MOOS SYSTEM RISER CABLE SPECIFICATION

(synthetic fiber rope) -Preliminary

Revision 3.0

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Rev. 2.1 – 29MAR02 Modified elongation specification and acceptance testing. Specified jacket color. mrc

Rev. 3.0 – 21MAY03 Changed introduction and added "CABLE APPICATION" section to reflect completion of first test mooring and to describe the cable application environment. A. Hamilton

1.0 INTRODUCTION

The Monterey Aquarium Research Institute (MBARI) is currently developing a deep ocean underwater science observatory. The maximum installed depth of the observatory is planned to be 4000 meters deep in seawater. The observatory design includes a wave following buoy system connected to a seafloor anchor with an electro-optical cable strength member referred to as the **Riser Cable**.

The riser cable is recognized as a critical link in the system and in 2002 a development and test cycle was undertaken in which a cable was designed, fabricated by South Bay Cable Corporation, and deployed in 1900 meters of water. Unfortunately, that cable suffered an optical fiber failure during the deployment and then parted completely after eleven days in service. In spite of these failures, a great deal was learned about the environment in which such a riser cable must survive and it is now possible to better characterize the loads that the cable will see during its lifetime. With this new information, MBARI is now setting out to refine the design of the system and deploy a second test mooring (or pair of moorings) in late 2003. When a suitable design is found, it is anticipated that further orders of the same cable construction will follow.

Failure analysis of the first mooring has identified a number of issues with the first deployment (outlined in Section 2.0) and it is hoped that incorporating the lessons learned from the first deployment into the design requirements for the riser cable will lead to a successful second deployment. It is recognized that some of the issues are unrelated to the cable design, and that if these issues had not been present, the riser designed and fabricated by South Bay Cable may well have served admirably in the application. Nevertheless, we feel that sharing our experiences may affect this round of quotations and further improve the final cable design. We are very interested in incorporating our knowledge of the application environment as much as possible into the design of the riser cable.

Because of the high cost of deploying these systems at sea, test protocols that specifically mimic the expected loading conditions of the cable are being developed. These are described in Section 2.0 and it is requested that the quotations include the cost and availability of a test section (50-100m) of the proposed design.

It is MBARI's intention that the cable vendor, not MBARI or its independent contractors, design the cable described in this document. Sections 4.0 and 5.0, represents MBARI's only firm requirements. Items indicated as To Be Determined (TBD) are open to further discussion between MBARI and the vendor.

All information supplied by cable vendors to MBARI in connection with this cable purchase, including proposed designs, estimated performance and cost will be held in strict confidence by MBARI. Non-disclosure agreements can be executed if necessary. For final evaluation of the cable designs specific permission will be requested from the vendor to share the design information submitted with a consultant assisting MBARI with the cable purchase.

2.0 CABLE APPLICATION

The design of the MOOS mooring relies on floatation installed along the riser cable to induce the riser cable to a "reverse catenary" shape shown in figure 1. This shape provides the compliance needed for the mooring to survive the conditions expected at the deployment site, where significant wave heights may exceed 9.5 meters. A dynamic analysis using the Woods Hole Oceanographic Institute's "WHOI-Cable" software has been performed and validated to be accurate to within 10% by comparison to measured tensions in the first deployment. This analysis forms the basis for the following predictions of the axial and bending load environment the cable must operate in.

