

**DYNAMIC ANALYSIS AND RELIABILITY OF  
MOORING LINES FOR DEEP WATER  
FLOATING SYSTEMS**

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# **Dynamic Analysis and Reliability of Mooring Lines for Deep Water Floating Systems**

by

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**Dedicated  
to  
My Parents**

## **CERTIFICATE**

This is to certify that the thesis entitled “**Dynamic Analysis and Reliability of Mooring Lines for Deep Water Floating Systems**” being submitted by Mr. K. Gurusurthy to the Indian Institute of Technology, New Delhi, India for the award of the degree of Doctor of Philosophy in Applied Mechanics Department is a record of the original bonafide research work carried out by him under my guidance and supervision. The thesis work, in my opinion, has reached the requisite standard fulfilling the requirements for the degree of Doctor of Philosophy. The results contained in this thesis have not been submitted in part or full to any other university or Institute for the award of any degree/diploma.

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## ABSTRACT

Traditionally the dynamic analysis of mooring lines has been carried out using decoupled method, where the floater motions computed by quasi-static approach are applied as boundary conditions at the top ends of critically loaded mooring lines. This method has been proven to be a proper design tool for mooring systems in shallow water. In deep water, the number of risers and mooring lines increase and these contribute significant inertia and damping due to their longer lengths, larger sizes, and heavier weights. Therefore, in deep water the motions of the floater hull are coupled with the dynamics of the mooring system. In the coupled dynamic analysis, the dynamics of floater hull, mooring lines, and risers are solved simultaneously and is usually performed in time domain to account for all non-linearities more accurately. However, coupled analysis is exceedingly expensive in terms of computational time and hence is unfeasible for the current design practice. Therefore, it is considered mainly as a tool for final verification purposes. For routine design of floating systems, a number of efficient methodologies have been developed with a view to balance the accuracy and efficiency. One of the efficient methodologies is the enhanced decoupled dynamic analysis. It is similar to the traditional decoupled dynamic analysis except that the floater motions are computed by coupled analysis considering a coarse finite element model of the mooring lines.

In the present study, a computer code has been developed incorporating an efficient coupling scheme to simulate the physically coupled floater-mooring system to obtain the response in time domain. The floater is modeled as a rigid body with six degrees-of-freedom. Mooring lines are modeled based on a slender rod theory and their dynamics are simulated using a non-linear finite element method. The coupling between the floater hull and mooring system is achieved at a given time step by

matching the forces and displacements of the hull and its mooring system at the fairleads. The solution of the equations of motion for floater hull is obtained using the fourth order Runge-Kutta time integration method and for mooring line using Adams-Moulton method. At each time step of the integration of equations of motion of the floater hull, a series of non-linear dynamic analyses of the mooring lines are performed using a domain decomposition method called subcycling technique. It takes into account the natural partition that exists between the floater hull and mooring lines and uses different time steps appropriate to each domain. Major non-linearities such as the geometric non-linear free surface force calculation, displaced position force computation, and non-linearities in equations of motion and fluid loading, and seabed interaction are considered. Wave kinematics is computed using linear Airy wave theory with Wheeler stretching method. The Morison equation has been used for wave force computation.

A catenary moored classic JIP spar floating system has been considered in two different water depths for dynamic analysis of mooring lines. To validate the mathematical and numerical model of spar-mooring system, static offset tests, free decay tests, the response of the spar-mooring system in regular waves and uniform current and the response of the spar-mooring system in random waves are conducted and the results are validated with published experimental and numerical results. The dynamic analyses of mooring lines have been carried out by different methods of analyses, i.e. quasi-static, de-coupled dynamic, coupled dynamic and enhanced de-coupled dynamic. The analyses are carried out for two different water depths (318 m and 1018 m) under random wave loading. The damping of the mooring lines significantly reduces the slow drift surge of the spar and the reduction increases with the increase in water depth. The tensions in the mooring lines are large in the wave-

frequency range and the tensions predicted by coupled dynamic approach are much greater than those predicted by the quasi-static approach especially in deep water (1018 m water depth). The traditional de-coupled dynamic analysis provides fairly good prediction of tensions in shallow water depth (318 m) and overpredicts the same in deep water (1018 m). The enhanced de-coupled dynamic analysis method predicts the mooring line tensions as good as coupled dynamic analysis with reasonable economy in computational time. In addition, to study the effect of current loading on mooring lines, the response of spar-mooring system under random waves with uniform collinear current has been carried out in 1018 m water depth using coupled dynamic analysis. The mean surge offset and the mooring line tensions are increased due to current forces on hull and further increased due to current forces on mooring lines. The low frequency standard deviation of surge and pitch is appreciably reduced in presence of current due to the increase in viscous damping.

Reliability analysis of most critically loaded mooring line of the JIP spar has been carried out for a water depth of 1018 m. Mooring line tension load time histories are generated using enhanced de-coupled dynamic analysis under extreme storm loads in intact condition. Based on the simulated results of loads on mooring lines, reliability analysis is carried out using representative probabilistic descriptions of the extreme met-ocean conditions. The uncertainty in the maximum loads on the mooring line due to the inherent randomness in loads from one storm event to another, the uncertainty due to extreme events that the spar may experience during its life time, and the uncertainty due to numerical model used to estimate the loads exerted on the spar are evaluated. The probability of failure and the corresponding reliability index during a 20-year design life has been calculated. The variation in reliability for different safety factors and the effect of variation in c.o.v. of line

capacity on probability of failure are studied. It is observed that the line capacity c.o.v. can significantly affect the mooring line reliability. It has been concluded that the enhanced de-coupled dynamic analysis can be used more efficiently for reliability analysis of mooring lines for deep water floating systems.

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