Dynamic Modeling and Actual Performance of the MOOS Test Mooring

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Abstract | This paper presents a comparison between model predictions made with WHOI-Cable and actual measurements of the tensions in a deep-water oceanographic mooring. The mooring is part of the MBARI Ocean Observing System (MOOS) that utilizes an electro-optical-mechanical (EOM) cable to deliver power and communications to a sub-sea network of instruments. The predictions agree acceptably with the measured results, and improvements to the model and validation system that will be incorporated in the next deployment are discussed. Also presented is an outline of the information learned about the mooring cables service environment, both from the deployment results themselves and from the cable dynamics model.

I. Introduction

In December 2002, the Monterey Bay Aquarium Research Institute (MBARI) deployed the rst prototype mooring of the MBARI Ocean Observing System (MOOS) [2]. This mooring is a deep-water oceanographic mooring designed to deliver power, data and time signals to the sea oor in support of the MOOS sub-sea network of instrumentation (see gure 2). The mooring system is sized to be deployable from regional class UNOLS vessels and relies on energy gathering (solar, wind and potentially wave) techniques to provide up to 40W of power. Satellite communications technology provides a low-bandwidth path from the buoy to shore while the mooring itself is designed to provide a high-bandwidth communication path from the buoy to the sea oor. The power and data transport is accomplished through an electro-optical-mechanical (EOM) mooring cable-riser system specially designed and built for this application. Figure 1 shows the mooring being deployed from the Point Sur on December 2, 2002.

The purpose of the prototype mooring was to test several aspects of the design and to validate modeling of the mechanical loads on the system during deployment and operation. The mooring's ability to harvest solar power using large-area vertical arrays, and harvest wind power using an o -the-shelf wind turbine, was also evaluated. High risk elements of the design that were tested included the survivability of the copper conductors and optical bers in storm conditions, the performance of the solar and wind power collection system, and the moorings tendency to twist up, which would make the connections to a xed sub-sea network more di cult.

During the design phase, cable dynamics modeling was performed using the Wood's Hole Oceanographic Institute's \Cable" software [1] to predict the loads in the system in various sea conditions. To allow validation of this model, the mooring system was equipped with load cell instrumentation to measure the actual tensions in the mooring cable on a continuous basis. The purpose of validating the modeled results is to increase the level of con dence with which the cable model can be used to predict eld loads.

Fig. 1
Buoy Deployment from the Pt. Sur, December 2, 2002.

Unfortunately, the EOM cable in this mooring system parted in a storm on December 15, 2002. The sea conditions at the time of failure approached, but did not attain, the 25 year storm conditions that were the maximum conditions the mooring was designed to survive. Subsequent recovery of all mooring components has allowed for a complete failure analysis to be performed, the results of which are being used to improved the design of the system.

In spite of the cable failure, valuable data and experience was obtained that allows some validation of the cable model and indicates changes in the data acquisition system necessary to improve the validation e ort in the next deployment. The continual improvement of the mooring model is an important goal of the project, allowing the MOOS system to be deployed con dently at new sites, based only on some knowledge of the sea-states likely in that area.

This paper presents the measured tension data collected during the deployment and makes comparisons to the predicted results obtained from the WHOI-Cable model. Results are compared for both the actual mooring installation phase and the operation phase of the deployment. An overview of the failure analysis is also presented and the cable dynamics model is again used to illuminate aspects

