International Journal of Offshore and Polar Engineering
Vol. 10, No. 3, September 2000 (ISSN 1053-5381)

Modeling the Dynamics of a Shallow-Water Oceanographic Surface Mooring Using Full-Scale Data

Mark A. Grosenbaugh,* Jason I. Gobat and Calvert F. Eck
Department of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution
Woods Hole, Massachussetts, USA

ABSTRACT

Full-scale measurements of the buoy motions and mooring-line tensions of a shallow-water, catenary-type oceanographic surface mooring are presented. The data were analyzed by fitting the tension spectra with a one-dimensional, mass-damper-spring model that takes into account only heave dynamics. The calculated mass coefficient of the model varied linearly with the mean tension at the top of the mooring line. For moderate to high sea states where mooring-line drag was important, the drag coefficient varied linearly with the product of the mean tension and the standard deviation of the heave velocity of the buoy. The spring coefficient had a small effect on dynamic tensions and was taken to be a constant equal to 1.7 times the weight-in-water per length of the bottom mooring chain. An analytical model for predicting the standard deviation of the tension at the top of the mooring line in irregular seas is presented. The analytical model, based on the same mass-damper-spring system used to analyze the experimental data, uses 5 parameters to predict dynamic tensions over a wide range of environmental forcing. Comparison between predictions and experimental measurements gave average absolute errors of less than 2%. The effect of surge and sway buoy motion on the results is discussed.

INTRODUCTION

This paper presents the results and analysis of a full-scale experiment to measure the buoy motions and tensions of a shallow-water oceanographic mooring. The mooring was part of the $10^1/_2$-month-long Coastal Mixing and Optics Experiment (Galbraith et al., 1997) that took place along the northeast coast of the United States. The deployment lasted from July 1996 to June 1997. The data set that was collected is unique in terms of the length of the deployment and the comprehensive on-site measurements of the environmental variables, including wave spectra, wind velocity, current profile, and water and air temperature.

The mooring used in the experiment was a catenary surface mooring designed with sections of chain interspersed between stainless-steel cage structures that held current meters, temperature and conductivity probes, and optical sensors. For this type of mooring, a significant portion of the chain lies on the sea bottom. The chain is free to lift off and fall back in response to changes in the current, wind, and wave loading. Moorings such as these are used extensively by oceanographers to deploy instruments along continental shelves where water depths are less than 200 m.

Catenary moorings constructed with stiff materials such as chain and wire rope are susceptible to extreme dynamic tensions because of the possibility of the mooring line undergoing longitudinal stretching. Ideally, the motion of the surface buoy is accommodated by changes in the shape of the catenary. Triantafyllou et al. (1985) showed by using frequency-domain simulations that there can be substantial transverse drag on a catenary mooring line, which can impede changes in the shape of the catenary. The result is that some of the buoy motion is accommodated by elastic stretching of the mooring. Though the stretching is small in the case of an all-chain or combination wire-rope/chain mooring line, the increase in dynamic tension is large because it is proportional to the mooring line's elastic stiffness. Webster (1995) used time-domain simulations to show that this phenomenon becomes more acute with increased static loads. For high static loads, the mooring line is pulled taut, and the motion becomes purely elastic. This regime is accompanied by very high dynamic tensions.

For deep-water oceanographic moorings, the motions due to currents and waves are accommodated by elastic stretching of synthetic rope, which is chosen for its low elastic spring constant (Berteaux, 1991). Use of synthetic lines is usually not possible in shallow-water environments due to the relatively short length that one would have to use in order to avoid bottom abrasion. Rubber shock cords have been used on some coastal moorings to add compliance. However, these moorings have less available space for subsurface instruments and are more susceptible to vandalism (Paul et al., 1999).

The advent of low-power miniature data collection systems has led to a number of field experiments on the dynamics of oceanographic surface moorings. Grosenbaugh (1996) measured buoy heave motion and dynamic tension of deep-water oceanographic moorings deployed in the North Atlantic in the summers of 1989 and 1991. Teng and Patton (1998) measured six-axis buoy motion and tension on a National Data Buoy Center (NDBC) deep-water inverse-catenary mooring that was deployed along the California coast for 6 days in 1995. Koterayama et al. (1997) measured 6-axis buoy motion of a combination wire-rope/chain catenary mooring that was deployed for 1 month in August 1996 off the coast of Japan in 1300 m. Teng and Patton (1998) made measurements of six-axis buoy motion and tension of a standard NDBC all-chain catenary mooring deployed in 17 m of water near the coast of Duck, North Carolina for 6 months beginning in July 1997. The latter two moorings had long sections of the chain lying on the sea bottom similar to the design analyzed in this paper.

Grosenbaugh (1996) showed that the dynamic tension of a deep-water mooring is dominated by the acceleration of the instrument string, which includes the wire rope, chain and connecting hardware, and to a lessor extent the longitudinal drag of the instruments. Teng and Patton (1998) confirmed this finding

*ISOPE Member.

Received September 3, 1999; revised manuscript received by the editors April 8, 2000. The original version was submitted directly to the Journal on August 27, 1999.
KEY WORDS: Surface-mooring dynamics, catenary mooring, mooring line damping, bottom interaction, field experiment.