PROVIDING ELECTRICAL POWER IN CONJUNCTION WITH ELASTOMERIC BUOY MOORINGS

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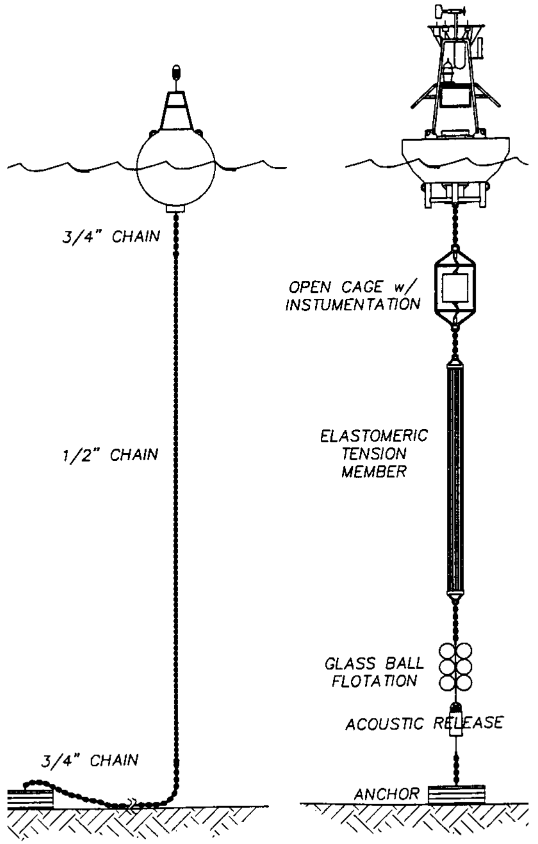
I. Special Mooring Requirements for Buoys in Shallow, Exposed Ocean Sites

A significant amount of oceanographic research is currently performed in 30 to 100-meter water depths. In these areas, wave height can become a significant portion of the water depth, both parameters greatly influence the design of buoy moorings. Aids to navigation buoys and weather buoys in water depths to 100 meters are anchored with all chain moorings. These buoys are large surface platforms with sufficient buoyancy reserve to lift the chain. In protected waters, the chain mooring is deployed with a scope of three to one, while more chain scope is frequently used in fully exposed locations. The extra chain length allows the formation of a cushioning catenary. The catenary results in a desirable horizontal pull of the chain tension at the anchor, when current loading and wave motions of the surface buoy react with the mooring. The surface buoy is raised, lowered, tilted, and rocked by the random motions of the waves; and dragged about by wind and current forcing. Heave motion of the surface buoy is continuously raising and lowering chain, causing severe inter-link abrasion in the chain section with intermittent contact with the sea floor and wear due to dragging along the sea floor. The drag load from ocean currents lifts additional chain off the bottom, thereby changing the shape and elastic characteristics of the catenary mooring.



(a) (b)

Figure 1 – All Chain Mooring (a) and Taut Mooring (b) to anchor buoys in shallow water.

An alternative to employing a chain with sufficient extra length as shallow water buoy mooring is to construct a taut mooring from a material with sufficient stretch to accommodate wave motions of the surface buoy. Both shallow water buoy mooring options are shown in Figure 1. However, large length changes are required in the taut mooring to allow the buoy to heave in waves and move laterally due to current drag. These large length changes are provided by rubber mooring elements, called elastomeric tension members or ETMs. No other material is available which renders the required elastic extensions of 100 percent and more than properly compounded rubber.[1] With a taut mooring, the buoy reacts to surface waves with relatively smooth heave response, and the more violent roll motions are greatly reduced. The much gentler buoy motion significantly increases the survivability of mooring hardware, instrumentation and antennas mounted on

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[1] In deep water taut buoy moorings the rubber mooring element is replaced by much longer lengths of nylon rope. Nylon rope with only eight to 10 percent extension within its working load range has insufficient stretch to accommodate the buoy heave in shallow water moorings.

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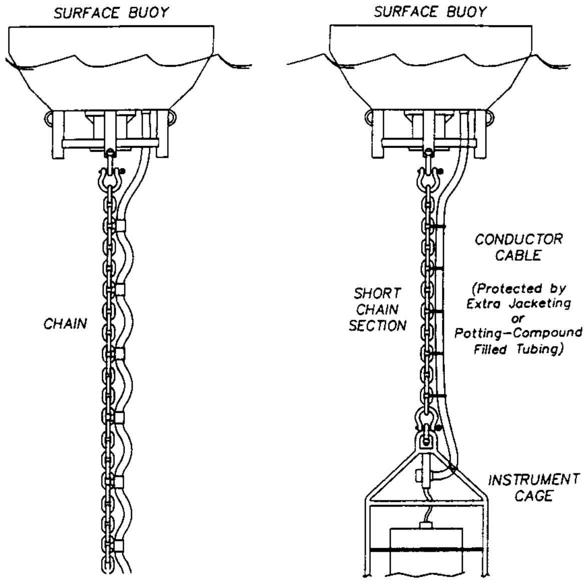
the buoy.

