

# Drilling Riser Management In Deepwater Environments

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## Abstract

Drilling in deepwater presents a significant challenge. With an increase in drilling operations in harsh environments, drilling riser requirements and limits have become more onerous due to uncertainties involved in response prediction and prolonged drilling programs. The following are the main objectives of this paper:

- Emphasize the criticality of conducting analysis of drilling risers in deepwater environments;
- Highlight drilling riser monitoring as a key integrity management tool;
- Discuss briefly the strides in development of alternatives to conventional deepwater drilling riser systems.

The factors that affect deepwater drilling riser integrity are as follows:

- Increased wall thickness for hoop load resistance from mud head and collapse resistance from water column;
- Higher top tensions, requiring increased wall thickness and vessel capability;
- Larger curvature resulting in potential wear issues from drill string rotation;
- VIV due to severe currents generating high fatigue damage in short periods of time;
- Conductor fatigue damage due to lower BOP stack vibrations at certain current speeds;
- Longer joint requirements – handling issues during riser deployment and retrieval;
- Increased importance of auxiliary line designs due to load sharing between main riser pipe and auxiliary lines.

Deepwater drilling riser engineering is complex. A high level of understanding is required of the response of the system to various conditions, and the design issues that govern the system.

The paper is based on extensive work pertaining to deepwater drilling riser projects that have been carried out during the past decade in the Gulf of Mexico, North Sea, offshore Brazil and West Africa. The lessons learned from these projects can be applied to improve future design practices. In addition, this also leads to knowledge transfer to other areas of the world with emergent deepwater developments.

## Introduction

Over the past two decades, drilling activities have progressively gone into deeper waters. These have presented a wide variety of challenges resulting from harsh environments, prolonged drilling programs and uncertainties involved in response predictions. This has resulted in more challenging drilling riser design and restrictive operating limits.

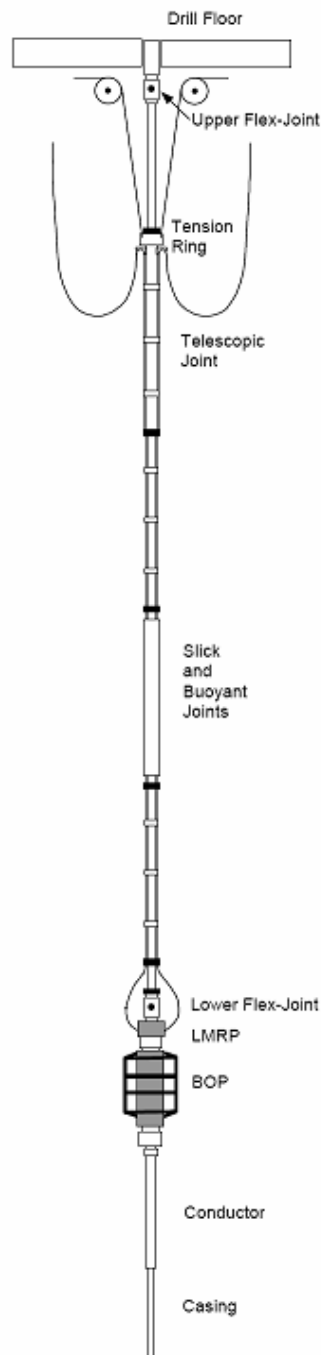
Deep water developments are typically characterized by high currents, leading to accelerated fatigue damage due to vortex-induced vibrations. These severe loading conditions can also potentially result in higher riser curvature and increased wear due to drill string rotation.

