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Effect of Buoyancy Section Diameter of Deepwater Steel Lazy wave Riser (SLWR) on VIV fatigue

[1]Cheta, H. I., [1]Douglas, I. E., [2]Theophilus-Johnson, K.
[1]Centre of Excellence in Marine and Offshore, Rivers State University, Port Harcourt, Nigeria
[2]Department of Marine Engineering, Rivers State University, Port Harcourt, Nigeria
Corresponding Author: Douglas, I. E,. Email: ibibadouglas@yahoo.com

ABSTRACT: *As offshore exploration and production of oil and gas moves into deepwater/ultra-deepwater fields up to 3,000m and beyond, the demand for buoyancy on deep water production and drilling risers is increasing at near exponential rates. This demand is driven by the need to reduce riser top tension and floater connection loads. Hence, it is important to investigation the effect of buoyancy Section diameter of deepwater steel lazy wave riser (SLWR) on fatigue performance of the riser with respect to vortex-induced vibration (VIV). This study aims to propose an approach that utilizes current profile concept to establish the relationship between current profiles and a long-term VIV induced fatigue damage of SCR. In this study, SCR model was modeled in OrcaFlex using the structural data and environmental data with reference to offshore Nigeria. Three difference buoyancy diameters will be used to generate simulation case files, which will be used to determine the influence of buoyancy section diameter in estimation of VIV fatigue damage. It was observed that the tension at the hang-off point decreases with increasing buoyancy element diameterand this clearlyshows that the buoyancy section diameter has a significant effect in deep water riser configuration design.*

KEYWORDS: *VIV, Buoyancy, SLWR, Fatigue and Deepwater*

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I. INTRODUCTION

There is deliberate policy decision to move oil and gas exploration activities into deepwater/ultra-deepwater fields up to 10,000 ft and beyond, due to the depletion of oil and gas deposit in onshore and shallow water [1]. This has presented several challenges including the design of technical and cost-effective riser systems. High current generates vortex-induced vibrations that give rise to high rates of riser fatigue damage accumulation which leads to failure. As water depth increases, riser designs become more complex and VIV presents one of the biggest uncertainties facing the riser engineers. The riser concept that can be used in such condition, is the Steel Lazy Wave Riser (SLWR) concept which has shown great promise in deepwater. SLWR have provided engineers with the riser solutions for a wide variety of challenging environment. SLWR combines the robustness of SCR with the fatigue characteristic of flexible riser, which make it to be the future riser configuration [1]. The SLWR system relies on a buoyant section in the riser to provide flexibility and enhanced fatigue life, particularly at the touch down zone.

As water depth increases, the interest in buoyancy element on deep water SLWR increases at near to exponential rates. This can be shown in Fig. 1, which shows the net buoyancy figures for a single riser in water depth from 100 to 2,000 meters. This interest is driven by the need to lessen riser top tensile stresses and floating vessel connection loads. However, buoyancy element also significantly increases the riser drag-to-weight ratio, which in turn influences riser dynamic response greatly. In most cases, the advantages to be gained by using buoyancy to lessen static top tension can to a great extent be wiped out by detrimental dynamic response effects.

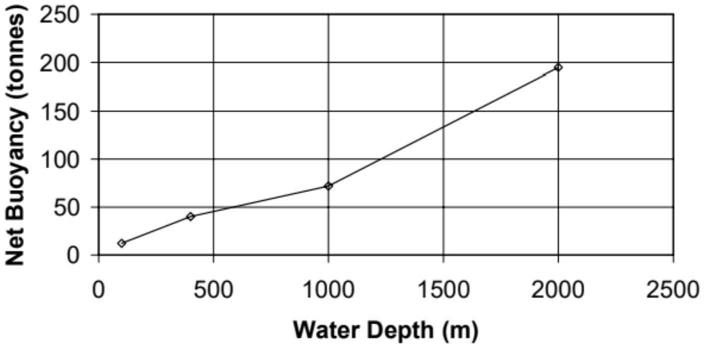

Fig. 1. Riser Buoyancy versus Water Depth[2]

According to O'Brien &O'Sullivan [2], most recent and new deepwater developmenthave between 40 to 100 risers connected to the floating production vessel. This increases the amount of distributed buoyancy elements required for a single field development. An ongoing deepwater study shows that the amount of buoyancy modules required could surpass the yearly limit of two of the major buoyancy elements producers in the United Kingdom.Thus, it is important to investigate the effect of buoyancy section diameter of deepwater riser on VIV and whether it is effectively utilized in performing riser configuration design. This research work is intended to address some of these issues and carry out analysis on the effect of buoyancy element of riser on VIV.

