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Design of Top Tensioned Risers

GP 65-74

Group Practice

Foreword

This is the first issue of Engineering Technical Practice (ETP) GP 65-74. This Group Practice (GP) is based on parts of heritage documents from the merged BP companies as follows:

British Petroleum

S/EPT/081/04 Rev2 Guidelines for the Design of Tensioned Vertical Risers.

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1. Scope

- a. This GP provides technical guidance on engineering and design of permanent top tensioned risers (TTRs).
- b. This GP is applicable to design of the following systems:
 1. Mechanically tensioned well and flowline riser systems.
 2. Aircan tensioned well and flowline riser systems.
 3. Tensioned high-pressure drilling risers systems (typically part of riser array).
- c. This GP addresses aspects of design of TTR system components, including:
 1. Flex joints.
 2. Conductors.
 3. Foundations.
 4. Riser and interface joints (including stress joints, keel joints, wear joints, stem joints, and couplings).
 5. Guides.
 6. Insulation.
 7. Auxiliary buoyancy
 8. Vortex suppression devices.
- d. This GP has implications for design of well control equipment (e.g., subsea wellhead, surface wellhead, tieback connector, surface Christmas tree/blowout preventers) that needs to withstand riser imposed loading.
- e. This GP does not cover the following:
 1. Temporary (low pressure) marine drilling risers with subsea BOP.
 2. Dedicated workover/completion riser systems.
 3. Hybrid type vertical risers (e.g., single leg hybrid risers, bundled hybrid offset risers). Refer to GP 65-77.
 4. Flexible riser elements in tensioned riser systems (i.e., flexible jumper design). Refer to GP 65-75.
 5. Requirements already stated in mandatory BP group Standard for integrity management.

2. Normative references

The following normative documents contain requirements that, through reference in this text, constitute requirements of this technical practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical practice are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

BP

BPA-D-001	BP Drilling and Well Operations Policy.
BPA-D-002	Well Control Manual.



GIS 80-020	Subsea Well Head Systems.
GN 36-009	Specification for Subsea Insulation and Buoyancy Materials
GN 36-010	Recommended Practice for Subsea Installation and Buoyancy Materials
GN 65-701	Riser Hydrodynamic Modelling.
GN 65-702	Riser Analysis Techniques.
GN 65-703	Riser Risk and Reliability Assessment.
GN 65-704	Riser Fatigue Calculation.
GN 65-705	Riser Design Verification.
GN 65-706	Riser Material Performance.
GN 65-708	Riser Thermal Performance.
GN 65-710	Riser In Service Performance and IMR.
GN 65-711	Riser Load Matrices.
GN 65-712	Riser Wall Thickness Calculation.
GN 65-713	Specialist Riser Components.
GP 36-10	Metallic Material Selection.
GP 65-72	Riser Vortex Induced Vibration Design Guidelines.
GP 65-75	Guidance for the Design of Unbonded Flexible Pipe Risers and Flowlines
GP 65-77	Guidance on Practice for Design of Hybrid Risers
Handbook	Subsea Reliability Handbook.

American Petroleum Institute (API)

API 5C2	Bulletin on Performance Properties of Casing, Tubing, and Drill Pipe.
API RP 1111	Design, Construction, Operation, and Maintenance of Offshore Hydrocarbon Pipelines and Risers.
API RP 2A	Planning, Designing, and Constructing Fixed Offshore Platforms, LFRD and WSD.
API RP 2RD	Design of Risers for Floating Production Systems (FPSs) and Tension Leg Platforms (TLPs).
API Spec 5L	Specification for Line Pipe.

American Society of Mechanical Engineers (ASME)

ASME VIII	ASME Boiler and Pressure Vessel Code, Section VIII, Pressure Vessels.
ASME B31.4	Pipeline Transportation System for Liquid Hydrocarbons and Other Liquids.
ASME B31.8	Gas Transmission and Distribution Piping Systems.

British Standards Institute (BS)

BS EN 10204	Metallic Products - Type of Inspection Documents.
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Det Norske Veritas (DNV)

DNV OS F101	Submarine Pipeline Systems.
DNV OS F201	Dynamic Risers.
DNV RP F201	Design of Titanium Risers.
DNV RP F202	Design of Composite Risers.
DNV RP F203	Draft Recommended Practice on Riser Interference.



International Organisation for Standardisation (ISO)

ISO 10423	Petroleum and natural gas industries - Drilling and production equipment - Wellhead and christmas tree equipment.
ISO 11960	Petroleum and natural gas industries - Steel pipes for use as casing or tubing for wells.
ISO 13628-8	Petroleum and natural gas industries - Design and operation of subsea production system - Part 8: Remotely operated vehicle (ROV) interfaces on subsea production systems.
ISO 13679	Petroleum and natural gas industries - Procedures for testing casing and tubing connections.

