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A Comparative Study of 4inch and 10inch Production Flexible Riser for Offshore Operations using FEA Sofeware

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ABSTRACT
Flexible riser has been a proven technology for riser solutions in offshore oil and gas production since the 1970s with over 2000 risers installed. The emerging challenges in oil and gas exploration and production activities in deep and ultra deep waters in harsh environments necessitates the need to develop innovative riser systems and design methodology capable of ensuring transfer of fluids from the seabed to a floating vessel and vice versa, with little or no issues with respect to influences of environment loads and vessel motions. Base on the design specification, 4'' (101.6mm) and 10'' (254mm) lazy wave production flexible riser configuration attached to a Floating production Storage and Offloading (FPSO) vessel has been applied to a global analysis in order to acquire the static and dynamic behaviour of the flexible riser along with manual computation of specific design consideration to verify the design of production flexible riser system for 4'' (101.6mm) and 10''(254mm) riser pipe and compare which is most suitable. The riser is approximated using three catenary curves for the three parts. The initial Hang-off angle at FPSO was established and optimized. The riser was subjected to extreme environmental conditions; static and dynamic response analyses were performed by the computer base programme Flexcom. Hand calculation was done to verify the damaging pull, contact pressure, burst pressure, bending strain. Finally, as a result of this study, both 101.6mm and 254mm risers have satisfied design requirements, but 101.6mm riser pipe is more suitable. 254mm riser pipe may observe buckling due to high compression. Maximum effective tension was measured at the vessel contact point and minimum at the touchdown point. The presence of buoyancy modules had significantly reduced the tension at hang-off point. Tensions in riser pipe have increase whereas curvature has decrease. This study does not incorporate fatigue analysis, thus it is recommended that due to high sea states and induced vessel motions fatigue analysis would be required to ensure riser pipe safety during its operational life.
Keywords: flexible riser, global analysis – static and dynamic, hang-off angle, effective tension, damaging pull, contact pressure, burst pressure, bending strain and curvature.

I. INTRODUCTION

Risers are very important in the offshore industry both when considering field development costs and technological feasibility. For a typical West Africa offshore development project, risers account for more than 7% of CAPEX (Petrocarbon, 2014). They can be used as drilling risers, production risers or intervention risers. The integrity of the risers is of high importance in oil and gas exploration in that it carries highly flammable hydrocarbon from the seabed to the platform. Exploration and production activities in deep and ultra deep waters in hostile environments necessitates the need to develop innovative riser systems capable of ensuring transfer of fluids from the seabed to a floating vessel and vice versa.

Among the riser concepts, flexible risers have been enjoying a widespread acceptability for deep and ultra-deepwater oil and gas production in recent years; since the 1970s with over 2000 risers installed (Zhimin et al, 2009). Due to the effect of ocean environment on ocean platform, the motion characteristics are of diverse kind and there are various requirements for the riser system. The capability of a flexible riser is different from other risers because of its special structure; which consists of several layers of different materials. It is superior to other kinds of risers because of its

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larger bending capability, and it can be applied to more undesirable environmental conditions. The advantage of a flexible riser cannot be over emphasized as the cost of installation and vessel requirement is reduced as compared to SCRs (Bai and Bai, 2010). This has led to increasing development of dynamic flexible risers especially for deepwater development tie backs.

However, in deepwater applications, because of the low bending stiffness compared to axial and torsional stiffness, flexible risers can suffer large displacements, causing them to demand geometrically special nonlinear analysis (Kordkheili and Bahia, 2007).

Therefore, Analysis of flexible riser plays an important role in the engineering of deepwater. This analysis must be performed in a logical way based on the inter-relationship among different analysis tasks. There are different types of analysis including strength, fatigue, ECA, static and dynamic as well as installation. In this paper, a flexible riser concept will be considered in order to perform static and dynamic analysis to aid the design integrity of a flexible riser for deepwater production.

In addition, an initial Hang-off angle was established; Hand calculation was done to verify the damaging pull, contact pressure, burst pressure, bending strain.

II. FLEXIBLE RISER CONFIGURATION

The design of the flexible riser system is an iterative process. To begin with, a riser configuration must be assumed and analyzed. Flexible risers can be installed in a number of different configurations. Riser configuration design shall be performed according to the production requirement and site-specific environmental conditions. Configuration design drivers include factors such as water depth, host vessel access/hang-off location, field layout such as number and type of risers and mooring layout, and in particular environmental data and the host vessel motion characteristics. Some of the common configurations are shown in figure 1 below.

