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The VLT: A Single-Point Mooring for 100+ Risers

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Abstract

Based on existing installed systems, it is generally perceived that the number of risers for a turret moored FPSO is limited to approximately 50. Riser congestion, available turret space as well as bearing size and load carrying capacity all tend to limit the number of risers for existing turret moored systems. Until now, spread moored FPSOs have generally been considered the only viable option for field developments requiring 50-100 risers. This paper describes the design and analysis of the Very Large Turret (VLT) and how previously limiting parameters are overcome for a cost effective single point mooring system with the capacity for 100+ risers.

The VLT application lies in deep to ultra deep water. The VLT is an internal turret with the ability to support both flexible and steel pipe risers. The ability to support a multitude of risers make it well suited for field developments with minimal or no subsea manifolding where each wellhead receives a dedicated riser bundle. The VLT is particularly well suited for field development concepts currently being considered for offshore Brazil and West Africa.

The results presented herein illustrate that the large diameter of the turret, typically considered a design constraint, actually contributes to the design efficiency and its ability to function in a dynamic environment. The VLT's inherent flexibility results in an improved bearing load distribution and the turret's unique arrangement requires a turret steel weight that is lower than other existing turret systems.

Today more than ever, large field developments (100,000 –250,000 bopd) are being considered. Ship-shaped production platforms with the storage capacity of a VLCC or larger are being specified. Passive fully weathervaning mooring systems that allow tandem offloading are preferred over spread moorings due to higher operation up time and lower

Introduction

The maximum production capacity of Floating Production, Storage and Offloading units (FPSOs) has steadily increased over the recent years. Production rates for these large fields are now reaching as high as 250,000 bopd. The increased flow capacity has driven a corresponding increase in the quantity and size of risers between the subsea wells and the floating vessel. As shown in Table 1, the selected mooring system for these vessels has almost invariably been a spread mooring.

Table 1: Large Field Development FPSOs

FPSO	Location	BOPD	Mooring
Kizomba A	Angola	250,000	Spread
Kizomba B	Angola	250,000	Spread
Dalia	Angola	225,000	Spread
Girassol	Angola	200,000	Spread
Erha	Nigeria	200,000	Spread
Albacora Leste	Brazil	180,000	Spread
Barracuda P43	Brazil	150,000	Spread
Caratinga P48	Brazil	150,000	Spread
Espadarte	Brazil	100,000	Turret
Marlim South P35	Brazil	100,000	Turret

All risers must pass through the inside diameter of the turret bearing on a single point moored FPSO. Until development of the VLT (PATENT PENDING), the bearing opening has been perceived as the governing factor limiting the number of risers that can physically fit within a turret. To achieve the production flow capacity, two methods have been used. One method has included the use of a spread moored vessel with riser porches on either side of the vessel beam. The other method includes the use of increased subsea manifolding requiring fewer (but larger size) risers. A third method is now available using the VLT.

Currently, the installed turret moored FPSO with the greatest number of risers is located in the Marlim field offshore Brazil with 47 risers. The spread moored Barracuda P43 FPSO, designed for offshore Brazil and currently under construction, will include riser porches for accommodating over 100 risers. This paper is presented to demonstrate the feasibility of a 100+ riser FPSO, while retaining the advantages of a weathervaning single point mooring system.

Applications for the VLT. The VLT provides a single point

Turret Mooring. The VLT is a turret mooring system for a ship-shaped FPSO. As such, it provides all the benefits of a weathervaning single point mooring including tandem offloading while eliminating the need for a remote offloading buoy.

Water Depth: The applicable water depth for the VLT is 500 meters to 3,000 meters.

Field Development Size: 100,000 to 250,000 bopd.

Risers: The VLT can be designed to support approximately 40 to 120 risers. The risers can be flexible pipe, steel pipe or a hybrid configuration.

Subsea Manifolding: The VLT reduces or eliminates the need for subsea manifolding. Without the use of subsea manifolding, each production well typically receives a dedicated bundle of three risers, namely produced fluid, gas lift and control umbilical. Similarly each injection well typically receives a bundle of two risers, namely injection fluid and control umbilical. Generally speaking, a field development will include one injection well for every two production wells. Therefore, a 90 riser VLT could support production from 22 production wells (66 risers) and 11 injection wells (22 risers) and likely a gas export with umbilical (2 risers).

Environment: Application of the VLT is no more limited by environmental conditions than other conventional turret moorings. Performance of turret moorings is generally superior to spread moorings due to the turret weathervaning capability.

VLT System Description

The VLT system includes similar components to those of smaller turrets. However, due to the unique arrangement, the VLT is capable of supporting over twice the number of risers of any existing turret system. Figure 1 provides a longitudinal elevation of the VLT. A description of the VLT arrangement and components follows.

Turret Size. The size of a turret is generally governed by the number of risers it is designed to support. The diameter of the main (vertical) bearing and the moonpool are two parameters typically sited when referring to a turret's size. In the case of the VLT, both the vertical bearing and moonpool have the same diameter. Figure 2 estimates the required size of the moonpool for the VLT based on the number of risers. Figure 3 provides an estimate of the required moonpool size based on the number of production wells assuming no subsea manifolding as described above.

Turret Structure. The VLT differs from other conventional turrets because it is a flexible structure. The inherent flexibility of the frame permits the turret main deck to conform to the deflected shape of the vessel under dynamic loading conditions. This is discussed in detail below.

The turret is a large space frame structure. The primary load carrying structural components include the turret main deck, chain table, support columns and I-tubes. Dimensional structural items include the pull-in and equipment deck and the access decks within the moonpool.

Main Deck. The main deck of the VLT is located at the vessel main deck elevation. It is a large wheel shaped structure including spokes and a hub. The main deck carries the entire vertical loading imparted on the VLT, including loading from the mooring, risers and self-weight of the turret. It is designed with sufficient strength to support these loads, yet compliant enough to flex with the vessel under extreme hogging and sagging conditions while providing a preferred bearing load distribution. Refer to Table 2 for particulars of the main deck.

Table 2: Main Deck Particulars

Number of Risers	60	90	120	Units
Outside diameter	23	32	41	m
Height	2.0	2.5	3.0	m
Skin plate thickness	30	30	30	mm
Stiffener plate thickness	15	15	15	mm
Weight	388	687	982	mt

Chain Table. The chain table of the VLT is located at the keel elevation of the vessel. It is a donut shaped structure. Chain support assemblies are integrated into the chain table structural design and provide a means of securing the mooring leg chains to the turret. The risers pass through the chain table but do not impart any vertical load on the chain table. Refer to Table 3 for particulars of the chain table.