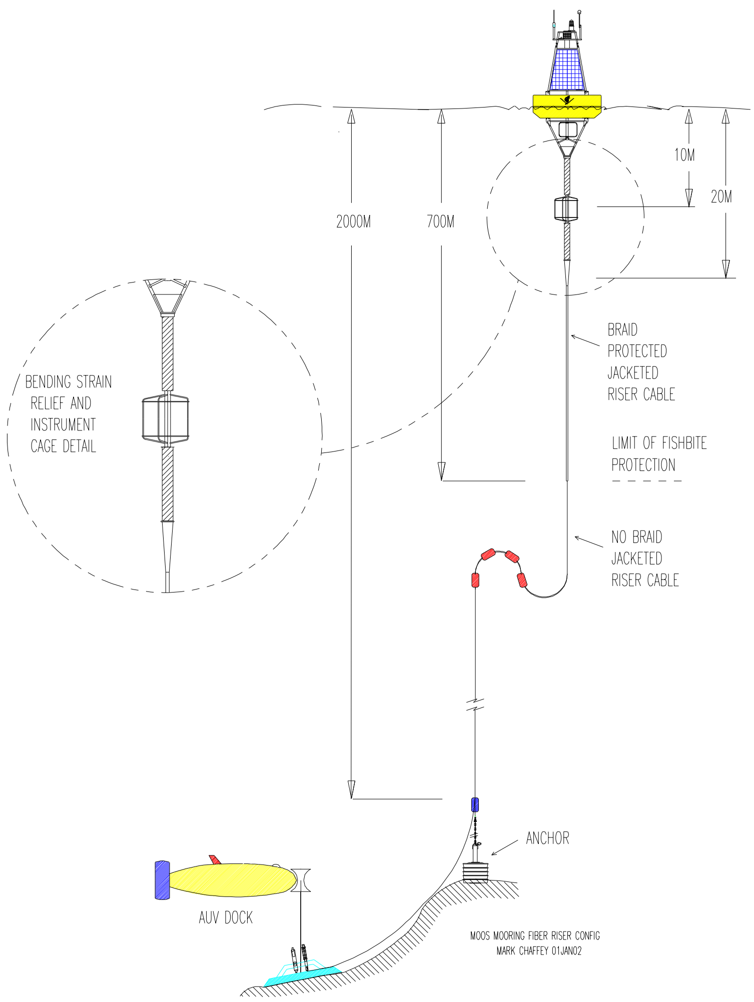

Figure 1: MBARI MOOS mooring design

Axial Loads
The MOOS mooring riser was analyzed for dynamic axial loads induced by wind, current, and seas. The three areas of interest were:

The high energy area beneath the surface float.
The area where the braided cable armor ends (referred to as the fish-bite junction in figure 2).
The area just above the anchor.

In an effort to isolate the riser cable from the high energy zone and related induced cyclic stress and strain, a shock absorbing strain relief system has been designed for the area below the surface buoy (see figure 1). The strain relief consists of a 16 meter long x 4"diameter fuel hose with the EO cable coiled inside in a "coil cord" arrangement with integrated instrument cage. This system has been designed by Woods Hole Oceanographic Institute and has a flange connector to mate with the vendor supplied cable beneath it. The surface energy will be partially absorbed through the stretching and bending of the strain relief, minimizing the amount that the vendor supplied cable will experience. In addition, conventional engineered bending strain relief systems will be utilized at all other "hard point" connections.

The dynamic loads are added to the static loads on the riser due to the weight of the cable, buoyancy-induced tensions, and current-induced tensions.

The dynamic analysis was performed for standard operating "design condition" (the condition that is not exceeded 90% of the time) and "survival condition" (25-year return period storm). The results are summarized in figure 2.

