Vortex Induced Vibration on Lazy Waves Steel Catenary Risers: A Case Study of Deep-Offshore Nigeria

Abisoye Abidakun¹, Franklin Okoro² ¹University of Aberdeen, United Kingdom ²Clean Script Group, Nigeria

Abstract:- This work was carried out on Deep - Offshore Nigeria JONSWAP based Steel Catenary Riser (SCR) design data of length of 3044m with buoyancy section of 600m clamped to an FPSO in water depth of 2000m. Also, appropriate meteocean data for Offshore Nigeria was used to simulate the environmental conditions. The entire process was statically and dynamically simulated using different wave spectra on Orcaflex software. The fatigue analysis results for the lazy-wave SCR with Vortex Induced Vibration (VIV) gave life and damage values as 15.4 years and 0.000177 respectively. While the fatigue life and damage results without VIV gave 17.99 years and 0.000152. At the buoyancy section, the Effective Tension (EF) for the VIV analysis at arc lengths 2000m, 2120m, 2240m, 2360m, 2480m and 2600m gave maxima values at 477KN; 418KN; 420KN; 477KN; 571KN and 685KN respectively. Similarly, results from the Non-VIV analysis for the arc lengths gave 440KN; 386KN; 390.8KN; 451KN; 547KN and 663.5KN respectively. The results show that VIV analysis led to a reduced fatigue life and higher damage value while buoyancy section gave higher tension when compared with Non-VIV. From the foregoing, this work shows that VIV plays a significant role in the overall fatigue of a lazy wave SCR in Deep Offshore Nigeria with great impact at the buoyancy section and hence should be properly taken into consideration in its design in Deep-Offshore Nigeria.

Keywords: Steel Catenary Riser, Deep-Offshore Nigeria, Vortex Induced Vibration, Orcaflex software.

I. INTRODUCTION

Increasingly oil and natural gas deep water exploration and production in deep waters has increased the cost and technological challengesof the riser systems. The use of steel catenary risers (SCR) has become a real-time potential solution for deep-water production systems and has become of increasing interest to oil and gas companies due to the low cost in relation to the flexible riser prices and the technical limitations imposed by the ultra-deep-water and deep-water scenarios (Mooroka and Tsukada, 2013).

A riser is a long cylindrical pipe employed in offshore oil fields to transport the produced hydrocarbon or injection fluids from subsea well to the offshore platforms or vessels or from a production platform to another. Based on the various operational offshore conditions, there are various configurations for the risers.

With an increasing deep offshore and forecasted increase in deep offshore activities in Nigeria, the lazy wave steel catenary riser would become increasingly popular.

A lazy wave steel catenary riser is a form of steel catenary riser with the attachments of buoyancy materials at certain length from the hang-off point of the riser, thus forming a wave configuration (called the hog bend or arch bend) at a certain height above the touch down location of the riser on the sea bed. As seen in figure 1.1, this riser configuration was the focus of this work.



Figure 1.1: Configuration of a lazy wave steel catenary riser. (Wang et al., 2015)

Vortex induced vibration (VIV) has been known as the most important design issue for slender marine structures such as cables, pipelines and risers, especially for environments with high current profile (Xue*et al.*, 2014). When the riser is exposed to fluid flow, vortices are generated in the wake of the riser. The alternate vortex shedding leads to oscillating cross-flow (CF) and in-line (IL) forces, which cause the riser to vibrate perpendicularly and in-line to the ambient flow (Wang *et al*, 2014). The high frequency vibrations generate severe cyclic stresses, which would contribute significantly to fatigue damage. This problem becomes more crucial in riser design as oil and gas explorations move to deeper water area, since large current variation acting on the riser may lead to the Strouhal frequency varying over the riser's length, having the effect that high order and multi-frequency can be candidate for lock-in oscillation (Xue*et al*, 2014).

SCR lines are commonly subjected to fatigue loads due to VIV, particularly in the touchdown zone, due to platform motions, waves and current and research has shown that the Touch- down point (TDP) where SCR starts to contact the seabed is one of the critical positions prone to fatigue failure. Therefore, it is essential to predict the VIV response near TDP accurately in a SCR design. (Wang et al, 2013).

According to Srinil et al. (2009), one of the key issues in the analysis and design of SCRs in the ocean current is to estimate and control the fatigue damage due to vortex-induced vibration. This is particularly important especially in the Offshore Nigeria waters where low currents exists at the bottom sea environment which incidentally is the Touch Down Zone (TDZ). At this region, as shown by Ezeonwumelu et.al (2017), fatigue damage accumulation is high especially due to In-line VIV. This is of great importance to International Oil Companies designing SCRs for Nigeria waters as taking into consideration VIV will minimize cost as well as maximize profit in the long term.

II. LITERATURE REVIEW

2.1 Concept of Flow around Cylindrical Bodies

An introduction to flow-induced vibrations, an examination of the fluid dynamic forces on a rigid body when placed in a flowing fluid and the way in which these dynamics are modified when the body is elastic or compliant is considered. The body experiences dynamic forces that are created by the way in which the fluid flows around and past the body. These forces, which are primarily a function of the shape of the body, arise from flow separation and possible reattachment, and can be both quasi-steady and fluctuating. If the body is not entirely rigid and able to deflect or respond to these dynamic forces, interactions transmitted through a displacement feedback mechanism from the structure can cause alterations to the forces such that continuous or near continuous structural vibrations can be excited. These are referred to as fluid-elastic vibrations and are especially common for circular cylindrical structures and cables (King, 1977). Such vibrations are the subject of this article.

2.1.1 Excitation of cylindrical structures

In steady flow, both steady and fluctuating forces are created on a circular cylindrical member due to flow separation and vortex shedding (King, 1977). Although the excitation mechanism considered here is restricted specifically to vortex shedding there are several other sources of excitation which are reported in varying degrees of completeness elsewhere.

In ocean waves (particularly long period waves) and in waves plus steady currents, transient vortex shedding and impact excitation have been recorded (Wiegel, 1964). Structures situated in the wakes of other structures can be excited by buffeting (generally broad band turbulence) as well as wake galloping and vortex shedding. Galloping (or flutter) of bridge decks and cables, particularly iced transmission lines is another related class of problem as is acoustic resonance in shell and tube heat exchangers. There are many other examples of fluid-elastic vibrations not covered in this paper including heat exchanger tubes, cooling towers, ships' hulls, hydraulic gates and valves (Weaver, 1976).

If the cylinder remains essentially stationary, the steady and fluctuating drag forces, and fluctuating lift forces (for an isolated cylinder there are no steady lift forces) can be calculated from empirical methods based on experimentally derived figures. According to King (1977), the ranges of these variables shows that they are functions of Revnolds number and that they are also dependent upon turbulence scale and intensity and body surface roughness. The cylinder "steady" deflection can be calculated by assuming a uniformly distributed loading of one velocity head and the appropriate force coefficient. In much the same way, the fluctuating deflection can be calculated, although this will probably result in an over-estimate because the vortex shedding occurs in "patches" along the cylinder length, with the vortex-generated forces in adjacent patches not necessarily being in phase or being equal in magnitude. The lengths of cylinder over which the vortex shedding patterns are comparable and complementary are termed the "correlation lengths" and these vary as a function of Reynolds number (Re) for a comparatively rigid cylinder, as shown in Table 2.1 below.

