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Hybrid Riser Foundation Design and Optimisation

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Abstract

Hybrid risers rely on axial tension, generated by a combination of aircan and distributed buoyancy, to control their static deflection and dynamic response. In deep water, the base tension required to achieve an acceptable response can be significant (70-1000Te). This tension must be reliably reacted into the seabed over the life of the development. Depending on the configuration of the selected foundation there may be, in addition to axial tension, bending moments, shear loads and loads arising from flexure of rigid base jumper spools. The result is a complex set of load conditions, which, when combined with installation issues, can lead to a foundation system that is a significant cost element in the overall riser system.

A number of foundation designs have been proposed and used for free standing risers however, the selection and design process is often not clear. This paper presents a review of the potential design solutions depending on water depth and design loads and outlines approaches adopted on existing projects. The key design and installation drivers are discussed, allowing improved understanding of the issues and the impact on the global riser design and installation strategy. The paper also discusses issues and implications of extending free standing risers to ultra deep water, which often have soft seabed conditions, further compounding the foundation design process.

Introduction

Free standing hybrid risers are a proven solution for deepwater floating production systems and have been utilised in West Africa and Gulf of Mexico with numerous current proposals and studies for their use in other parts of the world.

The free standing riser uses distributed and local buoyancy to support and tension a vertical riser, extending from the seabed and terminating near the water surface but typically below the influence of high currents and wave action. Aircan buoyancy has been used at or near the top of the riser to cost effectively generates the majority of the tension required to support and control the deflection of the riser under service conditions.

The riser is connected to the floating production system via a flexible jumper(s) configured in a catenary configuration. This arrangement is highly compliant and allows the riser to accommodate large vessel motions and excursions whilst maintaining acceptable storm and fatigue performance.

The ability to free stand without tension applied by a surface vessel offers free standing risers a strong benefit over other riser types in that it allows pre-installation to be considered. This can be an important selection factor for this riser type over catenary systems in that this ability can greatly reduce the risk and cost of the installation phase. This is particularly important in deep and ultra deep locations and also remote locations where the cost of mobilising installation vessels is high.

Freestanding hybrid risers can be either single pipe SLOR (Single Line Offset Riser), pipe in pipe COR (Concentric Offset Riser) or a number of pipes configured in an internal or external bundle, Figure 1.

Optimisation of the free standing hybrid riser response during the design phase is achieved by adjusting the following parameters:

- Volume and location of distributed buoyancy
- Upper aircan upthrust
- Offset distance of riser base from vessel
- Flexible jumper length and weight
- Directly applied top tension (in tethered arrangements)
- Depth of upper aircan to avoid high currents and waves

The structural response of the riser is highly dependent on the selected base tension, which results from the combination of distributed buoyancy, upper aircan and in some instances a top tension applied via hydro-pneumatically tensioned tethers from the vessel. The base tension, which typically ranges between 70-300Te for SLOR and COR and 400-1000Te for bundled risers, is reacted at the seabed via a foundation, which are critical components with complex design and installation requirements.

Existing Free Standing Risers

Existing and proposed free standing risers have selected a range of different foundation design approaches as summarised in Table 1 and discussed in the following sections.

Placid / Enserch Bundled Hybrid Riser

This non-offset, multi-pipe bundled hybrid riser was originally installed on Placid's Green Canyon development in the Gulf of Mexico in 469m water depth. The riser was later retrieved, refurbished and re-used on Enserch's Garden Banks development in 670m water depth. In the summer of 1999, however, this riser was decommissioned and recovered from Garden Banks due to reservoir issues. The repeated recovery and installation operations were feasible only because the riser was designed and installed like a large drilling riser, by flanging together individual joints through the vessel's drilling derrick and moonpool. In this design, riser tension is provided by a combination of buoyancy and vessel mounted tensioning units.

The Placid riser was connected via a titanium taper joint and wellhead style collet connector to a template structure that reacted the riser base loads into the seabed via 4 conductor piles each 42in diameter and 93m long with a penetration of 76m. The piles were installed by McDermot using a Menck MHU 500T-UWGPP hydraulic hammer and underwater power pack.

The relatively small diameter peripheral lines were each individually connected vertically to pre-installed piping spools located on the template. Direct connection, in this manner, was made feasible by the use of a titanium taper joint, careful control of tolerances and use of small diameter lines, which are relatively flexible.

Total Girassol - Bundled Hybrid Risers

The Girassol development, operated by Total, is located approximately 200 kilometres northwest of Luanda, Angola, in a water depth of 1350 meters. First oil was announced in December 2001. It comprises of 39 subsea wells tied back to a spread moored FPSO. The FPSO has 200,000 barrels of oil per day processing capacity and a two million barrel storage capacity.

The Girassol riser system is composed of three freestanding offset bundled risers. Each riser is positioned at an offset of approximately 200m from the side of the FPSO with each bundle consisting of the following lines in an internal bundle arrangement:

- 22 inch structural core pipe
- 4 off 8 inch production risers
- 2 off 8 inch water or gas injection risers
- 4 off 3 inch gas lift lines
- 2 off 3 inch service lines

The lines are arranged in the bundle within a number of syntactic foam modules (internal bundle) that provide both upthrust and thermal insulation. Additional buoyancy is generated by a single steel buoyancy tank located at the top of the riser. A steel upper taper joint provides a transition from the 22 inch structural core pipe to the buoyancy tank.

