



GUIDANCE NOTES ON

SUBSEA HYBRID RISER SYSTEMS

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Incorporated by Act of Legislature of
the State of New York 1862**

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Foreword

These Guidance Notes describe suggested practice for the design, materials, testing, manufacturing, installation and maintenance of hybrid riser systems to be classed or certified by ABS. These Guidance Notes are to be used in conjunction with other Rules and Guides published by ABS as specified herein, in particular the *ABS Guide for Building and Classing Subsea Riser Systems*. During the preparation of these Guidance Notes, ABS recognized that industry participation is a vital factor both to the rapidly progressing nature of this technology, and for the success of developing an appropriate standard which satisfies practical classification requirements. ABS appreciates the industry's input in the development of these Guidance Notes.

These Guidance Notes reflect the latest technology developments and industry practice for hybrid riser systems for deepwater installation. These Guidance Notes indicate detailed guidance for hybrid riser systems from configuration selection, engineering design to offshore installation. This does not exclude the use of other practices for a hybrid riser system, provided that relevant industrial design codes are followed, sound engineering practice is implemented, and justification for the use is adequately documented. Riser design engineers are encouraged to consult fabrication and installation specialists to establish the presence of constraints that will affect the design.

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

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SECTION 1 Introduction

1 Overview

The principal elements of a subsea hybrid riser system are a vertical, or catenary, steel riser(s) tensioned by a near subsurface buoyancy tank, and a flexible jumper connecting the riser(s) to a floater. The vertical, or catenary, riser(s) may be anchored to the seabed using a foundation pile or connected to a flowline end termination (FLET) directly.

A hybrid riser system may be installed before or after the Floating Production Installation (referred to herein as an FPI, or floater) is moored on site; (e.g., a Floating Production Storage and Offloading (FPSO) installation). The riser's own weight is supported by the buoyancy tank, resulting in lower reactions on the floater. The flexible jumper allows the riser to be substantially decoupled from the floater's motions, which makes the riser fatigue response typically insensitive to the floater's motions.

A hybrid riser system configuration combines the features of tensioned and compliant risers in an efficient manner. Most proposed designs are based on combining a self-supporting vertical riser column (e.g., by means of a buoyancy tank) with a flexible jumper at the upper end for connection to a floater. However hybrid risers tend to be very complex structural systems with special design challenges for both in-situ conditions as well as during the installation phase.

Hybrid riser systems are a field-proven concept; they have been installed in the Gulf of Mexico, offshore Brazil and offshore West Africa. Hybrid riser systems have been installed in water depths ranging from 1,500 ft. to over 8,600 ft.

Hybrid riser systems can be associated with any floater type. Typically such systems have been used with floating production installations (FPIs) as this takes advantage of one of the hybrid riser system's best aspects, which is its ability to decouple the rigid riser system from the FPI's motions. This decoupling can reduce the necessity of using a vessel with enhanced motion-performance.

3 Description of Hybrid Riser Systems

3.1 General

Although there are different versions of hybrid riser systems, and their configurations have been modified through the years, the key technical benefit of this concept remains that the major rigid vertical, or catenary, riser is isolated from the FPI using an upper flexible jumper as a connection. The rigid riser is thus substantially decoupled from FPI motion.

So far, the hybrid riser system concepts that have been developed are as follows:

- Hybrid Riser Tower (HRT)
- Single Line Hybrid Riser (SLHR)
- Tension Leg Riser (TLR)
- Hybrid 'S' Riser System (HySR)
- Hybrid Catenary Riser (HCR)

3.3 Hybrid Riser Tower Type (or Hybrid Tower Riser)

The riser tower consists of a center core tubular surrounded by production, water injection, and service lines internal or external to the bundle, either fully enclosed or attached on the periphery of the syntactic foam buoyancy module.

The vertical column of the riser tower normally consists of a bundle of steel risers. A buoyancy tank at the top provides the required tension, and syntactic buoyancy units along the length reduce the wet weight and may also provide insulation if riser pipes are enclosed within. The upper end of the vertical column is connected to the FPI by multiple flexible jumpers.

The tower type has been used for deepwater fields mainly in West Africa, although the first riser tower was installed in the Gulf of Mexico. All these riser towers were fabricated onshore, towed to sites and upended.