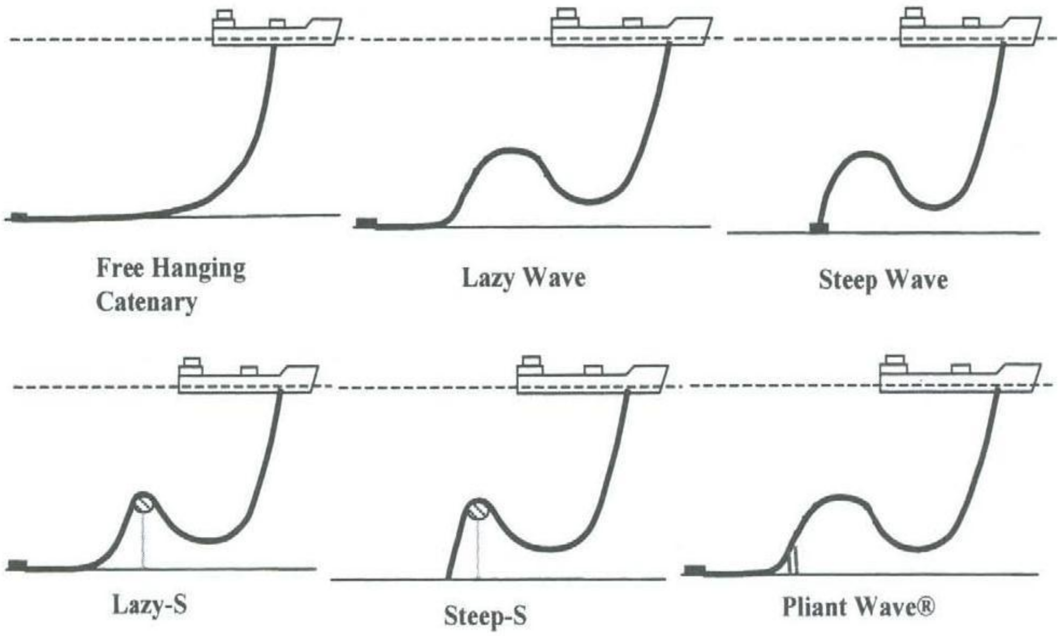

Figure 1: Standards Flexible Riser Configurations

In additional to the flexible riser itself, the typical components of a dynamic umbilical system in lazy-wave configuration are the hang-off assembly, the bending stiffener, and the buoyancy module. The typical components of a dynamic flexible riser system in lazy-S configuration are the hang-off assembly, the bending stiffener, and the mid-water arch. The riser system design must meet the requirements of API specification / DNV system.

Hang-Off Assembly

The top end of the dynamic flexible riser is terminated with a hang-off assembly to secure the riser to the vessel. The hang-off assembly is designed to withstand all installation and operational loads.

Bending Stiffeners

Bending stiffeners are utilized to provide the riser with a continuous transition between the riser, with its inherent low bending stiffness, and a rigid end fitting, which is very stiff. Bending stiffeners are made of a polyurethane moulded material, and are bolted to the end fitting. Each riser top connection is usually equipped with a bending stiffener.

Buoyancy Module

A lazy-wave configuration is obtained with a buoyant section which is provided by using buoyancy modules distributed over an appropriate length of flexible riser. The buoyancy modules are typically composed of an internal clamp and a syntactic foam buoyancy element.

2.1 Design of Flexible Riser

This section briefly present an overview of standards and rules used to assess and verify riser designs. More particularly, this paper focuses on unbonded Flexible Pipes. The design of the flexible riser is critical to the offshore field development as it provides the means to transfer hydrocarbon fluids from the subsea unit on the seabed to the floating production or storage unit on the sea surface. Two entities are considered as reference for flexible risers' recommendations, the American Petroleum Institute (API RP 2RD) and the Norwegian company DNV (DNV-OS-F201, 2001).

2.2 Boundary Condition

The top of the riser was attached to an FPSO, using the response amplitude operator (RAO) of the FPSO as the boundary condition at the top end of the riser. The bottom end of the riser is fixed to the seabed; the seabed friction is not considered in this study. It is very important to obtain accurate values of the RAO amplitude and phase if the dynamics of the system are to be correctly modelled.

2.3 Building the Model of the Flexible riser

Flexcom is used to simulate the flexible riser, the bottom end of the riser is completely constrained in all directions and rotations, and a regular wave is applied to the platform. The displacement of the connection point between FPSO and riser is taken as the boundarycondition at the top end of the riser. As the dynamic performance of the flexible riser is geometrically non-linear, time domain analysis is used in this study to analyze the performance of flexible riser.

III. MATERIALS AND METHOD

The entire riser configuration design was address based on the following tasks:

1. The riser configuration will be approximated using 3 catenary curves for the three parts of the riser of 130, 60 and 150 meters long.
2. Establish initial hang-off angle at the FPSO, and the sagbend and hogbend elevations (The 'hogbend' is the highest point in the buoyancy region; the 'sagbend' is the lowest point in the upper catenary);
3. Present static snapshot of effective tension and verify tension based on a simplified hand calculation;
4. Present static envelope of curvature and compare with allowable (Curvature = 1/MBR);
5. Based on the riser datasheet, each riser will be analysed for:

- Damaging Pull (i.e. tension at which tensile armours are 100% utilised)
- Burst Pressure (i.e. pressure at which pressure armour is 100% utilised)
- Contact Pressure of Damaging Pull
- Bending strain in the polymer layers at storage MBR

Assume that UTS=750 MPa for 4" pipe and 700 MPa for 10" pipe.