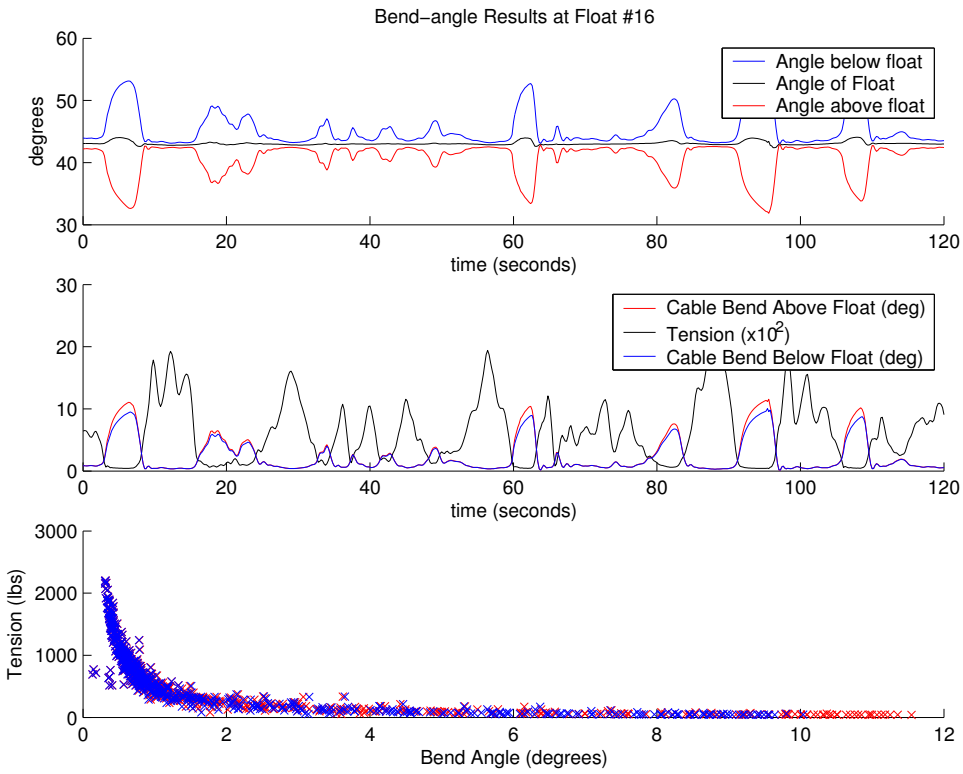

Fig. 9

Model results showing repetitive bending at float attachment points. **Top:** Time history of cable orientation during wave excitation. **Middle:** Variation of bend angle and cable tension. **Bottom** Bend angle versus tension relationship.

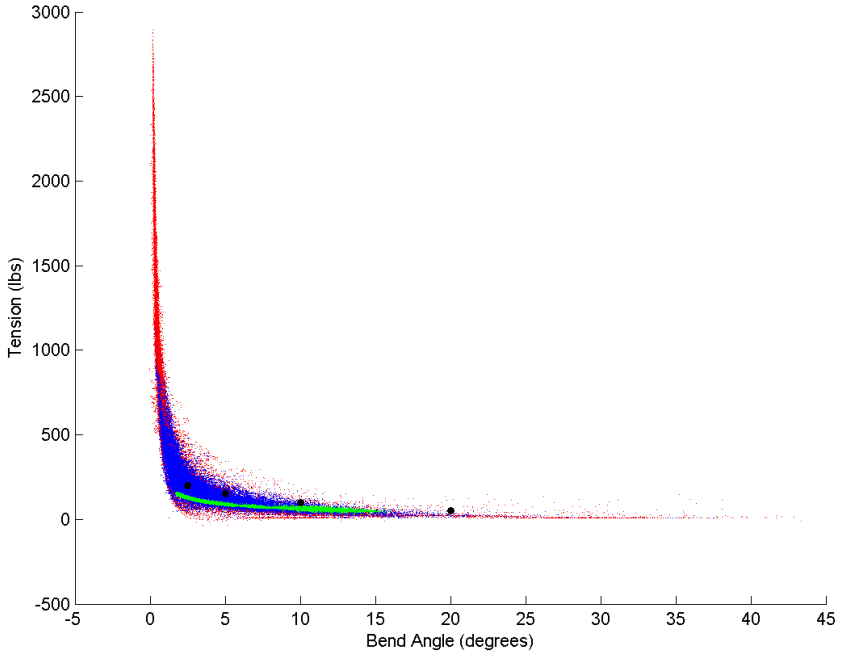

Fig. 10

Bend angle versus tension relationship for all float locations in all sea conditions.

