RESPONSE OF FLEXIBLE MARINE RISERS TO STATIC AND DYNAMIC FORCES

by

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LIFE IS SYNONYMOUS WITH PADDLING UPSTREAM. ONCE YOU STOP, THINKING YOU HAVE REACHED A CERTAIN POINT, YOU DO NOT STAY THERE, YOU FLOAT DOWNSTREAM. SO, IN ORDER TO REMAIN AT A POINT, THE LEAST YOU HAVE TO DO IS CONTINUE PADDLING UPSTREAM.

(AN OLD CHINESE SAYING)

DEDICATED TO KNOWLEDGE

CERTIFICATE

This is to certify that the thesis entitled, " **RESPONSE OF FLEXIBLE MARINE RISERS TO STATIC AND DYNAMIC FORCES** ", being submitted by **Mr. KAMAL ZARE MEHRJARDI**, 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 my supervision and guidance. 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.

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(KAMAL ZARE MEHRJARDI)

ABSTRACT

Floating production units are being favored for new offshore development because of several fundamental reasons, such as greater economical restraints, diminishing discoveries, improved subsea technology and drive towards deeper waters. Flexible risers are the simplest and most economical means of linking subsea equipment and floating facilities. Different possible configurations of flexible risers are in use. These are formed out of three basic types of configuration namely, Free hanging riser (single catenary type), "Lazy S" riser and "Steep S" riser. The "Lazy S" system comprises of a flexible line running down from the upper connection of the floater via a subsea buoy and a mid water arch in a double catenary. The first catenary suspended between the floater and the buoy is a long suspension line which absorbs most of motion induced by the current and wave. The second catenary is usually short and runs directly from mid water arch to the subsea equipment. The "Steep S" riser differs from the "Lazy S" in that the flexible riser itself is used to tension the sub-surface buoy terminating in a riser base at the subsea connection point.

Flexible risers are subjected to varied static, quasi-static and dynamic forces. For the safety of design, the behavior of the riser under these forces must be thoroughly investigated. In spite of the use of flexible risers since late 70's, the

available literature on this type of riser is surprisingly meager. It is, therefore, necessary to carry out studies on various problems associated with the flexible risers. The present work addresses a few of them namely, i) Static and quasi-static response of the riser to submerged self weight, current, quasi-static wave forces; ii) Dynamic response to regular and random wave forces and consequent vessel motion; iii) Statistical characteristics of the dynamic response; iv) Vortex induced oscillation due to steady current and wave.

For the purpose of analysis, the first suspended portion of the "Lazy S" riser between the floater and the mid arch buoy is considered since it absorbs most of the forces induced by current, wave and vessel motion. For the static and quasi-static analysis, finite difference formulation is presented in which the geometrically non-linear problem is solved by using a Newton-Raphson iterative procedure. The solution provides the geometric profile of the riser under its own submerged self weight. For obtaining the response of the suspended riser to current forces, a stiffness matrix approach involving beam-column elements is used. Using the proposed method of analysis, a numerical study is conducted to investigate the effect of different parameters on the riser response. The parameters include the riser tension, depth of mid arch buoy, slow vessel motion at the top of the riser and current velocity. The study shows that these parameters have considerable influence on riser response.

The dynamic analysis for regular and random wave forces and consequent vessel motion is performed using a finite element formulation. The dynamic analysis is carried out by considering the static profile of the riser under its self weight and applied tension as its mean position. The response is obtained in time domain using step by step numerical integration of the equation of the motion to take into account the relative velocity squared drag force. For the analysis under random waves, the sea surface elevation and water particle kinematics are simulated by using wave superposition technique. The motion of top vessel to random sea state is simulated with the help of an appropriate response amplitude operator (R.A.O) of the top vessel. With the help of the proposed analysis, a numerical study is conducted to investigate the effect of some important parameters on the riser response and to characterize the statistics of response. Parameters include wave height and wave period, current velocity in combination with the wave, long term and instantaneous vessel motion and nature of sea spectrum. The statistical analysis of the response comprises of finding the distribution of the response and its extreme value distribution. The distribution of the response is fitted to Pearson's family of frequency curves and the extreme value distribution of the response is fitted to Gumbel type-I and Weibull distribution. Chi-square test is utilized to find the 'goodness of fit' to the mathematical models.

The vortex induced transverse oscillation of the riser due to steady current is investigated under lock-in condition. During lock-in, the lift force is assumed to be monoharmonic in nature and fully correlated. The parameters used for determining the lift forces are taken from available experimental results on flexible cylinders in uniform flow. In-line response during lock-in is obtained by considering amplified drag coefficients due to vibration of the cross sectional modes of oscillation. The responses are obtained in time domain using numerical integration of equation of motion. The results of the study indicates that the dynamic stresses under lock-in condition are quite significant. Also, the in-line responses at lock-in are greatly amplified.

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