3. Terms and definitions

For the purposes of this GP, the following terms and definitions apply:

Effective tension

Axial wall force adjusted for contributions from external and internal pressures.

$$T_{\text{eff}} = T_{\text{wall}} - p_i A_i + p_e A_e$$

where T_{eff} is effective tension, T_{wall} is tension in the riser wall, p and A denote pressure and enclosed section area, and subscripts i and e mean internal and external.

Permanent riser

Riser designed for continuous operation over its design life, irrespective of environmental conditions and without anticipated recovery.

Vortex induced vibration (VIV)

An important cause of fatigue damage of offshore risers resulting from structural excitation caused by the alternating shedding of vortices generated from flow/riser relative motion.

Wake induced oscillation (WIO)

- In steady ocean currents, a riser situated in the wake of another riser would in general locate at an equilibrium position where all static forces are in balance.
- However, the equilibrium position becomes unattainable, i.e. loss of static stability, if the current is increased beyond a certain limit.
- A consequence of this loss of stability is that the downstream riser may start to wander in the wake. The wandering motion is characterised by its large amplitude and low frequency which may increase the probability of intermittent collisions with the upstream riser. This motion is referred to as WIO.

4. Symbols and abbreviations

For the purpose of this GP, the following symbols and abbreviations apply:

ALS	Accidental limit state.
BOP	Blowout preventer.
CFD	Computational fluid dynamics.



CP	Cathodic protection.
CVA	Certified Verification Agent
EPTG	Exploration and Production Technology Group.
FD	Frequency domain.
FE	Finite element.
FEA	Finite element analysis.
FLS	Fatigue limit state.
FM	Fracture mechanics.
FMEA	Failure mode and effect analysis.
GOM	Gulf of Mexico.
HAZID	Hazard identification.
HSE	Health, safety, and environment.
IMR	Inspection, maintenance, and repair.
LF	Low frequency.
LRFD	Load and resistance factor design.
MAR	Major accident risk.
MMS	Minerals Management Services
NDT	Non-destructive testing.
PIP	Pipe in pipe.
QRA	Quantitative risk assessment.
R&D	Research and development.
ROV	Remotely operated vehicle.
SCF	Stress concentration factor.
SCSSV	Surface controlled subsurface safety valve.
SEP	Single equivalent pipe.
SLC	Sustained load cracking.
SSC	Sulphide stress cracking.
TA	Technical authority.
TBC	Tieback connector.



TD	Time domain.
TLP	Tension leg platform.
TSJ	Taper stress joint.
TTR	Top tensioned riser.
VIM	Vortex induced motion.
VIV	Vortex induced vibration.
WF	Wave frequency.
WIO	Wake induced oscillation.
WSD	Working stress design.
XHP/HT	Extra high pressure/high temperature.

5. Overview

- a. This GP for design and analysis of TTR systems is intended to:
 1. Emphasise existing requirements of industry codes and standards.
 2. Specify additional requirements specific to BP.

Requirements are based on outcome from research and development (R&D) and project experience, both from BP operated and partner operated developments. As such, requirements in this document often have their origin in hard learned lessons.
- b. This GP should only be departed from if underlying issues and risks are clearly understood, independently reviewed, and documented.
- c. This GP should be used to prepare project specific design basis and design methodology.
- d. Riser system design should be performed in accordance with group integrity management standard, particularly aspects pertaining to risk, health, safety, and environment (HSE).
- e. This GP should only be shared with key contractors and consultants working with BP in accordance with terms of confidentiality agreement, and use should be restricted to BP activities.

6. System requirements

6.1. Fundamental requirements

- a. TTR system design shall fulfil all design and operation requirements safely, efficiently, cost effectively, and in accordance with:
 1. BP group standards pertaining to integrity management, risk, and HSE.
 2. Local and project specific safety philosophies and policies.
- b. TTR systems shall:
 1. Comply with BPA-D-001.
 2. Adhere to guidance in BPA-D-002.



6.2. Operational requirements and design principles

6.2.1. Operational requirements

TTR systems shall perform the following functions:

- a. Convey and retain fluids at required pressure, temperature, density, and flowrate between well/flowline and host platform for both normal operation and shut in.
- b. Provide pressure and fluid control for well risers for drilling, workover, completion, and pullover modes, as applicable.
- c. Guide and support internal casing and tubing strings.
- d. Guide and support tubing and umbilicals required for controls, chemical injection, gas lift, well control, and gas insulation.
- e. Guide riser inspection, downhole drilling, and workover tools into well.
- f. Resist degradation (corrosion, erosion, wear, fatigue) and interactions of these mechanisms as necessary to maintain aspects of performance, accessibility, and maintainability over specified design life. This should take into account physical composition of transported fluids, entrained solids, and how these may change over life of field.
- g. Resist specified loads imposed at interfaces to TTR (i.e., vessel and seabed/soil interfaces).
- h. Have same reliability levels as other equipment in production system. To achieve this, TTR and subsystems should be designed and constructed in accordance with processes outlined in BP subsea reliability handbook.
- i. Provide means to monitor performance and allow required inspection, maintenance, and repair (IMR) to be performed in place.

