DRILLING RISER/WELL SYSTEM INTERACTION IN DEEP WATER, HARSH ENVIRONMENTS

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ABSTRACT

Drilling riser configuration and wellhead system design practices adopted for shallow water, mild environment applications are being extended for use in deeper waters and harsher environments. The riser and wellhead system are subjected to more severe loading conditions and considerable effort may be needed to improve operating windows for drilling, coiled tubing and well test operations, in order to minimise idle rig time. Interaction of the drilling riser with the wellhead and conductor system must be carefully considered when optimising response for deep water harsh environments. The key design issues which must be addressed, methods by which response can be assessed and means by which operating windows can be improved are described.

INTRODUCTION

As exploration for offshore oil and gas developments moves into deeper waters and harsher environments the design requirements of the drilling riser system become more stringent. In mild environment, shallow water applications the riser and wellhead system arrangements are developed independently. Riser flex-joint angles which can limit drilling operations are small and rig position may be readily controlled. The riser is configured to produce a small base tension, a requirement which may be well within the tensioning capacity of the rig and does not necessitate the use of buoyant joints. The wellhead and conductor are designed statically, for internal pressure, tubing loads and snag loading from fishing gear on the xmas tree. In deeper water and harsher environments, dynamic loading is more severe and fatigue response of the riser and wellhead becomes a key design issue. In addition, the increase in riser loading reduces operational weather windows. Mild environment design practices must be refined to address the more severe loading regime and considerable effort is needed to optimise the riser, wellhead and conductor system configuration to maintain satisfactory weather windows, rig utilisation and levels of safety.

DESIGN REQUIREMENTS

The operational requirements of the drilling riser and wellhead system which must be considered to determine the optimum design arrangement cover all stages of well development.

Drilling

The riser must resist environmental wave and current loading and maintain small flex-joint angles in order to minimise downtime. The angle limit of the lower flex-joint at which drill string rotation is suspended is typically 1 degree.

Running and Retrieval of Completion

The tools run on the base of the completion riser during tubing hanger installation have a small diametrical clearance from the inside of the drilling riser. Small flex-joint angles, of typically 1 degree, are needed to ensure free passage of the tools without damage. Though the passage of tools is transient, a number of conditions must be considered:

* Entry of the tubing hanger into the diverter - requires control of the upper flex-joint angle;

* Entry of the tubing hanger into the BOP for landing - occurs simultaneously with entry of the completion riser cased wear joint into the diverter. Limits on this stage of the operation include both upper and lower flex-joint angles and rig heave;
* Retrieval - larger flex-joint angle limitations apply as the equipment stack-up on the base of the completion riser is reduced, but the benefit of tubing tension which assists in reducing drilling riser curvature is removed.

Completion, Coiled Tubing and Well Test Operations

Following running of the completion, coiled tubing and well test operations may be carried out. This may require use of the completion riser inside the drilling riser for a period of a week or more. However, drilling vessel motions limit the seastates in which the completion riser can remain connected to the wellhead. Heave motion of the rig may approach the stroke limits of the draw-works motion compensator and pitch may generate high stresses in the completion riser top assembly. A further requirement is that rig must be maintained in a position where emergency disconnect of the completion riser can be carried out. This requires withdrawal of running tools from the BOP which places a limit on the lower flex-joint angle.

Conductor Snag Loading

The subsea xmas tree and attached flowlines must be able to resist snag loading from fishing gear. This often drives the sizing of the conductor. A further consideration in the time for which the drilling riser is attached to the wellhead. Assuming a drilling program of 2 months and allowing for well intervention and some contingency, the wellhead must provide adequate fatigue resistance against riser movements for a period of about 4 months.

DEEP WATER HARSH ENVIRONMENT ISSUES

The design requirements described above are not particularly onerous in mild environments and shallow waters, but increases in water depth, wave and current loading all have a significant influence on riser system response.

Water Depth

As water depth increases the curvature over the length of a drilling riser increases for the same level of top tension. Higher tension levels are needed to maintain the same curvature as in shallower depths, or windows for conducting operations dependent on flex-joint angle are reduced.

Currents

Increased current speeds also produce larger riser curvatures for the same top tension, requiring increased tension to maintain the same operating limits. High currents also generate vortex induced vibrations which can increase drag loading and cause high levels of fatigue damage.

