MOORINGS

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doi:10.1006/rwos.2001.0304

Introduction

The need to measure ocean currents throughout the water column for extended periods in order to better understand ocean dynamics was a driving force that led to the development of oceanographic moorings. Today's moorings are used as 'platforms' from which a variety of measurements can be made. These include not only the speed and direction of currents, but also other physical parameters, such as conductivity (salinity), temperature, and sea state, as well as surface meteorology, bio-optical parameters, sedimentation rates, and chemical properties.

Moorings typically have three basic components: an anchor, some type of chain or line to which instrumentation can be attached, and flotation devices that keep the line and instrumentation from falling to the seafloor. Shackles and links are typically used to connect mooring components and to secure instruments in line. The choice of hardware, line and flotation for a particular application, as well as the size and design of the anchor, depends on the type of mooring and the environment in which it is deployed.

Most moorings fall into two broad categories – surface and subsurface. The main difference between the two is that the surface mooring has a buoy floating on the ocean surface, whereas the subsurface mooring does not. Although the two mooring types have similar components, the capabilities of the two are very different. With a surface buoy, it is possible to measure surface meteorology, telemeter data, and make very near-surface measurements in the upper ocean. The surface mooring, however, is exposed to ocean storms with high wind and wave conditions and therefore must be constructed to withstand the forces associated with the wind and waves. In addition, it may transmit some unwanted motion to subsurface instruments if care is not taken. The subsurface mooring, on the other hand, is away from the surface forcing and can be fabricated from smaller, lighter components, which are less expensive and easier to handle. However, it is difficult to make near-surface measurements from a subsurface mooring.

Early attempts at mooring work in the 1960s began with surface moorings. Problems with the mooring materials and the dynamic conditions encountered at the ocean surface resulted in poor performance by these early designs, and attention turned to developing subsurface moorings. The introduction of wire rope as a material for fabricating mooring lines and the advent of a remotely triggered mechanism to release the mooring's anchor were significant milestones that helped make the subsurface mooring a viable option. It has since proved to be a very successful oceanographic tool. Recent interest in the upper ocean and the air–sea interface prompted a reexamination of the surface mooring design. The evolution of the subsurface mooring as a standard platform for oceanographic observations and the more recent development of reliable surface moorings are summarized here.

Subsurface Mooring Evolution

Early moorings consisted of a surface float, surplus railroad car wheels for an anchor, and lightweight synthetic line, such as polypropylene or nylon, to connect the surface float to the anchor. Several kilometers of line are required for a full-depth ocean mooring, and weight of the line itself, even in water, is not negligible. Instrumentation was connected to the synthetic line along its length. The anchor was connected to the mooring line by means of a corrosible weak link. The initial method of recovering the moorings was to connect to the surface float and pull it with the hope that the tension would break the weak link leaving the anchor behind. Unfortunately, at the time of recovery the mooring line was often weaker than the weak link and would break, allowing the line and instrumentation below the break to fall to the seafloor.

Studies showed that the synthetic ropes were being damaged by fish. Analysis of many failed lines revealed tooth fragments and bite patterns that were used to identify the type of fish responsible for the damage. Statistics concerning the number of fishbites, their depths, and their locations were collected, and it was found that the majority of fishbites occurred in the upper 1500 m to 2000 m of the water column. Prevention of mooring failure due to fish attack required lines that could resist fishbite.

Ropes made of high-strength carbon steel wires were an obvious candidate. Wire rope would not only provide protection from fish attack, but also would have minimal stretch, unlike the synthetic ropes, and would provide high strength with relatively low drag. Many types of wire rope construction and sizes were tested, in addition to methods for terminating the wire rope; terminations are the fittings attached to the ends of wire sections. In constructing a mooring whose components can be shipped separately and handled safely on the deck of a ship at sea, the practice is to cut the wire into sections of specific lengths (shots) that allow connection to other wire shots or to instrumentation in series (end to end). A desirable termination is one that is as strong as the wire rope itself. If the technique used to terminate a rope imposes stress concentrations, which significantly reduce the strength of the wire rope, then the whole system is weakened. Methods of terminating wire include the formation of eyes into which shackles can be attached either from swaged fittings or from zinc- or resin-poured sockets. Swaged terminations utilize a fitting that is slid onto the end of the wire and pressed or swaged onto the wire with a hydraulic press. In the case of a poured-socket termination, the wire is inserted into the socket and the individual wires are splayed outward or 'broomed out.' Once the wires are properly cleaned and positioned, a filler material (molten zinc or uncured epoxy resin) is poured into the socket and allowed to harden. A strain relief boot is often used in conjunction with a swaged fitting termination, as well as with the poured sockets. The boots are often an injection-molded urethane material designed to extend from the fitting out over a short section of the wire to minimize the bending fatigue that can occur between the flexible wire and rigid fitting.

At present, galvanized 3×19 wire rope is widely used for oceanographic applications. The designation '3×19' denotes three strands or groups, each with 19 individual wires: The 19 wires are twisted together to form a strand. Three strands are then wound together to form the rope. The rotation characteristics of wire rope are critically important in certain oceanographic applications. If the rope has the tendency to spin or rotate excessively when placed under tension, there is a tendency for that wire to develop loops when the tension is reduced quickly. If the load is quickly applied again to the line, the loops are pulled tight into kinks, which can severely weaken the wire rope. Wire rope with minimal rotation characteristics is called 'torque balanced' and is preferred for mooring applications, particularly surface mooring work. Wire ropes are available with varying degrees of torque balancing. Swivels are sometimes placed in series with the wire to minimize the chances of kink formation. In addition to galvanizing the rope to provide protection against corrosion, some wire ropes have a plastic jacket extruded over the wire. Types of plastics used for jacketing materials include polyvinyl chloride, polypropylene and high-density polyethylene.

In the early years, mooring recoveries that were initiated by pulling on deteriorated mooring lines often resulted in line breakage and instrument loss. A preferable approach was to detach the mooring from its anchor prior to hauling on the mooring line. This would reduce the load on the mooring line since the line would never 'feel' the weight of the anchor nor the tension required to pull the anchor out of the bottom sediments. This approach became possible with the development of an acoustically commanded anchor release. The acoustic release is deployed in-line on the mooring and is typically positioned below all instrumentation and close to the anchor. To activate the release mechanism, a coded acoustic signal is sent from the recovery vessel. The acoustic release detects the signal and disconnects from the anchor.

