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Dynamic Analysis of a Flexible Riser in Shallow Water

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ABSTRACT: *This thesis work is focused on the dynamic behavior of a flexible riser in shallow water by providing a suitable riser configuration for deployment in conjunction with a Floating Production Storage and Offloading Unit (FPSO) in a harsh environment. This work is justified by the rising demand of exploration and production in shallow water, and harsh environments. A lazy wave riser (LWR) configuration that is attractive for shallow water deployments has been used. This configuration allows the FPSO motion to be decoupled from the touchdown point (TDP) of the riser when using a buoyant system. The design basis was established using typical environmental and design data for the Gulf of Guinea, taking into account the FPSO motions and hydrodynamics coefficients and checking against relevant design codes. To accurately predict the dynamic behavior of a flexible riser in shallow water, an analysis model has been created in orcaflex. The main objective when creating an analysis model is to reproduce the reality. FPSO motions and other hydrodynamic coefficient were imported to orcaflex and an evaluation of the static and dynamic analysis has done. Bending radius for all load cases considered are within (Maximum Bending Radius) MBR limit. The tension reported at the end A and (Pipeline End Terminal) PLET location are in a reasonable limit. The extreme response behavior is satisfactory. Overall, this thesis work showed that the LWR is a suitable riser configuration for deployment in conjunction with turret moored FPSO in shallow water, harsh environmental conditions.*

KEY WORDS*:waves, risers, dynamic analysis, static analysis, surge motion, heave motion, sway motion, roll motion, pitch motion, yaw motion, response amplitude operators.*

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I. INTRODUCTION

A riser is essentially a pipe that connects a floater at the water surface and the wellheads at the seabed [7]. Flexible dynamic risers are the main riser systems used for floaters in the 1980s. The concept of the dynamic flexible risers has been found successful and used for several years in different part of the world under relatively moderate weather conditions and is now largely used by the oil and gas industry for applications in very severe environments, North Sea included, since 1985.

The main riser system used for production in shallow water are the flexible risers attached with additional buoyancy modules which are used to form loops which uncouple the risers bottom section from the floating unit motions. They are critical components of offshore field developments, they provide the means of transporting production fluids from the subsea units to the production vessels and accommodate vessel motion and hydrodynamic loading by being flexible. The result of the configurations allows risers to be more suitable to the different field conditions by allowing different flexibility such as the “Lazy Wave”, “Steep Wave”, “Lazy-S”, “Steep-S”, “Pliant Wave”, etc.

Flexible riser systems are appropriate for shallow water and cyclonic conditions and are used in a number of fields located in West Africa, Gulf of Mexico, Asia Pacific regions, Brazil and in the North Sea.

Static and dynamic analysis of the riser system are carried out to determine the layout and demonstrate the full feasibility of the riser systems under all operating modes.

The static analysis is run to determine the equilibrium position of the riser system with itself loads while the dynamic analysis is run to simulate the dynamic behavior of the flexible riser systems subjected to hydrodynamic loading and vessel motion.

In recent years, several computer programs for analysis of flexible risers have been developed, to enable engineers to assess the dynamic behavior of risers. The methods and computer codes are also different with respect to user friendliness, generality, efficiency and accuracy. Orcaflex software was used in this thesis to analysis the Dynamic behavior of a riser in shallow water.

Flexible Pipe Concept

The key characteristic of a flexible pipe is its low relative bending to axial stiffness. To achieve this characteristics, a number of layers of different materials in the pipe wall during fabrication is used. So that when under the influence of external and internal loads these layer will be able to slip past each other and give the flexible pipe its property of low bending stiffness.

In Bai and Bai [1], the flexible pipe composite structure combines high stiffness with steel armor layers to provide strength and polymer sealing layers with low stiffness to provide fluid integrity. This combination gives flexible pipes a number of advantages over other types of pipelines and risers such as steel catenary risers.

