

Sensitive Analysis of Different Types of Deep Water Risers to Conventional Mooring Systems

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ABSTRACT

Structural response of different types of conventional deep water riser affected by mooring systems in harsh environment is focused in this study. With increasing water depth, the mooring system design of a floating-type production platform becomes more important and complicated from cost as well as safe operation point of view. With the development of offshore oil and gas exploitation, FPSO with many advantages can better adapt to the complicated environment of deep sea. According to the current mooring system development, this study compares the effect of spread mooring system and turret mooring system on riser structural response. Both systems consists of 12 mooring lines and each line is made from two components. Three types of more conventionally used deep water risers have been selected and applied with the mooring systems, resulting in 6 different case studies. The case studies have been modeled in OrcaFlex software with same extreme environmental conditions. Comparing bending moment in the risers, as one of the main design parameter, shows the effect of proper selection of the riser and mooring system.

1. Introduction

Floating structures are continuously exposed to environmental forces such as waves, wind and sea currents. One way of keeping the position of these structures during the operation, is using the mooring lines systems. Mooring system is one of the main solutions in order to preservation of platforms position. The system is composed of several mooring lines with different configurations which is affected by environmental forces as well as structure displacement induced forces. Safety of these systems significantly effects on platforms performance. Thus the extensive researches has been performed on the variety of mooring system failures. It is important to evaluate the failure of these systems due to alternative and random nature of forces acting on the system as well as the difficulty in inspection and maintenance of them [1].

Many studies have been performed about the platform response effecting by mooring system in recent years. For example Qiao and partners studied behavior of platform under mooring system conditions with different pre tensions [2]. Also Wu predicted behavior of semi-submersible platform by using numerical modelling [3]. A research group considered behavior

and created forces of mooring lines [4]. Maffra and partners investigated to optimize the mooring lines of semi-submersible platforms by using genetic algorithm in 2003. Ultimately, they evaluated the use of this method effectively [5]. Also in 2009, Waals studied about the effect of different directionality of the platform on second order force acting on it and on created tensile forces in mooring lines [6] [7]. A Chinese group calculated the dynamic responses analysis methods of catenary mooring system and taut mooring system of FPSO and then compared them to each other in 2013. The results indicated that the position ability and mooring strength of taut mooring system whose intermediate material is polyester are better than that of catenary mooring system on the premise that satisfies API specification at the same time [8]. Also in 2007, the method and theory of dynamic analysis of mooring systems specific dynamic parameters of these systems in deep water were introduced [9]. Comparison and study on the dynamic Characteristics of semi-submersible platform mooring system by using catenary mooring system and taut mooring system in 2009 was performed [10]. According to a study in 2006, recent experience has shown that the mooring system for several deep water

fields have been designed without taking into account all the relevant interfaces, leading to expensive mid-project changes, increased component costs, and impact on schedule and installation [11].

According to previous studies, the bending moment is one of the important governing design parameters and the critical area is located near the Touch Down Zone (TDZ) and the bending moments in the top region is considerably smaller than that in the touch down region [12]. So a comparison of the bending moment at the point which has the largest moment in different conventional deep water riser and mooring system configurations is the aim of this study to find out the importance of mooring selection in using any type of the risers.

Marine Riser and Mooring Systems

The riser system is in the interface between a static structure at the bottom interface and the dynamic floater structure at the top interface. The dynamic behavior of floater at the surface is the main challenge for riser system design. The most severe motion is heave from the first order vessel motion [12]. This is the main reason for next categorizing of riser system according to the ability of riser system to cope with floater motion [13]:

- Top tensioned riser
- Compliant riser. Hybrid riser is also the combination of tensioned and compliant risers.

Top Tensioned Riser

The riser in Top Tensioned Risers (TTRs) concept is supported in the floater by providing top tension force in order to maintain acceptable vertical movement. The horizontal motions of the floater induce stresses in the riser base and at the top end near the flex/keel joints. TTRs are applied for dry tree production facilities such as SPARs or tension leg platforms (TLPs). SPARs and TLPs have small heave motion which is desirable for TTR concept. To some extent, semi-submersibles can also be considered as host platform for TTRs by incorporating separate heavy compensation system to account for the floater motions. Generally, TTR can be used for drilling,

production, injection and export riser. The TTR runs directly from the subsea well to the vessel deck where a surface tree is located. Tension is applied to the riser by either buoyancy cans or deck mounted hydro-pneumatic tensioners. For spars, the installation of buoyancy cans is a complex, costly and time consuming process. Risers tensioned using hydro-pneumatic tensioners on spars or TLPs are less complex, and take less time to install in comparison to using buoyancy cans. For deep water application, the riser top tension requirements become significant to support riser weight and prevent bottom compression. The increase in riser tension affects the size of the tensioning system, the buoyancy requirements, as well as the size of the flex-joints or stress joints. In addition, harsh environments will give significant movement on the floaters and TTR itself. Therefore, at some level of combination between water depth and environmental conditions, TTR becomes technically unfeasible and uneconomical [14].

Compliant Riser

Compliant riser provides flexibility to cope with floater motions. Configurations of compliant riser are formed such that it could absorb floater motions without having additional equipment e.g. heave compensation system. The design flexibility to have high dynamic resistance allows compliant riser to work on deeper water depth and harsher environments. Compliant risers are mainly applied as production, export and injection risers. It can be applied to wide variations of floater such as TLPs, Semi-submersibles, and Ships. Different compliant riser configurations are shown in figure1. Compliant 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 [14].