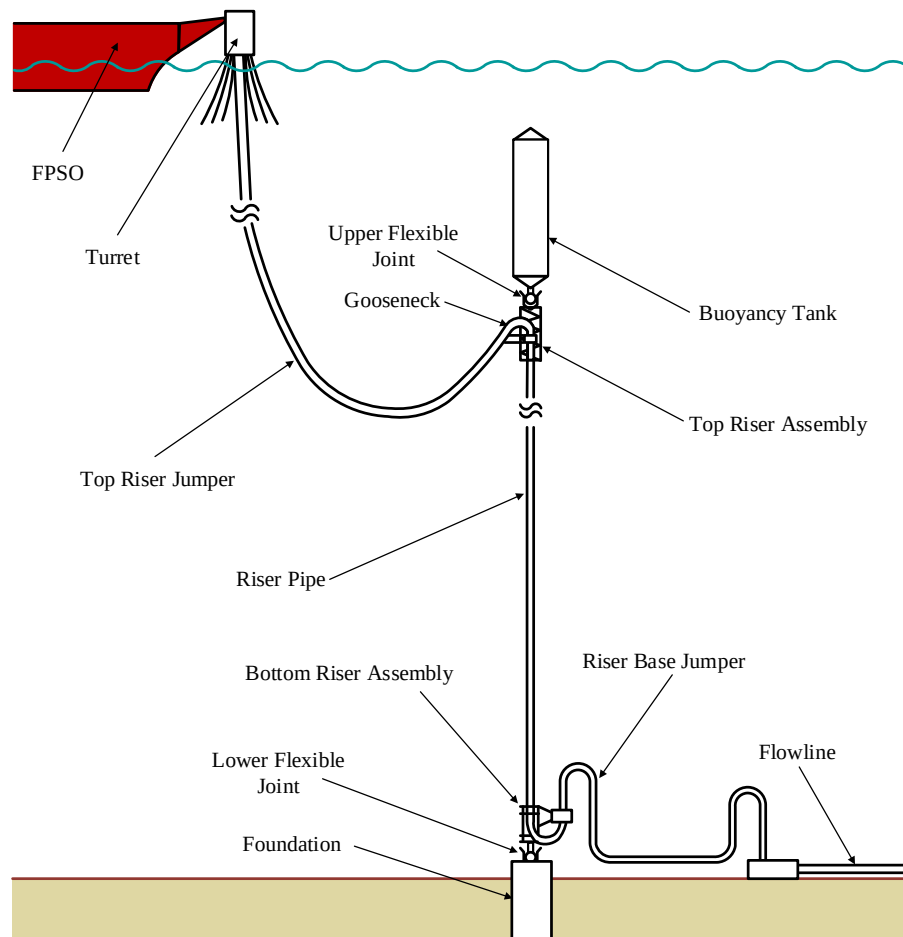
A typical HRT consists of the following components:

- Top Flexible Jumper(s)
- Buoyancy Tank
- Top Riser Assembly (TRA including Gooseneck Assembly)
- Continuous Riser Bundle Section
- Bottom Riser Assembly (BRA)
- Bottom Connector (e.g., latch type connector)
- Riser Tower Anchor
- Rigid Jumper Spool connection to FLETs

3.5 Single Line Hybrid Riser Type

A single line hybrid riser (SLHR) consists of a vertical rigid pipe anchored to the seabed via a foundation (e.g., suction pile) and tensioned by means of a near-surface buoyancy tank that provides the required uplift force. For the SLHR, one flexible jumper connects the rigid riser via a gooseneck to the FPI. The connection of the riser to seabed is by means of mechanical connector (e.g., latch type connector or taper joint). A riser base jumper, either flexible or rigid, connects BRA and FLET. A typical SLHR concept is illustrated in Section 1, Figure 1. Such a vertical rigid riser pipe can be installed using either J-lay or Reel-lay. There are several different names of SLHR, for example, single line (or leg) offset riser (SLOR), single top tension riser (STTR), single line free standing hybrid riser (SLFSHR), free standing hybrid riser (FSHR), and single line (or leg) hybrid riser. SLHR broadly includes the pipe in pipe (PIP) hybrid riser system as well.

FIGURE 1
Illustration of an SLHR



A typical SLHR is composed of the following components, as shown in Section 1, Figure 1 above:

- Top riser jumper (or jumpers for PIP)
- Umbilical (optional)
- Top riser jumper connector
- Buoyancy Tank (BT)
- Tether Chain/Flexible joint
- Top Riser Assembly (TRA including Gooseneck Assembly)
- Upper Tapered Stress Joint (UTSJ), if required
- Riser Joint/Buoyancy Modules/Coating/Insulations
- Inner riser joints, centralizers, bulkhead/injection forgings for PIP
- Lower Tapered Stress Joint (LTSJ), if required
- Bottom Riser Assembly (BRA)
- Foundation
- Riser Base Jumper (RBJ)
- Riser base jumper connector

3.7 Other Hybrid Riser Types

There are some other hybrid riser concepts such as Tension Leg Riser (TLR), Hybrid Catenary Riser (HCR), etc. However, so far, only one buoyancy supported riser (BSR) system has been installed.

5 Applicability

Except for HRT, SLHR and BSR systems, other hybrid riser concepts have not yet been deployed in offshore field development. Though these Guidance Notes are meant to be applicable to all types of hybrid risers, focus is given to the SLHR system.

7 Alternatives

7.1 General

ABS is at all times ready to consider alternative arrangements and designs which can be shown, through either satisfactory service experience or a systematic analysis based on sound engineering principles, to meet the overall safety, serviceability, and long-term strength standards of the Rules and Guides.

7.3 National Standards

ABS will consider special arrangements or design of subsea hybrid riser systems which can be shown to comply with standards recognized in the country provided that the proposed standards are not less effective.

9 Definitions and Abbreviations

9.1 Definitions

Bill of Material. A list of raw materials, sub-assemblies, intermediate assemblies, sub-components, parts and the quantities of each needed to manufacture an end product.

Bottom Connector. A mechanical device used to connect bottom adjacent components in the riser system to create a structural joint resisting applied load.

Bottom Riser Assembly. The assembly structure to connect the bottom riser string, riser base jumper and foundation pile.

Buoyancy Modules. Units of low density materials, usually foamed polymers, strapped or clamped to the exterior of riser joints, to reduce the submerged weight of the riser.

Buoyancy Tank. A buoyant structure attached to the top of the riser system anchored to the seafloor, keeping the riser in tension and in place.

Coiled Tubing Intervention. A typical well intervention, which can be a cost/time effective solution for well intervention operations.

Continuous Riser Bundle Section. A structure, which has multiple risers that are bundled together.