This paper investigates the effect of buoyancy Section diameter of deepwater steel catenary riser (SCR) to sea state loadings and applied floating vessel motions with particular focus on the role of buoyancy diameter in influencing VIVfatigue response. The paper concentrates on steel catenary risers and identifies how buoyancy might optimally be used in developing a cost-effective solution. It also gives some insight into the selection of buoyancy for top tensioned vertical risers.

Previous researches on buoyancy segment of a riser. Zhang., et al[3] investigated the hydrodynamic characteristics of flexible riser with staggered buoyancy elements, both for buoyancy element and bare pipe section. It was found that the VIV response of riser with buoyancy elements is over-predicted, as a result of the hydrodynamic force coefficients generalized from bare cylinder VIV tests may not be valid for cylinder with buoyancy elements. In other to investigate accurately VIV induced fatigue of a riser, Eileen,[4]proposed a new approach that uses current index concept and Fatigue Damage-Current Index (FD-CI) diagram to generate the relationship between current profiles and VIV short term fatigue damage of SCR for fatigue damage estimation. Shankaran et al,[5]carried out a comparative study between SLWR and SCR configurations for mild environment, deepwater applications representing offshore West Africa and for severe environment with moderate water depths, representing North Sea.

II. METHODS AND MATERIALS

The riser parameters used for VIV fatigue analysis for deepwater of the production riser is presented in the Table below:

Table I. Riser Parameters for Fatigue Analysis

Parameter	Values	Unit
External diameter	12.75 /0.324	Inches/m
Wall thickness	0.027	m
Modulus of Elasticity	207	GPa
Water depth	990	MPa
Riser Density	7850	Kg/m^3
Bending Stiffness EI	47.498	MN/m^2
Axial Stiffness EA	4877.713	MN
Mass per unit Length in air	188.122	Kg/m
Mass per unit length in water	109.857	Kg/m

Figure 2 below shows the schematic of the riser pipe with buoyancy section. The length of the buoyancy section, denoted L_b and the buoyancy section diameter OD_b. In this paper, the buoyancy section diameter was the key variable for this study.

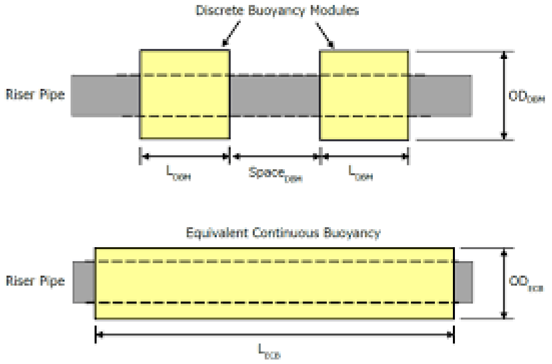

Fig. 2. Schematic of the Riser with a Buoyancy Section

The SCR is modelled in Orcaflex to carry out VIV fatigue analysis. The static configuration analysis of the SCR is performed without environmental loading to determine the equilibrium configuration of the riser upon the application of static loads such as the weight and buoyancy of the riser. The static analysis will be the basis and the starting point for the dynamic analysis.

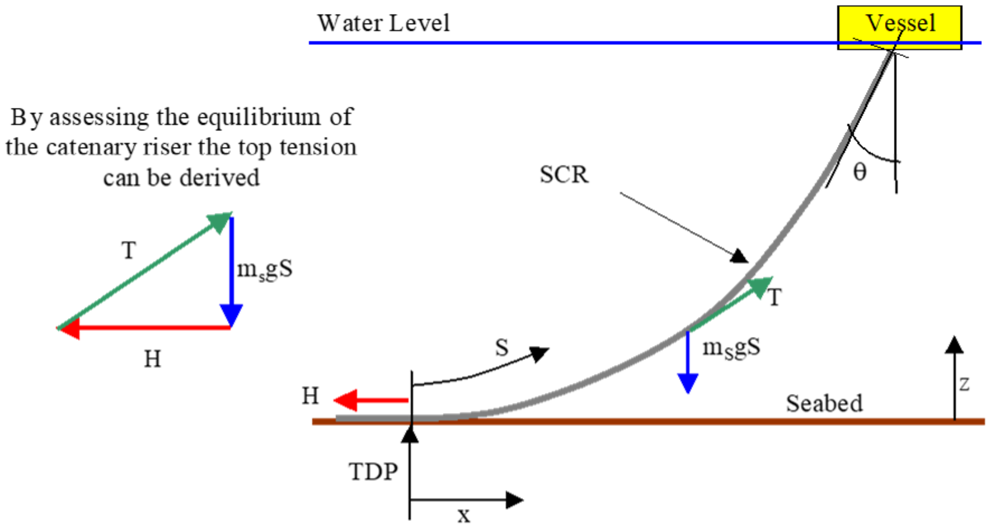

Fig. 3. Free body diagram for a Steel Catenary Riser[6]

