Alternative Construction for High Pressure High Temperature Steel Catenary Risers

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Abstract

The design of deepwater riser systems to accommodate high pressures, temperatures and extreme environmental conditions is a major challenge in the development of floating production facilities. Current industry practice for steel catenary riser (SCR) installation is by welded construction, however SCR's are fatigue sensitive structures, requiring good quality welds to maintain system integrity throughout field life. This paper discusses the impact of thick wall pipe on the design of SCR's and presents an alternative construction method using non-welded threaded and coupled connections.

Introduction

It has been observed in the past few years that there have been an increasing number of deepwater oil and gas discoveries that are often defined as high pressure and high temperature, commonly abbreviated to HPHT. In addition to the challenges faced by the increasing water depths at which reserves are currently being developed, the presence of the HPHT environment brings an additional set of challenging issues to all aspects of hydrocarbon recovery. In particular, riser systems are greatly affected by a HPHT environment, primarily due to the impact of increased riser wall thickness, which has many knock-on effects as discussed in this paper.

SCR's have become common place in deepwater field developments for both production and export functions. In it's simplest form, a SCR is often considered to be the least expensive riser configuration available due to their apparent low cost hardware and the familiarity of the technology to that associated with flowlines. However, for deepwater field developments which require SCR's to accommodate a variety of stringent design requirements such as high thermal performance, high design pressures, large vessel motions and potentially sour service environments [1], the resultant SCR configuration may be far from the low complexity solution that it is perceived to be.

The major CAPEX cost component of a SCR is the installation. SCR's are exposed to fatigue loads from the vessel motions and by current loads causing the riser to vibrate due to vortex shedding effects and are therefore sensitive to the accumulation of fatigue damage. The fatigue performance of a SCR is the most critical aspect of consideration during SCR design and is a direct correlation to the quality of the weld joining two pipes together. In order to maintain high quality welding, the industry has adopted the approach of utilising J-Lay and S-Lay vessels equipped with quality offshore welding systems. These vessels can command high day rates because of their speciality and limited availability. In consideration of more complex SCR design requirements, which include HPHT environments, the increase in riser wall thickness impacts the SCR installation cost as it is directly linked to the vessel tension capacity and the time required to weld and inspect each joint, resulting in increased installation costs.

In light of the potential impact HPHT environments have on SCR design, performance and installation requirements, an alternative method for connecting riser joints is considered. The use of threaded and coupled connectors provides an alternative, which is reliable, relatively low cost, has proven fatigue performance, and provides benefits with respect to installation costs.

This paper describes the challenges associated with thick wall welds for fatigue sensitive SCR's, required as a result of HPHT environments. It discusses how the use of high strength threaded and coupled connections can be considered an enabling technology for deepwater, HPHT SCR's. An example case study is included to demonstrate the relative performance of threaded SCR's against conventional welded SCR's.

Impact of HPHT on Conventional SCR Design

High pressure, high temperature applications present particular design challenges for steel catenary risers, particularly in ultra deep water depths defined here as 6,000ft and greater. High pressures above 10,000psi tend to give pipe wall thickness at the limits of manufacturability and high temperatures greater then 121 deg C requires temperature de-rating of steel yield strength.

For HPHT environments and a given pipe outer diameter, wall thickness requirements are driven by the internal design pressure and the yield strength of the pipe material. The nominal wall thickness requirement versus internal design pressure for a 12-3/4 inch OD pipe, grade X65, is given in Figure 1 based on API RP 1111 [2] burst and collapse design criteria. It can seen that for a 15,000 psi internal design pressure, a nominal wall thickness of 48mm is required compared with 20mm for an internal design pressure of 5,000 psi. It should be appreciated that this wall thickness requirement is purely to resist the burst and collapse pressures. When considering the axial stress component from the tension at the top of the riser in 10,000ft water depth, as required in API-RP-2RD [3], the wall thickness requirement increases to 64mm in order to maintain the static riser stress below the normal operating allowable of 2/3 yield strength. The comparison between the API RP 1111 and API RP 2RD sizing is shown in Figure 1. This wall thickness requirement is not considered to be feasible from a fabrication perspective, but also restrictive from an installation and operability point of view.

As wall thickness requirements increase with greater internal design pressures, there comes a stage where the increase in SCR wall thickness impacts the following:

- Pipe cost and availability
- Installation vessel availability
- Offshore construction and inspection of welded joint
- Installation lay rates
- Payload on floating production vessel

For a given pipe outer diameter, pipe weight per unit length approximately increases linearly with increases in wall thickness. As the pipe cost can generally be estimated based on a $ cost per tonne, increases in pipe costs become more significant in ultra deepwater developments requiring numerous thick wall SCR's.

Typically, subsea developments utilise production SCR's with outer diameters of between 6-5/8 inch and 12-3/4 inch. The maximum standard wall thickness of seamless line pipe is 31.8 mm [4]. Due to the growing demand for thicker line pipe to meet HPHT applications, a few specialist pipe mills have the capability to offer larger wall thickness sizes up to 40 mm, where the manufacturing process can achieve the dimensional tolerances and through thickness mechanical and material toughness properties required for SCR welded fabrication. Hence, a SCR design that requires a wall thickness of 40 mm results in a more costly manufacturing process. In addition, the availability of pipe mills that can offer such pipe is limited, which is potentially another factor that drives up procurement costs of plain riser pipe.