Design Life (Service Life). Time, usually expressed in years, that the system (or considered component or structural detail) will be exposed to loads or other demands after installation at the operating site.

Dog House. An assemblage including insulated material designed to maintain the thermal integrity of the system at the point of connection.

Dynamic Amplification Factor (DAF). A dimensionless number which describes by how many times the static responses (deflections and stresses) should be multiplied when dynamic effects are considered.

Engineering Criticality Assessment (ECA). An analytical procedure based on fracture mechanics principles that allow determination of the maximum tolerable sizes for imperfections in fusion welds.

Fatigue Life. (a) The minimum required Fatigue Life is the Design Life multiplied by a specified Fatigue Design Factor (FDF) that accounts for matters such as criticality, ease of inspection and repair, etc. (b) Calculated Fatigue Life is the quantity, usually expressed in years, obtained using the S-N curve method referred to in these GNs. The calculated Fatigue Life available for the Design Life should account for significant fatigue damage occurring before service (i.e. from installation or transit). The calculated Fatigue Life should equal or exceed the minimum required Fatigue Life.

Foundation Pile. A steel structure anchored to the seafloor and attached to the bottom of the riser system, to provide adequate axial and lateral support, as well as to satisfy the serviceability and installation requirements.

Fusion Bonded Epoxy (FBE). Fusion bonded epoxy, also known as fusion-bond epoxy powder coating (commonly referred to as FBE coating), is an epoxy-based powder coating that is widely used for the corrosion protection of: steel pipe used in pipeline construction, concrete reinforcing bars (rebar), and on a wide variety of piping connections, valves etc.

Gas Lift. An artificial lift technique of raising a fluid such as water or oil by introducing bubbles of compressed air, water vapor or other vaporous bubbles into the riser. Riser base gas-lift is a method that has been proven to work in subsea developments for production enhancement.

Glass Syntactic Polyurethane (GSPU). A type of thermal insulation which is made from Syntactic Polyurethane.

Gooseneck Assembly. The assembly structure to connect the TRA and the top flexible jumper. It may include the riser induction bend, the flexible jumper stiffener and the subsea connector.

Hazard and Operability (HAZOP). A method of assessing and evaluating potential hazards to personnel or equipment.

Hazard Identification (HAZID). A systematic critical examination of facilities to identify any potential hazards and the consequential effects on the facility as a whole.

Knockdown Factor. The term knock-down factor refers to the reduction in fatigue life in a corrosive environment (e.g., sour service), as compared to the fatigue performance in air.

Load and Resistance Factor Design (LRFD). Load and Resistance Factor Design (LRFD), commonly associated with Limit State Design (LSD), refers to a design criteria format used in structural engineering. A limit state is a condition of a structure beyond which it no longer fulfills the relevant design criteria.

Lower Tapered Stress Joint. Typically, a forged piece with a tapered shape that connects the standard riser pipe and the BRA.

Metal-To-Metal (MTM) Seal. Type of seal using resilient metal seals for applications involving high temperatures, high pressures or vacuum, or corrosive chemicals.

Minimum Bending Radius (MBR). Measured to the inside curvature, is the minimum radius one can bend a pipe, tube, sheet, cable or hose without kinking it, damaging it, or shortening its life.

Minimum Separation. The minimum separation is defined as the minimum surface-to-surface distance between the upstream and downstream riser pair.

Riser Base. The bottom end of the riser system which connects to the foundation pile.

Riser Base Jumper. A short piece of pipe, either flexible or rigid, connected between the lower end of each individual riser and the relevant FLET or manifold.

Riser Joint. A joint consisting of a tubular member(s) middle section that is welded or mechanically connected to adjoining riser joints.

ROV Hot Stab. A running tool which an ROV may connect directly to subsea equipment to hydraulically operate the equipment.

Stem Pipe. A large steel pipe in the center of a buoyancy tank that transfers the weight of SLHR to each bulkhead of the buoyancy tank, which can also be called the central pipe or core supporting pipe. 'Stem Pipe' can also be used to describe the piece of pipe at the bottom of the TRA or top of the BRA, which is installed in conjunction with, and is therefore considered as an integral part of, the TRA/BRA.

Stress Concentration Factor (SCF). The local peak stress at geometric discontinuities (including welds) divided by the nominal stress in the pipe wall.

Tension Leg Riser (TLR). One type of hybrid riser utilizing conventional steel catenary riser (SCR) and flexible pipe technology with a mid-water buoy tethered to the seabed.

Tie-back Connector. A type of hydraulically operated subsea connector which has metal-to-metal sealing.

Top Flexible Jumper. A flexible pipe connecting the TRA and a floater, such as an FPSO.

Top Riser Assembly (TRA). The assembly structure including gooseneck assembly to connect the tether chain/flexible joint, top flexible jumper and UTSJ.

Universal Transverse Mercator (UTM). A conformal projection using a 2-dimensional Cartesian coordinate system to give locations on the surface of the Earth. It is a horizontal position representation (i.e., it is used to identify locations on the Earth independently of vertical position), but differs from the traditional method of latitude and longitude in several respects.

Upper Tapered Stress Joint (UTSJ). A forged piece with a tapered shape that connects the TRA and the standard riser pipe.

Weld-on Connector. One type of pipe connector for which the male and female parts of the connector are welded on to ends of a standard pipe.

Working Stress Design (WSD). A design method wherein the structure is designed such that the stresses developed due to service loads remain within specified limits through the use of factors of safety.

Wye-piece Forging. A forged piece having a Y shape.