At the base the risers are anchored to the seabed by a suction pile foundation and an anchor latch incorporating an elastomeric joint. Figure 3. The suction pile is 8m diameter by 23m long, weighing 190Te and resisting a service tension of 450Te. During installation it was reported that the pile penetrated to a deeper depth than predicted. This was possibly due to a lower skin friction resulting partly from an internal paint coating and the presence of ring stiffeners that can cause remoulding and water entrapment. The design was subsequently modified to incorporate a post installed gravity component to offset the reduced skin friction and increase the maximum holding capacity.

Thermal expansion of the lines in the bundle is provided by carefully designed base jumpers, which also accommodate the rotation of the tower. Where necessary the jumpers are designed to be free-draining to meet flow assurance requirements.

West Africa - Kizomba A & B - SLORs & CORs

The Kizomba field is located in Block 15 approximately 80 miles offshore Angola in 1200m water depth near the entrance to the Congo River. The development partners are Esso (Operator), BP, Agip and Statoil with Sonangol (Angolan National Oil Company) as the concessionaire.

The first phase of the development, Kizomba A, consists of a TLP and a 2.2 million barrel spread moored FPSO and first oil was achieved in mid 2004. All production is through surface wells on the TLP. Partly processed fluids are then transferred to the FPSO for further treatment and storage through flexible transfer lines. Injection water and gas is delivered via surface wells on the TLP and subsea wells tied back directly to the FPSO with SLORs supplied by SaiBos.

The second phase, Kizomba B, currently in construction and installation, is essentially a duplicate of the Kizomba A configuration. However, a significant difference is the addition of remote subsea production wells tied back to the FPSO with CORs. The COR being a pipe-in-pipe version of the SLOR with the annulus being used for riser base gas lift.

There are a total of five water injection SLORs (10 and 12 inch), two gas injection SLORs (10 inch) and three production CORs (8 x 11 inch & 12 x 15 inch) with up to 5000 psi design pressures. All SLOR and COR foundations are offset from the FPSO with hang-offs at various positions around the vessel hull including the bow.

Each SLOR and COR comprises of a vertical welded steel pipe section tensioned by a fabricated steel buoyancy tank located at an elevation below the high surface current. The buoyancy tank is connected to the riser pipe section with a short length of chain and the flexible jumpers, connecting the riser to the FPSO, connect under the buoyancy tank.

At the base of the riser, a fabricated bottom assembly includes an off-take to facilitate connection to the flowline via a rigid steel jumper spool. Below the bottom assembly an anchor latch system incorporating an elastomeric joint is provided to connect the riser to a suction pile foundation. The pile is similar to that used on Girassol 8m diameter but with a shorter penetration. The piles typically weigh 100Te, which is similar to the operational base tension. The suction pile design combines suction and gravity resistance to achieve stability during all phases of operation including installation phases when the riser jumper is not attached.

BP Block 18

Block 18 is located in 1300m water depth offshore Angola and will utilise a single bundled hybrid riser. The arrangement, being developed by Stolt, is similar to Girassol but with an external bundle solution in which production lines are wet insulated. The base of the riser will utilise a suction pile design similar to Girassol with a tendon latch connection.

Petrobras P52

The P52 development is located in 1800m water depth offshore Brasil. It is planning to utilise an 18in diameter oil export SLOR. The detail design of the SLOR, developed by 2H Offshore, incorporates a 36in drilled and grouted pile 120m long with steel taper stress joint at the interface with the riser. A typical riser base arrangement of this type of riser system is shown in Figure 4.

Free Standing Riser Foundation Options

As free standing risers are typically used in deepwater, foundations must be suited to soft seabed conditions typified by shallow sediments and normally consolidated or under consolidated clays. A number of foundation options are possible:

- Gravity base
- Suction pile
- Drilled and grouted pile
- Jetted pile
- Driven pile

The considerations given to the selection of the optimum solution for recent projects are:

- Soil condition
- Predictability of load resistance
- Damage to soil effecting the predicted shear strength
- Magnitude of riser base tension
- Extent of lateral loads and bending moments
- Availability of installation vessels and specialist equipment
- Verticality tolerance required
- Ease of positioning and relocation
- Soil re-consolidation time
- Installation reliability in achieving specified capacity
- Local fabrication facilities
- Cost and schedule

Each of the candidate foundation designs is described below, along with an appraisal of its advantages and disadvantages:

Gravity Base

A steel or concrete structure weighted with ballast materials. It is the most primitive of all options, and uses the most understood and consistent of all design properties: gravity. It is however best suited to firm seabeds that limit sinkage and settling.

