Riser Selection for Deep Water Floating Production Systems

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INTRODUCTION

Floating production systems are increasingly being implemented for exploitation of offshore oil and gas reserves, and are being considered for a wider range of applications, on larger developments and in deeper waters. The flexible risers generally used with floating production systems are costly, and have technical limitations which can restrict subsea layout, export options and consequently vessel selection and utilisation. More versatile riser systems can facilitate more widespread use of floating production systems, offering improved production and export capacity for larger developments, and reducing cost in deeper water.

Two riser concepts which offer alternatives to flexible risers are the steel catenary and hybrid riser systems, both recently implemented in the Gulf of Mexico. In their current configurations, these risers offer a number of benefits which are described. They also offer a wider range of benefits which are yet to be realised, including sour service and high pressure/high temperature applications and further developments of the current arrangements are discussed which improve their scope of application. An assessment of the impact these riser systems may have on vessel utilisation and seabed layout is made which demonstrates the importance of integrated design and selection of vessel, risers and seabed layout in order to reduce cost. Furthermore, low cost measures for future-proofing using steel catenary risers are described which offer improved opportunities for accommodating reservoir uncertainties and reducing development risk.

CONVENTIONAL RISER OPTIONS AND LIMITATIONS

The type of risers used with a floating production system has traditionally depended on the platform and fall into two main categories: vertical tensioned risers, used on tethered facilities such as tension leg platforms (TLP's) and spars, and flexible risers, used on catenary moored facilities including semisubmersible and ship-shaped vessels and on TLP's for import and export lines. Various CALM and SALM systems also exist which are outside the focus of the current work.

Vertical Tensioned Risers

On tension leg platforms, access to wells directly below the platform is achieved by vertical top-tensioned risers. The risers are connected to the subsea wellhead by means of a hydraulic connector, above which a tapered stress joint is used to control riser curvature and stresses. At the surface, the riser is supported from the platform by hydro-pneumatic tensioners, which allow the riser to move axially, or stroke, relative to the platform. As relative motions between the platform and riser attachment to the seabed are small, the corresponding tensioner stroke range is also small, typically less than 2m. Similar arrangements can be used for export lines, though greater riser to riser spacing and costly platform deck space may be required, to prevent interference with adjacent risers.

Flexible Risers

Risers for catenary moored production facilities and satellite tie-backs to tethered platforms are generally designed using flexible pipe. For tethered platforms, dynamic movements are small and simple catenary configurations can be used. As platform motions become more severe, the riser arrangements must become more compliant. This is achieved by increasing suspended riser length by attachment of buoyancy, to produce steep and lazy wave arrangements.

Flexible pipe provides solutions for risers where large vessel movements must be accommodated and riser curvatures are small due to shallow water. However, flexible pipe can be unduly restrictive, particularly for deeper water.

Limitations include: high cost, which may increase disproportionately with depth due to the additional tension needed to support self weight and greater external pressure resistance required; limited diameter/internal pressure rating combinations, typically 11inch at 5000psi to 16inch at 2000psi, which can limit import and export options; and limited availability.

Catenary moored floating production systems are used across the full spectrum of field developments, from small, short term, low capital expenditure (CAPEX) developments, to large, high CAPEX developments, eg Foinaven, West of Shetland, where as many as 25 lines are being considered, in sizes up to 12 inches, to a single tanker. As flexible risers are used on almost all these systems, there is large potential for implementation of more versatile and cost effective riser arrangements which can improve platform utilisation.

RECENT RISER DEVELOPMENTS AND BENEFITS

Development of flexible riser systems has naturally progressed in recent years due to the need for improvements in pressure ratings, diameters, depth of application and materials for sour service, but the costs remain high. Development of rigid riser systems has been much slower due to the lack of acceptable configurations and a specialist rigid riser vendor. While subsea hardware vendors produce rigid riser systems to support the equipment they supply (drilling and completion risers), the risers are not generally viewed as core business by such vendors. Nonetheless, some major advances in rigid riser systems have been achieved which are being eagerly pursued due to the cost benefits and development opportunities that they offer.