9.3 Abbreviations

ABS	American Bureau of Shipping
AISC	American Institute of Steel Construction
ALS	Accidental Limit State
ANSI	American National Standards Institute
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
ASTM	ASTM International
BPVC	Boiler and Pressure Vessel Code
BRA	Bottom Riser Assembly
BT	Buoyancy Tank
CFD	Computational Fluid Dynamics
CoG	Center of Gravity
CP	Cathodic Protection
DAF	Dynamic Amplification Factor
DBD	Design basis document
DBM	Distributed Buoyancy Module
DFI	Design, Fabrication and Installation
DGPS	Differential Global Positioning System
DVRT	Differential Variable Reluctance Transducer
ECA	Engineering Criticality Assessment
EPS	Early Production System

FBE	Fusion Bonded Epoxy
FE	Finite Element
FEA	Finite Element Analysis
FJ	Flexible Jumper
FLET	Flowline End Termination
FLS	Fatigue Limit State
FOS	Factor of Safety
FPI	Floating Production Installation
FPS	Floating Production System
FPSO	Floating Production Storage and Offloading
FSHR	Free Standing Hybrid Riser
GoM	Gulf of Mexico
GSPU	Glass Syntactic Polyurethane
HAZID	Hazard Identification
HAZOP	Hazard and Operability
HCR	Hybrid Catenary Riser
HLV	Heavy Lift Vessel
HRT	Hybrid Riser Tower
HySR	Hybrid 'S' Riser System
ID	Internal Diameter
ISO	International Organization for Standardization
ITP	Inspection and Testing Plan
JONSWAP	Joint North Sea Wave Project
LRFD	Load and Resistance Factor Design
LTSJ	Lower Tapered Stress Joint
LVDT	Linear Variable Differential Transducer
MBR	Minimum Bending Radius
MLPP	Multiple Layer Polypropylene
MR	Material Requisitions
MRU	Motion Reference Units
MSST	Maximum Soil Setup Time
MTM	Metal-To-Metal
MTO	Material Take Off
MWL	Mean Water Level
NACE	NACE International
NDE	Non-Destructive Examination
OD	Outside Diameter
PO	Purchase Order

PP	Polypropylene
PR	Performance Requirement
PSL	Product Specification Level
QA	Quality Assurance
QC	Quality Control
RAO	Response Amplitude Operator
RBJ	Riser Base Jumper
ROV	Remotely Operated Vehicle
SAE	Society of Automotive Engineers
SCF	Stress Concentration Factor
SCR	Steel Catenary Riser
SIT	System Integration Test
SLFSHR	Single Line Free Standing Hybrid Riser
SLOR	Single Line (or Leg) Offset Riser
SLS	Serviceability Limit State
SMYS	Specified Minimum Yield Strength
STC	Stress Transfer Coefficient
STTR	Single Top Tension Riser
TLP	Tension Leg Platform
TLPE	Three Layer Polyurethane
TLPP	Three Layer Polypropylene
TLR	Tension Leg Riser
TRA	Top Riser Assembly
TSA	Thermal Sprayed Aluminum
TSJ	Tapered Stress Joint
TTF	Top Tension Factor
ULS	Ultimate Limit State
UTM	Universal Transverse Mercator
UTSJ	Upper Tapered Stress Joint
VIM	Vortex Induced Motion
VIV	Vortex Induced Vibration
WA	West Africa
WD	Water Depth
WSD	Working Stress Design
WT	Wall Thickness



SECTION 2 System Design

1 General

In general, hybrid riser design and analysis are to be in accordance with the criteria given in the *ABS Guide for Building and Classing Subsea Riser Systems (Riser Guide)* (or API STD 2RD) and relevant specifications.

Global analyses for normal and extreme environmental conditions are to be conducted to demonstrate compliance with the relevant specifications and industry codes. Fatigue strength (considering waves, VIM, VIV and installation conditions) and clearance/clashing responses are all to be assessed.

