory and the Naval Facilities Engineering Service Center to modify/update two other time domain models: CABUOY and KBLDYN. CABUOY is a two-dimensional model, and KBLDYN is a three-dimensional model. One of the current modifications of these two models is the cable/sea bottom interaction for NDBC shallow-water moorings. A frequency domain model, developed in 1972 for NDBC, is being used at NDBC for buoy/mooring analysis and design. Although handling nonlinearity is limited, the frequency domain, which is based on classic marine hydrodynamics, is still very useful in providing fairly accurate approximation and trend.

Lack of reliable field data is always a serious problem and is a shortcoming for study and analysis of buoy mooring dynamics. Currently, NDBC is conducting a buoy/mooring dynamics field experiment. Two 3-m discus buoys were deployed near the Harvest Platform on the California Coast on October 17, 1995. The main 3-m buoy at station 46024 is instrumented with a standard meteorological suite, a directional-wave system, a tri-axial accelerometer, a tri-axial rate sensor, two current meters (one on the buoy bottom and the other is on the mooring line), and two load cells. The supporting 3-m buoy at station 46051 is instrumented with a standard meteorological suite, a directional-wave system, and a tri-axial accelerometer. In addition to standard telemetried data, both buoys are equipped with time series data recorders. Under an agreement with NDBC, the Coastal Engineering Research Center of the U.S. Army deployed a directional Waverider near the platform and a pressure-gauge array on the platform. Data from these two sources will be used as references for NDBC's 3-m buoys.

Design of Instrumented Oceanographic Surface Moorings for Harsh Environments

Mark A. Grosenbaugh, Woods Hole Oceanographic Institution

A comprehensive methodology is presented for designing instrumented oceanographic surface moorings that is applicable to long-term deployments in coastal environments. In the past, the design of oceanographic moorings, especially deep water moorings, was based on static analysis as most systems were deployed in regions where wave forcing was small. But now, many surface moorings are being placed in ocean environments where the predominant forcing is from waves and where the major cause of failure is cyclic fatigue. Here, dynamic analysis becomes as important as the static calculations. In this presentation, we present the equations and numerical solution techniques for the statics and dynamics of a buoy/cable system with attached instruments. We also show how to combine the results of the static and dynamic analysis with data from laboratory strength and fatigue tests of mooring components to predict if the mooring will survive the deployment. An example is presented to illustrate the design procedure.

Interesting Engineering Hurdles in Design and Development of Miniature TZ Cable

Robert E. Lindberg, RELTEC
Harry Selsor, Naval Research Laboratory

Three years of extensive testing in the laboratory and at sea has revealed very interesting application engineering hurdles, failures and successes in the development and deployment of a new 120 meter miniature TZ (temperature vs. depth) cable. A torque balanced cable design incorporates thermistors in line for deployment with the newly released AN/WSQ-6 sonobuoy sized drifting oceanographic and meteorological buoy.

The Center for Tactical Oceanographic Warfare Support Program (TOWS) Program of the Naval Research Laboratory under the sponsorship of the Oceanographer of the Navy, has been investigating methods to reduce reliance on single profile expendable and ship observations by development of a series of sonobuoy sized, satellite reporting expendable mini drifting buoys. The specification includes 90 day life with various atmospheric, seasurface and subsea sensor packages, including subsurface temperature with depth (TZ) at various intervals down to 600 meters.

Twenty five prototype TZ test buoys have demonstrated the viability of reaching the desired design.

Corrosion in 5086 Aluminum Discus Buoys

W. Tod Newman, National Data Buoy Center

The National Data Buoy Center (NDBC) has successfully deployed buoy hulls fabricated from 5086 Aluminum for over twenty years. Recently, three NDBC buoys experienced unprecedented hull plate corrosion during their deployments. NDBC Engineering Division conducted an exhaustive investigation into the incidents and uncovered interesting information about intergranular corrosion of 5086 aluminum deployed in the marine environment. The investigation also noted trends in the first two corrosion incidents which resulted in conclusions that identified a third possible case in a deployed buoy. The buoy was returned early from deployment and was discovered to have an advanced case of the suspected corrosion.

