Loading Conditions and Design Requirements for CRP Riser Floatation and Bending Strain Relief

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1. Mooring Configuration and Dynamic Modeling

As shown in figure 1, the MOOS Mooring is an inverse-catenary mooring made up of a high-modulus electro-optical-mechanical cable which anchors a buoy in 1500 meters of water. Because of the high stiffness of the mooring cable, a 24 meter long elastic "snubber" element is included below the buoy to provide the required compliance in the system. This document outlines the expected loading conditions at the four bending strain relief's (BSRs) in the system; One at each end of the floatation element, one at the sub-sea connection, and one at the topside-connection between the snubber element and the EOM cable.

Dynamic analysis of the system has been performed using the Woods Hole Oceanographic Institutes cable dynamics software. The riser response in the expected wind, wave, and current conditions has been simulated and these results used to estimate the expected loading conditions.

Static Results (steady current and wind, but no waves)

The 27 meters of Linksyn syntactic-foam modules provides 400 lbs of buoyancy and induces the configuration shown in Figure 2 for maximum and slack currents. This result is a static result (no waves).

Of particular interest in designing the bending strain relief's is the relationship between the tension in the cable and the bend angle for which the BSR must maintain a minimum bend radius in the cable. Figure 3 shows the estimated bend angle of the cable versus the tension in the cable just above the LinkSyn floatation for the range of currents. In the static conditions, there is very little bending at the BSR's below the LinkSyn, at the BSR above the sub-sea connection, and/or below the topside connection.

Dynamic Results (waves included)

The wave conditions that are likely to be present at the deployment site range from calm conditions to significant wave heights of 9.8 meters in the "25 year" storm condition that the system is designed to survive. The wave conditions cause motion and low-tension points in the riser that increase the demands on the bending strain relief's beyond the static conditions. Also, the wave motion introduces bending at the sub-sea and topside connection.

In order to visualize the results of the dynamic modeling, animations of the predicted motion of the LinkSyn elements and the topside connection are included with this document as .avi files. These simulation runs model the effects of large waves with relatively small currents, this is viewed to be the most demanding situation as strong currents tend to stretch the system out and minimize bending at each transition (see Figure 2). All wave conditions are approximated by a Pierson-Moskowitz spectrum with the indicated significant wave height.

The files are organized as follows:

Filename	Location	Significant Wave Height	Surface Current
24mSnubBRBendResults-2.25.avi	Above Bend Restrictor	4.5 meter	15 cm/sec
24mSnubBRBendResults-4.25.avi	Above Bend Restrictor	8.5 meter	15 cm/sec
24mSnub-BendResults-2.25.avi	Bottom of Snubber	4.5 meter	15 cm/sec
24mSnub-BendResults-4.25.avi	Bottom of Snubber	8.5 meter	15 cm/sec

Figure 4 shows the bend estimate above the LinkSyn versus tension for a particular wave condition; as expected, when the tension in the system is high, the bend restrictor is pulled straight but when the tension drops, the floatation causes the bend angle in the cable to increase. It's this bending during which the BSR must maintain a minimum bend radius in the cable.

Because the bend behavior varies with sea condition, the results for all expected sea conditions must be considered. The next section show the conglomerate bend versus tension results that each of the bend stiffeners must tolerate. The model results are shown and a specification that includes a factor of safety is specified for each bend restrictor.

2. Floatation Bend Stiffeners

Above LinkSyn

Figure 5 shows the bend versus angle relationship for all expected sea-states. The red points indicate the worst 5% conditions, the green points indicate the calmest 5% conditions and the blue points are conditions that exist 90% of the time. The BSR at this location shall be designed to maintain a minimum bend radius of 1m for all conditions below the T = 1000/theta line shown.

Below LinkSyn

The bend restrictor below the LinSyn modules is always in tension and hence never sees significant bending, as seen in Figure 6. The most severe conditions are likely to happen during staging and deployment, when a tug on the cable by an operator should not over bend the cable.