Advantages:

- Resistance to load well understood
- Design largely unaffected by soil condition
- Installable by large number of vessel types, as ballasts can be “topped” up to keep within handling limits
- Can be re-positioned easily without disturbing the soil
- No soil consolidation time
- Low-tech fabrication which can most readily be done locally
- Typically low cost and not schedule critical

Disadvantages:

- Riser tension capacity limited by size
- May “walk” due to dynamic and lateral loads
- Verticality poorly controlled due to seabed unevenness and settlement
- Not suited to very soft soils

Suction Pile

A large diameter, 5-8m in recent designs, open bottom cylinder which first relies on self weight to “sink” in soft soil, followed by suction to install to full depth below the mud line. Resistance to riser tension is provided by a combination of skin friction and self weight. Tension capacity is first achieved by increasing diameter and, when reaching diameter limit of rolled plate facility, by increasing length.

Advantages:

- Can be designed to withstand high tension by increasing length
- High resistance to lateral loads

- Suction equipment easy to mobilise
- Good control of verticality initially (but less so during suction)
- Minimum environmental disturbance
- Can be removed by reversing installation procedure

Disadvantages:

- Requires soft soils and good prediction of soil properties
- Uncertainty in soil properties and skin friction calculations often results in reliance on the gravity element
- Large cylindrical structure dictates substantial transportation vessels and handling requirements particularly due to added mass of entrained water
- Easy to position initially, but because of soil disturbance on full or partial penetration, relocation in case of problems or non-conforming installation has to be a significant distance away.
- Large suction pile diameters can pose significant subsequent field layout problems
- Require substantial soil consolidation time (months) to effect full skin friction
- Rolled plate fabrication limits facilities available locally
- Cannot rely on suction for load carrying (only installation) due to valve reliability
- Penetration rate/depth effected by structural details such as stiffeners

Drilled and Grouted Pile

This is a conventional well construction method, used on the majority of the offshore subsea wells. The pile is assembled using mechanical connectors and is typically of 30 - 40 in. diameter depending on bending capacity and formed of joints of 40 ft in length. The pile is positioned in a pre-drilled hole, and the annulus is then filled with grout which will set over time (hours) to mobilise soil interaction for load resistance. Increased resistance to riser tension is achieved by increasing the conductor pile length and wall thickness. When used with a taper stress joint at the lower end of riser, good quality welds are required in the pile close to the seabed to provide fatigue resistance to dynamic lateral loads and bending moments.

Advantages:

- Soil conditions do not normally hinder the drilling process and hence low risk of not achieving desired depth
- Tension capacity easily and conservatively achieved by adding more conductor joints or wall thickness to increase axial load resistance without increasing transportation and handling requirements
- Conventional drilling derrick and its rotary equipment are used to install such a conductor pile
- Good control of verticality
- Easy positioning, and relocation in case of problems can be just a short distance away
- Short drilling and grout setting time

Disadvantages:

- Subject to drilling vessel priority and availability (but drilling vessels are usually already in the field constructing subsea wells)
- Not normally fabricated locally in case of good quality welding requirements
- Hole stability in deep water and soft sediments resulting in coning and collapse
- Damage and wetting of the hole reducing soil capacity

Driven Pile

Cylindrical pile, typically 20-90inches diameter, driven into the seabed by an underwater hydraulic hammer. To minimise driving losses the pile is normally fabricated without intermediate connectors although connectors are possible provided they are structurally efficient and can accommodate the piling loads. Fatigue performance of welds needs consideration depending on anticipated depths and blow counts. This method of piling is well suited to applications in conjunction with a template foundations with the latter anchored to the seabed by a number of driven piles that are swaged or structurally connected to the template.

Advantages:

- Minimum soil degradation through installation process giving highest skin friction potential and reliability
- Ability to drive open end and take advantage of the plug weight and internal skin friction
- Basic transportation and handling requirements
- Good control of verticality
- Minimal soil consolidation time
- Low-tech fabrication readily done locally
- Minimum environmental disturbance

Disadvantages:

- Hard soils, sand layers or rocks may hinder piling operations. An open ended pile is preferable in these situations
- Mobilisation of specialist underwater hammer
- Ultra deep water applications will require hammer and umbilical upgrades

Jetted Pile

Similar to the conductor pile, except that there is no drilling of the hole. The erosion and removal of soil inside the pile and around the tip to form the hole is by water jets as the pile is lowered. The process usually requires controlled vertical reciprocation. Jetting is now used by many drilling vessels, and recognized as a quick and efficient way to install well conductors. Conductor joints are made up using mechanical connectors to achieve the desired pile length and thus its axial capacity. The diameter dictates the bending capacity.

Advantages:

- Becoming standard practice for deepwater wells – quick and cost effective

- Tension capacity easily and conservatively achieved by increasing pile length, with little additional transportation and handling requirements
- Basic transportation and handling requirements
- Good control of verticality
- Long length allows penetration into stiffer soils

Disadvantages:

- Experience base largely limited to deep GOM
- Hard soils or rocks may hinder jetting operation
- Not normally fabricated locally in case of good quality welding requirements to resist dynamic lateral loads and bending moment
- Require soil consolidation time for skin friction to be fully effective
- Risk of a stuck conductor if jetting or reciprocation not well optimised or controlled
- Potential for excessive damage or wetting of the soil by excessive jetting reducing pile capacity.