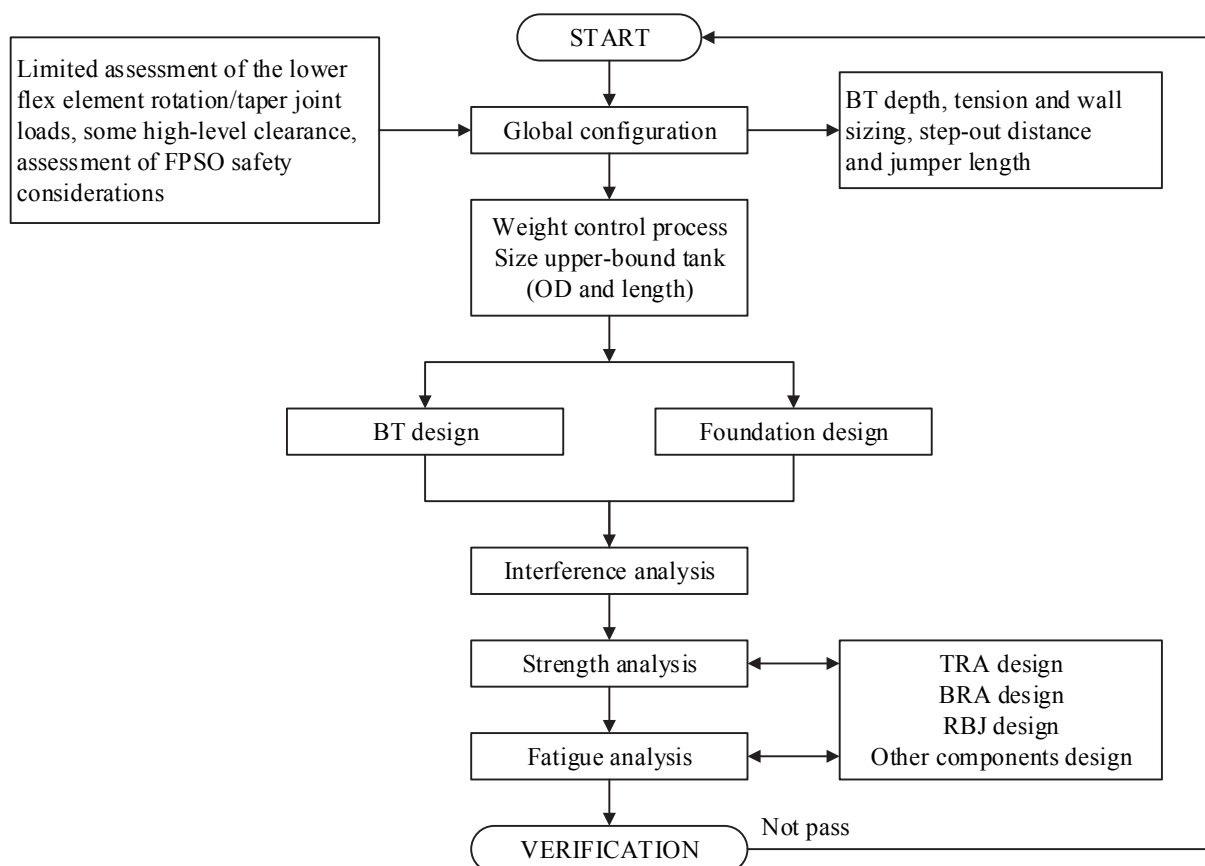
The detailed component design may be performed using finite element analysis (FEA).

3 Design Flowchart

Considering the complexity of the system and its sensitivity to fabrication and installation, a proven procedure for hybrid riser system design should be pursued.

The flowchart in Section 2, Figure 1 shows a suggested procedure and major issues to be considered during a typical engineering design of a deepwater hybrid riser applicable for all types of floaters.

FIGURE 1
Suggested Hybrid Riser Design Flowchart



5 Design Basis Data

At the beginning of the design and analysis process, an overall project design basis document is often written to denote the essential parameters and the acceptance criteria for a fit-for-purpose design and analysis of the hybrid riser system. The input to the basis of design is:

- *Metocean and Geotechnical Data:* Water depth and geotechnical data, wind, wave and current data dictate the selection of a production platform as well as the hybrid riser response; soil data dictates foundation design
- *Reservoir Data:* Pressure, temperature, and product contents affect the riser pipe wall sizing, and material selection. Reservoir data also affects the outcome of flow assurance calculations and thus the riser insulation requirements. High temperatures may result in yield strength de-rating
- *FPI Data:* Floater motion characteristics, major particulars, riser termination locations, floater offsets corresponding to different conditions, operating philosophy
- *Riser System Data:* Number and function of risers, diameters, thermal insulation requirements, subsea layout; manufacturer/ vendor supplied data
- *Design Requirements:* Design philosophy, applicable design codes and standards, design acceptance criteria, design constraints
- *Analysis Requirements:* Software selection and verification, types of analysis, analysis methodology, load case matrix, and validation of analysis results

The hybrid riser system design basis is often updated throughout the life of the project due to new flow-assurance information gathered during the drilling campaign, improvement of metocean hind-cast model, or other developments along the course of the project. Keeping the latest revision and distribution of the basis of design should be considered essential to the design.

The following aspects should be specifically considered when selecting a hybrid riser concept for a specific field development:

- Ability to withstand all design loads and load combinations for in-situ, as well as temporary conditions
- Capacity to perform its function for the specified service life
- Use of materials conforming to corrosion control requirements
- Flow assurance – avoidance of blockage or other flow impediments – maintenance of delivery temperature and minimum no-touch cool-down duration to minimize risk of hydrates/wax
- Access and smooth passage for intervention tools
- Means for integrity monitoring and inspection
- Access for pigging
- Ability to transfer high pressure fluids (oil, gas, water) between flowlines and FPI
- Fabrication considerations
 - Fabrication yard location and assembly (for riser tower)
 - Fabrication limits
- Installation considerations
 - Overall installation methodology
 - Tow route selection and duration (for riser tower)
 - Deployment of buoyancy tank and hookup
 - Installation of riser foundation pile/anchor

7 System Design

7.1 System Requirements

The design of each of the various riser system components from the seabed to the FPI should consider the following:

- Containment of hydrocarbons and control fluids throughout the design life under defined startup, normal, and shut down operations and accidental or damaged floater conditions
- Compliance to accommodate the environmental and operating conditions, hydrodynamic loadings, FPI motions and excursions that the riser system is subjected to throughout the riser system's life
- Thermal insulation performance and process remediation systems for the flow assurance performance requirements of the production system
- Protection from external and internal corrosion effects without introducing detrimental conditions, such as hydrogen embrittlement, that could affect riser system materials
- Strength, fatigue and corrosion resistance for the intended service to satisfy the required margins against failure due to cracking, leakage, rupture, collapse, yielding or buckling under the design conditions
- Reliability and redundancy of the buoyancy system for the riser system's life under defined startup, normal and shut down operations and accidental or damaged conditions
- Long-term polymer material 'aging' properties due to hydrostatic pressure, temperature and mechanical loading exposure during the riser system's life
- Clearances from other structures, risers, umbilical, mooring lines, and components in the floater's turret area
- Consistency with all agreed interface requirements for the FPI connections, hang offs, the flowlines and any directly-connected BRA and jumpers
- Hang-off loads within the identified capacity values under all operating conditions identified through HAZID and HAZOP processes (e.g., loss of Buoyancy tank compartment)
- Safe and reliable installation issues should be addressed (e.g., hybrid riser system pull-down, jumper pull-in through turret, jumper connection at TRA)