6. Assuming near and far offset for the two riser model, the riser will be reconfigured to accommodate the offsets effect of ±45m of the FPSO.

Summary of tables for flexible riser design data are given below:

Table 1: Flexible Pipe - 4" (101.6mm) ID Design Specification

Layer No.	Description	Mass (kg/m)	ID (mm)	Thickness (mm)
1	Internal Carcass	5.82	101.6	4
2	PA11 Internal Sheath	1.57	109.6	4
3	Pressure armour	15.94	117.6	6.2
4	Armour layer 1	6	130	2
5	Armour layer 2	6.2	134	2
6	High strength tape	0.59	138	1.95

7	PE External sheath	1.72	141.9	4
Diameter: outside (mm)				149.9
Weight in air, empty (kg/m)				37.86
Weight in air, full of seawater (kg/m)				46.77
Pressure: Normal bursting (bar)				591
Pressure: Hydrostatic Collapse (bar)				165
Damaging pull in a straight line (kN)				620.25
Minimum bend radius, for Storage (m)				0.97
Bending stiffness, at 20degC (kN.m2)				4.47
Relative Elongation for 100kN (%)				0.112160

- Design Pressure = 240 bar, Design temperature = 60 degC

Table 2: Flexible Pipe - 10" (254mm) ID Design Specification

Layer No.	Description	Mass (kg/m)	ID (mm)	Thickness (mm)
1	Internal Carcass	22.25	254	6
2	PA11 Internal Sheath	6.87	266	7
3	Pressure armour	47.96	280	8
4	Anti-wear tape	1.46	296	1.5
5	Tensile armour layer 1	24.09	299	3.6
6	Anti- wear tape	0.59	138	1.95
7	Tensile Armour Layer 2	1.72	141.9	4
8	Fabric Tape	1.6	316.4	2.3
9	PA11 external sheath	10.81	321	10
Diameter: outside (mm)				341
Weight in air, empty (kg/m)				141.62
Weight in air, full of seawater (kg/m)				195.68
Pressure: Normal bursting (bar)				400
Pressure: Hydrostatic Collapse (bar)				40
Damaging pull in a straight line (kN)				2803.87
Minimum bend radius, for Storage (m)				2.22
Bending stiffness, at 20degC (kN.m2)				50.95
Relative Elongation for 100kN (%)				0.019

- Design Pressure = 177 bar, Design Temperature = 77degC

Input Data

- 4'' and 10'' risers datasheets
- Buoyancy ratio is equal to -2. Assume 4" / 10" buoyancy module OD is 0.5m / 1.2m.
- FPSO RAO data, reference position, riser hang-off location with respect to reference position, length, breadth, draft etc are given below.

- Assumption:

Assume rigid, frictionless seabed.

Assume torsional stiffness for each pipe size as 60 times of its bending stiffness, i.e.

GJ = 60 x EI);

- polar inertia of cross-section per unit length for each pipe size is equal to 1.0;
- polar inertia of cross-section per unit length for the buoyancy foam is equal to 1.0.
- Piecewise linear current profile as below:

Sea surface (i.e. depth = 0m), Current = 0.9m/s, Depth = 10m, Current = 0.8m/s,

Depth = 50m, Current = 0.5m/s, Depth = 100m, Current = 0.2m/s, Depth = 145m,

Current =0m/s

3.1 GLOBAL ANALYSIS

The purpose of global riser system analyses is to describe the overall static and dynamic structural behaviour by exposing the system to a stationary environmental loading condition (DNV OS F201, 2010). In order to evaluate the performance of the riser, the optimized riser compliancy, hang off angle, effective tension, static configuration and extreme response of displacement, curvature, bending radius and moment on environmental effects shall be calculated in the global analysis respectively in other to ensure that the design is capable of maintaining the structural integrity of the riser.

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The global analysis includes two aspects: static analysis and dynamic analysis. The static analysis can determine the equilibrium configuration of the system under weight, buoyancy, and drag force. Additionally, it can also provide a starting configuration for dynamic analysis.

In most cases, the static equilibrium configuration is the best starting point for dynamic analysis. The dynamic analysis is a time simulation of the motion of the model over a specified period of time, starting from the position derived by the static analysis. The environment defines the conditions, to which the objects in the model are subjected, and it consists of the current, waves and seabed (Dikdognus, 2012).The operating water depth is 140m and the maximum wave height is 30m over a time period of 15seconds.