The weight of thick wall SCR's is an issue for installation. There are only a limited number of installation vessels able to install thick wall SCR's in deepwater and the number starts to diminish rapidly as water depths and pipe wall thickness increase. For instance, the hang-off load in 7,000ft water depth for a 12-3/4 inch pipe with 40 mm wall thickness is 563 Te flooded and 445 Te empty based on an 82 deg J-lay departure angle. In 7,000ft water depth, there are only 2 to 4 pipe lay vessels that have sufficient hang-off capacity to install such a riser, depending on installation philosophy. As the water depth increases to 10,000ft, and the wall thickness of the pipe increases to accommodate the increase in riser tension, there is potentially only one pipe lay vessel that can currently install this size SCR, although it is noted that this is within 5% of the vessels limit. A table of deepwater SCR installation vessels and their associated tension capacity is provided in Table 1. In addition, consideration should be given to potentially complex handover and pull in operation to the production facility.

SCR's are fatigue sensitive structures subject to several components of cyclic loading such as those induced by vessel motions and current induced VIV. Thus, the SCR requires high quality welds that qualify to a fatigue performance such as that of a DnV E classification [5] or API X' classification [6], with minimal stress concentrations.

Such requirements are generally typical of all SCR's attached to floating production vessels irrespective of function, size, water depth and geographical location. Much effort is placed during the engineering phase of a project to ensure weld quality and fatigue performance, through the following activities:

- Minimizing joint misalignment
- Weld procedure qualification tests
- Critical defect assessment and inspection
- Full scale fatigue testing

Control of out of roundness and wall thickness tolerances at the pipe ends is critical to reducing stress concentrations as a result of joint misalignment at the welded connection. Standard line pipe tolerances specified in API 5L [4] are seldom sufficient to meet a typical design SCF requirement of 1.2 or less [7]. In order to reduce misalignment, stricter pipe end tolerances can be specified. This inevitably increases the cost of the line pipe. Alternatively, a more cost effective approach to control misalignment of line pipe with standard tolerances is to pre-sort and match pipe ends and/or counter bore the ID of the pipes. Thick wall pipe inevitably requires this management of pipe end tolerances as its wall thickness variations are inevitably greater than that of standard pipe sizes.

An acceptable standard for the mechanical and material properties of the welded joints are confirmed through weld procedure qualification tests. Tensile, hardness and fracture toughness tests are performed to applicable standards such as API 1104 [8]. The fracture toughness property is of particular importance to the fatigue life of the welded joint as it defines the resistance of the joint to failure through fracture once flaw propagation has reached a critical size. The welded joint fracture toughness for high yield strength risers requires careful attention to line pipe properties and the welding processes. Generally, difficulties arise with higher strength steels that tend to have high hardness and low fracture toughness properties, which require extensive qualification to confirm weldability in an offshore environment that will provide long term fatigue performance. To date, the yield strength of SCR's installed has not exceeded 65ksi yield strength.

It is this limitation in yield strength that results in the thick wall requirement for HPHT applications. The thick wall presents challenges in the welding process as it provides a greater heat sink from which variations in material properties may occur across the wall of the heat affected zone if heat input requirements cannot be maintained across the pipe ruling section. Post weld heat treatment (PWHT) could be employed to stress relieve and stabilize the microstructure and mechanical properties across the pipe wall. However, this would not be desirable for offshore SCR welds, as the duration required for PWHT would significantly increase offshore construction time and cost.

Automatic ultrasonic testing (AUT) is typically employed as part of the offshore NDE program and is considered one of the most effective methods of inspection offshore to detect critical flaw sizes as small as 0.5 to 1mm in height [7], which is a possible requirement for highly fatigue critical SCR welds. The probability of detection of such small defects is widely debated in the industry and the introduction of thick wall pipe only adds to the challenges involved in detecting critical flaws. Extensive testing prior to offshore installation is required to ensure that AUT procedures and personnel are qualified as there is a very limited track record of its use on thick wall risers. Also, the size of wall thickness variations present in thick wall pipe may require multiple calibration standards for the AUT system resulting in longer inspection times offshore [9].

It has become common to carry out full scale fatigue testing on a resonant bending rig for welded riser joints. Even though this type of testing can be time consuming and costly, it is considered necessary as it is often unreliable to rely on previous testing of welded specimens with similar size, strength and welded joint design. This is because the fatigue performance of the weld is highly dependent on several inter-related factors including pipe and welded joint material properties, joint dimensional tolerances, welding processes and procedure, and inspection criteria. For this reason, fatigue qualification testing is typically carried out at the later stages of a project when actual production pipe can be used and the test specimens welded and inspected to the exact same procedures as those to be used by the installation contractor offshore.

Fatigue test programs can take up to 3 months to complete where 9 welded specimens are successively tested and all meet the required fatigue test targets. In the event that the fatigue performance requirement is not reached, modifications to the welded joint design and/or the welding and inspection procedure would need to be implemented and specimens re-tested. This can significantly impact the project schedule, as it can be sometimes difficult to identify the remedial action required without having to go through several fatigue test iterations. The probability of this scenario occurring is increased for thick wall HPHT SCR welded joints as the probability of critical flaw sizes increases with the greater number of weld passes.

Offshore installation rates are a major cost concern for deepwater field developments. Thick wall welded joints require more weld passes compared with thinner wall joints to ensure weld quality. This increases the time it takes to complete the welding and inspection of the joint. A typical lay rate on a J-lay vessel for a 12-3/4inch x 0.5inch SCR is considered to be in the order of 40-50 minutes per weld including inspection and placement of insulation field joint. A thicker pipe with 40mm wall is estimated to results in offshore weld times being as long as 100 minutes, including the AUT inspection and insulation field joint fitting. This is primarily due to the number of weld passes that are necessary to complete the weld.