Mounting

These bending strain relief's shall be split such that mounting to the Linksyn modules is possible as the LinkSyn modules are attached during the mooring deployment (Buoy first, anchor last).

3. Topside and Sub-Sea Bend Stiffeners

Topside Connection

Figure 7 shows the tension versus angle relation for the topside connection below the snubber. The BSR at this location shall be designed to maintain a minimum bend radius of 1m for all conditions below the T = 3000/theta line shown.

Sub-Sea Connection
Figure 8 shows the tension versus angle relation for the sub-sea connection above the anchor. The BSR at this location shall be designed to maintain a minimum bend radius of 1m for all conditions below the T = 1250/theta line shown.

Mounting
It is not required that the topside and sub-sea connection bending strain relief's be a split bend stiffener design. These units can be installed before termination of the cable if that simplifies the design and manufacture. These BSR's will mount to the synthetic cable terminations, which are a socket-cast style termination. A flange mount of appropriate size has been used in the past but this is not a design requirement.

4. Mooring Cable Specification
The mooring cable itself is a Vectran cable manufactured by JDR Cable Systems in the Netherlands. The upper 700 meters of the cable has a steel braid that acts as fish bite protection. This increases the diameter to 34.5 mm, compared to a diameter of 28 mm for the lower, unarmored section. The minimum bend radius specified by the manufacturer is ~ .5 meters. Because the LinkSyn system will hold a minimum bend radius of 1m, it is felt that the bending strain relief's should also hold a minimum bend radius of at least 1m when subject to the loading conditions outlined in Section 2 and 3 above.

Note: I am currently inquiring of JDR permission to pass along to CRP a drawing outlining the general construction of the cable. Regardless of how this works out, I can supply a sample length of a cable that is very similar to the cable used in the mooring application. --ah