The governing catenary equation is:

$$\frac{d^2z}{dx^2} = \frac{m_s g}{H}\left[1 + \left(\frac{dz}{dx}\right)^2\right]^{1/2} \tag{1}$$

Where:

Z = the vertical distance from the seabed to a point on the riser
X = the horizontal distance from the TDP to a point on the riser
m_s = the submerged mass per unit length
g = acceleration due to gravity
H = the horizontal force in the riser, and the tension at the TDP

The solution for the above catenary equation is:

$$Z = \frac{H}{m_s g}\left[\cosh\left(\frac{m_s g x}{H}\right) - 1\right] \tag{2}$$

$$S = \frac{H}{m_s g}\sinh\left(\frac{m_s g x}{H}\right) \tag{3}$$

Where:

S = the length of the riser from the TDP

$$H = \frac{m_s g S}{\tan\alpha} \qquad (4)$$

Where:

H = tension at the TDP
α = angle of the riser to the vertical

2.1 Mathematical model

The riser investigated in this paper is modeled as a beam-like continuous system. It is considered to have a uniform internal flow and harmonic excitation. The riser is submerged in the ocean and subjected to external hydrodynamic forces from both wave and current. The riser closest to the seabed is joined with the flowline and the top riser section is joined with the floating platform. The analysis of riser vibration in deep water depends mainly on the mathematical modeling and environmental loads. The environmental loads acting on the riser are waves and current. However, this study was based on the following fundamental assumptions.

- The riser cross section is homogeneous.
- The waves and ocean currents act in the same direction.
- The cross section of the riser is a uniform ring.
- The riser deformation is considered as a small deflection.
- The top and bottom boundary of the riser are hinged.

The equation below represents the transverse vibration of the riser which was modeled as a beam-like continuous system. It will be used as a mathematical model of the study.

$$m\frac{\partial^2 u}{\partial t^2} + EI\frac{\partial^4 u}{\partial x^4} + C\frac{\partial u}{\partial t} - \frac{\partial}{\partial x}\left[P\frac{\partial u}{\partial x}\right] = F_t \qquad (5)$$

Where:

U =Displacement of the riser,
M =Mass of riser and internal fluid inside the riser,
EI =Riser bending stiffness,
P =Riser effective axial tension
Ft =External force in the tangential direction.

2.2 External forces

The external fluid forces in the right-hand side of equation (5) is defined using Morison equation of lift and drag forces. Hydrodynamic drag force is modeled by the Morison equation as follows:

$$F_D = 0.5\rho_w \mathrm{D}\, C_D(\mathrm{V} - \dot{U})\left|V - \dot{U}\right| + \rho_w A_{OH} C_m(\dot{V} - \dot{U}) + \rho_w \mathrm{A}\dot{V} \qquad (6)$$

Where V, C_D, C_m are wave and current velocity, drag coefficient and added mass coefficient, respectively. The lift force which is the force induced by vortex shedding in transverse direction is given as:

$$F_t = 0.5\rho_w \mathrm{D} C_L V^2 \sin(\omega_v t) \qquad (7)$$

Where:

V =Instantaneous velocity, and
$V = V_m \sin(\omega t)$,

C_L is the lift coefficient and $\omega_v$is the vortex shedding frequency

2.3 Modal Analysis

Modal analysis is used to determine the mode shape and the natural frequencies of a vibrating system by ignoring the damping factor and setting the force term to zero for an equation of motion. In order to calculate the response of the riser (VIV), the riser governing equation of motion given in equation (5) is solved using finite element method. In this paper, time domain analysis with 3-hour duration is performed to develop the SCR response due to dynamic loading from waves and currents. By assuming the boundary condition as simply supported at both ends, the analytical values of natural frequencies are calculated as defined in eqution. (8) [7].

$$f_n = \frac{1}{2\pi}\sqrt{\frac{EI}{M}\left(\frac{n\pi}{L}\right)^4 + \left(\frac{n\pi}{L}\right)^2\frac{P}{M}} \qquad (8)$$

f_n= the nth natural frequencies of the structure

III. RESULTS AND DISCUSSIONS

Three different diameters of buoyancy elements were investigated for: D = 0.762 m; 0.807 m, and 0.838 m respectively. The starting position of the buoyancy element was set as 756 m from the hang off point and 300 m from the touch down point and the length of the buoyancy element was set at 450m. The effective tension, accumulated fatigue damage and VIV fatigue life for SLWR were calculated for the three diameters using a uniform current speed of 0.94m/s and the same riser data as mentioned above.