Table 3: Chain Table Particulars

Number of Risers	60	90	120	Units
Outside diameter	22	31	40	m
Height	2.0	2.0	2.0	m
Skin plate thickness	20	20	20	mm
Stiffener plate thickness	15	15	15	mm
Weight	221	318	489	mt

Support Columns. Six support columns run vertically between the main deck and the chain table. They are tubular structures that transmit loading on the chain table up to the main deck including the mooring loads and chain table weight. Refer to Table 4 for particulars of the support columns.

Table 4: Support Column Particulars

Number of Risers	60	90	120	Units
Outside diameter	1.5	2.0	2.5	m
Height	28	28	28	m
Wall thickness	25	25	25	mm
Weight, total for 6 columns	153	205	257	mt

I-Tubes. The I-tubes are vertical tubulars that individually encase and protect each riser within the moonpool volume. The I-tubes are not welded into the turret structure. They include an upset flange at the upper end allowing them to be hung off from the top of the main deck. The lower end of the I-tubes are guided at the chain table location. No I-tube weight is carried by the chain table. Refer to Table 5 for particulars of the I-tubes.

Table 5: I-Tube Particulars

Number of Risers	60	90	120	Units
Outside diameter, average	80	80	80	mm
Height	30	30.5	31	m
Wall thickness	12.7	12.7	12.7	mm
Weight, total, 1 per riser	482	734	993	mt

Other Turret Structural Items. The pull-in and equipment deck and the access decks below turret main deck are structural items. In comparison to the main deck and chain table, these are relatively light structures that provide a minor contribution to the overall stiffness of the turret structure.

The swivel torque tube is also a structural item. The top of the torque tube is secured to the torque arm. The base of the torque tube rests on a bearing assembly allowing it to rotate on the turret main deck as the vessel weathervanes. Individual torque arms, inside the torque tube, secure the outer housing of each swivel to the torque tube and complete the torque path between swivel housings and vessel main deck.

Off-Turret Items. Structural items associated with the turret, but incorporated into the vessel, include the torque arm designed to resist the torque required to rotate the swivel bearings and seals. Another off-turret structural item is the moonpool which is necessary to make the vessel watertight after cutting a hole in keel. The vertical main bearing is located at the top of the cylindrical moonpool. Therefore, the main bearing and moonpool have approximately equal diameters.

Bearing System. The bearing system consists of a vertical (thrust) bearing and radial bearing located at the vessel main deck elevation. Refer to Figure 4 for an illustration of the vertical and radial bearing assemblies. A lower bearing at the vessel keel elevation or a vertical (uplift) bearing at the main deck elevation may also be incorporated into the VLT design, depending on the turret diameter and loading conditions.

Vertical Bearing. The vertical bearing supports all the vertical loads from the mooring, risers and turret self weight. The bearing is an AmClyde type wheel and rail bearing assembly consisting of two concentric rows of roller wheels that ride on rails mounted below the wheels on the vessel moonpool and above the wheels on the underside of the turret main deck. Refer to Table 6 for diameter of the VLT vertical bearing.

Table 6: Vertical Bearing Diameter

Number of Risers	Bearing Diameter
60	23 m
90	32 m
120	41 m

Radial Bearing. The radial bearing reacts the horizontal loads in the plane of the vessel main deck elevation. This bearing consists of spring suspension cartridge assemblies distributed around the perimeter of the turret main deck.

quantity of radial bearing cartridges varies from 24 to 60 units depending on turret size and loading conditions.

Lower Bearing. A portion of the horizontal mooring load at the chain table location is reacted against the lower moonpool using a sliding type lower bearing. Varying the column stiffness and gap between moonpool and chain table changes the distribution of this horizontal load shared between the lower and radial bearings.

Riser Layout. Riser layout within the turret includes the use of I-tubes between the chain table and turret main deck. The I-tubes have a large diameter (in comparison with riser diameter) to allow passage of pull-in connection equipment and acceptance of bend stiffeners below the chain table. I-tubes sizes that have been required on past Petrobras projects are given in Table 7.

Table 7: Riser I-Tube Sizes

Risers Size (ID)	I-Tube (OD)
2 ½ inch / EHU	26 inch
4 inch	30 inch
6 inch	34 inch
10 inch	50 inch

For efficiency it is advantageous to arrange risers within the turret in a space as small as possible. However, due to riser interaction as well as riser installation and change out requirements it is necessary to ensure adequate spacing between each riser I-tube within the turret. To accomplish sufficient riser spacing, the VLT incorporates guidelines required on previous Petrobras turret projects. These guidelines are repeated below.

1. No riser shadowing (risers in the same radial direction) is acceptable. A maximum of two rows of risers are allowed within the turret chain table.
2. Minimum distance from I-tube center to the anchor leg limit is 750 mm.
3. Minimum distance between I-tube centers in the same layer is 1000 mm.
4. Distance between I-tubes outside walls (including the bell-mouth flange) in the outer layer shall not be less than the external diameter of the I-tube in the inner layer.
5. Departure top angles for the inner and outer riser layers are 7 and 9 degrees from vertical, respectively.

The riser layout at the chain table location using the above guidelines for 60, 90 and 120 riser VLTs are included in Figure 5.

Equipment. As with all large turrets, piping and manifolding constitute a significant portion of the total equipment space, weight and cost. Other turret equipment includes the swivel stack assembly and the winch and sheaves necessary to perform the mooring and riser pull-in operations. In conventional turret design, turret deck diameters are generally kept small and decks are added vertically as needed to satisfy the equipment space requirements. In the VLT however, the stack base at the main deck elevation, reducing the turret overall height.

Mooring System. The mooring system includes three groups of three anchor legs (3x3). The grouped mooring is selected to provide large corridors for the risers. The mooring leg components would likely be chain/wire/chain, or possibly polyester line rather than wire. Anchor selection would likely be suction embedded piles.

Vessel Considerations. Storage capacity requirements for an FPSO typically govern the size of vessel selected for the field development. Large fields, including many risers will require large vessels with storage capacities only available by conversion (or new build) of Very Large Crude Carrier (VLCC) or Ultra Large Crude Carriers (ULCC) sized vessels. VLCC beams range from 50 to 60 meters and ULCC beams range from 60 to 70 meters. New built FPSOs for the recent large field developments have beams within these same ranges for VLCCs and ULCCs.

Removing a section of the vessel's hull structure to make room for a large cylindrical moonpool is a design issue that must be considered. Bending and shear loading in the vessel hull are analyzed to determine the required vessel reinforcement. As illustrated in Figures 6 and 7, these maximum loads occur in the minimum draft / maximum cargo condition. For this case, the maximum shear and bending at the turret centerline is just slightly less with the turret installed than before installation of moonpool and turret. Therefore, the remaining cross section of a converted tanker at the moonpool location must be structurally reinforced such that its section modulus is approximately equal to the vessel's section modulus before the moonpool was installed.

