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# TENSION LEG RISER SYSTEM – AN EFFECTIVE SOLUTION FOR DEEPWATER RISERS

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## ABSTRACT

This paper presents the technical feasibility for the Tension Leg Riser (TLR) concept in deepwater production applications.

The TLR system is a hybrid riser system for deepwater production to a Floating Production System (FPS). Steel catenary risers (SCRs) extend from the seafloor to near the water surface, where they are supported by a large submerged buoy. Flexible pipe jumpers extend from the buoy to the FPS. The buoy is at sufficient depth (approximately 150 meters) to minimize direct wave loading. The jumpers are in a slack catenary shape to isolate the buoy from vessel motions. The SCRs are essentially static, which eliminates fatigue damage due to the surface vessel motions. The buoy is vertically moored by tendons and is compartmented with variable buoyancy needed for installation and damage stability.

Extensive riser analysis demonstrates the TLR system is a feasible deepwater riser solution. This analysis provides operators with the confidence that deepwater production in up to 3,000 meter water depths can be accomplished using the TLR system with little or no incremental risk or safety considerations compared with other deepwater projects currently operating in shallower waters.

## INTRODUCTION

As part of FMC Energy Systems focus on deepwater production systems, FMC SOFEC has conducted a series of feasibility studies on the patented Tension Leg Riser (TLR) system for deepwater project opportunities in the Gulf of Mexico and offshore West Africa and Brazil. The objective of this study has been to establish technical feasibility and commercial viability for the TLR concept in deep water and to provide a basis for comparing the TLR concept with alternative deepwater riser systems. The work has focused on establishing the feasibility and bounds of applicability for a range of design conditions, environments, water depths, and varying production scenarios.

The TLR system is a hybrid riser system used for deepwater production together with any Floating Production or Storage and Offloading System, including semi-submersibles, ship-shaped FSO/FPSOs, TLPs and mini-TLPs, and Spars. Steel catenary risers (SCRs) extend from the seafloor to near the water surface, where they are supported by a large submerged, vertically tethered buoy. Flexible pipe jumpers extend from the buoy to the floating facility. The jumpers are in a slack catenary shape to isolate the buoy from vessel motions.

The buoy is generally at sufficient depth (approximately 150 m) to minimize direct wave loading. It is a large H-shaped structure sized to provide sufficient over-pull tension on the tendons during operation and to withstand a flooded compartment condition. The buoy is vertically moored by four tendons and is compartmented for the variable buoyancy needed for installation and damage stability.

The SCR hang-off design includes the porch support structure and stress joint assemblies that protect the SCRs during buoy rotation. Also developed are the tendon hang-off design and the pull-down system.

The following sections present the description of a hypothetical TLR system in 3,000 meters of water supporting 15 SCRs. The TLR system components are described as well as related installation procedures. Global analysis including survival, stability and fatigue analysis is presented. Features and merits of the TLR system are discussed.

## BUOY DESCRIPTION

The net buoyancy of the TLR buoy must be sufficient to support the vertical loads and provide sufficient horizontal restoring force to limit bending of the SCRs. This greatest load condition occurs with all SCRs and jumpers installed and flooded (i.e. hydro-test condition).

The net buoyancy of the buoy is 150 percent of the operational vertical loads from the SCRs and jumpers. The ratio of required net buoyancy to vertical loads generally decreases with water depth and typically ranges from 1.5 to 2. For the 3,000 meter/15 riser case, the operational vertical load is about 5,000 metric tons, 95 percent of which is from the SCRs. The required net buoyancy is, therefore, about 7,500 metric tons.

The buoy is a large H-shaped structure consisting of a center section and port and starboard sections (or wings). Overall dimensions are approximately 60 meters wide, 30 meters long and 10 meters high for the 3,000 meter/15 riser case. Refer to Figure 1 of an illustration of the TLR buoy. All sections are designed square in cross-section using stiffened plate construction. The Buoy hull and bulkheads are designed for a hydrostatic head of 1.5 x buoy height.

All buoy compartments are "open bottom" to minimize the hydrostatic pressure from outside the buoy. Each compartment contains at least one manway on the bottom of the compartment, which is open to the sea. The manway nozzle lengths extend below tank bottom to prevent air loss from tanks during buoy rotations.

Internal vertical bulkheads divide the buoy sections into watertight compartments (or tanks). Buoy tanks are deballasted as required by injecting compressed air. Four tanks are dedicated as "trim" tanks and always remain fully deballasted. These trim tanks maintain positive net buoyancy during the installation pull-down operation. Bulkhead quantity, locations and compartments sizes are designed to satisfy the following operations or conditions:

- Pull-down operations (trim tanks are sized for net buoyancy in range of 400-600 metric tons)
- SCR installation and hydro-test
- Jumper installation and hydro-test
- Damaged / flooded tank condition.

The SCR hang-off system is designed to transmit the axial, radial and bending loads from the SCRs into the buoy structure. The system consists of an SCR support porch and a tapered stress joint assembly. Refer to Figure 2 for an illustration of the riser hang-system.