Table 2.1: Correlation Lengths and Reynolds Numbers of Smooth Cylinders (Source: King, 1977)

Reynolds number	Correlation length
40 <re<150< td=""><td>15-20d</td></re<150<>	15-20d
150 <re<10<sup>5</re<10<sup>	2-3d
1.1×10 ⁴ <re<4.5 x10<sup="">4</re<4.5>	3-6d
≥10 ⁵	0.5d
2×10 ⁴	1.56d

The frequency (fv) of pairs of vortices is a function of velocity (V) cylinder diameter (D) and Reynolds number. The non-dimensional wake Strouhal number, S, is defined as S $= f^*D/V$, and over a wide range of Reynolds numbers 102 < Re<105, S = 0.2. The general relationship between S and Re is well documented (Fig. 2.1), but absolute values of S also depend upon cylinder surface roughness, length/diameter ratio, turbulence levels, proximity effects and velocitv profiles. Also shown in the figure are the Reynolds number ranges of interest in typical marine applications. Each time a vortex is shed from the cylinder, it alters the local pressure distribution, and the cylinder experiences a time-varying force at the frequency of vortex shedding. If the natural frequency of the cylinder is sufficiently close to the dominant frequency of vortex shedding, and if the cylinder damping is sufficiently low, sustained vibrations of the cylinder can excited. During vibration amplitude build-up, be the correlation length of vortex shedding increases appreciably and the vortex shedding is controlled by the cylinder motions.

2.2 Overview on VIV in risers

As most of the oil and gas industry exploration and exploitation operations have been increasingly moving into the deep water offshore zones which has prompted the use of cylindrical risers in deep waters.

During production the risers are exposed various flow condition which contributes to the fatigue performance and life of the riser, one of which is VIV. Therefore, an extensive research into the fatigue of risers which are installed in deep water areas due to VIV needs to be more investigated. Although various VIV mitigation methods are have been implemented which includes VIV suppression device like fairings and strakes, VIV is still regarded as a very pivotal part in deep water SCR design process, especially when they operate in regions with high current(Bai & Bai, 2005).

2.2.1 Vortex induced vibration

Vortex-induced vibration is a prominent design problem affecting risers most especially in the deep-water offshore areas where the current intensity is high. VIV takes place whenever there is an alternate shedding of vortices behind a cylindrical structure due to the separation of flow by the cylindrical structure experiencing a steady flow developing an unsteady force of vibration which leads fatigue or when exposed to fluid flow resulting to the generation of oscillatory flow around the body close to its natural mode of frequency. Risers at greater depths of water (deep-water) have a higher tendency to experience VIV because, the intensity of currents are exceptionally higher in areas of greater depth, the longer the length of the riser the lower its natural frequency mode resulting in the reduction of the size of current needed to stimulate VIV (API RP 2RD,1998).

2.2.2 Types of vortex induced vibration

VIV effects on risers can be said to be in-line and cross-flow to the riser, with the later, being the most significant causes of fatigue damage on riser (API RP 2RD,1998).

Also, accurate prediction of VIV was dependent on whether the riser was in a shallow water or deep-water. On the first condition, the occurrence of VIV was based on the magnitude of the current which further determines whether it is in-line or cross-line. On the second condition, VIV will occur even in low magnitudes of current along the length of the riser due to the reduction of the natural frequency mode of the riser which in turn will vary along the length of the riser (API RP 2RD,1998).

This paper investigated the effect of VIV on the fatigue SWLR if applied in deep offshore West Africa environment.

III. METHODOLOGY

3.1 Riser Material Properties

A typical SCR design data for an FPSO in Offshore Nigeria was collated. Relevant data below were imputed into Orcaflex software interface.

Steel physical data include:

- i. Riser length 3044m (assumed)
- ii. Buoyancy length 600m (i.e. from 2000 6000m -Felisita et al, 2015)
- iii. Inner diameter 0.254m
- iv. Wall thickness- 0.026m
- v. Pipe material density -7850 kg/m^3

The general design criteria considered were the following environmental data.

- i. Design water depth: 2000m
- ii. Seabed Temperature: +4°C
- iii. Sea surface Temperature: + 30°C

As displayed in the figures 3.2-3.4, the Orcaflex interface for the modelling processing of the riser taking into consideration the above design materials and other design parameters and criteria.

		e type i (nomo	geneousripej					
. Set the as hen dick 'Ne	sociated Ho ext' to proce	mogeneous Pipe C ed.	oata.					
omogeneou	s Pipe Data	-					Properties	
laterial:			Pipe Geometr	v:			Contents Density (te/m^3):	
Steel		~	Outer		Wall		0.000	
latorial Done	sity (ta/m^3	0.	Diameter	(m)	Thickness (m))		_
	7 850]		0.306	0.03	26	[per unit length – including contents]	
lasticity:	11020	1					Weight in air: 1.761kN/m (0.180te/m)	
Young's M	odulus	Poisson					Weight in water: 1.021kN/m (0.104te/m)	
(kPa)	Ratio					Diam/Wt Ratio: 0.300m/(kN/m) (2.938m/(te/m))	
21	12.00E6	0,293					USED IN (& CONTENTS DENSITY)	
Diamete	are (m)	Mass ner Linit	7					
Diamete Outer	ers (m) Inner 0.254	Mass per Unit Length (te/m)]					
Diamete Outer 0.306 ension, Ben	ers (m) Inner 0,254 ding:	Mass per Unit Length (te/m) 0.180]					
Diamete Outer 0,306 ension, Ben B	ers (m) Inner 0.254 ding: Bending	Mass per Unit Length (te/m) 0.180 Axia]	Te	orsional			
Diamete Outer 0,306 ension, Ben B Stiffne	ers (m) Inner 0,254 ding: Bending ss (kN.m^2)	Mass per Unit Length (te/m) 0,180 Axia) Stiffne	ss Poissor	n St	orsional tiffness	Compression		
Diamete Outer 0,306 Tension, Ben B Stiffne X	ers (m) Inner 0.254 ding: Bending ess (kN.m^2) y	Mass per Unit Length (te/m) 0.180 Axia) Axia Stiffne (kN)	Poissor Ratio	n Si (ki	orsional tiffness N.m^2)	Compression is limited		
Diamete Outer 0,306 ension, Ben B Stiffne x 47.926E	ers (m) Inner 0,254 ding: Bending ss (kN.m^2) y 3	Mass per Unit Length (te/m) 0.180 Axia) Axia) Stiffne (kh) ~ 4.84	Poisson Ratio 19E6 0.2	n St (ki 93	orsional tiffness N.m^2) 37.066E3	Compression is limited No		
Diamete Outer 0,306 ension, Ben B Stiffne x 47.926E itress:	ers (m) Inner 0.254 ding: Bending ss (kN.m^2) y 3 	Mass per Unit Length (te/m) 0.180 Axia) Axia Stiffne (kl) ~ 4,84	Poisson Ratio 19E6 0.2	n St (ki 93	orsional tiffness N.m^2) 37.066E3	Compression is limited No		
Diamete Outer 0,306 Fension, Ben 8 Stiffne x 47.926E Stress Stress Dia Outer	ers (m) Inner 0.254 ding: bending ss (kN.m^2) y 3 meters (m)	Mass per Unit Length (te/m) 0, 180 Axia) Axia) Stiffne ((N) ~ 4,84	Poissor Ratio 9E6 0.2 Stress Loading	n Si (ki 93 Factors	orsional tiffness N.m^2) 37.066E3	Compression is limited No		
Diamete Outer 0,306 Fension, Ben 8 Stiffne x 47.926E Stress: Stress Dia Outer	ers (m) Inner 0.254 ding: bending sss (kN.m^2) y 3 meters (m) Inner	Mass per Unit Length (te/m) 0, 180 Axia) Axia) Stiffne ((dv) ~ 4.84	Stress Loading Bending	n Si 93 Factors Shear	orsional tiffness N.m^2) 37.066E3 Torsional	Compression is limited No		