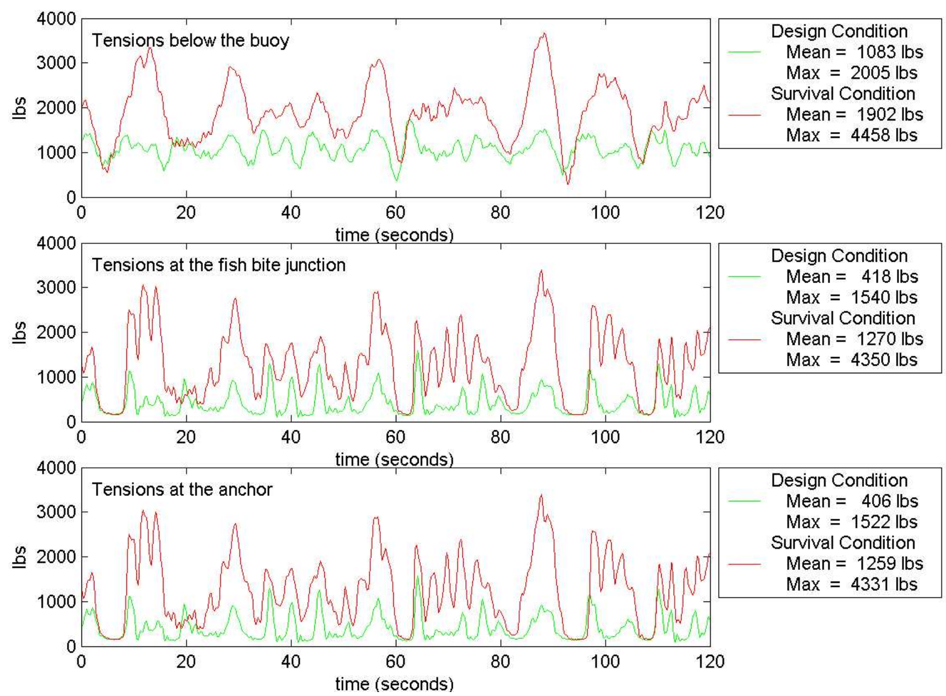

Figure 2: Mooring cable tensions in the design sea condition (green) and in the survival sea condition (red).

Bending Loads
Failure analysis of the first deployment break has led to the conclusion that the cable parting was directly due to repeated, low tension bending at the location of the cable float. Although the cable float attachment mechanism is being re-designed to improve the bending strain relief, it is desirable that the cable itself be as tolerant of these conditions as possible. In order to ensure the suitability of the improved float attachment mechanism and the survivability of the cable, test protocols are currently being developed at Tension Member Technology and at MBARI to simulate a large number of cycles of this expected load condition. In particular, the test is designed to repeatedly bend the cable through a specified number of degrees while modulating the tension such that the tension in the cable is at a maximum when the cable is straight, and drops to near zero at the maximum bend angle.

The WHOI-Cable model provides a prediction of this bending behavior near each float. Figure 3 shows typical results at a float location, the top graph illustrates the predicted angle (from horizontal) of the riser cable just below the float, at the float, and just above the float. It is clear that a significant bend is induced by the buoyancy of the float and that this bend angle changes in time as the surface waves affect the buoy. The middle graph plots the cable bend angle along with the tension in the cable, the inverse relationship between tension and bend angle is evident. The bottom graph plots this relationship between bend angle and tension for this float location in this particular sea state. These results vary with sea state and float location, figure 4 shows the superposition of the bend angle versus tension relationship for all the float locations across the entire range of expected sea conditions. The blue data points are the sea conditions that exist 90% of the time, the red data points are the storm conditions which exist 5% of the time, and the green data points are the very calm conditions that exist the remaining 5% of the time. The black dots indicate the bend-angle versus tension relationship found from static tests performed in MBARI's test tank.
It was this bending of the cable at low tensions, coupled with an insufficient bending strain relief that allowed a small bend radius at the float attachment points, that led to the failure of the first test mooring riser cable. It is felt that enforcing the cables minimum bend radius will allow the cable to survive for the short term, but the fatigue issues related to this repeated bending are also a concern. It is expected that during the three-year life of the system, there will be approximately 10 million bending cycles, 95% of which will be within the blue region of figure 4, and the remaining 5% due to storm events illustrated as red data points. The riser cable and the specified minimum bend radius need to be engineered for this condition. If this is not possible for the bending-tension relationship shown in figure 4, it is possible to reduce the maximum bend angle at each float by reducing the buoyancy of each float. This will increase the number of floats required and cause some operational inconvenience, but it is a possibility if the fatigue life of the cable due to bending is in question.

Finally, because the cable may occasionally (and unavoidably) go into a zero tension condition, it is felt that in general, the stiffer the cable the better. Of course the need to store the cable on a drum sets a practical upper limit on the cable stiffness. The computations leading to figure 4 are based upon a cable stiffness similar to that in the first test mooring cable. The cable dynamics model can be easily re-run for a different cable stiffness if this is helpful in the design process.

Currently, test equipment to simulate the bending versus tension relationship shown in figure 4 is being developed at Tension Member Technologies and at MBARI. This equipment will be used to verify the bending strain relief's ability to enforce the required minimum bend radius and ultimately to demonstrate the long-term survivability of the cable under these repeated bending conditions.