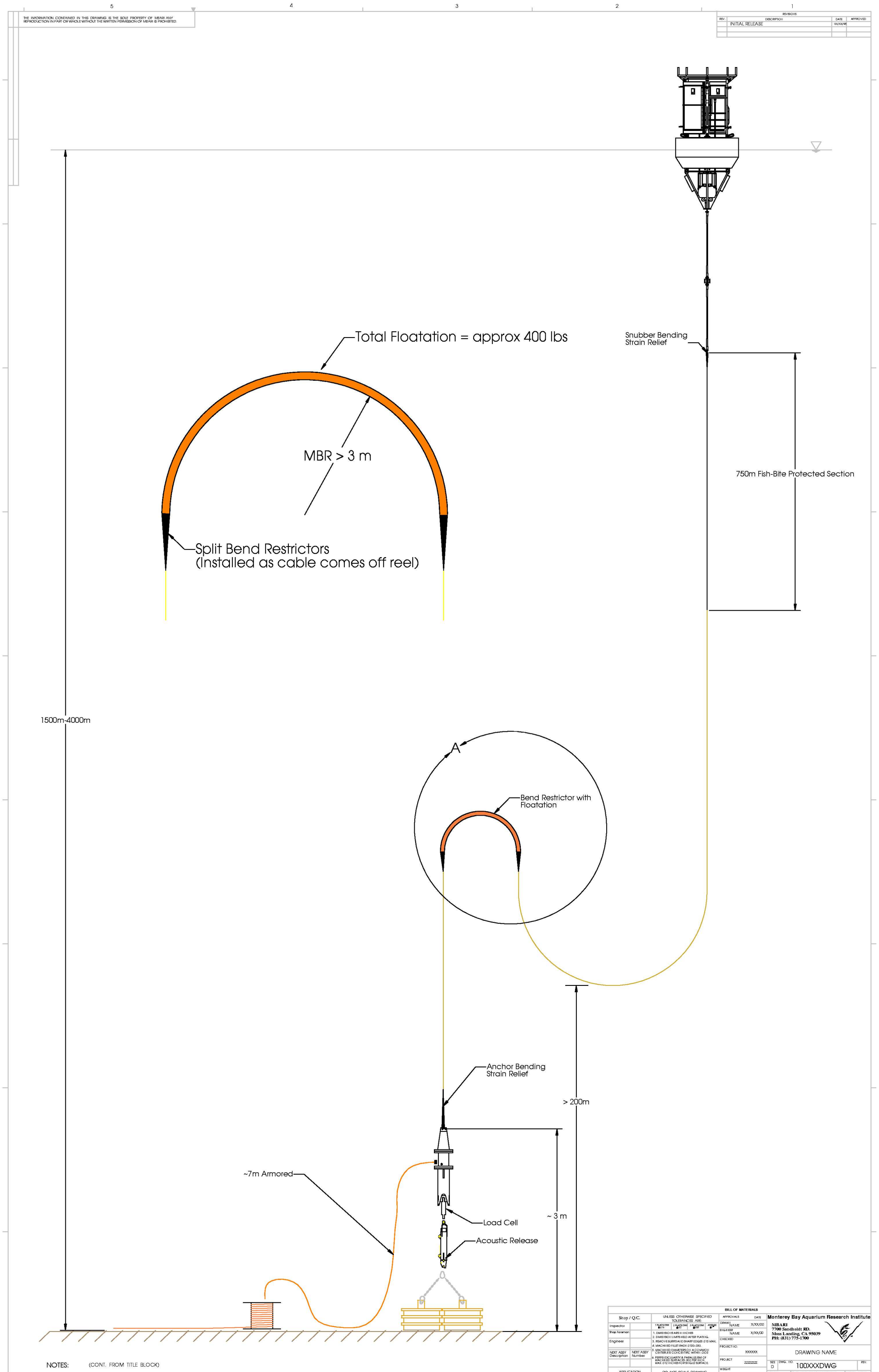

Figure 1: Schematic of MOOS Mooring Configuration

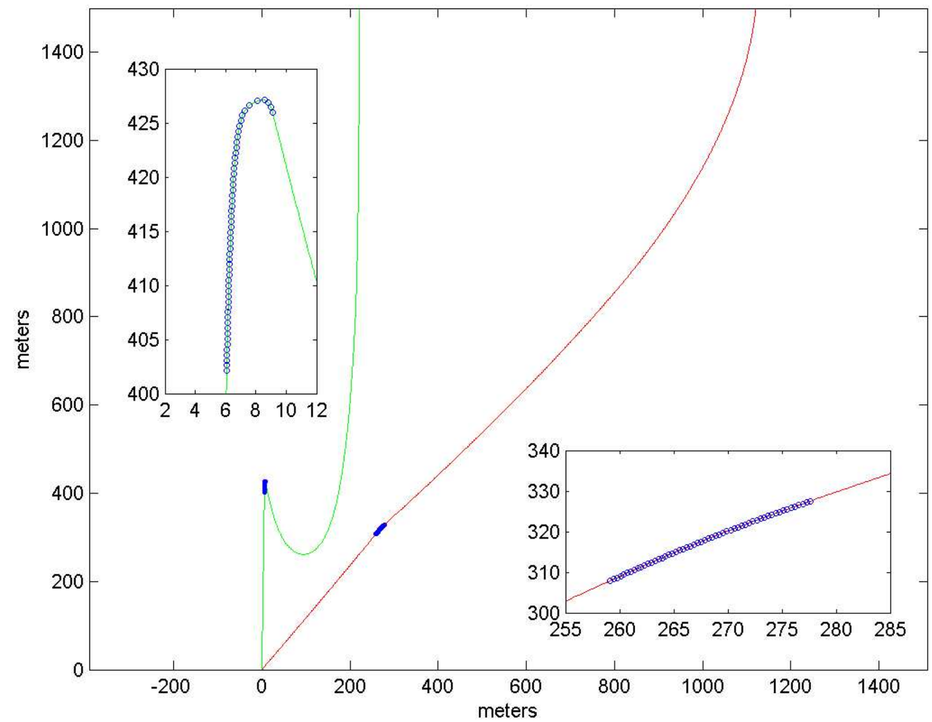

Figure 2: Static configuration of riser in maximum (red = 70 cm/s) currents and slack current conditions (green)

