GUIDANCE NOTES ON

DRILLING RISER ANALYSIS

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ABS Plaza
16855 Northchase Drive
Houston, TX 77060 USA

Foreword

These Guidance Notes are intended to assist users of the ABS *Guide for the Classification of Drilling Systems (CDS Guide)* to deal with the drilling riser analysis to meet ABS *CDS Guide* requirement.

These Guidance Notes provide the latest recommended practices for typical types of analyses that may be required for a drilling riser. The actual types and scopes of analyses that will be required for a particular drilling riser will be decided on a project specific basis. In addition, considerations and suggestions are also provided in these Guidance Notes on important features of these analyses with sufficient details including evaluation parameters, approaches, procedure, modeling, and sample figures of results, etc.

The design acceptance guideline of a drilling riser is based on API RP 16Q, while the detail analysis process is provided in these Guidance Notes.

In these Guidance Notes, the word “Unit” is used in general to refer to the structure from which the drilling riser is deployed. In an actual case, that structure can be a Mobile Offshore Drilling Unit, Floating Production Installation, or other type of structure as considered in the *CDS Guide*.

These Guidance Notes become effective on the first day of the month of publication.

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SECTION 1 Summary of Drilling Riser Analyses

The types of analyses typically required for a drilling riser may include those listed below. Section 1, Figure 1 depicts the general sequence of the analyses and gives the primary purpose of each analysis type.

The actual analyses types and scopes, which will be required in ABS's review of the riser for Classification in accordance with the ABS *Guide for the Classification of Drilling Systems (CDS Guide)*, will depend on the specifics of an individual project. The information given in these Guidance Notes is meant to give an indication of the possible scope for the listed types of analyses which may apply.

1 Riser Space-out and Stability Calculations

This is often the first step in the drilling riser analyses. The purpose of this analysis is to establish feasible riser space-out (i.e., layout or arrangement) configurations based on the water depth and available types of riser joints and to determine whether the top tensioning system has sufficient capacity to support the riser space-out and anticipated mud weight.

3 Storm Hang-off Analysis

The purpose of this analysis is to determine the limiting sea states (environmental window), in which the riser can be hung-off without damaging the riser. This analysis is especially important for a deep water riser, since the natural period of the riser's axial dynamic response may fall in the frequency range of highly energetic waves.

5 Operability Analysis

The purpose of this analysis is to determine, for each mud density, the operating envelopes that define the required top tension range and the allowable Unit offsets for normal drilling operation and/or for keeping the riser connected to well but no drilling.

7 Deployment/Retrieval Analysis

This analysis is performed when the Unit moves to a site that is in deepwater or is sensitive to the environment (e.g., high current). The purpose of this analysis is to determine the environmental window for running/pulling the riser.

9 Vortex Induced Vibration (VIV) fatigue Analysis

This analysis is often required when the Unit is operating in an area of strong current with riser either connected or hung off for long duration. The purpose of the analysis is to predict the fatigue damage induced by vortex induced vibration due to currents and to identify critical locations for regular inspection.

11 Wave Fatigue Analysis

The purpose of the analysis is to predict the fatigue damage induced by sea waves. Because drilling riser joints are in general considered robust and can be often inspected between deployments, this analysis may not be required. However, if the Unit is in high waves with the riser connected to a well or hung off in storm waves for long duration and/or multiple times, such analysis is often warranted to verify that no excessive fatigue damage is sustained by the riser joints.

13 Drift-off/Drive-off Analyses

These two analyses are specifically for dynamically positioned (DP) Units. The purpose of the analyses is to define the radius of the "yellow" and "red" watch circles for emergency disconnection when the Unit suffers a black-out or DP system malfunction.

15 Recoil Analysis

This analysis is typical performed for DP Units. The purpose of this analysis is to determine the requirements of the recoil system on a DP Unit for safe emergency disconnection.

17 Weak Point Analysis

This analysis is to identify the weak points in a drilling riser/well system under extreme Unit offsets due to drive-off/drift-off or mooring line failure. The focus of this analysis is on well integrity. Extreme offsets can lead to overloading of various components in the drilling riser/well system such as connectors, BOP stack, wellhead, and casing, etc. The maximum load predicated from the weak point analysis can be used for design/selection of the drilling riser and well system components or compatibility check between riser and existing well system. This analysis is often required before the Unit's first deployment or before an important drilling campaign by the Operator.

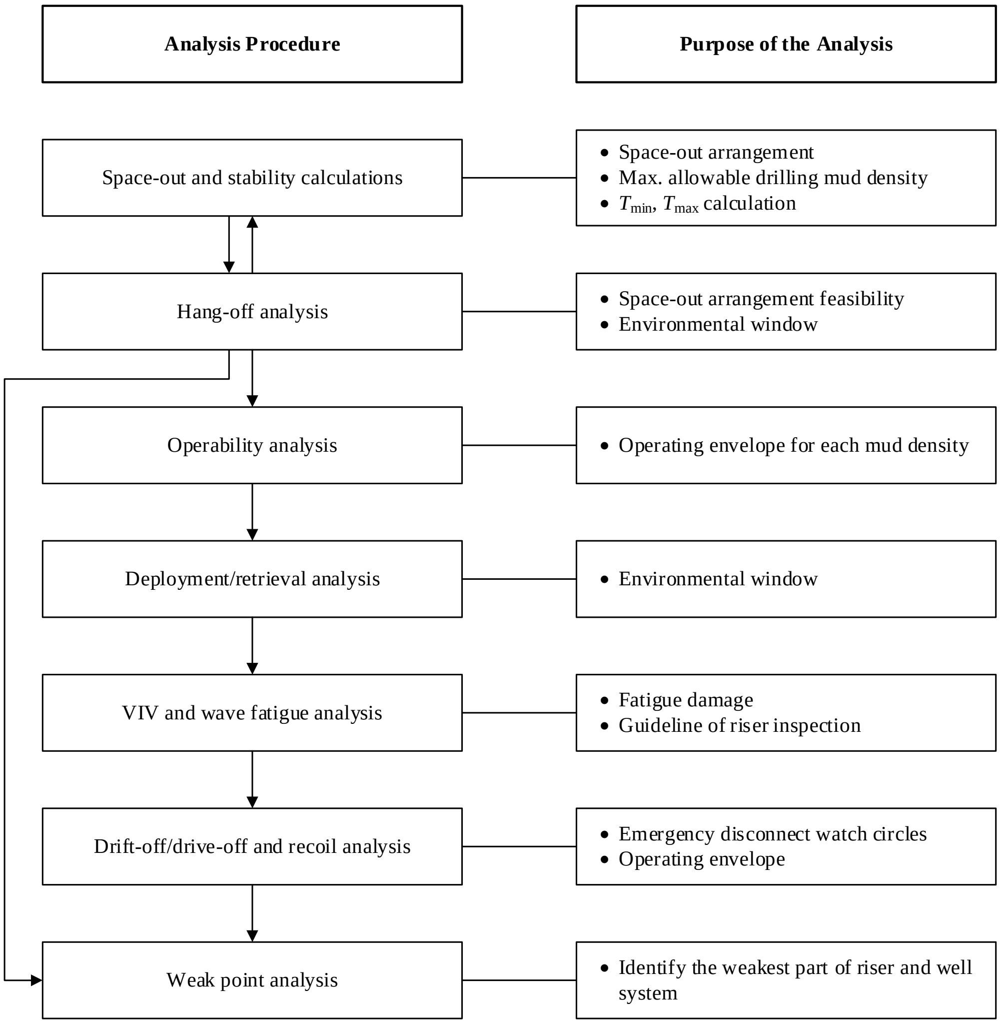
19 Abbreviations

BOP	Blow Out Preventer
C&K	Choke and Kill
DP	Dynamic Position
DTL	Dynamic Tension Limit of a tensioner
FEA	Finite Element Analysis
LMRP	Lower Marine Riser Package
MWL	Mean Water Level
PEL	Pressure End Load
RAO	Response Amplitude Operator
RKB	Rotary Kelly Bushing
SAF	Stress Amplification Factor
SMYS	Specified Minimum Yield Strength
TTF	Tension Transfer Function
VIV	Vortex Induced Vibration

21 Symbols

T_{MAX}	Maximum permissible tension setting at tensioner mid-stroke
T_{MIN}	Minimum required top tension of the riser system
T_{SRmin}	Minimum slip ring tension

FIGURE 1
Typical Drilling Riser Analysis Procedure



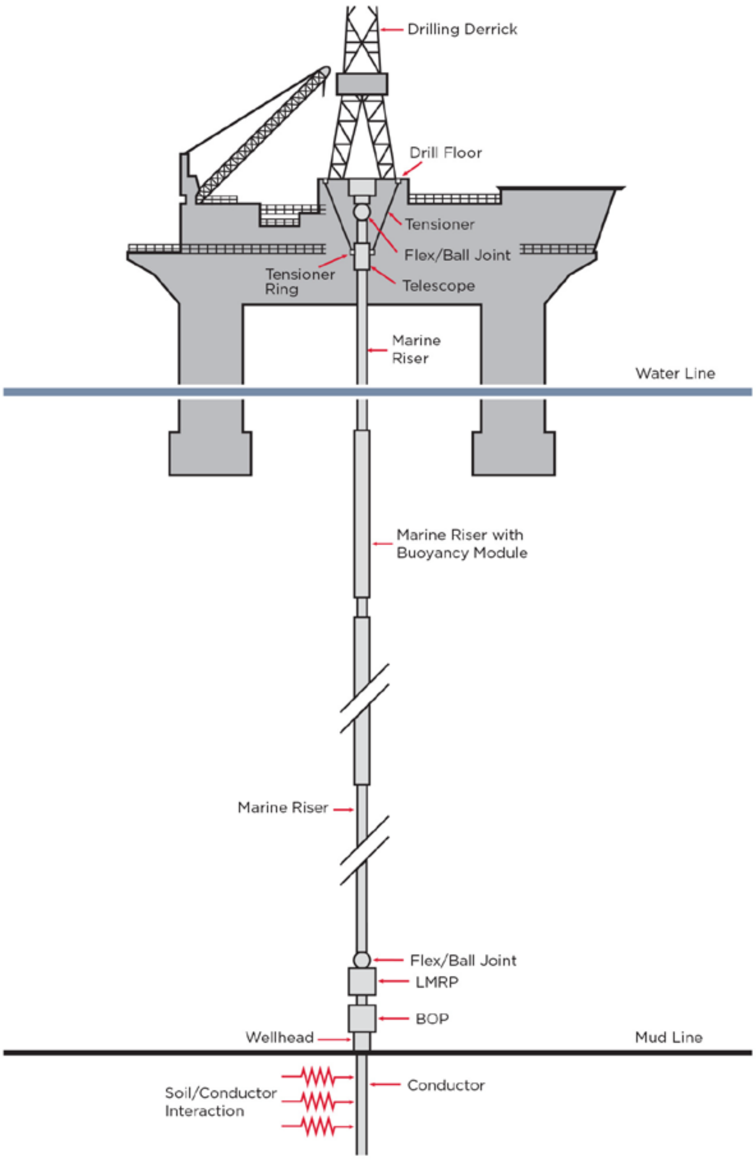
SECTION 2 Drilling Riser System Components

1 Overview of Riser System

There are many different components and subsystems that make up a drilling riser system. See Section 2, Figure 1 for a typical drilling riser system and components.

The following Subsections present descriptions of the main components of a drilling riser system.

FIGURE 1
Typical Drilling Riser System and Components



3 Top Tensioning System

The top tensioning system is used to pull at the top of the drilling riser to support the weight of the riser, its components, and the fluid inside the riser; and it is also used to control the shape of the riser when subjected to environmentally-induced load effects. The tensioning system is normally composed of a number of "tensioners". The number and rating of the tensioner units will determine the total capacity of the tensioning system.

