Accepted Manuscript

Nonlinear periodic response analysis of mooring cables using harmonic balance method

Lin Chen, Biswajit Basu, Søren R.K. Nielsen

PII: S0022-460X(18)30612-6

DOI: 10.1016/j.jsv.2018.09.027

Reference: YJSVI 14378

To appear in: *Journal of Sound and Vibration*

Received Date: 22 November 2017

Revised Date: 11 July 2018

Accepted Date: 10 September 2018

Nonlinear periodic response analysis of mooring cables using harmonic balance method

Lin Chen[a], Biswajit Basu[a,*], Søren R.K. Nielsen[b]

[a]School of Engineering, Trinity College Dublin, Dublin 2, Ireland
[b]Department of Civil Engineering, Aalborg University, Aalborg 9000, Denmark

Abstract

Mooring cables are critical components of ocean renewable energy systems including offshore floating wind turbines and wave energy converters. Mooring cable dynamics is strongly nonlinear resulting from the geometric effect, hydrodynamic loads and probably seabed interactions. Time-domain methods are commonly used for numerical simulation. This study formulates a nonlinear frequency domain multi-harmonic balance method for efficient analysis of a mooring cable subjected to periodic fairlead motions. The periodic responses are of particular interest to investigate the mooring effect on the platform. In the formulation, the governing equations of the three-dimensional cable motions are spatially discretized using the finite difference method; the nonlinear ordinary differential equations are subsequently transformed into frequency domain by expanding both the structural responses and the nonlinear nodal forces using truncated Fourier series, leading to a set of nonlinear algebraic equations of the Fourier coefficients. The equations are eventually solved using Newton's method where the alternating frequency/time domain method is used to handle the nonlinearity effect. The presented method is then compared to a time-domain method by numerical studies of a mooring cable. The results show that the method is of comparable accuracy as the time-domain method while it is generally more efficient. The proposed method shows promising results even when the cable tension becomes non-positive for a period of time during the cable motion, which is a known ill-posed problem for time-domain methods.

Keywords: Mooring cables; nonlinear dynamics; harmonic balance method; periodic response; alternating frequency/time domain technique.

1. Introduction

Offshore winds and waves are promising renewable energy sources and are receiving intensive research attention recently. Modeling mooring systems is one of the challenging tasks in simulation and design of such floating offshore structures [1, 2]. Several comparison studies have already shown the importance of mooring cable dynamics on floating wind turbines [3–7]. In the last decade, a number of cable models have been explored, validated or coupled with the multi-body dynamics of floating offshore wind turbines and wave energy devices for numerical simulation, including the finite element model [8, 9], the multi-body dynamics model [10], the lumped mass models [11, 12] and the finite difference model [13–17]. A review of the available models and simulation tools of mooring cables can be found in [18, 19]. Presently, mathematical modeling of mooring cables is still a topic area, e.g. a high-order spectral method has been developed by [20, 21] and modeling cables using bar elements in an open-source library has been conducted in [22].

Despite a large number of models available for dynamic analyses of the mooring cables, the understanding of the mooring cable dynamics is still limited. This is due to the complex nonlinearity arising from the geometric effect, hydrodynamic loads and the seabed contact. Besides, for nonlinear analysis, hundreds of degrees of freedom of one

*Corresponding author.
Email addresses: l.chen.tj@gmail.com (Lin Chen), basub@tcd.ie (Biswajit Basu), srkn@civil.aau.dk (Søren R.K. Nielsen)