Foundation Design Issues

Riser foundations must resist long term vertical, horizontal and bending loads. These loads are generated directly by the riser and also indirectly by the rigid jumpers that connect between the riser base and the seabed flowlines. Whilst the rigid jumpers are installed in an initially stress free condition, excluding stresses required to accommodate installation tolerances, the movement of the riser coupled with flowline expansion results in the generation of significant loads and stresses in the jumpers.

Typically the mean base angle of an offset free standing riser will be vertical during installation but it will be displaced to a mean angle of 3-7 degrees towards the vessel when the flexible jumpers are installed, Figure 5. A further deflection of +/- 5 degrees in any azimuth angle may occur due to environmental loads and vessel station keeping. The accommodation of this angle variation at the interface with the foundation is the crux of the foundation design process.

Two different riser base foundation design approaches are possible:

1) Pinned riser base allowing free riser rotation

This has been the most common approach and has the advantage that it does not generate large base moments. The arrangement uses allow rotational stiffness elastomeric flex element, similar to that used on TLP foundations, which is well proven and relatively easy to install. To date the flex element has served a purely structural purpose and not formed part of the fluid flow path. Its main disadvantage is its impact on the design of base jumpers. In this arrangement the base jumpers must be able to accommodate the variation in angle between the riser and flowline termination and this can lead to large flow spools with multiple flow bends to achieve the necessary degree of spool flexibility, Figure 6.

2) Fixed riser base resisting riser rotation

The second arrangement is to fix the base of the riser rigidly to the foundation thereby preventing any rotation of the riser relative to the foundation. This approach is similar to that used on top tensioned spar and TLP production risers. A disadvantage of this arrangement is that it generates high bending moments at the interface between the base of the riser and the foundation. These loads must be managed using high integrity components including taper joints. In some applications, particularly for high currents and large offsets, it is necessary to use a titanium taper joint. The main advantage of this arrangement is that it eliminates a high proportion of the relative movement between the riser and flowline termination simplifying the critical jumper design, Figure 7.

Previous, existing and planned freestanding risers have employed both the above design approaches, however the pinned arrangement has been more widely adopted. This has been for many reasons including contractual and technical constraints but primarily due to the preference for suction piles, which have a good track record in FPSO and FPU mooring applications and are relatively easy to fabricate and install. The preference to use suction piles has driven the riser base design towards a pinned solution since they are not good at accommodating high bending loads. However, this approach possibly underestimates the resulting additional complexity imposed on the jumper design.

Rigid Jumper Spool Design

In addition to loading from the flowline (expansion) and internal fluid (thermal and pressure) the rigid jumper spools must be designed to withstand loads imposed by the motion of the riser. For a rigid jumper spools that connects to the riser at an elevation of 5m from the seabed typical extreme deflections at the hub can be up to 0.2m for a fixed base foundation (due to conductor deflection) and up to 0.5m for a pinned base arrangement. In addition a pinned base arrangement transposes the riser rotation directly to the jumper spool connection hub, whilst the fixed base arrangement mostly removes this rotation component.

The higher motions of the pinned base arrangement introduces greater deflections and stresses (extreme and fatigue) in the rigid jumper. One of the most effective ways to reduce extreme stresses to an acceptable level is to increase the rigid jumper length, Figure 8. Adding additional bends or loops to the rigid jumper can also be used to increase jumper flexibility and reduce extreme stresses. It is noted that the size of the jumper and required number of bends increases significantly with the diameter. This is due to the need to maintain 3D bends for pigging and the increase in stiffness of the pipe section increasing to the 4th power of the diameter. However, whilst a longer jumper may reduce extreme stresses it can also introduce problems in other areas of the jumper design.

Self weight – Handling and Installation -The increase in self weight, length and size can present additional problems for handling and installation. Custom built installation aids such as spreader beams may be required and the size of transportation barges increased.

Metrology and Nominal Stress - A hybrid riser installed with a pinned base rotation will have a non-zero bottom angle even in its nominal static configuration due to the self-weight of the flexible jumper placed on one side of the riser. The bottom angle magnitude and direction is affected by current load on the riser and vessel offset and may also change due to the installation sequence, for example if flexible jumper is post installed.

Metrology for the rigid jumper spool installation can measure this angle at a particular point in time, although at that time the riser may not be at its nominal position and it may move further between metrology and jumper installation.

One solution to this problem is to discount the inclination of the hybrid riser when conducting metrology and fabricate the jumper as if the riser were vertical. However, this places an additional stress burden on the rigid jumper. Problems may also occur during installation if the riser side jumper hub is rotated such that it falls outside the limits of the rigid jumper connector tolerances.

Insulation - A longer jumper will have a greater total heat loss or require additional insulation.

Self Draining Requirement, Hydrates, Methanol Dumping - A requirement for the rigid jumper to be self draining to prevent hydrates forming can be made more difficult or impossible to achieve with the addition of bends and loops or an increase in jumper length. In cases where methanol dumping is required, injection volumes are increased by longer jumper lengths.