When mooring work was in its infancy, the surface buoy was a vital, visible link to the mooring below. Without it, the exact location of the mooring was unknown. The introduction of acoustic releases not only provided a way to disconnect the line and instruments from the anchor, but also provided a way to locate the exact position of the mooring by acoustic direction finding. This eliminated the need for a surface float, whose sole function was for recovery purposes. Instead of having a mooring that stretched all the way from the ocean bottom to the surface, the mooring was shortened so that the top of the mooring was positioned below the surface of the water. Sufficient buoyancy was placed at the top of the mooring to keep all of the mooring components as vertical as possible throughout the water column. With this design, which became known as the subsurface mooring, the mooring would ascend to the surface once it was acoustically released from its anchor. At the surface, it could be pulled out of the water by the waiting recovery vessel. A great advantage of the subsurface mooring is having the hardware below the ocean surface, which is the most dynamic part of the water column. As a result, there is a considerable reduction in component fatigue due to surface-wave action. In addition, the mooring is no longer visible to surface vessels and is less vulnerable to vandalism.

The buoyancy used on subsurface moorings is usually in the shape of a sphere, because of its low drag coefficient. Other shapes have been used depending on the specific application. Various materials are used, including steel spheres, glass spheres with protective plastic covers, and syntactic foam spheres. Syntactic foams consist of small pressure-resistant glass microspheres (2–300 μm in diameter), as well as larger glass-fiber-reinforced spheres (0.15–10 cm in diameter) embedded in a thermosetting plastic binder. An advantage of the syntactic foam is that it can be molded to form custom shapes. Unlike the steel spheres, whose use is depth limited (maximum working depth is approximately 1000 m), the syntactic foam can be engineered to withstand full ocean depth pressures. In addition, it can be designed to provide the same buoyancy as a string of glass balls (commonly 43 cm in diameter) with considerably less drag. This makes syntactic foam spheres attractive for use in high-current regimes, since the drag on the mooring will be less; consequently, less buoyancy will be needed to keep the mooring near vertical.

Subsurface moorings with a single element of buoyancy at the top are still at some risk. Should the buoyant element be lost or damaged, the mooring would fall to the bottom, leaving no secondary means of bringing it back to the surface when the acoustic release mechanism is activated. To provide a higher degree of reliability, buoyancy is often provided in the form of glass balls attached along the length of the mooring. In addition, buoyancy is often added to the bottom of the mooring, just above the acoustic release, to provide what is sometimes referred to as the 'backup recovery.' With this design feature (**Figure 1**), should a mooring component fail and the upper part of the mooring be lost, no matter where the failure occurs, there should be sufficient buoyancy below that point to bring the remaining section of the mooring back to the surface. Instrumentation that would otherwise have been lost if deployed with a single buoyant element is recoverable with this configuration. Equally important, the recovery provides the opportunity to identify the failed component and correct the problem. As a recovery aid, pressure-activated submersible satellite transmitters are frequently installed on the upper buoyancy sphere. In the event of a mooring component failure that causes the top of the mooring to surface, it can be tracked via satellite. This allows for possible recovery of whatever instrumentation hangs below.

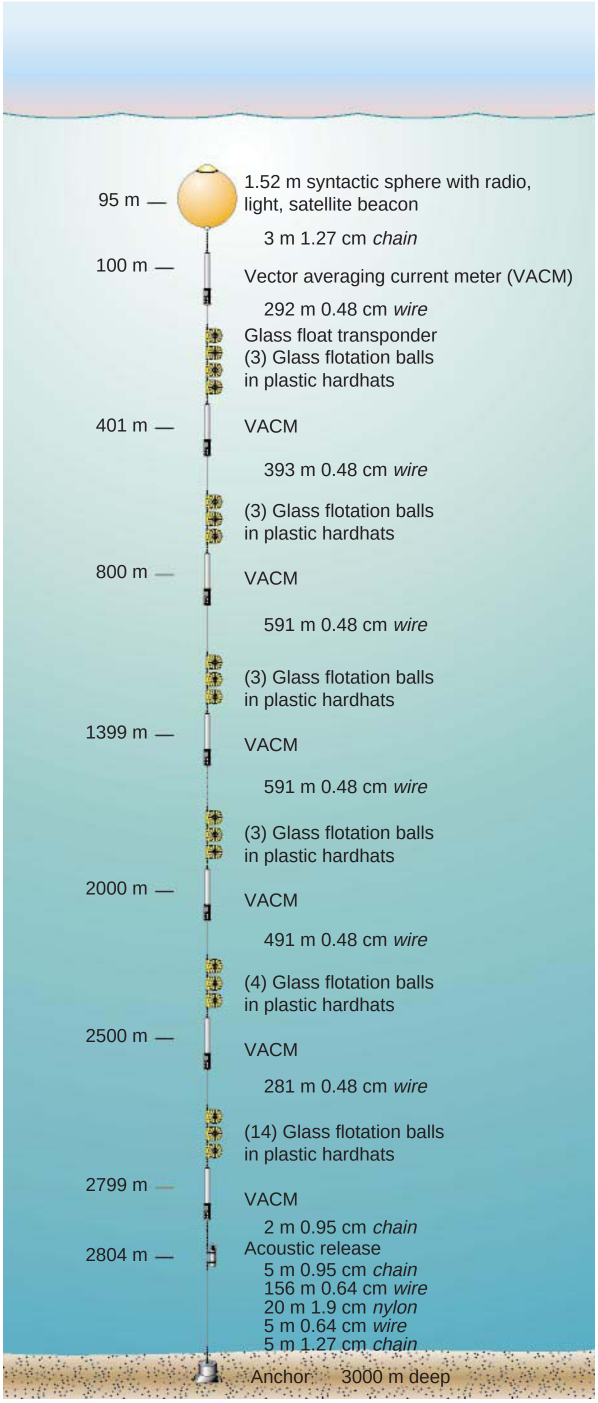

Figure 1 A typical subsurface mooring design. (Design by S. Worrilow.)