7.3 Global Configuration

Initial considerations in hybrid riser design include the following:

- Functional requirements
- Metocean criteria
- FPI excursions
- Subsea field layout
- Riser Installation methodology
- Field interference
- Flexible jumper performance
- In-place performance (standby and operating)

Controlling parameters governing the global configuration design of a hybrid riser system include the following:

- Depth from MWL to the top of the buoyancy tank
- Riser foundation offset to riser hang-off location at the FPI
- Flexible jumper length and departure angles at FPI and riser ends

- Connection between buoyancy tank and riser top
- Connection between riser end or BRA and pile/FLET
- Flowline routing
- Other detailed considerations that can affect global configuration including FLET/BRA/RBJ orientations, TRA/BRA concept and RBJ design.

9 Components Design

9.1 General

Compared with other types of deepwater riser concepts, there are some unique engineering design features of a hybrid riser system. Key design considerations of a hybrid riser system include the following:

- Global Configuration
- Riser base offset to the FPI
- Flexible jumper length
- BT Design
- Functional requirement: vertical access, gas lift, disconnection
- Global-Local interface design
- Installation method

Additionally, specific concerns for the following three components of SLHR are as follows:

- RBJ – complexity and coupling with BRA and global analysis
- BT – large pressure vessel
- BRA/TRA – complex fabricated structures with multiple interfaces and functions

Due to the complexity of the system, hybrid riser design can require increased consideration of the interdependency between procurement, fabrication, and installation. The installation method may have significant impact on the design of some components including BT, TRA, BRA, TSJ and the foundation pile. Early input about the installation is recommended to make the riser system more “installation friendly”.

Structural/load bearing members of the riser system should be designed to:

- Support all the loads produced by the BT, flexible jumpers and other riser assembly structures during each stage of the installation and operating phases of the riser system; and
- Meet the relevant mechanical and process fluid compatibility requirements, and should be suitably designed to account for all dynamic and transient load cases.

9.3 Riser String

9.3.1 Production Riser

A production riser should be designed to meet relevant mechanical and process fluid compatibility requirements. The riser should be insulated so that produced fluids retain their heat and remain free of hydrates and wax deposition.

API 5L X65 or X70 material is commonly selected for a production riser. A lower material grade such as API 5L X60 can be considered for sour service conditions. A higher material grade can be considered for non-welded connectors though not for permanent production applications (e.g., emergency response system).

The riser design should demonstrate that welds for dynamic service meet the required fatigue performance, and the non-destructive examination (NDE) methods used should be able to detect the minimum allowable defect or other characteristics needed to achieve the design life.

Insulation materials should retain adequate mechanical and thermal performance over the riser's design life to comply with thermal requirements.

Individual riser line pipe sections should meet the requirements of API 5L, and should be in general connected by welded joints. In a special case, mechanical connectors (e.g., weld-on connector) may be acceptable to connect the line pipes.

9.3.1(a) Pipe-in-Pipe. The pipe-in-pipe design may require a pipe hanger at the top and a bulkhead at the bottom to form the junction between inner and outer sections. The pipe-in-pipe system may enable fluid interaction between inner and outer sections (e.g., for gas lift injection into a production bore) and accordingly specific requirements should be included in the design, such as the size, position and orientation of injection holes. Centralizers may be required over the length of the inner riser to reduce buckling tendency of the inner pipe and the spacing of centralizers can be determined through analysis. Additional sealing and other interface requirements may need to be provided. Qualification testing may be required to verify these key design requirements.

The PIP design analysis should consider all the loading conditions, the appropriate tension distribution between pipes based on installation procedure, pipe and tension tolerances, fluid content and variations over the life of the field, to provide sufficient strength and fatigue performance. Specific interface components, such as bulkheads, should be adequately designed based on detailed FEA.

9.3.2 Gas and Water Injection Risers

Gas injection/export or water injection risers are typically deployed from the FPI. These risers can be manufactured from carbon steel material grades. Individual riser line pipe sections should be connected by welded joints.

Assessment from flow assurance should document that the riser is not at risk over time, since water injection could be subjected to hydrogen embrittlement or a higher level of H₂S content over time.

External corrosion protection should be in accordance with the criteria referred to in these Guidance Notes.

9.3.3 Gas Lift Risers

If PIP production risers are not selected, then a dedicated gas lift riser may be required with subsea manifolding to achieve the same function.

Insulation materials are to retain adequate mechanical and thermal performance over the riser's design life to comply with thermal requirements.

Injection points are provided either on the flowline termination (i.e., upstream of the riser base spool) or on the BRA.

9.3.4 Oil and Gas Export Risers

Produced and processed oil may be stored for offloading to a tanker or may be exported via a subsea pipeline network. Produced and processed/dried gas may be injected back into the reservoir or may be exported via a subsea pipeline network.

If either product is exported, export risers may be required. Design considerations are similar to the gas injection risers.