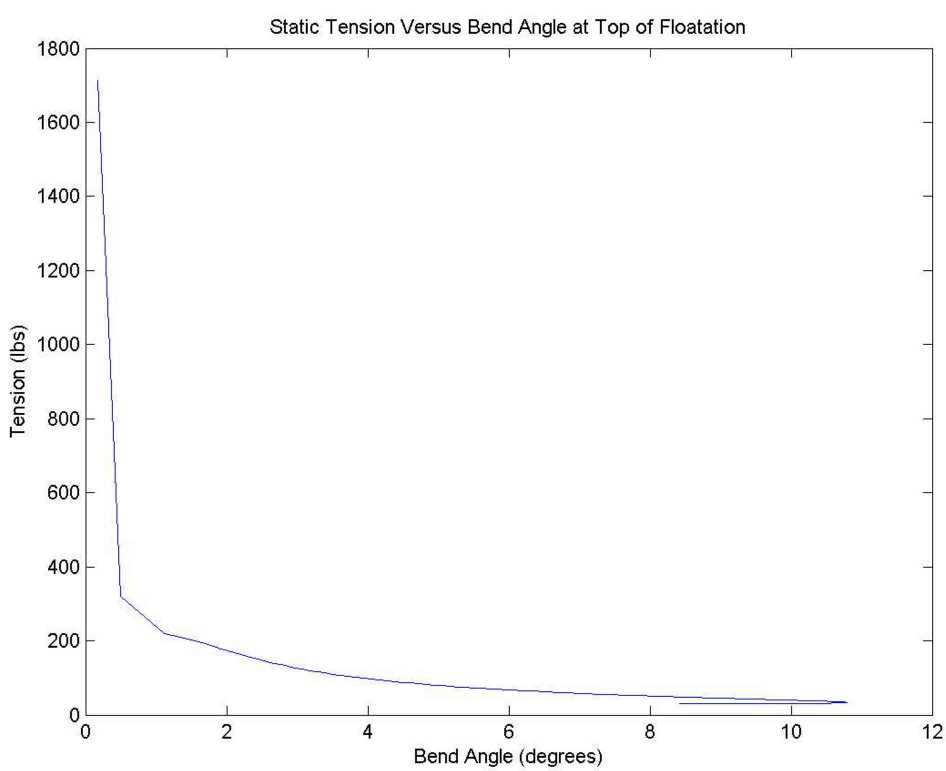

Figure 3: Tension versus bend-angle results for range of currents in static conditions.