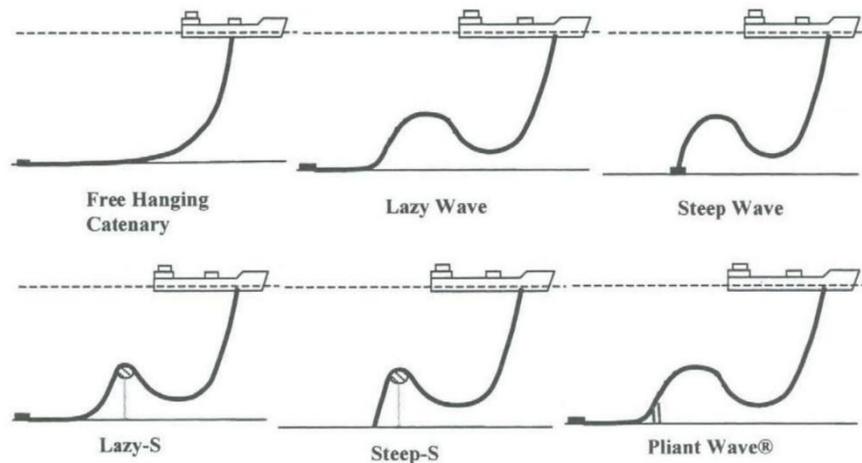


Figure 1: Standard Compliant Riser Configurations [15]

The free hanging catenary riser is widely used in deep water. This configuration does not need heave compensation equipment, when the riser is moved up and down together with the floater, the riser is simply lifted off or lowered down on the seabed. In deeper water the top tension is large due to the long riser length supported, to reduce the size of the top tensioner buoyancy modules could be clamped to the top end of the riser. The surface motion is directly transferred to the Touch down point (TDP), this means that the failure mode could be over bend or compression at the TDP. The most severe motion is heave from the first order vessel motion.

For lazy wave configurations, buoyancy and weight are added along some length of the riser to decouple the vessel motions from the touchdown point of the riser. Lazy waves are preferred to steep waves because they require minimal subsea infrastructure. However, while lazy waves are prone to configuration alterations if pipe content density changes during the riser's lifetime, steep wave risers are able to maintain their configuration even if the riser content density changes.

In steep wave configurations, there is a subsea buoy which is either a fixed buoy (fixed to a structure at the seabed) or a buoyant buoy. The addition of the buoy removes the problem associated with the touchdown point. The subsea buoy absorbs the tension variation induced by the floater, and the touchdown point eventually experiences only little or no tension variations. In case of large vessel motions, a lazy-S might still result in compression problems at the riser touchdown, leaving the steep-S as a possible alternative. Due to the complex installation procedure of 'S' configurations, they are considered only if catenary and wave configurations are not suitable for a particular field. A lazy-S configuration requires a mid-water arch, tether and tether base, while a steep-S requires a buoy and subsea bend stiffener.

Pliant wave configuration is almost like the steep wave configuration where a subsea anchor controls the touchdown point i.e. the tension in the riser is

transferred to the anchor and not to the touchdown point. This configuration is able to accommodate a wide range of bore content densities and vessel motions without causing any significant change in configuration and inducing high stress in the pipe structure. However, due to complex subsea installation that is required, it would be required only if a simple catenary, lazy wave or steep wave is not viable [14].

Most offshore floating production solutions (FPSO, TLP, SPAR and SEMI) require a reliable method of maintaining their physical position (mooring) in offshore waters during oil and gas production operations. These mooring systems allow the production facility to avoid excessive movement that could affect the reliability of both the structure and riser systems. Station keeping systems for floating structures used for oil and gas applications can be of many types, depending on the characteristics of the structure and on the environmental conditions. Single point moorings are frequently used for ship-shaped floating structures, while spread moorings are used mostly for semisubmersible or other types of structures when maintaining a particular orientation is important. A third type of station keeping system is dynamic positioning (DP). Dynamic positioning can be used with either ship-shaped or semi-submersible structures.

Spread Moorings (Catenary, Taut-Line and Semi-Taut-Line)

Figure 2 is an illustration of a fairly typical catenary spread moored FPSO. For floating production structures, spread moorings are often used with semi-submersibles. Since the environmental actions on a semi-submersible are relatively insensitive to direction, a spread mooring system can adequately hold the structure on location. This solution can also be used with ship-shaped structures, which are more sensitive to the directionality of the environmental actions, when the prevailing weather at the site comes

from one direction, so that the structure can be oriented with the narrow dimension into the weather. Spread moorings can incorporate chain, wire rope, synthetic fiber rope, or a combination of the three. Drag anchors or anchor piles are generally used to terminate the mooring lines. Alternative spread mooring systems include taut or semi-taut-line systems. The main advantage of a spread mooring system is that it fixes the orientation of the floating

structure, so that drilling, completion and well intervention operations can be carried out on subsea wells located immediately below the structure. On the other hand, a spread mooring system has a fairly large mooring spread (several times the water depth). The presence of anchors and mooring lines should be considered in the installation or maintenance of pipelines, risers or any other subsea equipment.