Rigid Jumper Fatigue Damage - Rigid jumpers can be fatigue sensitive with damage contribution from:

- Hybrid riser motions due to first and second order vessel motion and direct wave loading on the riser. Even in deep water these motions are transferred to the riser base
- Hybrid riser motions due to vortex induced vibration
- Direct vortex induced vibration of the rigid jumper
- Thermal fatigue e.g. due to facility shut down. This damage may be significant even for a small number of cycles as the stress amplitudes can be large
- Slugging fatigue

The severity of the fatigue damage incurred from direct Vortex Induced Vibration (VIV) is strongly linked to the length and flexibility of the jumper. Increases in rigid jumper length, designed to improve the extreme stress response of the rigid jumper, may have an adverse impact on fatigue response. For VIV an increase in jumper length has the effect of lowering the jumper natural frequencies, which in turn decreases the incident current velocity required for the onset of VIV.

The VIV contribution is of particular importance because of the lack of uncertainty that remains in VIV prediction and long term data for bottom currents and the fact that, when triggered, the contribution to overall fatigue damage from VIV can be very high requiring strakes to mitigate.

Fatigue contributions from other sources (first order fatigue for example) may decrease if the jumper is lengthened but the relationship is far weaker. Instead, for many of these damage contributors the magnitude of damage is strongly linked to the magnitude of the movement of the riser. For these sources a fully fixed riser foundation offers significant benefits by transferring smaller motions into the rigid jumper.

Recommended Riser Base Design Approach

Following close involvement in a number of freestanding riser detail design projects a preferred riser base / foundation approach is identified by the authors. This approach is well suited to a wide range of free standing risers in both deep and ultra deep water and has strong technical and commercial features.

Whilst suction piles have been most widely used to date the recommendation for a future development is the consideration of small diameter piles in the range 30-40in, depending on riser loads. The piles can be installed by a wide range of techniques including driving, jetting or drilling and grouting and hence installation can be conducted from a wide range of installation vessels including Mobile Offshore Drilling Units (MODU) and conventional pipeline/offshore construction vessels.

Importantly such piles are structurally suited to accommodating high bending loads as demonstrated by similar arrangements used for connecting top tensioned Spar and TLP production risers to subsea wellheads. The arrangement is structurally efficient and allows pipe grades up to X65 yield, high quality forgings up to N80 yield and high quality double sided welding to ensure resistance to fatigue loading.

Deep penetration, to depths up to 120m allow the pile to interface with soils of higher shear strength than typically found near the surface where suction piles must operate. This is increasingly important in ultra deep water where very soft seabed conditions are typical.

The self-weight of the pile can be adjusted by selection of appropriate wall thickness giving a variable gravity component to the design. Depending on final installation method (driven, jetted, drilled) varying reconsolidation assumptions may be made and varying reliance on skin friction contribution taken. The additional of ballast weight inside the pile using scrap chain is an economical method of increasing the gravity component such that skin friction is only used to resist storm load contributions.

An important aspect of this design proposal is the use of standard wellhead technology, hardware, and procedures. General arrangement of a typical SLOR foundation is shown in Figure 4 showing the pile interface with the riser. The riser is connected to the pile via a wellhead style collet connector that connects onto a wellhead style mandrel (18-3/4in 10m) at the top of the pile. The interface includes orientation helix to ensure correct final alignment of the riser offtake.

The structural and fatigue capacity of such an arrangement is well defined through control of material and weld quality as on a standard subsea wellhead system.

Whilst jetting is a well established approach for installing conductors of this size the main issues are the potential damage to the formation if the jetting is not well controlled and the uncertainty relating to rate of reconsolidation and maximum values that should be used in design calculations. Whilst this is not an issue for base tension loads less than 400Te, since the gravity component is a high percentage of the load, for base tensions higher than 400Te consideration of installation by subsea driving of the pile may be required. Driving prevents degradation of the soil and allows a much more reliable skin friction component to be assumed and is thus the recommended approach for high capacity foundations.

Cost Analysis

A cost analysis of the different foundation options concludes that the foundation hardware itself is not the main cost driver. Whilst it is typical for small diameter piles eg. 30in to be have a slightly lower steel and fabrication cost than the suction pile it is the installation cost and the cost of interfacing hardware such as flex joints and taper joints, which drives the total cost.

Where installation can be conducted using a MODU, the lower day rate compared to typical deepwater construction vessels and also the faster speed of installation, gives the potential for significant cost savings for drilled and jetted piles. This is particularly true for deep and ultra deep water applications.

Conclusion and Summary

The foundation system is a critical aspect of hybrid riser design since it has a significant performance and cost impact on the overall system. Recent projects have used suction piles with a pinned riser interface. However, the fixed base connection using a small diameter pile, as used in well construction methods and top tensioned spar and TLP risers, may be a more attractive alternative. The fixed base and small diameter pile is recommended over the suction pile for the following reasons:

- Most cost effective with respect to hardware and installed cost
- Suited to ultra deep installation on drill pipe using MODU
- Reduces loading on rigid jumper spools and jumper connectors
- Simplifies riser/rigid jumper/foundation interfaces
- Simplifies design of rigid jumper and foundation
- Pile can be installed by a number of methods
- Flexibility of using either drilling or construction vessels
- Well established design methodology
- Suited to very soft sea beds typically found in deep and ultra deep locations

However despite these advantages the main obstacle in adopting the fixed base approach is the selection of the lump sum contract strategy adopted by Operators. These lump sum contracts for flowlines, risers and umbilicals push the solutions towards the existing capabilities of deepwater construction vessels and the possibility of taking advantage of proven technology from the drilling and well construction sector is precluded.