There are two types of tensioner designs (i.e., wireline tensioners and direct-acting tensioners).

A wireline tensioner unit uses a hydraulic ram with a large volume air-filled accumulator to maintain near constant tension on the tensioner wires. One end of the wire is attached at the tensioner and the other is attached to the outer barrel of the telescopic joint through sheaves underneath the drill floor.

A direct-acting tensioner has a hydraulic rod and piston assembly, which are attached directly to the drill floor structure and the outer barrel of the telescopic joint.

5 Diverter System

The purpose of a diverter system is to direct mud returns to processing and to divert any low pressure gas in the riser away from the drill floor, and to discharge it to a safe area. The diverter is mounted in the housing directly below the drill floor. The upper flex/ball joint is typically attached below the diverter.

7 Flex and Ball Joints

Flex or ball joints are used at the top and bottom of the riser to allow for angular displacement thus reducing the bending stresses at both ends of the riser string. Intermediate flex or ball joint may also be fitted below the telescope joint. Typically flex joints have a rotational stiffness which makes them more effective in controlling riser angles.

9 Telescopic Joint

The basic function of the telescopic joint is to accommodate the relative translational movement between the Unit and the riser due to heave, tidal changes, Unit offset, and riser shape. A telescopic joint has an outer barrel which is connected to the riser string and an inner barrel which is connected to the drilling Unit. The telescopic joint also has brackets for the goosenecks which connects to the drape hoses for auxiliary lines. The tensioning system is connected to the outer barrel of the telescopic joint, normally through a tensioner ring, to provide tension to the riser string.

11 Riser Joints

11.1 Typical Riser Joint

A riser joint is typically an assembly of riser pipe, coupling box and pin, choke and kill lines, auxiliary lines, choke/kill/auxiliary line support brackets, and other devices for guidance and/or supporting buoyancy modules. A typical full length riser joint has length ranging from 50 to 90 feet.

11.3 Riser Couplings

Riser couplings are the connectors at each end of the riser joint that link one joint to another. The riser joint coupling rating often controls the maximum allowable tension that can be applied to the riser string.

11.5 Auxiliary Lines

Auxiliary lines typically include Choke/Kill lines to carry fluid along the length of the riser. C&K lines are used during well control and should be rated for the maximum expected well pressure. Besides the C&K lines, the auxiliary lines of modern drilling risers may also consist of a mud booster line, and one or two hydraulic lines. They are mounted to the main tube through supporting brackets. Depending on the design of the riser joint couplings, these lines may be able to share the tension load of the main tube.

11.7 Buoyancy Module

The main function of buoyancy modules is to reduce the top tension requirement for deeper water applications. The buoyancy modules are fixed to the riser joints with clamps. Syntactic foam is the most commonly used material for the module. Foam buoyancy modules are typically installed in pairs around the riser joint, several pairs per joint, and have cutouts to accommodate auxiliary lines. The buoyancy modules are normally rated for a specific water depth based on the foam collapse pressure.

11.9 Pup Joints

Pup joints are riser joints that are shorter than full length riser joints. The pup joints are normally available in variable lengths to accommodate different operating water depths.

13 Other Special Riser Joints

13.1 Spider and Gimbal

The spider is a device equipped with dogs to suspend the riser string at the rotary table during riser deployment and retrieval.

The gimbal is a device for hanging-off the riser in severe weather, which allows the top of the riser to rotate freely to avoid excessive bending moment.

Both the spider and gimbal have a maximum tension rating, which is often less than the tension rating of the tensioning system and/or the riser joints.

Gimbal also has rated rotation angle limit, which is not to be exceeded during operation.

13.3 Landing Joint

The landing joint is a riser joint temporarily attached above the telescopic joint used to land the BOP stack on the wellhead, when the telescopic joint is collapsed and pinned. It may also be used as the top-most joint for hanging-off the riser in a storm.

13.5 Subsea Fill-up Joint

The subsea fill-up joint is a special riser joint, which has a valve to allow the riser annulus to be opened to the sea in order to prevent the collapse of the riser pipe in case of mud loss. In order to have it function automatically, there is often a minimum water depth requirement.

13.7 Various Adapters

There are often various riser adapters in the riser string, which are special joints for the transition of different riser diameters, especially around the diverter and upper ball/flex joint at the top, and the LMRP and bottom ball/flex joint at the bottom.

15 Lower Marine Riser Package (LMRP)

The Lower Marine Riser Package (LMRP) usually includes a riser adapter, flex/ball joint, annular BOPs, subsea control pods, and a hydraulic connector, which mates the riser system to the BOP stack. The LMRP provides a disconnection point between the riser and the BOP stack. It also provides hydraulic control of the BOP stack’s functions through the control pods.

17 Blowout Preventer (BOP) Stack

The Blowout Preventer (BOP) stack, normally at the bottom of the riser string and on top of the wellhead, is able to shear the drill pipe and/or inner casing inside the riser main tube and close-off the well opening to prevent a blowout event or to prepare for an emergency disconnect. The time required to shear a drill pipe and/or inner casing is often the required lead time for the drift-off/drive off red circles.

SECTION 3 Riser Analysis Evaluation Considerations

1 General

The purpose of riser analysis is to evaluate if the riser system is adequate and fit for purpose, which should include evaluation on functional requirement and structural integrity. In general, the riser analysis is to evaluate the following:

i) The riser has sufficient top tension to maintain the structural stability of the riser string.

ii) The riser has sufficient top tension to resist environmentally induced load effects while performing its intended functions.

iii) The riser has sufficient top tension at emergency disconnection to prevent damaging subsea equipment and be able to keep the riser recoil to acceptable level.

iv) All riser components are operating within their intended limits.

v) The forces and moments transferred to the BOP stack, wellhead and casings are at or below specified limits to avoid damage to the well facility.

3 Riser Design Guidelines

API RP 16Q "Design, Selection, Operation and Maintenance of Marine Drilling Riser Systems" [3] provides drilling riser structural integrity acceptance guideline applicable to riser global responses, which include allowable flexible joint angle, allowable stresses, and top tension requirement as listed below. The results from the riser system analysis will be used to evaluate if the riser system is adequate and fit for purpose.

i) *Allowable Flexible Joint Angle.* Applicable to flexible joints at all locations of the riser system

- For normal drilling condition, the allowable mean value of 2° and allowable maximum value of 4° is applied. Less mean and/or maximum angle may be applied in order to reduce wearing to the flexible joint and avoid key seating.
- For condition riser is connected to well but no drilling or riser is disconnected from well, 90% flexible joint capacity is applied.

ii) *Allowable Stresses.* The maximum allowable nominal stress for strength check and significant dynamic stress range for fatigue check are considered.

- The maximum allowable nominal stress of 0.67 × *SMYS* is applied for all conditions. The stress refer to the static stress plus the maximum dynamic stress amplitude at the mid-wall of the main riser pipe away from any stress concentration, and it is to be calculated according to Von-Mises stress failure criteria,
- Significant dynamic stress range amplitude of 10 ksi for nominal stresses and 15 ksi for local peak stresses is applied for normal drilling operation condition. These values refer to the average of the one third highest variation ranges in principal stress time history, and they are not fatigue limits but are indicator that further fatigue analysis may be necessary.

iii) *Top Tension Requirement.* Three top tension requirements including the minimum top tension, dynamic tension limit, and maximum tension setting are considered.

- The minimum top tension (T_{MIN}) is the minimum top tension required to prevent global buckling of riser in the event of the sudden loss of pressure in a tensioner or tensioner pair.
- The dynamic tension limit (DTL) is the highest dynamic tension that tensioner can safely generate. Determination of the DTL should consider pressure and structure limits of each tensioner and its supporting structure as well as tension oscillation in any tensioner caused by Unit offset and wave induced motion.
- Maximum top tension setting (T_{MAX}): the highest permissible tension setting at tensioner mid-stroke. Sufficient margin should be considered so that any anticipated condition (such as wave-induced vessel motions, offset, and/or tide change) will not cause tension in any tensioner to exceed DTL.

Other considerations, such as riser or wellhead loads, riser recoil response, and minimum tension required to separate the LMRP connector for emergency disconnection may also affect the above top tension requirement and setting.

The determination of the minimum top tension, T_{MIN}, for a typical wire-rope tensioner system in-which sudden loss of tension due to failure of one or two tensioners, can be calculated by the following equations from [3]:

$$T_{MIN} = \frac{T_{SR\min} N}{R_f (N - n)} \quad (3.1)$$

$$T_{SR\min} = W_s f_{wt} - B_n f_{bt} + A_i (d_m H_m - d_w H_w) \quad (3.2)$$

where

T_{MIN}	=	minimum top tension
$T_{SR\min}$	=	minimum slip ring tension
N	=	total number of tensioners supporting the riser
n	=	number of tensioners subject to sudden failure
R_f	=	reduction factor relating vertical tension at the slip ring to tensioner setting to account for fleet angle and tension variation due to mechanical and hydraulic effects in the tensioner system. The amount of tension variation can increase as Unit motion increases (value of 0.9 - 0.95 is typically used for non-drilling and drilling modes)
W_s	=	submerged riser weight above the point of consideration
f_{wt}	=	submerged weight tolerance factor, minimum value = 1.05 unless accurately weighted
B_n	=	net lift of buoyancy material above the point of consideration
f_{bt}	=	buoyancy loss tolerance factor resulting from elastic compression, long term water absorption, and manufacturing tolerance, maximum value = 0.96 unless accurately measured by submerged weighing with compression of rated water depth
A_i	=	internal cross sectional area of riser including choke, kill, and other auxiliary lines
d_m	=	drilling fluid density
H_m	=	drilling fluid column to point of consideration
d_w	=	sea water density
H_w	=	sea water column to point of consideration including storm surge and tide.

For a typical direct-acting tensioner system, a sudden loss of all pressure on the rod side of a tensioner can produce a downward-acting force on the tension ring. In order to resist the pressure acting to the blind side of the piston as well as weight of the piston, rod, and portion of the ring supported by the failed tensioner, the determination of the minimum riser tension, $T_{\min}$, may be calculated by the following equation from [3]:

$$T_{\min} = \frac{N}{R_f\,(N-n)} \bullet \left(T_{SR\min} + nW_{piston/Rod} + \frac{nW_{Ring}}{N} + nF_{BSP} \right) \qquad (3.3)$$

where

$T_{SR\min}$ = defined by Equation (3.2)

N = total number of tensioners supporting the riser

n = number of tensioners subject to sudden failure

$W_{Piston/Rod}$ = weight of the failed tensioner piston and rod

$\frac{W_{Ring}}{N}$ = portion of the ring supported by the failed tensioner

F_{BSP} = force generated by pressure acting on the blind side of the piston.

Other failure scenarios, such as the failure of the upper connection of a direct-acting tensioner to the rig, or other tensioner system configurations may create a different set of loads that the remaining intact tensioners should support. If so, Equation (3.3) may require additional modifications to meet the intent of this sudden tensioner-loss criterion.

The minimum top tension settings should be set high enough that the failure scenarios will not produce momentary effective compression in the riser.

5 Other Analysis Evaluation Considerations

Other riser analysis considerations may include the following:

- Overpull requirement above specified riser location to maintain positive tension for safe riser operation.
- The stroke limit of the tensioners and the telescopic joint
- The clearance in the moonpool, which can result in an additional limitation on the upper ball/flex joint.
- Possible impact between the riser and diverter housing or moonpool during deployment and retrieval.
- The offset limit for a connected riser based on the capability of the station-keeping system
- The tension rating of the riser joints and couplings
- The fatigue life requirement when operating in areas with high/storm waves and/or strong current. A factor of safety of 3 is often applied for typical drilling riser with frequent inspection. For drilling riser cannot be inspected frequently, higher factor of safety may be required.