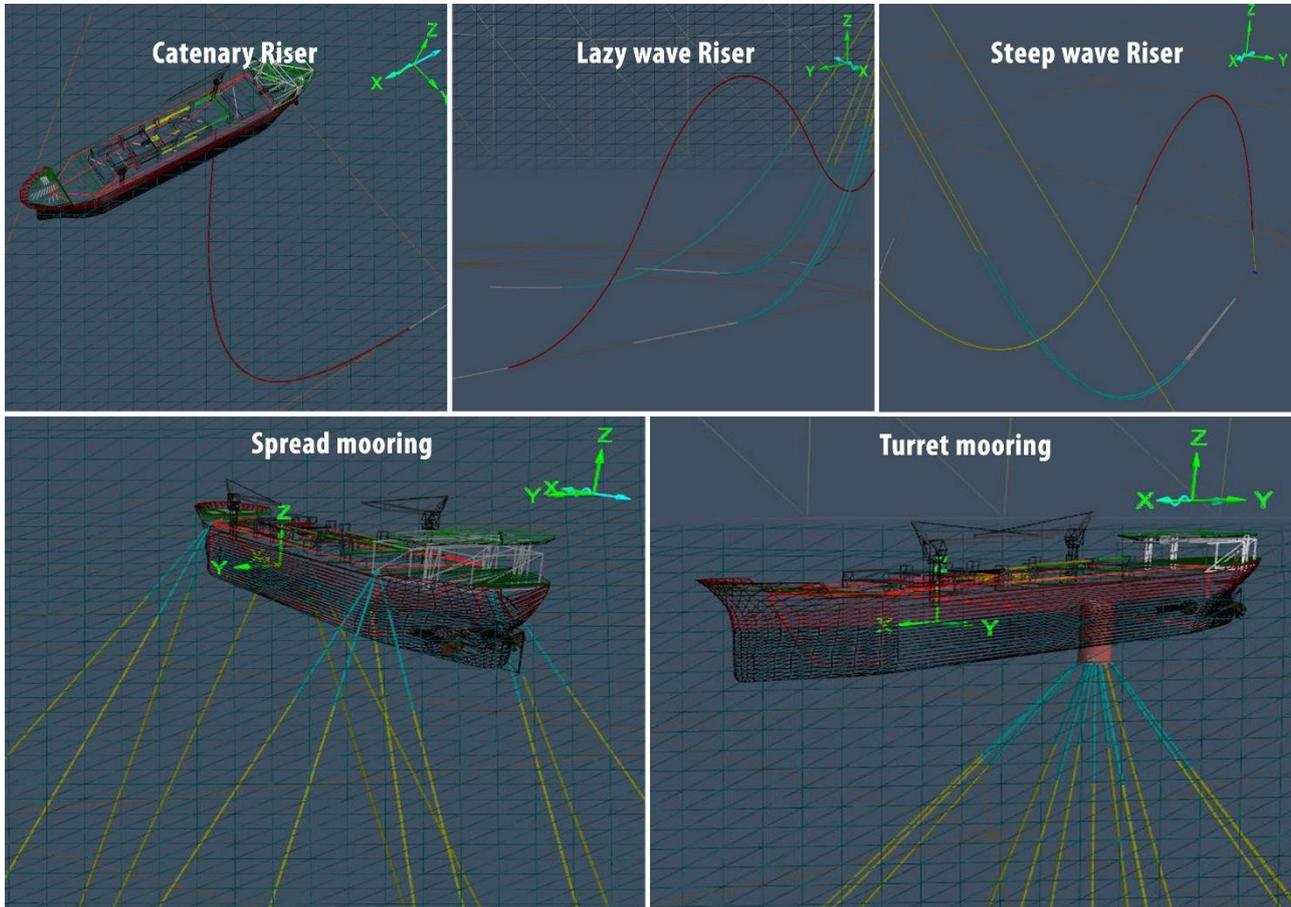


Figure 2: 3D models of 3 different risers and 2 mooring systems

Single Point Moorings

Single point moorings are used primarily for ship-shaped floating structures such as FPSOs and FSOs. Their main characteristic is that they allow the structure to weathervane. There is wide variety in the design of single point moorings but they all perform essentially the same function. Single point moorings interface with the production riser and the structure. A brief summary of typical single point mooring system is as follows.

Turret Mooring

In this type of mooring system, catenary mooring lines are attached to a turret, which is essentially part of the structure to be moored. The turret includes bearings to allow the structure to rotate (yaw) independently of the mooring system. The turret can be mounted externally from the structure's bow or stern with appropriate reinforcements or internally (Figure 2). The chain table can be above or below the

waterline. Flow from the turret into the process facilities is via marine hoses or flexible pipes that extend upward from the sea floor to the bottom of the turret. In some cases the turret is designed such that the lower chain table can be disconnected to enable the floating structure (usually self-powered) to depart from the location in advance of a foreseeable severe environmental event, e.g. a tropical cyclone or an approaching iceberg. After disconnection, the self-buoyant chain table remains submerged at a pre-set depth while supporting the mooring lines and risers. A variant of this arrangement is a buoyant submerged turret assembly designed for easy connection and disconnection in order to temporarily moor specially modified export tankers for direct loading of produced oil. This arrangement is also used for permanent floating structures (FPSO or FSO). In this design the turret assembly contains the main bearing that allows weather compatibility of the tanker or floating structure.

Mooring Line Components

Mooring lines for floating structures are usually made up of wire rope, chain, synthetic fiber rope or a combination thereof. Many possible combinations of line type, size and location, and size of clump weights or spring buoys can be used to achieve the required mooring performance.

Wire Rope: Being much lighter than chain, wire rope provides a greater restoring force for a given pre-tension. This becomes increasingly important as water depth increases. However, to prevent anchor uplift with an all-wire rope system, much longer line length is required. A disadvantage of an all-wire rope mooring system is wear due to long-term abrasion where it contacts the sea floor. For these reasons, all-wire rope mooring systems are seldom used for permanent moorings.