The SCR stress joints are designed for the operating rotational offset between the buoy and SCRs. For a 7 degree angular offset, stress joint lengths range from approximately 7 meters for a 6 inch riser, to approximately 19 meters for an 18 inch riser for a 3,000 meter water depth.

The support structures for the flexible pipe jumpers run over the top of the central portion of the buoy and partway down the sides. The jumper support is a flat-bottomed tray with sloping walls that support and restrain the jumpers over the top of the buoy, while maintaining the minimum bend radius of the flexible pipe jumper. Internal stiffeners within the buoy line up with these support tray locations.

The buoy is installed by pulling it down to its operation depth while partially flooded, but still positively buoyant. The pull-down method of installation was selected because of the buoy's open-bottom design. Maintaining constant positive buoyancy by deballasting the trim tanks allows a controlled lowering. For the 3,000 meter/15 riser case, steel weight of the buoy is over 2,000 metric tons, which exceeds most reasonable heavy lift vessel's lowering capability. The pull-down system minimizes the risk of a "runaway" buoyancy loss during buoy installation.

The buoy pull-down system is designed to pull the positively buoyant buoy from the surface to the installed water depth. It also secures the buoy at this depth for the duration of its service life. The system consists of the tendon hang-off assemblies and the buoy pull-down winches. Refer to Figure 3 for an illustration of the buoy mounted pull-down winch.

The TLR buoy is pulled down using four ram winch type chain jacks. Pull-down chain, attached to the top of the mooring tendon, is strung through the ram winch and used to pull the buoy down to depth. For the 3,000 meter/15 riser case, each winch assembly must have a load capacity of approximately 600 metric tons. Furthermore, it should be capable of overboarding the excess chain, be reversible, retrievable and re-deployable. Allowing for some reserve power, pulling the buoy down to depth in an eight-hour period requires a 300 horsepower HPU.

Flooding / deballasting piping runs along the bottom of the buoy between the buoy compartments and an ROV control panel. The piping allows air to enter and exit the buoy compartments as required during installation operations. The piping serves two purposes. Firstly, it allows controlled flooding of the buoy compartments. The flooding reduces buoyancy of the buoy, enabling the pull-down system to lower the buoy to installation water depth. Secondly, it allows the buoy compartments to be deballasted. Compressed air, provided by a surface installation vessel, is injected into the compartments through the piping, forcing water out the manway openings located at the bottom of the compartments. Deballasting increases buoyancy of the buoy in preparation for installation of SCRs and jumpers.

## MOORING SYSTEM DESCRIPTION

The TLR mooring system consists of vertically loaded tendons connecting the sub-surface buoy to the anchor piles. Suction embedded anchors are used, which rely upon self-weight plus skin friction, to react the nearly vertical tendon tension load. For the 3,000 meter/15 riser case, the 4 anchor piles are fabricated from 2-inch steel plate, each weighing approximately 350 metric tons and having dimensions of 10 meters diameter x 24 meters long.

In ultra-deep water, tendon assemblies consist of successive sections of chain and spiral strand wire rope. Multiple sections are required due to manufacture and handling length limitations of the large diameter wire rope. Each tendon includes a subsea connector at the anchor point connection. Synthetic rope tendons are not desirable due to unacceptable elevation changes of the buoy with changes in vertical load (i.e. tendon stretch). For the 3,000 meter/15 riser case, each tendon is made up of 3 sections of 140 millimeter sheathed spiral strand wire rope with short sections of 150 millimeter chain joining the wire rope sections.

## GLOBAL ANALYSIS

The feasibility and response of the TLR system described above has been studied for different water depths ranging from 1,000 meters to 3,000 meters and for different number of risers ranging from 6 to 18. The following paragraphs present some global analysis results for the hypothetical case considered in the Gulf of Mexico.

Preliminary riser sizing (i.e. pipe wall thickness determination) is accomplished prior to the start of the global analysis. Riser wall thickness is calculated in accordance with recommendations given in API RP 1111 [1]. Global analysis is performed in accordance with the criteria specified in API RP 2RD [2].

The program used for the static and dynamic analyses of the TLR system is the program Visual Orcaflex™ [3]. The TLR buoy is modeled as a 6 degrees of freedom lumped buoy. Its geometric and hydrodynamic properties are accurately derived and imported into Orcaflex™. All SCRs, jumpers, tendons and mooring lines are also included in the model to accurately evaluate buoy motions and possible interference problems. Figure 4 presents the overall TLR system model as well as a close-up of the buoy model.

