

# **DYNAMIC RESPONSE AND PROBABILISTIC ANALYSIS OF COMPOSITE RISERS**

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# **DYNAMIC RESPONSE AND PROBABILISTIC ANALYSIS OF COMPOSITE RISERS**

**by**

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*Submitted*

In fulfillment of the requirements of the degree of Doctor of Philosophy

to the



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*Dedicated to Beloved*

*My Brother (Late) Shree Mandeep Malik*

## CERTIFICATE

This is to certify that the dissertation entitled “*Dynamic Response and Probabilistic Analysis of Composite Risers*” being submitted by *Mr. Manander Singh* to the Department of Applied Mechanics, Indian Institute of Technology Delhi, for the award of the degree of *Doctor of Philosophy* in Applied Mechanics, is a record of original the bonafide research work carried out by him under my guidance and supervision. He has fulfilled the requirement for submission of the thesis, which is 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.

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## ABSTRACT

The idea of introducing composite materials for marine risers started a decade ago after seeing the success of composite materials in the aerospace industry. Composite materials have attracted substantial attention from the offshore industry, primarily due to their high specific strength. In addition to weight reduction, composites are expected to offer additional benefits such as excellent fatigue, damping, and thermal (insulation) properties, and high corrosion resistance. The main functional requirement of a production riser system is to convey fluid and gas from the subsea oil field to a surface platform. Composite risers have attracted the attention of many researchers for quite some time, especially for deepwater conditions. In spite of higher manufacturing costs of composite risers, the transition from metallic risers to composite risers has become inevitable due to their influence on other system components and operational costs. The differences in material and construction, analysis of a composite riser may require different approaches than conventional riser analysis, and it is necessary to identify the particulars to which attention must be paid when analyzing a composite riser. Risk and reliability assessment is, all the more, important because the behavior of offshore structure under deep water condition is unpredictable and uncertain than in shallow water depth.

The composite riser, under study, is considered to be a part of Tension Leg Platform (TLP) to be installed at a depth of 2000 m. Local analysis is required because the riser is made up of composite material. The dynamic response of composite production risers to both regular and random waves is obtained in the time domain. For random sea states, time histories of sea surface elevation, water-particle kinematics and vessel top motion are simulated by harmonic superposition technique. The bending stresses in presence of fluctuating axial tension are obtained for various sea states expected in deep offshore fields in the Indian ocean. Power spectral density functions are obtained to investigate the possibility of resonance. The free vibration response characteristics provide the expected natural frequencies and facilitate the investigation of the probability of resonance arising in the system.

The composite riser under study consists of the alternative hoop and axial layers. There is a marginal coupling between these two orientations, hence, the riser is spatially orthotropic. An attempt has been made to carry out a detailed local analysis of a segmental length under critical loads. The results of the global analysis are used to act as boundary/initial condition for the local and detailed dynamic analysis of the segmental length modeled as finite element assemblage of shell elements. Initiation and propagation of debonding between the liner and

composite have been studied. In burst analysis, the maximum internal pressure is applied to the riser section and the stresses in all (hoop and longitudinal layers) the composite layers are checked against the failure. The debonding through circumference and length are studied. The stresses so obtained are compared with their ultimate strength.

Fatigue is identified as the primary failure mechanism affecting the risk for a production riser between its base at the mud-line and its top at the sea level. The S-N curve approach is used in the assessment of the fatigue life of composite riser. The combined loading responses are obtained in two steps -global and local analysis. Twelve sea states are considered for the simulation of a wide range of offshore environment and estimation of accumulated damage. The rain-flow cycle counting method is used to estimate the cumulative fatigue damage. Palmgren-Miner's rule is used to calculate the damage caused by stress signals of variable amplitudes. The damage fractions are then summed linearly to give an estimate of the total fatigue life for a particular stress history. The cumulative estimate for its entire service life is hence estimated considering all expected sea states.