Modifications to Improve Reliability of SEATEX Databuoy Surface Tether

George H. Tupper, Woods Hole Oceanographic Institution

A surface-following SEATEX Wavescan Databuoy tethered to a subsurface mooring in 3200 meters of water went adrift after one month on station. The buoyant nylon tether had been cut. Analysis of this failure showed that the most vulnerable portion of the mooring system was that portion of the tether which remained on the water's surface. This resulted in a decision to change the tether material from 18mm diameter nylon to 3/8" trawler chain. The buoy was subsequently deployed in the western mid-Atlantic, again tethered to a subsurface mooring, in 5400 meters of water. The buoy remained on station for the duration of the three-month long winter (1993-1994) deployment. The details of the tether re-design are discussed, and plans for a shallow water deployment in summer 1996 are presented.

Shallow Water Acoustic Release

Robert A. Catalano, Benthos, Inc.

Benthos, Inc. Has developed a new low cost, light weight, receive only acoustic release. With the advent of high resolution and cost effective coastal navigation (GPS and DGPS), acoustic range measurements for recovery are not required in shallow, coastal water. Designed to allow the coastal researcher a reliable and cost effective means of acoustic recovering shallow water instrumentation packages, the design criteria was rugged, reliable, and inexpensive. The design can be utilized to release a buoyed tag line for recovery of the entire package or to release a buoyant instrument package from an anchor.

The MTS/ONR Buoy Workshop presentation will be used as a forum to present a design package based on available customer feedback. Instrumentation will be available for review and comment. This presentation will establish a two way dialog with a wider audience with more varied requirements in an environment of scientific exchange to foster product development to meet the dynamic needs of the coastal shallow water research community.

Sinking the Unsinkable

George M. Greider, The Gilman Corporation

Woods Hole Oceanographic Institution was one of the pioneers in using Ionomer foam flotation for ocean buoys. WHOI has found it a versatile material which can be formulated in a range of densities, sizes and shapes that can be constructed without molds.

In 1995, while dragging for another mooring, WHOI brought up an ionomer hull sunk for over a month at 75 meters. The report will present before and after dimensions, discuss probable cause of the sinking, and illustrate the extent that the retrieved buoy has returned to original dimensions. Other submergence experience and indications for sub-surface use of ionomer will also presented.

US Submarine Fleet Program for Addressing Cable Assembly Problems: Cause and Solutions

Robert A. Roush,Naval Undersea Warfare Center, New London, CT

The Navy has had a major problem over the past few years with cable and connector failures. These failures can be serious enough to require a submarine to be drydocked to fix the assembly or to jeapordize the safe operation of the vesel. Therefore the Navy placed a high priority on studying cable assembly and connector failures in the marine environment, identifying their failure modes and determining how to correct the problem. The failure modes of these cable assemblies are common throughout the marine environment and apply to buoy systems as well.

This presentation will be an overview of the Navy's program to increase the longevity of cable assemblies and connectors in the marine environment. It will include a brief review of the failure analysis of cable and connectors, their major failure modes and solutions to correct these problems. It will also include a brief review of the new NAVSEA Molding Document (which addresses the manufacture of cable assemblies) and continuing work to improve cable assemblies in the marine environment.

Transient Tension Measurements During Mooring Deployments

Jim Hamilton, Bedford Institute of Oceanography

Tensions recorded during the deployment of using the "buoy first" technique demonstrate that transient peaks in tension occur which exceed the tension measured during the steady state decent of the Mooring to the bottom. This transient behavior is described with a simple analytical model which ultimately allows for the calculation of an "effective" Young's modulus of elasticity for the mooring lines used. This effective Young's modulus may have practical value in that it describes the combined effect of material type and rope construction.