3.2 Design Equations

- **Catenary Equation**

Using Catenary Equation we can calculate Suspended Length of the riser

$$s_T = \frac{T_o}{W} \sinh\left(\frac{X_T W}{T_o}\right)$$
(1)

Horizontal Projection can be found from

$$y_T = \frac{T_o}{W}\left(\frac{WX_T}{T_o}\right) - 1$$
(2)

Tension in the cable

$$T = T_o \cosh\frac{WX}{T_o} = T_o + W_y$$
(3)

- **Effective Tension**

$$T_e = T_w + P_e A_e - P_i A_i$$
(4)

Where:
T_w = true wall tension
p_i = internal (local) pressure
p_e = external (local) pressure
A_i = internal cross-sectional area
A_e = external cross-sectional area

The effective tension offers a more significant representation of riser axial behaviour than true wall tension. That is why this study focused on this output. Tension is a key design parameter, essential for risers' dimensioning.

- **Damaging Pull – tensile armour**

$$\sigma_t = \frac{T_w}{2tF_f \pi r_{mean} \cos^2\alpha}$$
(5)

Where:

t= wall thickness

$$F_f, pressure\ armour = \frac{m_{given}}{m_{obtained}}$$
(6)

- **Contact Pressure**

$$P_T = \frac{T_w X tg^2\alpha}{2\pi r_{mean}{}^2}$$
(7)

- **Bending Strain**

$$\varepsilon_b = \frac{r}{R}$$
(8)

Where:
r = internal sheath radius
R = external sheath radius

IV. RESULTS AND DISCUSSION

4.1 The Static Analysis

The aim of static analysis is to determine the initial static geometry of the flexible riser configuration. The design parameters to be selected in the static analysis are typically length, weight, buoyancy requirements, and location of seabed touchdown point and subsea buoy.

Initial configuration of riser system is made by approximating Cartesian coordinates. Input values of length of riser sections and vessel coordinates were then used to build up the riser model in FLEXCOM along with the material and geometrical properties.

The riser was divided into 3 parts, i.e., Section1 (lower riser part), Section 2 (buoyancy part) and Section 3 (upper riser part). To simplify the presentation, these three different parts are then sub-divided into two section each given as follows:

Section 1 – Lower Riser Part – S_{11} (Riser on the seabed) and S_{21} (Riser above seabed-suspended), Section 2 – Buoyancy part – S_{12} and S_{22}, Section 3 – Upper Riser Part – S_{13} and S_{23}.

After several iterations performed by changing nodal coordinates and touchdown points, the approximate configuration of both the pipes is shown in Table 3 and Table 4. X (m) gives the horizontal coordinate of the pipe system whereas Y (m) gives the vertical coordinate of the system.
The snapshot of the configuration and tension is presented in Figure 2 and Figure 3 below.

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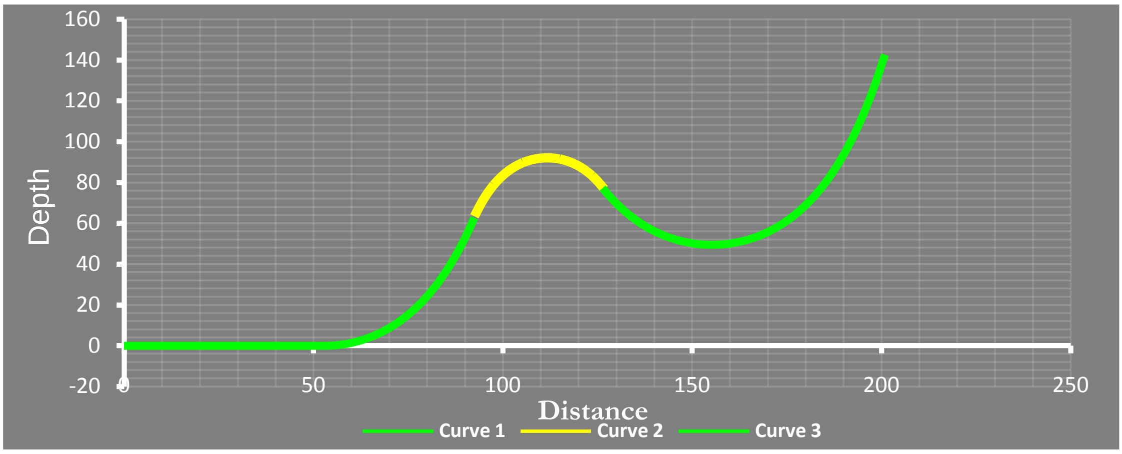

Figure 2: Riser Configuration

Table 3: Riser Configuration

Point No.	Section 1		Section 2		Section 3		Hang off Angle
	Start	End	Start	End	Start	End	Vessel Contact
X (m)	0.00	90.68	90.68	124.84	124.84	200.59	10.1 deg
Y (m)	0.00	63.32	63.32	83.28	83.28	140.00	
Length	130		60		150		
T_0 (KN)	8.92	8.92	8.92	8.92	8.92	8.92	