The rapid development of deepwater areas such as in the Gulf of Mexico and West Africa offer the advantages of tieing back smaller subsea developments to existing floating production infrastructure. However, the reserve payload capacities of potential host vessels offer a limitation to the number and weight of individual SCR's that can be tied back. For weight sensitive platforms, tie-backs of HPHT SCR's will require weight optimization through the use of the highest yield strength line pipe that still permits an acceptable standard of weldability and fatigue performance. In some cases, the yield strength required to meet payload limits will be outside the current capability in offshore welding and other avenues will have to be explored such as using a connection method that allows the use of high strength steel or the use of an alternative riser solution with less payload.

An issue that has not been discussed is that of H_2S. For a welded X65 riser, a weld overlay is required, which further complicates inspection and increases material and weld costs. For the threaded solution, proprietary steel casing grades offered by suppliers for sour service conditions can be considered.

Alternative Construction Approach

The industry has continued to use welded construction as the method of connecting riser pipes in deepwater subsea field developments. This is primarily a function of the industry culture, level of confidence and track record in offshore welded connections. Historically shallow water flowlines (less than 100m) were installed using low strength, readily weldable steel using the S-Lay technique and thus this approach has been continued to be adopted as the industry strides into deeper water. However, as discussed earlier, the combination of high pressure, high temperature and deepwater results in thick wall risers with complex welding requirements.

An alternative construction method is described, facilitating the use of high strength steel pipe that is outside the current limits for welding. This allows for the design optimization of an SCR with respect to weight in ultra deepwater and HPHT environments, whilst providing comparable installation rates and long-term integrity during service as with conventional welded construction. In addition, the method described is believed to be an enabling technology for extreme design cases, where the use of conventional welded SCR's is not desirable due to issues relating to pipe manufacture, joint construction, installation vessel tension capabilities or host vessel payload weight.

The method proposed utilizes premium mechanical connections in the form of non-welded threaded and coupled (T&C) casing connections. Typical connections are presented in Figures 2 and 3. The features, track record and benefits of T&C connections in riser applications are discussed in [10] and the main benefits are summarized below:

- Faster offshore make up speed compared to welding
- Wider selection of vessels for installation including drilling rigs
- Improved fatigue performance
- Cost effective
- Application of high strength steel
- Application of corrosion resistant alloys (CRA)

It is the benefit of using high strength steel that is the most advantageous for HPHT SCR applications. High strength steel grades such as T95 and P110 have 45% and 70% higher yield strengths respectively compared with X65 line pipe. The high strength steel can resist greater burst loads from internal pressure and results in significantly smaller pipe wall thickness requirements. This in turn results in much lower riser payloads exerted on the host production facility. However, it is noted that a larger wall thickness will be required in HPHT applications compared with the previous applications of T&C connections on spar and TLP top tensioned risers.

Heavy wall designs are available from the main premium connection suppliers in high strength grades. For instance, 10-3/4 inch OD pipe with 1.0 inch wall thickness in grades up to P110 are specified in supplier catalogues with a 1.25 inch wall available from one supplier [11]. This is supported by an extensive track record of heavy wall casing use in down-hole applications. Casing wall thickness greater than 1.25-inch is limited by the thickness of the coupling and the ability to achieve the required through thickness material properties. Development work is required for the heavy wall connection design to make the transition from static down-hole application to dynamic riser service. However, such procedures are already in place as the existing riser T&C connections used on smaller wall thickness risers for Spar and TLP developments are enhancements of standard down-hole connection designs.

The mechanical strength of grades such as P110 is very high as a result of the hardenability of the alloy influenced by the addition of specific chemical elements such as chromium, manganese, molybdenum and nickel. This grade of steel is also quenched and tempered. Both chemical composition and the application of heat treatment practices affect the material fracture toughness, which is the essential property for riser fracture and fatigue performance. Hence, tighter specifications on mechanical and material properties are required for high strength steel grades to be used for dynamic riser service compared with static down-hole applications. This is achieved through careful control of the steel chemical composition and heat treatment processes during the manufacturing process.

The use of high strength steels also requires restrictions on material hardness in order to limit susceptibility to the embrittling influence of hydrogen. Hydrogen embrittlement is associated with the presence of nascent hydrogen that results from the disassociation of water and ingresses into the substrate material and consequently reduces its ductility. Attention to the casing and coupling stock heat treatment processes is required to attain the desired hardness level. Also, hydrogen embrittlement is deterred by introduction of a high integrity environmental seal in the pin and box annulus as developed and presented by 2H [10] and a field joint corrosion and insulation barrier. Both serve to prevent seawater ingress into the last run out threads of the connector where the largest geometric stress concentrations exist.

An advantage with T&C connections is that a thicker wall design does not translate into longer offshore construction make up times as with welded joints. In addition, connection make up integrity can be verified quickly and with a high degree of certainty using computerized torque turn graphs in comparison with welded joints, which require considerable effort to detect small fatigue critical defects.

Extensive fatigue testing on T&C connections has been carried out in the 2H TRF JIP [10] and in several spar and TLP field developments, which consistently show the fatigue performance of these connections to be better than a good quality single sided weld. The T&C fatigue test data includes different steel grades, connection designs, and diameters, and shows less variability compared to welded joints. Hence, fatigue qualification of a T&C connection can be carried out early in the engineering phase of a project as casing pipe from the production batch is not necessarily required for fatigue testing unlike in a welded fatigue qualification program. This is because make up of the mechanical connection does not change the critical material properties important to fatigue performance unlike the welding process.

Furthermore, the pin connection threads are machined directly onto the ends of the casing thus alleviating the issues associated with pipe end tolerances and joint fit up that requires much effort and planning to ensure successful welded joint fabrication offshore and in-service fatigue performance.