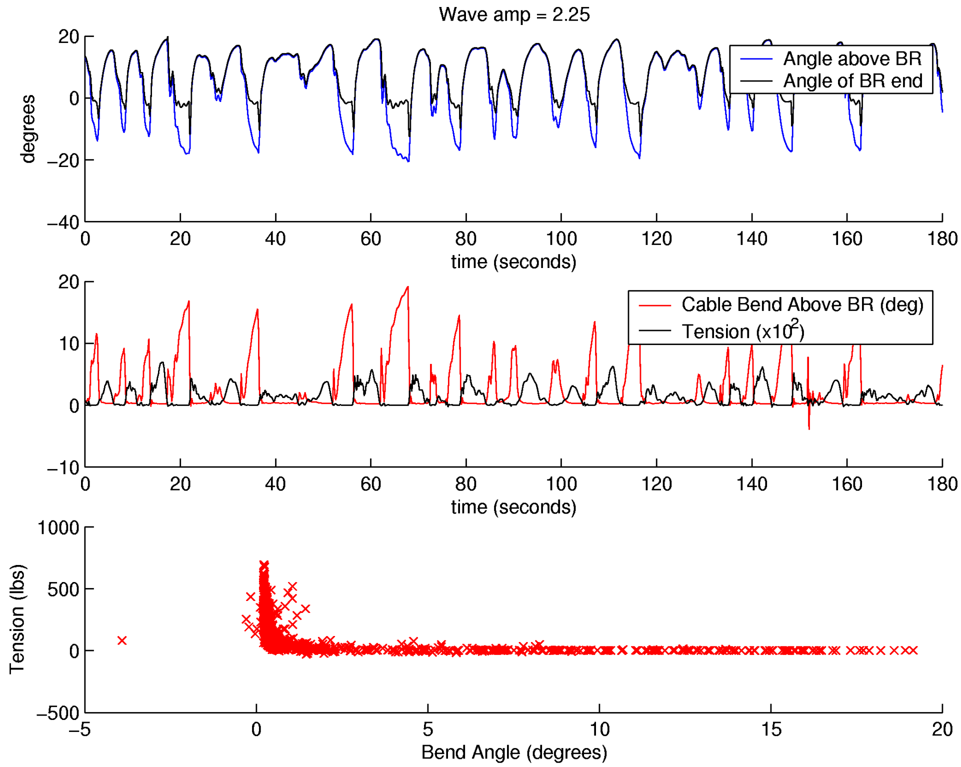

Figure 4: Top Figure: Cable angle change at upper end of LinkSyn Floatation
Middle Figure: Inverse Relationship of Tension and Bend Angle.
Bottom Figure: Tension versus angle plot at top of Floatation in this sea condition.

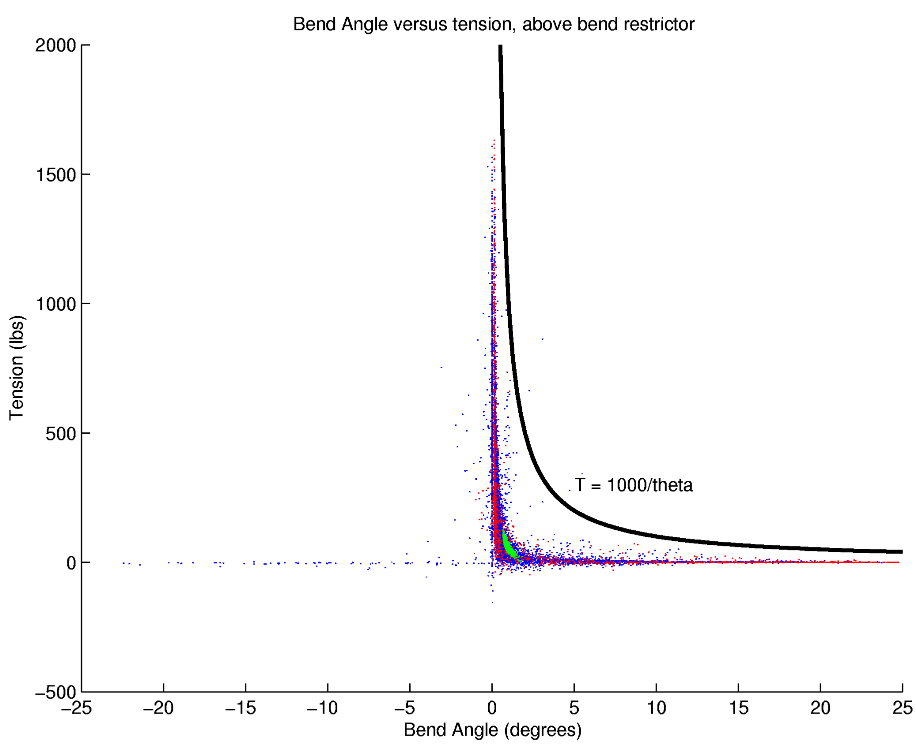

Figure 5: Tension versus bend angle above LinkSyn floatation, all sea conditions.

