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Dynamics in the Touchdown Region of Catenary Moorings

Jason I. Gobat and Mark A. Grosenbaugh*
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA

ABSTRACT

The dynamics of catenary moorings in the region surrounding the touchdown point are studied using experiments and numerical simulations. When the touchdown point speed exceeds the transverse wave speed of the mooring line, a shock forms in the tension. The analytical derivation of the shock criterion is reviewed, and the criterion is verified quantitatively using the experimental results. Shocks during upward motion of the mooring are manifested as snap loads in the tension record. Shocks during downward motion appear as slack tension at the touchdown point. Numerical simulations using an elastic foundation approach to modeling bottom interaction are accurate for cases with and without shocks. Simulations in which tension shocks are present are much more sensitive to the numerical parameterization of the bottom and the artificial bending stiffness of the mooring chain than cases in which no shocks are present. Analysis of a full-scale oceanographic mooring found unloading shocks under a wide range of forcing conditions, but loading shocks only during storms.

INTRODUCTION

Catenary moorings are common in oceanographic, meteorologic and offshore applications. These systems accommodate current, wind, tidal and wave-induced deformations by lowering and lifting excess line to and from the seafloor. The interaction of the mooring line with the seafloor can play an important role in the dynamic response of the system.

Several different approaches have been used to model this bottom interaction in numerical simulations. Frequency domain models (e.g., Triantafyllou et al., 1986; Shukai, 1999; and some time domain models ñ e.g., Teng and Wang, 1995) cut the mooring off at the static touchdown point (TDP) and attached an equivalent linear spring. Generally, this approach is valid only for small dynamic motions about the static touchdown point. Chatjigeorgiou and Mavrakos (1998) compared results from this approach with a technique that computed the instantaneous TDP from quasi-static considerations and then generated a complete dynamic solution for the suspended portion of the cable by applying vertical and horizontal spring forces at the touchdown point. They concluded that their approach was more accurate and valid even for larger amplitude motions. A third method is the liftoff and grounding approach described by Nakajima et al. (1982) and Thomas (1993). In this method, the mass of the discrete nodes or elements is reduced to zero as they approach the bottom. As with the model from Chatjigeorgiou and Mavrakos (1998), this simulates a perfectly rigid bottom with no impact loads and a smooth rolling and unrolling of the cable. The final approach is to model the seabed as an elastic foundation. This method has been used by Inoue and Surendran (1994) and Webster (1995). The primary difficulty with this approach is in determining appropriate stiffness and damping constants to associate with a given type of soil.

The latter 3 methods can be effective in representing the geometric nonlinearity introduced by the movement of the touchdown point, the instantaneous point of contact between the mooring line and the seafloor. This dynamic lifting and lowering of line is the most obvious and significant effect of bottom interaction on system dynamics. Other effects do contribute to the response, however. For example, Thomas and Hearn (1994) and Liu and Bergdahl (1997) used numerical simulations to study the effect of friction between the line and seafloor, concluding that friction due to in-plane motion does contribute to mooring line damping.

In contrast to numerical studies that focused on gross scale system response, Aranha et al. (1997) and Pesce et al. (1998a, b) examined the detailed dynamic response near the touchdown point using an analytical boundary layer approximation. Their goal was to provide better predictions of the cyclic bending moment of riser pipes. Their analysis assumes that there is no impact force between the line and the bottom. Based on the work of Burridge and Keller (1978) and Burridge et al. (1982), which describes the motion of a string on a unilateral constraint, Triantafyllou et al. (1985) showed that this assumption is valid so long as the translational speed of the touchdown point does not exceed the transverse wave speed of the mooring line. If this criterion is exceeded, a shock wave will form and there will be an impact force.

In this paper, laboratory experiments are used to investigate dynamics in the touchdown region in the presence of tension shocks. A derivation of the analytic shock condition is given, and its validity and implications are demonstrated using the experimental results. Under these extreme conditions, the suitability of the elastic foundation approach in numerical simulations is investigated. Simulation results for an oceanographic mooring demonstrate the presence of shocks in a full-scale system.

DESCRIPTION OF LABORATORY EXPERIMENT

The laboratory experiments were conducted in the Iselin flume at the Woods Hole Oceanographic Institution. The flume is a freshwater tank 20 m long with a cross-section approximately 1.2 m square. Water temperature in the tank is not controlled; over the course of the experiments it ranged from 10° to 15°C. The experiments used a section of mooring chain deployed at a fixed

* ISOPE Member.
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