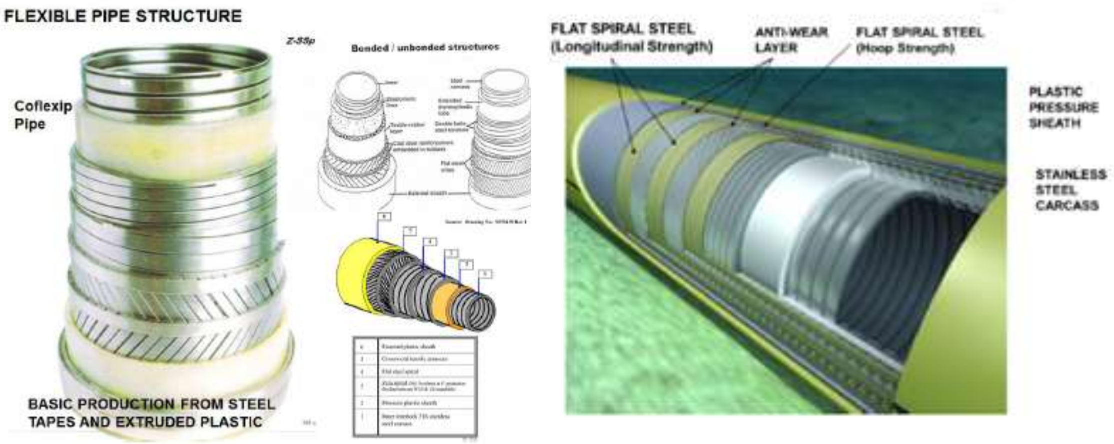

Figure 1: Flexible Pipe Structures

Source – Azur Offshore Ltd

There were two types of offer in the 1980s, which are BOUNDED rubber- based type and the UNBOUNDED thermoplastic-steel type. However, today the UNBOUNDED structures are only commonly used for flexible dynamic risers because BOUNDED structures can only be used where they can be easily replaced at the top of a drilling riser for floating offloading hoses with short lengths of flexible pipe jumpers.

Since the adoption of a flexible pipe as marine risers, it has form an integral part of offshore production system and it is no longer looked at as exploratory in nature. Recent installations of key systems worldwide according [2] have proved the concept to be technically acceptable, economically attractive and often representing a unique solution.

Riser System Configurations

The practice in the offshore industry requires a number of different types of riser configuration which are usually used in conjunction with the offshore floating systems.

According to [2], even though the dynamic behavior of a flexible riser system in operational and extreme environmental conditions plays the key role in selection of a particular configuration, there are other important factors which should also be considered during this selection;

- Inspection and work over operations
- Activity of other vessels in the vicinity
- Interference with other riser systems and mooring lines

The typical flexible riser configurations currently in service are given in figure 2.

