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Analytical Approximation for the Dynamic Bending Moment at the Touchdown Point of a Catenary Riser

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ABSTRACT

This paper introduces an analytical approximation, of a boundary layer type, for the dynamic bending moment at the touchdown point of a catenary riser. The approximation is based on a quasi-linear frequency domain solution of a cable (*EJ* = 0), the only source of nonlinearity being the viscous drag on the riser, and it takes care of the motion of the touchdown point, a specially important phenomenon in the fatigue analysis. In spite of the fact that this motion is predicted from a quasi-linear frequency domain model, the final expression for the moment is strongly nonlinear and compares very well, for the low sea states used in the fatigue analysis, with results obtained from nonlinear time domain simulation; as a matter of fact, even for the extreme sea condition in Campos Basin the comparison between the analytical approximation and numerical results is reasonable. The expression for the moment depends nonlinearly, although in an explicit way, on two quasi-linear dynamic variables of the cable: the displacement $x_0(t)$ of the touchdown point and the dynamic tension $\tau(t)$. In this way, the obtained expression can also become useful in the study of the complex nonlinear statistical behavior of the riser's bending moment in the vicinity of the touchdown point.

INTRODUCTION

The oil industry has lately become interested in the study of the technical feasibility of a steel catenary riser anchored in a deep-water floating production system (Phifer et al., 1994). Besides some aspects related to their installation, the troublesome spots of the steel catenary riser are located at the suspended end, where a flexible joint has to be used, and at the touchdown point, where the bending moment, both static and dynamic, must be evaluated.

The problem is essentially nonlinear, the main sources of nonlinearity being the fluid drag along the suspended length and the unilateral contact force between the soil and riser in the touchdown region. Thus, several commercial computer programs, developed to analyze this problem, use time domain simulation, a procedure that is complicated by the existence of discrepant time and length scales in the problem. In fact, besides the "large" time and length scales of the catenary, one must deal with a "short" time scale, related with the axial elastic stretching, and with a "short" length scale, due to the bending stiffness effect near the touchdown point and the flexible joint.

If discrepancies in scales cause, in general, numerical difficulties in time domain simulation, they make it easier to derive asymptotic approximations. In this paper, a quasi-linear frequency domain solution of a cable (bending stiffness $EJ = 0$) is used to develop an approximation, of a boundary layer type, for the dynamic moment at the touchdown point of a steel catenary riser. The only source of nonlinearity in the cable's ($EJ = 0$) dynamic solution is the fluid drag, which is dealt with in a standard way, namely, by using an equivalent linear damping based on the equality of the dissipated power and an iterative technique to obtain the final response.

The analytical expression for the bending moment takes care of the horizontal motion of the touchdown point, an essential aspect in the fatigue analysis of the riser. As will be seen along the paper, the bending moment in the touchdown region depends, in a strong nonlinear way, on only two quasi-linear dynamic variables of the cable ($EJ = 0$): the displacement $x_0(t)$ of the touchdown point and the dynamic tension $\tau(t)$.

The comparison between the analytical results here derived with the numerical results obtained from nonlinear time domain models shows a very good agreement for the low sea states used in the fatigue analysis; as a matter of fact, the comparison is reasonable even for the extreme sea state in Campos Basin if the riser is assumed to be anchored in a semisubmersible platform.

This work reviews the basic geometric definitions, discusses some features of the static catenary solution and introduces a local bending stiffness correction in the vicinity of the touchdown point. In addition, the dynamic problem is analyzed and the analytical approximation for the dynamic moment at the touchdown is derived. Finally, some numerical results, displaying the agreement between the analytical approximation and nonlinear time domain models are presented.

BASIC DEFINITIONS AND STATIC SOLUTION

One considers here the geometric configuration of a cable ($EJ = 0$) with a weight q per unit of length, suspended at sea level by a tension T_B and subjected also to an ocean current $V(z)$. The cable touches the ground at point O, supposed to be the origin of the Cartesian system (x,z), with the z axis being vertical and pointing upwards. The water depth is h, the suspended length of the cable is l, and the cable is assumed anchored at point A on the ground, distant l_G from O; the total length of the cable is $l + l_G$. If s is the curvilinear coordinate along the suspended length, with $s = 0$ at O,

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