Figure 3. 1: SCR Material Description on Orcaflex Interface 1

*******							Include	Torsion:	Top End:	P-y Model:				
ieel Ca	atenary Rise	e					No	~	End A	~ (none)		~		
nectio	on:													
		Cor	nnect	to			Object I	Relative Po	osition (m)	Height above	End	d Orientation (d	leg)	Release at
d		C	bject	É			x	У	z	seabed (m)	Azimuth	Declination	Gamma	Start of Stag
F	PSO					~	34.904	0.07	2 -7.02	2	0.00	0.00	90.00	~
A	nchored					~	1696.07	0.06	5 -0,51·	-0.667	0.00	0.00	0.00	~
nectio	on Stiffness:							5	Statics:					
			Sti	ffness (kN	I.m/deg)	15		Included	Statics Meth	nods	Include Seabe	ed Lay Azimut	h As Laid
hd	хb	pending			y bend	ing	Twist	ing	in Statics	Step 1	Step 2	Friction	(deg)	Tension (
A	0.00		~	~		~		~	$\mathbf{\nabla}$	atenary 🗸 F	ull Statics 🗸	\sim	180.0	0.0
3	0.00		~	~		~		~					5	et Lay Azimul
tructu	0.00 Ire Pre-ben	d Attachmer	nts (~ Contents	Applie	d Loads Ca	tenary Cor	vergence	Full Statics	Convergence Fluid	d Loads VIV	/ Results [Drawing VIV Dr	iet Lay Azimut awing
3 tructu ection	0.00 re Pre-ben s: 10	d Attachmer	Iengt	~ Contents th = 3044.	Applie 000m	d Loads Ca	tenary Cor	nvergence	Full Statics	Convergence Fluid	d Loads VIV	/ Results [Drawing VIV Dr	e Values
3 tructu ection No.	0.00 re Pre-ben is: 10	d Attachmer Total Line Typ	lengt e	~ Contents th = 3044.	Applie 000m	d Loads Ca Section Length (m)	tenary Cor	Expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m)	d Loads VIV Number of Segments	/ Results (Clash Check	Drawing VIV Dr Cumulativ Length (m)	iet Lay Azimut awing e Values Segments
ructu ection	0.00 re Pre-ben is: 10	d Attachmer Total Lin. Typ	Its I lengt e	~ Contents th = 3044.	Applie	d Loads Ca Section Length (m) 300.000	tenary Cor	Expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000	d Loads VIV	/ Results (Clash Check	Cumulativ Length (m) 300.000	e Values Segments
ection No.	0.00 re Pre-ben is: 10 1 Line Ty 2 Line Ty	d Attachmer Total Linx Typ pe 1 pe 1	lengt ie	~ Contents th = 3044.	Applie	d Loads Ca Section Length (m) 300.000	tenary Cor	expansio Factor	Full Statics	Convergence Flui Target Segment Length (m) 30.000 30.000	d Loads VIV	/ Results (Clash Check	Cumulativ Length (m) 300.000 600.000	e Values Segments
ructu ection No.	0,00 re Pre-ben is: 10 1 Line Ty 2 Line Ty 3 Line Ty	d Attachmer Total Linu Typ pe 1 pe 1 pe 1		~ Contents th = 3044.	Applie	d Loads Ca Section Length (m) 300.000 300.000	tenary Cor	Expansio Factor	Full Statics	Target Segment Length (m) 30.000 30.000 30.000	d Loads VIV	Clash Check	Cumulativ Length (m) 300.000 900.000	e Values Segments
ection	0.00 re Pre-ben is: 10 1 Line Ty 2 Line Ty 4 Line Ty	d Attachmer Total Line Typ pe 1 pe 1 pe 1 pe 1 pe 1	lengi e ie	~ Contents th = 3044.	Applie	d Loads Ca Section Length (m) 300.000 300.000 300.000	tenary Cor	Expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000 30.000 30.000 30.000	A Loads VIV	Clash Check	Cumulativ Length (m) 300.000 600.000 900.000 1200.00	e Values Segments 10 30 40
ection No.	0.00 re Pre-ben is: 10 1 Line Ty 2 Line Ty 3 Line Ty 4 Line Ty	d Attachmer Total Lin Typ 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1	lengt lengt	~ Contents th = 3044.	Applie	d Loads Ca Section Length (m) 300.000 300.000 300.000 300.000	tenary Cor	Expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000 30.000 30.000 30.000	A Loads VIV	/ Results 1 Clash Check	Cumulativ Length (m) 300.000 600.000 900.000 1200.00 1500.00	e Values Segments 10 20 40 50 50
ection No.	0.00 re Pre-ben is: 10 1 Line Ty 2 Line Ty 4 Line Ty 5 Line Ty 6 Line Ty	d Attachmer Total Un Typ pe 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1	lengi e e	~ Contents th = 3044.	Applie	d Loads Ca Section Length (m) 300.000 300.000 300.000 300.000 300.000	tenary Cor	Expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000 30.000 30.000 30.000 30.000 30.000	d Loads VIV Number of Segments 10 4 10 4 10 4 10 4 10 4 10 4	/ Results I Clash Check	Cumulativ Length (m) 300.000 600.000 900.000 1200.00 1500.00 1800.00	e Values Segments 10 20 30 40 50 60
No.	0.00 Pre-ben is: 10 1 Line Ty 2 Line Ty 3 Line Ty 4 Line Ty 5 Line Ty 6 Line Ty 7 Line Ty	d Attachmer Total Lin Type 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1 pe 1	lengi e xe	Contents	Applie	d Loads Ca Section Length (m) 300.000 300.000 300.000 300.000 300.000	tenary Cor	expansion Expansion Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000 30.000 30.000 30.000 30.000 30.000	d Loads VIV		Cumulativ Length (m) 300.000 600.000 1200.00 1200.00 1500.00 2100.00	e Values Segments 20 30 40 50 60 70
action No.	0.00 Pre-ben is: 10 1 Line Ty 2 Line Ty 4 Line Ty 5 Line Ty 6 Line Ty 8 Line Ty 8 Line Ty	d Attachmer Total Lin Type 1 pe 1	lengi e xe	~ Contents th = 3044.	Applie 000m	d Loads Ca Section Length (m) 300.000 300.000 300.000 300.000 300.000 300.000	tenary Con	expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000 30.000 30.000 30.000 30.000 30.000 30.000 30.000	Number of Segments VIV 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4	/ Results (Cumulativ Length (m) 300.000 600.000 900.000 1200.00 1500.00 1500.00 1500.00 2200.00	e Values Segments 10 20 30 40 50 60 70 80 80
action No.	0.00 rre Pre-ben is: 10 1 Line Ty 2 Line Ty 4 Line Ty 4 Line Ty 5 Line Ty 6 Line Ty 7 Uine Ty 9 Line Ty	d Attachmer Total Lin Typ pe 1 pe 1		~ Contents th = 3044.	Applie 000m	d Loads Ca Section Length (m) 300.000 300.000 300.000 300.000 300.000 300.000 300.000	tenary Cor	vergence Expansio Factor	Full Statics	Convergence Fluid Target Segment Length (m) 30.000 30.000 30.000 30.000 30.000 30.000 30.000 30.000 30.000	Number of Segments VIV 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4 10 4	Results	Cumulativ Length (m) 300.000 600.000 900.000 1200.00 1500.00 1800.00 2100.00 2400.00 2400.00	e Values Segments 10 20 30 40 50 60 70 80 90 90