Steel Catenary Risers

The Auger platform is the first floating production facility to implement steel catenary risers, 2, 12inch lines being used for oil and gas export. In this arrangement, the riser forms an extension of the flowline which is hung from the platform in a simple catenary. Relative rotational movement between riser and platform is accommodated using a flex-joint. Hard piping mounted on the outside of the hull, is used to transport fluids from the process facilities above sea-level to the riser connection to the platform on the pontoon. In this application, the benefits of the catenary riser compared to the vertical tensioned arrangement include a fixed valve stack and elimination of the riser base. Perhaps more important, is the reduction in wellbay deck space required. Whilst the similarity of production and injection risers enables close spacing of all risers accessing the wells beneath the platform, differences in response between the production and export risers requires increased spacing. Gaps in the riser deployment pattern, referred to as spare slots, may thus be necessary. Similarly, export risers of different size and export risers containing different fluids may also require increased spacing which adds to the deck space requirement and number of spare slots needed.

The steel catenary risers implemented on Auger and proposed for the Mars and Ram-Powell TLP's, can be seen as a direct alternative to flexible lines. They may be used at larger diameters, pressures and temperatures and may be procured more easily. Steel lines are cheaper than flexibles and may be used in greater water depths without a disproportionate increase in cost. The ability to use larger diameters can reduce congestion at the vessel, which may simplify turret design on ship-shaped vessels and porch construction on semi-submersibles. The larger diameters may also enable greater production flow rates to be achieved, thus offering better use of the production vessel. The opportunities for developing high pressure, high temperature fields are also improved by the development of steel catenary risers though their use in shallower water depths is limited.

Steel catenary risers are well suited for use with tethered platforms such as TLP's. Platform motions due to wave action are mostly lateral, with a small degree of vertical movement or set-down from the inverted pendulum action of the tethers. Consequently, the nominal catenary shape does not change significantly. Large water depths, such as found on Auger, are also beneficial in that dynamic excitation from wave action at the surface is damped as it travels to the seabed. The concept is being taken a stage further by Petrobras, who intend implementing a 10inch steel catenary riser for gas export from the Petrobras XVIII semisubmersible floating production facility in the Marlim field. In this configuration, the riser is exposed to the heave and pitch induced heave motions of the platform. While the magnitude of the extreme dynamic motions are not particularly severe, typically less than 5m, due to the relatively mild environmental conditions of Marlim, platform drift motions significantly larger than those experienced with a TLP, up to 15% of water depth, must be accommodated. This is an important development, which paves the way for more widespread use of steel catenary risers with catenary moored production vessels.

Variations on the steel catenary riser arrangement of Auger and Marlim are currently proposed [2, 3] which use buoyancy and weights to shape the riser, giving steep and lazy wave arrangements similar to those used for flexible lines. These concepts improve the ability of the riser to resist dynamic loads and vessel motions and enable greater offsets to be tolerated. Feasibility of these concepts has been demonstrated in diameters up to 30inches, for harsh environments, where platform heave motions up to 30m and vessel offsets up to 25% water depth must be accommodated. Though well within these bounds, such an arrangement is currently being considered for the Agip Aquila development in the Adriatic Sea.

Hybrid Risers

Another riser concept which has been recently rejuvenated is the hybrid riser, previously installed on Placid's Green Canyon development and recently refurbished and extended for use on Ensearch's Garden Banks development [4]. The main section of the hybrid riser consists of a central structural tubular, around which syntactic foam buoyancy modules are attached. Peripheral production and export lines run through the buoyancy modules and are free to move axially in order to accommodate thermal and pressure induced extension. The central structural member is connected to the riser base by way of a hydraulic connector and stress joint. The peripheral lines are attached to hard piping on the base, which provides connection to the subsea flowlines, and terminates in goosenecks some 30 to 50m below the water surface. Flexible piping is attached between the goosenecks and porches on the pontoons of the semisubmersible production vessel, providing the flowpath to the vessel whilst accommodating relative movements between the rigid riser section and the platform.