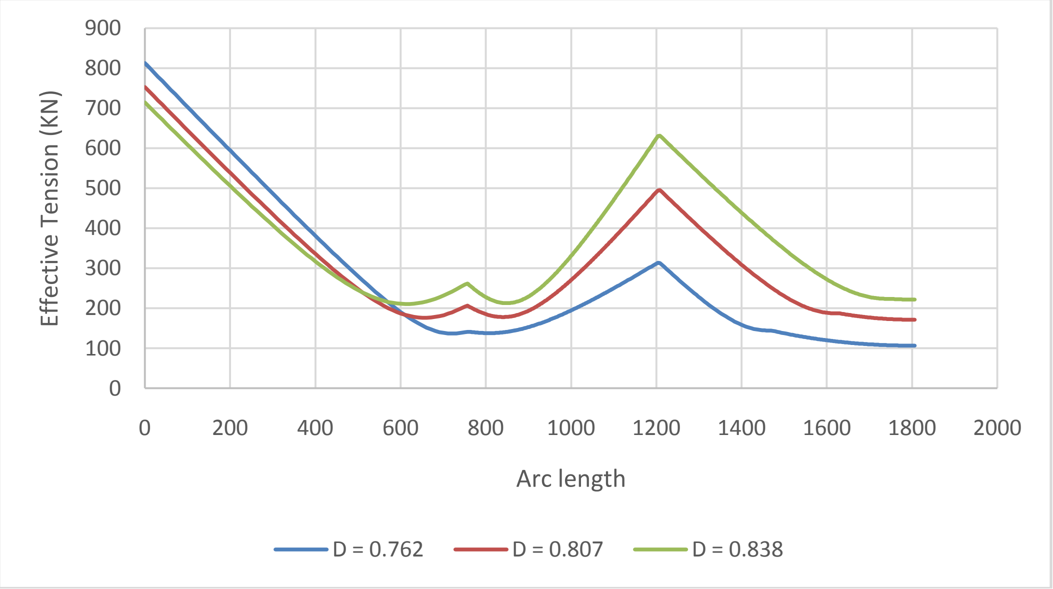

Fig. 4. Effective Tension for Various buoyancy section diameters

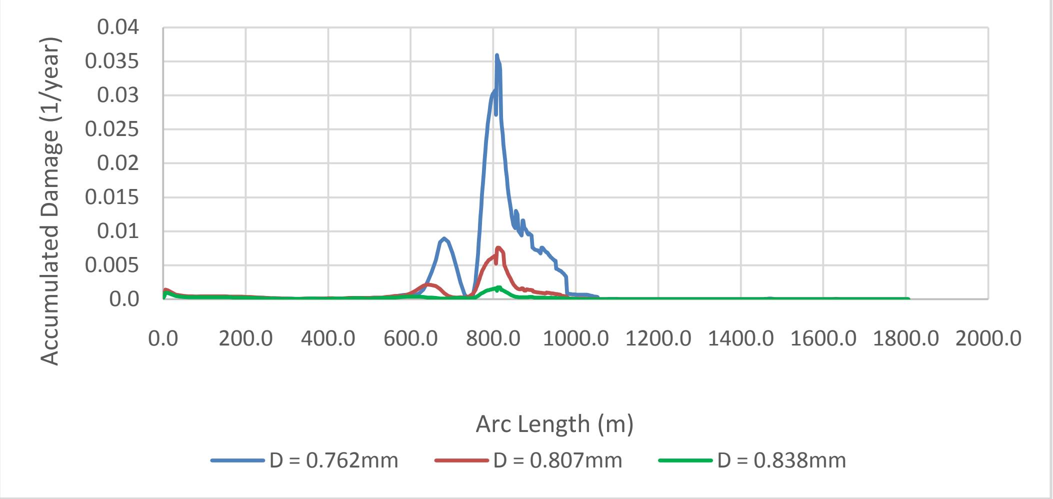

Fig. 5: Fatigue damage for various buoyancy section diameter

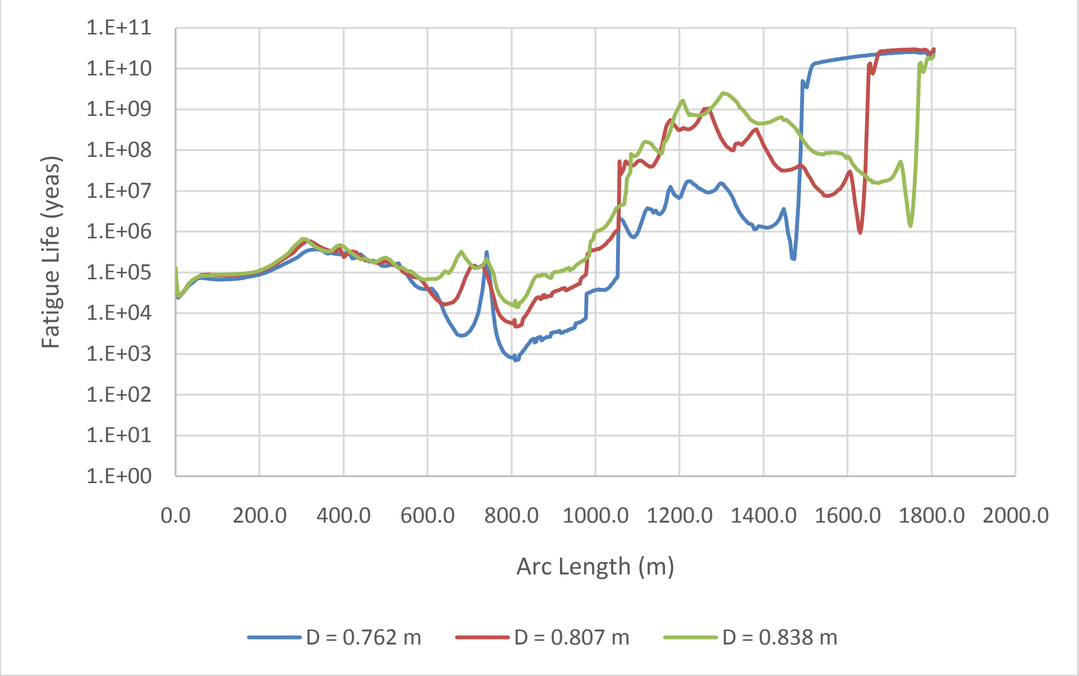

Fig. 6. Fatigue Life for various buoyancy section diameter

Table II Summary of the Results

Diameter	T_{top} (KN)	D_F(1/year)	FL (years)
0.762m	812	0.05180	482
0.807m	752	0.00759	3292
0.838m	714	0.00175	14290

The results in Table II above indicates that the tension at the hang-off point decreases with increasing buoyancy element diameter and in increasing the buoyancy element diameter, the fatigue life of a SLWR increases. It can also be observed from figures 3 and 4 above that the worse fatigue damage is no more at the touch down point as the case of a SCR, but at the sag bend of a SLWR due to high curvature at that area. The buoyancy modules in SLWR helps to decouple the effect of vessel motion and surface hydrodynamic loads at the touch down point.

IV. CONCLUSION

In this study, the model of transverse vibration of a SLWR in deep water was carried out with Orcaflex to investigatethe effects of buoyancy section diameter on VIV fatigue. The current speed, effective tension, and stress were the primary factors affecting the fatigue performance of SCR. In this study, it was observed that the fatigue of SLWR varies along the arc length and are more critical at the hang off point and the touch down zones.

From this study, it can be deduced that:

SLWRs will be a preferable option over SCRs for deeper water depth when riser hang-off tensions are very high or needs to be controlled and in severe environments for improved strength and fatigue response. This can be seen from Stone and perdido oil field which are Shell asset with SLWR and operated at water depth of nearly 3000m.

The results in Fig. 5 above indicate that the tension at the hang-off point decreases with increasing buoyancy element diameter and from the Fig. 6 above increasing the buoyancy element diameter the fatigue life at the touch down point increases.

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Nomenclatures

Symbols	**Definition**
CFD	Computational Fluid Dynamics
DFF	Design Fatigue Factor
DNV	Det Norske Veritas
FPSO	Floating Production Storage and Offloading
FEM	finite element method
GOM	Gulf of Mexico
HRT	Hybrid Riser Tower
SCR	Steel Catenary Riser
SLWR	Steel Lazy Wave Riser
TDR	Touch Down Region
TDP	Touch Down Point
TLP	Tension Leg Riser
TTR	Top Tension Riser
VIV	Vortex induced Vibration

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