SECTION 4 Riser System Modeling

Drilling riser system is complex, and it can be modeled by different approaches depending on the purpose of the analysis. Since riser analysis evaluation focuses on riser global system response and performance, these Guidance Notes concentrate on the global modeling approaches and modeling considerations applicable to riser system analysis.

For conditions that riser is connected to a well, realistic simulation in the drilling rise system analysis may require appropriate modeling of the well system including the wellhead connector, well conductor/casings, and soil interaction with well conductor.

1 Required Information

1.1 Information about the Riser String

The modeling of the riser system requires complete information about the riser string, which includes:

i) Properties of tensioner system:

- Number of tensioners
- Number of tensioners which can fail with a single point failure
- DTL
- Maximum stroke, and the position of the telescopic joint corresponding to the mid or full-stroke

ii) Properties of slick riser joints:

- Number of available slick joints
- Joint length
- Main pipe OD
- Main pipe ID
- Flange OD
- Steel joint weight in air
- Steel joint weight in water
- Yield stress
- Tension rating of the riser joint and couplings
- Collapse pressure rating of the riser joint
- Stress amplification factor (*SAF*) at weld details

iii) Properties of buoyed joints with buoyance module:

- Buoyancy module water depth rating
- Number of available joints for each depth rating
- Joint length
- Main pipe OD
- Main pipe ID
- Steel joint weight in air

- Steel joint weight in water
- Material properties
- Tension rating of the riser joint and couplings
- Collapse pressure rating of the riser joint
- Stress amplification factor (*SAF*) at weld details
- Buoyancy module OD
- Buoyancy module weight in air per riser joint
- Buoyancy module net lift in water per riser joint
- Buoyance loss factor (if applicable)

iv) Properties of VIV suppression device (if applicable)

- Dry weight
- Wet weight

v) Properties of pup joints, fill-up joint, etc.:

- Joint length
- Main pipe OD
- Main pipe ID
- Steel joint weight in air
- Steel joint weight in water
- Material properties tension rating of the riser joint and couplings
- Stress amplification factor (*SAF*) at weld details
- Minimum water depth for the fill-up joint

vi) Properties of auxiliary lines:

- Number of lines
- Auxiliary line OD
- Auxiliary line ID
- Auxiliary line seal diameter
- Auxiliary line distance to main pipe
- Auxiliary line pressure rating
- Scenarios of operational pressure in auxiliary lines
- Gap at connector shoulder, if sharing load

vii) Properties of telescopic joint:

- Collapsed length
- Extended length, or maximum stroke
- Length at preferred initial stroke
- Outer barrel OD
- Outer barrel ID
- Outer barrel length

- Inner barrel ID
- Outer barrel weight in air
- Outer barrel weight in water
- Total joint weight in air
- Slip ring weight, if counted separately
- Slip ring position respect to the base of outer barrel
- Tension limit when collapsed, if any
- Tension limit when fully stretched, if any

viii) Properties of top and bottom ball/flex joints:

- Joint height
- Stiffness or stiffness curve
- Maximum rotation angle
- Tension limit, if any

ix) Properties of diverter:

- Height from RKB to the bottom of the diverter or the diverter flex joint
- Opening ID of the diverter housing
- Height from RKB to the bottom of the diverter housing

x) Properties of LMRP and BOP:

- Stack height
- Overall dimensions
- ID
- Structural effective OD
- Weight in air
- Weight in water
- Overpull requirement for emergency disconnect
- Bending capacity rating of connectors
- Tension limit, if any

1.3 Information about the Unit

A static analysis requires the following Unit information in general:

i) Operating and/or survival drafts

ii) Elevation of RKB to MWL, baseline or keel

iii) Moonpool dimensions or the limiting angle to maintain clearance

A dynamic analysis often requires the following additional Unit information:

iv) Motion characteristics:

- Motion RAOs or load RAOs with other load effects of Unit at the operating and/or survival drafts. Other load effects may include hydrostatic restoring forces, added mass, radiation damping, wave drift QTF, wave drift damping, current and wind loads, etc.

- Coordinate system of the RAOs
- Convention of wave directions for the RAOs
- Phase angle definition of the RAOs
- Reference point of the RAOs and its coordinates

v) Drill floor information:

- Relative longitudinal, transverse and vertical position from RKB to the reference point of the RAOs

1.5 Information of the Site

Typical riser analyses need the following site-specific information:

i) Water depth

ii) Wellhead elevation from seabed

iii) Maximum anticipated mud weight

iv) Metocean conditions, including:

- Current profiles, with current velocities and directions at different water depth levels
- Associated waves, with significant wave height, peak period, wave spectrum and its parameters, and wave directions

In case it is required to assess the effects of well construction, the following information is required:

v) Well construction scheme

vi) Wellhead bending capacity

vii) Properties of the conductor and inner casings:

- Length of joint for each segment
- OD
- ID, wall thickness, or unit length weight
- Material properties
- Connector bending capacity and stiffness

viii) Properties of soil:

- *p*-*y* curves for different penetration depths; or
- Soil undrained shear strengths, submerged unit weights and strains at 50% of the maximum stress on laboratory undrained compression tests at different penetration depths

3 Riser String

3.1 Riser Joints

In the riser system analysis, riser joints is generally modeled as homogenous pipes. Since the drilling riser joints normally have auxiliary lines attached and with couplings at the ends, the modeled homogenous pipe should be equivalent to the riser joint in the following aspects:

i) Mass and buoyancy, including the riser fluid in main tube and auxiliary lines

- The mass should include the mass of the whole riser joint and the mass of the fluids in the auxiliary lines.
- The modeled pipe OD and ID should provide the same buoyancy and submerged weight as the riser joints in water.

ii) Hydrodynamic added mass and drag

- The equivalent added mass and inertia coefficients should include the effect of auxiliary lines and buoyancy modules if present.
- The equivalent drag coefficient and drag diameter should include the effect of auxiliary lines and buoyancy modules if present.

iii) Structural stiffness in tension and bending, which may include the main tube and auxiliary lines

- The stiffness of auxiliary lines, especially the tensile stiffness, may be included in case of load-sharing design. Load sharing may be applied to full or partial riser length. For partial load sharing case, load sharing length range and locations are to be specified.

iv) Structural cross section or the main riser pipe OD and ID may be used for the calculation of stresses. For load sharing design, load distribution on main and auxiliary lines should be determined before the stress calculation.

3.3 Load Sharing from Auxiliary Lines

For some riser joint designs, the auxiliary lines are capable of sharing axial load from the main riser pipe. Typically these auxiliary lines have a gap at the coupling and only start sharing the tension when the main pipe elongation exceeds the gap. If the riser joint is only in tension, the tension in the main pipe can be calculated as follows:

$$T_M = T_0 \qquad \text{for } T \le T_0 \qquad (4.1)$$

$$T_M = T_0 + (T - T_0)\frac{A_M}{A_M + A_A} \qquad \text{for } T > T_0 \qquad (4.2)$$

$$T_0 = E\,A_M\,\frac{gap}{L} \qquad (4.3)$$

where

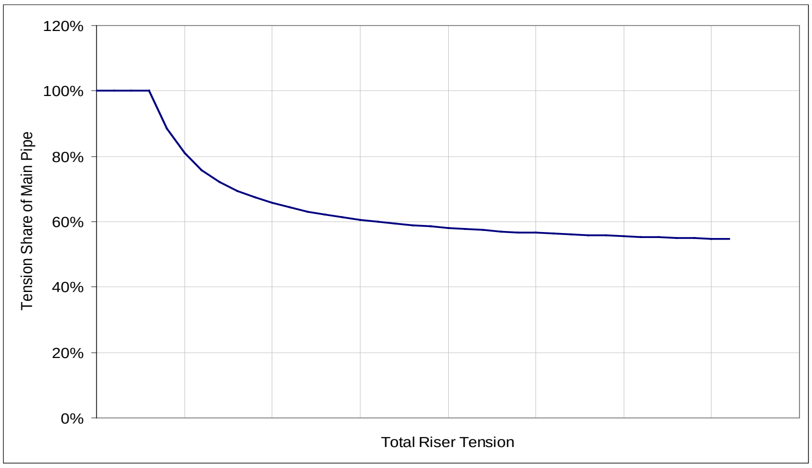
T	=	total riser tension
T_0	=	total riser tension to close the gap of auxiliary lines
T_M	=	tension in the main pipe
A_M	=	steel cross section area of the main pipe
A_A	=	total steel cross section area of the auxiliary lines
L	=	riser joint length

Section 4, Figure 1 depicts an example of the load sharing factor of the main riser pipe.

The exact load sharing is more complicated than the above equations and requires nonlinear finite element analysis (FEA) to predict. The riser is not only in tension but also in bending and twisting. The tube end conditions, gaps and standoff at connectors, tolerances, flange flexibility, brackets, buoyancy system, thermal effects, and pressure effects can all affect the load sharing results.

Based on the example in Section 4, Figure 1, the riser analysis can be simplified by assuming the main riser pipe takes 100% of riser tension when the riser tension is less than a set level, and then 80% of the riser tension is taken by the main riser pipe when the riser tension exceeds this level. More realistic modeling for load sharing should be considered when load sharing characteristics become available.

FIGURE 1
Example of Riser Main Pipe Load Sharing Factor



3.5 Telescopic Joint

Telescopic joint can be modeled implicitly or explicitly.

For implicitly modeling, the telescope joint length change is to be tracked for the stroke.

For explicitly modeling, the telescopic joint may be modeled as two parts: the outer barrel and the inner barrel. The outer barrel may be modeled in the same way as normal riser joints. The inner barrel may be modeled with minimal tension stiffness and a normal bending stiffness to simulate the stroke.

3.7 Ball/Flex Joint

The ball/flex joint is normally modeled as a rotational spring. The flex joint normally has lower rotational stiffness at a larger angle. It is preferred to have a non-linear rotational spring model to reflect the stiffness curve. If linear rotational spring modeling is used, the stiffness corresponding to the limiting angle is suggested.

3.9 Conductor and Casings

Well conductor can be modeled as a section of homogenous pipe. The well design often has one or more inner casings cemented together with the well conductor. Generally, a model of only the outer pipe (well conductor) with representative thickness is adequate since the interior strings have relatively low bending resistance. Sometimes, the well conductor and inner casings may be modeled with the riser system for the evaluation of well integrity. In this case, cement level and modeling is an important factor and should be included in a detailed FEA, which also requires pipe-in-pipe (PIP) modeling of the conductor and casings.

The modeling of the well conductor and/or casings should be deep enough to cover the complete range that produces significant bending moments and deflections.

5 Boundary Conditions

5.1 Top Boundary Condition

The top boundary condition normally has the following options:

i) *Fixed.* If the riser is connected or hanging-off on the diverter through the collapsed telescopic joint, the top boundary condition should be considered fixed to the Unit.

ii) *Pinned.* If the riser is in the deployment, retrieval or hanging-off on the gimbal, the top boundary condition may be considered as pinned unless specified otherwise by the gimbal rotational stiffness. In this case, the top riser angle related to the Unit often needs to be limited to maintain the clearance to the diverter housing and/or moonpool.

The position and motions of the top end are often modeled as follows:

i) *Specified.* The top end position and motions may be calculated first, and then input for riser analysis. The motions can either be a time history, or a set of harmonic motions, which represents the Unit's maximum motions in a storm condition.

ii) *Calculated.* The top end motions may be calculated in the riser analysis using sea states data and Unit's motion RAOs or load RAOs with other load effects. For this case, an initial mean position which represents the Unit's initial offset and/or low frequency motions, may be superposed to calculate the top end motions.