Advances in Surface Mooring Technology

Growing interest in understanding interactions between the ocean and the atmosphere has rekindled interest in using surface moorings. The surface mooring is a unique structure. It extends from above the surface to the ocean bottom, providing a platform from which both meteorological and oceanographic measurements can be made in waters that range from shallow to 5 km in depth. Surface-mooring designs must consider the effects of surface waves, ocean currents, biofouling, and other factors that can vary with the time of year, location, and regional climate and weather patterns. The success of a surface-mooring deployment often depends on the abilities both to accurately estimate the range of conditions that the mooring may encounter while deployed and to design a structure that will survive those conditions. The primary goal of any mooring deployment is to keep the mooring on location and making accurate measurements. Adverse environmental conditions not only influence the longevity itself but also impact the instruments that the mooring supports. It is often very difficult to keep the instruments working under such conditions for long periods.

Surface moorings are used to support submerged oceanographic instrumentation from very close to the surface (sometimes floating at the surface) to near the bottom, which is typically 5 km in depth. Measurements of physical properties, such as temperature, velocity, and conductivity (salinity), as well as of biological parameters, such as photosynthetically available radiation (PAR), beam transmission, chlorophyll fluorescence, and dissolved oxygen, are routinely made from surface moorings. The surface buoy also provides a platform from which meteorological measurements can be made and a structure from which both surface- and subsurface-collected data can be telemetered via satellite. Meteorological sensors typically deployed on a surface buoy measure wind speed, wind direction, air temperature, relative humidity, barometric pressure, precipitation, and long-wave and short-wave radiation. The meteorological data are stored in memory and telemetered via satellite to a receiving station ashore. The telemetered data often play an important part in real-time analysis and reaction to conditions on site. The data can also be passed to weather centers for forecasting purposes.

There are a number of different types of surface buoys. Some shapes have been in use since the early days of mooring work, and others are relatively new. Buoy shapes include the toroid or 'donut,' the discus, and the hemispherical hull. The toroid hull in various configurations is widely used throughout the scientific community. Where a significant amount of instrumentation must be supported, a discus buoy of 3 m diameter, with as much as 4500 kg of buoyancy, may be used for both deep- and shallow-water applications. The discus buoy design is widely used by the US National Data Buoy Center in Mississippi in coastal waters, at the Great Lakes stations, and for directional wave measurements. The three-meter discus-shaped hull was also adopted by the Atmospheric Environment Service in Canada for its coastal buoys. Smaller discus-shaped hulls are used for shallow-water applications.

Buoy hulls are made of aluminum, steel, fiberglass over foam, and various closed-cell foams. Several closed-cell foams are extremely resistant to wear and have low maintenance. Ionomer foam and polyethylene foam are common materials for buoy and fender applications. Depending on the material, various outer skin treatments are used to increase the hull's resilience to wear. These include the application of heat and pressure, as well as bonding a different material, such urethane, to the exterior of the hull.

The mooring materials used on surface moorings resemble those used on the subsurface moorings. Component sizes are usually increased to compensate for the larger forces and the increased wear. Materials include chain, plastic-jacketed wire rope, and synthetic line. Chain is used directly beneath the buoy for strength, for ease of handling and, because of its additional mass, for stabilization of the buoy during its deployment. If the water is sufficiently deep and the design permits, the wire rope is usually extended to a depth of at least 1500 m and often as deep as 2000 m for fishbite protection.

The surface mooring needs some form of built-in 'compliance' (ability to stretch) to compensate for large vertical excursions that the buoy may experience during the change of tides and with passing waves and swell. The compliance also compensates for the buoy being displaced laterally on the surface by the drag forces associated with ocean currents and prevents the buoy from being pulled under when such forces are applied. In deep-water applications, compliance is provided through the use of synthetic materials, such as nylon. The synthetic line acts like a large rubber band that stretches as necessary to maintain the connections between the surface-following buoy and the anchor on the bottom.

A challenge in the design process, particularly in shallow water, is to achieve an appropriate mix of compliant materials and fishbite-resistant materials, which tend to be unstretchable. The 'scope' of the mooring—the ratio of the total unstretched length of the mooring components to the water depth – can be one of the sensitive design factors. A mooring with a scope of less than 1.0 relies on the stretch of the nylon for the anchor to reach the bottom. Such a taut mooring remains fairly vertical with a relatively small watch circle (the diameter of the area on the ocean surface where the buoy can move about while still anchored to the ocean bottom), but it carries a penalty: Such a vertical mooring is under considerable tension, or 'preloaded,' at the time of deployment. Currents and waves impose additional