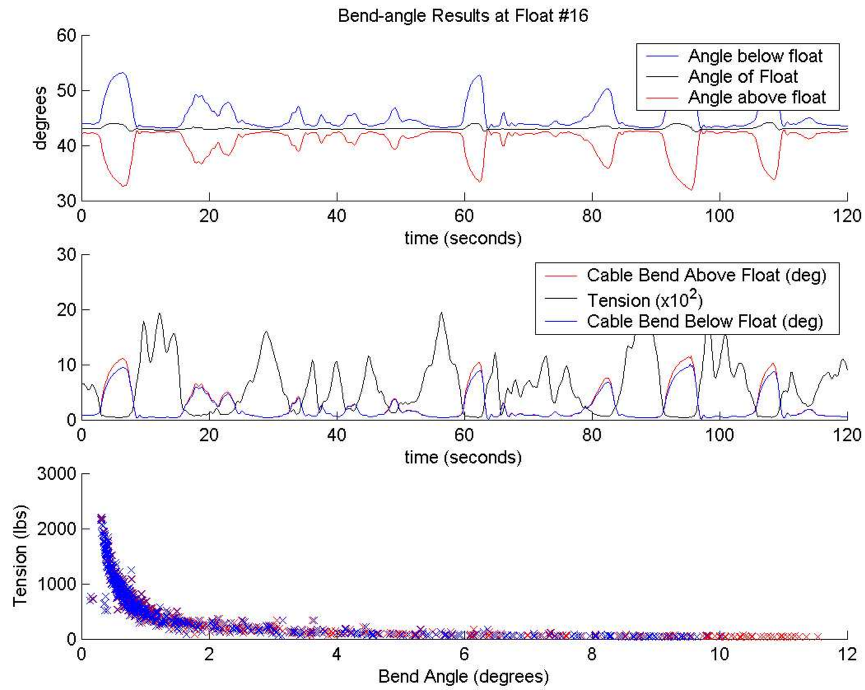

Figure 3: Cable bending at float location, 3 meter significant wave height.

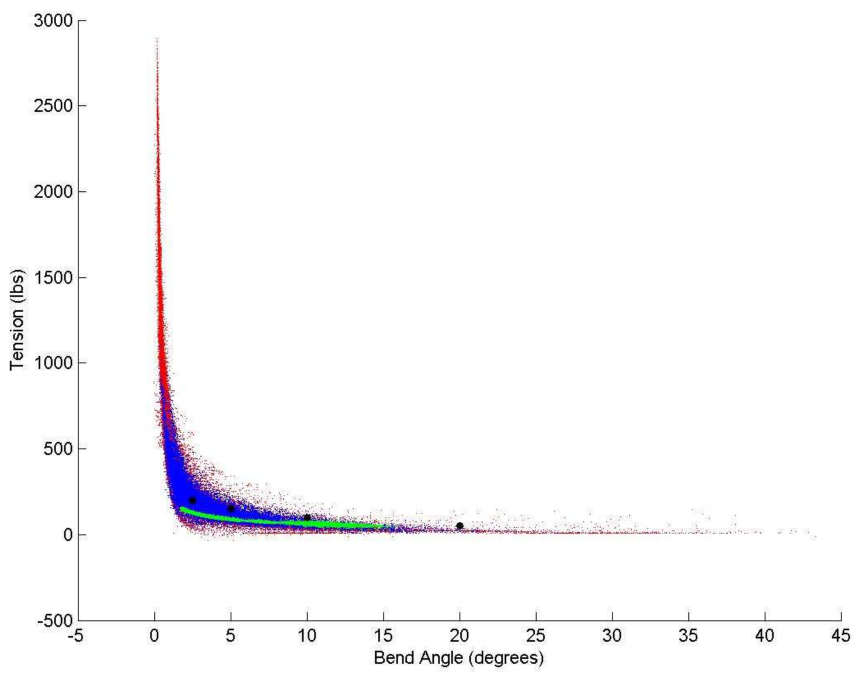

Figure 4: Tension versus bend angle for all sea conditions, note near-zero tensions at significant bend angles.

3.0 CABLE PROPOSAL REQUIREMENTS.

Prospective vendors are invited to submit proposed cable designs and should include the following information:

3.1 Design and estimated performance documentation.

3.1.1 Description of the cable construction materials, approximate sectional dimensions and illustration for both fishbite protected and non-protected cable cross-sections (see fishbite protection section below).