Evaluating the required hull strengthening includes considering the portion of beam occupied by the moonpool. Figure 8 is provided to assist this evaluation and selection of FPSO tanker size. If, for example, it was required that the moonpool for a 90 riser VLT occupy ½ the vessel beam, then a vessel with a beam of approximately 64 meters would be selected. And from Figure 9, it can be seen that there are several existing ULCC tankers with this beam [Ref. 1].

Analysis

A design premise has been assumed for further development of the VLT and Finite Element Analysis (FEA) has been completed on three VLT sizes, including 60, 90 and 120 riser turrets. The FEA modeling details are presented including loading conditions and the applied boundary conditions. Results of the analysis are provided.

Design Premise. It is not required to fully develop designs of the VLT for all number of risers in all possible water depths. Therefore, a design premise has been established to develop design details. The design premise applicable to all analysis presented is summarized in Table 8.

Turret location is approximately 40 meters aft of the

Table 8: Design Premise for VLT Analysis

Environment	Campos Basis, Brazil
Water Depth	1,300 m
Survival	100 year storm
Vessel Size	285,000 dwt VLCC
Vessel LBP	325 m
Vessel Beam	58 m
Vessel Depth	30 m

FEA Modeling. Three FEA models were created and analyzed for VLT sizes with the capacity to support 60, 90 and 120 risers. Figure 10 provides images of the 90 riser FEA model, where one image omits the I-tubes for clarity. The goal of the analysis was to evaluate the turret's global performance including global stresses, deflections and bearing load distribution. The analysis attempts to realistically represent the turret's global stiffness and loading conditions. Therefore, the major structural items have been modeled including the main deck, support columns, chain table, and I-tubes. All turret component weights and external loads were applied. The software package RISA-3D was used for FEA structural modeling.

Loading Conditions. Loading conditions applied in the FEA are included in Table 9. The weights of equipment and items not modeled have been estimated and are included. The static and dynamic mooring and riser loads are based on detailed global analysis of an FPSO using the design premise stated above.

All mooring loads are applied at the chain supports located in the chain table. All riser loads are applied at their hangoff location on the turret main deck. The breakout torque, representing the total load required to overcome the frictional resistance of the swivel seals and bearing system, is applied at the chain supports.

Table 9: FEA Loading Conditions

Number of Risers	Note 1	60	90	120	Units
Equipment weight	Fz	-574	-814	-1,054	mt
Structural weight not modeled	Fz	-100	-144	-180	mt
Static mooring	Fz	-720	-720	-720	mt
Static risers	Fz	-4,000	-6,000	-8,000	mt
Dynamic mooring	Fx	300	300	300	mt
Dynamic mooring	Fz	-800	-800	-800	mt
Dynamic mooring	My	3,500	3,500	3,500	mt-m
Dynamic risers	Fz	-6,000	-9,000	-12,000	mt
Dynamic risers	My	8,000	12,000	16,000	mt-m
Breakout torque	Mz	1,200	1,800	2,400	mt-m

Note 1: X = forward, Y = port, Z = up.

The selected static design gap at the lower bearing is 50 mm. For all three turrets evaluated, this gap is closed prior to reaching the maximum dynamic mooring force, Fx=300 mt. Therefore, the dynamic mooring force, Fx, is represented by applying a forced displacement of the chain table equal to 50 mm. This results in an equivalent global effect on the turret structure.

The FEA loading conditions also include forced maximum value at both the extreme forward and extreme aft of the bearing foundation. Table 10 provides the maximum vertical forced displacement applied in the FEA to the bearing foundation.

Table 10: Maximum Displacement of Vertical Bearing

Number of Risers	60	90	120	Units
Sag Condition	+10	+15	+20	mm
Hog Condition	-10	-15	-20	mm

Boundary Conditions. The boundary conditions applied in the FEA include the roller reaction points representing the vertical bearing wheels and the spring loaded radial bearings. Additionally, two guided reaction points are applied at the main deck preventing its rotation and representing the frictional resistance of the bearing and swivel seals. This results in a twisting effect of the global turret structure about its centerline due to the application of the breakout torque at the chain table.

FEA Analysis Results. Results of the FEA have been generated for numerous load combinations including static and dynamic conditions, with and without riser, and hogging and sagging conditions. The most onerous combination includes the vessel in a sagging condition with risers installed in a 100-year storm environment. The results presented below have been generated for this specific load combination.

Global Stresses. Maximum stress values reported from the FEA are provided in Table 11.

Table 11: Maximum Stress Values

Number of Risers	60	90	120	Units
Plate Von Mises Stress	21	24	27	ksi
Column Combined Stress	15	16	17	ksi

The columns experience relatively minor tensile stresses from vertical mooring loads and weight of the chain table. Their primary loading occurs due to horizontal mooring loads and the frictional breakout torque of the main bearing and the swivel stack. This loading induces maximum bending stresses at the main deck and chain table connections. These design stresses must be kept low to satisfy fatigue life requirements as the loading is cyclic with the breakout torque being fully reversing.

Deflections. Maximum deflection values reported from the FEA are provided in Table 12. Figure 11 provides exaggerated deflection images in the longitudinal and transverse directions. I-tubes were included in the analysis, however are omitted in the images for clarity.

Table 12: Maximum Turret Deflections

Number of Risers	60	90	120	Units
Horizontal, at lower bearing	50	50	50	mm
Vertical, at center of main deck	-30	-23	-30	mm
Rotational, at chain table OD	61	47	30	mm

the vertical bearing load distribution over the entire circumference of the bearing foundation.

Load carrying capacity of the vertical bearing is much greater than the maximum values reported from the FEA. Table 14 provides typical capacities for the vertical bearing. Capacity for the standard wheel and rail design is almost twice the maximum loading for a 120 riser VLT in 1,300 meters water depth. If needed, bearing capacities can be increased further through heat treatment and use of widened wheels and rails. For this reason, it is predicted the capacity of the bearing system is not a limitation for application of the VLT in water depths up to 3,000 meters.

Table 13: Vertical Bearing Loading

Number of Risers	60	90	120	Units
Minimum loading	29	39	49	mt/m
Average loading	87	125	165	mt/m
Maximum loading	139	181	231	mt/m
Maximum total load	8,755	12,602	16,546	mt

Table 14: Vertical Bearing Capacity

Standard Wheel and Rail	400	mt/m
Hardened Wheel and Rail	600	mt/m
Wide and Hardened Wheel and Rail	800+	mt/m

The units of mt/m used in Tables 13 and 14 are based on the bearing load per meter of bearing circumference including both rail circles.