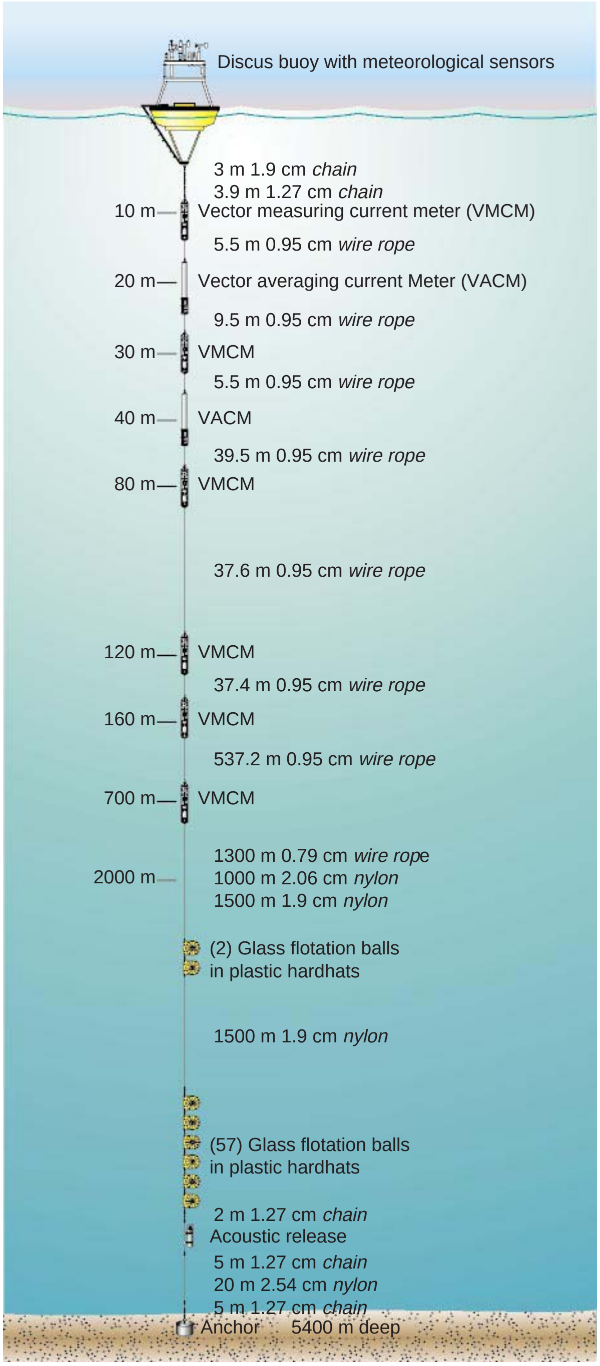

Figure 2 A semitaut surface mooring design. (Design by P. Clay.)

loads beyond the initial preloaded condition. Moorings with scopes between 1.0 and approximately 1.1 are generally referred to as 'semitaut' designs. The mooring shown in **Figure 2** is typical of a semitaut design.

Early surface moorings were designed using only a static analysis program, which used steady-state current profiles as input to predict mooring performance. However, experience has shown that it is necessary to consider the combined effects of strong currents and surface waves. An investigation of the dynamic effects of surface forcing on the performance of surface moorings found that semitaut moorings could have a resonant response to forcing in the range of surface wave periods, causing high dynamic loads. These high tensions limit the instrument-carrying capacity of the mooring and can lead to failure of mooring components.

An alternative design fashioned after the US National Data Buoy Center 'inverse catenary' mooring has evolved in response to difficulties encountered using taut surface mooring designs. With wire rope in the upper part of the mooring and with nylon line spliced to polypropylene line below, the inverse catenary design (**Figure 3**), offers larger scope (typically 1.2) for high-current periods, yet still performs well in lesser currents. In low currents, the buoyancy provided by the polypropylene keeps the slightly negatively buoyant nylon from tangling with the rest of the mooring below it. Thus, the inverse catenary design can tolerate a wider range of environmental conditions. The inverse catenary design lowers the static mooring tension, as shown in **Table 1**. The dynamic tension contribution to the total tension, however, is unchanged, and care must still be taken in the design process to prevent the mooring from having a resonant response to forcing in the range of surface wave periods.

In some regions of the world's oceans, the dynamic loading due to high wind and sea state conditions may be so severe that ultimate strength considerations are superseded by the fatigue properties of the standard hardware components. In these cases, in addition to appropriate mooring design, attention must be paid to the choice and preparation of mooring hardware. Cyclic fatigue tests revealed that, in certain applications, mooring hardware that had been used reliably in the past lost a significant part of its service life owing to fatigue and either failed or showed evidence of cracks. Where possible, different hardware components that are less susceptible to fatigue failure in the range of expected tensions are now substituted.

In situations where there is no replacement hardware available, the fatigue performance is improved by shot peening. Shot peening is a process whereby a component is blasted with small spherical media, called shot, in a manner similar to the process of sand blasting. The medium used in shot peening is more rounded rather than angular and sharp, as in sand blasting. Each piece of shot acts like a small ball-peen hammer and tends to dimple the surface that it strikes. At each dimple site, the surface

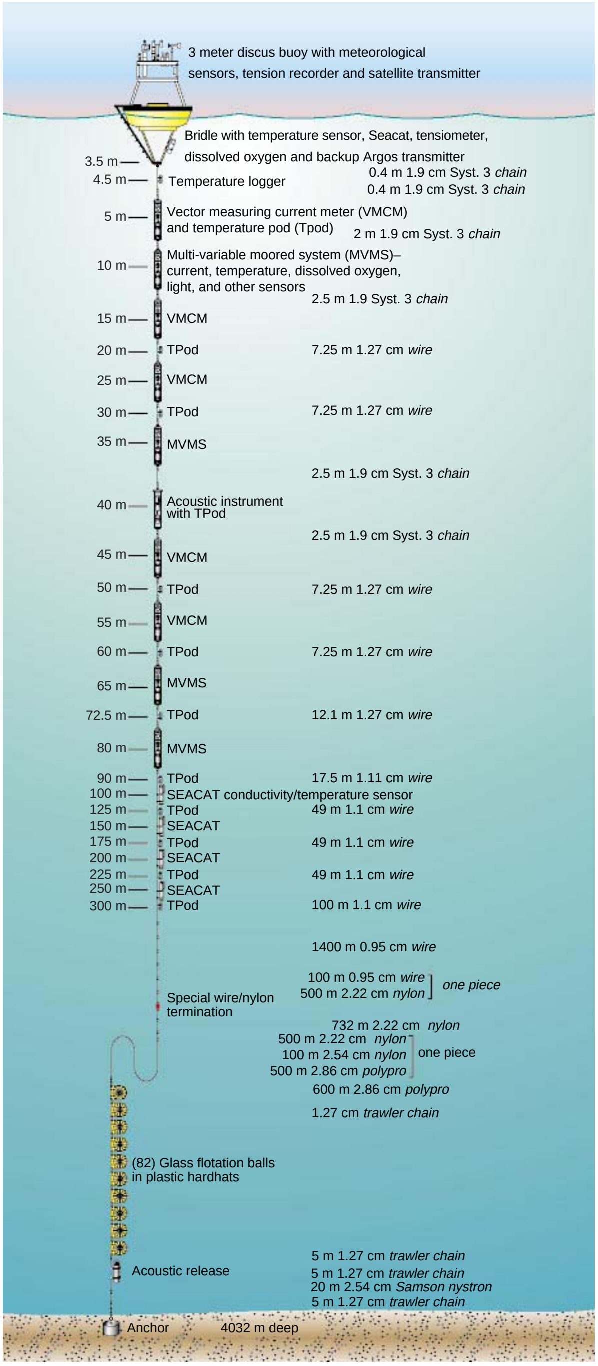

Figure 3 An inverse catenary mooring design. (Design by G. Tupper.)

structure of the material is placed in tension. Immediately below the surface of each dimple, the material is highly stressed in compression so as to counteract the tensile stress at the surface. A shot-peened part with its many overlapping dimples, therefore, has a surface layer with residual compressive stress. Cracks do not tend to initiate or propagate in a compressive stress zone. Since cracks usually start at the surface, a shot-peened component will take longer to develop a crack, thereby increasing the fatigue life of the part.