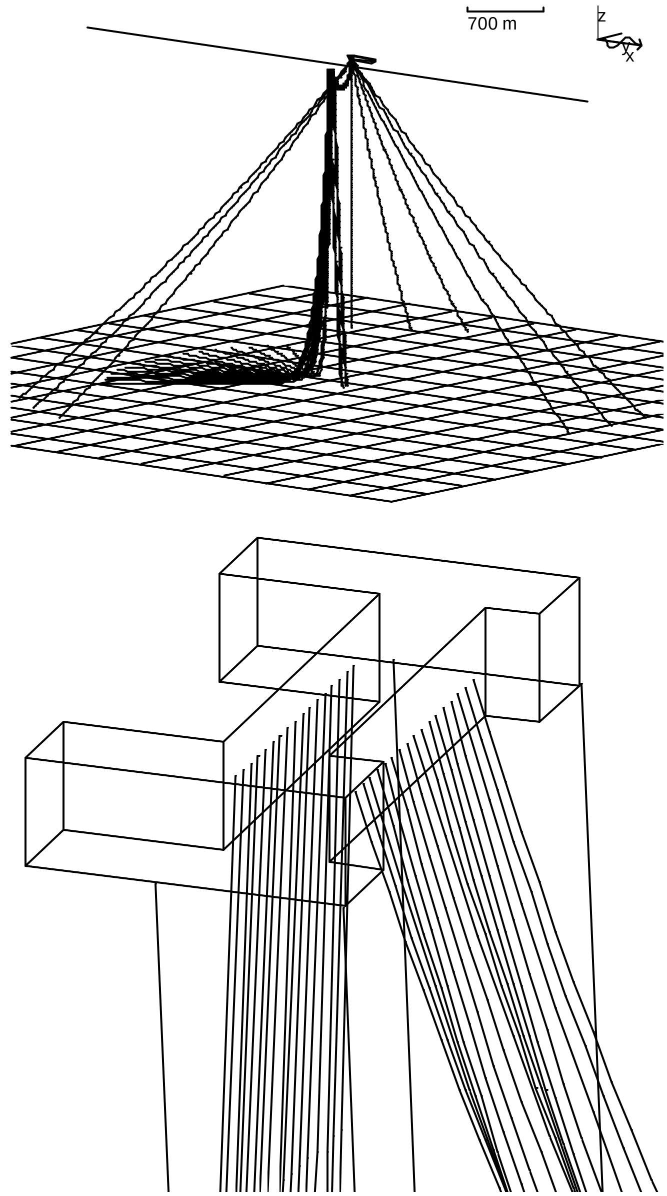
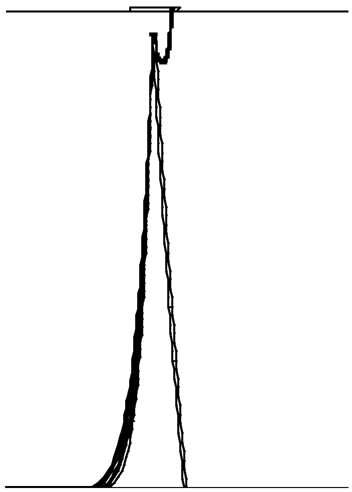


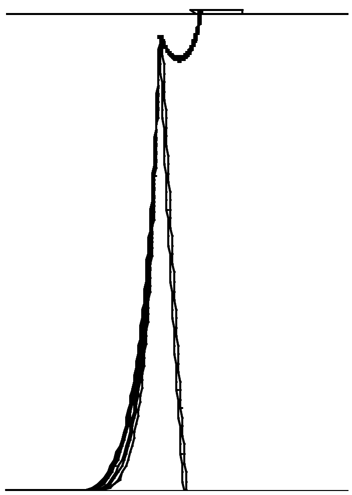

Figure 4: TLR Buoy Model

## SURVIVAL ANALYSIS

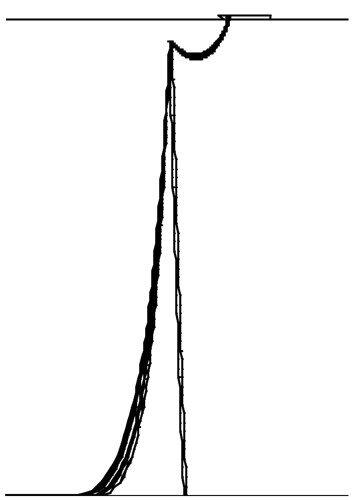
For the survival analysis, the performance of all risers, jumpers and TLR buoy under extreme storm conditions (Waves: Hs = 12.2 meters, Tp = 14 seconds, Current of 1 meter per second (surface)) has been analyzed for different offset cases (near, far and transverse) using regular wave analysis. A slow drift extreme offset of 180 meters (6 percent of water depth) was used for the host vessel along with response amplitude operators (RAOs) to simulate the wave frequency motions. A limited number of design cases, which most likely will control the design of the riser system, were analyzed. Near, mean and far position elevation views of the TLR system are presented Figure 5.