## Deepwater Drilling Riser Analysis

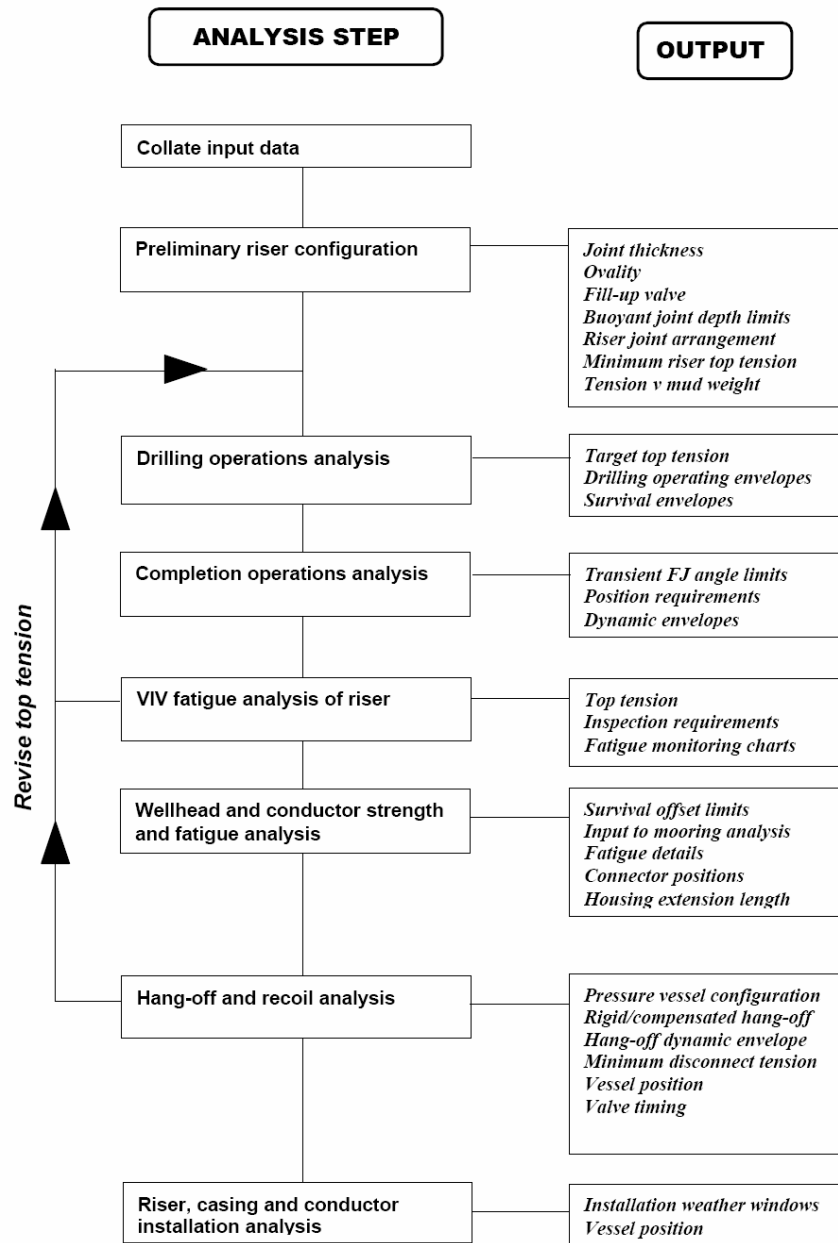
### General

Drilling risers are required to resist environmental loading whilst maintaining small flexjoint angles for optimum utility. In shallow water, this may be achieved by the use of standard joints without using buoyancy and a low top tension. In deepwater, increased riser tension and specific stack-up configurations are required for productive operation.

Extent of analysis typically covers the riser system from mudline conductor up to the diverter flex joint. A typical deepwater drilling riser is shown in Figure 1. Due to the complexity of riser response in deepwater, riser configuration development is an iterative process, potentially requiring a number of loops. A flowchart is shown in Figure 2.



**Figure 1 – A Typical Deepwater Drilling Riser**



**Figure 2 – Deepwater Drilling Riser Analysis (Ref. 1)**

### Preliminary Configuration

Prior to conducting drilling riser analysis, some initial calculations must be conducted in order to determine basic riser design requirements and preliminary configuration. The pipe wall thickness is based on the following:

- Hoop stresses caused due to the heavy mud weights used for drilling,
- Collapse pressure due to the large water depth, and
- Top tension.

