USE OF NEW TECHNOLOGIES FOR OPTIMUM DRILLING RISER CONFIGURATION IN DEEP WATER

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ABSTRACT

In deeper water, drilling riser systems are subjected to increased loads and maximising productive rig time is more difficult. Operators are faced with the need to assess the suitability of drilling facilities for their developments and drilling contractors must choose between making the most of what they've got, upgrading, or procurement of new facilities. Assessing the adequacy of existing equipment is a complex process. Riser fitness-for-purpose is not only affected by rig tension capacity but also by buoyancy arrangement, hang-off control, wellhead configuration and local environmental conditions. Much can be done to optimise riser usage through increased attention to riser configuration and improvements to operational procedures. The design issues which must be addressed, impact of deeper water and methods of optimising riser usage are described.

INTRODUCTION

Exploration in the Gulf of Mexico and West Africa is moving into water depths of over 2000m and in the harsher areas West of Shetland and in the Voring Basin into water depths of over 1000m. The increased water depth and severe currents experienced in most of these areas place more severe design requirements on the drilling riser system. These conditions can not simply be compensated for by increasing riser tension or use of buoyant joints. All stages of riser operation from installation through to disconnect become more difficult and significant reduction in riser utilisation may be experienced unless the riser configuration is carefully optimised. In addition, it is not sufficient to consider the riser in isolation as interaction with the wellhead and conductor becomes more important. Conventional practices of riser configuration and operation must therefore be enhanced to maximise productive rig time.

DESIGN REQUIREMENTS

The operational requirements of the drilling riser 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 2 degrees.

Running and Retrieval of Completion

The tools attached to the base of the completion riser for running the tubing hanger 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 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 [1]. 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.

Disconnect and Hang-Off

The larger riser tensions needed to maintain control of riser curvature during drilling are more difficult to contend with during disconnect. Whereas in shallower water it may be feasible to reduce riser tension prior to disconnect, the large curvatures that may be generated can make such an approach impractical in deeper waters. Consequently, the disconnect system must accommodate larger overpulls and larger reductions in tension from connected to disconnected mode.

Following disconnect, the larger riser diameters arising from the use of buoyant joints result in increased lateral load on the riser. This can produce high curvatures, and the possibility of riser buckling as the vessel heaves is increased. Consequently, the environmental conditions in which hang-off may be conducted can be more restrictive than in shallower water depths and more attention must be paid to the hang-off arrangement to maximise operational limits.

Conductor 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. Increased riser base tension, required in deeper water, increases bending loads on the wellhead and conductor. Consequently, conductor sizing may be driven by extreme loading from the drilling riser in failed mooring line or drift-off conditions. A further consideration is 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 ISSUES

Riser Curvature

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. The high current speeds seen in many deep water developments also produce larger riser curvatures for the same top tension, requiring increased tension to maintain the same operating limits. Large current speeds also generate vortex induced vibrations which can increase drag loading and cause high levels of fatigue damage.

Buoyancy Limitations

The buoyancy needed for riser joints in greater water depths is more dense than that for shallower waters. Increased buoyancy volumes are therefore need to provide the same level of upthrust as in shallower waters. This leads to an increase in buoyancy diameter which in extremes of depth is limited to about 49in, in order that running of the riser through the rotary table can be effected with the buoyancy in place. The increase in diameter causes an increase in lateral loading on the riser and hence increase in curvature. Hence, the effectiveness of buoyancy when applied at increased depth may be greatly reduced.

Collapse

Provision of adequate collapse resistance may have an impact on riser joint design requirements for greater water depths. Sudden loss of annulus fluid downhole may lead to emptying of the riser. The riser must have adequate resistance to collapse from external hydrostatic pressure which can affect the riser arrangement. Thicker wall joints, increased material grades or use of a fill-up valve may be required near the base of the riser.

VORTEX INDUCED VIBRATIONS

Large currents speeds typical of those observed in many deep water developments 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.