Near Position



Mean Position



Far Position

Figure 5: Near, Mean and Far Static Positions

Static top angle for the SCRs is minimized to approximately two degrees from vertical to increase ease of installation and reduce static buoy offset. The low frequency motions have very small impact on the riser system. The only impact from slow drift motions is on the jumpers top angle which varies from approximately 4 degrees (from vertical) to 40 degrees between the near position and the far position. The low frequency motions of the TLR buoy are also limited to approximately 20 to 35 percent of the vessel motions. Jumper length should be therefore carefully chosen to accommodate the large low frequency motions of the host vessel and to minimize the wave frequency impact on the buoy motions.

Dynamic survival analysis results confirm the effectiveness of the TLR de-coupled system. The buoy maximum single amplitude motions for the 100-year storm condition are presented in Table 1.

Table 1: TLR Buoy Dynamic Motions

| Amplitude of Motion | Surge (m) | Sway (m) | Heave (m) | Roll (deg) | Pitch (deg) | Yaw (deg) |
|---|---|---|---|---|---|---|
| near | 0.9 | 0.0 | 0.8 | 0.1 | 1.5 | 0.1 |
| far | 0.8 | 0.0 | 1.4 | 0.1 | 3.9 | 0.5 |
| transverse | 0.2 | 0.9 | 1.2 | 0.2 | 3.7 | 0.2 |

Both the de-coupled effect from the jumpers and the depth of the buoy (150 meters) at which the influence of the wave kinematics is minimized contribute to the very limited buoy motions. In the far condition, higher pitch motions are seen due to the large horizontal load change at the jumper connection side. Since the jumpers act as a filter for the buoy motions, the use of a regular wave is not sufficient to identify all the characteristics of that filter. A detailed analysis using random waves needs to be performed during detailed design to analyze the filter and its properties.

The SCRs are not much affected by the 100-year storm condition. Minimum bending radii are well above minimum requirements. Extreme loads are also acceptable. Dynamic amplification from the wave action is limited to less than 5 percent, which confirms that the TLR system is almost quasi-static. There is no compression expected for any condition, and maximum stresses stay below allowables. Relative top angle variations (with respect to the buoy) are also limited to a few degrees. The jumpers are more sensitive to the extreme environment as expected. Their integrity is not affected by the 100-year storm conditions, but some interference problems can occur. Careful attention should be paid to the design of the jumpers. Staggering the jumpers is one solution to the interference problem. Some limited compression loads can also occur in the lighter jumpers such as gas-filled flexible jumpers.

Since the TLR system is almost static even under 100-year environmental conditions, the buoy mooring tendons can be designed statically with a safety factor of 3.0, which will result in a damaged Safety Factor of 1.5. The analysis showed that dynamic Safety Factor are kept above 2.7 (intact) and 1.35 (damaged).

## BUOY STABILITY

Tendon porch locations are selected to provide yaw stability for SCR installation and to limit buoy rotation in the event of a tendon failure. The intersection of diagonals through the tendon porches lies between the SCR and Jumper porches so that the horizontal loads increase yaw stiffness. Since the SCR loads are larger than jumper loads and the SCRs are installed before the jumpers, the intersection of diagonals is closer to the jumper side than the SCR side. The intersection of diagonals is set to be at the centroid of vertical forces to minimize the overturning moment in the event of tendon failure. The tendon porches are located near the bottom plane of the buoy to maximize the rotational stiffness about the diagonals.

Failure of a tendon can occur due to accidental events such as dropped objects and incidental damage, or may be a result of a high corrosion problem. If required, a tendon can be replaced (with or without a failed tendon). In the event of failure of a tendon, the buoy will tilt due to asymmetry of the vertical loads from the three remaining tendons. The tension in two of the remaining three tendons increases substantially and the tension in the tendon diagonally opposite to the failed tendon decreases. As a result, the buoy moves up and rotates about the diagonal through the two high tensioned tendons.

The unbalanced vertical loads contributing to the buoy rotation include:

- The weight of the remaining tendons
- Initial (intact) over pull on the remaining tendons
- Added over pull equal to the tension loss from the failed tendon

The impact of a tendon failure can be evaluated in Orcaflex™. The buoy will pitch and roll heavily when one tendon only is broken. When two opposite tendons are broken, the buoy moves upward but remains flat and does not rotate in any direction. In the transient cycle, the buoy rotation can go up to 40 degrees in the 3,000 meter/15 riser case. Table 2 presents the static buoy motions after one or two tendons have failed.

In case a tendon replacement is needed, a compartment near the tendon to be replaced would be flooded so that when the tendon is removed, the buoy remains flat. The amount of ballast needed is about 75 percent of the nominal tendon top tension, or about 15 percent of the excess buoyancy of the buoy.

Table 2: Buoy Motions due to Tendon Failure

| | Surge (m) | Sway (m) | Heave (m) | Roll (deg) | Pitch (deg) | Yaw (deg) |
|---|---|---|---|---|---|---|
| 1 failed tendon | 3 | 0.3 | 5.4 | -12.5 | -23 | -1.9 |
| 2 failed tendons (opposite) | 5 | 0.2 | 10.4 | 0.5 | -2 | -1.9 |

If a large tilt in a tendon failure condition is found unacceptable, an alternative mooring system can be designed by using an 8 leg mooring system (2 tendons at each corner). This will reduce the maximum tilt by a factor of approximately three. In shallower water, the elongation of the tendons is less (since they are not as long), so the heave and tilt are reduced, roughly in proportion to the length of the tendons.