Buoyancy modules are required to reduce the large top tensions required in deepwater. However, in deep water, buoyancy syntactic foam density requirement increases. The higher the buoyancy rating, the larger its diameter, which in turn is restricted by rotary table opening.

Riser joint stack-up arrangement is driven by the following:

- Curvature and drag loading : Reduce large diameter buoyancy joints in the region of high currents;
- VIV : Reduce fatigue by staggering buoyant and slick joints (Ref. 1);
- Hang-off : Buoyant joints to be kept below wave action zone;
- Installation and retrieval : Lower joints to be kept slick to improve riser response during installation and recoil.

Maximum top tension ranges are recommended for drilling risers with corresponding mud weights. These are based on calculations from API16Q (Ref. 2). However, riser analysis is required to define acceptable tension ranges for in-service loading conditions to manage flexjoint angles, component capacities and riser fatigue damage.

The water depth over which the drilling riser operates, results in higher in-service weights due to mud column and steel weight. With typical tensioners ratings in excess of 2000 kips for riser systems rated for 10,000ft water depth, thicker wall sections are required for tension, hoop and collapse capacity. A typical drilling riser joint may consist of 21" outer diameter (OD) 1" wall X80 seam welded pipe with 6.5" OD" X80 15ksi choke & kill lines, 5.5" OD X80 mud booster line and 4.5" OD stainless steel hydraulic line.

### In-place Operating Envelopes

An evaluation of the upper and lower flexjoint angle variation with varying current speed and top tension should be conducted. Together with varying mud weight, this assessment provides limiting vessel upstream and downstream offsets based on certain criteria for drilling and non drilling in-place conditions.

Typically during drilling operations, mean flexjoint angles should be limited to 1-2 deg. The angles are kept low in order to prevent potential wear issues that arise from drilling string rotation. A typical drilling riser operating envelope is shown in Figure 3.

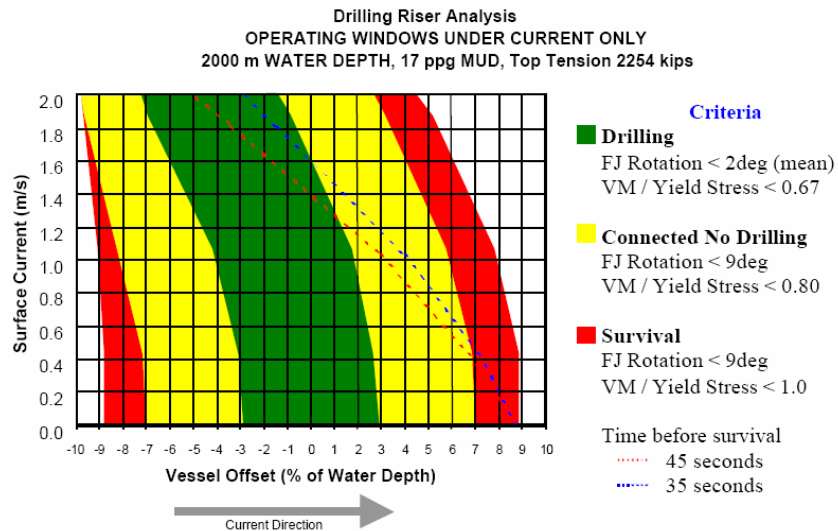


Figure 3 – Typical Operating Envelope

Other criteria in determining limiting envelopes during drilling and non-drilling conditions are as follows:

- Riser and conductor Von-Mises stresses less than specified allowable;
- No interference with vessel allowed;
- Maximum telescopic joint stroke must not be exceeded;
- Wellhead connector capacity must not be exceeded;
- Riser connector strength must not be exceeded;
- BOP & LMRP connector capacities must not be exceeded.

## Fatigue

High current speeds characteristic of those observed in deepwater environments result in vortex induced vibrations (VIVs), whereby the drilling riser vibrates perpendicular to the dominant current direction. Currents along the deepwater risers change in magnitude as well as direction making VIV prediction much more complex than for short span risers such as those on fixed platforms in shallow water.