With current technology developments, there is a shift from self-recording instrumentation on buoy moorings which requires ship visits to access data, to near real- time data access through radio, cell phone, and satellite telemetry. Therefore, the development of a reliable conductor between submerged in-line instrumentation and the surface platform becomes highly desirable. However, both the chain and the taut rubber moorings make it almost impossible to accommodate electrical conductors from the surface buoy to in-line submerged sensors. Possible ways to construct a conductor path along the all chain and elastomeric taut shallow-water buoy mooring options are presented below.

II. Electrical Conductor Options

A. Conductor Cable and Chain Mooring: Except for short lengths of a few meters, a chain would have to be equipped with eyelets welded to the outside of individual chain links in order to control the motions and position of a separate conductor cable (see Figure 2-a). The conductor cable would have to be tied to the eyelets with sufficient extra length to allow for chain motion in service. Adequate extra cable length is needed to protect the cable, when the chain goes slack or gets flexed. But too much cable slack leads to early failure due to "flapping" of the cable under wave interaction. The conductor cable has to be both flexible and extremely rugged. The attachment method used to tie the conductor cable to the chain link requires special attention. A conductor link works with a short chain section, shackled to a cage with sensors a few meters below a surface buoy (Figure 2-b). The conductor cable, with sufficient slack, is covered by a protecting hose and connected to the chain with tie wraps. Such assemblies work successfully at sea. The cable connectors plug into the bottom of the surface buoy and the submerged sensor cage junction box below. However the survivability of a conductor cable strapped to a longer length of chain is questionable due to the random and uncontrollable motions of the anchor chain, particularly near the bottom. The least chance to survive, even for short periods of service time, has conductor cable tied to the chain section which is in alternating positions, changing from contact with the sea floor to a suspended location in the water column.

B. Conductor Cable and Elastomeric Buoy Moorings: Oceanographic buoys using Elastomeric Tension Members (ETMs) are anchored with good success in fully exposed shallow water sites, such as George's Bank off the New England coast in 42 to 100 meters of water. Recorded wave heights, which peak at 14 meters at these sites require elastic elongation of the ETM of 100 percent or more, depending on the geometry and pretension of the rubber mooring components and the water depth.



(a)
CONDUCTOR CABLE
EASHED TO LONG LENGTHS
OF ANCHORING CHAIN

(b)
CONDUCTOR CABLE SECURED
TO SHORT CHAIN SECTION
BETWEEN INSTRUMENT CAGE
AND SURFACE BUOY

Figure 2 – Conductor path along long- and short-chain moorings for buoys.

A typical buoy system with ETM mooring elements is shown in Figure 1-b (Irish, 1997). The buoy is equipped with a number of meteorological sensors mounted on the surface buoy, and submerged instruments mounted inside a cage form part of the buoy mooring. A chain section connects to an acoustic release, which in turn terminates in the dead weight anchor block. The 10-meter long ETM is prestretched to half of the maximum wave heights in order to prevent slack conditions when the buoy is positioned in the deepest wave trough [2].

The elastomeric tension member is manufactured from specially formulated NATSYN rubber, and extruded into cylindrical "rode" with one-inch outer

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[2] In the design for 14 meter maximum wave height the pretensioned length at calm water is 10 + 7 = 17 meter. When the buoy is at the top of a 14 meter wave, the extension of the ETM is 140 percent. In typical three-meter sea state the extension at the wave peak is 100 percent.

diameter. The NATSYN rubber rodes have shown good endurance as buoy mooring elements, and retain their elastic properties in service. However, their shortfall is low strength: at 100 percent extension only 200 lbs of tension is developed per element. In order to support the current drag loading of the mooring, six to eight elements are arranged in parallel. The NATSYN rodes are furnished with factory installed eyelet terminations at each end (Wyman, 1982).

A conductor link between the upper and lower termination of the rubber element has to be able to extend the same amount as the elastomeric tension member; 100 percent or more in severe sea state and currents. A solution for this problem is the use of coil cords, which were developed for the SSAR drifting buoys in the GAMOT program.[3] By arranging one of the six or eight NATSYN ETMs in the hollow center of the coil cord, the coil cord is positioned and restrained in the water column.