Table 1 A comparison of semi-taut surface mooring and an inverse catenary design (subjected to the same ocean-current forcing).

	Semi-taut	*Inverse catenary*	*Difference*
Mooring scope	1.109	1.285	
Tension at the buoy	2065 kg	1602 kg	463 kg
Anchor tension	2292 kg	1783 kg	509 kg
Horizontal excursion	1208 m	1735 m	527 m

With both the semitaut and the inverse catenary surface mooring designs, it is difficult to make deep-current measurements because the mooring line at these depths is sometimes inclined more than 15° from vertical. This is a problem for two reasons: First, some instruments fitted with compasses do not work well if the compass is inclined more than 15°; and second, some velocity sensors require the instrument to be nearly vertical. An inverse catenary mooring, with its greater scope, has inclination problems at shallower depths than the semitaut design. **Figure 4** compares the mooring shape of a semitaut design with that of an inverse catenary mooring subjected to the same environment conditions.

In addition to the inclination problem, there is also a depth-variability problem. Compliant members on a surface mooring are usually synthetics, which must be placed below the fishbite zone (nominally 2000 m depth). The deep instruments are, therefore, in line in the synthetics; and their depth can vary by several hundred meters depending on the stretch of the material. A pressure sensor on the instrument can be used to record the instrument depth; but if a particular depth is desired, it is not possible with the conventional design. Hence, the trade-off for being able to withstand a wider range of environmental conditions is a reduction in the depth range for making certain kinds of measurements.

A partial solution to the problem of deep measurements on a surface mooring is illustrated in the mooring design shown in **Figure 5**, which combines features of both the subsurface and inverse catenary type moorings. The upper 2000 m of the mooring are similar to any surface mooring, with the instrumentation at the appropriate depths and wire rope in between. The lower part of the mooring from the bottom up to the 3500 m instrument is

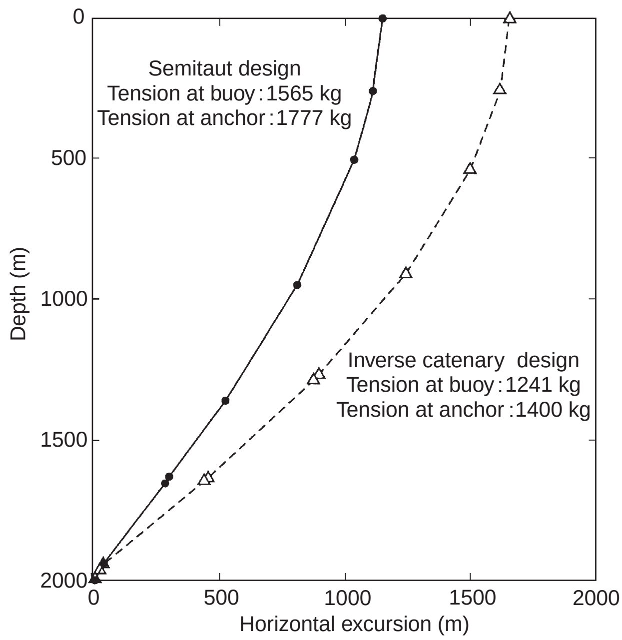

Figure 4 A comparison of the shape of a semitaut design with that of an inverse catenary design when subjected to the same ocean current forcing. Note the differences in buoy and anchor tensions as well as the horizontal excursions at the surface.

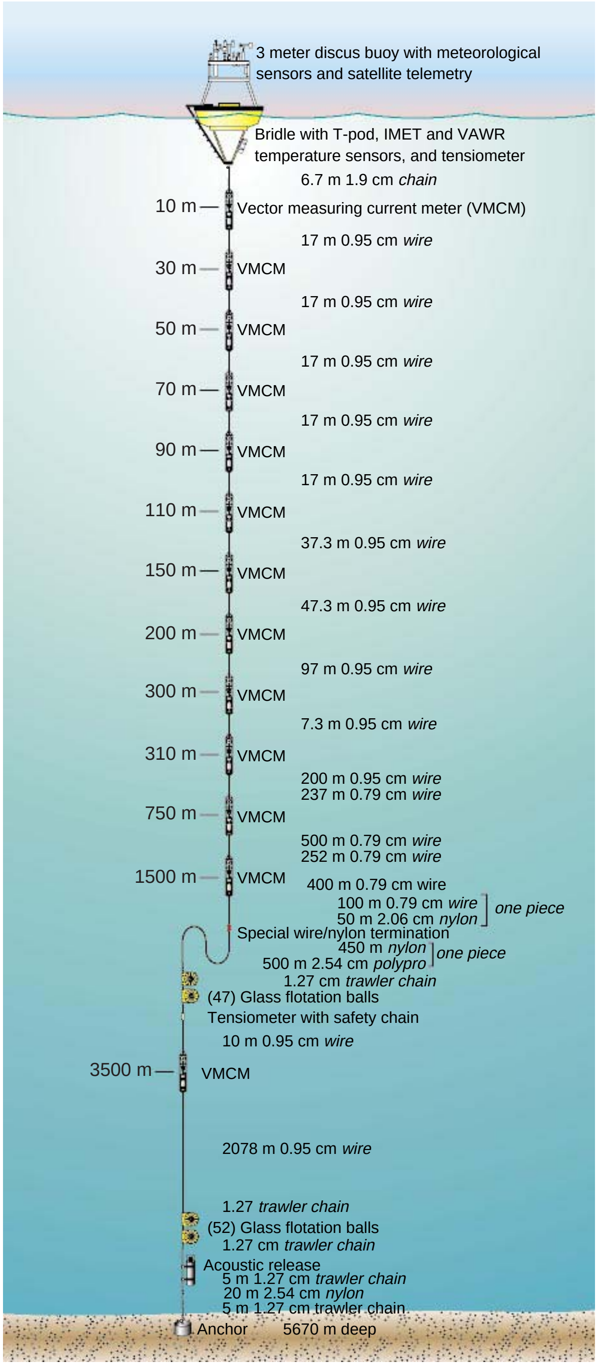

Figure 5 A mooring design that combines the features of an inverse catenary mooring with those of a semitaut mooring in order to improve the quality of deep (3500 m) current measurements made from a surface mooring. (Design by G. Tupper.)