Hybrid risers offer a number of benefits compared to flexible riser systems. Compact subsea arrangements can be realised which may reduce flowline costs and facilitate simultaneous production and workover or drilling from a single vessel. The hybrid riser offers the further benefit of enabling disconnection of the production system in the event of adverse weather conditions. Disconnection near the surface may be effected, enabling reductions in mooring system and riser costs to be achieved. In shallow water depths, prone to ice movements, the riser may be disconnected at the base and the rigid section raised into the moonpool in readiness for complete platform removal.

Some concerns exist regarding the hybrid riser which generally relate to use of a single riser bundle - all the eggs in one basket - and the consequences of failure of the central tubular member. By careful design, the potential for structural design problems can be greatly reduced. Furthermore, seals on base and surface connectors may be replaced individually and surface jumper hoses are accessible and replaceable. Whilst to the authors' knowledge no current field development programmes incorporate a hybrid riser, a number of operators are evaluating the concept for future developments.

The hybrid riser implemented by Ensearch is run offshore in a manner similar to that used for drilling riser installation. This process takes some time and limits the feasibility of the concept for harsher environments where weather windows for installation are shorter. However, bundle construction and installation by tow-out has been investigated [1] and shown to offer substantial savings in cost and installation time, offering improved scope for application of the concept in even greater depths and with smaller production flow rates. It has also been shown that the concept may be used with a ship-shaped vessel, though not with small diameter turrets in harsh environments.

Common Benefits

The scope for using steel catenary and hybrid riser in water depths less than 300m is limited and conventional flexible riser systems are likely to continue providing the most suitable solution for some time. Many benefits can be realised from the rigid riser options at greater depths. As direct alternatives the flexible riser systems, steel catenaries and hybrid risers offer distinct advantages in terms of cost and service. Both systems can give installed cost benefits of over 40%, which increase with increasing water depth. For high pressure, high temperature (HP/HT) developments or sour service conditions, possible concerns regarding the use of flexible lines can be alleviated with steel catenaries or a hybrid riser. The critical components in each system, namely the flex-joint for the steel catenary and flexible lines for the hybrid riser, are located near the surface where they are accessible and readily replaceable.

RISER/VESSEL INTERACTION

Floating production facility selection depends on many factors, notably, reservoir knowledge and size, existing infrastructure, vessel availability, environmental conditions, production fluids and workover needs. The combination of these parameters for any development is unique. Consequently, the most cost-effective development scenario varies from field to field. Conventional riser systems can limit vessel selection and facility utilisation, and add cost. This may lead to small fields and fields in deeper water appearing uneconomic and lead to unnecessary economic risks being taken on larger developments with high CAPEX. The recent riser developments described above can provide additional flexibility to vessel selection and improve the viability of marginal developments.

Use of large diameter steel catenary risers with a catenary moored production vessel increases the viability of these vessels for medium to large developments. Congestion in the turret of ship-shaped vessels and on the pontoons of semisubmersible vessels limits the production potential of these facilities. This may limit revenue, or require the use of multiple production vessels. Larger diameter import and export lines can be used to increase flow areas whilst reducing congestion, which may provide the opportunity for choosing between a single larger facility or multiple smaller facilities. This flexibility improves the scope for using existing vessels, which can enable fast track development and reduce cost. On larger developments, a catenary moored vessel may be selected in preference to a tethered platform such as TLP. While drilling and workover can be carried out at reduced cost from a TLP, most developments of this kind require a semisubmersible drilling vessel for pre-drilling and workover of satellite wells. Furthermore the cost of the new-build platform may be considerably greater than that of an available floating facility. The different solutions give trade-offs between CAPEX and OPEX which must be considered against reservoir sizes and knowledge.