Deepwater drilling risers accumulate fatigue damage at a much higher rate than shallow water under such conditions (Ref 1). Therefore, increased rates of fatigue damage accumulation and higher levels of tension applied in deepwater can both lead to increased susceptibility to fracture failure.

Fatigue damage along the riser length may drive joint rotations along the riser string. Other methods of improving VIV fatigue response include increasing top tensions and reducing the joint drag diameter in high current regions (i.e. replacing buoyant joints with slick joints).

High currents also result in the BOP stack/conductor system oscillating at its natural frequency when riser VIV frequencies coincide. Various instances of "flag poling" of the BOP stack have been observed over the past few years, especially in the Gulf of Mexico. This becomes especially critical at the first conductor connector below the mudline. Typically the conductor connectors are not designed for fatigue but rather for strength and fast make-up on the rig. A typical bending moment stress distribution below mudline due to conductor VIV in GoM soft soils is shown in Figure 4.

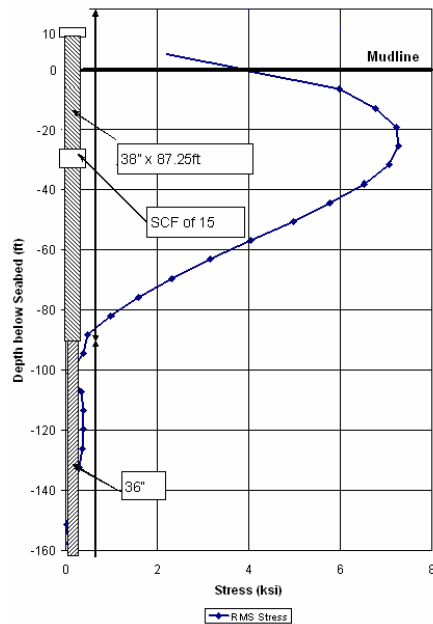
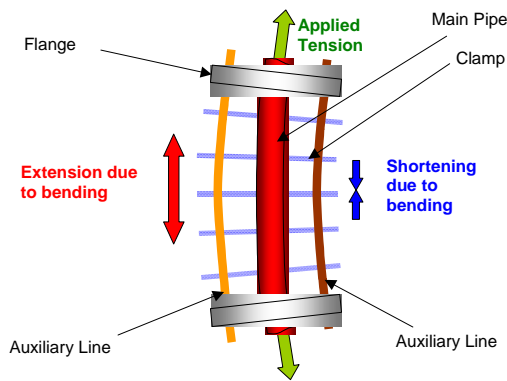


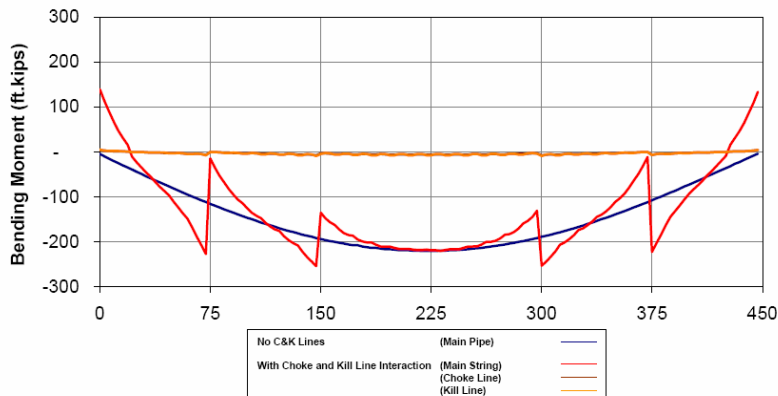
Figure 4 – Conductor Cyclic Bending Moment in High Currents

Results from fatigue analysis form the basis for definition of a riser inspection program. Herein, the riser may be inspected periodically or after a major event.