all wire with a cluster of glass ball flotation just above the release near the anchor and one immediately above the 3500 m instrument. The compliance of the mooring consists of 1500 m of nylon and polypropylene inserted between the 3500 m instrument and the base of the wire at 2000 m. The combination of nylon and polypropylene gives the mooring enough stretch (from the nylon) and built-in buoyancy (from the polypropylene) to handle the range of expected current conditions. The polypropylene actually performs a double duty in that during low current periods the buoyant polypropylene keeps the excees nylon from tangling with the lower part of the mooring; when the currents increase, that buoyant member becomes available in the form of extra scope. The shape of the combination mooring design is compared with the shape of an inverse catenary design in **Figure 6**.

Telemetry of data from subsurface instruments on surface moorings is possible through various techniques. One approach is to utilize electromechanical (EM) cable for the transmission of an electrical signal. One type of EM cable has electrical conductors in the center with an outer armor of steel wire that provides strength, as well as fishbite protection of the conductors. These cables are terminated using thermoset resin-poured sockets. Provisions are made in the termination to breakout the conductors so that the electrical connections can be made.

Another EM cable design that has been used successfully is 3×19 oceanographic cable with three conductors laid in the valleys that are formed by the

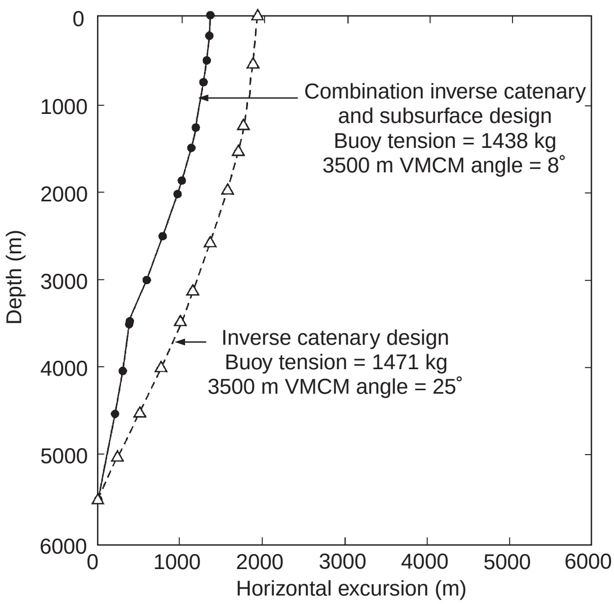

Figure 6 A comparison of the shapes of two mooring designs subjected to the same ocean current forcing, showing the differences in mooring inclination at 3500 m depth.

three strands. The plastic jacket is then extruded over the wire and conductors. The advantage of using the 3×19 wire rope is the ease with which it can be terminated using a swage fitting. The conductors are not swaged with the wire rope, but rather are spliced to a pigtail with an electrical connector and incorporated into a molded strain-relief boot. A disadvantage of this design is that the conductors are on the outside of the strength member and are more susceptible to fishbite damage than in a cable with the outer armor. Use of compliant rubber hoses with electrical conductors inside is another technique for maintaining electrical connectivity where compliance is needed. In such an application the conductors are usually preformed in the shape of a coil so that, as the hose stretches, the coil of conductors lengthens with no damage to the individual conductors.

Mooring Deployments

Deep-ocean surface and subsurface moorings are typically deployed using an anchor-last technique. As the name implies, the anchor is the last component to be deployed. The entire mooring, starting at the top, is put over the side and strung out behind the deployment vessel and towed into position. At the appropriate location the anchor is dropped.

If the current and the wind are from the same direction, the deployment begins by positioning the ship downcurrent of the desired anchor-drop position. By doing this, the ship can maintain steerage as it slowly steams against the current while the mooring components are deployed and are carried away from and behind the ship by the wind and current. When the wind and current are opposing each other it becomes necessary to alter the deployment plan. In such cases, the important factor is the relative speed of the ship with respect to the water. Depending on the length of the mooring, its complexity, and the wind and current conditions, the start position could be as much as 10 km from the anchor-drop position. The goal is to put the mooring line over the side at a rate that is slightly less than the ship's speed through the water and, thus, have the entire mooring stretched out without kinks and loops behind the ship by the time it arrives at the anchor-drop site.

With the ship at the position for the start of the deployment sequence, the upper buoyancy of the mooring is lowered into the water. **Figures 7A** to **7G** illustrate the deployment sequence of a deep-water surface mooring. The mooring components are attached in series and paid out with the assistance of a winch. The ship's speed is typically 50–100 $\mathrm{cm\,s^{-1}}$ through the water. Instruments are attached to the mooring at the appropriate locations between premeasured mooring line shots. The last component put in line is the anchor. The ship tows the mooring into position with the anchor still on deck and actually steams past the desired anchor position by a distance equal to approximately 7–10% of the water depth for a surface mooring and less for a subsurface mooring. Once the ship is beyond the site by the appropriate distance, the anchor is deployed. Either it is slid into the water by means of a steel-tip plate that is elevated on one end causing the anchor to slide off the plate; or the anchor is placed into the water with the use of a crane and mechanically released from the lowering cable once it is just below the surface. As the anchor falls to the bottom, the mooring is pulled under with it. The mooring line takes the path of least resistance, following the anchor as it descends, resulting in the top of the mooring moving toward the anchor-drop position as the anchor falls to the bottom. The normal drag on the mooring line is greater than the tangential drag; therefore, a water-sheave effect takes place as the anchor falls to the bottom. The anchor does not, however, fall straight down but rather falls back a distance equal to a small percentage of the water depth. Experience shows that this fallback for surface moorings is the 7–10% mentioned above. Depending on the design of the mooring, the anchor can fall at a rate of approximately 100 $\mathrm{m\ min^{-1}}$.