Table 4: Nodes and Coordinates

Nodes	**X**	**Y**	**Z**
1	0	0	0
66	63.32	90.68	0
96	83.28	124.84	0
171	140.00	200.59	0

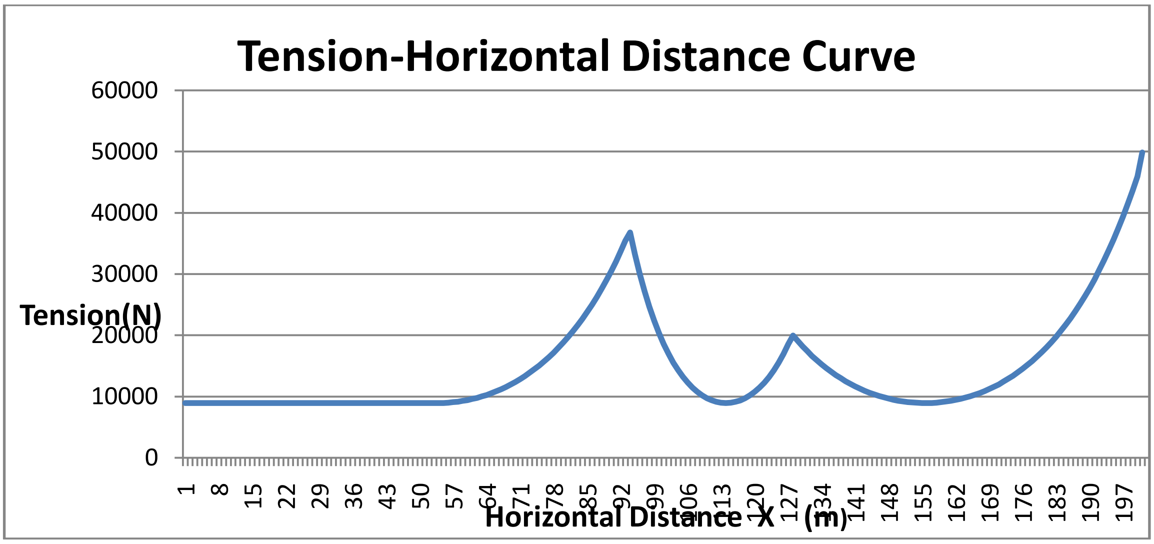

Figure 3: Horizontal Tension Curve

4.2 Configure Static Model and Analysis

Having achieved the configuration from the Task 1, with additional properties for 4” and 10”, the Risers are modelled in FLEXCOM ensuring hang off angle falls within the specified range. Vessel is kept stationary and the hang off was achieved by moving touchdown point; alternatively, the vessel position can moved with the touchdown point held stationed.

4.3 Optimized Static Riser Configuration

The initial Hang-off angle from hand calculation was 10.1deg but from project specification the hang-off angle should be between 4-7deg. So the model was adjusted to obtain the in-range value of hang-off angle by a combination of changing the elevation of Sagbend and Hogbend, and offsetting the touchdown point in the configuration. Detailed graphs and snapshots of the hang-off angle graph and model is shown in Appendix B in the main work. The summary of results is tabled below.

The Un-optimised Riser configuration is presented in Table below:

Table 5: Un-Optimised Riser Configuration

Parameters Obtained		Unit	Riser	
			101.6mm	254mm
Static Envelope of Curvature	Sag bend	/m	0.109	0.105
	Hog bend		0.055	0.055
Hang off angle at vessel contact		deg	9.66	9.64
Sag bend Position (along the curvature)		m	168	168
Hog bend Position (along the curvature)		m	232	232

Table 6: Optimised Riser Configuration

Parameters Obtained		Unit	101.6mm Riser		254mm Riser	
			Near	Far	Near	Far
Static Envelope of Curvature	Sag bend	/m	0.152	0.152	0.142	0.143
	Hog bend		0.078	.0785	0.077	0.077
Hang off angle at vessel contact		deg	6.87		6.83	
Sag bend Position (along the curvature)		m	168		168	
Hog bend Position (along the curvature)		m	234		234	

4.4 Damaging Pull, Burst and Contact Pressure, and Bending Strain

As mentioned in Task 3 of project specification, Damaging Pull, Burst pressure, Contact Pressure and Bending Strain are calculated for 4” (101.6mm) and 10” (254mm) Risers. The results of the detailed calculations are summary in Table 7 below:

Table 7: Summary of Result for Task 3

Calculated Parameters	101.6mm Pipe	254mm Pipe
Damaging pull (kN)	787	2942
Burst pressure (MPa)	76.68	42.83
Contact pressure (MPa)	13.68	9.96
Bending strain for internal sheath at storage MBR	0.058	0.063

Bending strain for external sheath at storage MBR	0.077	0.077

Pipe 4 inch
Damaging Pull

Comparing the amount of damaging pull in datasheet which is given 620.25 KN, indicate that the calculated damaging pull is higher than allowance criteria. So it means the %100 of utilisation shall cause a damaging pull. It is recommended to reduce the maximum tensile stress to 78% of utilisation.