Chain: Chain has shown durability in offshore operations. It has better resistance to bottom abrasion and contributes significantly to anchor holding capacity. However, in deep water an all-chain system imposes an increasing penalty on the floating structures payload capacity because of its weight and pre-tension requirements.

Synthetic Rope: Synthetic fiber ropes made of polyester, HMPE or aramid fibers are increasingly being used in deep water mooring systems due to their much lighter submerged weight and greater elasticity compared with steel wire rope. Synthetic fiber ropes also have very long fatigue lives compared with steel ropes.

Chain/rope Combinations: In these systems, a length of chain is typically connected to the anchor. This provides good abrasion resistance where the mooring line contacts the sea floor and its weight contributes to

anchor holding capacity. The choice of chain or wire rope at the structure's end and the type of termination depends on the requirements for adjustment of line tensions during operations. By proper selection of the lengths of wire rope and chain, a combination system offers the advantages of reduced pre-tension requirements with higher restoring force, improved anchor holding capacity and good resistance to bottom abrasion. These advantages make combination systems attractive for deep water mooring [16] [17].

Modelling

OrcaFlex is a fully 3D non-linear time domain finite element program capable of dealing with arbitrarily large deflections of the flexible from the initial configuration. A lumped mass element is used which greatly simplifies the mathematical formulation and allows quick and efficient development of the program to include additional force terms and constraints on the system in response to new engineering requirements. In addition to the time domain features, modal analysis can be performed for either the whole system or for individual lines. RAOs can be calculated for any results variable using the Spectral Response Analysis feature [18].

Risers and mooring lines are defined as "Line". The line is divided into a series of line segments which are then modelled by straight massless model segments with a node at each end. The model segments only model the axial and torsional properties of the line. The other properties (mass, weight, buoyancy etc.) are all lumped to the nodes, as indicated by the arrows in figure 3. OrcaFlex uses a finite element model for a line as shown in figure 3 [18] [12].

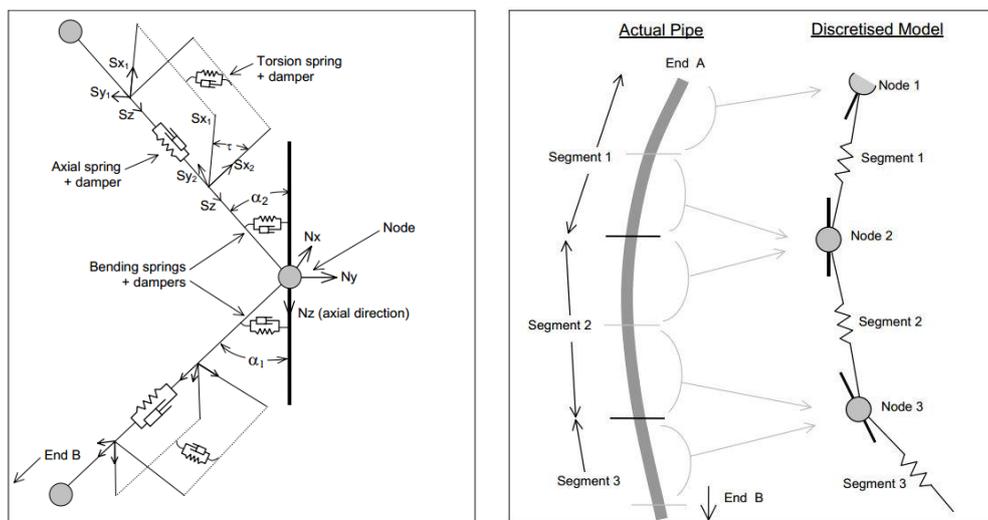


Figure 3: Finite element modelling method in OrcaFlex

Model

A typical Steel Catenary Riser, Lazy Wave Riser and Steep Wave Riser each one supported by a FPSO

which is once moored by Spread type and once by Turret mooring system (six configurations) located in deep water and faced to harsh environmental loads

considering wave, current pattern and riser-soil interaction are modeled to analyze their static and dynamic behavior and to compare different configurations in order to select the best mooring system configuration for each marine riser. For deep water spread moored FPSO units, the number of

anchor legs required may range between 12 and 20 lines, compared to 6 to 12 anchor legs for a turret moored system [19]. Environment and Riser input data used in this analysis is listed in table 1 [14]. RAOs of the floater should also be imported in OrcaFlex.

Table 1: Environment, Riser and Mooring Data

Environment	Sea	Water depth		1000 m				
		Water density		1025 kg/m ³				
	Wave	Stokes 5th		Significant Height		8 m		
				Peak period		21 s		
	Current	As water depth		Surface		0.93 m/s		
-50				0.68 m/s				
-300				0.47 m/s				
-1000				0 m/s				
Soil	Transverse friction stiffness		0.5					
	Normal stiffness		600 Kpa					
Riser			SCR	LWR		SWR		
	Riser Geometry	Length	2350 m	Hose	2100 m	Float	750 m	1350 m
		Diameter	0.254 m		0.254 m	1.2 m	0.254 m	1.2 m
		Mass per unit length	150 kg/m		184 kg/m	359 kg/m	184 kg/m	359 kg/m
	Riser material	Material density	7850 kg/m ³ , X65 Carbon steel	High pressure	400 kg/m ³	High pressure	400 kg/m ³	
		Young's modulus	210 GPa					
		SMYS	448 MPa					
		Poisson ratio	0.3					
	Riser Hydrodynamic Coefficients	Normal Drag Coefficient	0.9	1.2	1	1.2	1	
		Normal added mass Coefficient	1	1	1	1	1	
Riser content	Content density	800 kg/m ³	800 kg/m ³	800 kg/m ³	800 kg/m ³	800 kg/m ³		
Mooring			Spread		Turret			
	Line number	12		12				
		Chain	Rope	Chain	Rope			
	Length	1205 m	630 m	1205 m	630 m			
	Type	Stud link	Polyester	Stud link	Polyester			
	Nominal(Bar) Diameter	0.126 m	0.275 m	0.126 m	0.275 m			
	Mass per unit length	348 kg/m	60 kg/m	348 kg/m	60 kg/m			
Normal Drag Coefficient	1.200	1.200	1.200	1.200				

Figure 2 shows Catenary, lazy wave and steep wave riser types also spread and turret type mooring systems modeled separately using orcaflex. Figure 4

shows 3D models of all 6 possible configurations between riser and mooring systems which are considered in this research.