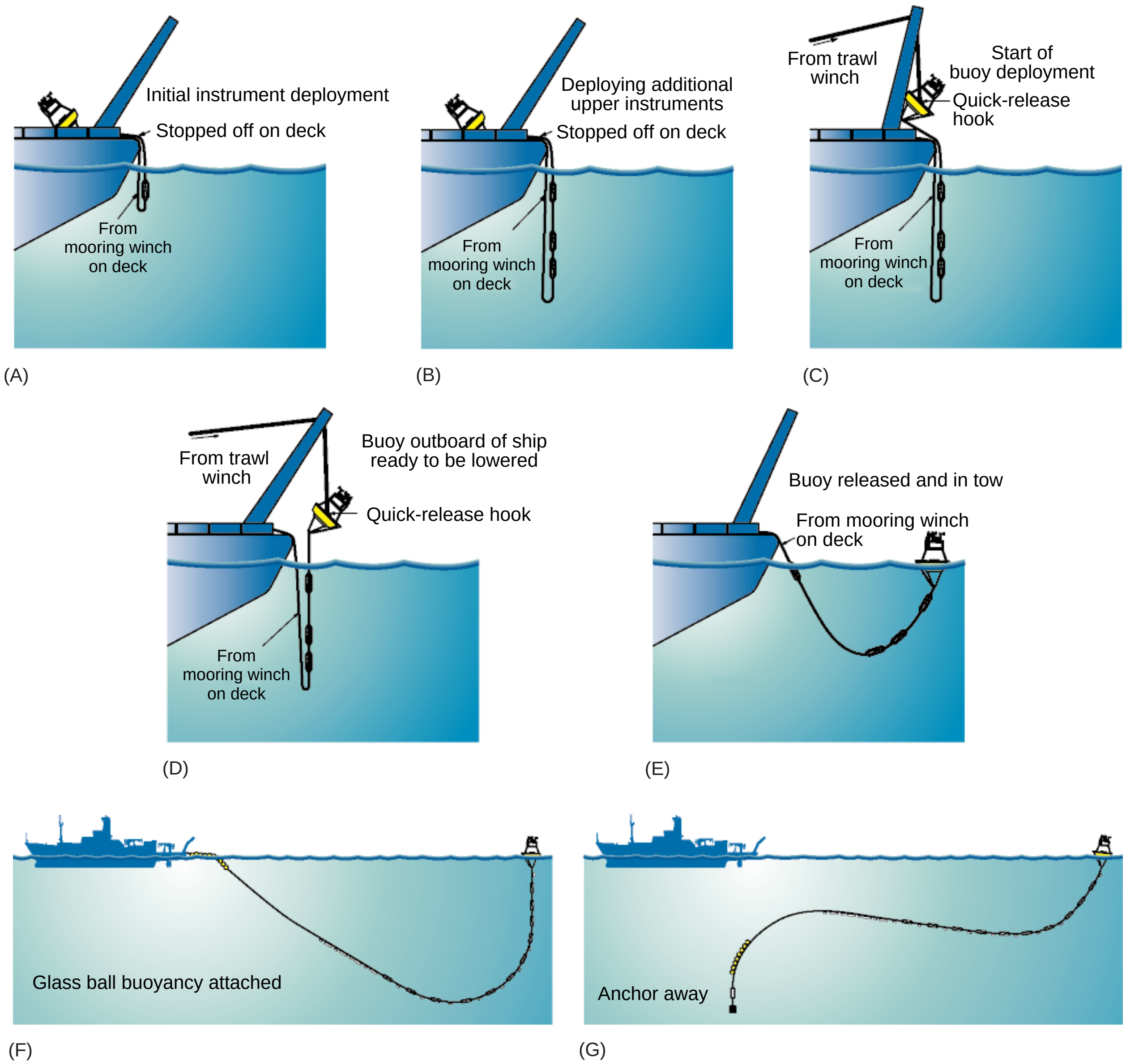

Figure 7 Surface mooring deployment sequence. (A) The first instrument is lowered into the water. (B) Instrumentation in the upper part of the mooring is lowered into the water before deploying the buoy. (C) The upper part of the mooring is attached to the surface buoy. (D) The surface buoy is placed into the water. (E) The ship steams forward slowly as additional mooring line and instrumentation are deployed. (F) The entire mooring is in tow behind the ship as the glass ball buoyancy is deployed. (G) The anchor free-falls to the ocean bottom, pulling the buoy along the surface.

Discussion and Summary

All moorings have similar components, but each design is unique. Factors such as the mooring's intended use, the environment in which it will be deployed, the water depth, the payload it must support, and the deployment period greatly affect the design. Although we have discussed vertical arrays, not all moorings are vertical arrays. For some applications, a U-shaped array (**Figure 8**) is required, or a mooring may require multiple legs to provide stability and to minimize mooring motion. A horizontal mooring (**Figure 9**) may be needed to investigate spatial variability. The ability to model mooring performance both statically and dynamically now permits extensive design studies before the mooring is taken into the field. As a result, it is possible to explore new designs and have greater confidence in how they will perform prior to cutting any wire or splicing any line. It is important to point out, though, that regardless of the amount of time spent designing, modeling, and fabricating a mooring,