As important as riser VIV response is that of the wellhead system. Due to the rigidity and height of the BOP, small angles at the lower flex-joint combined with large riser base tensions can generate significant bending moments in the wellhead and conductor system. In conjunction with other finite element analysis software SHEAR can also be used to predict wellhead fatigue damage. The results 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.

DESIGN OPTIMISATION

Optimisation of the riser and wellhead system is necessary to improve operating windows and resist the effects of VIV's. The factors which may need to be considered to improve the operability of both existing and new-build riser systems.

Tension

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 fluctuating 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 and buoyant joints are needed to increase tension. However, the increase in tension must be reacted through the conductor and while riser response is improved, wellhead fatigue damage can be 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.

Buoyancy

Many aspects of riser response can be improved by varying the buoyancy configuration. The key aspects to be considered are as follows:

- Riser curvature - by avoiding use of buoyant joints in regions of greatest current loading riser curvature and hence flex-joint angles can be reduced. Similarly, as smaller buoyancy volumes are needed for the same upthrust in shallower depths, optimum distribution of buoyancy throughout the water column can assist in reducing curvature;
- VIV - staggering buoyant and slick joints can reduce the levels of fatigue damage induced by vortex induced vibrations [7]. Using a profiled surface may also offer reduced fatigue damage;
- Hang-off - keeping buoyant joints below the wave zone minimises the lateral loading on the riser and can increase limiting hang-off conditions;

Some conflicts between the requirements to optimise different aspects of response arise but for any given riser application, improvements in the weaker aspects of response can be effected using some of the steps described above.

Ballast Control and Rig Positioning

Where operational limits are dictated by the angle across the upper flex-joint the rig can be ballasted to reduce the angle and improve operating limits. In drilling operations where limits are dictated by the angles across both the upper and lower flex-joints, ballast control in conjunction with rig positioning can be used to reduce both upper and lower flex-joint angles. Firstly the ballast is adjusted to reduce the upper flex-joint angle. The rig is then moved to reduce the lower flex-joint angle. Finally the ballast is adjusted to compensate for the increase in upper flex-joint angle arising from repositioning to reduce the lower flex-joint angle.

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 and 20. Further improvements may be made by applying increased attention to detailing to reduce stress concentration factors.

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 [4-6]. 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. Handling difficulties may be limited if the devices can be implemented over a short length only. However, high through depth currents such as found West of Shetland may require use of suppression devices over a large proportion of the riser length.

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 [7]. 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.

Recoil and Hang-Off

Higher riser base tensions needed to control riser curvature and increased drag resulting from the use of buoyant joints increase the difficulties of controlling recoil and subsequent hang-off response following disconnect. It may not be feasible to reduce riser tension prior to disconnect as the increases in riser curvature that result may lead to snagging of the LMRP connector on the BOP below. Potentially large vertical accelerations of the riser must be controlled by the recoil system. Greater reduction in tension from normal operation to hang-off conditions are seen in deeper water which require careful sequencing of the closure of recoil speed control and accumulator shut-off valves.

Increased drag from buoyancy and longer riser strings with the same weight LMRP at the base of the riser can result in increased riser movements during hang-off. Buckling of the upper riser can occur and interference with the moonpool is more likely. Limiting conditions for hang-off may be more restrictive than for the connected riser and attention must be paid to optimising the hang-off arrangement without adversely affecting other operations. Possible means of achieving this aim are to add weight to the LMRP or introduce a retainer valve at the base of the riser such that it may be filled with heavy mud prior to disconnect.

FORECASTING AND MONITORING

Forecasting weather conditions and monitoring of riser response can be beneficial for ensuring that operating windows are maximised and that riser system operations are conducted safely with reduced risk of equipment damage. Some of the areas that warrant consideration for deep water environments are described below.

Forecasting

Forecasting environmental conditions has an important role to play in deep water drilling operations. Running and retrieval of tools through the riser and the riser itself take longer and operational conditions may be more restrictive than in shallower waters. The possibility of equipment damage is therefore increased unless greater attention is paid to forecasting weather conditions and rig movements. A systems for forecasting vessel heave is being developed by the AMJIG group and has already been implemented with some success [8]. Extensive use of such techniques will be required as prolonged deep water drilling programmes become more widespread.