Installation Strategy

The feasibility of threaded connections for SCR's is heavily dependent upon the industries acceptance of T&C connectors for fatigue critical applications. A significant amount of work has been conducted and continues to be conducted by various establishments to further develop the application of T&C connections for fatigue critical riser systems. However, a key consideration in this equation is the ability to install threaded SCR's. To date, the use of T&C connections has remained with applications, which inherently require installation from a drilling derrick, specifically designed to efficiently handle and install pipe with threaded connectors. This includes down-hole casing and more recently casing strings for top tension risers.

Although drilling vessels have not been used for installation of flowlines or SCR's, the facilities available on these vessels are well suited for J-lay mode. The available handling equipment such as spiders and torque tongs are tailored for the use of threaded connections. The derrick capacity is variable, but is usually in excess of 1.5 million pounds (670Te), far greater than the majority of J-lay installation barges. This provides an important benefit in that there is a multitude of drilling rigs potentially capable of installing threaded SCR's. In addition, the motion characteristics of a MODU are much superior to those of a pipelay barge. The peak roll and heave response periods of MODU's are far from the wave periods that occur in installation conditions, leading to decreased periods of installation downtime. Furthermore, barges tend to be more sensitive to vessel heading and must be orientated during installation towards the waves. This can lead to difficulties during lay operations.

The drilling derrick is specifically designed for pipe make up in the vertical orientation whilst SCR's require a small top angle to ensure stability of the catenary. However, for threaded connections, make up angles of more than a few degrees are not acceptable and make stabbing and supporting of the riser impractical. In order to provide the catenary with the necessary stability during installation from a MODU, it is possible for the riser to be held vertically at the drill floor and deflected off the vertical immediately below, providing clearance with the moonpool and pontoons is maintained. This approach requires a vertical stinger to be fitted below the drill floor to control catenary curvature. This is illustrated in Figure 4. The stinger would be designed to be fitted into place for SCR installation mode, and removed upon completion, ready for the rig to return to its normal drilling duties.

As with AUT inspection of welded joints, threaded and coupled connections require integrity confirmation upon completion of the make up. Poor make up of T&C connections is eliminated by the introduction of computer controlled torque tongs with feed back logic control. This has allowed the precise control of threaded connection make up, producing torque turn charts, allowing the operator to efficiently confirm whether a good connection has been made.

Threaded connections can be made up in 2-5 minutes and it conservatively estimated that completion of each 80ft double joint can be done in a total of 15 minutes. This includes the joint make up, integrity confirmation, installation of field joint half shells and application of a heat shrink sleeve. Unlike welded construction, the lay rate of threaded pipe is not sensitive to variations in pipe diameter or wall thickness.

Case Study Comparison

In order to validate the benefits of using threaded and coupled connections for SCR's, a comparative assessment between welded and threaded SCR's is undertaken to quantify the difference in response for strength and fatigue loading, riser payload and installation rate. The following defines the primary basis design parameters used in this comparative study:

- 10 ¾ inch riser diameter
- 5,500 ft water depth
- Semi submersible production facility
- 13,000 psi SITP at mudline
- 135 deg C design temperature
- 3mm corrosion allowance
- 2 inches thermal insulation
- 14 degree departure angle
- Oil filled riser
- Welded riser – X65, material grade
- Threaded riser – P110, material grade

Riser wall thicknesses for both welded and threaded risers are checked for resistance to internal pressure loading, external pressure loading, and the interaction between bending and external pressure. Riser sizing is carried out for all operating conditions in accordance with API-RP-2RD [3]. The wall thickness required to resist buckling propagation is not considered as buckling of the riser will require removal and repair of the entire riser.

The high strength steel allows the pipe wall thickness to be reduced to 22 mm compared with a 36 mm requirement for the conventional X65 riser. The use of the high strength steel risers reduces the payload exerted on the production facility by 40% and increases the flow area by approximately 30%.

In order to further investigate the use and limits of both welded and threaded catenary risers, additional wall thickness calculations are carried out for the following conditions:

- 10 ¾ inch riser diameter
- 15,000psi SITP at mudline
- 135 deg C design temperature
- 5,000 ft and 10,000 ft water depths
- X65, T95 and P110 material grades

The results of this assessment are illustrated in Figure 5. It is interesting to note that in this high pressure and temperature regime, the wall thickness requirement for conventional X65 material is 44mm and 55mm for 5,000 and 10,000ft water depth applications respectively. As discussed previously, wall thickness sizes above 40mm are not currently offered by the pipe mills and the welding of such thick wall joints would be very challenging and are require extensive qualification. This is not the case, however, for the higher strength steels where for the P110 material, the wall thickness is slightly above 1 inch at 28mm for both water depths, although it is appreciated that for threaded pipe, the resultant coupling thickness is the most important consideration.

Heavy wall coupling designs are currently available for 28mm wall thickness casing in P110 grade. Design modifications will be required in order to develop the connection design to be fatigue enhanced, suitable for this application, however, as mentioned previously, such procedures are already in place.

Limited strength and motion fatigue analysis is conducted in order to demonstrate the response of a threaded SCR, in comparison with a conventional welded SCR in 5,500 ft water depth. Previous work conducted as part of the Threaded Riser and Flowline JIP has shown that the T&C couplings can achieve a fatigue performance equivalent to the DnV B S-N curve [5] with a stress concentration factor (SCF) of 2.0. However, for this comparative analysis, an SCF of 3.0 has been conservatively adopted. The welded SCR assumes a DnV E class fatigue detail [5] with a SCF of 1.25.