Edit Li	ine Data: Steel Catenar	yittisei											
e:					I	n <mark>clud</mark> e Torsi	ion: Top	e End:	P-y Model				
el Ca	atenary Riser					No	~ En	id A 🔻	(none)		~		
ecua	on: Ci	onnect to			0	bject Relati	ive Position	(m)	Height above	Enc	d Orientation (dec	a)	Release a
		Object			×	<u> </u>	y	z	seabed (m)	Azimuth	Declination	Gamma	Start of Sta
F	PSO			1	/ 34	.904	0.072	-7.022	Te le en	0.00	0.00	90.00	~
A	Anchored			~	/ 169	6.07	0.066	-0.514	-0.667	0.00	0.00	0.00	~
ectio	on Stiffness:	Crifferen	(1.01 - 1.1)	6			Static	s:	Charling Ma		Testuda Cashad		6
a	x bendina	Surnes	v bendi	na.	1	Twisting	in St	atics	Step 1	Step 2	Friction	(deg)	Tension
	0.00	~ ~	1.000		\sim		-	Cate	enary 🗸	Full Statics 🗸		180.0	00 0.
	0.00	~ ~			~	8	4					5	Set Lay Azimu
									1.22				
uctu	re Pre-bend Attachm	ents Conte	nts Applied	d Loads	Catena	ry Converg	ence Full	Statics Co	nvergence Flu	id Loads VI	V Results Dra	awing VIV Dr	rawing
atics	VIV:	D	ynamics VIV	•			1.1						
one		~	Milan Wake (Oscillator	Ś.	\$	~						
Whole	e Line VIV Properties:												
	Filter												
	Period (s)	10.0	000										
_	84- d-1	1.4.	10			1		1.4	1.0.	- 4-	-7	T-10.1	Charles 1
	Parameters	Klacc	k2acc		r lacc	r2ad	CC	K laer	k2aer	r laer	r2aer	Value	Strouhal
De	fault	1.364	0.3	200	5.40	0 0	0.000	3.100	0.050	2.150	0.450	0.100	0.200
ectio	on VIV Properties:												
No	Line	50	ction	VT	v	Dunam	ics VIV	Ŧ	nline Drag	Traces	erse A		
110.	Type	Leng	th (m)	Diamet	er (m)	Enal	bled	Ampli	fication Factor	Force F	actor		
5	5 Line Type 1		300.000		2	2	2	1.000		~	1.000		
6	6 Line Type 1		300.000		~		4	1.000		~	1.000		
	/ Line Type 1		300.000		~	\simeq		1.000		~	1.000		
e Typ	pes Attachment T	ypes	900.000 P-y Models. Figu	w	ake Mode	els Si Material	HEAR 7 Dat	1.000 ta V tion on (VA Data Drcaflex Inte	Profile Grap	1.000 V	Cancel	Nex
e Typ Edit L	pes Attachment T	ypes	P-y Models. Fig	w	ake Mode	els Si Material	HEAR 7 Dat Descrip	1.000 ta V: tion on (VA Data Drcaflex Inte P-y Model	Profile Grap	1.000 ♥	Cancel	Nex
e Typ Edit L ie: eel C	pes Attachment T Line Data: Steel Catenar Catenary Riser	ypes	P-y Models. Fign	w	ake Mode 3: SCR	els SI Material nclude Tors No	HEAR7 Dat Descrip	tion on (P-y Model	Profile Grap	1.000 ¥	Cancel	Nex
e Typ dit L e: eel C	pes Attachment T Line Data: Steel Catenar Catenary Riser	ypes	P-y Models. Fig	w	ake Mode 3: SCR	els SI Material nclude Tors No	HEAR7 Dat Descrip	1.000 tia Vi tion on (o End: nd A	VA Data Drcaflex Into P-y Model	Profile Grap	1.000 ¥	Cancel	?
e Typ dit L e: eel C	Line Data: Steel Catenar Catenary Riser	ypes	P-y Models. Fig	w	ake Mode	els Si Material nclude Tors No	HEAR 7 Dat Descrip	1.000 tra V: tion on (p End: nd A	VA Data Drcaflex Into P-y Model (none) Height above	Profile Grap	1.000 V	Cancel	? Release a
e Type dit L e: eel C	pes Attachment T Line Data: Steel Catenar Catenary Riser on:	ypes	P-y Models. Fig	w	ake Mode B: SCR	Material Ndterial	HEAR7 Dat Descrip ion: Top V Er ive Position	1.000	VA Data Drcaflex Inte P-y Model (none) Height above seabed (m)	Profile Grap orface 3	1.000 V h OK) Cancel	? Release a Start of Sta
dit L e: eel C	pes Attachment T Line Data: Steel Catenar Catenary Riser on: C	ypes	P-y Models. Fig] w		Material ndude Tors No bject Relati (.904 c o 7	HEAR7 Dat Descrip	1.000 tia V: tion on (b End: tim) z -7.022	VA Data Drcaflex Internet of the second s	Profile Grap	1.000 V h OK Contentation (dec Declination (dec Declination (dec	Cancel	? Release a Start of Star
dit L e: eel C F f	pes Attachment T Line Data: Steel Catenar Catenary Riser on: C PPSO Anchored	ypes	P-y Models. Fig	w	~ ake Mode 3: SCR	Material Ndude Tors No bject Relati (.904 .904	HEAR7 Dat Descrip	1.000 tia V: tion on (b End: d (m) z -7.022 -0.514	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667	Profile Grap prface 3 Azimuth 0.00 0.00	1.000 ¥ h OK V d Orientation (deg Declination 0.00 0.00	2) Gamma 90,00 0.00	? Release a Start of Sta
e Typ dit L e: eel C f f f	pes Attachment T Line Data: Steel Catenar Catenary Riser on: C EPSO Anchored on Stiffness:	ypes	P-y Models. Fig	w	ake Mode 3: SCR	Material Material ndude Tors No bject Relation	HEAR7 Dat Descrip	1.000	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667	Profile Grap prface 3 Azimuth 0.00 0.00	1.000 V	Cancel Cancel Gamma 90.00 0.00	? Release a Start of Sta
e Typ dit L e: eel C f f f f f f f d	pes Attachment T Line Data: Steel Catenar Latenary Riser on: C EPSO Anchored on Stiffness: x bending	ypes	P-y Models. Figt	w	ake Mode 3: SCR	Material Material ndude Tors No bject Relati (1.904 1.607	HEAR7 Dat Descrip	1.000	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1	Profile Grap prface 3 End Azimuth 0.00 0.00 hods Step 2	1.000 V h OK V d Orientation (deg Declination 0.00 0.00 0.00 Include Seabed Friction	a) Gamma 90.00 0.00 Lay Azimut (deg)	? Release a Start of Sta ~ ~ h As Lai Tension