Benefits of the VLT

The VLT has clear benefits in comparison to existing turret and spread moored systems. These benefits are discussed below.

WeathervaningMooring System. The weathervaning feature of the VLT allows offloading export crude to shuttle tankers in a tandem configuration. Its ability to point into the weather permits offloading operations to occur a greater portion of time than that for spread moored FPSOs. The reliance on tugs and/or dedicated dynamic positioned shuttle tankers permits greater up time for spread moored tandem offloading. However, collision risk during approach and changing weather conditions still exists. For the large spread moored FPSOs in deepwater West Africa, this risk is being mitigated with the use of remote offloading systems that include midwater pipelines a large CALM type buoys. However, a comparison of CAPEX and OPEX for spread verses turret moored systems has concluded the spread moored with remote offloading results in a higher overall field development cost [Ref. 2].

Riser System. The VLT is capable of supporting multiple types of risers, including flexible pipe, steel pipe or a hybrid combination. In ultra deep water, steel pipe risers are likely to be specified. Figure 13 illustrates the VLT hangoff configuration for a steel riser. In this case, no I-tube is required and a split insert is used rather than a bend stiffener required with flexible pipe. The configuration also includes a added advantage of allowing the upper portion of the flowline within the turret to be rotated and permits selection of the riser declination departure angle to be selected later in the project schedule, including after turret construction has begun.

Riser and flowline congestion is a design consideration in all offshore field developments. This is especially true in large fields requiring many risers. Maximum spacing between riser touchdown points is preferred to limit midwater riser interaction and possible overlap of the seabed flowlines due to current loading and vessel offsets. A common misconception is that a spread mooring, with its relatively long riser porches, provides a greater riser spacing. The turret mooring actually provides greater riser touchdown spacing at water depths greater than approximately 500 meters. This is graphically illustrated in Figures 14, 15 and 16. Plan views of a spread and turret mooring are laid out to scale for a 90 riser FPSO in 1,300 meter water depth. Risers are simple catenary with a vertical departure angle of 7 degrees. At this water depth, a turret mooring provides over twice the available touch down point length than a spread mooring using riser porches on both sides of the vessel. From Figure 16 shows the benefit of a turret mooring increases with water depth, where at 3,000 meter water depth, the turret mooring provides approximately 3 times more touchdown space than a spread mooring.

Turret Arrangement. In contrast to conventional turret systems, the VLT arrangement provides generous space for placing turret equipment. The main deck diameter is large enough to locate all turret piping from riser hangoff to swivel inlet, including manifolding and pig launching/receiving facilities. The large area permits use of skidded piping modules facilitating lower cost fabrication and minimizing installation time. Less expensive, non-compact manifolding valves can be used as well as flow metering requiring long straight inlet and outlet runs.

Another benefit of the VLT arrangement is the ability to locate the swivel stack base directly on the turret main deck thereby reducing the overall turret height. This becomes possible with use of the torque tube that eliminates the need for individual torque arms between the each outer swivel housing and a turret surround structure secured to the vessel main deck.

In addition to supporting the winch, hydraulic power unit and turndown sheaves, the pull-in and equipment deck has generous space for placing any other possible turret equipment. With the exception of the swivel stack in the center, the inner portion of this deck is clear of any equipment to allow unobstructed rigging of lines for riser and pull-in operations. The outer area of this deck is sized for turret equipment as required, including control room, chemical injection equipment etc.

Bearing System. The VLT bearing is a robust system with its roots in offshore heavy lift crane designs. Its history includes field proven applications with design lifes well in excess of 20 years. Extremely high peak loads are

The vertical, radial and lower bearings are simple configurations that allow easy access for maintenance and inspection. Removal and replacement of bearing components can be accomplished in-situ without disturbing the turret operation.

Fabrication. A reduction in fabrication tolerances is realized in construction in a VLT. In conventional turrets, the vertical bearing typically incorporates a three-row roller bearing and requires extremely tight tolerances on the bearing mounting surfaces (+/-0.30 mm) to prevent binding during rotation. The VLT vertical bearing however, can tolerate much larger machining tolerance on the rail mounting surfaces (+/- 1.0 mm). Another major advantage of the VLT results in its lower tolerance on the concentricity requirement between turret and moonpool. The VLT lower bearing gap is in the range of 25 to 75 mm. Design and fabrication controls to prevent pinching of the chain table during hogging condition is no longer a critical issue as it is with conventional turrets where the lower bearing gap is in the range of 5 to 15 mm.

Another fabrication benefit of the VLT is the ability to install all turret components from above. The constant diameter cylindrical moonpool allows the chain table and other structural items can be lower from above. This takes delivery of the lower turret structure off the critical path of vessel construction or conversion.

Fabrication and inspection is reduced by omitting the need to weld the I-tubes in place. They are simply installed by lowering them through the deck openings. Their weight is carried at the upper end by the turret main deck and the lower end is guided in openings within the chain table.

Turret Weight. A major advantage of the VLT is its efficient use to turret steel required to carry the riser payload. Table 15 illustrates this by a comparison of the VLT with two other turrets. The VLT is by far more efficient than these other turrets installed in shallower water, requiring nearly half the amount of turret steel per riser. It should be noted that structural design of the VLT has not yet been optimized and the weights reported in Table 14 are based on the particulars provided in Tables 2 through 5 above. Detailed design of a VLT for a specific project is expected to result in even lower weight of turret steel.

Table 15: Turret vs Weight/Riser

Turret	Number of Risers	Water Depth	Turret Weight	Turret Weight per Riser
Albacora P31	28	330m	1,669 mt	60 mt/riser
Barracuda P34	34	840 m	1,817 mt	56 mt/riser
60 Riser VLT	60	1,300 m	1,953 mt	34 mt/riser
90 Riser VLT	90	1,300 m	2,803 mt	31 mt/riser
120 Riser VLT	120	1,300 m	3,740 mt	31 mt/riser

Conclusion

The paper demonstrates feasibility of a very large turret with the capacity to support over 100 risers in water depths up to 3,000 meters. Benefits of the VLT are realized in comparison

Acknowledgements

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[2] LT England, A. Duggal, A. Queen, *"A Comparison Between Turret and Spread Moored F(P)SOs for Deepwater Field Developments"*, Deep Offshore Technology 2001