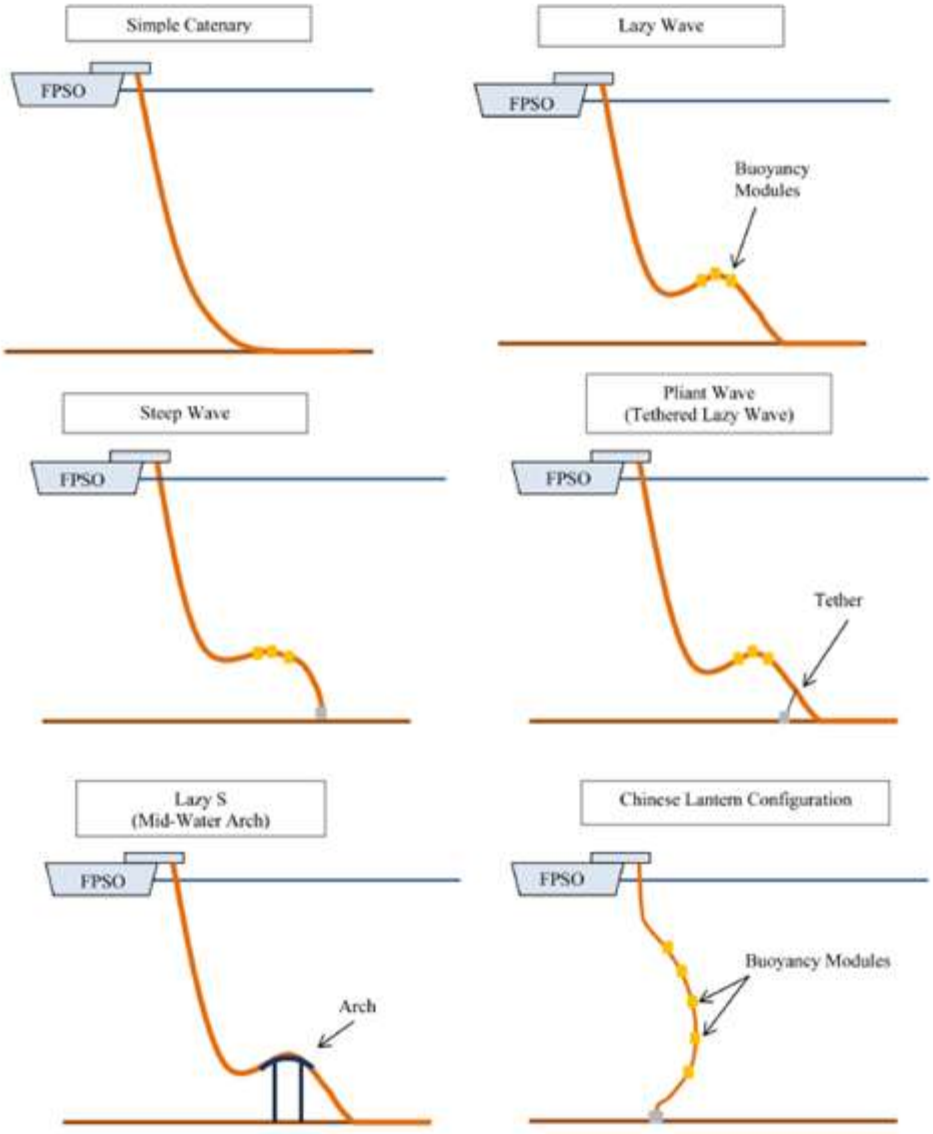

Figure 2: Typical Flexible Riser Configurations

Source: Gurung et al (2015)

Design Principles

According to [3], before a riser can be used for installation in the oil and gas industry, it is first designed with respect to the appropriate design codes requirement. The basic design requirement is to ensure the riser can withstand the intended conditions, self and external load effects that may likely encounter during its service life. According to [4], the riser with relation to maintenance cost must have acceptable durability.

To achieve these, the riser is designed with different safety guidelines or requirements

This gives the possibility of the riser to be design with different safety requirements, depending on which class that the riser belongs.

Riser Design Loads

Classify the loads to be considered in the design of riser systems as follows[7] and [5]: Functional and Pressure Loads: Functional loads refers to as loads that occur as a result of the physical presence of the system and by operating and controlling the system, without the presence of accidental or environmental loads. Whereas, pressure loads are loads strictly due to combined effect of hydrostatic internal and external pressures. The functional and pressure loads included in the analysis are:

- Weight of riser, subsurface buoy, contents, and coating
- Internal pressure due to contents, and external hydrostatic pressure

- Nominal top tension
- Buoyancy
- Vessel constraints

Environmental Loads: These are loads imposed directly or indirectly by the ocean environment. These are:

- Wave loads
- Current loads
- Vessel motions
- Seismic loads
- Ice loads
- Wind loads

Only the first three types of environmental loads are included in the analysis in this write-up.

Accidental Loads: this refers to loads that a riser is subjected to because of technical failure, abnormal or incorrect operation. They typically result from unplanned occurrences. These include:

- Partial loss of station keeping capability
- Small dropped objects
- Tensioner failure
- Fires and explosions
- Flow-induced impact between risers
- Vessel impact

Material Selection

Material selection is an important part in Flexible pipe design; general criteria for their selection will be introduced in this part. For a specific layer, the associated material must be able to fulfill its function so that the integrity of the flexible pipe would be kept during its service life. According to [6], even though this fulfils the primary criteria in material selection, there are other secondary criteria that is been considered by the designer and manufacturer which could affect the final material selection. [8] Among other criteria is the functional suitability of the material, which means that the mechanical requirements is met in the overall pipe design. Hence main criterions for Material Selection are maintain integrity during service life, functional requirements, long-term integrity, ease of manufacture and supply, certification requirement, client specification, economic viability.

Waves

In the design and analysis of riser system during operation or installation, it is important to have a basic understanding of wave. Firstly, a single wave method can be considered. In this method, the wave height and wave period is given as the design wave. The single wave method is more easy and simple to predict the response behavior of the riser system and also to analyze for a given period, the maximum wave height that may occur. A regular (linear and non-linear) wave is commonly used for a single wave method.

Secondly, the wave spectrum method could also be used to present the real description of ocean wave of a particular field. A suitable wave spectrum model is normally chosen to represent anappropriate density distribution of the sea waves at the particular site.

Theoretical spectrum models like Pierson-Moskowitz Spectrum, Bretschneider Spectrum, JONSWAP Spectrum, etc. are made available and used by engineers. According to [9], the most suitable spectrum is a measure design wave spectrum at the site, even though the data is not always available for use.

II. MATERIALS AND METHODS

Element formulation

In orcaflex, line is used to model the actual flexible riser in the Lazy wave configuration. The discretized line model is made up of massless segments with torsional and axial properties as well as nodes that defines the actual riser segment such as weight, mass, buoyancy, drag forces and many others.