TTR functional and operational requirements dictate quantity of risers and system arrangement, such as spacing, arrays, riser cross section configuration (dual casing versus single casing risers), number of inner tubings, thermal insulation, component specification, stackup arrangement, support mechanisms, and tensioning requirement.

When feasible, the designer should always consider using already field proven solutions when they exist as developing a new solution can have a significant time and cost implication.

6.2.2. Design principles

TTR systems should be designed in accordance with the following principles:

- a. Equipment should be selected based on simplicity, reliability, performance history, and robustness in relation to loading uncertainties during storage, transportation, installation, in place, and decommissioning phases.
- b. Multidiscipline approach (including riser, well systems, drilling and completions, subsea, and floating systems expertise from design, operations, and maintenance) should be used to determine details of riser functional requirements to ensure that optimum trade-off of effort and cost is achieved between design and operations.

Functional requirements will usually be dictated by the design of the well and subsea systems, and flow assurance requirements. The selection of a SCSSV should be addressed and finalised early in the design cycle; since the SCSSV will define the maximum pressure functional requirements. Changes to the functional requirements as designs mature can have significant cost, schedule and risk implications.

An issue that should be resolved between the designers of the riser and the designers of topside facility design is to agree the limits defining the application of the



riser/flowline design codes and the topside codes. The use of topside ASME design codes to determine the wall thickness can make in-line inspection difficult. The application of riser design codes of the flowline should continue to the pig launcher and receiver.

- c. Design shall clearly define riser operating limits to ensure safe operation and durability of riser system.
- d. Because of a level of uncertainty in functional and operational requirements, assessment of design sensitivity to uncertainties in fundamental input data should be performed.
- e. Riser system should be designed to facilitate optimised maintenance and operational activities, including maximised remotely operated vehicle (ROV) accessibility.

Design review should be organised with operating team to confirm suitability for operation and address issues, such as inspectability and maintenance. An inspection plan should be issued as part of the design while the design team is intact.

7. Design requirements

7.1. General

- a. In preparation for TTR system design, the following shall be established:
 - 1. Design basis or equivalent documentation covering functional and operational specifications for the following:
 - a) System.
 - b) Site specific conditions.
 - c) Metocean data.
 - d) Fluid properties.
 - e) Design methodology.
 - f) Loading conditions.
 - g) Vessel motions.
 - h) Interface requirements.
 - i) Seabed properties.
 - j) Requirements for in-service performance monitoring
 - 2. Drilling and completion data for well risers, including:
 - a) Kick pressures.
 - b) Mud weights.
 - c) Drilling casing programme.
 - d) Completion design.
 - e) Predrill equipment (e.g., wellhead, conductor, connectors).
 - f) Surface tree.
 - g) BOP arrangement.
 - 3. Hierarchy of codes, standards, and criteria based on 8.1.

Designer should ensure that available information is sufficient to complete design to specified requirements.



- b. In particular, the following shall be required:
1. During all modes of operation for well risers, system shall always have well barriers that comply with BPA-D-001.
 2. Pressure barriers, as follows:
 - a) Dry tree TTRs shall be designed with minimum of two pressure containing strings around production tubing.
 - b) Wet tree TTRs shall be designed with minimum of one pressure containing string around production tubing.
 - c) Strings shall be pressure rated to contain leak originating from shut in production tubing or packer.
 - d) Outermost riser pipe may provide one pressure barrier.
 - e) Designs that use no internal casing string (i.e., consisting only of tubing and riser pipe) may be proposed if justified by quantitative risk assessment (QRA) of lifetime risk adjusted cost with respect to safety, environmental, and operational parameters.

Methodology for QRA is available from Exploration and Production Technology Group (EPTG) riser engineering discipline (Bibliographic refs [9] and [10]).
 3. Qualification testing or experimental verification for new concepts, materials, and components shall be identified at early stage to minimise potential effect on both design and procurement of system. This is further described in GN 65-706.
 4. Equipment should be designed and manufactured for application under development. Re-use of equipment may be considered on case by case basis and shall be subject to authorisation by relevant technical authorities (TAs).

7.2. Structural conditions

- a. Riser system and associated components shall be designed to withstand all loading conditions that may be encountered during the design life with an acceptable low probability of failure.
- b. Acceptance criteria for structural assessment of TTR systems are further detailed in later chapters.
- c. Minimum requirements for TTRs shall be satisfied (e.g., wall thickness, strength, coupling size), but potential savings on system weight should be considered using hull design weight saving principles.