The results of the strength response during a 100-year hurricane with the production facility in a 'near' offset position are illustrated in Figure 6. The results show that despite the thinner wall thickness, the threaded riser has a lower stress utilisation during the storm events by approximately 11% compared to the welded risers. Figure 6 shows that both configuration meet the survival design criteria for the case considered, however, in deep water field developments, the robustness of the riser system is critical. Throughout the SCR engineering phase of a project, it is common for the SCRs to be subjected to a wide range of changing parameters and therefore the more robust the riser design and configuration is, the better.

The comparative first and second order fatigue response of the threaded and welded SCR's is shown in Figure 7. The fatigue analysis conducted, examines the response of the risers for a single fatigue sea-state, representative of a sea-state expected to provide a reasonable contribution to the overall fatigue damage. The analysis demonstrates that the high strength steel riser has an improved motion fatigue response by a factor of 2. In addition, the fatigue life response can be further improved in the event that project specific fatigue qualification testing can qualify a SCF of 2.0 for a T&C connection. This would improve the fatigue life by a further factor of 5, resulting in the threaded riser being an order of magnitude better in fatigue that the welded SCR.

Installation rates for threaded connections are determined to be approximately 2 km per day for the insulated threaded SCR in 5,500 ft water depth. This lay rate assumes that the MODU is making up 80ft double joints and that the efficiency of the installation is 85% uptime. For the equivalent thick wall welded SCR with hex joint installation, this equates to a lay rate of 1 km/day, base on 100 minutes per weld that includes inspection and fitting of insulation field joint, and the provision for 1 weld cut out per day.

In the specific example given, the riser length is approximately 2.5km long, including a 600m section on the seafloor. In terms of installation cost, the following is determined:

- Threaded Installation $150,000 per riser lay
- Welded Installation $625,000 per riser lay.

These costs are for the riser lay activity only and assume vessel day rates of $120,000 per day for a MODU or subsea construction type vessel, and $250,000 per day for a J-lay barge. It can be seen that the combination of increased lay rate and low cost vessel day rates, makes the installation of threaded SCR's an attractive cost effective solution.

Conclusions

It has been demonstrated that the use of high strength steel with threaded and coupled connections is a technically feasible and commercially attractive solution for HPHT SCR's in deepwater applications. This methodology of joining pipes together is shown to provide many benefits over conventional welded solutions as summarized below:

- Use of high strength steel leading to a reduction in riser wall thickness and greater availability of pipe manufacture
- Reduction in installation tensions and vessel payload (40%)
- Elimination of requirement to pre-sort, match pipe ends and/or counter bore pipe ID
- Improved confidence in joint make up integrity
- Faster installation using widely available, less expensive installation vessels
- Lower stress utilization during extreme events, leading to more robust design
- Improved fatigue performance (2 to 10 times that of welded SCR)
- Less variability in connection fatigue performance
- Ability to conduct fatigue qualification prior to procurement of actual production pipe
- Less development work required to meet the challenges of HPHT and deepwater applications

The benefits listed above show that the use of T&C connections for SCR's should be evaluated at project level for suitable applications. However, it is appreciated that the current contracting strategies for SCR design and installation are not suitable for the implementation of threaded SCR's, primarily because the installation contractors have significant investment in welding technologies. It is believed that for applications where the conventional methodologies are no longer feasible, threaded SCR's will be seen as an enabling technology to allow the development of such applications.

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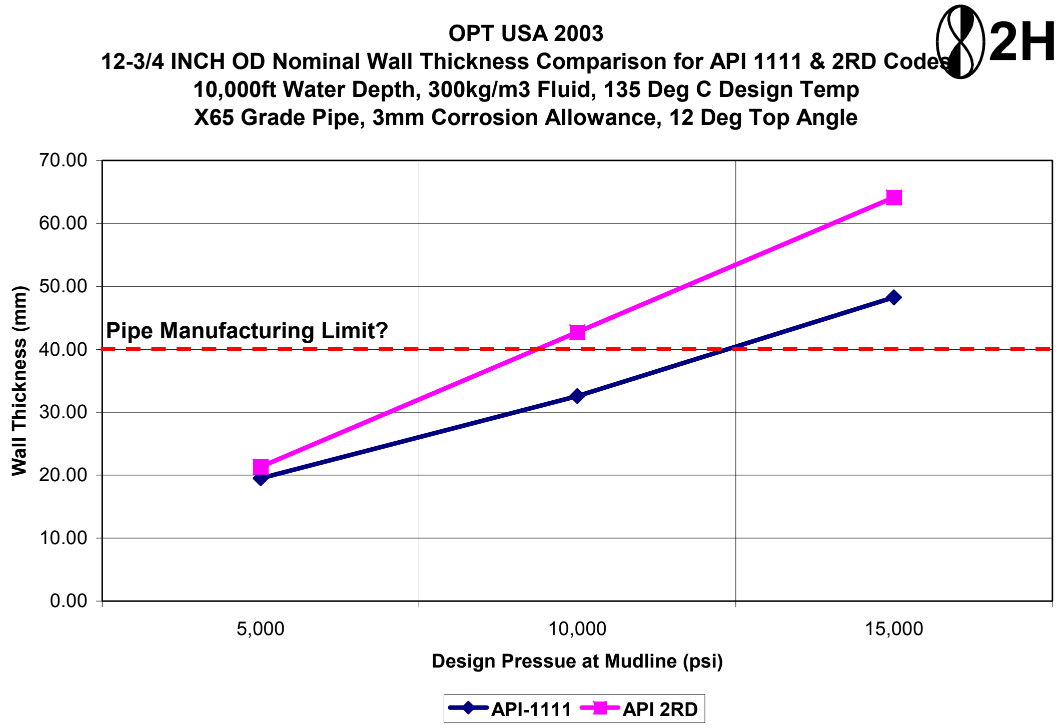