Figure 1: Very Large Turret

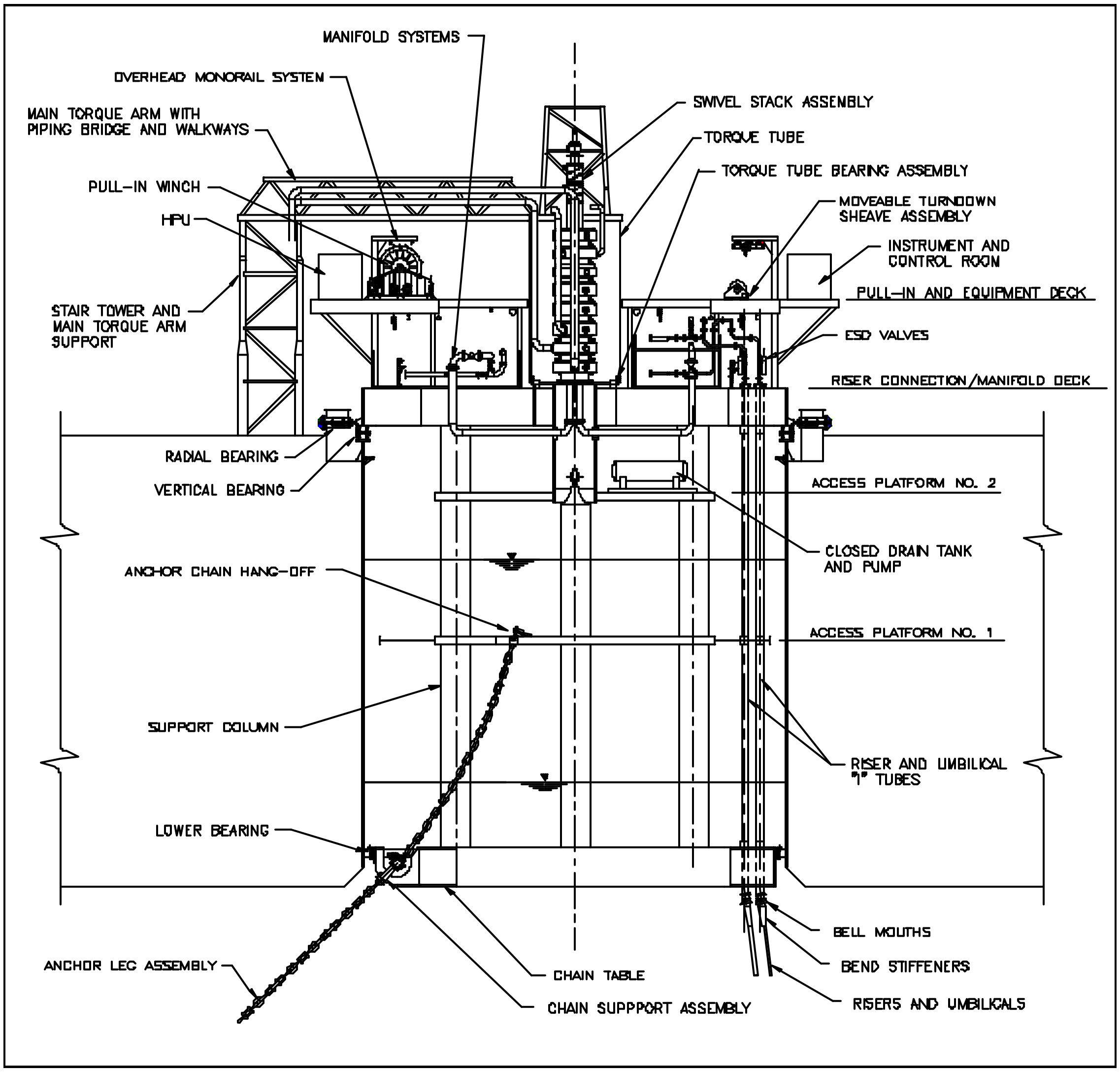


Figure 2: Moonpool Diameter vs Number Risers

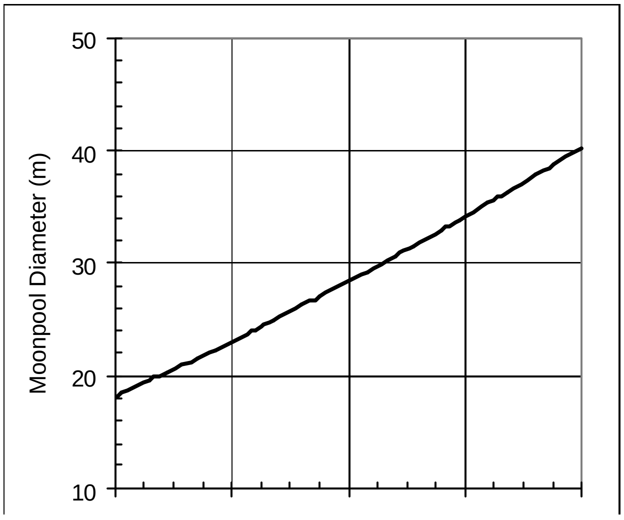


Figure 3: Moonpool Diameter vs Number Production Wells

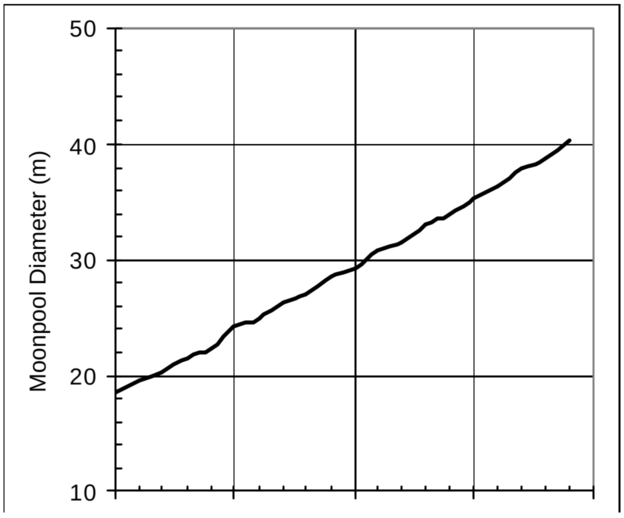