Cyclic Fatigue Testing of Mooring Hardware

Richard B. Trask, Woods Hole Oceanographic Institution

Cyclic fatigue tests conducted on a variety of mooring hardware components provided valuable information which was used to specify the hardware for the heavily loaded WHOI surface mooring deployed in the Arabian Sea in 1994/5. Special care was taken during the design of the Arabian Sea surface mooring since environmental conditions were expected to be more severe than in other deep water regions where surface moorings have been deployed in the past. Moorings deployed in coastal locations also present challenging design problems. The information gained from these materials tests is applicable to moorings deployed in both deep waer and coastal regions.

For years the efforts to investigate air-sea interaction and upper ocean variability with surface moorings have focused on regions characterized by light to moderate atmospheric forcing. Wind and wave conditions have therefore not been considered critical factors in the design process. Recently the desire to increase the understanding of air-sea interaction processes has required the capability to make time series observations of forcing and response in both deep and shallow water severe environments. Surface moorings designed for severe environments have begun to consider strong atmospheric forcing along with the steady current conditions. Waves generated by strong wind events impose a dynamic load on mooring components. Superimposed on the background static tension from the currents is an oscillating dynamic tension that is generated by each passing wave. In a 1989 experiment south of Iceland, mooring tensions ranged from less than 1000 to over 8500 pounds with excursions from 1500 to 6500 pounds occurring over less than four seconds.

The dynamic loads can be so severe that ultimate strength considerations can be superseded by the fatigue properties of the standard hardware components. A surface mooring deployed in a dynamic environment where the wave period is approximately 7 seconds can easily accumulate 2.5 million load cycles during a six month deployment.

Concerns about all in-line mooring components and their fatigue endurance dictated the need for an independent series of cyclic fatigue tests. The components tested included shackles of various sizes, configurations, and manufacturers, wire rope, instrument cages, chain, and a variety of interconnecting links such as weldless sling links and end links. All tests were conducted in a dry environment and the frequency of the applied cyclic loads was between 3 and 5 hertz.

The results of the cyclic fatigue tests conducted as part of the Arabian Sea surface mooring design effort will be presented. The merits of shot peening to extend the fatigue life of shackles will also be discussed.

Profiling for the Long Haul

George Fowler and Jim Hamilton, Bedford Institute of Oceanography

To study the long term variability of the Labrador current, it has been proposed to develop a remotely operating, moored profiler capable of recovering data in near real time from daily transits to 2000M and for months per deployment. The original engineering objectives and development sequence for the device to meet the requirement is outlined. Initial prototype design and tests are described along with project redirection as a result of field testing. A new concept in profiler operation, discovered during field testing, is described along with its theory of operation, the data retrieval methods employed and initial field testing. Plans for future Developments are outlined.

Eliminating Mooring Vibration for Improved Current Meter Measurements

Jim Hamilton and George Fowler, Bedford Institute of Oceanography

Although mooring systems which provide data in near-real time are advantageous in many applications , there is still a role to be played by traditional mooring technology. For example, sub-surface current meter moorings continue to be an effective tool for collecting long time series of oceanographic data, and room for the improvement of data quality from this source still exists.

Large current meter rate errors have been attributed to mooring vibration. This vibration is shown here to be caused by flow-induced oscillation of spherical in- line buoyancy packages. Errors in rotorvane and electromagnetic type current meters are as high as 40% in flows typical of coastal areas.

A new streamlined package used to replace the spherical buoyancy is shown to eliminate the vibration problem thereby eliminating the current meter rate error problem. Other advantages of the streamlined buoyancy package are discussed.