5.3 Top Tensioning System

The top tensioning system and tensioners may be modeled with the following approaches, as appropriate:

i) A fixed upwards force in the Unit's local coordinate system on the top of the riser string:

- The fixed force can represent the total tension provided by the tensioning system.
- The telescopic joint is normally modeled implicitly with this method.
- A lateral spring on the outer barrel of the telescopic joint may be modeled to simulate the lateral restoration force from the tensioning system when the riser is rotating around the upper ball/flex joint. The spring stiffness may be calculated by the following equation:

$$k = T/h \qquad (4.4)$$

where

k = lateral spring stiffness

T = top tension on the outer barrel

h = height from the ball/flex joint to the tensioner ring on the outer barrel

ii) One winch, at a fixed tension level, with one end attached to the Unit's drill floor center and the other end attached to the outer barrel of telescopic joint at the centerline:

- The fixed tension level can represent the total tension provided by the tensioning system.

iii) One spring with one end attached to the Unit's drill floor center and the other end attached to the outer barrel of the telescopic joint at the centerline:

- Stiffness of the spring should be the same as the tensioning system.
- The spring should have an initial length and produce the required tension at the designed telescopic joint stroke.

iv) Multiple winches, each at fixed tension level, with one end attached to the Unit's drill floor and the other end attached to the outer barrel of the telescopic joint:

- The fixed tension level should represent the tension of each tensioner.
- The attachment point on the drill floor should be defined such that the winch line has a proper initial fleet angle relative to the riser string.
- The attachment point on the outer barrel of the telescope joint may be either at the centerline or at an offset location. The latter approach may require additional modeling for the tensioner ring.

v) Multiple springs with one end attached to the Unit's drill floor and the other end attached to the outer barrel of the telescopic joint:

- Stiffness of each spring should be the same as each tensioner.
- Each spring should have an initial length and produce the required tension at the designed telescopic joint stroke.
- The attachment point on the drill floor should be defined such that the spring line has a proper initial fleet angle relative to the riser string.
- The attachment point on the outer barrel of the telescope joint may be either at the centerline or at an offset location. The latter approach may require additional modeling for the tensioner ring.

5.5 Bottom Boundary Condition

The bottom boundary condition normally has the following options:

i) *Fixed*: The bottom boundary can be modeled as fixed at sea bed level. This condition, in general, will provide conservative results in term of the lower ball/flex joint angle and the bending moments at the LMRP, BOP, and wellhead connectors.

ii) *Rotational and Lateral Springs*: If there are sufficient supporting data, well conductor at the seabed level may be modeled by a rotational and lateral springs to allow a rotation and deflection at the seabed level.

iii) *Restrained by Soil*: In the case of riser drift-off/drive-off and weak point analyses, well conductor is often found to be the critical component and therefore is required to be included into the analysis model. In this case, the conductor is often modeled with sufficient length and the bottom end is often modeled as free end, and the well conductor is restrained by soil in term of p-y curves in lateral direction and friction in axial direction.

iv) *Free*: If the riser is disconnected during riser deployment, retrieve, or storm hung off.

5.7 Soil Restraint

Soil restraint is normally modeled as a series of soil resistance-deflection curves, or *p*-*y* curves. A *p*-*y* curve is normally given up to a particular soil depth based on conductor/casing diameter and soil properties.

A method in API RP-2GEO may be applied to calculate *p*-*y* curves using the soil undrained shear strength, submerged unit weight, and strain at 50% of the maximum stress from laboratory-conducted undrained compression tests. Soil type is to be checked before applying the method.

When calculating *p*-*y* curves, there are two approaches; static and cyclic. The static approach normally produces stiffer soil springs, while the cyclic approach tends to result in softer soil springs. A stiffer soil is often more conservative for the lower ball/flex joint angle and the bending moment on the LMRP, BOP and wellhead connectors. A softer soil is often more critical to the bending moment on the well conductor/casings. Due to uncertainty of the soil properties, both lower and upper bound values may be considered for both static and cyclic approaches.

The static approach is often used for riser drift-off/drive-off and weak point analyses, especially for deep water, because there are little dynamics effects that would be transferred down to the seabed level. However, if tensioner is stoke out, large dynamic loading can be transferred to the seabed level, using cyclic soil stiffness may be more appropriate.

For areas having strong bottom current, riser VIV could cause cyclic loading to the soil. In this case, using cyclic soil stiffness may be more appropriate.

SECTION 5 Riser Space-out and Stability Calculation

The purposes of this first step drilling riser analysis are:

- To determine the riser space-out configuration based on the water depth and available riser joints, and
- To determine whether the top tensioning system has sufficient capacity to support the specified mud weight.

In order to verify the feasibility of a space-out arrangement, dynamic hang-off analysis including hard hang and soft hang-off is to be performed to check if positive effective tension can be maintained along the riser string. This analysis is often iterated until feasible riser space-out arrangement is obtained.

1 Required Information

The required information is listed in Subsection 4/1.

With regard to the water depth, one of the following should be provided:

- Water depth from wellhead to RKB
- Water depth from seabed to RKB
- Water depth from seabed to MWL
- Water depth from wellhead to MWL

In case for site specific space-out, clarification is often required to establish the correct riser string length for the analysis to determine adequate pup joint length.

3 Riser Space-out

The riser space-out should satisfy the following considerations as minimum:

i) The collapse pressure rating of the riser joints should be checked, taking into account wall thickness wear and wastage. For deep water operation, the fill-up joint may be added at an appropriate water depth (reliability of this device may require attention).

ii) Enough buoyant joints should be applied to minimize the total wet weight to allow the required top tension within the capacity of the tensioning system for the specified mud weight.

iii) The water depth ratings of buoyancy modules should be checked against the water depths where they are to be placed.

iv) Sufficient number of slick joints should be arranged towards the bottom of the string to prevent the string from experiencing compression during hang-off and to provide enough submerged weight for deployment.

v) In regions of high current, if there is sufficient top tension capacity, staggering buoyant joints with slick joints may be considered to mitigate VIV.

vi) If there is sufficient top tension capacity, slick joints may be selected instead of buoyant joints in regions of greatest current and wave loads, such as the splash zone.

vii) The Unit's telescopic joint should be at a proper initial stroke to allow for the Unit's heave motions and lateral offset as well as riser response shape in the environment. The maximum up and down stroke length should be evaluated from riser dynamic analyses.

viii) A pup joint may be added near the top of the LMRP to allow the stack to quickly pass the splash zone during deployment and retrieval.

5 Riser Stability Calculation

5.1 Minimum Top Tension

The stability calculation is to calculate the minimum required top tension to verify that the tensioning system has sufficient capacity for the structural stability of the riser string with anticipated mud weight and possible of loss of one or two tensioners.

In addition to the above requirement, the minimum top tension should be sufficient to maintain satisfactory top and bottom angles for drilling operations and satisfactory riser recoil response in case of an emergency disconnect of a DP Unit. Refer to Section 7 for drilling operation analysis and Section 12 for riser recoil analysis.

5.3 Maximum Top Tension

Besides the minimum top tension requirements, maximum allowable top tension of the riser string is often limited by factors other than the tensioning capacity. These factors include the following:

- The structural capacity of the drill floor which supports the tensioning system
- The tension rating of the riser joints and couplings
- The tension limit of the LMRP, BOP and/or wellhead
- The tension for safe emergency disconnection and riser recoil
- The pressure end load (PEL) from auxiliary lines

For deep water risers, the auxiliary lines are often operating at a very high pressures. Such pressures acting on the seal of an auxiliary line and its connector at the top becomes a large additional tension on the riser coupling, which is then transmitted to the riser string. This additional load is called pressure end load (PEL).

The PEL of an auxiliary line can be estimated from the following equation:

$$PEL_i = A_{Si}[P_i - (\rho_i - \rho_{sw})\, g\, WD] \quad (5.1)$$

where

PEL_i	=	pressure end load of the *i*-th auxiliary line
A_{Si}	=	cross sectional area of the connector seal of the *i*-th auxiliary line
P_i	=	rated pressure at the BOP stack of the *i*-th auxiliary line
ρ_i	=	fluid density of the *i*-th auxiliary line
ρ_{sw}	=	sea water density
WD	=	water depth at the BOP stack

The allowable tension on the riser can then be calculated as follows:

$$T_{\text{allow}} = (T_R - \sum PEL_i - T_a + W_a)/R_f \quad (5.2)$$

where

T_{allow}	=	allowable tension of riser joint
T_R	=	minimum tension ratings of the investigated riser joint and coupling
PEL_i	=	pressure end load of the *i*-th auxiliary line at particular operating condition
R_f	=	reduction factor relating vertical tension at the slip ring to tensioner setting to account for fleet angle and mechanical efficiency

T_a = additional allowance for the bending load from the environment or tensioner loss, as well as the additional tension caused by tensioner stroke and stiffness

W_a = weight allowance for the riser string wet weight, including the mud, above the investigated riser joint

Because the riser joints may have different wall thicknesses and hence tension ratings, the maximum tension may be controlled at a lower riser joint.

5.5 Riser Space-out and Stability Calculation Procedure

The main purposes of the analysis are:

- To determine feasible riser arrangement configuration based on water depth and available riser joints
- To determine allowable maximum drilling fluid (mud) density
- To determine if the top tensioning system has sufficient capacity

A suggested analysis procedure is:

i) Obtain a preliminary riser space-out arrangement using required information and riser space-out considerations in Subsections 5/1 and 5/3, respectively

ii) Calculate T_{allow} based on the minimum tension rating of the investigated riser joint/coupling and the effect of end pressure load as indicated in 5/5.3.

iii) Check if $T_{\text{allow}} \le DTL*N$. If $T_{\text{allow}}/N > DTL$, $T_{\text{allow}} = DTL*N$.

iv) Calculate total riser string submerged weight, $T_{SR\text{min}}$, using eq. (3.2). In the calculation, all riser joints above LMRP or the point of consideration including main joint, drilling mud, buoyancy module, and component lines such as choke, kill and auxiliary lines as well as their internal fluid are to be taken into account.

v) Use Eq. (3.1) to calculate T_{MIN}, the minimum required toptension.

vi) Varying drilling mud density to calculate the corresponding $T_{SR\text{min}}$ and T_{MIN} using eq. (3.1) and (3.2) and validate the maximum allowable mud density by checking if the associated T_{MIN} is less than T_{alllow}.

vii) Carry out storm hang-off dynamic analyses including hard and soft hang-off for the worst expected environmental conditions to validate the preliminary riser space-out arrangement by checking if effective tension is positive along the riser string during hang-off operation. Detail of the hang-off dynamic analysis can be found in the Section 6.

viii) If the hang-off analysis results are not satisfactory, a revised space-out arrangement is required and the analysis procedure in this section is to be iterated until feasible space-out arrangement and associated maximum allowable drilling mud density is obtained.

SECTION 6 Storm Hang-off Analysis

The purpose of this analysis is to determine the limiting sea states in which the riser can be hung-off without damaging the riser or to determine the number of riser joints that have to be retrieved before evacuation for severe storms. It is especially important for deep water risers, since the natural period of the riser's axial dynamic response may be in the wave's frequency range.

1 Required Information

In addition to the information listed in Subsection 4/1, the following information is required for this analysis:

i) The riser space-out as developed in Section 5

ii) The hang-off arrangement, including:

- Hard hang-off
  - Whether the diverter, upper ball/flex joint and telescopic joint will be retrieved
  - Whether additional riser joints will be retrieved and whether a landing joint will be deployed
- Soft hang-off:
  - Strokes of the telescopic joint and tensioners.

Because this analysis is focused on hang-off performance in severe environments, the required metocean conditions are the extremes for the operating and survival situation, especially the waves.