Figure 4: Vertical and Radial Bearing

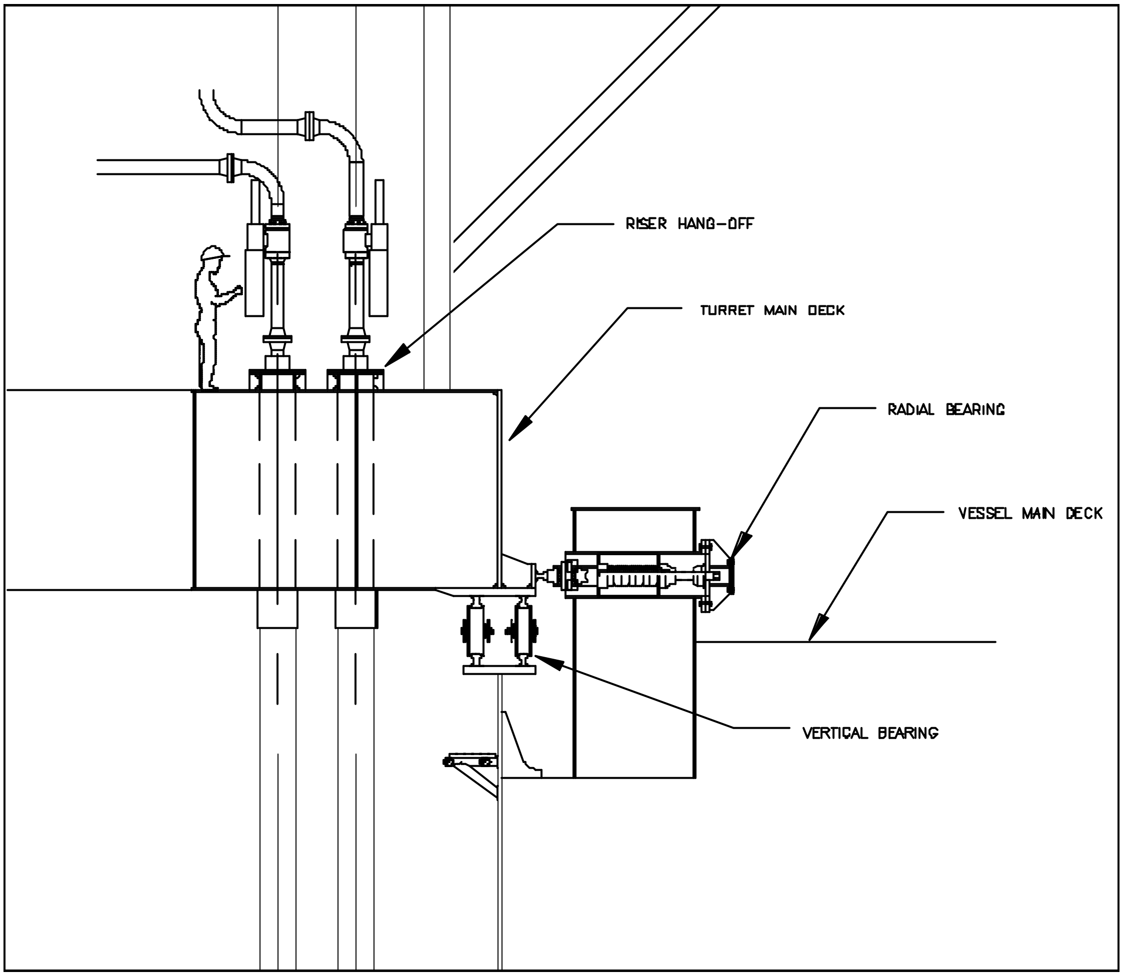


Figure 5: VLT Chain Table

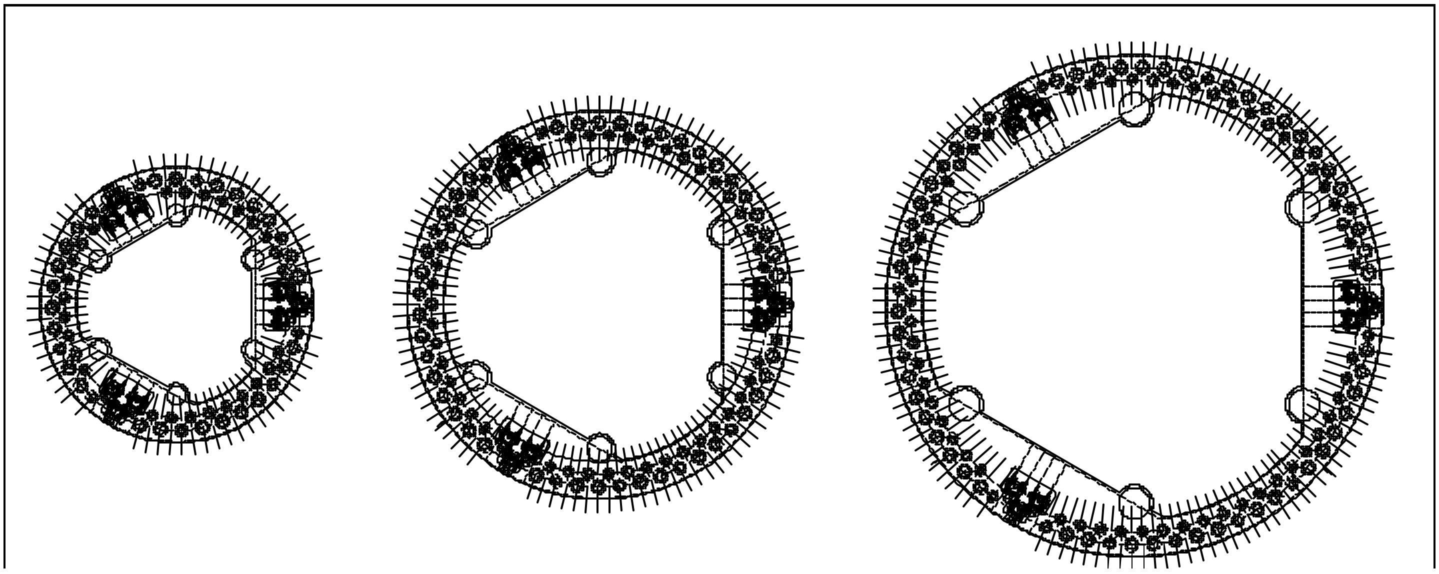
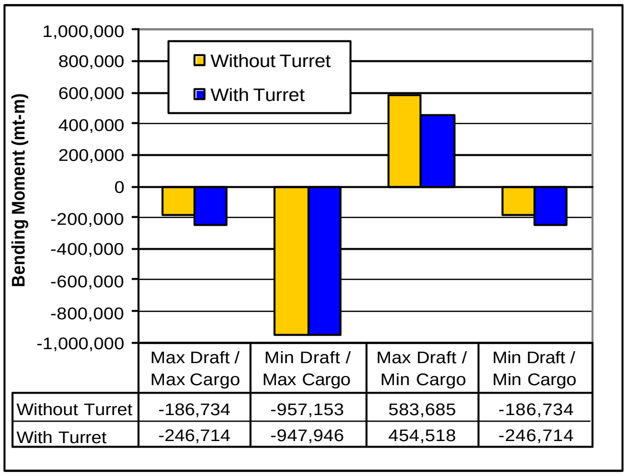
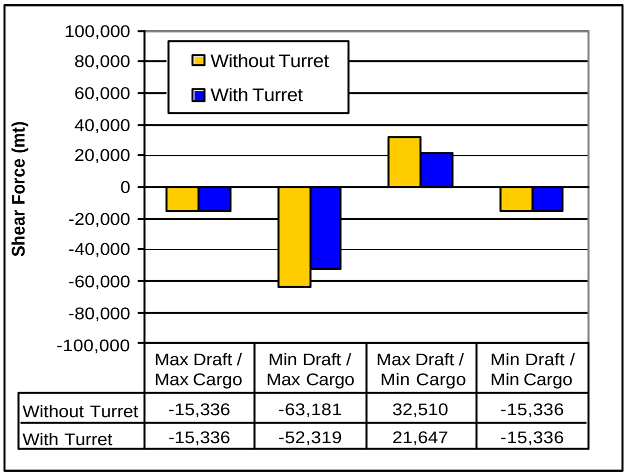