However, as depths increase so does the technical complexity of the foundation systems and their installation. As such Operators may find it technically and commercially beneficial to consider alternative contract arrangements to allow alternative solutions to be considered. This may be particularly attractive for remote deepwater locations where MODUs may be significantly lower cost due to mobilisation issues.

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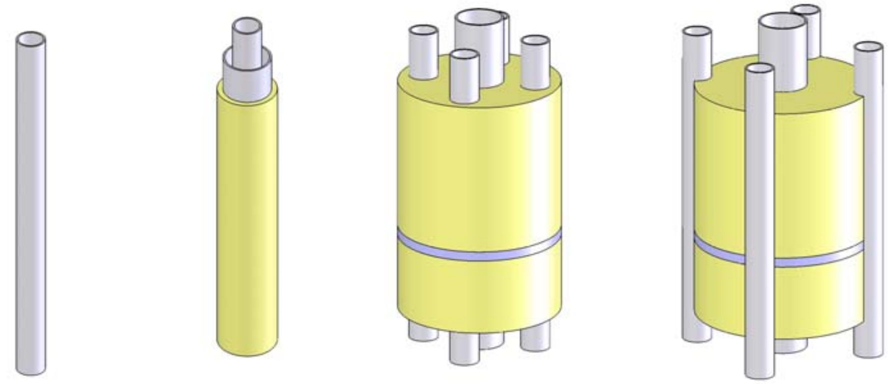
Field Development	**Riser Type**	**Foundation Type**	**Riser/Foundation Transition**	**Riser Transition Hardware**
Placid Green Canyon	Internal Bundle	Driven Piles	Fixed	Ti Taper Joint
Enserch Garden Bank	Internal Bundle	Driven Piles	Fixed	Ti Taper Joint
Total Girassol	Internal Bundle	Suction	Rotation	Anchor Latch
Exxon Kizomba A	SLOR	Suction	Rotation	Anchor Latch
Exxon Kizomba B	SLOR/COR	Suction	Rotation	Anchor Latch
BP Block 18 (planned)	External Bundle	Suction	Rotation	Anchor Latch
Petrobras P52 (planned)	SLOR	Drilled Pile	Fixed	Steel Taper Joint