Engineering Properties and Deployment Experience of SEAFLEX Elastic Moorings

Lars Brandt, ANCRO MARIN AB, Sweden

Surface buoy moorings for shallow offshore waters require a large amount of stretch in order to accomodate the sea state lift and surge of the buoy. The constant tugging of the buoy introduces high levels of shock loading and cyclic tension on the mooring unless sufficient compliance is provided in the mooring link. Elongation levels up to 100 percent under working tensions are possible with the Seaflex rubber cables, thereby greatly improving fatigue endurance of a mooring. The constant moving of the moored object together with corrosion also accelerates the wear in a traditional mooring layout. The talk will report on ongoing test programs and at sea performance results of moorings with Seaflex cables.

Elastic Mooring Technology for Shallow Water Buoys

David M. Wyman, Buoy Technology, Inc.

Surface buoy systems incorporating a compliant (elastic mooring have been used in the shallow waters around the world to improve instrument performance and equipment survivability. For over twenty years, elastic mooring technology has been utilized for data collection and marker buoy applications in water depths mostly between 50 and 200 meters.

In these cases, a custom-engineered array of elastic mooring links provided the compliance to accommodate the relatively large water level fluctuations associated with waves and tide. This mooring compliance eliminated the large mechanical shock loadings of conventional slack moors while maintaining continuous tension in the mooring string itself to limit buoy roll and horizontal displacement ("watch circle").

Specific examples of this technique are presented, ranging from the collecting and telemetry of oceanographical and meteorological data in the near-shore environment to the positioning of geophysical survey ships from large, highly stable, multi-leg, elastically moored platforms in the open ocean.

Criteria for proper design and configuration of elastic mooring arrays are presented as well as deployment and retrieval implications. Problems specific to elastic mooring technology are discussed. These include vulnerability of the elastic links to ultimate failure from tension (rare) and failure from being cut by fishing gear.

Fishbite Resistant Surface Buoy Mooring Interface with Stretchable Conductors

Walter Paul, Woods Hole Oceanographic Institution

The upper portion of an instrumented surface buoy mooring should best be a flexible, easily stretchable torque-free electro-mechanical cable. It should be furnished with a hard jacket to resist fishbite damage and sufficient strength to hold the buoy on station. The low elastic stretch of copper conductors does not survive well in this environemnt. After addressing mooring compliance needs as function of water depth the talk will describe a recently developed technique to keep a copper conductor assembly stress-free in compliant surface buoy moorings. This is achieved by fabricating a large telephone (coil) cord inside a water filled stretch hose. The hose serves as a compliant strength member and is equipped with counter-helical layers of Kevlar fabric for fishbite protection. The hose compliance is controlled and adaptable by counter-helical layers of nylon tire cord, embedded in a rubber hose wall and vulcanized as composite. Lab and sea test results will be presented for the conductor and stretch hose assembly.

Henri Berteaux
CDMS
Box 8006
La Jolla, CA 92038-8006

Lars Brandt
ANCRO MARIN AB
P.O. Box 115
Umea, SWEDEN 901 03

Jay C. Brown
SAIC
3990 Old Town Ave., Suite 303C
San Diego, CA 92110

Robert A. Catalano
Benthos
49 Edgerton Drive
N. Falmouth, MA 02556-2826

Tor Chamberlain
Cortland Cable Company
P.O. Box 330
Cortland, NY 13045-0330

Ray Chiou
NFEC
560 Center Drive
Port Hueneme, CA 93042-4328

Paula J. Christina
SeaCon/Brantner & Assoc., Inc.
52 Airport Rd.
Westerly, RI 02891-1854

Elly Chung
SeaCon/Brantner & Assoc.
120 Vernon Way
El Cajon, CA 92020

Tom Coughlin
Vector Schlumberger
533 Industrial Drive
Sugar Land, TX 77478-2899

Terry Dailey
Vector Schlumberger
555 Industrial Rd.
Sugar Land, TX 77478-2899

Ole Damlien
UCSB
Ocean Engineering Lab.
6740 Cortona Drive
Goleta, CA 93117

Jim Dufour
Scripps Institution of Oceanography
9500 Gilman Drive
La Jolla, CA 92093-0230