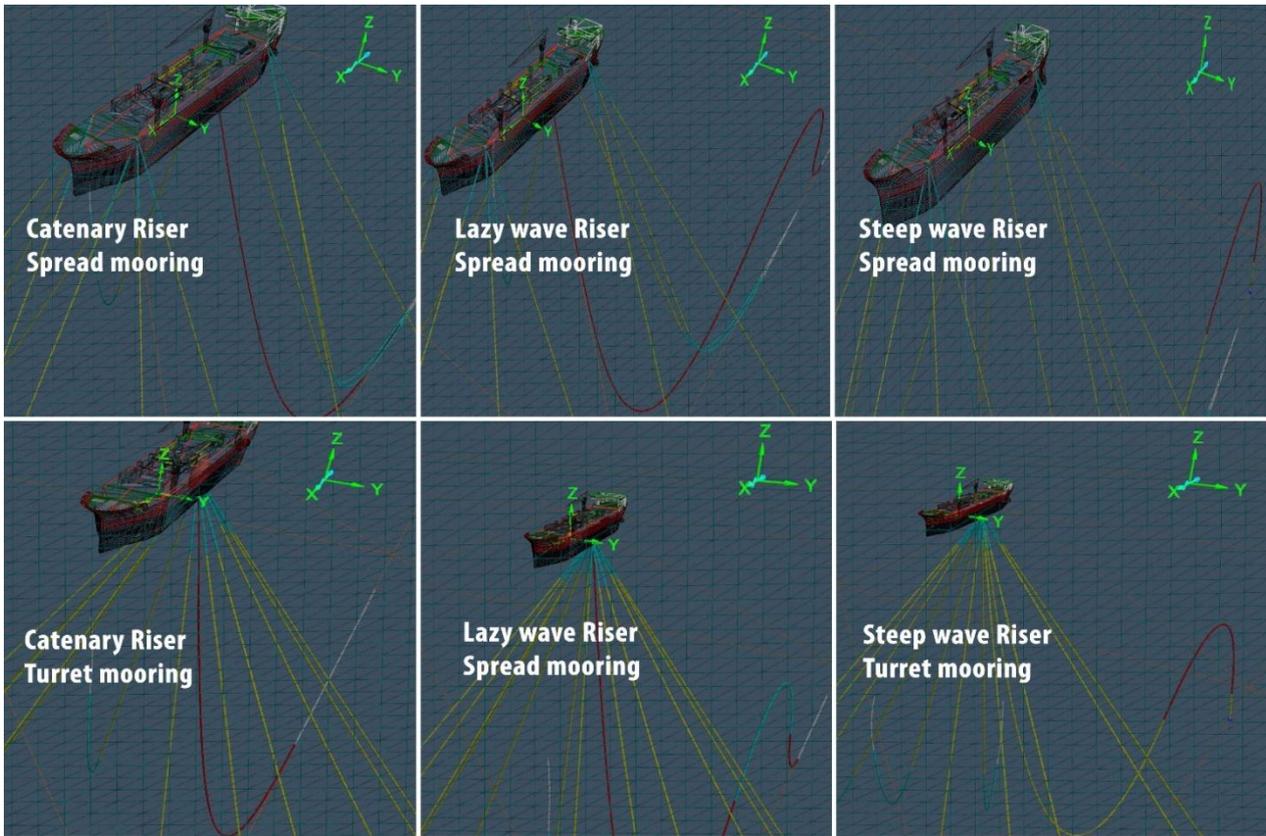


Figure 4: 3D models of 6 different riser and mooring system configurations modeled in Orcaflex software

Analysis has two stages, static convergence is done before starting the stages. Stage zero is the buildup period in which the wave and the current form and the simulation gets ready for time response analysis; this stage is shown from -21s to 0s in diagrams. At the start of the stage 1 the time response analysis starts and the simulation lasts for 64 seconds.

Results

The assessment of mooring type system effect on bending moment of riser, as a one of the governing

design factors, is the main objective of this study. Figure 5 shows the maximum bending moment versus the arc length of the catenary riser. Over plotting of the same diagrams of both spread and turret mooring systems shows that there is a difference in the amount of the maximum bending moment which indicates lower bending moments are applied on a catenary riser while the floater is using a spread mooring system to maintain its position. Figure 6 shows the bending moment of the point which undergoes the maximum moments during whole simulation time.