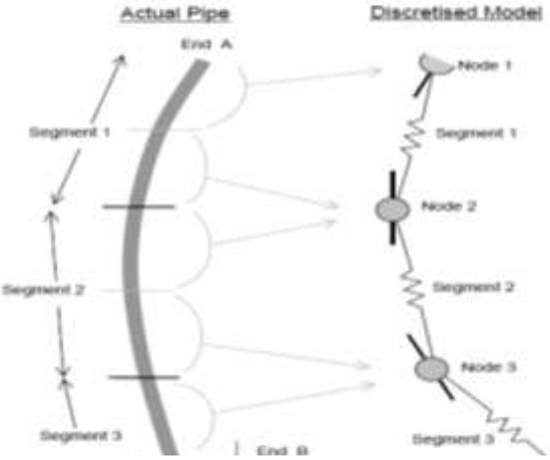

Figure 3: Orcaflex line model [10].

Orcaflex establishes a finite element model for the riser analysis. The finite element method is a general and efficient tool that can be applied to numerous structural applications and is therefore often used in the analysis of a marine riser [11]. As shown in Figure 3 the node in each end is a combination of the properties of the half-length segment on each side of the nodes. Forces and moments are also applied at the nodes [10].

The segments in the model give the axial and torsional properties of the physical segment. The segment can be illustrated, in Figure 3, which gives a more detailed representation of the line model, including three various types of spring-damper systems that actually defines the line properties [10].

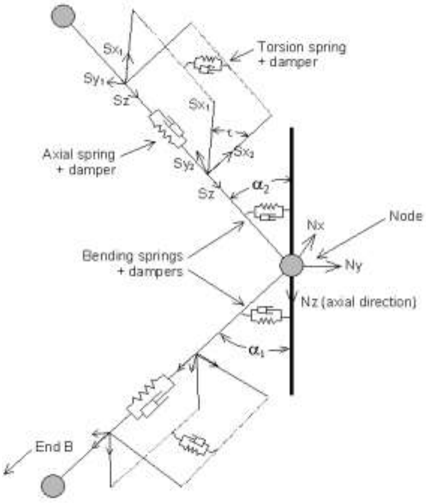

Figure 4: Orcaflex line segment model [10].

The axial spring/damper system is placed in the center of each segment in the model, and applies an equal and opposite effective tension to the nodes at end of the segment.

The rotational spring-damper system is placed at both of the sides of the node to represent the bending properties of the line. This system allows modeling with various bending stiffness along the length of the line model.

In addition to the two mentioned systems a rotational spring/damper-system is positioned in the ends of each segment to maintain the bending properties assigned to the segments. This system makes it possible to have different bending stiffness over the length of the model [10]. If torsion is not considered, then the system is not included in the model and the segment is twisted freely relative to each other.

Loads on Flexible Risers

To adequately analyze the dynamic behavior of the riser, one has to be aware of the different loads acting on the riser. The loads taking into consideration in an analysis of the riser include the following:

1. Weight of the riser, including flanges, internal fluid and buoyancy modules etc.
2. Hydrostatic forces from the water surrounding the riser
3. Forces on the riser caused due to vessel motion and offset

4. Hydrodynamic loads from waves and current, including drag and inertia forces.

Dynamic waves and currents acting on a riser over a long period of time generate fatigue stresses and fatigue is a parameter that has to be considered when the riser is designed. However, fatigue is not in focus here, as the environment for the analysis is given. Rather the fatigue life is very important here, because it must withstand wave action on the host platform for decades, while supporting its own weight and containing internal pressure.

A large part in the analysis of the riser system is devoted to the calculations of forces and moments. These calculations are carried out in five steps as follows:

1. Tension forces;
2. Bending moments;
3. Shear forces;
4. Torsion moments (if included);
5. Finally, total load.

The analysis can be run once the model is built up and the correct environmental conditions are specified in the model. In OrcaFlex the analysis is comprised of two main parts, a static analysis and a subsequent dynamic analysis.

Static Analysis

A static analysis is run to determine the equilibrium position of the riser system with itself loads such as weight, buoyancy, drag, etc. this is done by iteration from the initial position of the riser system by the giving input parameters with the assumption that the line ends are fixed.

The resultant force and moment from the riser system is then determined. A new position of the entire riser system can be found afterwards. This is repeated until the resultant force is equal to zero. The equilibrium configuration of the system is then used as an initial position for the dynamic simulation/analysis [10].

Dynamic Analysis

A dynamic analysis is run to simulate the dynamic behavior of the riser system in a defined environment over a time duration. This gives the displacements, forces, and moments under the given load. For a smooth transition from the static to full dynamic, a build-up time is defined where the wave and vessel movements are ramped up from zero to full dynamic motion.

The dynamic analysis is performed in Orcaflex by solving the equation of motion [10].

$$M\ddot{x} + C\dot{x} + Kx = P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where

M Mass matrix

C Damping matrix

K Global stiffness matrix

P External loads

$\ddot{x}, \dot{x},$ and x Are acceleration, velocity and displacement respectively.