Figure 1 –Comparison of Riser Wall Thickness Requirements for Different API Codes and a Range of Design Pressures

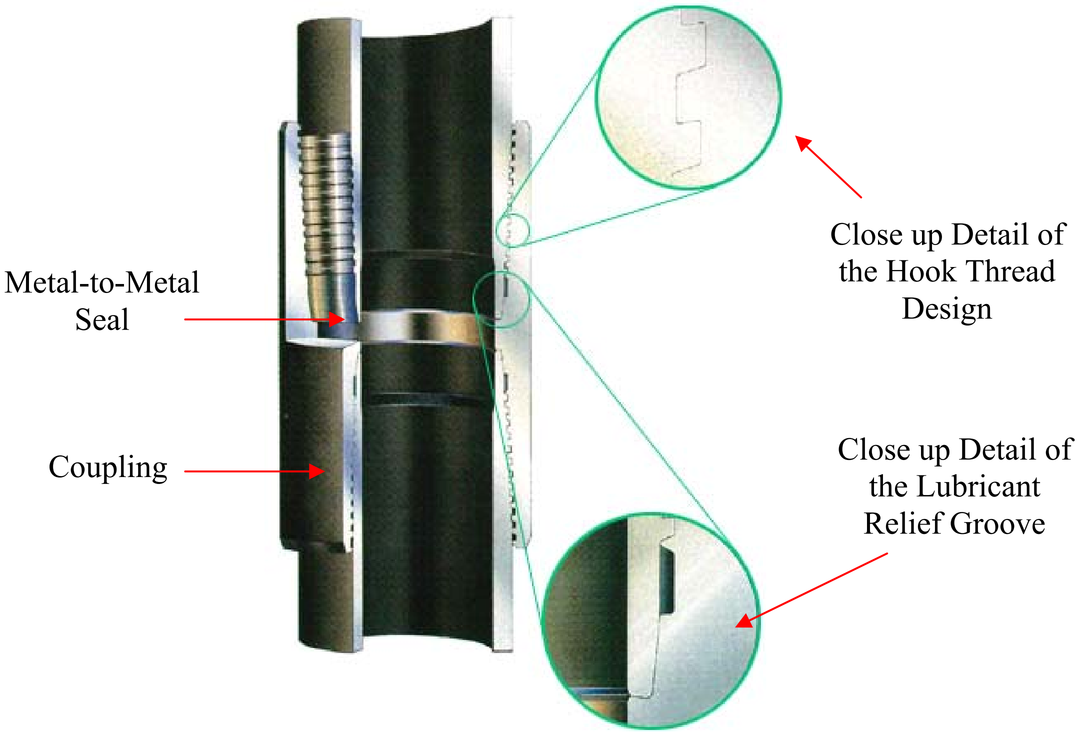

Figure 2 - Hunting SL-RP Connection

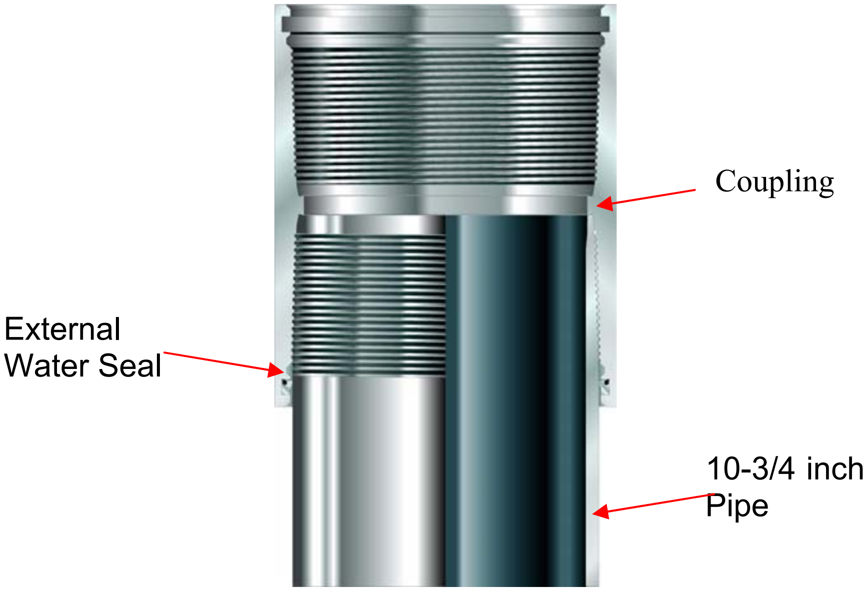

Figure 3 – Grant Prideco HFR1 connection