Burst Pressure

The Nominal burst pressure given in datasheet equal to 591 bar (59.69 Mpa).On the other hand the resistance armours can overcome up to 76.68 Mpa ,so the estimated burst pressure can be sustained by the armours.

Contact Pressure

The Nominal collapse pressure has been given in datasheet equal to 165 bar (16.66 Mpa).On the other hand the resistance armours can overcome up 13.68 Mpa ,so the estimated contact pressure cannot be sustained by the armours.

Pipe 10 inch
Damaging Pull

Comparing the amount of damaging pull in datasheet which is given 2803.87 KN, indicate that the calculated damaging pull is higher than allowance criteria. So it means the %100 of utilisation shall cause a damaging pull and the tensile armours cannot tolerate the maximum loads.

Burst Pressure

The Nominal burst pressure has been given in datasheet equal to 400 bar (40.4 Mpa).On the other hand the resistance armours can overcome up to 42.83 Mpa ,so the estimated burst pressure can be sustained by the armours.

Contact Pressure

The Nominal collapse pressure has been given in datasheet equal to 40 bar (4.04 Mpa).On the other hand the resistance armours can overcome up to 9.96 Mpa ,so the estimated contact pressure can be sustained by the armours.

4.5 RISER CONFIGURATION WITH CURRENT

Near and far offset of vessel are -45m and +45m according to the design specification. Riser configurations are analysed for both of these positions. Environmental loads are applied in form of current and the results obtained are mentioned below:

Current directions are considered as 180deg for near position and 0deg for far position conservatively. Detailed graphs and snapshots are available in the main work.

Table 8: Summary of Result for Task 4

	101.6mm			254mm		
	Static	Offset	Offset + Current	Static	Offset	Offset + Current
Near offset analysis						
Effective Tension (kN)	29.93	29.93	29.27	106.47	103.95	103.91
Maximum Curvature (/m)	0.152	0.266	0.266	0.142	0.256	0.228
Far offset analysis						
Effective Tension (kN)	29.93	31.31	31.27	106.47	111.45	111.02
Maximum Curvature (/m)	0.152	0.143	0.083	0.143	0.135	0.082

From Table 8, the values for static is seen to be the same for both Far and Near cases, this is because both the vessel and the riser is not experiencing any external forces from the environment yet prior to offset, current and wave effects.

4.6 Dynamic Analysis with Wave

This analysis contains inclusion of sea waves in the FLEXCOM model.

Maximum Wave Height = 30m
Time Period = 15s
Once the Maximum wave height and Time period applies to the model, Vessel motions under the direct effect waves were seen in the dynamic model. The effective tension is found to be under allowable limits as mentioned in Task2. Some of the graphs and snapshots are shown below:

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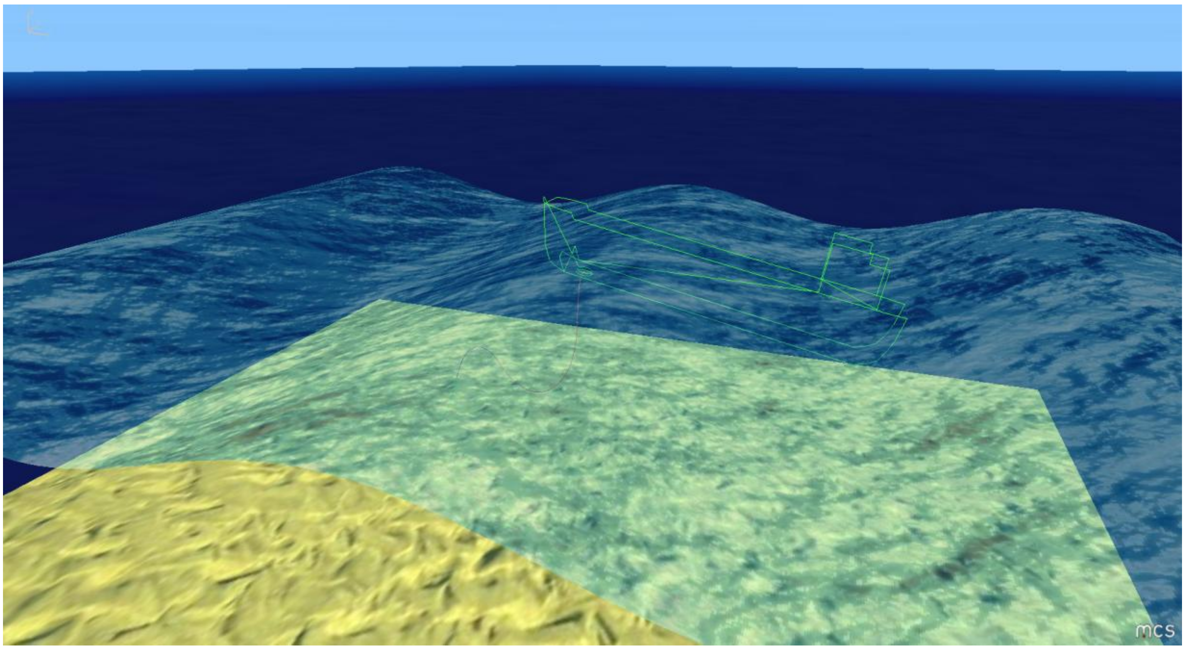


