DYNAMIC MOTION ANALYSIS OF SPAR PLATFORM AND RELIABILITY ASSESSMENT OF ITS MOORING SYSTEM

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JANUARY 2012

Dynamic Motion Analysis of Spar Platform and Reliability Assessment of its Mooring System

by

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Submitted in fulfillment of the requirements of degree of

DOCTOR OF PHILOSOPHY

to the

INDIAN INSTITUTE OF TECHNOLOGY DELHI

HAUZ KHAS, NEW DELHI – 110016, INDIA

JANUARY 2012

CERTIFICATE

This is to certify that the thesis entitled ***Dynamic Motion Analysis of Spar Platform and Reliability Assessment of its Mooring System***, being submitted by Mr. Mohd Umair to the Indian Institute of Technology, Delhi, New Delhi, India, for the award of the degree of ***Doctor of Philosophy*** in Civil Engineering, is a record of the bonafide research work carried by him under my supervision. He has fulfilled the requirements for submission of this thesis, which to the best of my 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.

Dated: January 2012

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ACKNOWLEDGEMENTS

I express all my gratitude to Almighty Allah – *Lord of the heavens and the earth,* for the successful completion of this thesis under the able guidance of Prof. A. K. Jain. I shall always be indebted to him for his invaluable guidance, support, inspiration, constructive criticism and the remarkable temperament throughout this study. May Almighty Allah bestow the best of the bounties on him in this world and the life to come.

I fail to find words to thank Dr. Syed Danish Hasan, Dr. Muhammed Moonis Zaheer Dr. Amit Kumar Agarwal and Dr. Mohammed Jameel, for their invaluable help in carrying out this study. I will always be obliged to them.

I feel immense pleasure in expressing my profound regard and deep sense of gratitude to Prof. Mehtab Alam, Head, Civil Engg. Deptt., and Prof. Khalid Moin, Dean, F/O Engg. & Tech. and former Head, Civil Engg. Deptt., JMI, for their administrative support and bearing with me all through this study. I will always be grateful to them.

I sincerely thank Mr. Fardeen Razi for drawing the figures for my thesis and Mr. Amit Bundela and Mr. Gehlot for assisting me during work in computational laboratory.

I extend my sincere thanks to all my friends and colleagues specially Dr. Muhammed Ahmadullah Farooqui, Dr. Fauzul-Azeem Seikh, Dr. Azhar Husain, Dr. Shakeel Afsar, Dr. Naved Ahsan, Dr. Saif Saeed, Dr. Kafeel Ahmad, Dr. Asif Husain, Dr. Aqueel Ahmad, Prof. Farhan Kidwai, Prof. Shamshad Ahmad, Prof. M Shakeel and Prof. N. U. Khan.

The author is thankful to all the authorities, faculties and staff members of Civil Engg. Deptts. at IIT Delhi and Jamai Millia Islamia.

The author attributes the successful completion of this thesis to the sincere prayers, continuous support, love and affection of all his family members. They have always been a major source of motivation and strength for all time endeavors.

Finally I sincerely thank to all those who helped me directly or indirectly in the completion of this research work.

(Mohd Umair)

ABSTRACT

The offshore spar platform is a floating type of compliant structure used for the deep water applications as drilling, production, processing, storage and offloading of the ocean deposits. It is modeled as a rigid cylinder with six degrees-of-freedom (three displacement degrees-of-freedom i.e. Surge, Sway and Heave along X, Y and Z axis respectively and three rotational degree-of-freedom i.e. Roll, Pitch and Yaw about X, Y and Z axis respectively) at its center of gravity (CG). The platform is connected to the floor by four multi component cables placed perpendicular to each other. The main emphasis of the present study is to carry out the nonlinear dynamic response analysis of spar platform under various environmental loadings consisting of random waves along with wind and current. Response analysis is carried out in all the six degrees-of-freedom at the center of gravity considering both the horizontal and vertical springs. The analysis is simplified by replacing the mooring system by nonlinear horizontal as well as vertical springs due to horizontal and vertical excursions of the mooring lines. Various nonlinearities considered in the study are: geometric nonlinear static force-excursion relationship of cables, interaction of all degrees-of-freedom giving rise to response dependent stiffness matrix, nonlinear hydrodynamic drag force due to relative velocity square term in Morison's equation, variable submergence effect in wave forces, added mass and, force evaluation at the instantaneous position of structure.

In the present study, firstly the stochastic response of the spar platform under random wave only is obtained by time domain simulation technique as there are a number of nonlinearities present in the system. The variable sea surface elevation above the mean

sea level is considered as the representative parameter of the sea state. The random wave is regarded as a superposition of an infinite number of independent regular waves of different heights and periods with some arbitrary phase angles and thus its distribution becomes Gaussian. In the present simulation procedure, waves are assumed to be stationary, homogeneous and ergodic in statistical sense. The modified Peirson-Moskowitz (PM) spectrum model is assumed to represent deep water random sea state adequately. A unidirectional random wave is used for computing the wave kinematics. Airy's linear wave theory is used in this study for the evaluation of water particle kinematics produced by waves. To incorporate the effect of variable submergence, Hogben's modification is incorporated in the theory. Morison's equation is employed to calculate the forces exerted by the waves on the structure. Diffraction effects have been ignored. Newmark's β method is used to solve the equation of motion and the response time histories are obtained in an iterative fashion. The analysis that has been performed with the time histories of the structural response of Spar platform in various degrees-of-freedom is the evaluation of power spectral density functions (PSDFs). Few of the results are validated with those of the published work. Parametric analysis is done by taking different initial tensions in the mooring lines and the time histories and PSDFs are obtained. Response time histories are then statistically analyzed and characteristics like maxima, minima, mean and standard deviation are obtained. PSDFs are analyzed for determining peak frequencies and mean square of the process.

Secondly, nonlinear dynamic analysis is done again taking wind also into consideration along with random waves and current. The aerodynamic force coefficient of the superstructure is derived using a projected area approach. It is assumed that the wind approaches the spar at zero angle and has no contribution to the aerodynamic force in the sway direction. Wind spectrum suggested by Emil Simiu is used in this study to describe longitudinal wind velocity fluctuation. The equation of motion is solved in time domain by using numerical integration technique, presented by Bathe and Wilson (1976), incorporating the nonlinear characteristics of the system at each time step. The incremental form of the equations of motion is considered using Newmark's Beta method. Parametric analysis is done by taking different Hs, Tz along with corresponding wind velocities. Wind and waves are taken as uncorrelated. Different current velocities are taken for study of current effect on response behavior. Response time histories are then statistically analyzed and characteristics like maxima, minima, mean and standard deviation are obtained. PSDFs are analyzed for determining peak frequencies and mean square of the process.

Probabilistic analysis and reliability assessment of the coupled spar-mooring system is also conducted. Proper modeling is done for the uncertainties associated with the various random parameters representing stress and resistance characteristics. Ultimate limit state is formulated for the mooring lines. FORM and Monte Carlo methods are employed for the reliability assessment. Probabilities of failure and reliability indices are obtained for the twelve sea states covering the stipulated service life of 20 years. Sensitivity analysis of performance functions, with respect to random parameters involved has been carried out. It works as an effective optimization tool for the probabilistic design of the system.

Conclusions at the end of each chapter are listed as per the detailed discussions of the results. In the end, conclusions have been again drawn on the basis of investigations, and subsequent discussions of the results obtained for the dynamic response analysis of spar platform under: random waves, random waves and current and random waves and current along with wind, and also for the reliability assessment analysis. Recommendations for the scope of future work are given at the end of the thesis.

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