RPSEA-0028-04 GRI-05/0038

Ultra-Deepwater Composite Risers: Structure-Fluid Interactions with Vortex-Induced Vibration

TOPICAL REPORT
CEAC-TR-04-0105

(September 2003 – September 2004)

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Prepared for:

RESEARCH PARTNERSHIP TO SECURE ENERGY FOR AMERICA
Subcontract No. R-511

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December 2004

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 2004	Topical Report September 2003-September 2004

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Ultra-Deepwater Composite Risers: Structure-Fluid Interactions With Vortex-Induced Vibration	RPSEA Subcontract R-511 GRI Contract 8693
6. AUTHOR(S): T. P. Yu and S. S. Wang	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Composites Engineering and Applications Center (CEAC), and Department of Mechanical Engineering University of Houston, 4800 Calhoun Road, Houston, TX 77204-0931	8. PERFORMING ORGANIZATION REPORT NUMBER CEAC-TR-04-0105
9. SPONSORING ORGANIZATION NAME AND ADDRESS Research Partnership to Secure Energy for America 1650 Highway 6, Suite 300 Sugar Land, TX 77478	10. SPONSORING/MONITORING AGENCY REPORT NUMBER RPSEA-0028-04 GRI-05/0038

11. SUPPLEMENTARY NOTES

The work documented in this RPSEA report was funded under GRI Contract 8693 with RPSEA, Technology Development for Unconventional and Ultra Deep Offshore Natural Gas Resources.

12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Structure-fluid interactions, including vortex-induced vibration (VIV), are studied for ultra-deepwater composite risers for offshore petroleum exploration and production (E&P) operations. In this report, theoretical and numerical models and analyses have been conducted on structural dynamics of composite risers with VIV motion. The time-dependent composite riser stiffness properties with structural damping have been formulated by the use of polymer viscoelasticity, composite micromechanics and cylindrical laminate shell structure theory. Composite structural dynamic analysis methods are then developed to investigate the basic nature of composite riser dynamics subject to combined ocean current, wave and VIV loading. Numerical results for various cases are given to illustrate the fundamental characteristics of the structure-fluid interaction of the composite risers in ultra-deepwater environments. The effects of resin matrix material, damping factor, lamination lay-up parameters, waves, and lifting and drag coefficients on the VIV dynamics are investigated.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Offshore, ultra-deepwater, drilling, composite, riser, vortex-induced, vibration	52
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

ABSTRACT

Structure-fluid interactions, including vortex-induced vibration (VIV), are studied for ultra-deepwater composite risers for offshore petroleum exploration and production (E&P) operations. The riser dynamics with VIV is recognized to be associated with transverse lift force, which is dynamic and hydroelastic in nature. The hydrodynamic force, caused by periodical shedding of vortices, is governed by riser structural stiffness and geometry. As the vortex-shedding frequency approaches, or is coincident with, the riser structural natural frequency, significant transverse oscillations of the risers may occur. Reduced top tension is expected on a composite riser due to its weight reduction; thus the lateral structural stiffness of the riser string may also be reduced. This could result in large transverse and vertical motions as well as bending stresses in the composite riser under platform motion and hydrodynamic loading to cause seriously fatigue damage and failure of the risers.

Polymer-matrix composites generally have an inherent damping capacity, which is significantly higher than that of conventional steel. Thus the complex composite riser dynamics may be controlled by introducing high damping materials in the composite, and also by selecting the suitable polymer matrix and liner for the riser-body structure. Energy dissipation in a composite riser is expected to actively offset the dynamic motion and bending stress caused by current, waves and vortex-induced loading, and at the same time, alter the basic dynamic characteristics of the riser.

In this report, theoretical and numerical models and analyses have been conducted on structural dynamics of composite risers with VIV motion. The time-dependent composite riser stiffness properties with structural damping have been formulated by the use of polymer viscoelasticity, composite micromechanics and cylindrical laminate shell structure theory. Composite structural dynamic analysis methods are then developed to investigate the basic nature of composite riser dynamics subject to combined ocean current, wave and VIV loading. Numerical results for various cases are given to illustrate the fundamental characteristics of the structure-fluid interaction of the composite risers in ultra-deepwater environments. The effects of resin matrix material, damping factor, lamination lay-up parameters, waves, and lifting and drag coefficients on the VIV dynamics are investigated.

1. INTRODUCTION

Recent advances of lightweight, high-strength, corrosion-resistant composite riser technology [1, 2] provide attractive enabling capability and significant potential of cost savings for ultra-deepwater exploration and production (E & P) operations. At present most research and development work on composite risers have focused on manufacturing and material issues [3, 4], static design and failure evaluation [5, 6], and riser connector integrity [7]. However, fundamental, but also critical, issues on structure-fluid interactions and dynamic responses of deepwater composite risers, especially the vortex-induced vibration (VIV), in ultra-deepwater E & P environments remain unexplored.

The critical issue of structure-fluid dynamic interactions, especially the VIV, of offshore marine risers has received a significant amount of attention [8, 9] in the last few years. The VIV is recognized [10, 11] to be associated with transverse lift force on the risers, which is dynamic and hydroelastic in nature. The hydrodynamic force, caused by periodical shedding of vortices, is governed by riser structural stiffness and geometry. As the vortex-shedding frequency approaches, or is coincident with, the riser structural natural frequency, significant transverse oscillations of the risers may occur. Reduced top tension is expected on a composite riser due to its weight reduction; thus the lateral structural stiffness of the riser string may also be reduced. This could result in large transverse and vertical motions as well as bending stresses in the composite riser under platform motion and hydrodynamic loading. The VIV may increase fluid-structure drag forces, affect static equilibrium and dynamic motions, and cause seriously fatigue damage and failure of the risers.

Polymer-matrix composites generally have an inherent damping capacity, which is significantly higher [12] than that of conventional steel. Thus the complex composite riser dynamics may be controlled by introducing high damping materials in the composite, and also by selecting a suitable polymer liner for the riser body structure. Energy dissipation in a composite riser is expected to actively offset the dynamic motion and bending stress caused by current, waves and vortex-induced loading, and at the same time, alter the basic dynamic motion characteristics of the riser. Equally important, proper introduction of the inherent composite damping together with suitable anisotropic material, structural and lamination tailoring will present the most unique opportunities in optimal design and construction of large composite riser structures to meet the stringent dynamics and strength requirements for advanced riser systems in ultra-deepwater environments.

The objective of this research is to conduct a combined theoretical and numerical study on structure-fluid interactions and structural dynamic behavior of ultra-deepwater composite risers with VIV motion. In the analytical model development, time-temperature dependent material behavior of composite riser joints is considered. The time-dependent viscoelastic composite riser stiffness properties with structural damping are formulated by the use of polymer viscoelasticity, composite micromechanics, and cylindrical laminate shell structure theory, as discussed in Section 2.1. Composite structure-fluid dynamic analysis methods are then developed in Sections 2.2 and 2.3 to investigate the basic nature of composite riser dynamics subject to combined ocean current, wave and VIV loading. Computational mechanics models and algorithms are presented in Section 3. Numerical results for various cases are given in Section 4 to illustrate the fundamental characteristics of the structure-fluid interactions and dynamic response of the composite risers in ultra-deepwater environments. The effects of resin matrix material, damping factor, lamination lay-up parameters and liner materials of composite risers on vortex-induced vibration of deepwater composite risers are investigated. The effects of ultra-deepwater environments, such as ocean waves, lifting and drag coefficients, on the composite riser dynamics are also studied in Section 4.