III. The Coil Cord Design

The coil cords developed for the GAMOT program look like enlarged and very robust telephone handset cables. The coil cord is designed to easily stretch a large distance, and to retract to its original length when the external tension is removed. A view of a coil and section is shown in Figure 3. The coil cord cable consists of the following components: (1) A center strength member constructed as a spliceable braid with circular cross section, made from Vectran high performance fibers. (2) Five heavily insulated #20 AWG conductors, spiralled in a single-served layer around the center strength member. (3) A thick outer neoprene rubber jacket.

During the manufacturing process, the cable with its unvulcanized rubber jacket is spiralled tightly around a one-inch diameter mandrel in 2.5 to 3-meter coiled lengths. Subsequent heat treatment vulcanizes the rubber jacket in its spiralled shape and creates a strong elasticity of the coiled cable assembly. When the load on a tensioned and extended coil cord is suddenly released, the coil cord snaps back vigorously into its tightly coiled position. The ability to retract is paramount to the proper functioning of the coil cord, and is generated by the elasticity of the heavy rubber jacket.

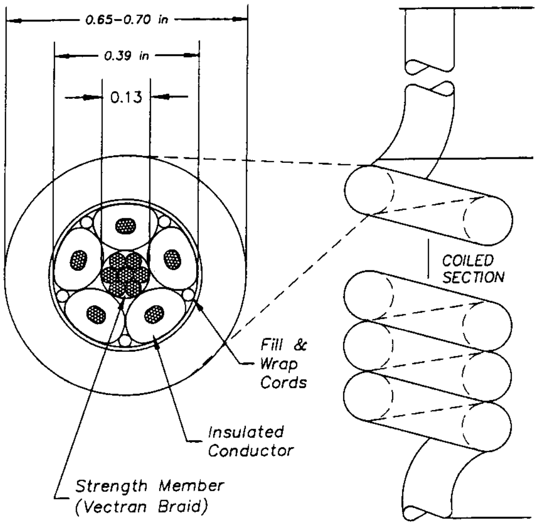

Figure 3 – Side view of coil cord section.

Another feature of the design is the proper wrap angle of the conductor around the Vectran center strength member. The conductors respond to cable stretch by extending their helical spiral – similar to a steel spring or "slinky" – without stressing the conductor wires (Paul, 1995). The conductors are spiralled with sufficient space between wires to permit the coiling of the cable around the mandrel without creating layer blockage on the inside of the conductor assembly. Layer blockage can severely reduce the survivability of the conductor's package inside a cable.

A. The Coil Cord Assembly: The rubber rode of the planned buoy mooring has an unstretched length of 10 meters. Four sections of 2.5-meter contracted coil cord (the longest currently producible length), were joined by electrical and mechanical splices to form the conductor link (see Figure 4). Removed sections of rubber cable jacket in the spliced zones were replaced with suitable material to maintain the flexural and torsional rigidity of the cable.

During tests at the Woods Hole Oceanographic Institution, it was found that due to its spiralled geometry, the coil cord has a tendency to rotate around its axis when water is moving parallel to the coil cord axis. This motion is similar to that of an unrestrained ship propeller. The rotation reverses,

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[3] The SSAR drifting buoy systems were designed to receive acoustic signals from fixed underwater sources several thousand kilometers away. The GAMOT program has the goal to investigate ocean temperature changes and thereby the issue of global warming. The coil cord was developed as the conductor path arranged inside a fluid filled underwater stretch hose, and has proven its endurance in extensive laboratory and sea tests (Paul et al., 1994).

when the water flow direction reverses, which happens due to the buoy response with each passing wave. The 2.5-meter coil cord sections were produced with both left and right-hand spiralled geometry. The sections will rotate in opposite directions (see Figure 5). The overall rotation of the connected coil cord assemblies will be approximately zero when moving up and down relative to the water in contact with the mooring.