Gary Eckley
Columbus McKinnon Corp.
Midland Forge Division
PO 1627 101-50th Avenue, SW
Cedar Rapids, Iowa 52404

Martin J. Finerty, Jr.
Marine Technology Society
1828 L-St., NW #906
Washington, DC 20036-5104

Barbara Fletcher
IMETRIX
1235 Route 28A
Box 152
Cataumet, MA 02534

John Flory
Tension Technoloby International Inc.
4 Tower Lane
Morristown, NJ 07960

William L. Foley
Macwhyte Company
SPC. Div.
2906 - 14th Ave.
Kenosha, WI 53140

George Fowler
Bedford Institute of Oceanography
Ocean Physics Section
P.O. Box 1006
Dartmouth, NS B2Y 4A2 CANADA

Daniel E. Frye
Woods Hole Oceanographic Institution
MS 18
Woods Hole, MA 02543

Tom Gaseor
D&G Technologies
8876 Gulf Freeway
Houston, TX 77017

Ron George
SonTek, Inc.
7966 Arjons Drive, Suite D
San Diego, CA 92126

Jason Gobat
Woods Hole Oceanographic Institution
MS #7
Woods Hole, MA 02543

George M. Greider
Gilman Corporation
Main Street
Gilman, CT 06330

Mark Grosenbaugh
Woods Hole Oceanographic Institution
MS 7
Woods Hole, MA 02543

Bill Hagey
Pisces Design
7945-B Dunbrook Rd.
San Diego, CA 92126

Jim Hamilton
Bedford Institute of Oceanography
Ocean Physics Section,
P.O. Box 1006
Dartmouth, B2Y 4A2 Canada

Jim Hannon
Sippican, Inc.
7 Barnabas Road
Marion, MA 02738

Kevin Hardy
Scripps Institution of Oceanography
A-025
Inst. of Geophysics & Planetary Physics
La Jolla, CA 92093-0225

Paul J. Harvey
Scripps Institution of Oceanography
Univ. of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0200

J. Michael Hemsley
Chief, Program Management Division
P.O. Box 2028
Bay St. Louis, MS 39521

Michael M. Holland
Sparta Marine Instrumentation
9455 Town Center Drive
San Diego, CA 92121

Stephen R. Karnoski
NAV FAC ENG SVC CTR
560 Laboratory Avenue
Port Hueneme, CA 93043-4328

James F. Katsos
CTA Space Systems
1521 Westbranch Drive
McLean, VA 22102

Andrew Klimowich
IMODCO, Inc.
27001 Agoura Rd., Suite 350
Cavabasas Hills, CA 9101

Donald J. Klimowich, PE
Zeta Associates, Inc.
Suite 500
10300 Eaton Place
Fairfax, VA 22030

Donald Liberatore
Zeta Associates, Inc.
Suite 500
10300 Eaton Place
Fairfax, VA 22030

Robert E. Lindberg
RELTEC
P.O. Box 6718
Santa Rosa, CA 95406

William Macha
NCCOSC /RDT&E
RDT&E, Div. 562
53560 Hull Street
San Diego, CA 92152-5001

Christian Meinig
NOAA Pacific Marine Environ. Lab
7600 Sand Point Way NE
Seattle, WA 98115

Hugh Milburn
NOAA PMEL
7600 Sand Point Way, NE
Seattle, WA 98115

Howard Miller
NRaD
Code 662
49595 Beluga Rd.
San Diego, CA 92152-6520

Joe Mingrone
C&M Technology, Inc.
2 Business Park Rd.
Old Saybrook, CT 06475

Brian Musselman
NDBC
811 N. Lake Washington
Slidell LA 70461

W. Tod Newman
National Data Buoy Center
Bldg 1100
Stennis Space Center, MS 39529

Jim Nowatzki
Allied Signal
15825 Boxford Street
Sylmar, CA 91236-3597

Jack Olson
NCCOSC/RDTE
Code 541, Bldg. 106
271 Catalina Blvd.
San Diego, CA 92152