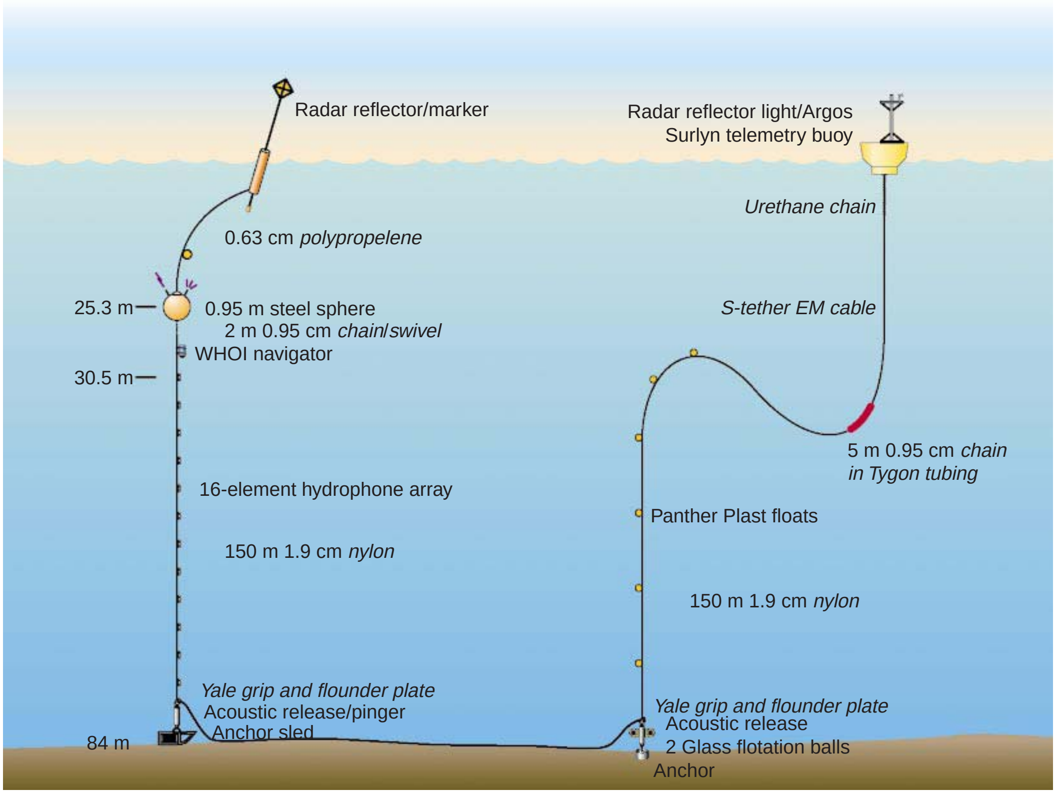

Figure 8 A U-shaped moored hydrophone array. (Design by J. Kemp.)

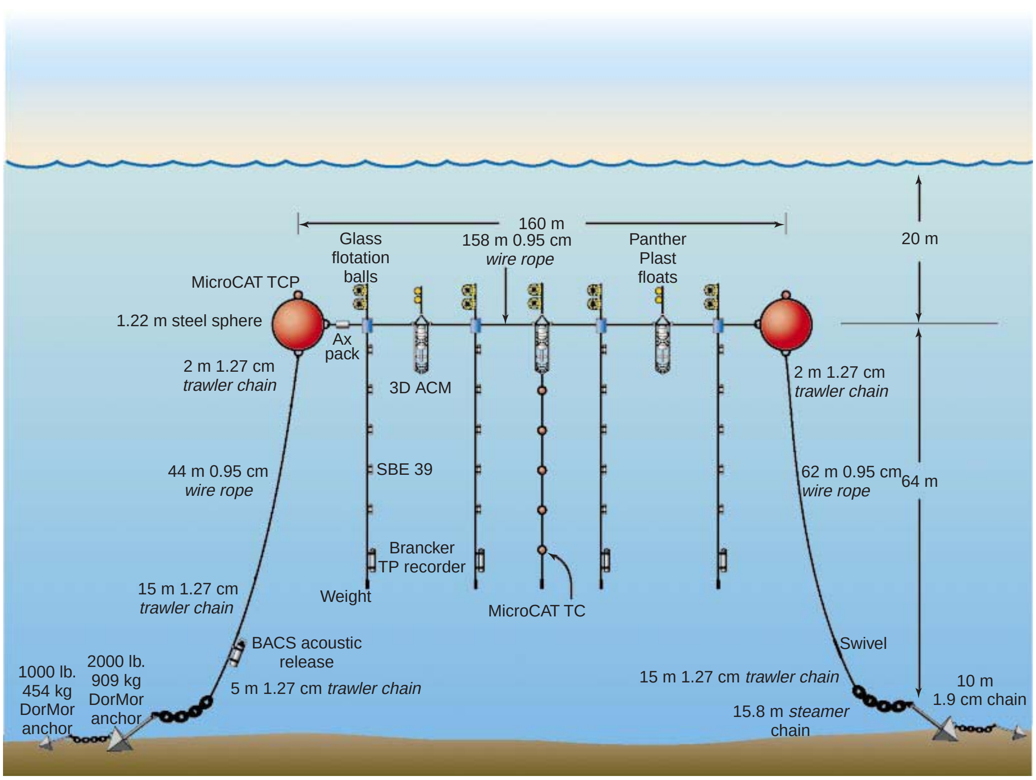

Figure 9 A two-dimensional moored array. (TCP, Temperature, Conductivity and Pressure; BACS, Binary Acoustic Command System; SBE, SeaBird Electronics; ACM, Acoustic Current Meter; Ax Pack, Acceleration package. Design by R. Trask.)

the success of a deployment will often come down to the ability of trained personnel to pay close attention to all the details and to get the mooring safely in and out of the water while working under extremely adverse conditions at sea.

See also

Drifters and Floats.

Further Reading

Berteaux HO (1991) *Coastal and Oceanic Buoy Engineering*. Woods Hole: Henri Berteaux.

Berteaux HO and Prindle B (1987) *Deep Sea Moorings Fishbite Handbook*, Woods Hole Oceanographic Institute Technical Report WHO 87–8. Woods Hole, MA: WHOI.

Dobson F, Hasse L and Davis R (eds) (1980) *Air–Sea Interaction: Instruments and Methods*. New York: Plenum Press.

Warren BA and Wunsch C (eds) (1981) *Evolution of Physical Oceanography, Scientific Surveys in Honor of Henry Stommel*. Cambridge, MA and London: Massachusetts Institute of Technology Press.

MUD FLATS

See **SALT MARSHES AND MUD FLATS**