## FATIGUE ANALYSIS

Fatigue is the main design issue with SCRs directly connected to a turret moored FPS. The large vertical motions at the turret dramatically increase the fatigue damage of the riser near its top connection and its touchdown region, making the SCR solution possibly not feasible for turret moored FPSOs. The main advantage to the TLR system is to provide a riser system that is de-coupled from the wave induced motions and satisfies very high fatigue requirements. The adequacy of the TLR riser system to resist fatigue was assessed by separately computing damage induced by wave action and damage induced by vortex induced vibrations (VIV). Both damages are combined to obtain a minimum fatigue life. Fairly conservative assumptions and parameters were used to conduct the fatigue analysis for our hypothetical case. The fatigue was evaluated for all risers in operating configurations, with an intact (undamaged) FPSO mooring system. The wave induced fatigue analysis was conducted using a 13-bin wave scatter diagram and running 20-minute time domain simulations using RAOs to model the wave frequency motions of the FPSO. The standard deviation of stress at each node along the length of the riser was then computed for input into the fatigue analysis. A Rayleigh damage equation was used with an API X' SN Curve [4] to evaluate the fatigue damage. The minimum wave induced fatigue life obtained for a 16 inch riser is above 40,000 years, well above any specified design life requirement.

The fatigue damage due to VIV was computed using the program Shear 7 [5]. A pinned-pinned beam model of uniform riser is used to determine the VIV fatigue damage generated by the currents present at the field location. Even though the riser is not subject to the background currents present in the Gulf of Mexico, the common strong loop current events will produce VIV fatigue and result in the need for strakes to be installed in the upper part of the steel risers. Length of the strakes will depend on project specific requirements such as minimum fatigue design life, stress concentration factors, etc.

## INSTALLATION

Vessels required for installation of the 3,000 meter/15 riser TLR system include a deepwater pipe lay vessel, a derrick barge with heavy lift capability, an AHTS, a transportation barge and a flexible pipe installation vessel. The pipe lay vessel would likely install the SCRs dry. The vessel would however be required to handle an 18-inch pipe with a flooded weight of approximately 800 metric tons. The derrick barge would perform lowering/installation operations of the four suction piles each weighing approximately 350 metric tons. The derrick barge would include A/R winch and hang-off porch for tendon installation. Air compression, an HPU and full deepwater ROV spread would also be included. The AHTS is required to perform TLR buoy wet tow out as well as delivery of anchors, tendons and other equipment to site using the transportation barge.

The anchors are lowered from the derrick barge using its A/R winch and installed using conventional suction embedment method with ROV support. A subsea connector allows disconnection of the installation line after lowering and embedment, followed subsequently by connection of the tendon at the same point on the anchor. Sufficient set up time of soil around the anchor pile must be allowed for and is a function of many properties including anchor size, soil properties, mooring loads, etc. An estimate of seven days minimum set up time is required before loading anchor piles.

The wire rope / chain tendons are installed from the derrick barge. Wet weight of each tendon is approximately 250 metric tons for the 3,000 meter/15 riser system. To prevent damage to the wire rope sheathing during installation due to its self weight, the top assembly end is hung from a porch while the bottom segment end is lowered using A/R winch.

The buoy is delivered via wet tow to the installation site. The tendons are transferred from the derrick barge and hung-off the buoy with pre-rigged lines through its four chain jack assemblies. Air and hydraulic lines are connected between the derrick barge and buoy and the buoy jack down operation begins. All buoy tanks are flooded except the trim tanks that receive compressed air during pull down. The ROV continuously monitors the manway openings to ensure that bubbles are exiting each trim tank and that no buoyancy is lost. The slightly positively buoyant buoy (approximately 500 metric tons) is jacked down to operating depth. The installation chain and chain jacks are retrieved and the buoy is ready to begin the deballasting operations in preparation for SCR installation.

As pipelay of the steel flowlines approach the TLR buoy, compressed air is injected into buoy tanks to increase its net buoyancy an amount equal to weight of the SCR to be installed. All SCRs are installed and hydro-tested in this manner. Deballasting/installation steps follow a pre-determined sequence to control buoy yaw, roll and pitch as well as keep tendon tensions within acceptable minimum and maximum limits. Assuming a 4,000 standard cubic feet per minute compressor, deballast time to prepare to install a water filled 18-inch SCR in 3,000 meters is approximately two hours.

After installation of the SCRs and the host vessel, the jumpers are installed on the buoy and pulled into the turret using conventional installation methods. A total installation period of approximately four months is expected for the 3,000 meter/15 riser TLR system, including pipelay of static flowlines and SCRs from a scope distance of approximately four kilometers from the FPS turret.