3.1.2 Cable weight per meter in air and seawater for both fishbite protected and non-protected cable cross-sections.

3.1.3 Estimated axial stiffness of the cable (EA) seawater for both fishbite protected and non-protected cable cross-sections. Load vs. strain curve should also be included.

3.1.4 Estimated strain induced rotation of the proposed cable design.

3.2 Cable cost.

3.3 Cable delivery time ARO.

3.4 Availability, cost, and delivery time for sample sections (~50-100 meters) of the proposed design.

4.0 CABLE CONSTRUCTION REQUIREMENTS.

4.1 **Length.** Cable shall be delivered in a continuous length of <u>**2500 meters**</u>. A minimum of five meters shall be accessible at both ends of the cable to allow for testing on the shipping drum. Because the overall system is being designed for 4000 meter water depths, the design should not limit the ability of the vendor to make a 5000 meter length at a later date.

4.2 **Strength member.** The cable strength member shall be synthetic fiber consistent with a minimum seawater weight and good fatigue life over the service life.

4.3 **Fishbite protection.** Section of cable shall be protected as shown in figure 5 with a braided stainless steel wire layer or layers.

4.4 **Jackets.** All sections of the cable shall be jacketed with a non-conductive polymer jacket to protection and to allow the operation of inductively coupled data modems on the riser cable. The outer jacket color shall be BLACK for the fishbite protected section and YELLOW in the non-fishbite protected section (inner jacket). The jacket shall be free of any skips or gaps that would expose the armor to seawater except where shown in figure 5**,** at the exposed end of the fishbite protection armor braid. In the first deployment, the polyurethane cable jacket suffered several small nicks and abrasions after some rough treatment during recovery. It was felt that the polyurethane was only marginally tough enough to withstand the deployment and recovery process.

5.0 CABLE PERFORMANCE REQUIREMENTS.

5.1 **General and Environmental.** The riser cable performance shall not be degraded by conditions typical of the working environment, including:

5.1.1 Continuous submergence in seawater over working life.

5.1.2 Temperatures from 0 to 25 degrees Centigrade.

5.1.3 Hydrostatic pressure equivalent to 4000 meters seawater (6000 psi).

5.1.4 Service Life. The Riser cable shall provide a minimum of three years of service while continuously submerged in a dynamic ocean environment (see section 2.0).

5.2 Mechanical

5.2.1 Diameter and weight (minimize)
In general, the cable diameter and weight affect the rest of the system and should be minimized. However, the highest priority is weight in water and resistance to damage from bending. If improvements in either of these can be achieved at the expense of a slightly larger cable, then this is to be preferred.

5.2.2 Working Strength 6000 lbs.

5.2.3 Breaking Strength 30000 lbs. minimum.

5.2.4 Elongation. The strain on the optical package in the cable is not to exceed 0.65% at 6000lbs. load including initial constructional stretch.

5.2.5 Rotation. The mooring design does not include a swivel, therefore it is important that the cable be torque balanced as much as possible and strain induced rotation shall be minimal in keeping with good design practice.

5.2.6 Minimum Bend Radius. TBD. Needs to be storable and deployable from a drum.

5.2.7 Fatigue Life. The cable materials and construction shall be suitable for the dynamic loading of continuous operation as a buoy mooring cable. Section 2.0 describes the expected cyclic bending and loading conditions in detail.

5.2.8 Packaging: standard cable reel suitable for shipping.

5.3 Optical

5.3.1 <u>Fiber Count</u>. There shall nominally be **<u>four</u>** single-mode optical fibers. Fibers shall be Corning "Titan SMF CPC5" or other suitable fiber selected by cable vendor. Use of alternate fiber shall be by written agreement between vendor and MBARI. The optical specifications must be met over the specified cable service life during continuous operation under the conditions described in the "General and Environmental" and the "Mechanical" sections above.