dit L eel C eecto f d	pes Attachment T Line Data: Steel Catenar Catenary Riser on: C FPSO Anchored on Stiffness: x bending 0.00	ypes y Riser ionnect to Object Stiffnes	P-y Models. Fign s (kN.m/deg y bendi	w ure 3. 3		Material Material ndude Tors No bject Relati 4.904 1.904 1.904 1.904 1.904	HEAR7 Dat Descrip	1.000	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary	Profile Grap prface 3 Azimuth 0.00 0.00 hods Step 2 Full Status	1.000 V h OK Orientation (dec Declination 0.00 0.00 Include Seabed Friction	a) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0	Release a Start of Sta ~ ~ h As Lai Tension 00 0.0
dit L eel C F A hectio	pes Attachment T Line Data: Steel Catenar Catenary Riser on: C FPSO Anchored on Stiffness: <u>x bending</u> 0.00 0.00	ypes	P-y Models. Figt	w ure 3. 3	ake Mode 3: SCR	Material Material ndude Tors No bject Relation 4.904 1.904	HEAR7 Dat Descrip	1.000	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Statics Me Stap 1	Profile Grap prface 3 Azimuth 0.00 0.00 hods Step 2 Full Statics	1.000 ¥	a) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 S	Release a Start of Sta ~ ~ h As Lai Tension 00 0.0
ection dit L e: eel C f f f f f f f f f f f f f f f f f f f	Attachment T Line Data: Steel Catenar Catenary Riser on: C PPSO Anchored on Stiffness: x bending 0.00 0.00 cre Pre-bend Attachm mments: 31	ypes	s (kN.m/deg y bendi	W are 3. 3	ake Mode 3: SCR I Catena	Include Tors No Dispect Relation No Dispect Relation No Twisting Twisting Position (m)	HEAR7 Dat Descrip ion: Top ive Position y 0.072 0.066 Static inst inst ence Full	1.000 tia V: tion on (o End: d A -7.022 -0.514 s: ded atics Cate Statics Co	VA Data Drcaflex Inte P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary	Profile Grap Profile Grap Pr	1.000 Include Seabed Friction Results Dra Orien	a) Gamma 90.00 0.00 Lay Azimut (deg) 180.0 5 awing VIV Dr tation (deg)	Release a Start of Sta Start of Sta ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu rawing
dit L e: eel C F A A ection d uctu	Attachment T Line Data: Steel Catenar Catenary Riser on: C PPSO Anchored on Stiffness: x bending 0.00 0.00 re Pre-bend Attachm mments: 31	ypes	s (kN.m/deg y bendi	w are 3. 3	ake Mode 3: SCR I Catena X	A second	HEAR7 Dati Descrip ion: Top ive Position y 0.072 0.066 Static Indu in St ence Full 2 2 2 2 2 2 2 2 2 2 2 2 2	1.000 ia V: tion on (b End: d A -7.022 -0.514 s: ided atics Cate Statics Co z relative to	VA Data Drcaflex Interest of the second	Profile Grap Profile Grap Pr	1.000 Include Seabed Friction Results Drain	a) Gamma 90.00 0.00 Lay Azimut (deg) 180.0 5 awing VIV Dr tation (deg) otation 2 F	Release a Start of Sta ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu awing
dit L e: eel C f f f f f f f f f f f f f f f f f f f	Catenary Riser Caten	ypes	s (kN.m/deg y bendi	W are 3. 3	ake Mode 3: SCR I Catena X 0.00 0,00	Indude Tors No bject Relati c Twisting ry Converg Position (m) y 0,000	HEAR7 Dat Descrip ion: Top ✓ Er ive Position Y 0.072 0.066 Indi in Static Indi static Indi static 2000.00 2020.00	1.000 ia V: tion on (b End: a (m) z -7.022 -0.514 s: ided atics Cate	VA Data Drcaflex Interest of the second	Profile Grap	1.000	Cancel Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 sawing VIV Dr station (deg) otation 2	Release a Start of Star ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu rawing
dit L e: eel C f f f f f f f f f f f f f f f f f f f	Line Data: Steel Catenar Line Data: Steel Catenar Catenary Riser on: C C C C C C C C C C C C C	ypes	s (KN.m/deg y bendi	W are 3. 3	~ ake Mode 3: SCR I		HEAR7 Dat Descrip ion: Top v Er ive Position y 0.072 0.066 Static Inst v v v v v v v v v v v v v	1.000 ia V: tion on (b End: d A c (m) z -7.022 -0.514 s: ded atics Cate 2 relativ to End A End A End A End A	VA Data Drcaflex Inter- P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary	Profile Grap	1.000	Cancel Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 swing VIV Dr tation (deg) otation 2	Release a Start of Stat A As Lai Tension 00 0.0 Set Lay Azimu rawing
dit L e: eel C d f f f f f f f f f f f f f f f f f f	Construction C	ypes	s (dN.m/deg y bendi	W are 3. 3	ake Mode 3: SCR 1 0 34 169 Catena x 0.00 0.00 0.00	A series of the	HEAR7 Dat Descrip ion: Top v Er ive Position y 0.072 0.066 Static In St inst ≥ 2000.00 2020.00 2040.00 2060.00	1.000 tion on (b End: tion on (b End: tion on (c End: tion on (c End: tion on (c End: c End A End A End A End A End A	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary	Profile Grap Profile Grap Pr	1.000 Include Seabed Friction Results Dra Orien Rotation 1 R	2) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 sawing VIV Dr itation (deg) otation 2 f	Release a Start of Sta ~ ~ h As Lai
dit L e: eel C f f f f f f f f f f f f f f f f f f f	Line Data: Steel Catenar Line Data: Steel Catenar Catenary Riser on: C C C C C C C C C C C C C	ypes	s (kl.m/deg	w are 3. 3	~ ake Mode 3: SCR I	Image: Second	HEAR7 Dat Descrip ion: Top v Er ive Position y 0.072 0.066 Static inst Static inst Static 2000.00 2020.00 2020.00 2080.00 2080.00	1.000 tion on (b End: d A -7.022 -0.514 s: ided 2 cate Statics Co 2 relativ to End A End A End A End A	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary v	Profile Grap prface 3 Azimuth 0.00 0.00 hods Step 2 Full Statics VIII id Loads VIII mme	1.000 Include Seabed Friction Rotation 1 Rotation	Cancel Gamma 90.00 0.00 Lay Azimut (deg) 180.0 Sawing VIV Dr tation (deg) otation 2	Release a Start of Sta ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu rawing