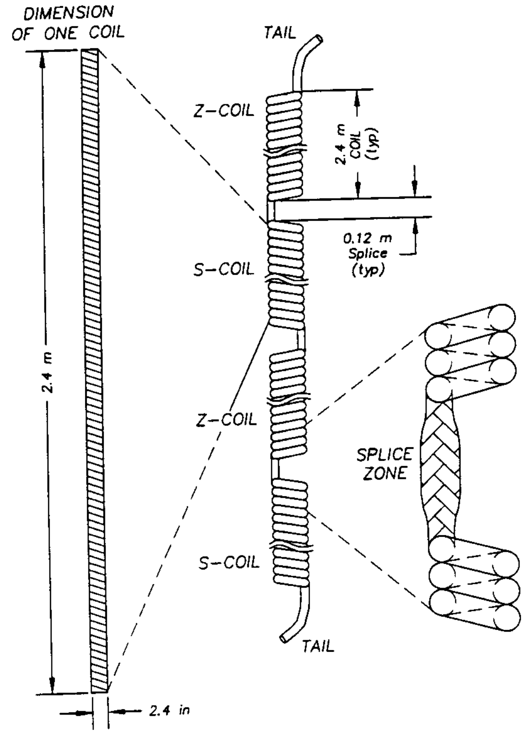

Figure 4 – Coil cord assembly from sections with opposing twist direction.

Calculation of the geometric configuration of the stretching coil cord shows that with up to 200 percent extension the internal diameter of the coiled cord hardly decreases. The enclosed rubber element, however, reduces its diameter considerably, following approximately isochoric behavior. The result is the loss of frictional contact between the ETM and coil cord. In order to prevent the drop of 10 meters of coiled cord assemblies to the bottom termination under gravity forcing, the diameter of the rubber rode is increased sufficiently at the three junction areas of coil-cord sections and attached to the ETM by tape. The diameter increases, built up from rubber tape, reacting as stoppers for the segments. The stoppers should contain the drop within each coiled 2.5-meter long section.

The continued assembly of coil cord elements and a single ETM, forming an electro-mechanical high stretch cable, is shown in Figure 5. The coil cord is spiralled around the rubber rode, positioning the section splice area parallel to its stoppers. Sufficiently long pigtails at the top and bottom end terminate in connectors to the buoy and instrument cage, respectively. Together with five parallel ETMs, the electro-mechanical high stretch cable is forming the electro-mechanical high stretch tension member. The thimbled eye terminations of the rubber rodes are shackled into a common galvanized steel ring at each end, thereby transfering the mooring tension.

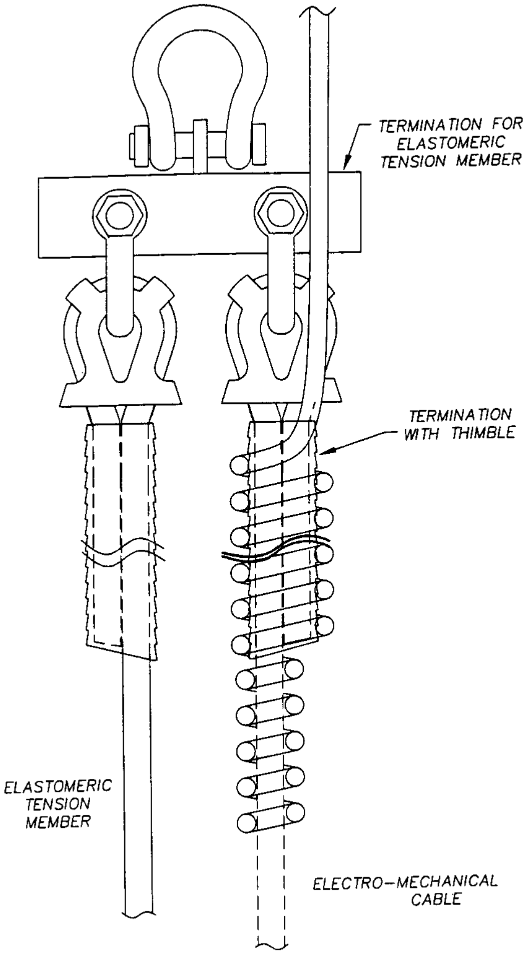

Figure 5 – Termination of elastomeric tension members and coil cord conductors.

IV. The Test Program

A one-month sea test of the high stretch electro-mechanical cable as part of a buoy mooring is scheduled to start in late August 1998. The electrical connection will be used to transfer data from a pressure meter to the surface buoy. At the time of the Ocean Community Conference in November 1998, the results of the sea test will be reported.

The expected survivability of the electro-mechanical high stretch tension member is only moderate. Although the required compliance is easily met by all selected components, the unknown friction and rotation interaction between the rubber element and the surrounding coil cord in severe sea state and high currents has to be determined through testing at sea. It is expected that most likely the ETM inside the coil cord assembly will suffer more severely from rubbing abrasion due to relative motion differences between the two components. If a reasonable service life span can be achieved at sea, then a viable two-way telemetry link (power down and signal back) between submerged sensors and an oceanographic service buoy has been established.

V. Acknowledgements

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