5.3.2 <u>Optical Attenuation</u>. Attenuation in each fiber shall not exceed the following values under cable working conditions (see mechanical specifications for working condition values):
0.7 dB per kilometer at 1310 Nm. wavelength
0.7 dB per kilometer at 1550 Nm. wavelength

5.3.3 <u>Optical Attenuation Uniformity</u>. No single point attenuation discontinuity in any fiber in the finished cable shall be greater than 0.15 dB at either 1310 Nm. or 1550nm. wavelengths, as measured with an OTDR.

5.3.4 <u>Optical Dispersion</u>. Individual fiber specifications for optical dispersion in the completed cable shall meet the pre-cabled fiber manufacturer's specifications for the fiber used, as measured by EIA/TIA 455-175.

5.3.5 <u>Fiber Proof Test</u>. Individual fibers will be proof tested at the time of manufacture to a minimum of 150kpsi.

5.3.6 <u>Fiber Identification</u>. Fibers or their over-jacketing shall be color coded or otherwise indelibly marked at least every meter for identification.

5.4 Electrical

5.4.1 General. The cable will be used for electrical power transmission while submerged in the marine environment. The cable shall provide a minimum of two electrical conductors insulated from one another, and from seawater.

5.4.2 Working Voltage. The cable will be used at a working voltage between conductors, or between conductors and seawater, of up to 425 Volts DC. At this voltage, the maximum electrical stress present at any point in the cable insulation system shall be less than or equal to 2.0 kV/mm (51 volts/mil). The insulation system used must be suitable for continuous high D.C. electric field stress.

5.4.3 Insulation Resistance. The Insulation Resistance of each conductor in the as-built cable shall be a minimum of 3,000 Megohms per kilometer, measured at the working voltage of Section 5.4.1 above. The resistance shall be measured between the test conductor, and the other conductor(s) plus the cable armor plus any other metallic cable elements, tied together.

5.4.4 Conductor Resistance. The cable will be used at a working current of up to one ampere per conductor. The maximum as-built, as-cabled, round trip (two way) resistance of the two cable conductors in series shall be a maximum of 8.6 ohms per kilometer (nominally 4.3 ohms per kilometer per conductor, although equal resistances are not required), measured at a conductor temperature of 20 degrees C. The as-built conductor resistance shall have a tolerance of +/- 5%.

5.4.5 Production Testing. Each individually insulated conductor shall be tested for insulation resistance, before cable assembly, in a water bath. The test conditions and criteria for acceptance shall be as specified in Section 5.4.2 above. The completed cable shall be evaluated for Partial Discharge at the working voltage of Section 5.4.1 above. No detectable discharge is permitted, within the detection limits of the test equipment employed.

5.4.6 Conductor Identification. The individual conductors shall be color coded or otherwise made visually distinguishable from one another, either throughout their length, or at regular increments not to exceed 0.33 meter.

6.0 CABLE QUALIFICATION TESTS.

The cable manufacturer shall perform the following test at manufacturer expense and forward the results to MBARI prior to final acceptance by MBARI of the completed cable.

6.1 Strain on the optical package at 6000lbs. cable tension. The cable shall be tensioned to 6000 lbs. and the elongation of the optical package measured over ten cycles from 0 to 6000lbs. The total elongation due to initial constructional stretch and load strain on the cable shall not exceed 0.65% on the first through the tenth load cycle. Failure to meet this requirement is cause to reject the cable.

The following tests will be performed by MBARI or an independent test contractor at MBARI expense prior to final acceptance of the cable. Failure to meet the specified Cable Performance Requirements in section 4.0 is cause to reject the cable.

6.2 **Electrical.** A riser cable specimen will be subjected to conductor resistance and insulation resistance tests to obtain the as delivered values.

6.3 **Optical Static Attenuation.** The riser cable will be tested for optical attenuation at 1310Nm and 1550Nm wavelengths to obtain the as delivered values.

6.4 **Optical Characterization.** The optical attenuation in response to tensile loading will be measured.

6.5 **Mechanical Characterization.** A riser cable section will be tested for tension induced changes in elongation, diameter, torque and rotation. The riser cable will also be tested for yield and breaking strength, and for susceptibility to damage by repeated bending as described in Section 2.0.

7.0 DELIVERY.

Delivery shall be quoted FOB destination, Moss Landing, California, 95039. Cable shall be delivered suitably packaged for transportation and storage.