The reduced cost of steel catenary risers and increased flexibility to use existing vessels as opposed to new-build can reduce economic risk. For large developments, where estimates of production rates are quite broad, implementation of a moored facility (as opposed to TLP) could be used to reduce CAPEX to a justifiable level based on lower bound production estimates. For smaller developments, reduced riser cost may enable reservoir uncertainties to be accommodated and initiation of developments based on smaller production rates, possible using extended well testing (EWT). Further exploratory drilling can be carried out to improve reservoir knowledge while revenue is being generated. This reduces economic risk and facilitates fast track development with placement of subsea systems in locations best suited to maximising production, based on the knowledge gained in the early phases of production testing. However, realisation of the maximum potential of such developments in this way requires appropriate measures to accommodate upper bound production estimates.

Future-proofing of riser systems can be obtained at relatively low cost by use of steel catenary risers. Provision for increased production capacity can be achieved by incorporating spare slots for additional import lines on the vessel and designing export lines to operate at higher pressure. For developments in new provinces, installation of an export pipeline may be difficult to justify based on initial estimates of reserves, and export will be achieved initially by off-loading to a shuttle tanker. However, by allowing for retrofit of an export riser, the potential for using pipeline export exists when production rates increase and field economics justify the installation of export infrastructure.

The hybrid riser concept, as implemented by Ensearch, enables use of the production facility for simultaneous drilling or workover. The requirement for additional vessels is at worst reduced and at best eliminated with varying degrees of cost reduction. The magnitude of the savings depends on the development, but could be important on developments where well problems are anticipated and significant periods of workover are considered likely.

RISER/FLOWLINE INTERACTION

Steel catenary risers offer means of improving subsea layout and reducing subsea system cost. Use of larger diameter risers enables greater flowline diameters to be used. This facilitates wider use of manifolding which can reduce the number of lines required and associated installation costs. The ability to integrate the riser and flowline can eliminate subsea connections, used for attachment of flexible risers to rigid flowlines, giving increased reliability and offering additional cost savings. A further potential benefit of integrating riser and flowline comes with the use of mechanical connectors, such as recently used for flowline installation on the Harding development [5, 6]. Use of couplings for offshore make-up of flowline and risers allows decisions regarding field layout to be taken at a later stage of development planning. Pipe can be ordered prior to making final decisions regarding placement of subsea systems, giving improved flexibility. Furthermore, additional pipe can be ordered and stored for later use. At relatively low cost, this provides future-proofing for accommodation of production which exceeds initial expectations.

RISER/MOORING SYSTEM INTERACTION

The forces exerted on vessels by riser systems often causes concern to the vessel designers. As water depths increase, so do riser loads. Support of increased riser weight can be achieve by the addition of riser buoyancy, but this can be costly, both in terms of the buoyancy and additional installation time. However, the increased forces, if considered in detail, may enable cost benefits to be realised.

The risers and mooring systems for a floating production system are generally designed by independent organisations. Though static riser forces are accounted for in mooring system design, dynamic effects are not usually evaluated in detail. Such effects may enable specification of less severe platform offsets or reduced mooring system design and inspection requirements. On TLP's in deep water, the tension needed to support the risers can approach the force necessary for tethering the platform. This has led to the proposal of the heave restrained platform [9] where the tethers and tether foundations, which are costly components of the platform, can be eliminated. Platform restraint is provided entirely by the risers and reacted through the subsea wellhead and conductor. Similar possibilities exist for designing integrated riser/mooring systems on catenary moored vessels.

FUTURE DEVELOPMENTS

Little of the technology involved in the riser system concepts described is new. There are a number of areas where developments are being made which will enhance the benefits offered and remove the limitations that may be perceived in these systems.