dit L e: eel C d f f f f f f f f f f f f f f f f f f	Line Data: Steel Catenar Line Data: Steel Catenar Catenary Riser on: C C C C C C C C C C C C C	ypes	s (kl.m/deg	W are 3. 3	~ ake Mode 3: SCR I	Image: Second	HEAR7 Dat HEAR7 Dat Descrip ion: Top v Er ive Position y 0.072 0.066 Static Indt inst 2000.00 2020.00 2020.00 2080.00 2080.00 2080.00 2080.00	1.000 tion on (b End: d A r (m) z -7.022 -0.514 s: ded atics Z relative to End A End A End A End A End A End A End A End A	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary w researce Flue N e N e N e N e N e N e N e N e N e N	Profile Grap	1.000 Include Seabed Friction Results Dra Orien Rotation 1 R	a) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 2 swing VIV Dr station (deg) otation 2 F	Release a Start of Sta ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu rawing
dit L e: eel C d f f f f nection d t t ad t t ad t f f f f f nection t t ad t f f f f f f f f f f f f f f f f f f		ypes	s (kt.m/deg y bendi	W are 3. 3	ake Mode 3: SCR I 34 34 34 34 34 0.00	Image: Second	HEAR7 Dat HEAR7 Dat Descrip ion: Top v Position v Position v Position v Position v Indu in St in St v Indu in St v 2 v 2 v 2 v 2 v 2 v 2 v 2 v 2	1.000 tion on (b End: tion on (c End: tion on (c End: tion on (c End: tion on (c End: c End: End A End A	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary v	Profile Grap	1.000 Include Seabed Friction Results Dra Orien Rotation 1 Results Dra	a) Gamma 90.00 0.00 Lay Azimut (deg) 180.0 Sawing VIV Dr station (deg) otation 2 F	Release a Start of Sta ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu rawing
dit L e: eel C d f f f f nection d t t ad f f f f f nection t t ad f f f f f f f f f f f f f f f f f f		ypes	s (kl.m/deg y bendi	W are 3. 3	ake Mode 3: SCR 1 3: 34 169 Catena X 0.00	Els SI Indude Tors No No SI bject Relation SI 1.904 SI<	HEAR 7 Dat HEAR 7 Dat Descrip ion: Top v Fr vv Position y 0.072 0.066 Static Indu in St v v v v v v v v v v v v v	1.000 tion on (b End: tion on (c End: d A v r(m) z -7.022 -0.514 s: ided v atics Z relative to End A End A End A End A End A End A End A	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary v	Profile Grap	1.000 Include Seabed Friction Results Dra Orien Rotation 1 Results Dra	a) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 Sawing VIV Dr station (deg) otation 2 f	Release a Start of Sta ~ ~ h As Lai Tension 30 0.0. Set Lay Azimu awing
dit L e: eel C d d f f f f f f f f f f f f f f f f f		ypes	s (kN.m/deg y bendi	d Loads	ake Mode 3: SCR 1 34 34 169 2 34 34 169 2 34 2 0.00		HEAR 7 Dath HEAR 7 Dath IDescrip ion: Top v Fr v Fr v Indu 0.072 0.066 Static Indu v E v Indu v Indu v E v Indu v Indu v E v Indu v Indu <	1.000 tion on (tion on (c End: d A -7.022 -0.514 s: ided atics C Catr Statics Co z relative to End A End A En	VA Data Drcaflex Inte	Profile Grap	1.000 Include Seabed Friction Rotation 1 Orien Orien	a) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 Sawing VIV Dr station (deg) otation 2	Release a Start of Star of Sta
dit L e: eel C f f f f f f f f f f f f f f f f f f f		ypes	s (kN.m/deg y bendi	W are 3. 3	ake Mode 3: SCR 1 3: SCR 4 3: 169 2 34 34 169 2 34 2 34 0.00	Els Si ndude Tors No blject Relatic Si Twisting Twisting Position (m) Υ 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	Image: Application of the second state of the second s	1.000 ia V: tion on (b End: a (m) z -7.022 -0.514 s: ided atics Z relativ to End A End A	VA Data Drcaflex Inte	Profile Grap	1.000 Include Seabed Friction Rotation 1	Cancel Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 station (deg) otation 2	Release a Start of Star of Sta
dit L e: eel C f f f f f f f f f f f f f f f f f f f		ypes	s (kN.m/deg y bendi	d Loads	ake Mode 3: SCR 1 34 6 169 6 7 34 169 7		Image: Application of the second	1.000 ia V: tion on (o End: a (m) z -7.022 -0.514 s: d datics Z relativity d end A End A E	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary V e Nvergence Fk v v v v v v v v v v v v v v v v v v	Profile Grap	1.000	cancel Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 sawing VIV Dr station (deg) otation 2 F	Release a Start of Sta ~ ~ h As Lai Tension 00 0.1 Set Lay Azimu rawing
e Typ Edit L nection n		ypes	s (kN.m/deg y bendi	W are 3. 3 are 3. 3	ake Mode 3: SCR 1 34 6 169 6 7 34 169 7 7 7 8 7		HEAR7 Dat Descrip ion: Tor v Er ive Position y 0.072 0.066 Static Inft Static Inft 2000.00 2020.00 2040.00 2040.00 2140.00 220.00	1.000 tion on (b End: tion on (b End: d A v c End: to End: to End: z relative c End A End A E	VA Data Drcaflex Into P-y Model (none) Height above seabed (m) -0.667 Statics Me Step 1 enary V e N v v v v v v v v v v v v v v v v v v	Profile Grap	1.000	2) Gamma 90.00 0.00 Lay Azimuti (deg) 180.0 sawing VIV Dr tation (deg) otation 2 F	Release a Start of Stat ~ ~ h As Lai DO 0.0 Set Lay Azimu rawing