In deepwater drilling risers, an additional complexity is introduced due to load sharing between the main pipe and the auxiliary lines (Ref 7). Many deepwater drilling riser systems share axial tension between the main pipe and the auxiliary lines, in proportion to their cross sectional area. Clamps along the drilling riser joint ensure that lateral deformation in the auxiliary lines match that of the main riser pipe. As shown in Figure 5, the auxiliary line on the outside stretches and the inside line compresses due to bending. This results in differential levels of tension in the auxiliary lines in proportion to the average curvature of the joint, which causes local bending effects at the flanges as shown in Figure 6, where 6 X 75ft riser joints are represented under a sinusoidal load. Peak bending moments in the main pipe could be up to 1.5 times those predicted by conventional analysis assuming no auxiliary line interaction. In the flanges, bending moment carried in the bolts could be up to 4 times those calculated using current analysis methods. Moment magnification due to load sharing could therefore result in maximum fatigue damage being 2 to 3 times greater than that computed with current analysis practice.



**Figure 5 – Bottomed-out Joint Load Sharing**



**Figure 6 – Bending Moment Magnification**

### Hang-off and Recoil

Conditions may arise during drilling operations in deepwater environments, wherein the operator is forced to keep the riser in a hang-off position. Increased lateral drag loading due to the effect of deepwater currents on the buoyant joints and long suspended riser string may result in increased riser movements during hang-off. Some potential dangers in this condition are interference with the vessel, buckling of the upper riser and VIV of the riser during hang-off.

More restrictive limiting conditions may exist for hang-off than for a connected riser condition. Improvement of the hang-off window may require the vessel to drift in the direction of the current, reduction of buoyant joints to increase riser suspended weight in water and decoupling the riser motions from the vessel motion by allowing the telescopic joint to stroke during hang-off.

During an emergency disconnect, such as drift-off following failure of drilling vessel DP system, the riser is subject to recoil due to its high top tension. It must be ensured that during recoil:

- The angle of the LMRP does not exceed the allowable departure angle of the connector;
- LMRP should rise fast enough to avoid clashing with the BOP when the vessel heaves down;
- The telescopic joint should not reach maximum stroke at high speed.

The result of recoil analysis gives recommendation on maximum and minimum tension settings prior to disconnect and the timing of tensioner valve operation for desired response.

### Riser, Conductor and Casing Installation

During installation of riser, conductor or casing strings, especially in deepwater environments, substantial lateral displacements can occur due to large current loading. In addition, the strings may see significant stresses due to bending and it may be necessary to re-position the vessel for proper stab-in of the sting into the well at the seabed, as shown in Figure 7. Analysis yields the following recommendation:

- Limiting currents and seastates for installations;
- Requirement for vessel positioning during seabed stab-in;
- Optimum riser arrangement to maximize installation environmental windows.

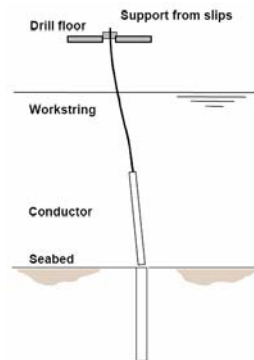


Figure 7 – Conductor Installation

### Uncertainties in Deepwater Drilling Riser Behavior

Vortex-induced vibration (VIV) is responsible for majority of the fatigue damage in deepwater drilling risers. Damage from VIV is a major issue and, potentially, very dangerous. Of primary concern are the uncertainties involved in VIV prediction. These uncertainties come from various sources:

- The variation in magnitude and direction of deepwater long term currents;
- Complex multi modal characteristics of VIV in deepwater environment;
- Non-scalability of tank test results;
- Uncertainties in the design input parameters which require calibration based on measurements in the field;

Consequently, monitoring the riser response will allow comparisons between predicted and measured response for different environmental conditions. Analysis conducted can be used to calibrate VIV analysis software based on the comparison of the monitored riser response (Ref 6). This allows for

rationalization of design methods, confirmation of long term integrity and provides riser inspection interval recommendations.