3 Types of Riser Hang-off

Riser hang-off can be done in at least two ways: hard and soft hang-offs. The hang-off configuration can support just the LMRP, after an emergency disconnect or a planned disconnect, or it can support the BOP during its deployment or retrieval. Riser hang-off is intended for limited sea conditions, not for hurricane or tropical revolving storms.

In the case of hard hang-off, there are several options. The primary option is hanging-off the riser on the gimbal after retrieving the diverter and upper ball/flex joint with the telescopic joint collapsed and locked. If time allows, the telescopic joint and some additional riser joints may be also retrieved. With this option, the landing joint is put beneath the gimbal to avoid impact damage to the riser joint by the corner of diverter housing.

The hard hang-off is typically analyzed by time domain approach. The main concerns of hard hang-off are possible compressive load, excessive top tension due to axial dynamics, and possible impact of the riser to diverter and/or moon-pool, the analysis should be focused on the axial dynamics caused by waves and the riser clashing to diverter and/or moon-pool by waves and current.

In the case of soft hang-off, the riser is allowed to stroke on the telescopic joint with support coming from either the tensioners or the combination of the tensioners and the heave compensator. In this case, the tension fluctuation in the riser is reduced. As a result, its weather envelope could be larger than that of a hard hang-off, provided that the maximum stroke of the telescopic joint and tensioners can accommodate the riser dynamic motions.

The time domain approach is typically used to simulate the soft hang-off. The telescopic joint and tensioners are allowed to stroke during the soft hang-off, which could be fully collapsed or fully stretched under severe environmental conditions.

5 Considerations in Modeling

The riser model should be created in accordance with Subsections 4/3 and 4/5. In addition, there are several special considerations as follows for the hang-off analysis.

5.1 Riser Fluid

Normally the riser's main pipe is considered to be flooded by sea water. The riser fluid in auxiliary lines may be also considered flooded by sea water.

5.3 Time Domain Riser Dynamic Simulation for Hard Hang-off

There is a special consideration in case the riser string is hung-off on the gimbal:

i) In case a riser joint, such as a landing joint or buoyed joint, is allowed to have contact with the diverter housing and/or moon-pool, the diverter housing or moon-pool may be modeled as contact elements so that the contacts between the riser and diverter housing or moon-pool can be tracked and the resulting load effects in the riser joint can be predicated. An alternative is to use a non-linear spring to simulate the gap between the riser joint and diverter housing or moon-pool.

5.5 Time Domain Riser Dynamic Simulation for Soft Hang-off

There are several special considerations when modeling the telescopic joint and tensioners:

5.5.1 Telescopic Joint

The inner barrel of the telescopic joint may be modeled as a segment with minimal tensile stiffness to simulate the stroke. In case the telescopic joint may collapse and induce a significant pulse of compression load, the inner barrel model may need to be adjusted to accommodate a greater up stroke.

5.5.2 Tensioner Ring

In order to simulate the off-center effect from tensioners, the tensioner ring may be modeled with offset, which admits each tensioner connecting to the tensioner ring at its adequate location.

5.5.3 Tensioners

The tensioners may be modeled as non-linear springs connecting the drill floor to the tensioner ring with four steps of stiffness:

i) Completely slacked, with zero tension

ii) Slacked, with the stiffness of the tensioner

iii) Tensioned within the allowable stroke, with the stiffness of the tensioner

iv) Stroked out, with the stiffness of the tensioner

A typical spring length versus tension curve is depicted in Section 6, Figure 1. The model should correspond to the top tension applied, the stroke setting and the stiffness of the tensioner.

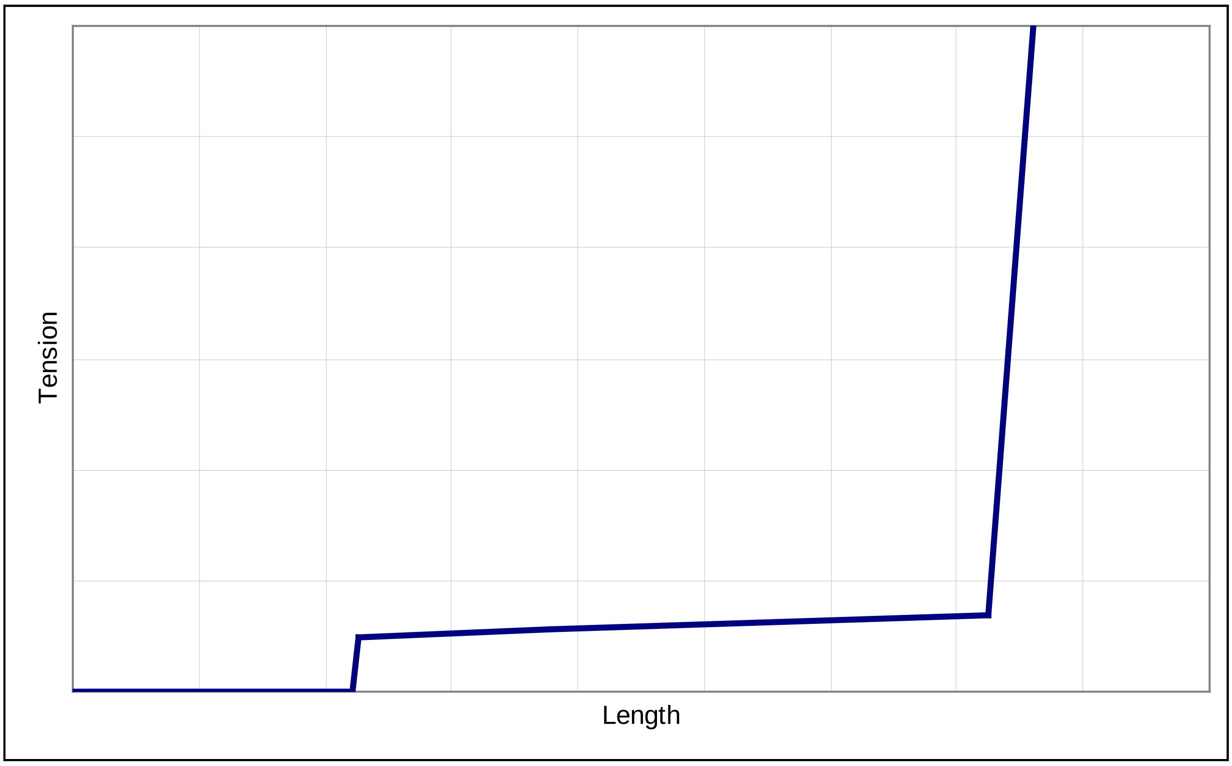
5.7 Added Mass and Damping in Hang-off Analysis

5.7.1 Added Mass

It is important to properly estimate the axial or tangential added mass of the riser joints because it directly affects the natural period of axial responses. Estimate of the added mass should consider the following:

- Axial added mass from LRMP and/or BOP
- Axial added mass from riser flanges and buoyancy modules
- Axial added mass from the uneven surfaces on the riser joints, such as clamps, straps, etc.

FIGURE 1
Spring Length versus Tension Curve for a Wire Tensioner



5.7.2 Damping

The hydrodynamic drag in the axial direction provides the majority of the damping for axial dynamics. The main contributors include:

- Axial drag of LRMP and/or BOP
- Axial drag from riser flanges and buoyancy modules
- Axial drag from the friction of both external surfaces and internal annular surface

7 Analysis Procedure

7.1 Time Domain Riser Dynamic Simulation for Hard Hang-off

Irregular wave approach may be used in the time domain simulations for riser hard hang-off. The analysis may be carried out as follows:

i) Create the Unit's model with the motion RAOs and phase angles of the corresponding loading draft.

ii) Create the drilling riser model from the drill floor to the suspended LMRP and/or BOP with proper boundary conditions, and check the accuracy of the effective tension along the riser string.

iii) Apply the environmental conditions, including the current and waves, and perform time domain simulations. In the irregular wave approach, multiple simulations with different wave seeds may be necessary to obtain the extremes. Sensitivity studies may be needed to cover the variation of wave peak periods.

iv) Evaluate the gimbal or ball/flex joint angles, stresses, and effective tensions from the simulation results.

v) The minimum effective tension along the riser string should be positive to avoid riser buckling, and the maximum tension should be within the tension limit of the gimbal or the minimum tension limit of the collapsed telescopic joint, upper ball/flex joint and diverter. The gimbal or ball/flex joint angle should be checked for riser clearance from the diverter housing and/or moonpool, unless contact modeling for diverter housing and moonpool is included in the simulation.

7.3 Time Domain Riser Dynamic Simulation for Soft Hang-off

Irregular wave approach may be used in the time domain simulations for riser soft hang-off. The analysis may be carried out as follows:

i) Create the Unit's model with the motion RAOs and phase angles of the corresponding loading draft.

ii) Create the drilling riser model from the drill floor to the suspended LMRP and/or BOP with proper boundary conditions, and check the accuracy of the effective tension along the riser string.

iii) Apply the environmental conditions, including the current and waves, and perform time domain simulations. In the irregular wave approach, multiple simulations with different wave seeds may be necessary to obtain the extremes. Sensitivity studies may be needed to cover the variation of wave peak periods.

iv) Evaluate the flex joint angles, stresses, effective tensions, as well as telescopic joint and tensioner strokes from the simulation results.

v) The minimum effective tension should be positive along the riser string to avoid riser buckling. The telescopic joint should be within the stroke range. The ball/flex joint angle should be checked to maintain the clearance from the moonpool, unless contact modeling for moonpool is included in the simulation. .

9 Mitigation for Riser Axial Dynamics

Riser hang-off axial dynamic response is affected by the mass and effective tension distribution long the riser string. In order to reduce the axial dynamic response, fewer buoyed joints and/or to put heavier weight at the bottom is recommended as a mitigation method when establishing the riser space-out. This may be achieved by assigning a sufficient number of slick joints at the bottom of the riser string.

SECTION 7 Operability Analysis

The purpose of this analysis is to determine, for each mud density, the operating envelopes that define the required top tension range and the allowable offsets of the Unit for normal drilling operation and/or no drilling but keeping the riser connected to well.

1 Required Information

In addition to the information listed in Subsection 4/1, the following information is required for the operability analysis:

- The riser space-out as developed in Section 5
- *Maximum Offset for Moored Unit:* If adjusting a moored Unit's position by active winching is impossible, its station-keeping capability may limit the maximum offset. In this case, the maximum Unit's offset from a mooring analysis is needed. .

3 Operating Modes

There are two main operating modes for a connected drilling riser: the normal drilling mode and the non-drilling mode. Each mode has a different set of requirement, especially in terms of lower, intermediate, and upper ball/flex joint angles. During normal drilling, the drill string is rotating inside the riser. This necessitates smaller ball/flex joint angles to reduce wearing and avoid keyseating. During non-drilling mode, larger allowable ball/flex joint angles is permitted so that the riser can stay connected in more severe environmental condition.

Riser operability may be analyzed by either the frequency domain or time domain approach. The analysis is often performed for a range of Unit offsets and top tension settings. Due to the large number of simulation cases, frequency domain approach is often used. In case of time domain simulations, irregular wave approach may be used.

5 Considerations in Modeling

In general, the riser model should be created in accordance with Subsections 4/3 and 4/5. In addition, the well construction and soil restraint may be modeled in case these are considered critical to assessing operations.

7 Analysis Procedure

The analysis procedure for the connected riser operability may be as follows:

i) Create the Unit's model with the motion RAOs and phase angles of the corresponding loading draft.