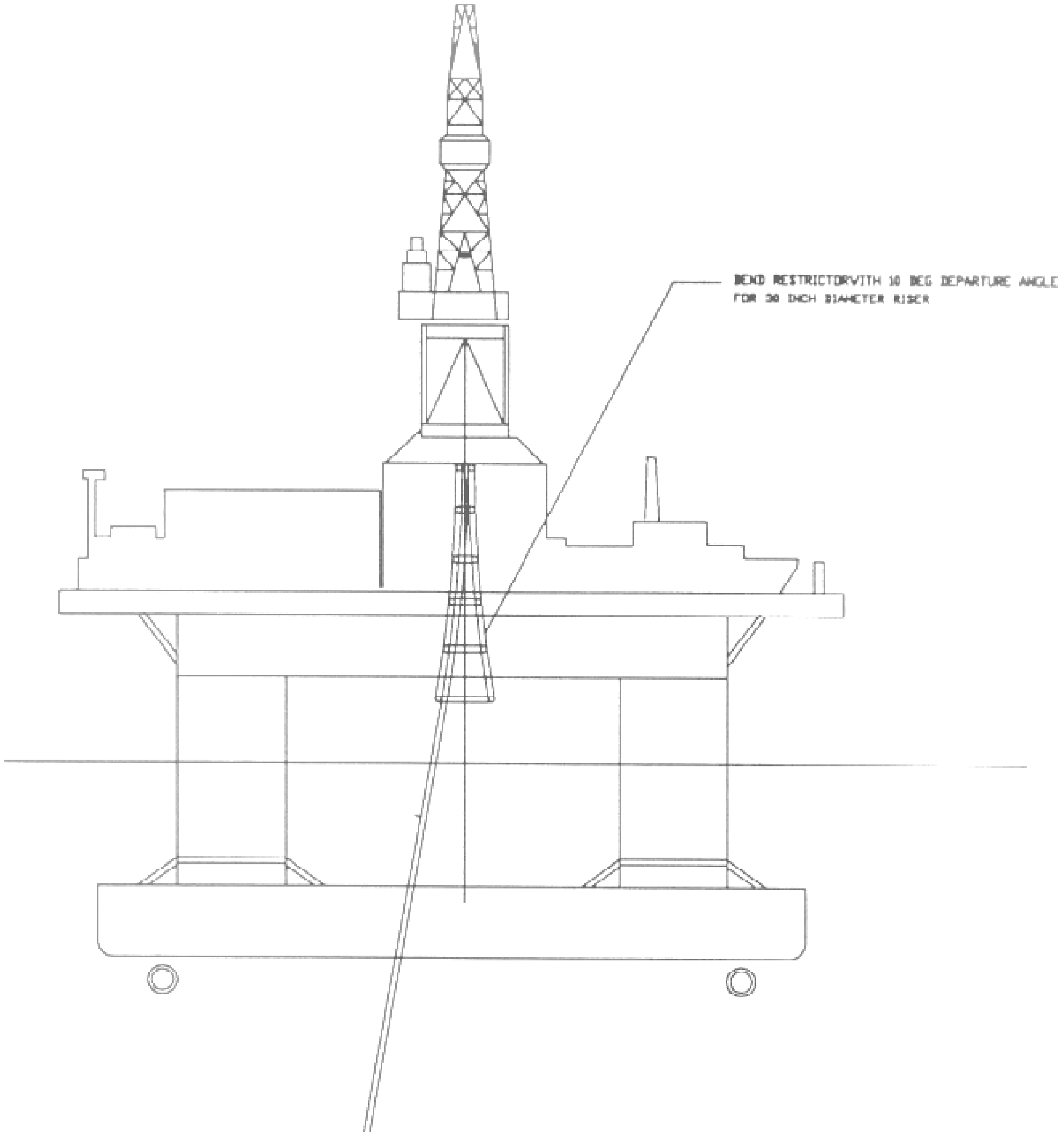

Figure 4 - SCR Installation Stinger Fitted Below Drill Floor

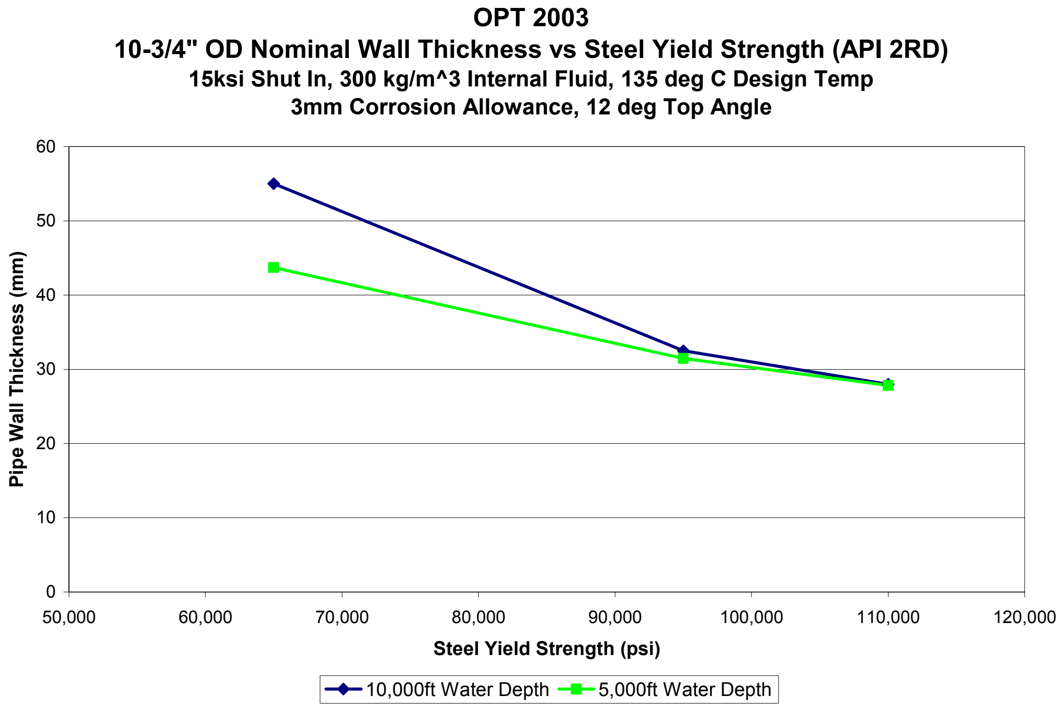

Figure 5 - Wall Thickness Comparison between X65 and P110 Material Grades For 15ksi Design Pressure in 5,000 and 10,000 ft Water Depth