Figure 6: Vessel Bending Moment Loading at Turret Location



	Max Draft / Max Cargo	Min Draft / Max Cargo	Max Draft / Min Cargo	Min Draft / Min Cargo
Without Turret	-186,734	-957,153	583,685	-186,734
With Turret	-246,714	-947,946	454,518	-246,714

Figure 7: Vessel Shear Loading at Turret Location



	Max Draft / Max Cargo	Min Draft / Max Cargo	Max Draft / Min Cargo	Min Draft / Min Cargo
Without Turret	-15,336	-63,181	32,510	-15,336
With Turret	-15,336	-52,319	21,647	-15,336

Figure 8: Moonpool vs Tanker Beam Selection

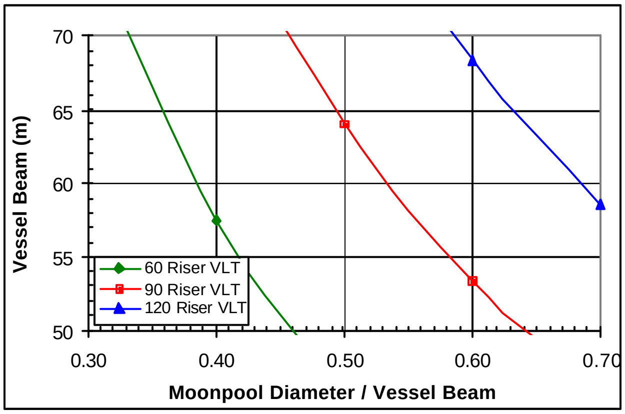


Figure 9: Existing VLCC and ULCC Tankers

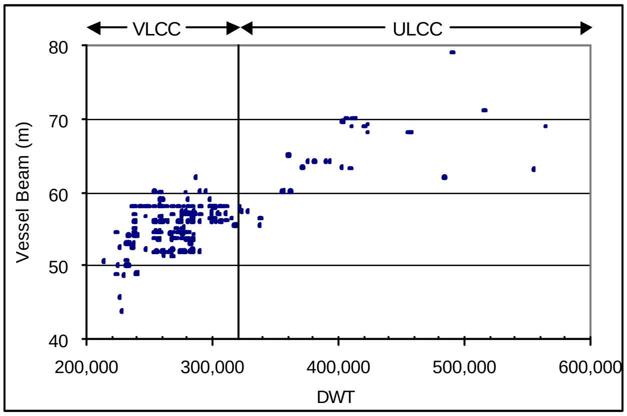