Flex-Joint Angle Measurement

Current systems for monitoring drilling riser response typically consist of an inclinometer on the lower flex-joint, with an accuracy of around +/-1 degree. Angles less than 2 degrees are required for drill string rotation and angles less than 1 degree during running completions. For both of these operations, measurement of the angle across the flex-joint is required not simply the verticality of the upper flex-joint as provided by the inclinometer. As the wellhead may not be true to vertical and taking account of inclinometer tolerances, the flex-joint angle may be substantially different from the measure provided by the inclinometer. This may lead to reduced operating windows if the flex-joint angle is overestimated and undue wear during drilling or equipment damage when running completions if the angle is underestimated. Consequently improved methods of flex-joint angle measurement are needed.

For effective implementation of ballast control and rig positioning to improve operating windows, as described above, measurement of upper flex-joint angle must be taken. At present, this is widely obtained by visual assessment of the slip-joint. Automated measurement and feedback to the control room is needed in order that this approach to improving operating windows can be implemented effectively.

Currents

Current flows may be strong when environmental conditions such as wave and wind observed at the surface are mild. Weather windows for operations involving the tubing hanger, coiled tubing or well testing 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. For future developments, current measurements also provide data needed to correlate riser response observations with analytical results and establish the severity of riser service history.

Riser Response

Measurements of riser response can be used for monitoring fatigue damage accumulation calibrating results of riser analysis. 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 and in the Voring Basin. 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.

Monitoring riser response provides a means of logging fatigue damage accumulation, which may be accelerated in deeper waters. This would account of 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 in terms of the severity of riser operating conditions rather than the more conventional time based approach.

CONCLUSIONS

Assessing the adequacy of drilling equipment for deep water activity is a complex process involving many variables. Much can be done to optimise drilling riser response. A complete system approach must be taken, in which riser, wellhead and conductor system interaction and all stages of riser operation are considered. Increased use of weather forecasting and improved methods of monitoring can help in ensuring that operations are conducted safely and that productive rig time is maximised. The increased rates of wear and fatigue damage accumulation bring an added dimension to assessment of riser fitness-for-purpose that require more rigorous record keeping of riser usage and rationalisation of inspection procedures to reflect the severity of riser operations.

REFERENCES

[1] Caulder, I. - “New Concerns in Deepwater and Harsh Environment Coiled Tubing and Workover Riser Operations”. SUT Seminar “An Update on Subsea Technology”, The Marcliffe Hotel, Aberdeen, July 1996.
[2] Vandiver, J.K. And Li, L. - “ User Guide for SHEAR7 Version 2.0". MIT, September 1996.
[3] Rogers, A.C. - " An Assessment of Vortex Suppression Devices for Production Risers and Towed Deep Ocean Pipe Strings". Paper OTC 4594, OTC, Houston, May 1983.
[4] Grant, R. and Patterson, D. - "Riser Fairing to Reduce Drag and Vortex Suppression". Paper OTC 2921, OTC, Houston, May 1977.
[5] Gardner, T.N. and Cole, M.W. - "Deepwater Drilling in High Current Environment". Paper OTC 4316, OTC, Houston, May 1982.
[6] Denison, E.B., Howell, C.T., Ju, G.T., Gonzalez, R., Myers, G.A. and Ashcombe, G.T. - “Mars TLP Drilling and Production Riser Systems”. Offshore Technology Conference, Paper No OTC 8514, Houston, May 1997.
[7] Brooks, I.H. - "A Pragmatic Approach to Vortex-Induced Vibrations of a Drilling Riser". Paper OTC 5522, OTC, Houston, April 1987.
[8] Mitchell J. - “Vessel Response Forecasting”. - SUT Seminar “BP/Shell Atlantic Margin Metocean Workshop”, Airport Skean Dhu Hotel, Aberdeen, April 1997.