9.5 Top Flexible Jumper

The flexible jumper should be designed to be post-installed on the riser after the installation of the vertical hybrid riser in the field. The flexible jumper may be installed after the arrival of the FPI or be pre-installed and clamped along the riser length while waiting for FPI to arrive on site (stand-by modes). The flexible jumper should also be replaceable without the need to retrieve the entire string or remove any structural or buoyancy elements.

Process fluids should be transferred to/from the FPI by means of flexible jumpers configured in an appropriate manner to avoid undue loading on the top of the hybrid riser system and to avoid clashing. Jumpers should be designed for dynamic service for at least the design life of the vertical riser under the specified design conditions.

Dynamic analysis of the flexible jumper should be performed to provide the FPI designer and the flexible jumper manufacturer with: the interface loadings and their applied directions under the applicable metocean conditions, FPI motions and FPI excursions to provide a robust strength and fatigue resistance for all interface components of the jumper.

Consideration should be given to the study of interference between a flexible jumper and the FPI hull/appurtenances (e.g., lift/dump hoses), in addition to the interference between the flexible jumper and any adjacent umbilical, flexible jumper or mooring line. The hybrid riser system should be designed to avoid any interference that can bring potential damage to the system, such as impact or abrasion.

Damage to the outer sheath of the flexible jumper during installation can result in a reduced service life. Flexible jumpers should be fitted with protection at potential clashing points to reduce damage risk.

The risk of VIV damage to the internal carcass generated by gas flow through a flexible riser should be assessed.

9.7 Buoyancy Tank

Once installed, the riser should be designed to be self-supporting by means of the BT. The BT can be manufactured with individual compartments connected by a ballasting system of pipes and valves. This enables buoyancy load or its position in the water column to be adjusted following installation or during operation.

BT design should take account of the following key factors; including:

- Design Life
- Load transfer paths between the BT and the riser structure
- Stresses from hydrostatic pressure, extreme and fatigue loading and sloshing loads
- Loss of buoyancy over the design life due to partial or complete flooding of one or two compartments of the BT
- Additional weight and drag forces induced by marine growth, particularly at the upper end of the riser structure
- Additional weight due to riser pipe fabrication tolerances and base tension tolerance caused by weighing and deballasting inaccuracy
- Fatigue loads, especially at the connection between the BT and the TRA
- Fatigue of structural and piping welds due to pressure variations (e.g., caused by wave, tide, setdown due to current, liquid sloshing inside compartment)
- Fatigue of girth weld due to riser VIV for connector at bottom of BT (if applicable)
- ROV impact on ROV panel and outer shell of BT
- Impact due to dropped objects
- Global and pitting corrosion due to microbial action in the presence of residual seawater and oxygen (depending on purity of Nitrogen used to de-ballast the compartment) remaining in each compartment at the end of installation
- Collapse loads on air filled central pipe

In addition the following factors from a HAZID study should be considered in the design:

- Additional weight from accidental failure of the flexible jumper at the FPI, resulting in jumper hanging vertically from the riser gooseneck interface (or designed to remain like this during stand-by operations)
- Feasible combinations of the above factors should also be considered
- Handling points for installation and padeyes for secondary buoyancy elements to be added in emergency situations

The BT can be designed on the basis of the following functional requirements:

- To support the hybrid riser dead weight
- To provide sufficient pulling tension for the dynamic equilibrium of the hybrid riser
- To minimize the angle at the riser lower assembly by limiting the maximum offset of the riser due to FPI excursion even in the loss of one compartment condition
- To support the jumper, the jumper supporting structure, the rigid goose neck and associated structures
- To provide appropriate partition of the compartments to meet in-place damaged stability requirements

In addition the following facilities should be incorporated in the design:

- Pressurizing/ballasting/deballasting system
- Tension monitoring system (with sufficient accuracy to detect leaks/compartment failure)
- ROV connectable device for nitrogen injection and control panel
- Transportation supports
- Connections for sea fastening
- Lifting and up-ending device for fabrication/transportation/installation

9.9 Top Riser Assembly

The TRA should provide a safe and reliable means of connecting the lower end of a flexible jumper spanning from the FPI to the top of the riser. The connection system should take into account predicted load conditions, interface requirements with the flexible jumper/TRA and subsea intervention. More than one jumper is required for a PIP system with associated additional connection equipment and piping.

Provision should be made at the upper end of a riser to enable fluids to be transferred to/from the FPI by means of dedicated flexible jumpers. The TRA incorporates the load transfer path(s) to the BT. Each load path should be analyzed for the predicted applied loads, both individually and in combination.

The TRA should be designed to enable the flexible jumper(s) to be safely installed and replaced (if needed), by divers or Remotely Operated Vehicle (ROV), during the life of the riser. The TRA should also be designed to accommodate the loads induced by installation guides, winches and support structures.

Pigging requirements (if applicable) should be considered when bend radii are selected and in handling ID transitions between piping, forgings and connectors.

For a production system, provision may be required for hydrate remediation (access forgings, valves and connection points) with associated structural support. For a PIP system, additional piping and forgings are required to inject the gas lift fluid into the PIP annulus.

9.11 Bottom Riser Assembly

The BRA should provide the transition from the vertical pipe section to the RBJ. Pigging requirements (if applicable) should be considered when bend radii are selected.

Key considerations for a gas lift system located at the BRA of the PIP hybrid risers are as follows:

- Thermal performance and proper insulation of the system
- Reliability of the non-redundant components incorporated in the system

- Material selection for components and piping and their compatibility
- Selection of seals and materials
- Access for underwater intervention
- Availability of space to incorporate the gas-lift system in the frame of the BRA
- Accommodation of anticipated loads both during installation and operation.