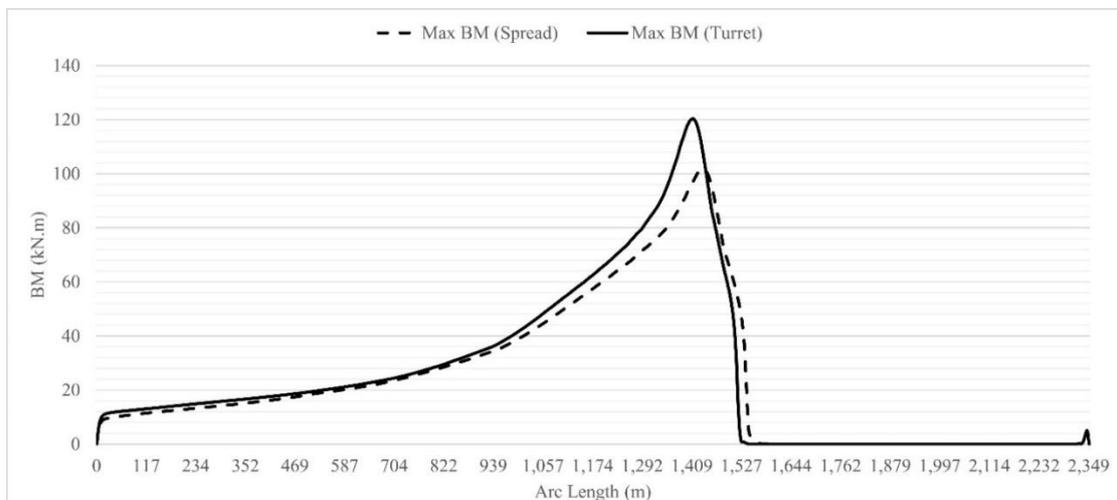


Figure 5: Max bending moment in catenary riser length in both Spread and Turret type mooring systems

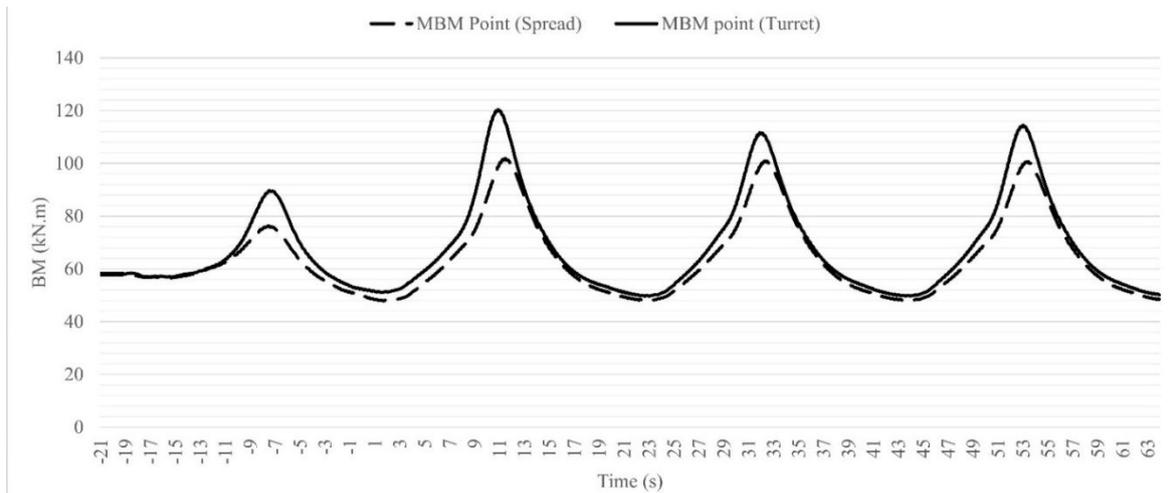


Figure 5: Time history diagram of governing point with maximum Bending moment in catenary riser length in both Spread and Turret type mooring systems

Changing the type of the riser to the lazy wave type results in a major decrease of the bending moment amounts and this is due to the compensation of the floater’s heave motion in its special lazy curve configuration. As shown in figure 7, there is a close difference between the maximum bending moments

on riser in both mooring configurations which is not so significant. figure 8 also shows the close difference in maximum bending moment amounts at the point which undergoes maximum bending moments once with spread type mooring system and once with turret type, during whole simulation time.

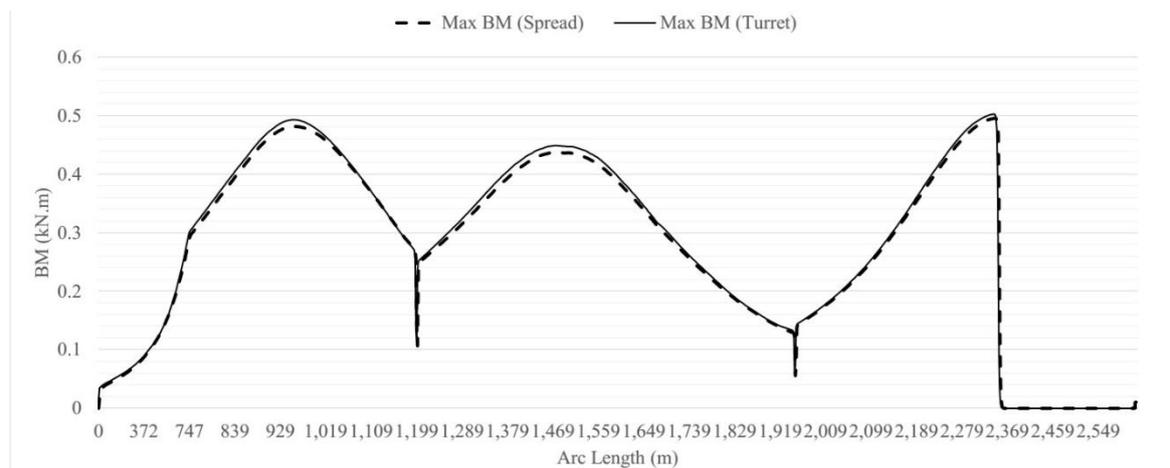


Figure 6: Max Bending moment in Lazy wave riser length in both Spread and Turret type mooring systems