In Orcaflex, the dynamic calculation is done in two methods, which are the implicit and explicit method, both methods compute the new riser system geometry for each time step.

1. The explicit method; this uses forward Euler with a constant time. In this method, all the forces and moments that act on each node and body of the riser model are calculated. This is achieved when the initial positions of the riser system are found from the static analysis. The results are used to form the individual local equation of motion for every free body and node in the riser model, [10].
2. The implicit method; it's done in the same way as the explicit method, but the integration uses the generalized-$\propto$ integration so that the equation of motion is solved at the end of the time step.

The choice of time step in the analysis is a balance between stable integration, accuracy in calculation and efficiency in computational time.

Table 1: Riser input parameters

Parameters	Dimension	Unit
Length	190	m
Inner Diameter (ID)	0.254	m
Outer Diameter (OD)	0.356	m
Weight in air, empty	0.184	Kg/m
Minimum bending radii	3.675	m
Allowable tension	5000	KN
Axial stiffness	711.220E3	KN
Bending stiffness	124.869	KNm^2
Torsional stiffness	10.000	KNm^2

Table 2: Segmentation of the components in the model

Component	No.of segments	Target segment length (m)	Total length (m)
10” flexible	12	4	50
10” flexible	30	1	30
10” + floats	80	0.625	50
10” flexible	40	1	40
10” flexible	5	4	20

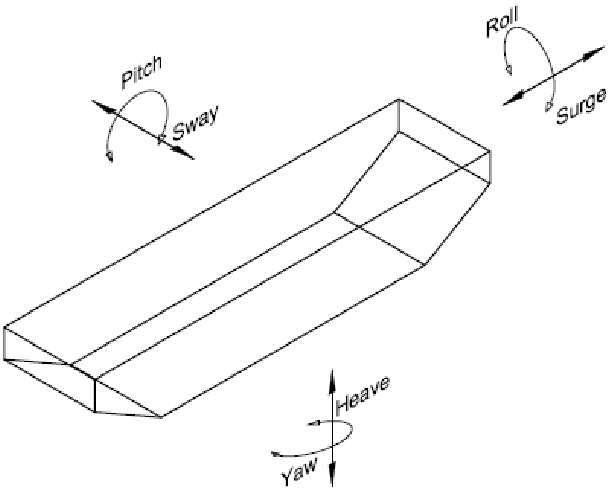

Figure 5: Ship Response Modes

III. RESULT AND DISCUSSIONS

Static Analysis Results

Table 3: Static analysis Result

Load Case	Minimum Bending Radius at tether con. (m)	Riser Tension at End A (KN)	Riser Tension at End B (KN)	Moment at End A (KN.m)	Riser Tension at PLET (KN)	Riser line Clearance from Surface
1	16.8	92.32	16.39	0	16.49	93.47
2	18.2	93.35	16.87	0	16.99	93.92
3	20	100.98	18.87	0	18.83	96.08

Table 4: Minimum Bending Radius

Load Case	FPSO Offset	FPSO Loading Condition	Min Bending Radius (KN)	Location	Utilization
1	Far	Full Loaded	16.8	107.9	56.2
2	Near	Full Loaded	18.2	39.1	31.5
3	Cross	Full Loaded	20	231.5	88.75

Table 5: Extreme axial Tension at Turret Connection Location

Load Case	FPSO Offset	FPSO Loading Condition	Min Tension at turret (KN)	Max Tension at turret (KN)	Static Tension (KN)	DAF
1	Far	Full Loaded	86.7	92.32	56.2	1.9
2	Near	Full Loaded	84.5	93.35	31.5	1.2
3	Cross	Full Loaded	78.9	100.98	88.75	2.6

Table 6: Extreme axial Tension at Tether connection point

Load Case	FPSO Offset	FPSO Loading Condition	TetherMin. Tension (KN)	TetherMax. Tension (KN)	Static Tension (KN)	DAF
1	Far	Full Loaded	17	18.4	22	28
2	Near	Full Loaded	16.9	18.5	19	25
3	Cross	Full Loaded	17.6	19.8	20	23

Table 7: Extreme effective Tension at PLET connection

Load Case	FPSO Offset	FPSO Loading Condition	Min. Tension at turret (KN)	Max. Tension at turret (KN)	Static Tension (KN)
1	Far	Full Loaded	17	18.4	37.1
2	Near	Full Loaded	16.9	18.5	59.1
3	Cross	Full Loaded	17.6	19.8	75.5