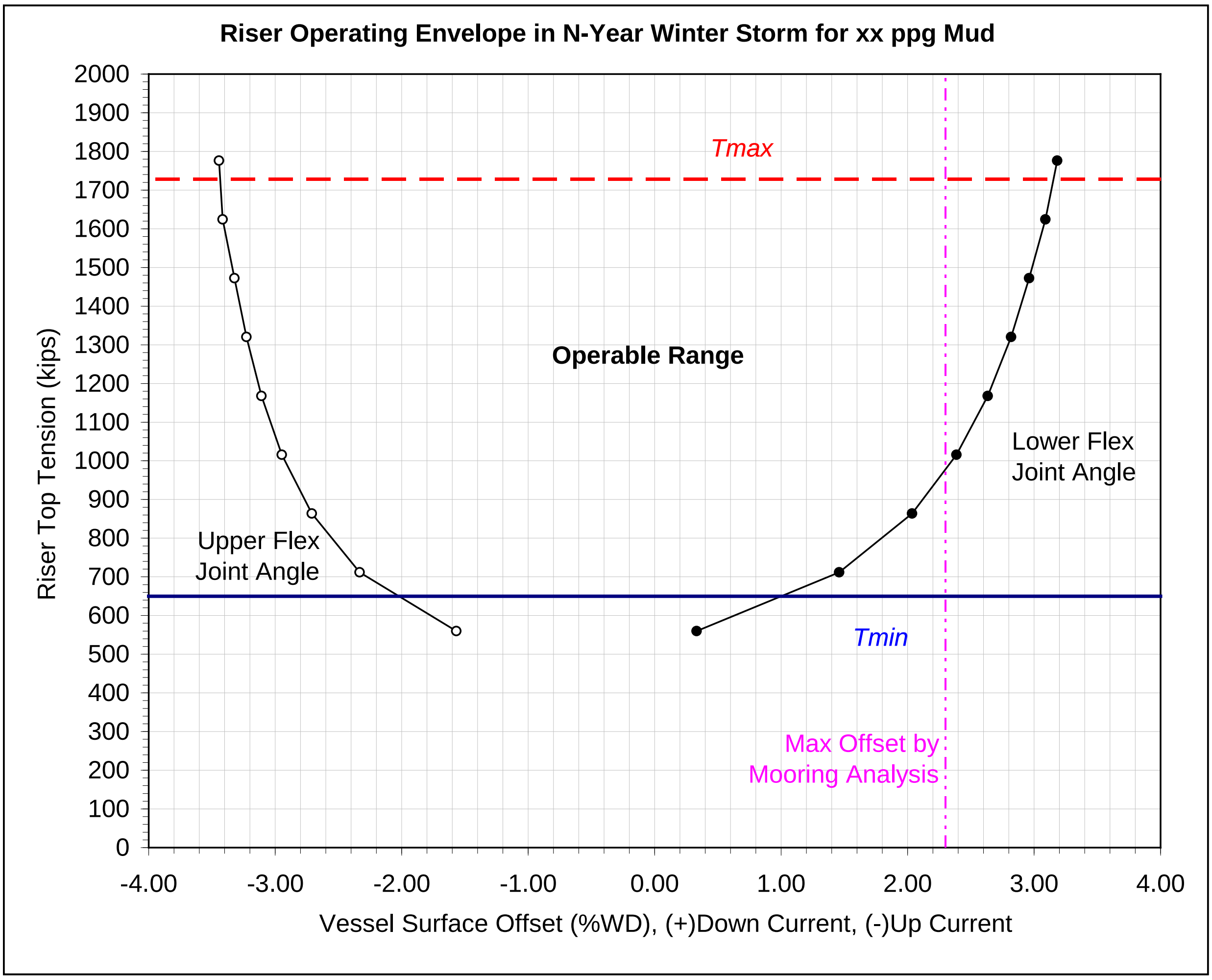
ii) Create the drilling riser model from the drill floor to sea floor or to well conductor, if required, with proper boundary conditions, and check the accuracy of the effective tension along the riser string.

iii) Apply the environmental conditions, including the current and waves, and perform frequency domain analysis or time domain simulations for a range of the Unit's offsets and top tension settings. For time domain irregular wave approach, multiple simulations with different wave seeds may be necessary to obtain the extremes.

iv) From the analysis results, evaluate the lateral displacements, ball/flex joint angles, stresses, effective tensions, bending moments at connectors, and tensioner and telescopic joint strokes, etc.

v) Create tension-offset envelopes based on the analysis evaluation as specified in Section 3. Section 7, Figure 1 depicts a typical riser operability tension-offset envelope plot.

FIGURE 1
Typical Riser Operability Plot for Drilling



SECTION 8 Deployment and Retrieval Analysis

The deployment and retrieval analysis is often performed when the Unit is to operate in a region for the first time. The purpose of the analysis is to determine the environmental window for running/retrieving the riser safely.

1 Required Information

In addition to the information listed in Subsection 4/1, the riser space-out as developed in Section 5 is required for this analysis.

Additionally, the allowable impact loads of the buoyancy modules may be used to evaluate the contact force between the buoyancy modules and the diverter housing or moonpool during the deployment and retrieval.

Because the riser deployment and retrieval operation is often started in a relatively mild environment, the metocean conditions normally consist of a set of scaled current profiles in association with a less extreme wave condition.

3 Operation Stages

The analysis should cover several stages of deployment and retrieval operation, which include at least the following:

i) The slick joint at the bottom of the riser string in the diverter housing: The contact between the slick joint and diverter housing should be avoided in order to prevent damage to the auxiliary lines;

ii) Half of the riser string deployed: The impact load between the buoyed joint and diverter housing should be investigated;

iii) The topmost buoyed joint in the diverter housing: The impact load between the buoyed joint and diverter housing should be investigated;

iv) Full length of the riser string, except the telescopic joint, deployed: The pup or slick joint should avoid impact with the diverter housing in order to prevent damage to the auxiliary lines;

5 Considerations in Modeling

In general, the riser model should be created in accordance with Subsections 4/3 and 4/5. In addition, there are several special considerations as follows.

i) The hang-off point should be considered at least one joint length above the drill floor. The top boundary condition can be considered as pinned.

ii) Deployment and retrieval analysis typically is carried out by time domain analysis. In the analysis, the diverter housing and moonpool may be modeled as contact elements so that the impact between the riser and diverter housing or moonpool can be tracked and the resulting stress in the riser joint can be included. An alternative is using a non-linear spring to simulate the gap between the riser joint and diverter housing or moonpool.

7 Analysis Procedure

7.1 Time Domain Simulation

Irregular wave approach may be used in the time domain simulations for riser deployment and retrieval analyses. The analysis may be carried out as follows:

i) Create the Unit's model with the motion RAOs and phase angles of the corresponding loading draft.

ii) Create the drilling riser model from the hang-off point to the suspended LMRP and/or BOP, add the contact model for the diverter housing and/or moonpool, and check the accuracy of the effective tension along the riser string.

iii) Apply the environmental conditions, including the current and waves, and perform time domain simulations. For irregular wave approach, multiple simulations with different wave seeds may be necessary to obtain the extremes. Sensitivity studies may be needed to cover the variation of wave peak periods.

iv) Post-process the analysis results and evaluate the lateral deflection, top riser angle, stresses, effective tension, and contact loads, etc.

v) Repeat the analysis for different stages of deployment or retrieval, different current velocities and different wave heights to determine the allowable environmental window for deployment and retrieval based on the analysis evaluation as specified in Section 3.

SECTION 9 VIV Fatigue Analysis

The VIV fatigue analysis is often required when the Unit is operating in an area of strong currents with the riser either connected or hung-off. The purpose of the analysis is to predict the fatigue damage produced by vortex induced vibration (VIV) due to currents.

Since drilling risers are routinely retrieved to the deck and thus can be readily inspected, the fatigue analysis is often used to calculate fatigue damage for survivability check in an extreme event or fatigue damage during one drilling operation cycle to provide guidance on critical locations for inspection.

1 Required Information

In addition to the information listed in Subsection 4/1, the following information is required for this analysis:

- The riser space-out as developed in Section 5
- The S-N curve and stress concentration factor (SCF) of the riser joint with associated cross section, usually for the weld details between the flange and riser pipe.
- The S-N curve and stress concentraction factor (SCF) of the riser joint connector.

In general, current profiles are required for the VIV analyses, and the following types of current data may be applied for the drilling riser VIV fatigue assessment:

- Extreme current conditions for the survivability of extreme events. A current speed build-up profile of an extreme event may be considered.
- A set of current profiles with their occurrence probabilities for predicting the accumulated fatigue damage during drilling operations
- A recorded time history of current profiles for tracking the accumulated fatigue damage during a drilling operation

Although riser VIV was once considered a cross-current vibration, it was found that the riser is actually oscillating in a figure 8-shape with an in-line component. With the right current condition, the in-line amplitude could reach the same level of as the transverse component. Since in-line component is typically not included in the VIV analysis, the directionality of the current flow may be ignored when calculating the accumulated fatigue damage unless demonstrated otherwise.

3 Analysis Approach

3.1 S-N Curve

S-N curve approach is often used for assessing VIV fatigue damage. In the assessment, appropriate S-N curve data should be used in term of the structural detail, weld geometry and environment. For details of the selection of S-N curve, refer to the ABS *Guide for the Fatigue Assessment of Offshore Structures*. With this approach, the number of fatigue cycles to failure is often given by the following expression:

$$N = \left[\frac{A}{2 \cdot \sigma \cdot SCF}\right]^{B} \quad \text{(9.1)}$$

where

N = number of fatigue cycles

σ = single amplitude of dynamic stress

SCF = stress concentration factor

A, *B* = fatigue constants derived from corresponding S-N curve.

3.3 VIV Analysis Method and Software

The analytical prediction and description of VIV are very complex. VIV often depends on the interaction between the vortex shedding frequency and the riser string lateral vibration modes. Hence, the riser VIV analysis use specialized software. Most of the VIV analysis software are frequency domain programs developed from experimental database and empirical formulation to predict the VIV amplitude and frequencies based on the current profile and riser string lateral vibration modes.

The VIV analysis software often can output the most probable mode for VIV and calculate the VIV amplitude, VIV bending stress and corresponding VIV damage. Because real current typically has different velocities, and even directions, at different water depths, the riser may oscillate in multiple modes or frequencies, and multi-frequency responses are often used to evaluate the riser fatigue life.

In frequency domain analysis, the fatigue life of single mode response is calculated as follows:

$$N(z) = \frac{A}{\Gamma(1+B/2)} \bullet \left(\frac{1}{2\sqrt{2} \cdot \sigma_{rms}(z)} \right)^{B} \quad \text{(9.2)}$$

where

$N(z)$ = fatigue life in cycles for the investigated location along the riser length z

σ_{rms} = dynamic stress RMS value

The fatigue life of multi-frequency responses is often calculated by the following equation:

$$L_M(z) = \frac{1}{\sum \frac{f_i}{N_i(z)}} \quad \text{(9.3)}$$

where

L_M = multi-frequency fatigue life

N_i = number of fatigue cycles caused by the VIV bending stress of the *i*-th participating mode

f_i = VIV frequency of the *i*-th participating mode

5 Modeling Considerations

In general the riser model should be created in accordance with Subsections 4/3 and 4/5. In addition, there are several special considerations as follows.

i) Since Unit's motions in waves are normally ignored in the VIV analysis, a connected drilling riser can be modeled up to the upper flex/ball joint with a linear spring top boundary. The stiffness of the spring and initial elongation should be set to simulate the top tension properly.

ii) Since the bottom stack is normally very rigid and not prone to VIV fatigue, a connected drilling riser can be modeled down to the lower flex/ball joint with a linear spring bottom boundary.

iii) In case riser segments beyond the upper and/or lower flex/ball joint are required to capture their effect to VIV fatigue, the riser segments beyond the upper and/or lower flex/ball joints including well conductor/casing, linearized flex/ball rotational stiffness, and/or soil *p*-*y* curves, should be modeled properly.

iv) The selection of added mass coefficients for modal analysis should appropriately reflect the current velocity and the riser's cross sectional properties.