Leroy O. Olson
University of Washington
Applied Physics Lab.
1013 NE 40th Street
Seattle, WA 98105

William Ostrom
Woods Hole Oceanographic Institution
MS 30
Woods Hole, MA 02543

Walter Paul
Woods Hole Oceanographic Institution
MS #9
Woods Hole, MA 02543-1053

Stephen Pearlman
InterOcean Systems, Inc.
3540 Aero Court
San Diego, CA 92123-1799

Bernard Petolas
Metocean Data Systems
P.O. Box 2427
40 Fielding Ave.
Dartmouth, NS Canada B2W4A5

Steven Ramp
Office of Naval Research
800 N. Quincy St., MS 322PO
Arlington, VA 22217-5660

Gery W. Riley
Macwhyte Company
Speciality Division
2906 - 14th Avenue
Kenosha, WI 53140

Kenneth E. Rogers
NCCOSC/RDT&E
Div. 714 [NRaD]
49590 Lassing Road, Rm. A456
San Diego, CA 92152-6161

Robert A. Roush
NUWC
Code 2131
B-80, Rm 1109
New London, CT 06320

Doug Scally
National Data Buoy Center
Bldg. 1100
Stennis Space Center, MS 39529

Rick Schulze
NUWC Division Keyport
610 Dowell Street
Keyport, WA 98383

Meredith Sessions
Scripps Institution of Oceanography
Rt 1, Box 131A
Del Mar, CA 92014

R. David Simoneau
Woods Hole Oceanographic Institution
MS 19
Woods Hole, MA 02543

Kenneth E. Steele
NOAA National Data Buoy Center
255 D East Scenic Drive
Pass Christian MS 39571

H. Scott Stevenson
Submarine Cable Systems, Inc
424 Severnside Drive
Severna Park, MO 21446

J. Mark Stevenson
NCCOSC/RDT&E
Code 541
49575 Gate Rd., Bldg. 106
San Diego, CA 92152-6435
John Stidd

Joh Stidd
Cortland Cable Co.
P.O. Box 330
177 Port Watson St.
Cortland, NY 13045

William Strahle
U.S. Geological Survey
384 Woods Hole Rd.
Woods Hole, MA 02543

Thomas Swean, Jr.
Office of Naval Research
800 N. Quincy St., MS 321OE
Arlington, VA 22217-5660

William L. Tell
Consolidated Prod. Corp.
South Bay Cable Division
P.O. Box 67
Idyllwild, CA 92549

Chung-Chu Teng
National Data Buoy Center
Bldg. 1100
Stennis Space Center, MS 39529

Eric Terrill
Scripps Institution of Oceanography -
MPL
8605 La Jolla Shores Drive
La Jolla, CA 92093-0230

Gerald Timpe, PE
US Coast Guard Research & Development Ctr.
1082 Shennecossett Road
Groton CT 06375

Richard Trask
Woods Hole Oceanographic Institution
MS 29
Woods Hole MA 02543

George H. Tupper
Woods Hole Oceanographic Institution
MS 29
Woods Hole , MA 02543

Keith von der Heydt
Woods Hole Oceanographic Institution
MS 17
Woods Hole, MA 02543

Samuel Welch
UC Santa Barbara
Ocean Engineering Lab.
6740 Cortona Drive
Goleta, CA 93117

Scott Worrilow
Woods Hole Oceanographic Institution
MS #90
Woods Hole, MA 02543

David Wyman
Buoy Technology, Inc.
P.O. Box 922
Concord, NH 03302

Jesus Zuniga
NCCOSC RDTE Div. 562
53560 Hull Street
San Diego CA 92152-5001

Notes