Riser Motion Results

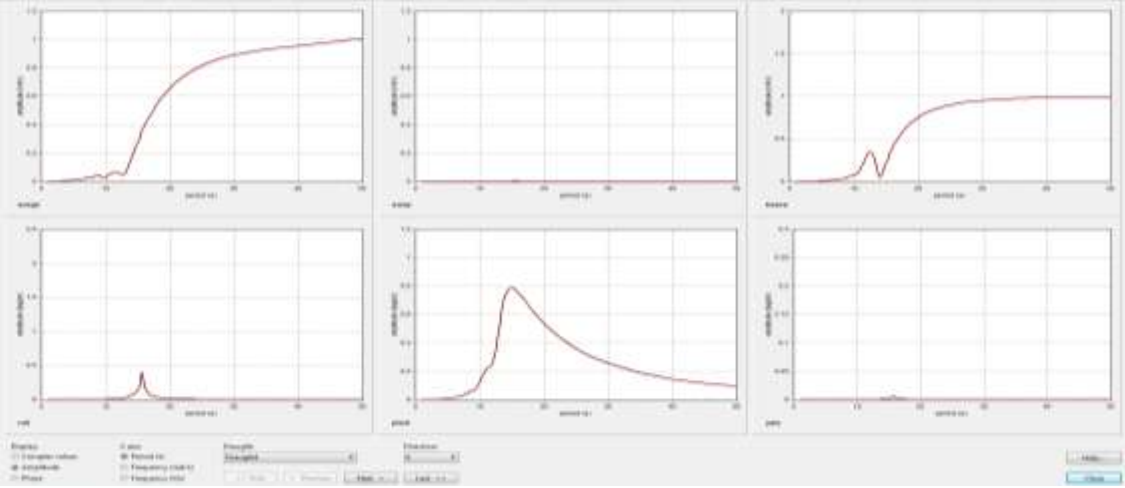

Figure 6: Plot of Risers Motion against Wave Period at 0° Phase Angle

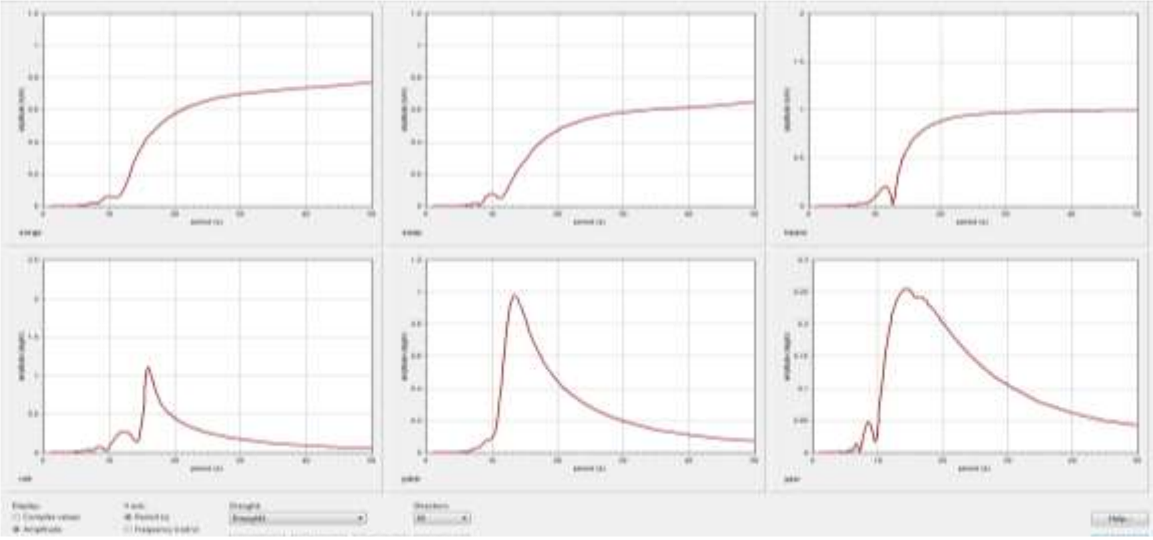

Figure 7: Plot of Risers Motion against Wave Period at 40° Phase Angle

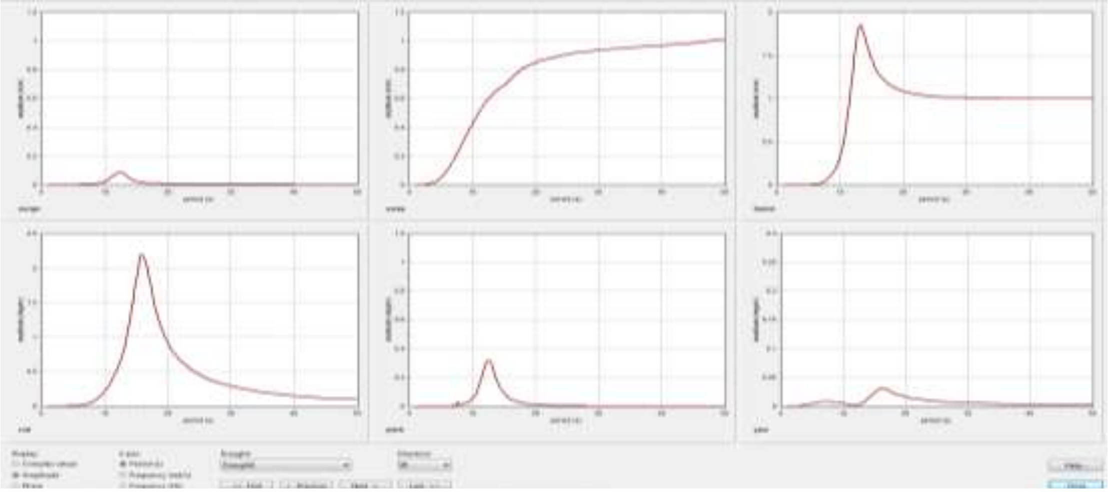

Figure 8: Plot of Risers Motion against Wave Period at 90° Phase Angle

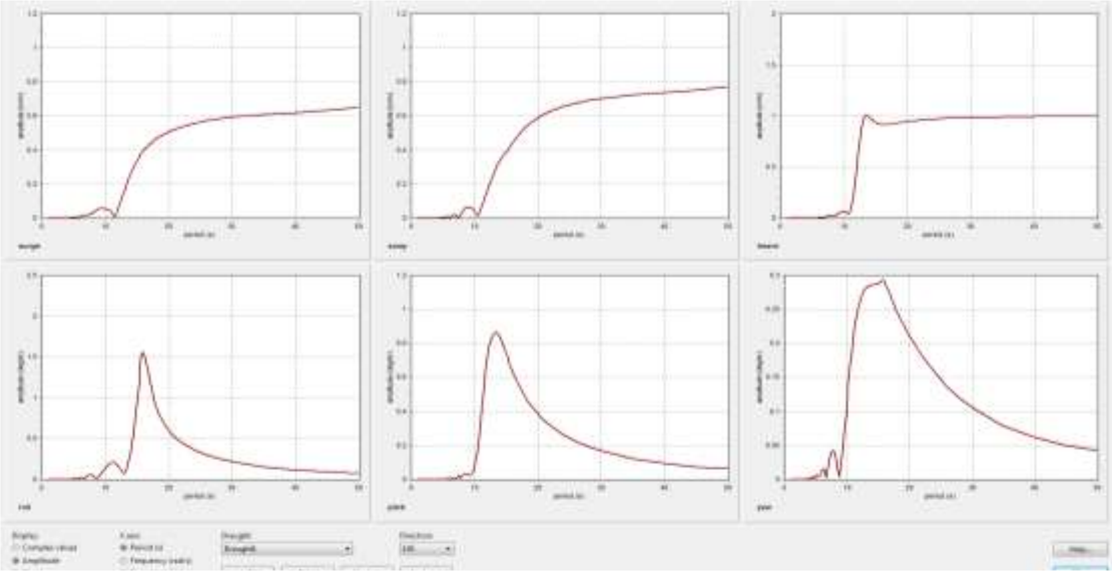

Figure 9: Plot of Risers Motion against Wave Period at 130° Phase Angle

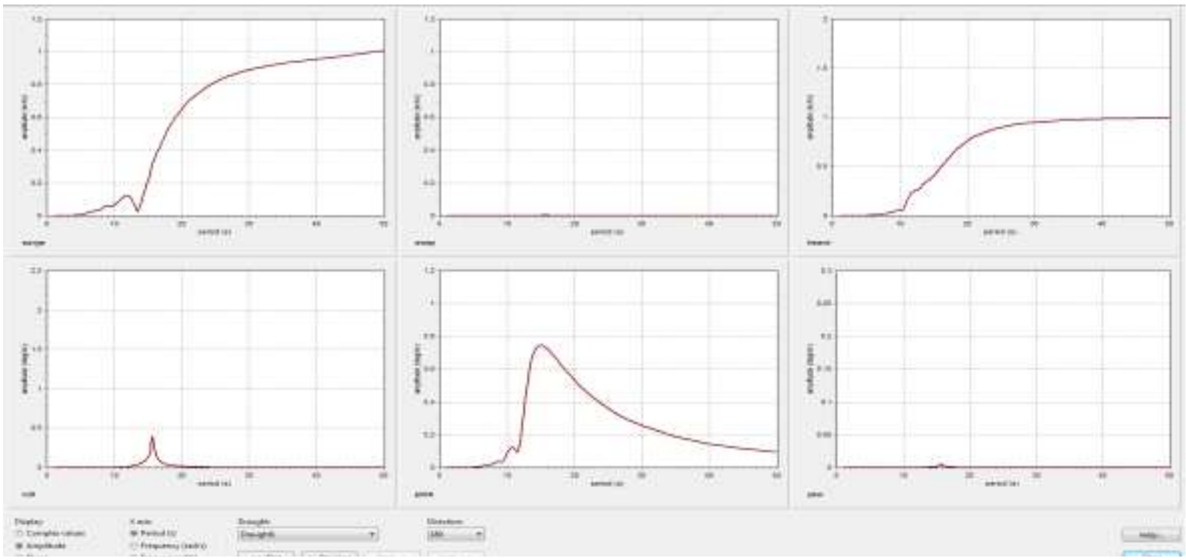

Figure 10: Plot of Risers Motion against Wave Period at 180° Phase Angle

Figure 7 is the risers six motion against the wave period at zero degree phase angle, with the first plot showing the surge motion of the risers against vary wave period at 180° wave phase angle and it show that the surge motion of the risers amplitude operator remain at nearly zero with increase wave period until about 1.0s when the surge amplitude operator begins to increase with increase wave period and is maximum at maximum wave period, and show a total increase in magnitude and size when compared to figure 6 and literal mean that the surge amplitude operator increases in magnitude and sizes with increase wave phase angle from 130° to 180°, the second diagram show the sway motion of the risers with wave amplitude operator nearly zero and remain so with increase wave period, which mean that the sway response amplitude operator of the risers decreases in magnitude as the wave phase angle increases from 130° to 180° at vary wave period, thou it was observed that the maximum value of the sway amplitude operator decreases when figure 5 figure 6 and figure 7 is compared, and the third diagram show the heave amplitude