Cable shall be delivered in a continuous length. The anchor end of the cable (the end without the fish-bite braid) shall on the outside of the shipping drum and a minimum of five meters shall be accessible at both ends of the cable to allow testing on the shipping drum.

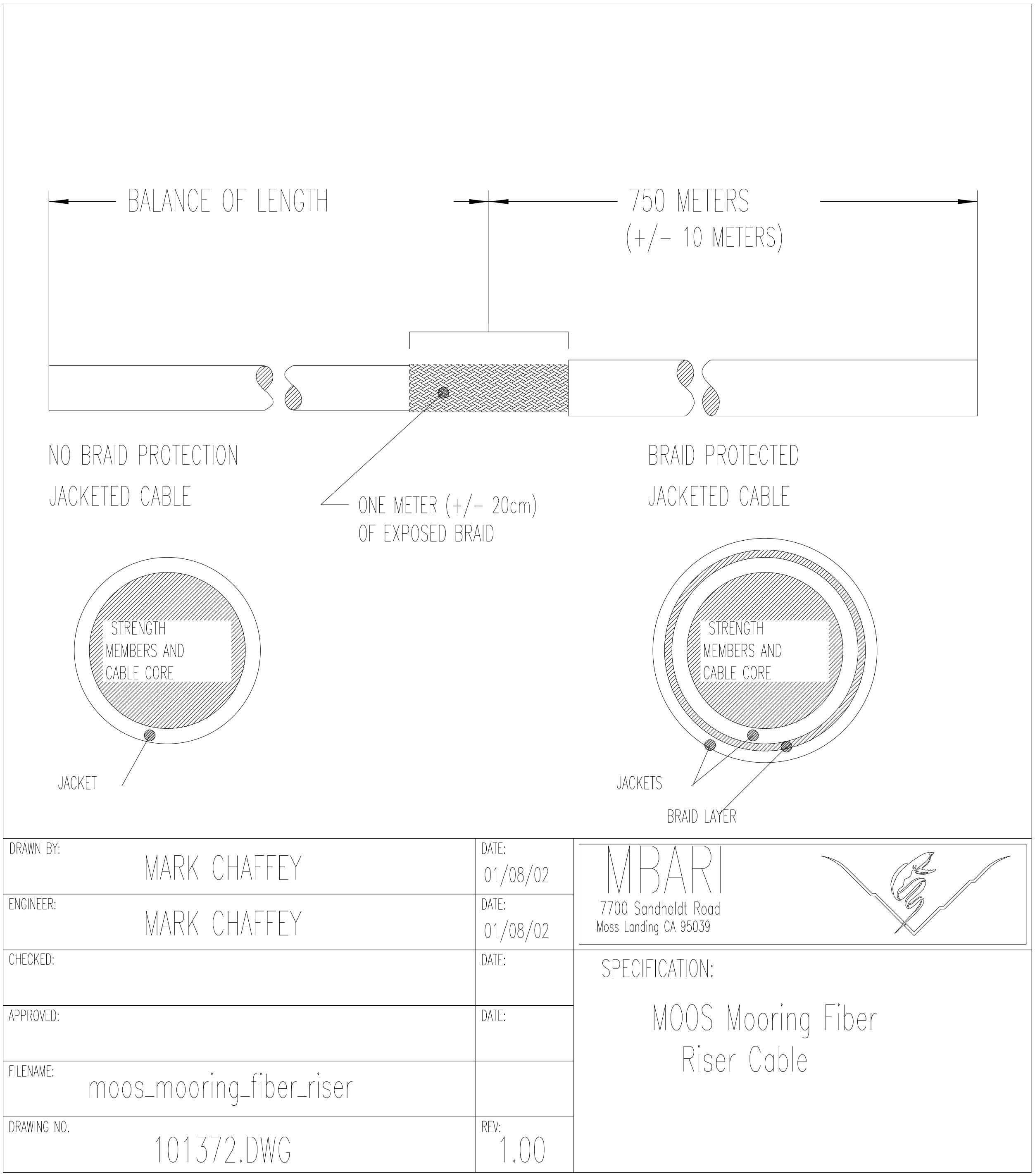

Figure 5: Schematic of riser cable construction