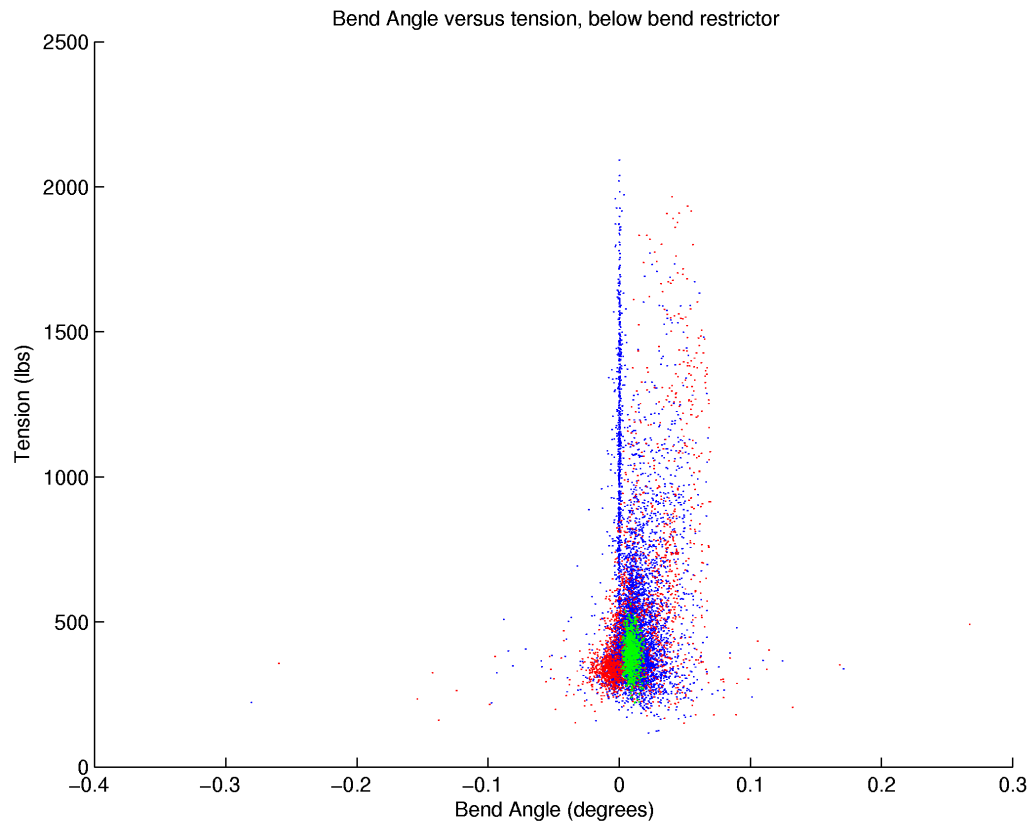

Figure 6: Tension versus bend angle below LinkSyn floatation, all sea conditions.