## DISCUSSION

As a result of this recent study, it is concluded that the TLR riser system is a feasible and attractive development concept for deepwater riser applications. The work has shown that the TLR system is not only feasible, but is also a straightforward technology utilizing mostly proven equipment and familiar fabrication/installation procedures. The work provides operators with the confidence that deepwater production in water depths up to 3,000 meter can be accomplished using the TLR system with little or no incremental risk or safety considerations compared with other deepwater projects currently operating in shallower (500-1,500 meters) water depths. In addition, the TLR technology is ready today with no outstanding development work necessary.

Although the TLR buoy, tendon and anchoring system would require a customized design for each project application, a number of preliminary cost and schedule estimates have been prepared for comparison with other deepwater riser systems. Results show that the TLR system could be the most cost effective solution for deepwater field developments requiring a high number of large diameter risers.

Delivery schedules for the TLR system prove to be well within the delivery schedule for any deepwater floating production facility such that installation of the TLR and the associated SCRs can be completed before the floating production facility arrives offshore. This permits the floater to be installed, hooked-up, and commissioned within days of its arrival on site leading to an accelerated start of first oil.

This study has addressed a broad range of design conditions and has investigated the TLR system for the following design basis parameters:

- From shallow 1,000 meter water depths to ultra-deep water depths up to 3,000 meters.

- From the mild West African environment to the extreme hurricane environment of the Gulf of Mexico.
- From simple applications having only six low pressure export lines to complex systems having up to eighteen high pressure pipe-in-pipe production/injection lines including several large diameter oil/gas export lines.
- From conventional ship-shaped FSOs and FPSOs to the smallest mini-TLPs.

This study has been all-inclusive including dynamic and fatigue analyses of the risers, VIV analysis, global system and hardware design, development of fabrication and installation procedures, and review of operational risk factors.

Sufficient analysis has been conducted to assess installation scenarios and all significant operational, survival and damaged conditions. The entire TLR system, including SCRs, tendons, buoy, jumpers and host vessel has been modeled and analyzed using the time domain finite element program Orcaflex™. The results demonstrate excellent de-coupling of host vessel motions from the buoy. Damaged scenarios have found to be acceptable for the preliminary design. With a simple four (4) tendon system, large transient buoy pitch motions may be experienced following a failed tendon. Although the system is stable during this event, an eight (8) tendon system has also been developed which results in much lower pitch angles during this failed tendon condition.

Design work conducted to date has also confirmed that the structural aspects of the system are well within familiar design practices and the mechanical systems are generally available from the industry with only minimal extensions to off-the-shelf technology.

Fabrication documents have been prepared and supplied to experienced fabricators who have confirmed the feasibility of using familiar flat-plate panel line construction. Launch and transportation philosophies based on a wet tow to the offshore site have also been developed.

Installation procedures (for the anchors, tendons, buoy, SCRs and jumpers) have been developed to a sufficient level of detail to confirm the feasibility of using familiar offshore practices. Anchors and tendons can be installed using a derrick barge similar to the DB 50. Buoy installation is a significant operation, utilizing buoy-mounted ram winches to pull the buoy down to operating depth. Pipelay and installation of large export flowlines will require mobilization of a heavy lift J-Lay vessel. Installation of the jumpers to the SCRs will be an ROV (diverless) operation. A key feature of the TLR is the ability to install the SCRs in multiple phases or mobilizations to suit any strategy for a phased field development.

There exist several aspects of the TLR system which require further development to lower its cost or improve reliability. Some of these include; further evaluation of the vertically tensioned foundation design, possible use of synthetic fiber rope tendons, consideration of alternative mooring tendon configurations, and a safety assessment including risk assessment, failure conditions, and risk. Optimization of these design aspects would be developed further during detailed design.

The global analysis has also showed that special attention needs to be given to the design of the flexible jumpers and the stress joint at the top of the SCRs. Failure of one of the buoy's tendons could also govern the design of the SCRs and/or mooring system.

In summary, the global analysis of different TLR systems for different environments and water depths have confirmed the great advantage of this de-coupled system over other coupled riser systems. The TLR system behaves almost quasi-statically and eliminates nearly all wave induced fatigue problems for the steel risers.

## CONCLUSIONS

The TLR system proves to be a feasible, cost-effective deepwater riser technology. It is not only a cost competitive solution in its own right, but it also offers the potential for significant cost savings on the floating production facility, particularly for floating systems having payload limitations or turret moored FPSO's where riser loads contribute to increased costs in the turret system.

## ACKNOWLEDGMENTS

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FMC SOFEC is currently a licensee of the TLR technology covered under ExxonMobil's US Patent Number 5,639,187.

This paper is not an offer to sell the equipment or perform the services described herein. An offer to sell the subject matter of this paper can only be submitted after (1) specific details of the system are described; (2) pricing of the specific system and installation methods has been accomplished; (3) patent clearance for the subject matter has been obtained; and (4) authorization to submit a bid has been obtained by an FMC/SOFEC officer.