Plate 1: 3D Snapshot of 10" Flexible Riser Dynamic Analysis

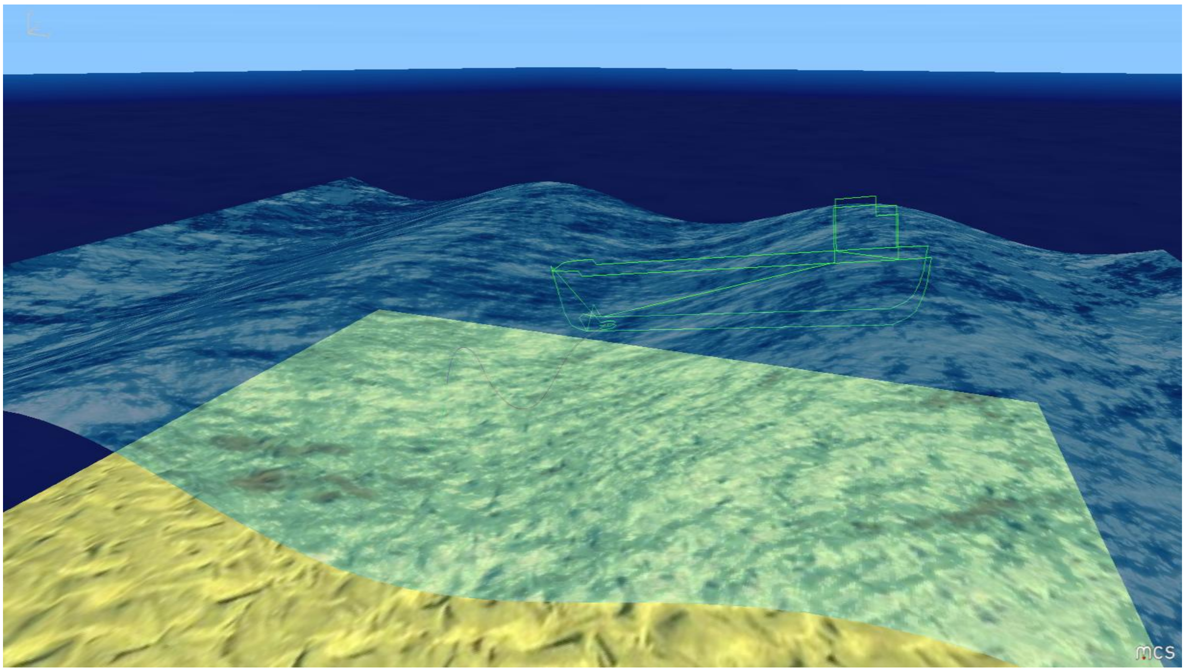
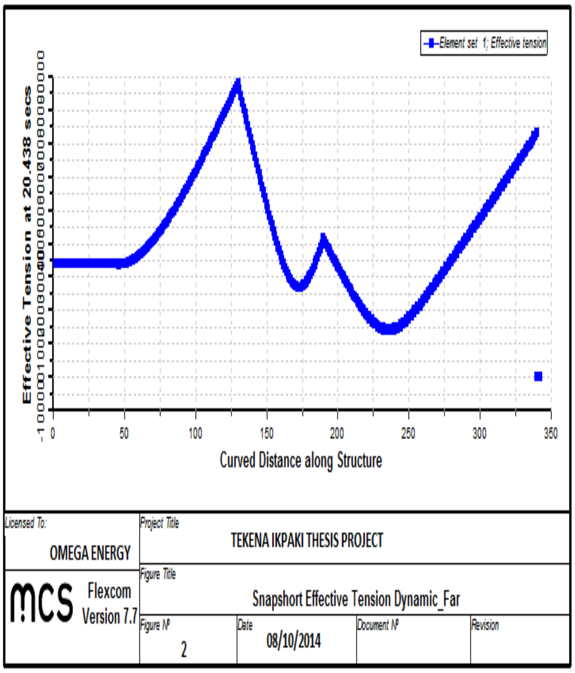