Finally, probabilistic analysis and risk assessment of composite risers for cumulative fatigue is a vital design requirement for its satisfactory service and survival for a stipulated period. Unlike conventional risers, the wall structure of a composite riser is more complicated. Therefore, multiple failure mechanisms are used jointly to assess the safety of the composite riser. A non-linear limit state function is derived based upon the above-given approach to calculate the fatigue life. Important uncertainties associated with random variables are considered while deriving the limit state function. Numerical methods, such as Monte Carlo simulation and Advanced First Order Reliability Method, are used for the calculation of the reliability. The sensitivities of various random variables on the overall probability of failure have been studied and design points have been located on failure surface. Probabilities of failure for important parameters are investigated.

## सार

एयरोस्पेस उद्योग में समग्र सामग्रियों की सफलता को देखने के बाद एक दशक पहले समुद्री राइज़र के लिए समग्र सामग्री शुरू करने का विचार शुरू किया। समग्र सामग्रियों ने मुख्य रूप से अपर्याप्त उद्योग से काफी ध्यान आकर्षित किया है, मुख्य रूप से उनकी उच्च विशिष्ट शक्ति के कारण। वजन घटाने के अलावा, कंपोजिट्स से उत्कृष्ट थकान, नमी, और थर्मल (इन्सुलेशन) गुण, और उच्च संक्षारण प्रतिरोध जैसे अतिरिक्त लाभ प्रदान करने की उम्मीद है। उत्पादन रिज़र सिस्टम की मुख्य कार्यात्मक आवश्यकता उपसाइड तेल क्षेत्र से तरल पदार्थ और गैस को सतह के प्लेटफार्म में व्यक्त करना है। समग्र राइज़र कुछ समय के लिए, विशेष रूप से गहरे पानी की स्थितियों के लिए कई शोधकर्ताओं का ध्यान आकर्षित किया है। समग्र राइज़र की उच्च विनिर्माण लागत के बावजूद, धातु राइज़र से समग्र राइज़र में संक्रमण अन्य सिस्टम घटकों और परिचालन लागत पर उनके प्रभाव के कारण अपरिहार्य हो गया है। सामग्रियों और निर्माण में अंतर, एक समग्र राइज़र के विश्लेषण के लिए पारंपरिक राइज़र विश्लेषण की तुलना में विभिन्न दृष्टिकोण की आवश्यकता हो सकती है, और एक समग्र राइज़र का विश्लेषण करते समय ध्यान देने के लिए आवश्यक विवरण की पहचान करना आवश्यक है। जोखिम और विश्वसनीयता मूल्यांकन, और भी महत्वपूर्ण है, क्योंकि गहरे पानी की स्थिति के तहत अपतटीय संरचना का व्यवहार अप्रत्याशित और उथले पानी की गहराई से अनिश्चित है।

अध्ययन के तहत समग्र राइज़र को 2000 मीटर की गहराई में स्थापित करने के लिए तनाव लेग प्लेटफार्म (टीएलपी) का हिस्सा माना जाता है। स्थानीय विश्लेषण की आवश्यकता है क्योंकि राइज़र समग्र सामग्री से बना है। समय-समय पर नियमित और यादृच्छिक तरंगों के लिए समग्र उत्पादन राइज़र की गतिशील प्रतिक्रिया प्राप्त की जाती है। यादृच्छिक समुद्री राज्यों के लिए, समुद्र की सतह की ऊंचाई के समय इतिहास, पानी-कण कीनेमेटिक्स और पोत शीर्ष गति हार्मोनिक सुपरपोजीशन तकनीक द्वारा अनुकरण की जाती है। भारतीय महासागर में गहरे अपतटीय क्षेत्रों में अपेक्षित विभिन्न समुद्री राज्यों के लिए उतार-चढ़ाव वाले अक्षीय तनाव की उपस्थिति में झुकने पर जोर दिया जाता है। अनुनाद की संभावना की जांच के लिए पावर स्पेक्ट्रल घनत्व कार्य प्राप्त किए जाते हैं। निः शुल्क कंपनी प्रतिक्रिया विशेषताओं अपेक्षित प्राकृतिक आवृत्तियों प्रदान करते हैं और सिस्टम में उत्पन्न अनुनाद की संभावना की जांच की सुविधा प्रदान करते हैं।