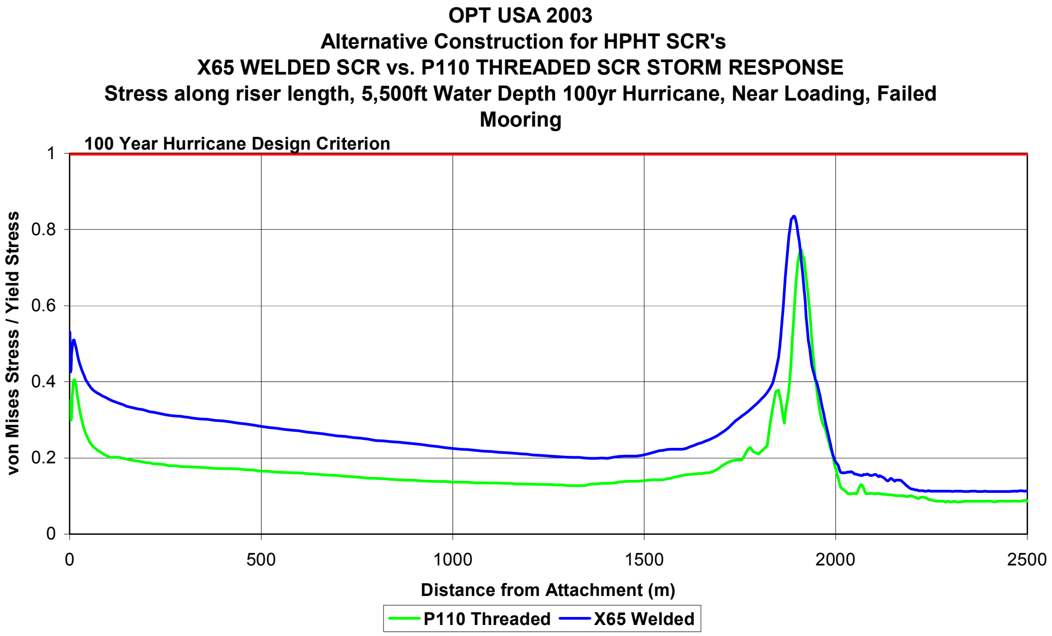

Figure 6 – Strength Plot

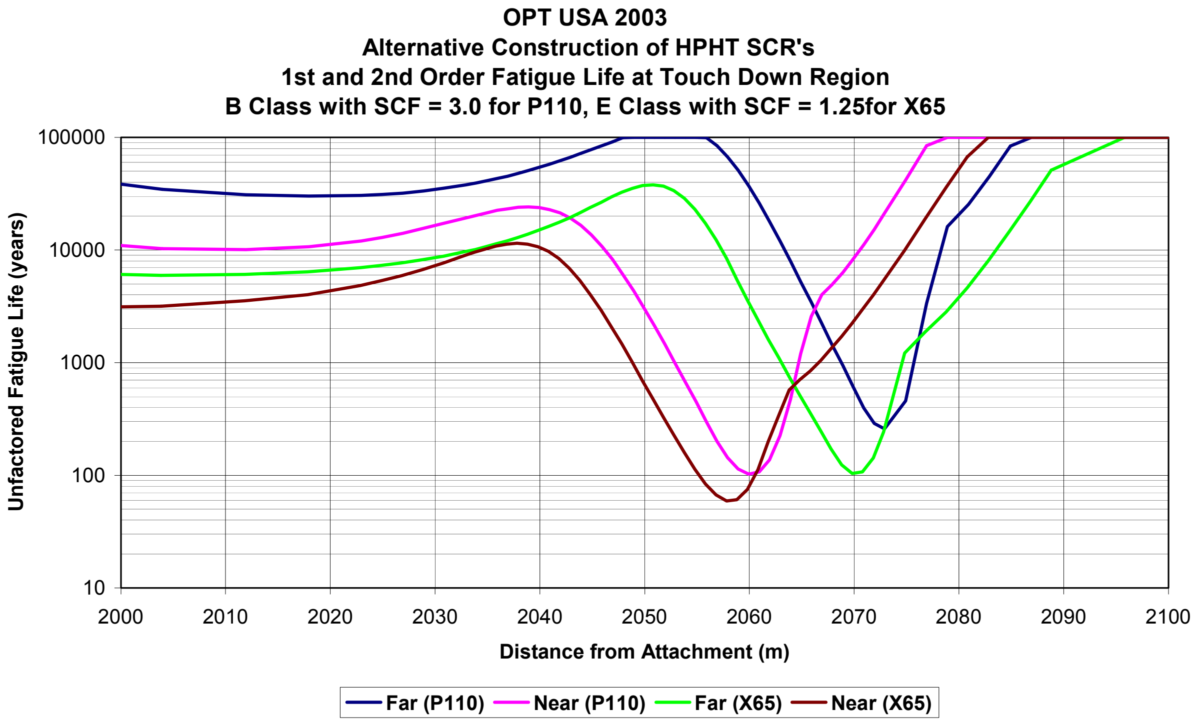

Figure 7 – Fatigue Plot

Company	Vessel	Lay Tension	Lay Type	Max Pipe Size
		(kips)		(in)
Heerema	Balder	2800	J	32
CSO	Deep Blue	1210	R, J	26
Global Ind.	Hercules	1200	S, R	60
Saipem	S-7000	1160	J	32
Allseas	Solitaire	1150	S	60
J.Ray.McDermott	DB50	1250	S, J, R	20
Saipem	FDS	881	J	20

Table 1 – Summary of Deepwater SCR Installation Vessel Capabilities [12]