Plate 2: 3D Snapshot of 4" Flexible Dynamic Riser analysis

Effective Tension for Far Offset



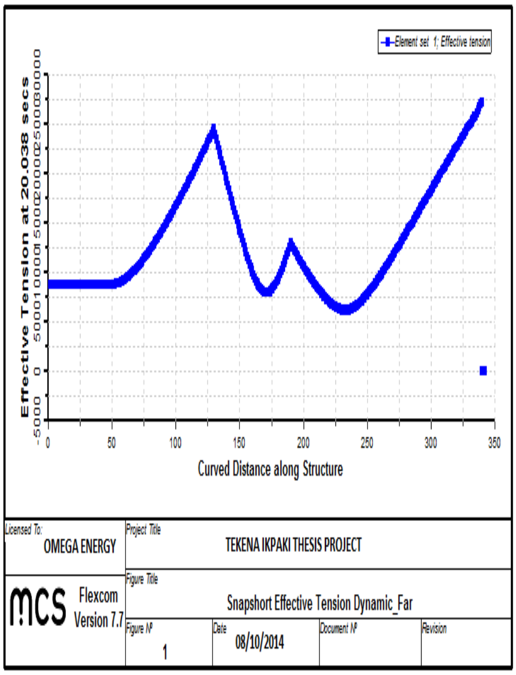
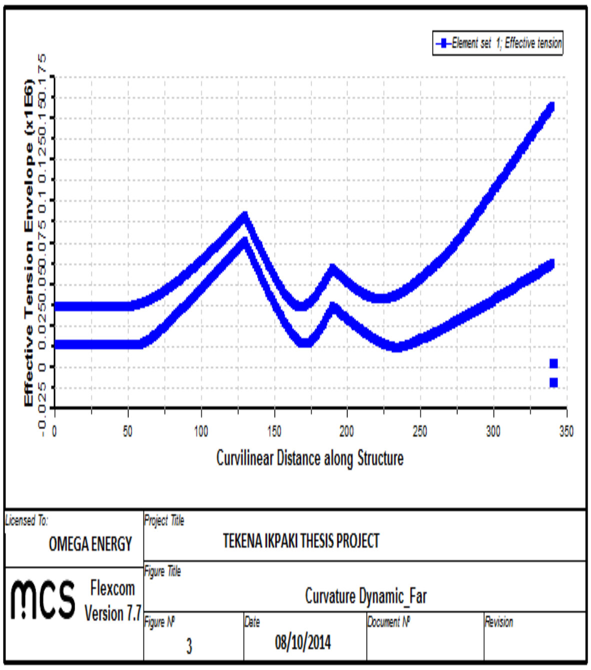


Figure 4: Effective Tension for far Offset Dynamic – 10" Figure 5: Effective Tension for far Offset dynamic – 4"

Curvature for Far Offset



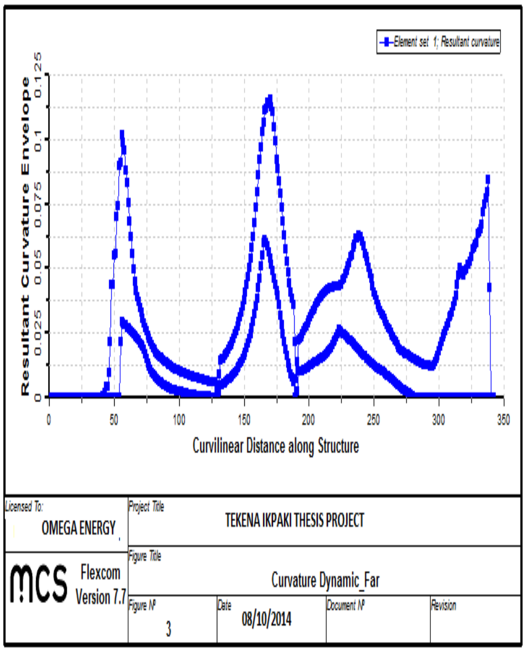


Figure 6: curvature for far Offset Dynamic -10" Figure 7: Curvature for Far Offset Dynamic – 4"

V. CONCLUSION

Base on the design data; employing API-RP-2RD and DNV OS F201, the design verification of a 101.6mm (4 inch) and 254mm (10 inch) production flexible riser carried out through static and dynamic analysis along with manual computation of specific design consideration have been made. A lazy wave flexible riser model has been built in order to analyze the dynamic response of the riser on the wave and current near and far offset vessel position.

The results show that:

- Both 101.6mm and 254mm risers have satisfied design requirements but 254mm pipe may buckle due to high compression. This can be avoided by reducing wall thickness and using higher grade pipe.
- Tension in pipe has changed significantly between far and near offset. Due to the pulling nature of far offset.
- Tension in pipe has increased whereas curvature has decreased. The difference on tension between far and near offset is 1.91KN and 15.7KN for 101.6mm and 254mm respectively.
- Maximum tension was measured at the vessel contact point and minimum at the seabed. The presence of buoyancy modules had significantly reduced the tension at Hang-off point.
- On application of wave and current loads on the riser, compression was measured at 254mm riser as indicated Section Task 5 results.

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