Wave Heights

Larger wave heights increase riser loading and vessel heave and pitch motions. Increases in day to day wave heights can have a greater impact on drilling riser and wellhead system design requirements than increases in extreme 1 year wave heights. The increased loading and vessel motions increase the difficulty of running and retrieval operations and reduce the weather windows in which coiled tubing and well test operations may be conducted.

VORTEX INDUCED VIBRATIONS

Large current speeds typical of those observed in a number of deep water developments can give rise to vortex induced vibrations, whereby the drilling riser vibrates normal to the predominant direction of current flow. High levels of fatigue damage can be generated in this way, along the entire riser length. Analysis of riser vortex induced vibrations is widely carried out using the program SHEAR7 [2], developed at MIT under a joint industry research study. The program enables prediction of riser VIV response under uniform and sheared current flows and has been extensively validated using model tests.

A limitation of SHEAR is its inability to model both riser and conductor. As a result, the two must be analysed independently. One approach is to analyse the riser between lower and upper flex-joints using SHEAR then apply the riser base tension and angle variation found using SHEAR to the BOP and wellhead system using another finite element analysis program. This approach has the limitation that dynamic interaction of riser and conductor is not addressed. A more detailed approach whereby the wellhead system stiffness is accounted for in the riser modal response used by SHEAR shows that the more simplified approach may underestimate wellhead and conductor fatigue damage. In view of the criticality of the wellhead and the high levels of fatigue damage which have been predicted, it is recommended that the more rigorous approach is adopted.

Application of SHEAR to drilling risers in West of Shetland and Voring Plateau environments shows that VIV's and fatigue damage accumulation occur throughout the year. This is due to high year round current speeds which do not diminish significantly lower down the water column as in some other deep water developments such as the Gulf of Mexico and West Africa. Nonetheless, there is a strong seasonal distribution of fatigue damage, with the most severe 6 month period producing twice the fatigue damage accumulated in the rest of the year. The results also show that the wellhead and conductor system may accumulate significantly higher levels of fatigue damage than the drilling riser. Configuration of the riser system may therefore be dictated by the wellhead and conductor response. While VIV suppression systems have not been implemented in current West of Shetland developments, such systems may well prove necessary as drilling activity in deeper waters becomes more intensive.

DESIGN OPTIMISATION

Optimisation of the riser and wellhead system may be necessary to improve operating windows and resist the effects of VIV's. The factors which may need to be considered in order to optimise response are described below.

Tension and Buoyancy

In higher currents, higher riser tensions are needed to reduce curvature and limit flex-joint angles in order to maximise operating windows for drilling and completion operations. It is also generally recognised that increasing tension has the beneficial effect of reducing VIV motion amplitudes with an associated reduction in fluctuation bending stresses and hence fatigue damage. This may be achieved by simply increasing the tension applied from the rig. But in water depths of 500m or so many rigs are at the rig tensioning capacity. Buoyant joints may then be used to increase tension. However, the increase in tension must be reacted through the conductor and while riser response is improved, wellhead fatigue damage is increased. Riser tension and buoyancy must therefore be configured to suit rig tensioner limitations and meet a balance between riser and wellhead system fatigue damage.

Fatigue Details

Improvement in riser and wellhead system fatigue details is a relatively straightforward means of improving resistance to VIV induced fatigue damage. Use of C-class welds (double-sided, ground flush) as opposed to F2-class welds (single-sided) increases fatigue resistance by a factor of between 10 to 20. Further improvements may be made by applying increased attention to detailing to reduce stress concentration factors.

Conductor Sizing

Conductors are conventionally sized to resist loading on the xmas tree and attached flowlines from snagged fishing gear. A 30in diameter is generally adopted with the wall thickness and material grade selected to suit snag loading level, soil strength and ease of fabrication. As loads increase and soil strength reduces, a 36in conductor may be adopted. However, the stiffness of the conductor can have a major influence on the fatigue damage transmitted from the riser into the wellhead system. The extent to which stiffness influences response depends on individual design. Increasing conductor diameter to prolong fatigue life may be readily achieved but reducing diameter to improve fatigue response may be difficult, whilst at the same time providing adequate resistance to snag loading. Use of higher grade materials and a plastic design approach may be needed to meet this objective.

Seasonal Drilling

Conducting drilling and completion operations in the winter months may place particularly severe design requirements on both the riser and wellhead system. More severe currents generate higher levels of fatigue damage from VIV's. Riser curvatures and flex-joint angles are also increased as a result of which longer periods of downtime are to be expected, rig operations become prolonged and wellhead fatigue damage is further increased. Scheduling of drilling and completion operations for the summer months can reduce riser and wellhead system design requirements, although the feasibility of such an approach may be limited by drilling rig contracts and development schedules.