Dynamic response of riser systems is becoming well understood. A number of analysis programs are available for determining extreme load response and benchmarks exist for validating the results. There is little published data on comparisons between in-service riser response and analysis results, but positive experience with risers in-service is growing which possibly suggests that the analysis tools employed and criteria set for design are satisfactory. Considerable work has been carried out to improve predictions of riser response to vortex induced vibrations (VIV's) [7]. This work has been focused largely on top-tensioned risers, where good agreement between theoretical predictions and experimental observations has been made. The analysis program SHEAR7 resulting from this work is now commercially available. Further work is also being conducted to improve application of the software for catenary risers and assess the effectiveness of VIV suppression devices.

Interaction of riser and mooring system response requires analytical evaluation. While the static riser forces may be accounted for to some extent in determination of vessel/mooring response the dynamic resistance of the riser systems needs to be evaluated in more detail. This is a relatively complex analytical problem but can no doubt be solved with the analytical tools currently available to riser and mooring system designers.

Accommodation of large diameter lines in the turrets of ship-shaped floating production systems requires some design development. The larger diameter lines must eventually connect to the vessel piping, achieved by the use of swivels or drag chains. This may require the use of multiple lines in the case of the drag-chain system, or multiple flow paths if a swivel is used. Resolution of these difficulties may improve the feasibility of using catenary moored vessels for gas developments where large diameter risers may be required for export by pipeline.

Material data on strength, fatigue and fracture performance of steels conventionally used in riser systems is well established and design guidance exists. Such materials are suitable for HP/HT applications using steel catenary and hybrid risers at lower cost than flexible risers. The development of clad steel pipe, whereby an alloy liner is explosively bonded to steel sheet prior to rolling, further improves the potential of using conventional grades while offering the necessary properties for sour service. Higher strength steels and, in some circumstances, titanium alloys offer even broader scope of application of the hybrid and catenary riser concepts. Some work is needed to improve knowledge of fatigue and fracture performance of these materials which is being carried out in current joint industry research programmes.

A significant proportion of riser system costs may result from installation. Improved methods of installation, notably tow-out, for the hybrid riser, and use of threaded couplings for catenary risers, discussed above, offer a number of possible advantages. Tow-out has been used successfully on flowline bundles and TLP tethers, but some unfortunate problems have occurred [8]. These have generally been concerned with the tow-out equipment, rather than the process itself, and shows the need for careful design of installation and handing equipment.

For catenary risers, mechanical connectors offer potential benefits both for installation and in-service performance and this approach has already been adopted for flowlines [5, 6]. Welded connections, traditionally used with S-lay or J-lay installation of flowlines, are generally perceived to be the most suitable method of joining steel pipe and there appears to be some lack of awareness of the capabilities of mechanical connections. Installation can be carried out from smaller, less expensive vessels and risers and flowlines could even be run from the production vessel. Installation time can be reduced, and the elimination of offshore welding offers scope for use of higher grade materials. Furthermore, mechanical connections can have fatigue lives over 20 times those of welded connections. Couplings such as Hunting's Merlin used on TLP tethers, and the premium threaded couplings of NKK and Mannesman, used in vertically tensioned risers, have been developed for dynamic applications and are well suited for use in catenary riser systems.

CONCLUSIONS

Recently implemented steel catenary and hybrid riser systems offer alternatives to flexible riser systems which are conventionally used on floating productions systems. In water depths less than 300m their use is limited, but in larger water depths the benefits of these alternative riser systems can be significant. Cost reductions in excess of 40% and improved performance for HP/HT and sour service applications can be achieved.

Riser systems have a key role in determining seabed layout, export options and vessel selection. The hybrid riser and steel catenary riser systems offer improved choice of vessel and improved vessel utilisation, which can lead to cost reductions and increased revenue. Integration of the design and selection of vessel, risers and seabed layout is needed in order to realise the maximum cost benefits offered by these systems. Furthermore, steel catenary risers offer means of providing low cost future-proofing, which may enable reservoir uncertainties to be accommodated and reduce development risk.

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