Figure 10: FEA Model of 90 Riser VLT

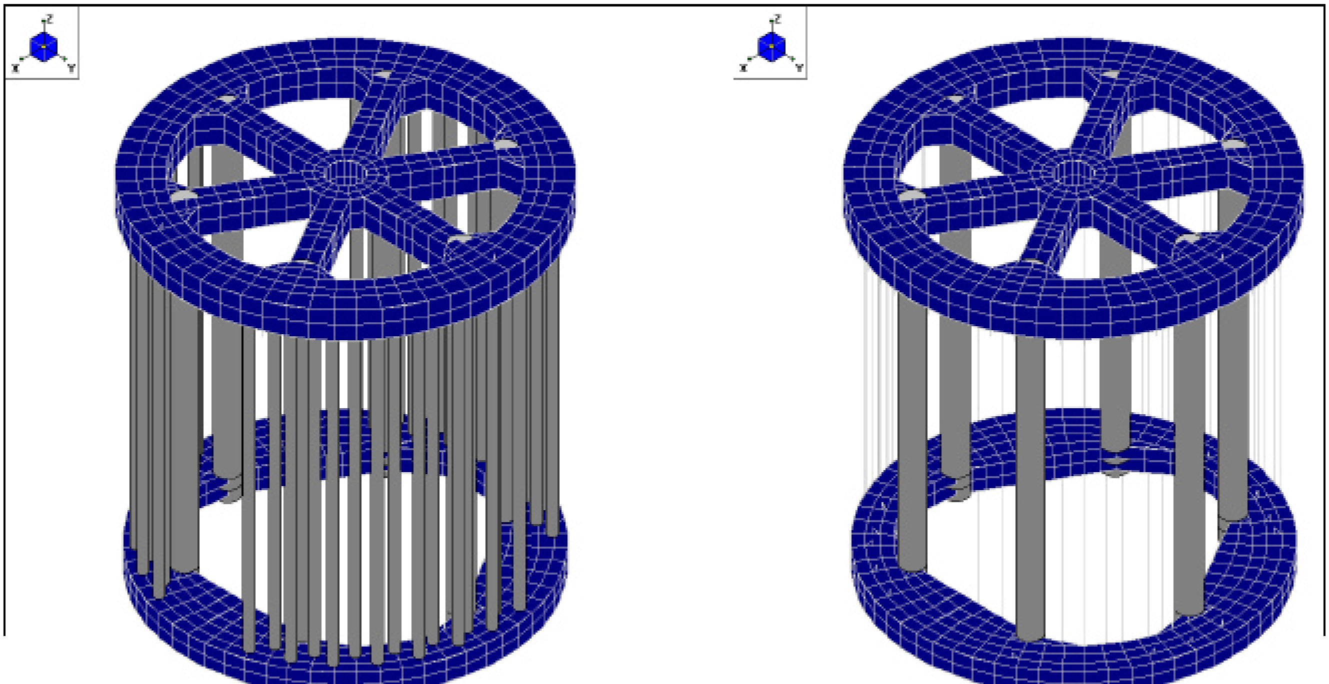


Figure 11: Exaggerated Deflection of 90 Riser VLT in Dynamic Sag Condition

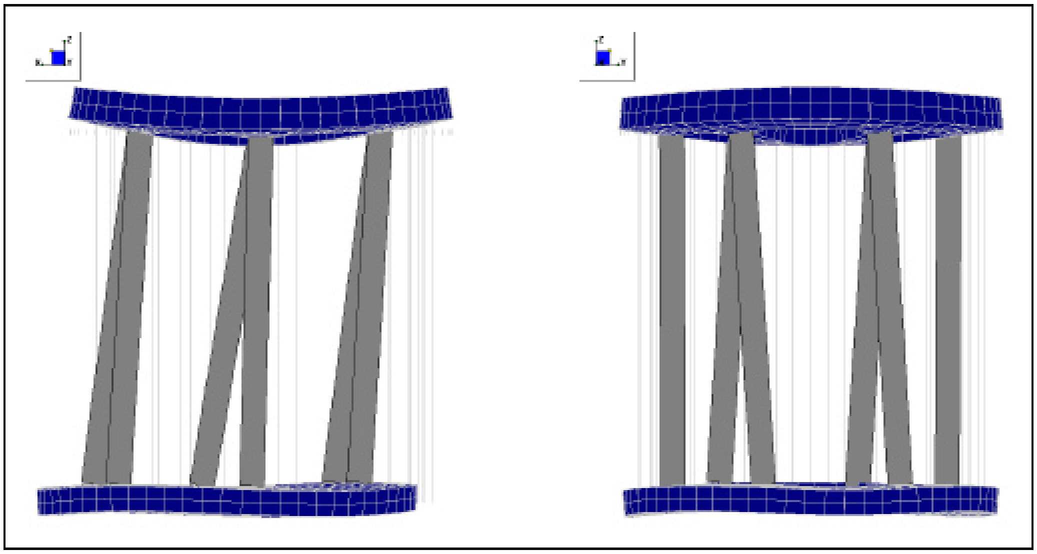


Figure 12: Vertical Bearing Load Distribution in Dynamic Sag Condition

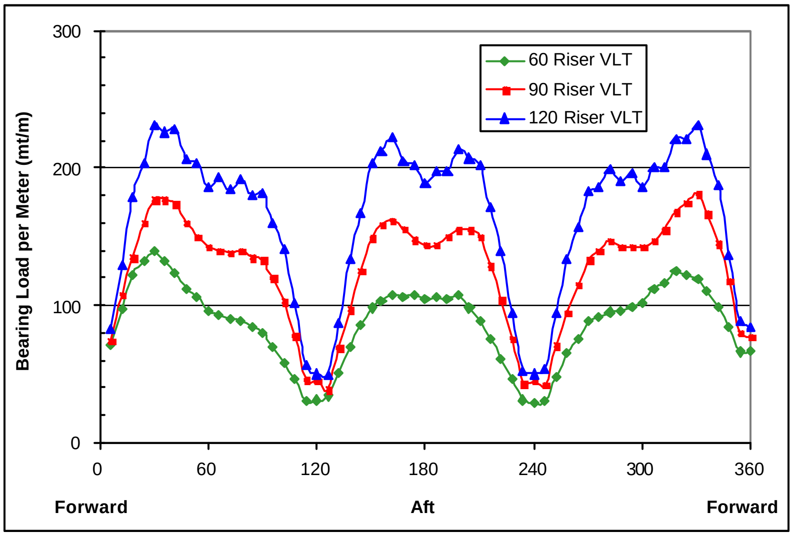


Figure 13: Steel Riser Hangoff Configuration

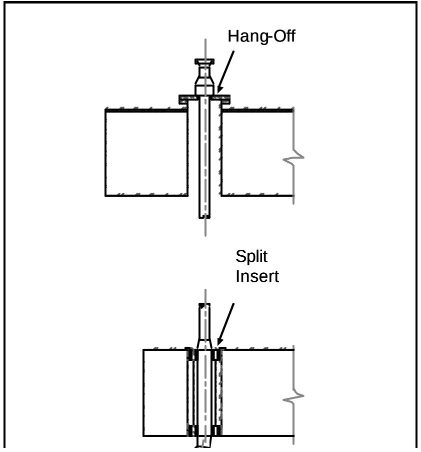


Figure 14
Riser Touchdown Point Spacing for 90 Riser Spread Mooring in 1300 mwd

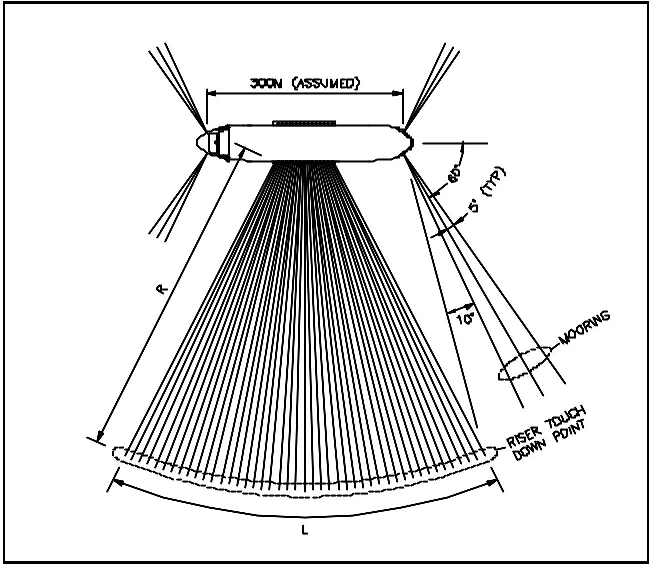


Figure 15
Riser Touchdown Point Spacing for 90 Riser Turret Mooring in 1300 mwd

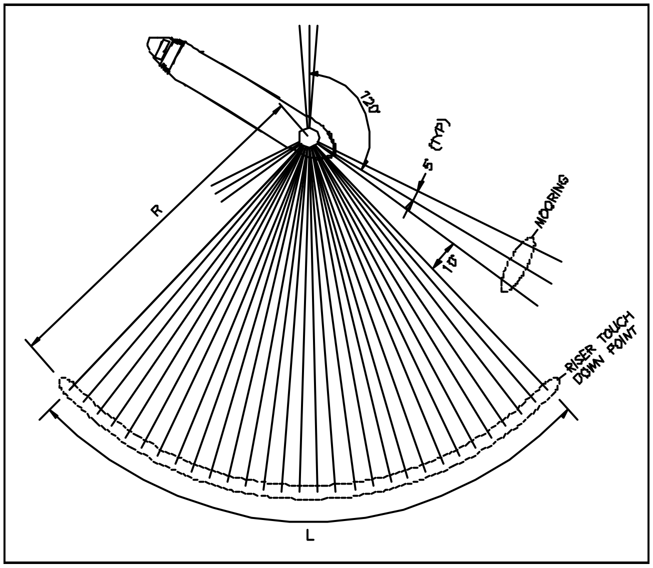


Figure 16: Riser Touchdown Point Length