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[5] Shear 7 Version 3.0, User Manual, MIT

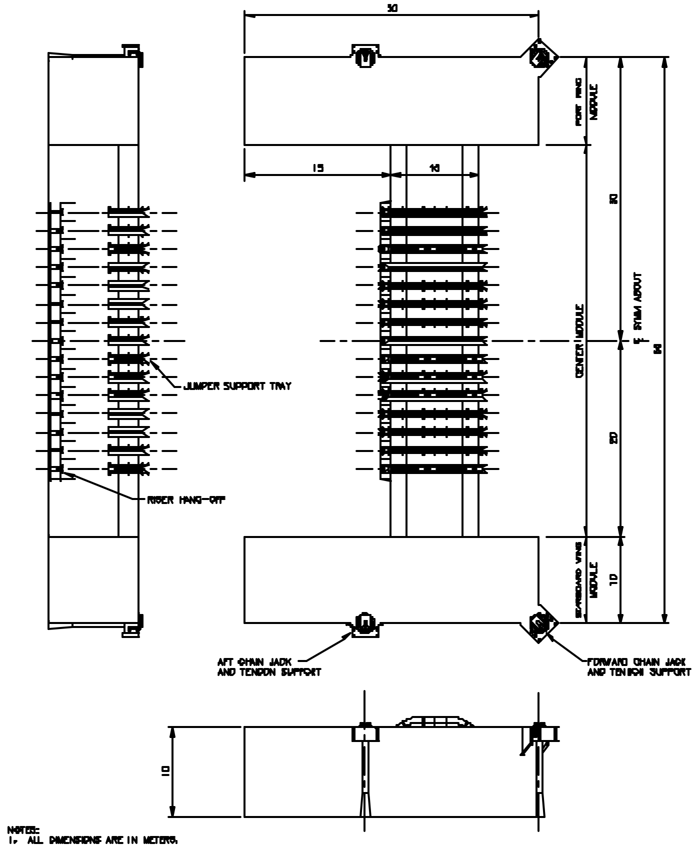




Figure 1: TLR Buoy General Arrangement

Figure 3: Buoy Pull-Down Winch Assembly

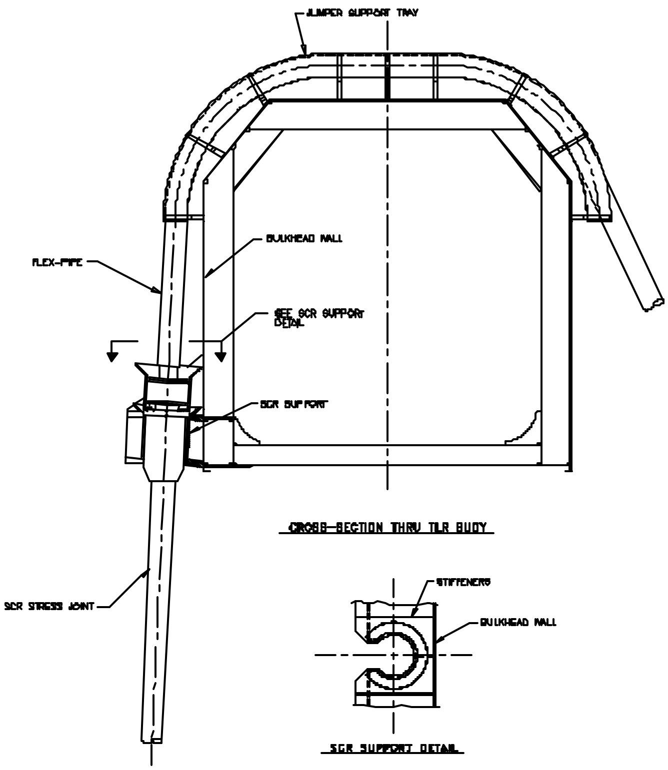
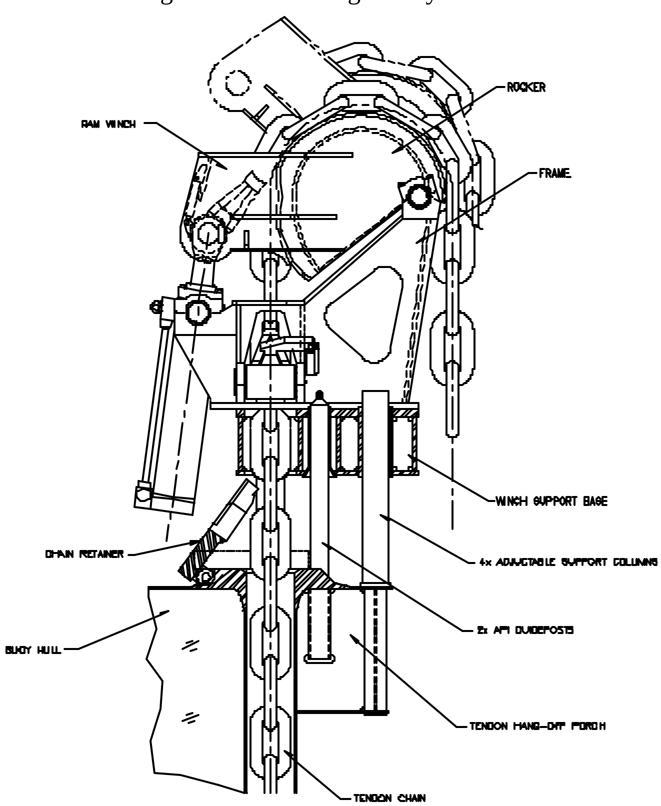



