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# TECHNICAL NOTE
# Use of Safe-Moor for Wave-Following Buoys
# January 2020

**Background**:
A common need in coastal engineering and oceanographic studies is the measurement of ocean waves. Knowledge of waves informs many coastal engineering designs: coastal engineering structures, beach nourishment, and many other purposes. Waves cab be measured using a variety of instruments, both *in situ* and remotely. Common amongst these are wave-following buoys moored in relatively shallow water. A key problem identified with these buoys is that moorings fail, leaving the wave buoy to drift, requiring mobilization of resources to retrieve the buoy. Safe-Moor is a rugged, durable mooring element developed in part to provide more reliable wave-following buoy deployments.

A key component to the accuracy of wave-following buoy measurement systems is the use of a near-surface compliant tether. Such a tether allows some degree of extension so the small buoy can follow the surface waves without degradation from the mooring. A suitable mooring element must be not only compliant, but also rugged and durable. Failures of these near-surface compliant members are frequent, given that a wave buoy may undergo six million or so cycles a year, leading to mooring fatigue. Queensland, Australia has documented numerous walk-abouts in their 40-year experience with waverider buoys, due to failure of the compliant mooring elements. Safe-Moor was developed to introduce a technological solution that has proven rugged in the presence of extreme ocean waves, and has proven durable over time frames of a decade.

The ruggedness of the Safe-Moor can be compared visually with a rubber cord produced by a competitor. As the photos show, the Safe-Moor on the right has a rugged stainless steel termination, compared to the lighter termination on the competitor’s sample. The top of Safe-Moor is a swivel termination to eliminate torsion build-up that could reduce the lifetime of such tethers.

Rubber Cord on left panel; Safe-Moor on right panel

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Rubber Cord on left with safety line attached; Safe-Moor on right requiring no safety line because of built-in strength members. Rubber cord has exposed rubber outer skin, whereas Safe-Moor has an engineered, more durable neoprene outer skin.

Safe-Moor is intended to serve the commercial, military, and academic markets for strong, mechanically compliant stretch risers for a variety of applications. Typically available in a 5 meter length, Safe-Moor has a working load stretch of 2.5x its resting length, and a working load tension of about 1200 kg (2500 lb or 12,000N). Safe-Moor can be concatenated either serially to provide a longer mooring line, or in parallel to provide a stronger mooring line.

Typical applications for Safe-Moor include small boat moorings, mooring of seasonal small docks, maritime safety barrier anchorage, various marine environmental monitoring moorings, and compliant members in longer moorings. Developed based on engineering design criteria and methods patented by the Woods Hole Oceanographic Institution, this class of mechanically compliant moorings has a history of decades of at-sea experience. Rugged, compliant mooring elements (risers, rodes, etc.) are key elements of marine installations.

Since one intended use of Safe-Moor is for wave-following buoys of various sorts, the question arises how well Safe-Moor allows buoys to follow ocean waves, compared to competitor tethers. That is the topic of the remainder of this note.

**Modeling**

In order to investigate the use of Safe-Moor for directional wave buoys, computer modeling was performed, comparing how buoys tethered by Safe-Moor respond to waves, compared to a competitor rubber cord that is used in some applications. The modeling was performed using Proteus DS, a flexible ocean dynamic modeling tool used for marine industries. The modeling is performed in the time domain, data from which are then analyzed to extract buoy/wave energy at various wave frequencies.

**Input parameters**

The model input involved various wave periods (5, 7, 12, and 18 sec; equivalent frequencies are 0.2, 0.1429, 0.08333, and 0.0556 hz), using only Airy waves of a single frequency during each model run. This frequency range spans much of the energetic wave spectrum for open oceans and enclosed seas. By modeling these scenarios, the resulting buoy motion can be intercompared, and the ratio of measured wave energies to those input to the model can be used to estimate the transfer function coefficient associated with that wave frequency and that tether. The transfer function tells us much about how wave signal is attenuated or amplified by the mooring characteristics; a value of one is ideal. Superimposed on the waves, and co-linear with the waves, is a 0.5 m/sec steady, depth-independent current.

The waves acted on a simple mooring in a water depth of 30 m. A 15 m elastic tether was attached to the bottom of a wave buoy. Below this tether was a polyline of length approximately 13 m (shorter length allows for pre-stretch of the elastic tether). The waverider was a circular buoy, approximately 0.9 m in diameter, with a dry weight (mass) of 200 kg.

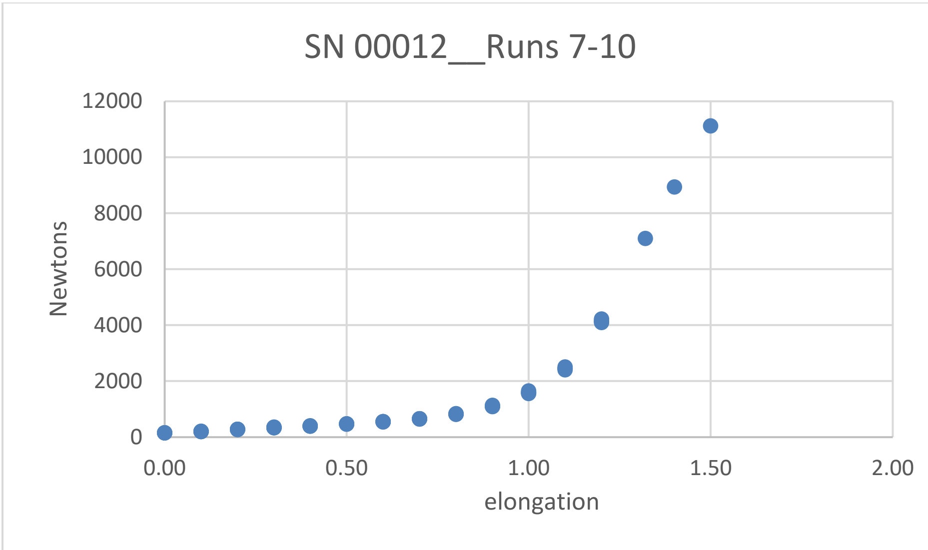
Four tethers were considered. Three are commercially available and commonly used with waveriders: their performance was estimated based on published values of stretch properties of these tethers. Proteus DS permits use of nonlinear stress-strain characteristics to represent how an elastic tether performs. The commercially available tethers have published characteristics shown below:

| **Elongation (%)** | **Force (kg)** | | |
|---|---|---|---|
| | **27 mm** | **35 mm** | **50mm** |
| 0 | 0 | 0 | 0 |
| 100 | 50 | 100 | 300 |
| 200 | 110 | 230 | 800 |
| 300 | 250 | 500 | 2000 |
| 400 | 500 | 1000 | |

This table shows that the thicker the rubber cord, the more tension it takes to achieve a certain elongation. These tethers are highly elastic, as they can stretch to four or five times the original resting length of the rubber cord.

The fourth tether, Safe-Moor, has been tested extensively at the University of Maine's Advanced Structures and Composites Center. Several Safe-Moor hoses were stretched and relaxed repeatedly over time, to determine their stress-strain characteristics. As with any elastic medium with built-in strength members, it takes several stretches to relax the fibers in the hoses. Some hoses were then subjected to cyclical testing to investigate durability, and two hoses were stretched until they parted. The hose testing confirmed the design parameters for these hoses were met. Subsequent field testing of the Safe-Moor confirms its suitability for field use.

The measured stress-strain curve for the Safe-Moor is as follows:




The vertical axis in this case is force in Newtons, which is roughly equivalent to force in kg multiplied by 9.81 (the acceleration of gravity). The hoses were designed to stretch to 2.5 times the resting length, as shown in the graph (the graph shows percent elongation, which is calculated from the total stretch less the resting length). Separation of the hose occurs at roughly 20,000 Newtons.

**RESULTS**:
These four tethers were tested in the configuration described above using Proteus DS, for the four different wave conditions. The table below summarizes the results. DW-50, DW-35, DW-27 refer to rubber cord tethers that are 50mm, 35mm, and 27mm in thickness. Safe-Moor refers to the Safe-Moor product.

Tether type is self-explanatory. Maximum tension is the maximum tension during the wave cycle in the tether itself. Transfer function coefficient is the energy measured by the buoy motion compared to the wave energy input into the Proteus DS model (a value of 1 is optimal). Maximum surge is the maximum horizontal in-line (with waves and currents) excursion of the spherical buoy.

| Wave Period (sec) | Tether type | Maximum Tension (N) | Maximum Tether Length (m) | Transfer function coefficient | Maximum surge (m) |
|---|---|---|---|---|---|
| 18 | DW-50 | 973 | 22.6 | 0.938 | 15.9 |
| | DW-35 | 556 | 23.9 | 0.970 | 17.6 |
| | DW-27 | 355 | 25.9 | 0.984 | 20.6 |
| | Safe-Moor | 460 | 23.8 | 0.975 | 17.1 |
| | | | | | |
| 12 | DW-50 | 887 | 22 | 0.927 | 15 |
| | DW-35 | 516 | 23.2 | 1.079 | 17 |
| | DW-27 | 326 | 25 | 1.094 | 19.3 |
| | Safe-Moor | 420 | 23 | 1.046 | 26 |
| | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| 7 | DW-50 | 902 | 22.3 | 0.878 | 26.3 |
| | DW-35 | 515 | 23.1 | 0.963 | 17.5 |
| | DW-27 | 324 | 24.8 | 0.984 | 20.4 |
| | Safe-Moor | 400 | 22.9 | 0.971 | 16.6 |
| | | | | | |
| 5 | DW-50 | 1113 | 23.3 | 0.871 | 19.7 |
| | DW-35 | 797 | 26.4 | 1.081 | 24.7 |
| | DW-27 | 549 | 31 | 1.092 | 31.7 |
| | Safe-Moor | 618 | 26.5 | 1.141 | 24.7 |

The results demonstrate that the behavior of a tether in a wave environment depends both on the wave characteristics (period in this case) and the non-linear stress-strain relationship of the tether itself.

Of the four tethers investigated, the stiffest is the DW-50; this tether has the poorest transfer function characteristics, particularly at short wave periods. The DW-35 and Safe-Moor have similar characteristics under all waves, in terms of stretch and transfer function performance. The DW-27 also has good transfer functions. As expected, the DW-27 has the highest stretch lengths, under all wave conditions. Consequently, it also has the largest horizontal excursion (watch circle). The DW-50, being the stiffest, has the smallest watch circle.

**CONCLUSIONS**:
Proteus DS modeling shows the Safe-Moor is roughly equivalent to existing mooring solutions for waverider buoys in terms of spectral response to a wide range of waves. Mechanically, the Safe-Moor is a much more robust tether, with a resistant outer cover of neoprene that has proven itself in more than a decade of global oceanographic mooring deployments. This robustness contrasts with the other tethers modeled, which are made of natural rubber with no external coating, as opposed to the rubber/fabric combination used both in Safe-Moor (covered by neoprene) and in radial tire technology.

Safe-Moor is a viable tether for wave-following buoys.

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