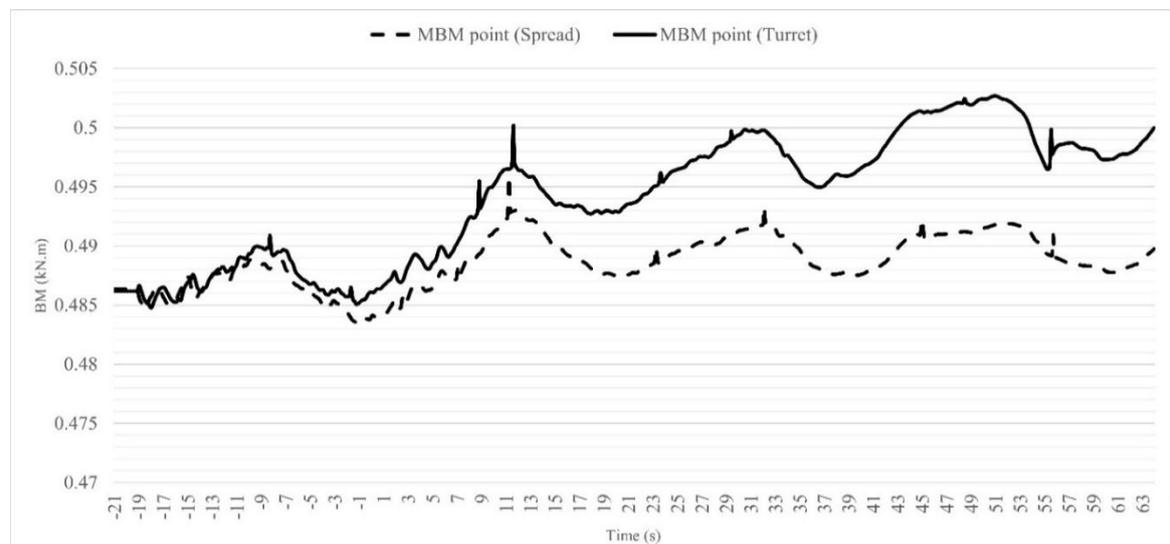


Figure 7: Time history diagram of governing point with maximum Bending moment in Lazy wave riser length in both Spread and Turret type mooring systems

It could be predicted that the maximum bending moment in the arc length of the steep wave type riser should occur at its end where the riser is connected to the subsea buoy and fixed to the seabed. As shown in figure 9 the amount of bending moments in the length of the steep type riser can be considered as zero in

comparison with its seabed connected end. Also there is no significant difference in the amount of maximum bending moments at riser end in comparison of both mooring systems. Figure 10 shows this little difference at the seabed connected end of the steep type riser.

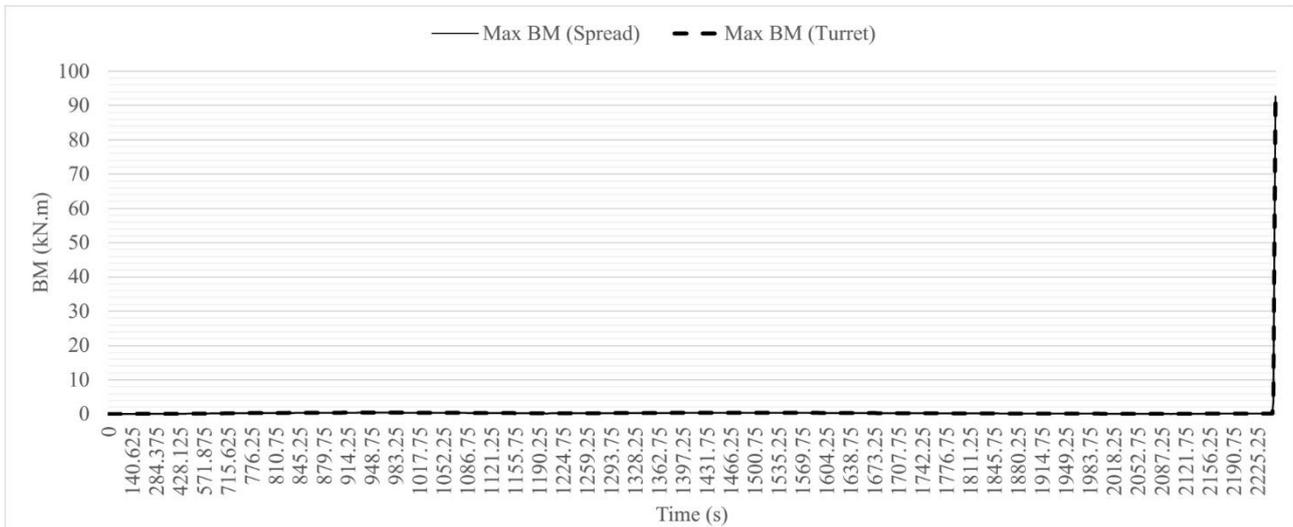


Figure 8: Max Bending moment in steep wave riser length in both Spread and Turret type mooring systems