Figure 3. 4: SCR Material Description on Orcaflex Interface 4

2280.00 End A

Profile Graph

OK

Cancel

0.00

Line Types... Attachment Types... P-y Models... Wake Models... SHEAR7 Data... VIVA Data...

0.00

Buoyancy Module

Next

3.2 Meteocean data

Meteocean data for Offshore Nigeria showing water depth, current factor, rotation, near-surfaces and near-bottom current speed and direction were inputed into the Orcaflex platform for JONSWAP wave spectra. They are shown in Table 3.2 to 3.6.

Table 3. 1: Current Profile of Riser Environment

Number	Depth(m)	Factor	Rotation(deg)
1	0	0.6	0
2	250	0.6	45
3	500	0.8	90
4	750	1	135
5	1000	0.6	180
6	1300	0.6	225
7	1600	1	270
8	2000	1	315

Table 3.2 shows environmental data for the current factor and the angle of rotation at the various levels of water depth.

Table 3. 2: Current Direction (Near Surface)

Simulation Time(s)	Direction(deg)
0	0
2	45
4	90
6	135
8	180
10	225
12	270
14	315
16	360

Table 3.3 shows the current direction at near surfaces corresponding to the simulation time on the Orcaflex software.

Table 3. 3: Current Velocity (Near Surface)

Simulation Time(s)	Velocity(m/s)
0	0
2	0.103
4	0.206
6	0.309
8	0.412
10	0.514
12	0.617
14	0.72
16	0.823

Table 3.4 shows the velocity of the current at near surfaces corresponding to the simulation time on the Orcaflex software.

Table 3. 4: Current Direction	(Bottom	Surface)
-------------------------------	---------	----------

Simulation Time(s)	Direction (deg)
0	0
2	45
4	90
6	135
8	180
10	225
12	270
14	315
16	360

Table 3.5 shows the current direction at the bottom surfaces corresponding to the simulation time on the Orcaflex software.

Table 3. 5: Current Velocity (Bottom Surface)

Simulation Time(s)	Velocity(m/s)
0	0
2	0.103
4	0.206
6	0.309
8	0.412
10	0.514

Table 3.6 shows the velocity of the current at near surfaces corresponding to the simulation time on the Orcaflex software.

3.3 Methods

The steel catenary riser material characteristics and meteocean data were inputed into the Orcaflex 9.8b software and simulated using the Milan wake oscillator model for VIV. Results were obtained for the Fatigue Life and Damage as well as the effective tension at the buoyancy section using JONSAWP spectra for VIV and Non-VIV conditions.

3.3.1 Procedure for dynamic analysis of riser on Orcaflex

- i. Click on model browser and input the general and environmental data.
- ii. Click on vessel and drop on the sea surface.
- iii. Attach a line of 3044m to the vessel (End A is to the vessel while End B is anchored).
- iv. Under Line type 1 data, increase the sections to 10
- v. Under "Attachment Type" click Clump type and values for buoyancy modules from 2000m to 2600m of each line.

- vi. For Riser use "Homogenous Pipe" and attach the relevant design data.
- vii. Run static simulation (lazy wave configuration).
- viii. Then run dynamic simulation to check the riser response.
- ix. Click "Select results" icon and select "Time history"
- x. Check results for Effective Tension at buoyancy length.

3.3.2 Procedure for fatigue analysis of riser on Orcaflex

- i. Click on model browser and input the general and environmental data.
- ii. Click on vessel and drop on the sea surface.
- iii. Attach a line of 3044m to the vessel (End A is to the vessel while End B is anchored).
- iv. Under Line type 1 data, increase the sections to 10
- v. Under "Attachment Type" click Clump type and values for buoyancy modules from 2000m to 2600m of each line.
- vi. For Riser use "Homogenous Pipe" and attach the relevant design data.
- vii. Run static simulation (lazy wave configuration).
- viii. Then run dynamic simulation to check the riser response.

- ix. Click "Results" icon and select "Fatigue Analysis"
- x. Input simulation and calculate fatigue.
- xi. Results for both fatigue life and damage are presented in graphical and tabular format.

IV. RESULTS AND DISCUSSION

4.1 Results

The dynamic and fatigue analysis due to VIV and Non-VIV were simulated using Orcaflex 9.8b software and effective tension, fatigue life and damage values were obtained. The results were well represented figuratively for proper understanding. Meteocean data for Offshore Nigeria which includes wave, current speed and direction where properly simulated for JONSWAP wave spectra alongside the riser design parameters. Based on these, the effective tension were properly analyzed at the buoyancy section of the SCR on a graph. Comparison was also made between fatigue life and damage values for VIV and Non-VIV conditions using JONSWAP wave spectra and proper inferences were made. Proper conversion was made from English to Metric units from raw data sources prior to simulation.



Figure 4. 1: Completed Dynamic Simulation of SCR lazy wave on Orcaflex

For Non-VIV the following results were obtained for effective tension at the different arc lengths;



Figure 4. 2: Effective Tension- Time graph of SCR at 2000m Buoyancy Section

Maxima (t, EF) = (4, 439); (12, 440). The highest maxima is 440KN.



Figure 4. 3: Effective Tension- Time graph of SCR at 2120m Buoyancy Section.

Maxima (t, EF) = (4.8, 385.2); (12.3, 386). The highest maxima is 386KN.



Figure 4. 4: Effective Tension- Time graph of SCR at 2240m Buoyancy Section.

Maxima (t, EF) = (4.9, 390.5); (12.2, 390.8). The highest maxima is 390.8KN.



Figure 4. 5: Effective Tension- Time graph of SCR at 2360m Buoyancy Section

Maxima (t, EF) = (5, 451); (12.2, 451). The highest maxima is 451KN.



Figure 4. 6: Effective Tension- Time graph of SCR at 2480m Buoyancy Section

Maxima (t, EF) = (5, 547); (12.2, 547). The highest maxima is 547KN.



Figure 4. 7: Effective Tension- Time graph of SCR at 2600m Buoyancy Section

Maxima (t, EF) = (5, 663.5); (12.2, 663.5). The highest maxima is 663.5KN.

For VIV the following results were obtained for effective tension;



Figure 4. 8: Effective Tension- Time graph of SCR at 2000m Buoyancy Section

Maxima (t, EF) = (5.5, 477); (13.6, 472). The highest maxima is 472KN.



Figure 4. 9: Effective Tension- Time graph of SCR at 2120m Buoyancy Section

Maxima (t, EF) = (5.5, 418); (13.3, 417). The highest maxima is 418KN.