Figure 2: Riser Hang-Off System



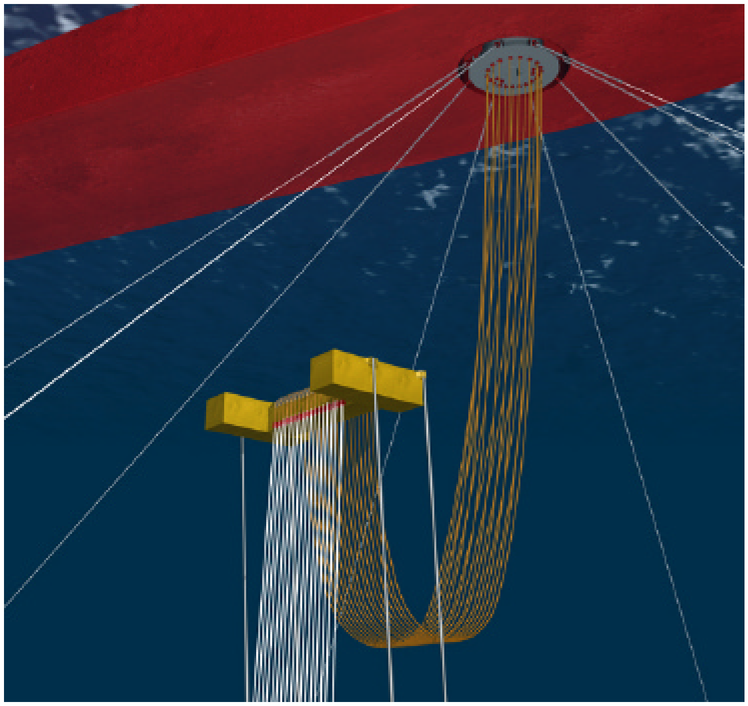


Figure 6: TLR Buoy with Turret Mooring System

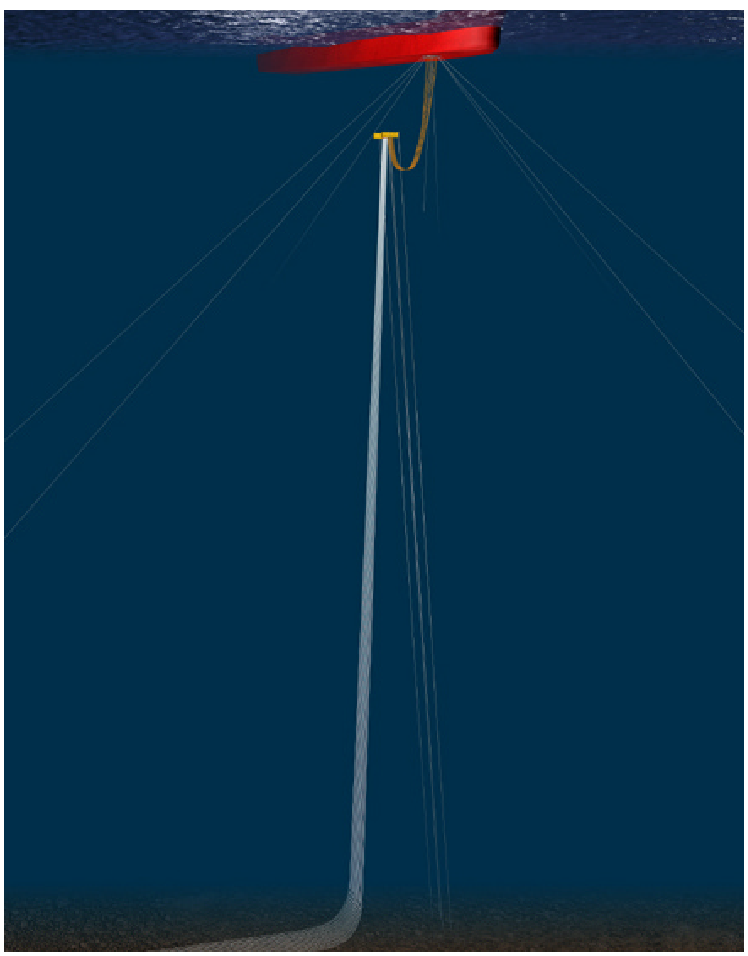


Figure 7: TLR System with Turret Moored FPS