7 Analysis Procedure

The analysis procedure for VIV fatigue calculation can be as follows.

i) Model the drilling riser by incorporating all the considerations addressed in the subsection of 9/5, and check the accuracy of the effective tension along the riser string.

ii) Apply the current profile and perform static and modal analyses to obtain riser vibration modes and corresponding natural frequencies.

iii) Create analysis case matrix based on the current flow profiles. The case matrix should cover all applicable extreme events and combinations of possible drilling riser models, top tensions, and current profiles together with their occurrence probabilities.

iv) Conduct VIV analysis for each case in the case matrix.

v) Post-process the analysis results for each case in the case matrix and evaluate the dominant VIV modes, VIV amplitudes, VIV bending stresses, and fatigue damage, etc. Identify the critical locations with the lowest fatigue lives.

vi) When calculating accumulated fatigue damage, perform the VIV analysis for all cases in the case matrix, and calculate the accumulated fatigue damage. Identify the critical locations with the lowest fatigue lives.

vii) A factor of safety of 3 is typically applied in the fatigue life calculation, and higher factor of safety may be required if the riser is not inspected frequently.

9 Mitigation Options for Riser VIV

VIV suppression devices are typically used to break up the vortex street in the wake of the riser, which in turn reduces the potential for VIV to occur. Fairings are the most commonly used VIV suppression device for drilling risers. Fairings can reduce the current drag and widen the operability envelopes in strong current. However, the additional work is required to fit and strip the fairings during the riser deployment and retrieval, thus slowing the deployment operation. Helical strakes are an alternative, which will increase current drag load but will not require additional work to fit or strip when running or retrieving the riser.

When the riser tensioning system has sufficient margin, staggering buoyed joints with bare joints could be an option in the top section if strong current is normally present. The staggering pattern reduces the correlation of vortex shedding in two adjacent riser joints and therefore reduce the VIV amplitude.

If the riser system allows, a higher top tension often can reduce VIV. However, for some current profiles, the VIV fatigue damage could be increased with higher riser top tension. Therefore it may be necessary to do a thorough study on accumulated fatigue damage with a series of operational current profiles.

SECTION 10 Wave Fatigue Analysis

The purpose of the wave fatigue analysis is to predict the fatigue damage produced by wave loading.

Because the drilling riser joints are, in general, considered robust and can be frequently inspected between deployments, this analysis is often not required. However, if the Unit is in high waves with riser connected to well or in storm waves with the riser hung off for long duration and/or multiple times, fatigue analysis is warranted so that no excessive fatigue damage is sustained by the riser joints.

1 Required Information

In addition to the information listed in Subsection 4/1, the following information should be obtained for this analysis.

- The riser space-out as developed in Section 5
- The S-N curve and stress concentration factor (SCF) of the riser joint with associated cross section, usually for the weld details between the flange and riser pipe.
- The S-N curve and stress concentraction factor (SCF) of the riser joint connector.

Wave fatigue analyses of drilling risers often ignore the effects from the Unit's offset, and normally consider zero current drag for smaller drag damping. Therefore, only wave data as follows is normally required:

- High or storm wave conditions for short term fatigue damage calculations, including wave direction, significant wave height, wave peak period, wave spectrum parameters.
- Directional wave scatter diagrams for predicting the long term accumulated fatigue damage during a drilling operation.
- A recorded time history of waves, which normally is a series of significant wave heights, wave peak periods and wave directions for a period of time, for tracking the accumulated fatigue damage during a drilling operation

If there are possibilities that the riser may make contact with the moon-pool or diverter housing, the maximum Unit offset and current drag could become an important factor. Then, the following information associated with each wave condition should be provided as well:

- The predicted maximum Unit offset and direction, excluding the maximum wave frequency motions
- The current profile and direction

The low frequency motion of a moored Unit due to 2nd order of wave loads may cause additional fatigue damage to the drilling riser. In general, the low frequency fatigue damage is low and not significant compared to the damage caused by the first order of wave loads, and hence is often ignored. In case fatigue damage caused by the low frequency Unit motions needs to be investigated, the following information associated with each wave condition should be obtained:

- Significant amplitude of low frequency movement and direction
- Natural period of the mooring system or the low frequency of the movement

3 Analysis Methods

3.1 S-N Curve

The S-N curve approach is often used for assessing wave-induced fatigue damage. In the assessment, an appropriate S-N curve should be selected in terms of the structural detail, weld geometry and environment. For guidance on the selection of S-N curve, refer to the ABS *Guide for the Fatigue Assessment of Offshore Structures* [1]. With this approach, the number of fatigue cycles is often given by the following expression:

$$N = \left[\frac{A}{2 \cdot \sigma \cdot SCF}\right]^{B} \quad (10.1)$$

where

N	=	number of fatigue cycles
σ	=	single amplitude of dynamic stress
SCF	=	stress concentration factor
A, B	=	fatigue constants derived from corresponding S-N curve.

3.3 Frequency Domain Analysis Method: Spectral-based

Wave fatigue analyses of drilling risers may be carried out using spectral-based frequency domain assessment method. The short term fatigue life in cycles of a sea condition can be calculated as follows:

$$N(z, \theta) = \frac{A}{\Gamma(1 + B/2)} \bullet \left(\frac{1}{2\sqrt{2} \cdot \sigma_{rms}(z, \theta)}\right)^{B} \quad (10.2)$$

where

N	=	fatigue life in cycles
SCF	=	stress concentration factor
A, B	=	fatigue constant derived from selected S-N curve
z	=	investigated location along the riser length
θ	=	investigated location on the riser pipe girth
σ_{rms}	=	dynamic stress RMS value

Equation 10.2 is derived from the spectral-based fatigue analysis closed form expression in [1] with assumption that S-N curve is one-segment linear, the stress response in waves is narrow band, and the stress range probability density function is of Rayleigh distribution.

For long term fatigue life in cycles for a number of sea states can be calculated as follows:

$$N(z, \theta) = \frac{A}{\Gamma(1 + B/2) \cdot (2\sqrt{2})^{B}} \bullet \left(\frac{f_0}{\sum_{i=1}^{M} f_{oi}\, p_i \left(\sigma_{rms}(z, \theta)\right)^{B}}\right) \quad (10.3)$$

where

f_{0i}	=	zero-up-crossing frequency of the stress response in i^{th} sea state in a scatter diagram
p_i	=	joint probability of i^{th} sea state in a scatter diagram

f_0 = average frequency

$$= \sum_{i=1}^{M} f_{0i} p_i$$

M = number of sea states in a scatter diagram

In case the low frequency fatigue damage is required, the RMS low frequency dynamic stress may be calculated quasi-statically by comparing the stress between the riser at the mean Unit position and the riser at the mean position plus RMS or significant low frequency movement. The total damage may be calculated by simple summation:

$$D(z, \theta) = D_W(z, \theta) + D_L(z, \theta) = \frac{f_W}{N_W(z,\theta)} + \frac{f_L}{N_L(z,\theta)} \quad \text{(10.4)}$$

where

D = total damage of a wave condition

D_W = wave frequency damage

D_L = low frequency damage

N_W = wave fatigue life in cycles

N_L = low frequency wave fatigue life in cycles

f_W = wave average frequency of a wave condition

f_L = average frequency of a low frequency loading condition

The equation (10.4) may be adjusted as follows for more conservative estimation:

$$D(z, \theta) = [D_W(z, \theta) + D_L(z, \theta)] \cdot \frac{[\sigma_{Wrms}(z,\theta) + \sigma_{Lrms}(z,\theta)]^B}{\sigma_{Wrms}^B(z,\theta) + \sigma_{Lrms}^B(z,\theta)} \quad \text{(10.5)}$$

where

σ_{Wrms} = wave frequency dynamic stress RMS value

σ_{Lrms} = low frequency dynamic stress RMS value

Other appropriate alternative methods to combine the wave and low frequency fatigue damage can also be used.

3.5 Time Domain Analysis Method

For fatigue analysis using time domain analysis method, rainflow counting technique is typically applied for fatigue assessment from a series of combined wave frequency and low frequency time domain irregular wave simulations. This method can calculate the wave frequency and low frequency time domain stress ranges more accurately but may take longer computing time.

5 Considerations in Modeling

The riser model should be created in accordance with Subsections 4/3 and 4/5 in general. Based on the stage of riser operation, the considerations as listed in Subsection 6/5, 7/5 or 8/5 may be applied accordingly.

In addition, it is preferred that the riser model considers tension variation due to the tensioner stroke.

7 Analysis Procedure

The wave fatigue analysis may be performed as follows:

i) Frequency domain analysis based on spectral-based method

- Determine stress transfer function**,** at a location of interest for specified ranges of wave frequencies and headings.
- Generate a stress energy spectrum by scaling the wave energy spectrum of a sea state
- Calculate the spectral moments
- Using the spectral moments, the Rayleigh probability density function describing the short term stress-range distribution and the zero up-crossing frequency of the stress response.
- In the case of long term accumulated fatigue damage, perform the analysis for all anticipated sea conditions, and calculate the accumulated fatigue damage. Identify the critical locations with the lowest fatigue lives

Please refer [1] for details of the spectral-based frequency domain analysis procedure.

ii) Time domain fatigue analysis method:

- Follow the analysis procedures as described in Subsection 6/7, 7/7 or 8/7 to perform the domain analysis for each sea condition.
- Obtain the dynamic stress along the riser length and on the riser pipe's girth, and calculate the short term fatigue damage for a sea condition. Identify the critical locations with lowest fatigue lives.
- In the case of long term accumulated fatigue damage, perform the analysis for all anticipated sea conditions, and calculate the accumulated fatigue damage. Identify the critical locations with the lowest fatigue lives.

iii) A factor of safety of 3 is typically applied in the fatigue life calculation, and higher factor of safety may be required if the riser is not inspected frequently.

9 Mitigation Options for Riser Wave Fatigue Damage

The wave induced fatigue damage is often caused by the Unit's motions in waves and riser response in waves. To reduce wave-induced fatigue, one or two slick joints may be considered in the region of wave zone (above and below the water surface) instead of joint with buoyance module to reduce wave loads. Similarly, one or two slick joints may also be placed in the region of the wave zone when hanging-off the riser in a strong storm. During the riser deployment, bottom stack should pass through the wave zone quickly.

SECTION 11 Drift-off/Drive-off Analysis

The drift-off and drive-off analysis specifically apply to a DP Unit. A black-out event could cause the Unit to “drift” off location, and a DP system malfunction could “drive” the Unit off location. The purpose of the analyses is to define the radius of the yellow and red watch circles for emergency disconnection when the Unit suffers a black-out or DP system malfunction.

1 Required Information

In addition to the information listed in Subsection 4/1, the following information should be obtained for both drift-off and drive-off analyses.

- The riser space-out as developed in Section 5
- The recommended top tension for the anticipated mud weight, obtained from the riser operability analysis of Section 7
- Initial Unit heading related to the environment based on operational practice
- The Emergency Disconnect Sequence (EDS) for the required time period to make a no shearing disconnect, pipe shearing disconnect, or casing shearing disconnect
- The time period to prepare for emergency disconnect
- Additional Unit information, including:
  - Principle dimensions and the location of RKB
  - Location of center of gravity at the operating draft
  - Displacement and yaw inertia at the operating draft
  - Added mass matrix for surge, sway and yaw
  - Wind force coefficients for surge, sway and yaw
  - Current force coefficients for surge, sway and yaw, and yaw-rate drag coefficients
  - Wave drift force coefficients or QTFs
  - Additional damping matrix for surge, sway and yaw, if any
  - Coordinate system and conventions of force coefficients:
    - Definition of the coordinate system axes
    - Reference point and its coordinates
    - Conventions of environmental directions.