Figure 4. 10: Effective Tension- Time graph of SCR at 2240m Buoyancy Section





Figure 4. 11: Effective Tension- Time graph of SCR at 2360m Buoyancy Section

Maxima (t, EF) = (6.2, 476); (13.6, 477). The highest maxima is 477KN.



Figure 4. 12: Effective Tension- Time graph of SCR at 2480m Buoyancy Section







Maxima (t, EF) = (6.7, 685); (14, 683). The highest maxima is 685KN.

The fatigue damage results were shown below;

Fatigue Damage Summary		
OrcaFlex 9.8b: Abi(Jonswap_VIV).ft	g (modified 11:03 AM on 18	/09/2018 by OrcaFlex 9.8b)
Title: Fatigue Analysis Example Data		
Damage Calculation: Homogeneous p	ipe stress	
Analysis Type: Rainflow		
Worst Damage]
Damage over Total Exposure	0.000177765	1
Total Exposure Time (years)	0.002737851	
Life (years)	15.40151622	
Arc Length (m)	2934.545455	
Theta (deg)	45	
SN-curve	S-N Curve1	
Radial Position	Outer	
SCF	1.3	
Thickness Correction Factor	1	

Figure 4.14: Fatigue Life and Damage for SCR (VIV)

Fatigue Damage Summary	
OrcaFlex 9.8b: Abi(Jonswap).ftg (mo	dified 11:01 AM on 18/09/2
Title: Fatigue Analysis Example Data	L
Damage Calculation: Homogeneous p	bipe stress
Analysis Type: Rainflow	
Worst Damage	
Damage over Total Exposure	0.000152155
Total Exposure Time (years)	0.002737851
Life (years)	17.99388586
Arc Length (m)	45
Theta (deg)	270
SN-curve	S-N Curve1
Radial Position	Outer
SCF	1.3
Thickness Correction Factor	1

Figure 4.15: Fatigue Life and Damage for SCR (Without VIV)

4.2 Discussion

Considering the JONSWAP spectra Non-VIV and VIV in the analysis of the buoyancy section of the SCR, the results for

Non-VIV were shown in figure 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7. SCR at buoyancy arc length 2000m, 2120m, 2240m, 2360m, 2480m and 2600m gave highest maxima EF values for

440KN; 386KN; 390.8KN; 451KN; 547KN and 663.5KN respectively. It can be seen that the EF values at the hog bend were highest at the buoyancy section close to the touchdown zone. Similarly, for VIV, results were shown in Figure 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13. SCR at buoyancy arc length 2000m, 2120m, 2240m, 2360m, 2480m and 3000m gave highest maxima EF values for 477KN; 418KN; 420KN; 477KN; 571KN and 685KN respectively. Also it can be seen that the EF values on the hog bend were highest at the buoyancy section close to the touchdown zone. Figure 4.7 and 4.13 show the highest maxima EF values for Non-VIV and VIV respectively at 663.5KN and 685KN for 2600m. Generally, EF results show that VIV increases the tension the SCR experiences. From the literature review, JONSWAP though it was designed for the North Sea, is used almost anywhere because the bandwidth can be adjusted by changing its peakedness parameter γ . According to Felisita*et al.* (2015), SCR applications are challenging in deep water due to fatigue at the touch down zone and applying buoyancy gives the lazy wave configuration which affects fatigue of SCR model by improving its performance.

Therefore, the fatigue analysis for the lazy wave SCR for VIV and Non-VIV gave life and damage values as 15.4 years; 0.000177 and 17.99 years; 0.000152 respectively. The result clearly shows that VIV is a major factor in fatigue life reduction as its number of years before failure is less than that without VIV.

V. CONCLUSION

From the results and discussion in Chapter four, the dynamic analysis on the SCR gave highest maxima effective tension values at the buoyancy section arc lengths (i.e. 2000m, 2120m, 2240m, 2360m, 2480m and 2600m) for the VIV against the Non-VIV. While the fatigue life due to VIV showed lesser number of years to failure and a higher damage value when compared to Non-VIV. This clearly shows that using JONSWAP wave spectra, VIV plays a significant role in the overall fatigue of a lazy wave SCR in Deep Offshore Nigeria with the right application of buoyancy modules. Design and installation of buoyancy modules on the SCR for installation in Deep-Offshore Nigeria should be adapted to Ochi-Hubble wave spectra.

The results of this work show that VIV analysis led to a reduced fatigue life and higher damage value while buoyancy section gave higher tension when compared with Non-VIV. From the foregoing, this work shows that VIV plays a significant role in the overall fatigue of a lazy wave SCR in Deep Offshore Nigeria with great impact at the buoyancy section and hence should be properly taken into consideration in its design in Deep-Offshore Nigeria.

REFERENCES

- [1] API RP 2RD, A. R. (1998). Recommended Practice for Design of Risers for Floating Production Systems and TLPs.
- [2] Bai, Y., & Bai, Q. (2005). Subsea Pipelines and Risers. United Kingdom: Elsevier Ltd.
- [3] Ezeonwumelu, T. C., Chinwuba V. Ossia and Ibiba E. D. (2017). Fatigue Damage of Vertical Rigid Risers due to In-Line Vortex Induced Vibration in Nigeria Shallow Waters. *American Journal* of Mechanical Engineering. 2017; 5(2):33-40. doi: 10.12691/ajme-5-2-1
- [4] Felisita, A., Gudmestad, O., Martinsen, L., &Karunamaran, D. (2015). Review of Steel Lazy Wave Riser Concept for North Sea. St. John's, Newfoundland, Canada: ASME International of Conference of Ocean, Offshore and Artic Engineering.
- [5] King, R. (1977). A review of vortex shedding research and its application. Ocean Engineering 4, 141-171.
- [6] Morooka, C. K., &Tsukada, R. I. (2013). Experiments with a steel catenary riser model in a towing tank. Applied Ocean Research, 43, 244-255.
- [7] Srinil, N., Wiercigroch, M., & O'Brien, P. (2009). Reduced-order modelling of vortex-induced vibration of catenary riser. Ocean Engineering, 36(17-18), 1404-1414.
- [8] Wang, J., Fu, S., Baarholm, R., Wu, J., & Larsen, C. M. (2014). Fatigue damage of a steel catenary riser from vortex-induced vibration caused by vessel motions. Marine Structures, 39, 131-156.
- [9] Weaver C.E., 1976. The nature of TiO2 in in kaolinite, Clays and Clay Minerals, 24, pp. 215-218
- [10] Wiegel R.L., 1964, Oceanographical Engineering, Englewood Cliffs, New Jersey: Prentice Hall. Linear Theory of Ocean Surface Waves
- [11] Xue H., Tang, W., & Qu, X. (2014). Prdeiction and Analysis of fatigue damage due to cross-flow and in-line VIV for marine risers in non-uniform current. Ocean Engineering, 83, 52-62.