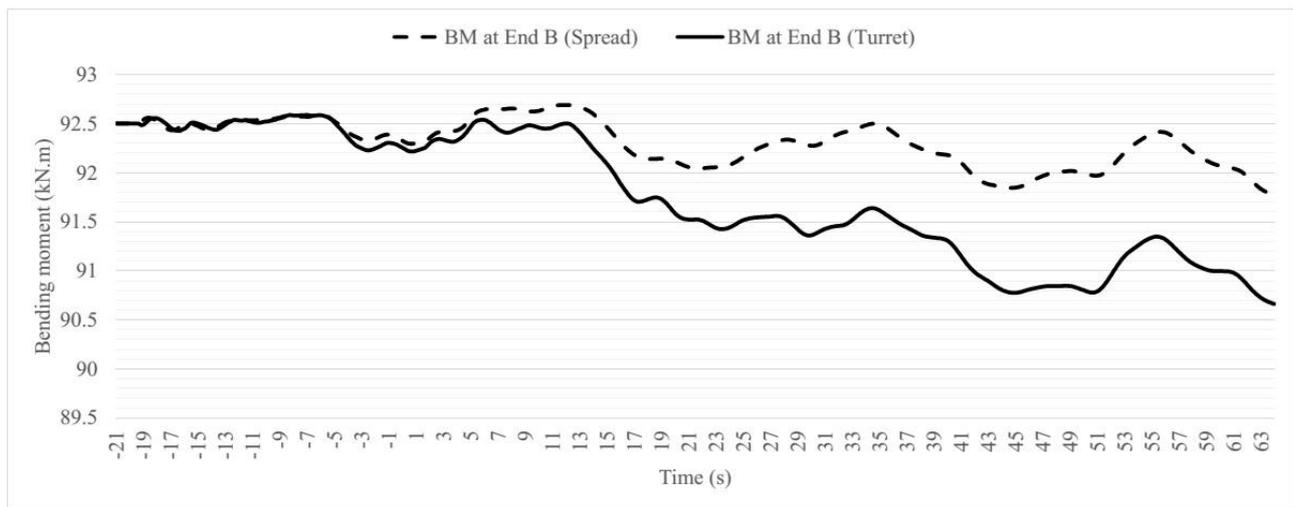


Figure 9: Time history diagram of governing point with maximum Bending moment in steep wave length in both Spread and Turret type mooring systems

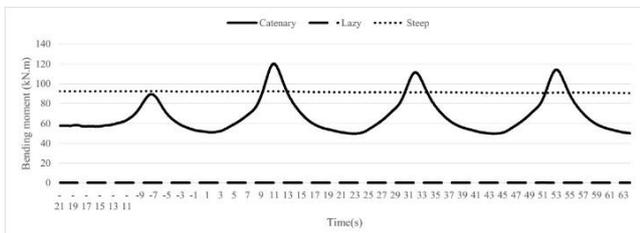


Figure 10: Bending moment of the point with maximum moment in 3 types of risers connected to a FPSO moored turret type

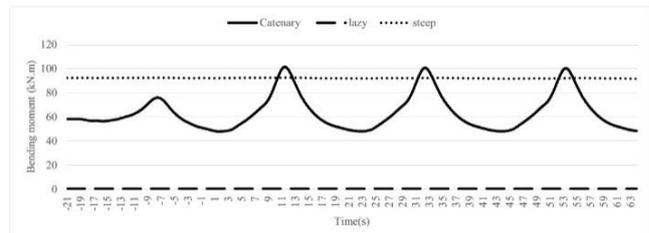


Figure 11: Bending moment of the point with maximum moment in 3 types of risers connected to a FPSO moored spread type

The difference of maximum bending moment when the FPSO is moored turret type or spread type and the riser is a wave configuration is not so significant but as it is shown in figure11 and figure12 this difference is remarkable about catenary riser.

Conclusion

Compliant riser provides flexibility against floater motions. Configurations of compliant riser are formed such that it could absorb floater motions without having additional equipment. They have high dynamic resistance allows compliant riser to work on deeper

water depth and harsher environments. It can be applied to wide variations of floater such as TLPs, Semi-submersibles, and Ships. The free hanging catenary riser is widely used in deep water. The most severe motion is heave from the first order vessel

motion. Lazy waves are preferred to steep waves because they require minimal subsea infrastructure. In steep wave configurations the addition of the buoy removes the problem associated with the touchdown point.

Table 2 Maximum bending moment comparison between different risers and mooring system configurations

Riser	Mooring systems						
	A) Spread			B) Turret			Difference $\frac{ A-B }{B} * 100$
a) Catenary	101.850 kN.m			120.363 kN.m			15.4 %
b) Lazy Wave	0.496 kN.m			0.503 kN.m			1.4 %
c) Steep Wave	92.692 kN.m			92.590 kN.m			0.1 %
Difference %	$\frac{ a-b }{a}$	$\frac{ a-c }{a}$	$\frac{ c-b }{c}$	$\frac{ a-b }{a}$	$\frac{ a-c }{a}$	$\frac{ c-b }{c}$	
	99.5	9.0	99.5	99.6	23.1	99.5	

As modeled and analyzed 3 different compliant risers (Catenary, lazy wave and steep wave) each one with 2 different mooring systems (Spread and turret) connected to a FPSO located in deep water with harsh environment, results shows that the maximum bending moment on a Catenary riser reduces significantly if the mooring system changes to spread type mooring system and the bending moment difference is remarkable as shown in table 2. For lazy wave and steep wave risers this difference is not so significant because the effect of the heave of FPSO is compensated in the configuration of the wave risers, so the change of the mooring system does not affects so much on the bending moment amounts in comparison of both mooring systems with same wave risers. So considering the costs, complexity and difficulties of installation and maintenance of subsea structures, lazy wave riser seems more preferable.

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