Table 1



SLOR **COR** **InternalBundle** **External Bundle**

Figure 1 – Free Standing Riser Pipe Arrangements

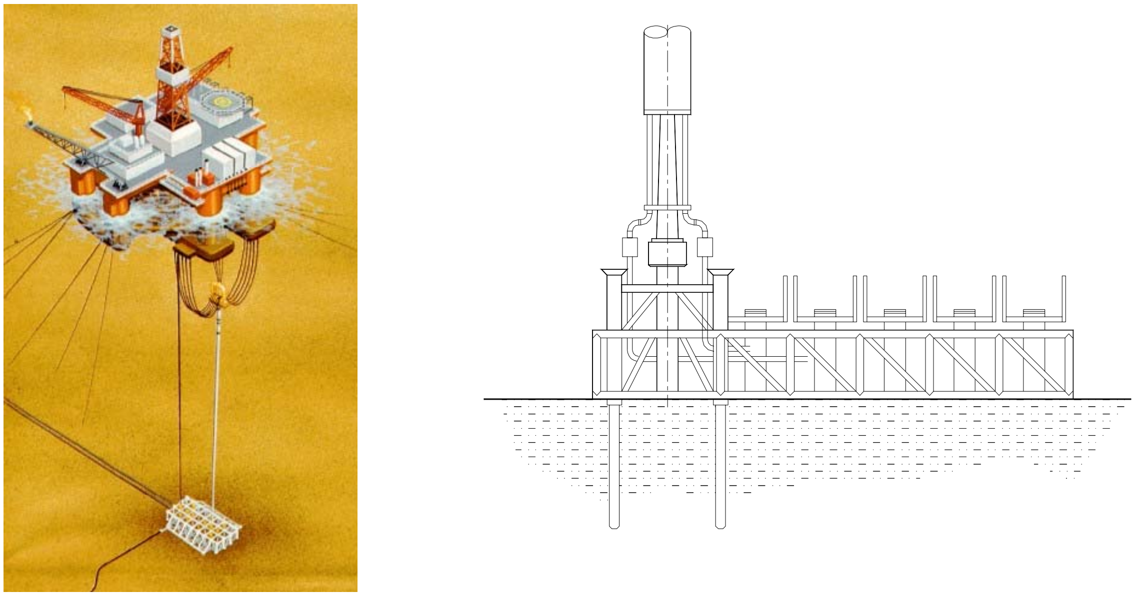


Figure 2 – Enserch Garden Banks 388 Non-offset Hybrid Riser

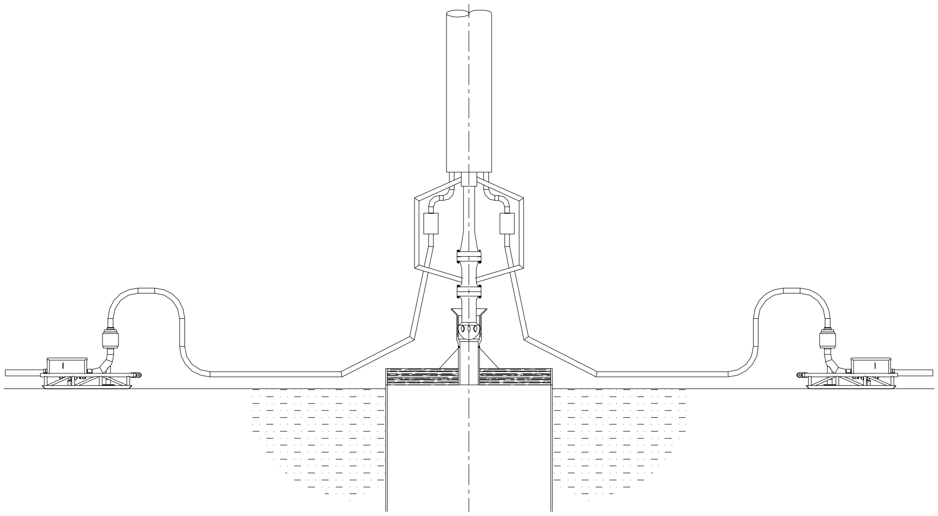


Figure 3 – Girassol Riser Base Schematic

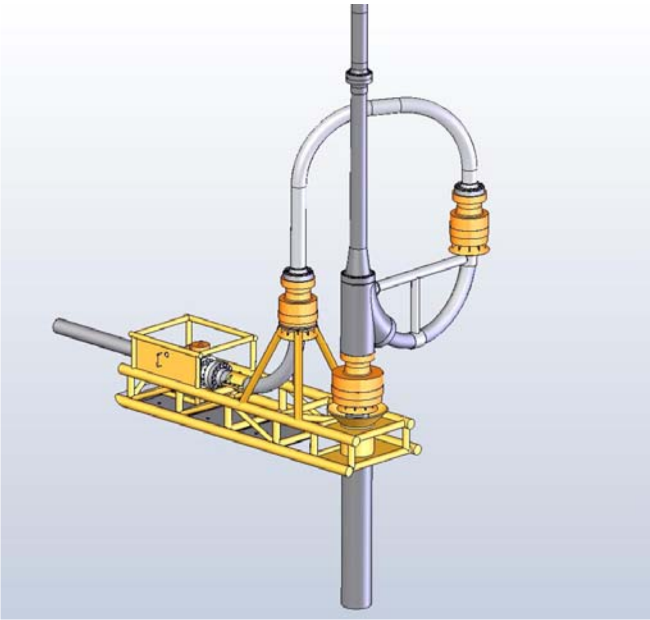


Figure 4 – SLOR Bottom Assembly Using a 36in Pile