Deepwater riser monitoring can be conducted either using a stand-alone system or real time data monitoring system, each having its advantages and drawbacks. Standalone systems, typically, require lower CAPEX, are simple to install, limited by memory and battery capacity and have higher OPEX. Real time monitoring systems, on the other hand, provide real time data acquisition, but are more expensive and require more complex interfaces. A typical stand-alone monitoring motion sensor attached to an auxiliary line is shown in Figure 8.



**Figure 8 – Stand-alone Motion Monitoring System**

Monitoring systems measure deepwater riser response in terms of motion or strain along the length. Motion monitoring systems measure the global response, are relatively inexpensive and have a proven track record in deepwater. However, they require large amount of data processing to calculate stresses and fatigue. Strain measurements can be used calculate fatigue damage with little data processing, but the monitoring equipment is, generally expensive, has more complex interfaces with the pipe, lower subsea reliability and has little track record in deepwater.

## **Alternatives to Conventional Deepwater Drilling Risers**

Conventional deepwater drilling risers have a number of problems during operations which can seriously hinder efficient working of the risers and drilling of a well. Various factors can result in the riser being retrieved, e.g. failure of seals on the joint flanges, control pod issues in the lower stack and environmental events such as hurricanes and loop currents. The trip times involved in the riser being retrieved and then redeployed under such conditions run into several days in deepwater.

During recent years, alternatives to conventional deepwater drilling risers have been proposed to address these issues. These also address the problem of 5<sup>th</sup> generation rig availability.

### **Free Standing Drilling Riser (FSDR)**

A FSDR has the ability to disengage at an interface component, called a Near Surface Disconnect Package (NSDP), located a short distance below the water surface. The lower riser section is left freestanding and held up by a buoyancy can system. This significantly reduces installation and retrieval time, as well as it also allows the rig to park the free-standing riser on a temporary wellhead and move off location for other non-drilling activities. The FSDR, thus, provides a beneficial alternative to deep water drilling operations where weather windows regularly suspend drilling activities (Ref 5).



## **Artificial Buoyant Seabed (ABS) Drilling Solution**

The ABS system allows for a conventional shallow water drilling riser and its subsea BOP to be run to the ABS. An ABS is installed at shallow depth below the rig, with a well casing acting as a tether to anchor it to the actual seabed. As a result, no equipment remains on the real seabed. On approach of bad weather, the shallow water riser can be disconnected and retrieved, leaving the BOP behind on the ABS for well control (Ref 4).

## **Subsea Mudlift Drilling (SMD)**

In conventional deepwater drilling systems, problems are often encountered during mud circulation. One major concern is to keep the wellbore annulus pressure above the pore pressure so that the well does not “kick” and below the fracture pressure so that the well does not hydraulically fracture and lose circulation. This pressure range can be increased by reducing annular pressure to that of seawater. This can be achieved by providing mud pumps on the seafloor to pump mud via, smaller return lines changing the pressure gradient in the wellbore to a more favorable one (Ref 3). One benefit of such a system is that it facilitates the use of an older generation rig with a lower tension capacity than that required for a conventional deepwater drilling riser as the main 21” riser can be filled with seawater for the entire drilling program.

## **Conclusions**

Deepwater drilling riser analysis is quite complex and is required to define operational limits and top tension requirements under in-service loadings to manage flexjoint angles, component capacities and fatigue damage. Analysis addresses strength, fatigue and clashing issues during in-service operations, hang-off, recoil, installation and retrieval. Fatigue damage due to load sharing between main pipe and auxiliary lines is also addressed.

However, uncertainties do still remain due to variations in environmental conditions, complex response characteristics and uncertainties in design input parameters. Monitoring of drilling riser systems addresses these uncertainties by allowing comparisons between results from measured and predicted response in order to calibrate the design model.

Alternatives to conventional deepwater drilling riser systems are also available. These systems address the problem of 5<sup>th</sup> generation rig availability as well as downtime due to bad weather.

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