VIV Suppression

If the methods of riser and wellhead system optimisation described above cannot provide adequate operating envelopes or fatigue life requirements, consideration may be given to the use of VIV suppression devices. Many systems have been proposed [3]. Two systems that provide high levels of suppression and have been used in previous operations are helical strakes and fairings [4, 5]. Both strakes and fairings can reduce VIV fatigue damage by over 80%, but both systems also introduce handling difficulties. Strakes have the added disadvantage of increasing riser drag and hence flex-joint angles whereas fairings can reduce drag loading and hence top tensions. Handling difficulties may be limited if the devices can be implemented over a short length only. However, West of Shetland, the high through depth currents may require use of suppression devices over a large proportion of the riser length. In water depths up to 500m, careful optimisation of the riser system has obviated the need for suppression devices. In depths of a 1000m or more where exploration is currently being carried out, some form of VIV suppression system may well prove necessary as drilling activity increases.

The high levels of VIV suppression provided by strakes or fairings may provide unnecessarily long riser and wellhead system fatigue lives. More simple, less effective, methods of suppression which do not introduce handling difficulties may provide a more satisfactory solution to fatigue life improvement. One such approach is to stagger slick and buoyant riser joints, as used in the Faroe-Shetland Channel [6]. Alternative methods, such as use of profiled buoyancy may also provide satisfactory levels of VIV suppression though the levels of suppression such approaches may offer need to be determined.

MONITORING

Monitoring of riser response and operating conditions can be beneficial for ensuring that riser system operations are conducted safely and providing feedback for use on future developments. Some of the areas that warrant consideration for deep water harsh environments are described below.

Flex-Joint Angles

Current monitoring of drilling riser response typically consists of an inclinometer on the lower flex-joint, with an accuracy of around +/-1 degree. For running completions, improved accuracy is required to prevent damage to equipment as it is passed through the upper and lower flex-joints. As the wellhead may not be true to vertical and the rig may be trimmed out of plane such devices need to measure relative rotation across the flex-joint, not just inclination of one half.

Riser Response

Measurements of riser response can be used for calibrating results of VIV analysis and monitoring fatigue damage accumulation. Measurements may be taken using strain gauges to give riser stresses directly or accelerometers to give displacements. Using the latter approach riser stress variations and accumulated fatigue damage may be inferred from comparisons between analysis results and field measurements. Such a system is currently being implemented West of Shetland. By either approach the accuracy of response prediction methods can be determined and fatigue life predictions of riser and wellhead updated accordingly. This may have minimal benefit on the development on which the monitoring is conducted but may prove useful on subsequent developments in the same region. A further benefit of riser monitoring is that riser joint fatigue damage accumulation can be logged. This would account for seasonal variations of riser usage and actual rather than predicted field conditions. Records of accumulated fatigue damage would also assist in rationalising riser inspection schedules.

Currents

Current flows may be strong when environmental conditions such as wave and wind observed at the surface are mild. Weather windows for landing the tubing hanger and subsequent coiled tubing or well testing operations are all dependent on current speed. Measurements of current can assist in determining the feasibility of conducting such operations and requirements for rig positioning in order that they may be carried out. They also provide a means of determining the proximity of the actual operating conditions to the allowable limits. Current measurements also provide data needed to correlate riser response observations with analytical results.

Vessel Position

Vessel position is in itself of little direct importance to riser operations provided flex-joint angles are closely controlled. However, feedback on typical drift motions from tidal currents, wind and wave may prove useful in determining rig positioning requirements. Where allowable offset ranges for a particular operation are small, mooring line tensions may need to be increased to control variable offset. For landing tubing hangers, very small flex-joint angles are needed and the requirements for control of vessel position, that is, whether by thruster assist or mooring line adjustment, can be predicted.

CONCLUSIONS

Deep water, high currents and larger wave heights present significant challenges for the configuration of drilling riser and wellhead systems. The interaction of the riser and wellhead system must be carefully considered in order that the operating windows for drilling and completion operations can be maximised. It is not sufficient to address the issues of riser and wellhead system independently. As exploration moves into deeper waters West of Shetland and on the Voring Plateau these issues are becoming more important and greater effort is needed to optimise riser and wellhead system configuration to provide satisfactory levels of serviceability and safety.

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