Since the well integrity is often one of the governing factors, the information of well construction and soil properties as specified in 4/1.5 is normally required.

In the case of drive-off analysis, the following additional information should be obtained.

- The scenarios of DP system malfunction, which could include:
  - Locations of malfunctioned thruster or thrusters,
  - Thrust force and direction of each malfunctioning thruster,
  - Thrust reduction factor caused by interactions with other thrusters and/or the Unit’s hull,
  - Possible variation of thrust force and direction, if any.

The environmental conditions for the drift-off analysis are normally severe. For drive-off analysis, the environment is normally considered as minimal.

3 Analysis Approach

3.1 Drift-off Simulation

The drift-off simulation can typically be conducted as a fully-coupled or uncoupled time domain analysis approach.

Fully-coupled analysis approach would solve the equations of motion for the vessel and the riser to the environmental conditions at every time step. In this type of analysis, riser restoring and dynamic forces as well as the vessel load RAOs with other load effects should be applied simultaneously.

Uncoupled analysis could be done by simulating the vessel motion to environmental conditions using vessel motion RAOs and applying the vessel motion in the riser analysis at every time step.

Since environmental condition for drift-off analysis is normally severe, vessel motion may be affected by riser response. For realistic drift-off simulation, fully-coupled analysis approach can be considered.

In the drift-off analysis, vessel heading, motion, and position as well as the maximum riser responses due to collinear wave, wind, and current from 0° ~ 90° of the vessel heading is typically calculated at every drift-off time step.

3.3 Drive-off Simulation

Drive-off analysis is similar to drift-off analysis, but all possible scenarios of DP system malfunction and associated forces from thrusters should be considered and simulated in the analysis. Since environmental condition for drive-off analysis is normally minimum, vessel motion in waves is small, uncoupled analysis approach can be considered.

In the drive-off analysis, vessel heading, motion, and position as well as the maximum riser responses due to collinear wave, wind, and current from 0° ~ 90° of the vessel heading is typically calculated at every drive-off time step.

5 Considerations in Modeling

In general, the riser model should be created in accordance with Subsections 4/3 and 4/5. The well construction and soil properties are normally modeled in the analyses.

A more detailed model of the Unit is required to perform drift-off and drive-off simulations, which may include the following:

i) Motion RAOs or Load RAOs with other load effects at operating draft as well as associated phase angles and reference location.

ii) Other load effects used together with the Load RAOs may include the following.

- Hydrostatic restoring forces
- Mass and added mass matrix
- Wind and current force coefficients for surge, sway and yaw, including the yaw-rate drag coefficients
- Wave drift force coefficients or QTFs
- Other damping matrix for surge, sway and yaw, if any
- Proper definition of the center of gravity and reference points of various force coefficients

iii) Proper definition of the RKB location

7 Analysis Procedure

7.1 Drift-off Analysis

The analysis procedure for the simulation of drift-off may be as follows:

i) Considering fully-coupled time domain approach for the drift-off analysis, load RAOS with other load effects to the Unit at the corresponding loading draft should be obtained.

ii) Create the drilling riser model from the drill floor to well conductor with proper boundary conditions, and check the accuracy of the effective tension along the riser string.

iii) Apply the environmental conditions for the drift-off simulation, including the wind, current and wave loads, then perform time domain simulations for the drift-off time history.

iv) Post-process the drift-off time history to obtain elapsed time versus Unit offsets, heading, drift-off speed, and position.

v) Post-process the riser responses and evaluate lateral displacements, ball/flex joint angles, stresses, effective tensions, and bending moments, as well as tensioner and telescopic joint strokes, etc.

vi) Determine the point of disconnection (POD) based on the riser analysis evaluation considerations in Section 3, and then establish the red watch circles based on the required time period for EDS and yellow watch circle based on the required time period for preparing EDS as depicted in Section 11, Figure 1.

7.3 Drive-off Analysis

The analysis procedure for the simulation of drive-off analysis may be performed as follows:

i) Considering uncoupled analysis approach for the drive-off analysis, motion RAOs as well as associated phase angles of the Unit corresponding to the loading draft should be obtained.

ii) Create the drilling riser model from the drill floor to well conductor with proper boundary conditions, and check the accuracy of the effective tension along the riser string.

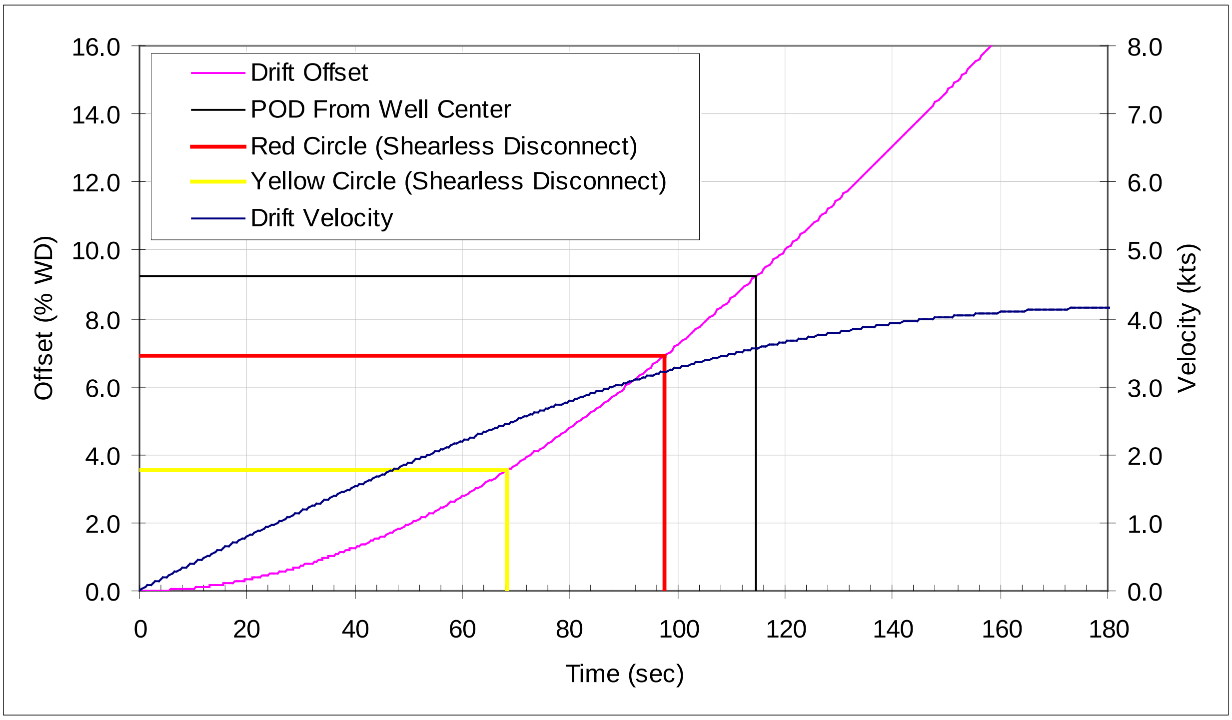
iii) Apply the environmental conditions for the drive-off simulation, including wind, current, and wave loads, as well as forces from thrusters. Then perform time domain simulations for the drive-off time history.

iv) Post-process the drive-off time history to obtain elapsed time versus Unit offsets, heading, drive-off speed, and position.

v) Post-process the riser responses and evaluate lateral displacements, ball/flex joint angles, stresses, effective tensions, and bending moments, as well as tensioner and telescopic joint strokes, etc.

vi) Determine the point of disconnection (POD) based on the riser analysis evaluation considerations in Section 3, and then establish the red watch circles based on the required time period for EDS and yellow watch circle based on the required time period for preparing EDS as depicted in Section 11, Figure 1.

FIGURE 1
Typical Watch Circle Plot for Drift-off/Drive-off



SECTION 12 Recoil Analysis

The recoil analysis is specifically for a dynamically positioned (DP) Unit. The purpose of the recoil analysis is to determine the requirements of the recoil system for emergency disconnection.

Upon an emergency disconnect, the riser tensioning system with the recoil system should continuously apply force so that the riser LMRP is lifted clear of the BOP. Then, an anti-recoil system on the tensioning system, if required, should regulate the tensioners carefully to avoid an upwards riser movement causing complete collapse of the telescopic joint, or causing slack in the wire tensioners or compression in direct acting tensioners.

The recoil analysis should cover the following issues:

i) Establish the initial riser overpull tension and recoil settings, so that the LMRP will be able to clear the BOP stack for a specific wave condition.

ii) Establish the riser tension and recoil and/or anti-recoil settings, so that the continuous riser movement will not cause the total collapse of the telescopic joint, slacked wire tensioners or compressed direct-acting tensioners, negative tension along the riser string, or impact back to BOP stack for a specific wave condition.

iii) Establish a set of recoil control parameters for a range of environmental conditions, if required.

Riser recoil is a complex dynamic process in which the recoil and anti-recoil hydraulic controls of the tensioning systems have to be evaluated jointly with riser dynamic response. Reliable simulation typically requires a special analytical tool that has been developed specifically for this purpose, especially for the hydraulic controls of the tensioning system.

SECTION 13 Weak Point Analysis

This analysis is to identify the weak points in a drilling riser/well system under extreme Unit offsets due to drive-off/drift-off or mooring line failure events. The focus of this analysis is on well integrity. The maximum load predicated from the weak point analysis can be used for design/selection of the drilling riser and well system components or compatibility check between riser and existing well system. This analysis is often required before the Unit's first deployment or before an important drilling campaign by the Operator.

1 Required Information

In addition to the information listed in Subsection 4/1, the following information is required for the weak point analysis.

- The riser space-out as developed in Section 5
- The recommended top tension for the anticipated mud weight, obtained from the riser operability analysis of Section 7
- The yield strength and/or tension and bending capacity at yield strength for all components along the riser string

Since the well integrity is the main focus of this analysis, the information of well construction and soil properties as specified in 4/1.5 should be obtained.

3 Analysis Approach

The weak point analysis is similar to the drift-off/drive-off analysis in that the same system limits are monitored. However, the analysis is typically a static analysis where static riser responses are calculated for various Unit offsets, and the analysis is often focused on large offsets when the telescopic joint or tensioners are stroked out. The wave loading is typically not considered, although current loading may be included.

The failure of any component in the riser system is normally based on yield strength, although reaching yield strength does not reflect true failure and there should be considerable residual strength in ductile steel. A true riser failure is normally considered as a rupture or separation of a riser joint, and the weak points could alternatively be defined as the break or separation points. In this case, analysis based on ultimate capacity of each riser component may be considered.

5 Considerations in Modeling

In general, the riser model should be created in accordance with Subsections 4/3 and 4/5. The well construction and soil restraint should be provided.

In addition, the model should accurately define the stroke-out condition of the telescopic joint and tensioners.

7 Analysis Procedure

The analysis may be performed as follows:

i) Create the drilling riser model from the drill floor to well conductor with proper boundary conditions, and check the accuracy of the effective tension along the riser string.

ii) Position the Unit at a series of offset locations, apply current profile, if any, and perform static analyses for each Unit position and for each current profile.

iii) Evaluate ball/flex joint angles, stresses, tensions and bending moments, and determine at which offset and which component reaches the limit.

SECTION 14 References

1. ABS, Guide for the Fatigue Assessment of Offshore Structures, 2003
2. API, Recommended Practice for Design, Selection, Operation and Maintenance of Marine Drilling Riser Systems, API RP 16Q, Second Edition, April 2017
3. API, Recommended Practice for Geotechnical and Foundation Design Considerations, API RP 2GEO, First Edition, Addendum 1, October 2014