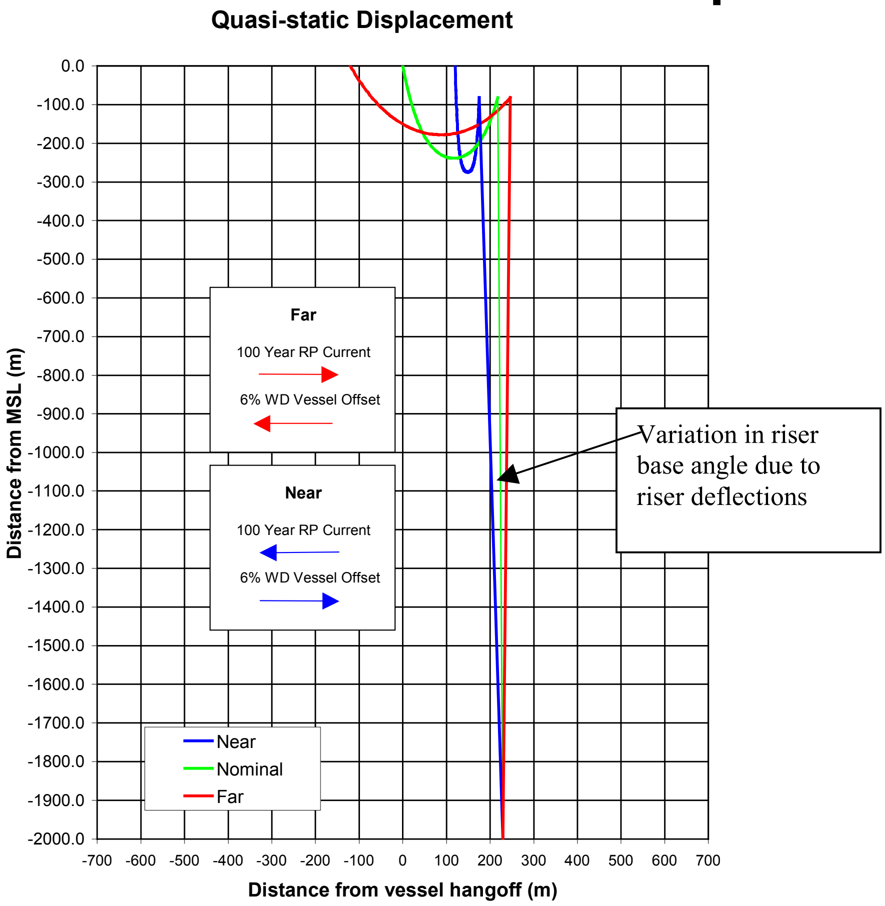


Figure 5 – SLOR Configuration showing Variation in Base Angle

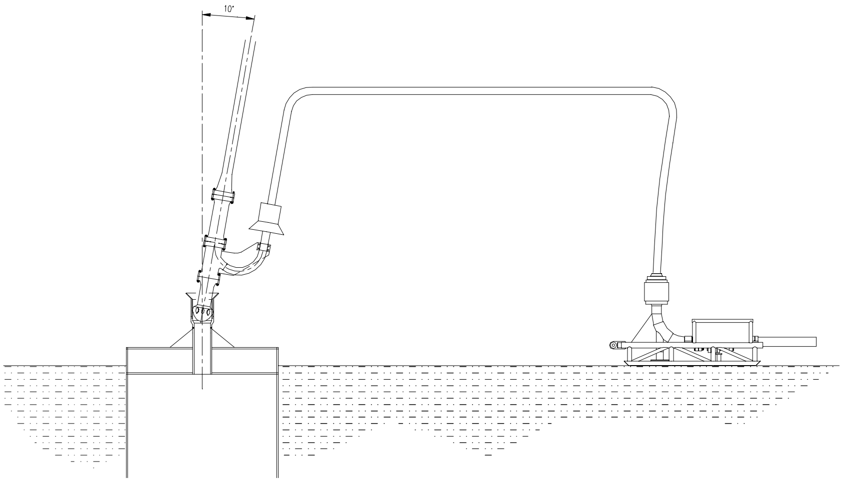


Figure 6 – Suction Pile With Pinned Riser Connection

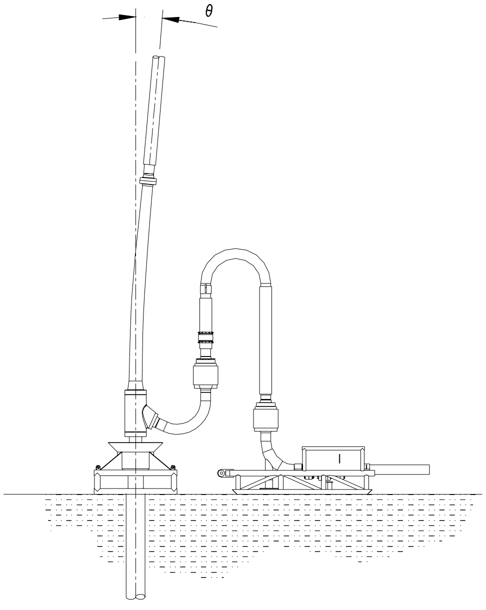


Figure 7 – Jetted Pile with Fixed Riser Connection

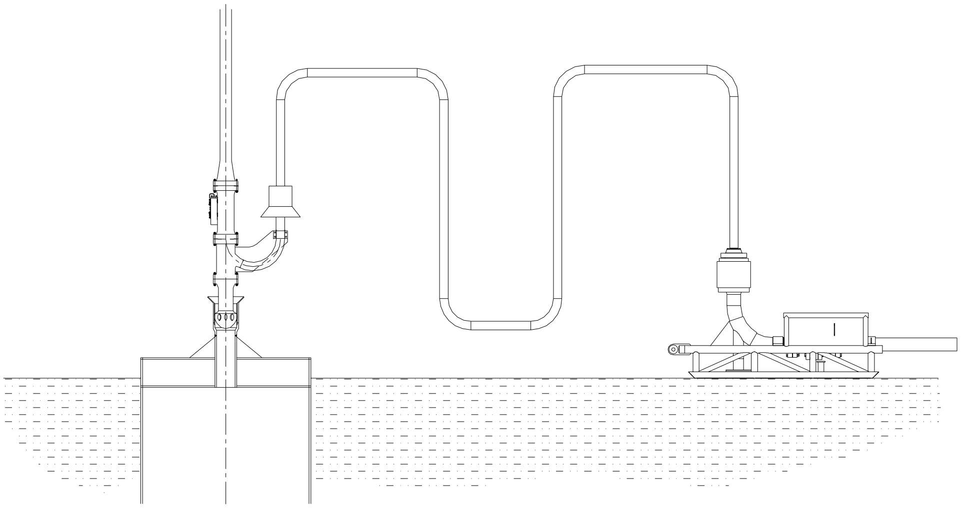


Figure 8 – Increasing Jumper Flexibility by Additional Flow Loops