अध्ययन के तहत समग्र राइज़र वैकल्पिक उछाल और अक्षीय परतों के होते हैं। इन दो अभिविन्यासों के बीच एक मामूली युग्मन है, इसलिए, राइज़र स्थानिक रूप से ऑर्थोट्रॉपिक है। गंभीर भार के तहत विभागीय लंबाई का विस्तृत स्थानीय विश्लेषण करने के लिए एक प्रयास किया गया है। वैश्विक विश्लेषण के परिणाम शैल तत्वों के परिमित तत्व संयोजन के रूप में मॉडलिंग की विभागीय लंबाई के स्थानीय और विस्तृत गतिशील विश्लेषण के लिए सीमा / प्रारंभिक स्थिति के रूप में कार्य करने के लिए उपयोग किए जाते हैं। लाइनर और समग्र के बीच बहस की शुरुआत और प्रसार का अध्ययन किया गया है। विस्फोट विश्लेषण में, अधिकतम आंतरिक दबाव राइज़र खंड पर लागू होता है और सभी (हुप और अनुदैर्घ्य परतों) में तनाव विफलता के खिलाफ समग्र परतों की जांच की जाती है। परिधि और लंबाई के माध्यम से बहस का अध्ययन किया जाता है। प्राप्त किए गए तनाव की उनकी अंतिम ताकत के साथ तुलना की जाती है।

थकान को प्राथमिक विफलता तंत्र के रूप में पहचाना जाता है जो मिट्टी रेखा पर इसके आधार और समुद्र तल पर इसके शीर्ष के बीच उत्पादन रिज़र के जोखिम को प्रभावित करता है। एस-एन वक्र

दृष्टिकोण समग्र राइज़र के थकान जीवन के आकलन में प्रयोग किया जाता है। संयुक्त लोडिंग प्रतिक्रिया दो चरणों में प्राप्त की जाती है - वैश्विक और स्थानीय विश्लेषण। बारह समुद्री राज्यों को अपतटीय पर्यावरण की एक विस्तृत श्रृंखला के अनुकरण और संचित क्षति के आकलन के लिए माना जाता है। बारिश प्रवाह चक्र गिनती विधि संचयी थकान क्षति का अनुमान लगाने के लिए प्रयोग किया जाता है। पामग्रीन-माइनर का नियम परिवर्तनीय आयामों के तनाव संकेतों के कारण होने वाले नुकसान की गणना करने के लिए उपयोग किया जाता है। तब किसी विशेष तनाव इतिहास के लिए कुल थकान जीवन का अनुमान देने के लिए क्षति के अंशों को रैखिक रूप से समझाया जाता है। अपने पूरे सेवा जीवन के संचयी अनुमान का अनुमान है कि सभी अपेक्षित समुद्री राज्यों पर विचार किया जाए।

अंत में, संचयी थकान के लिए समग्र राइज़र के संभाव्य विश्लेषण और जोखिम मूल्यांकन इसकी संतोषजनक सेवा और निर्धारित अवधि के लिए उत्तरजीविता के लिए एक महत्वपूर्ण डिजाइन आवश्यकता है। पारंपरिक राइज़र के विपरीत, एक समग्र राइज़र की दीवार संरचना अधिक जटिल है। इसलिए, समग्र रिज़र की सुरक्षा का आकलन करने के लिए संयुक्त रूप से कई विफलता तंत्र का उपयोग किया जाता है। थकान जीवन की गणना करने के लिए उपर्युक्त दृष्टिकोण के आधार पर एक गैर-रैखिक सीमा राज्य कार्य व्युत्पन्न होता है। सीमा राज्य समारोह को प्राप्त करते समय यादृच्छिक चर से जुड़े महत्वपूर्ण अनिश्चितताओं पर विचार किया जाता है। मोंटे कार्लो सिमुलेशन और उन्नत प्रथम ऑर्डर विश्वसनीयता विधि जैसे संख्यात्मक तरीकों का उपयोग विश्वसनीयता की गणना के लिए किया जाता है। असफलता की समग्र संभावना पर विभिन्न यादृच्छिक चर की संवेदनशीलता का अध्ययन किया गया है और डिजाइन बिंदु विफलता सतह पर स्थित हैं। महत्वपूर्ण मानकों के लिए विफलता की संभावनाओं की जांच की जाती है।

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