operator of the risers which increases with vary wave period at 130° wave angle and when compared with figure 6 it is observe that the maximum heave amplitude operator remain same as the wave phase angle increase from 130° to 180° and did not show an sign of variation with increase wave phase angle from 0° to 40° too. Also the fourth diagram show the roll amplitude operator of the wave on the riser as wave period increases, it is shown that the roll amplitude operator remain at zero until the wave period of 0.7s, the roll amplitude operator begin to rise to maximum at 1.5s before a gradual decline of the roll amplitude operator as the wave period increases from 1.5s to 2.0s wave period at 130° wave phase angle, and it was observed that the roll amplitude decreases in magnitude and size as the wave phase angle increases from 90° to 180° with the maximum value of the roll amplitude operator also decreases from 2.2 to 0.4, and the fifth diagram show the pitch amplitude operator increasing as wave period increases until the pitch amplitude operator is maximum at 1.5s with pitch amplitude operator of about 0.75 before it experience gradual decrease as wave period move from 1.5s to 6.0s at 180° wave phase angle, and when compared to figure 6 it was observe that the pitch amplitude operator decreases in both magnitude and size as the wave phase angle increases from 130° to 180°, then the sixth diagram which is the yaw amplitude operator remain at nearly zero as wave period increases from 0s to 6.0s at 180° of the wave phase angle, and when compared with figure 6 it was observed that the maximum value decreases in size and magnitude as the wave phase angle move from 130° to 180°.

IV. CONCLUSIONS

The present study has looked into the dynamic behavior of a flexible riser in shallow water which results to the usage of the riser configuration known as the lazy wave riser supported by subsurface buoy.

I can conclude from the above results that the static analysis is favourable to that of case 1 (far FPSO offset) this so because the minimum bending moment, the riser tension at point A, the riser tension at point B, the riser tension at PLET and the riser line clearance from surfaces all have their minimum value at the far FPSO offset, and of the value have practical implications as the farer the riser the lest minimum bending moment.

I can also conclude that the risers motions are in line with what is obtainable in practice as all the six motions under consideration follow a wave pattern with the maximum surge motion of the riser decreases with increase wave angle until it get to 90° before the maximum surge motion begin to rise again, and the maximum sway motion of the riser increases with increase wave phase angle until it get 90° before the maximum sway motion begin to decrease as wave phase angle increases 180° when the sway motion becomes minimum again. Also the maximum heave motion of the risers thou slow but also increases with increase wave phase angle and decreases after wave phase angle 90°, and the maximum roll motion of the risers follow an opposite pattern to that of the maximum surge motion and the is so because the roll motion is the angular motion of the riser in x direction.

Finally, I can conclude that the results obtained so far from the Orcaflex are in line with what is obtainable by using other software or by making reference to text.

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