NONLINEAR RESPONSE OF A MOORED VESSEL

by

ARSHAD UMAR

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CERTIFICATE

This is to certify that the thesis entitled, **"Nonlinear Response of a Moored Vessel"**, being submitted by **Arshad Umar**, to the Indian Institute of Technology, New Delhi, for the award of the Degree of **"DOCTOR OF PHILOSOPHY"** in Civil Engineering is a record of the bonafide research work carried out by him under our supervision and guidance. He has fulfilled the requirements for submission of this thesis, which to the best of our knowledge, has reached the requisite standard.

The material contained in this thesis has not been submitted in part or full to any other University or Institute for the award of any degree or diploma.

(Dr Suhail Ahmad)
Associate Professor
Applied Mechanics Department
Indian Institute Of Technology
New Delhi – 110016, INDIA

(Prof. T.K.Datta)
Professor and Head
Civil Engineering Department
Indian Institute of Technology
New Delhi – 110016, INDIA

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Arshad Umar

(Arshad Umar)

ABSTRACT

Response of a multi-point mooring system is nonlinear because of the nonlinear force excursion relationship of the mooring lines. Under certain conditions, the nonlinearity of the system may produce complex response behaviour including many instability phenomena like period doubling, symmetry breaking bifurcation, 3T and 5T solution etc. There have been several studies on the development of the method of analysis of mooring systems and flexible or floating structures anchored to the seabed. Also, there have been studies in characterizing their responses in both regular and random waves. However, very few studies are reported on the stability analysis of such systems under different kinds of wave excitations. The present study specifically addresses this problem and investigates different types of instability phenomena that may occur in a mooring system. For this purpose, a moored buoy, consisting of a large diameter cylinder anchored to the seabed by means of six mooring lines in 150m depth of water, is considered in the analysis.

Wave forces on a large diameter cylinder are calculated by a number of methods and are compared for a parametric study, in order to determine the most suitable methods to be adopted for calculating the wave forces on the buoy. The results of the parametric study indicate that (i) the methods for calculating first order and second order wave forces in regular sea proposed by Eatoc Taylor and Hung [1987] are quite satisfactory. (ii) Also, the same method provides good

estimates of primary wave forces in random sea and (iii) Newman's method of calculating the second order drift force in random sea is quite suitable.

A procedure for the stability analysis of the moored system is presented for periodic wave excitation. It consists of finding the approximate response of the system by harmonic balance method. A two-term solution is used in the harmonic balance method and the restoring force of the nonlinear mooring system is approximated by a 5^{th} order antisymmetric polynomial. The conditions for determining the local and global stability of the approximate solutions are established using Hill's variational approach and Floquet's theory. Further, the procedure for examining the possible instability phenomena and chaos of a nonlinear system are outlined. The computer programs are developed based on the procedures developed. The program is validated by solving a problem of taut mooring lines reported by Gottlieb and Yim [1992]. The results of the stability analysis of the moored system are compared with those obtained by Gottlieb and Yim. It is found that the results obtained by the proposed methods compared fairly well with those presented by Gottlieb and Yim for all the cases.

Stability analysis of the moored buoy is carried out for different frequencies of harmonic excitation in order to illustrate the possibility of instability phenomena that can occur in the system. It is shown that the system can have period doubling, symmetry breaking bifurcation of solutions. Also, the system can undergo chaotic behavior under certain conditions of excitation. The possibility of instability phenomena occurring under three regular sea-states namely, 8m/5sec, 12m/10sec and 18m/15sec are also examined. It is shown that the system shows problems of stability when subjected to primary wave forces for 12m/ 10sec and 18m/15sec waves. However, the system is found to be stable under second order wave forces for all the three sea-states. Under the action of combined first and second order wave force, the results are found to be similar to those for primary wave force.

The responses of the moored vessel for idealized narrow band sea states and two actual sea states are obtained and analyzed to study the response characteristics. The two states correspond to significant wave height and average time period as 5m/5sec and 18m/15sec. For the two idealized sea-states, the bifurcation of the solutions may occur. However, for the real states, the system remains stable. Probabilistic characteristics of the responses show that (i) the distribution of the responses of the system deviates considerably from the Gaussian distribution, (ii) the peak value distribution does not follow Gumbel Type I distribution. (iii) The power spectral density function (PSDF) of the second order wave force is relatively broad banded.

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