Satisfaction of structural integrity checks in this GP and in other codes and standards should not be assumed to guarantee total performance. Equipment may be found to be "acceptably" damaged but still suffer partial or full loss of functionality.

7.3. Failure modes and hazard assessment

- a. Risk assessment shall be performed to identify and manage risks and hazards associated with TTR as required in BP group standard for integrity management.
- b. During early design phase, risk assessment may take form of hazard identification (HAZID) and major accident risk (MAR) assessment.
- c. Failure mode and effect analysis (FMEA) shall be performed during detailed design as means of identifying critical failure modes.

Exploration and Production integrity management segment implementation guide (Bibliographic ref [3]) has guidance on risk assessment processes and their place in BP capital value process.



- d. Risk register
 - 1. Risk register shall be maintained for TTR throughout design, construction, and operation phases.
 - 2. Risk register shall document mitigation strategy required to minimise risks.

BP risk management guidelines for major projects (Bibliographic ref [2]) offer guidance on risk register process.
- e. Table 1 lists most common TTR failure modes.
- f. Further guidance on system failure modes is given in GN 65-703 and GN 65-713.

Table 1 - Typical TTR failure modes

Structural failures	Operation failures	Component failures
Buckling	Mooring line	Tensioner failure
Collapse	Leak	Buoyancy can flooding
Bending	Wax/hydrate blockage	Connector failure
Burst	Emergency shutdown	Jumper failure
Fatigue	Impact related failure	
Corrosion/erosion/wear		
Note: This list is indicative and not exhaustive.		

7.4. Technical assurance and design verification

- a. Technical assurance plan for TTR system that details system components to be assessed, review processes to be used, and schedule for these activities should be developed at start of project execution.
- b. TTR and subsystems should be designed and constructed following processes outlined in BP subsea reliability handbook.
- c. During design process, measures, such as peer technical review, audit, or independent verification analysis, should be taken as appropriate to check and verify proposed TTR design.
- d. Further guidance for design verification requirements is in GN 65-705.

For GoM applications, under the Code of Federal Regulations, an MMS approved CVA firm is required to be appointed for design verification and validation of the analysis process

8. Design principles and loading conditions

8.1. Design codes

- a. TTR riser systems shall be designed, fabricated, tested, and installed in accordance with existing industry codes and standards.
- b. The following principal codes set out design load combinations and acceptance criteria applicable for TTR systems that should be complied with, subject to amendments noted herein and project specific requirements:
 - 1. API RP 1111.
 - 2. API RP 2RD.
 - 3. DNV OS F101.



4. DNV OS F201.

- c. This GP does not assume a preference for particular design codes.

API RP 2RD normally takes precedence over API RP 1111. DNV OS F201 normally takes precedence over DNV OS F101. This is because TTR systems are dynamic applications.

For conflicts between API RP 2RD and DNV OS F201, if clearly equivalent checks are performed the least onerous of the two may be used, subject to project and regulatory requirements. As a general rule, however, mixed use of codes is considered bad practice and should be avoided where possible..

8.2. Design approaches

8.2.1. General

Fundamental differences exist between design approaches associated with each code as described in 8.2.2 through 8.2.4.

8.2.2. Working stress design (WSD)

- a. WSD is a traditional and widely used industry approach to steel design that relates allowable stress to yield stress.
- b. Allowable stress is considered theoretical maximum value (beyond which some failure condition is deemed to exist) divided by single safety factor.

This is the simplest design approach and is based on safety factors refined over many years of experience. The safety factor accounts for all material, constructional, and loading uncertainties and incorporates allowance for consequence of failure. The approach, while straightforward to apply and adequate for the majority of riser designs, can however lead to overdesign as well as to some uncertainty in the true margin of safety.

API RP 2RD provides design requirements based on WSD. DNV OS F201 also offers the option of designing according to the WSD approach but is primarily based on load and resistance factor (LRFD) design approach as described in Section 8.2.3 below.

8.2.3. Load and resistance factor design (LRFD)

- a. LRFD is limit state design approach that relates allowable loading to ultimate strength.
- b. Multiple (or partial) safety factors are used, depending on load effect and limit state considered.

DNV OS F201 provides design requirements based on LRFD approach. Recommended partial safety factors account for failure consequence, material resistance and loading, or manufacturing uncertainties. This approach relies on associating both strength and load terms with uncertainties, leading in general to more efficient design. For deep water applications in particular, LRFD approach has potential to offer less conservative and, hence, lower cost solutions.

8.2.4. Reliability based design/risk based design

- a. Reliability based design involves establishing acceptable levels of reliability from probability distributions of strength and load by determining LRFD partial safety factors.
- b. Reliability based design probabilistic approach may be further extended by risk based design approach in which safety, economic, and environmental consequences of failure are explicitly accounted for in determination of required reliability and partial safety factors.