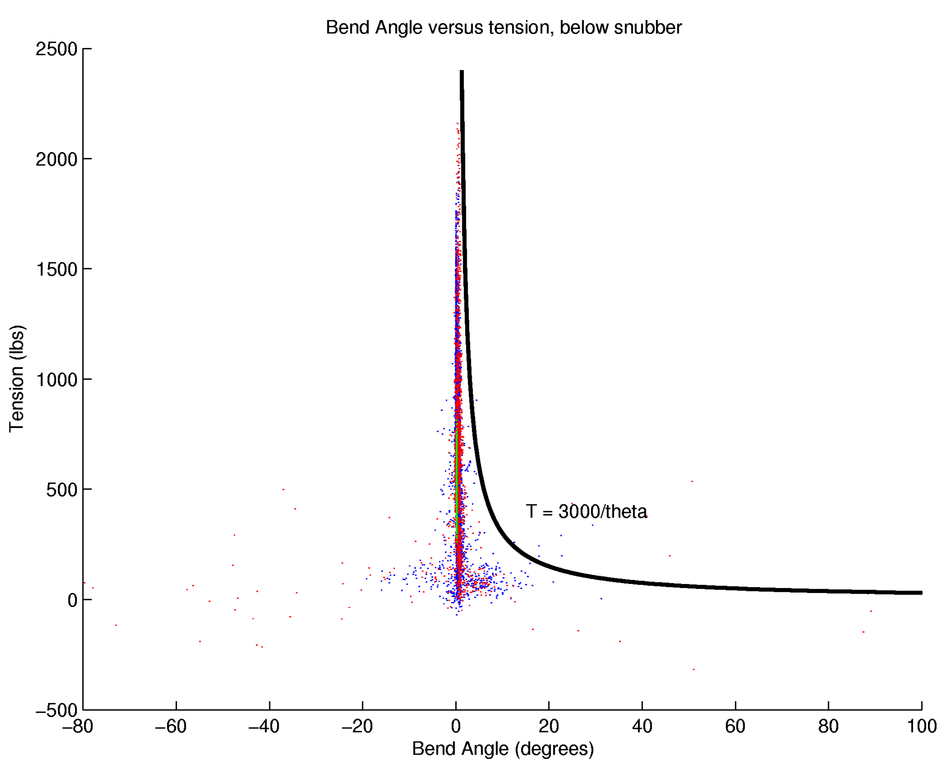

Figure 7: Tension versus bend angle below snubber connection, all sea conditions.

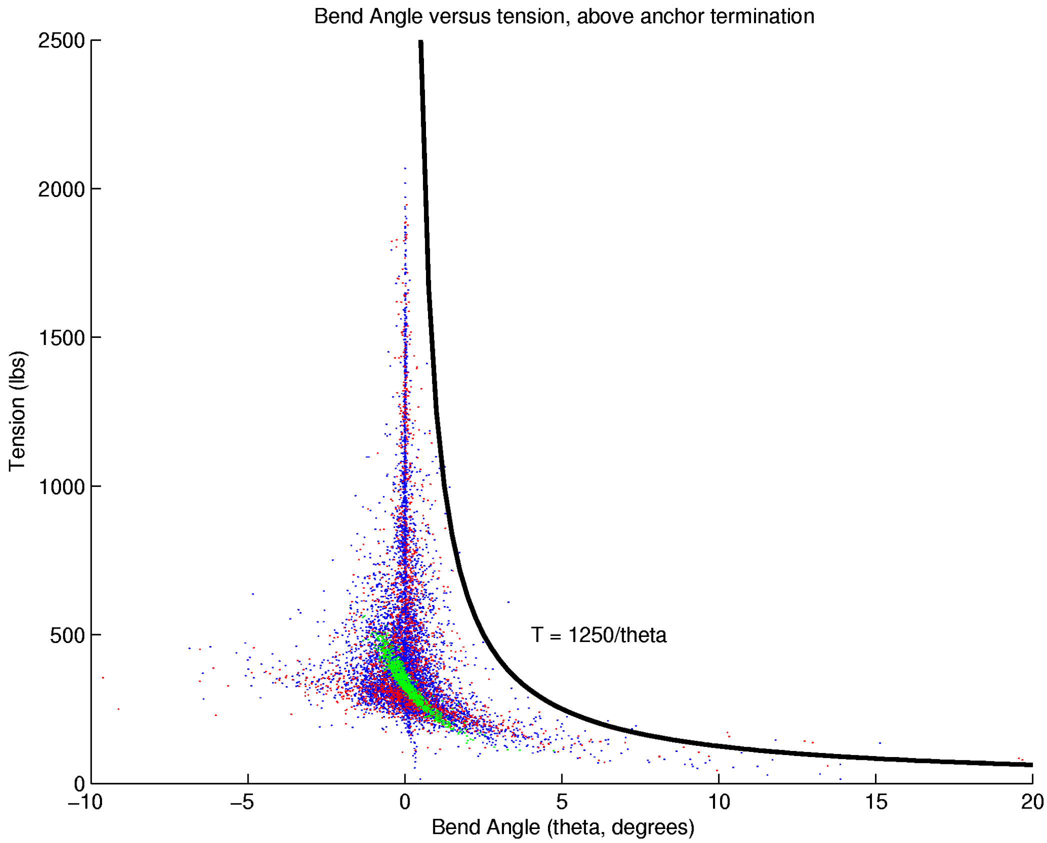

Figure 8: Tension versus bend angle above Sub-Sea connection, all sea conditions.