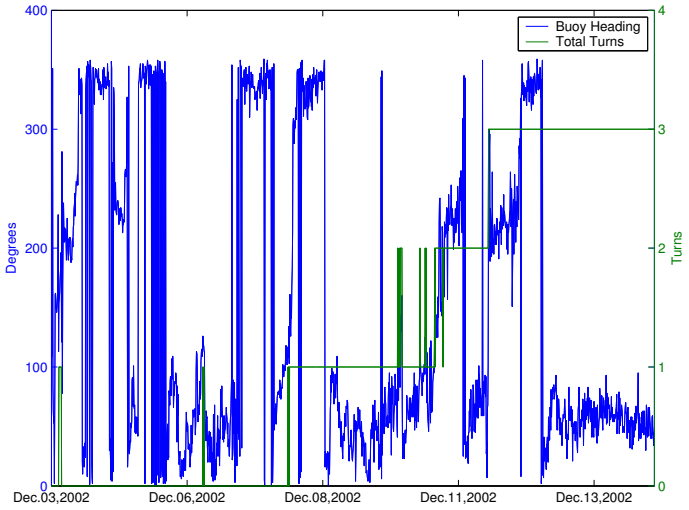

Fig. 11
Buoy heading and total turns during the deployment.

the cable goes slack, a large bend occurs, when the cable is pulled tight, the cable straightens. The period of this bending matches roughly the period of the wave exciting, meaning that millions of bending cycles per year will occur at the float locations. The bottom graph plots the tension versus bending relationship at each time-step of the model simulation. To design a bending strain relief for the float attachments, it is necessary to consider the bending at all of the float locations in all sea conditions. The cable model was run for the entire range of sea-conditions expected at the Outer Monterey Bay site in a year and figure 10 shows a plot of the bend versus angle relationship for all the float locations. The blue markers represent the conditions that occur 90% of the time, the red markers show the storm conditions which occur 5% of the time, and the green markers show the calmest conditions that occur 5% of the time. The black circles plot the bend versus tension relationship determined from static tests in MBARI's test tank. Because of the millions of bend cycles that will occur during the lifetime of the system, the cable and float system must be designed to withstand this repetitive bending.

VII. Buoy Rotation

Figure 11 shows the buoy heading and the total number of turns the buoy underwent during the deployment. The buoy performed three complete rotations during the deployment. At this rate, the rotatioin would pose a problem in the long term. However, the short duration of the deployment precludes any conclusion from these results, it is unknown if the rotation resulted from environmental forcing or simply from the relaxation of twists that existed in the cable or were induced into the system during the deployment. Similar heading data will be collected on subsequent deployments in order to answer this question. There is no evidence that this rotation contributed in any way to the cable failure.

VIII. Conclusion

The cable dynamics modeling of the MOOS Mooring with the WHOI-Cable software was generally successful in predicting the maximum axial loads in the system. The maximum loads during the anchor free-fall deployment were similar to those predicted and the tensions at the anchor matched very closely the predicted loads at the anchor end of the riser cable. At the buoy, the predicted loads were below the measured loads. Possible reasons for this discrepancy are a mis-estimation of the environmental conditions at the buoy location, and/or inaccuracies in estimating the material characteristics of the elements of the riser system. These results show the need to measure the wind, wave and current conditions at the buoy more accurately, and to use data from a longer deployment to adjust the model to give results that are valid over a range of conditions. If this is possible, it should enhance the confidence with which the MOOS mooring may be deployed in new locations. The failure of the mooring cable has led to new insights into the loading environment this mooring cable must endure in its lifetime, and will lead to an improved design. Quite a bit of valuable information was learned through this short deployment, and MBARI intends to deploy an improved system in late fall 2003.

References

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