Due to potentially high collapse pressures in deep-water applications, ovalization and thinning of the piping should be assessed through detailed FEA.

For production systems, a method for injecting gas lift fluids into the production bore may be required. The source of these fluids can be:

- An annulus (in the case of a PIP riser), in which case a (passive) perforated bulkhead can be implemented
- A dedicated gas lift riser, in which case a valve assembly and injection forging will be required either on the BRA or on the flowline termination.

9.13 Foundation Pile

A latch type riser base connector or a lower taper joint can be used to connect the riser to the foundation.

Installation tolerances, which account for positional accuracy, orientation and verticality requirements should be considered in the foundation design. These tolerances should be listed in the riser's Installation Manual.

Dynamic load conditions during foundation installation, riser system installation, life of field operations and decommissioning should be determined and considered in the foundation design. Accidental cases should be considered and additional inclination should be accounted for when determining tolerances on the installation of the foundation.

9.15 Riser Base Jumper

Depending on the particular field application, installation requirement and required lead time, the RBJ can be rigid or flexible. The RBJ should be designed to provide the connection between the lower end of each individual riser and the relevant FLET or manifold. The RBJ should be configured to provide the necessary flexibility to cater to pressure and thermal effects (flowline and RBJ itself), as well as the motions of the hybrid riser, slugging loads and other mechanical effects, and to meet the installation tolerance requirements. The RBJ should also be designed in consideration of the proposed installation sequence, whether prior or after hook-up of the flexible jumpers to the TRA.

Due to the susceptibility to high fatigue loading, the fatigue performance of the rigid RBJ should be fully evaluated. Both the weight and inertial effects should be considered in slugging evaluation, particularly where multiple tight (3D/5D) bends are incorporated in the design, and the weld should be in accordance with welding requirements for the RBJ.

A production RBJ should be insulated so that the production fluids retain their heat and remain free of hydrates and wax deposition in accordance with the flow assurance performance requirements. Pigging requirements (if applicable) should be considered when bend radii are selected.

9.17 Connectors

Connectors typically have the following applications in a hybrid riser system:

- Gooseneck connection to flexible jumper
- BT connection to TRA
- BRA connection to foundation pile
- FLET/BRA connection to RBJ

Particular attention should be given to the connections. A single point of failure should be avoided. The connection between BT and TRA should be designed with a contingency in case of load path failure. The same principle should apply to the bottom connection if there is BRA connecting to a pile.

Subsea hydraulic connectors, if used, should be designed and tested in accordance with ANSI/ASME B31.8 or ANSI/ASME B31.4, as applicable. All hydraulic connectors, hubs and ancillary equipment should be designed in accordance with API Spec. 6A and 17D with Product Specification Level (PSL) 3G, Performance Requirement (PR) 2 for function testing with temperature in accordance with project requirements.

Hydraulically operated components should be flushed in accordance with SAE AS4059 Class 6B to 6F hydraulic fluid cleanliness, and should be designed to operate in SAE AS4059 Class 12B to 12F.

Connectors should be designed to use pressure energized metal-to-metal (MTM) seals, field replaceable without recovering the connectors to the surface. Non-metallic seals should only be used as backup seals. The hardness of the MTM seals should be less than the hardness of the connector and hub seal surfaces.

External seal tests should be performed at an agreed pressure differential. A one-off qualification test should be performed on each gasket size to determine the external pressure capability of each seal type. Each seal should be tested to at least the hydrostatic head pressure at the design water depth.

Connection hubs should include a reaction can or ring that provides passive guidance and orientation, facilitates passive latch engagement, and protects the seal gasket preparation on the hub from impact from the connector. Connectors are to be designed to resist unintentional release.

Connectors should be designed to prevent damage to any control lines from dropped objects, handling, installation, and intervention, etc.

Subsea flooding caps should be provided with all male hubs. Flooding caps should:

1. Be field installable and retrievable;
2. Incorporate a test port for venting, injecting or monitoring the sealed cavity; and
3. Incorporate a field-operated ball valve for flooding operations.

Suitable redundancy should be provided in the design of the connections to prevent catastrophic failure of the riser system due to a single point failure.

11 Design Criteria

The design criteria for the design and analysis of the hybrid riser system should include the following:

- Industry codes, standards, and specifications to be used in the design
- Minimum design life requirement
- Transportation and installation
- Minimum bend radius versus effective tension envelope for flexible jumpers
- Fatigue curves, stress concentration factors and ECA for typical welds and connectors
- Interference criteria in terms of diameters between risers or the permissible impact energy
- Material loss allowances and mitigation measures
- Operational requirements – cool down time, start up and shut down cycles, water injection, and gas lift requirements
- Inspection and maintenance criteria
- Thermal insulation requirement from flow assurance

The system design should satisfy the ABS *Riser Guide* or API STD 2RD as a primary design code while codes and standards listed in Subsection 2/19, “Applicable Codes and Standards” of these Guidance Notes should be used to address individual components.

13 Flow Assurance

Flow assurance criteria should be specified. Thermal insulation coating should be provided for a hybrid production riser, which is defined by:

- U-value requirement, and
- Cool down time requirement

For irregular pressure containing component (e.g., TRA and BRA), CFD can be a useful tool to determine thermal coating requirements.

Providing a Dog House is a common practice to provide thermal insulation for connectors, which could be used to tie a riser string to its base.

Slugging-induced internal fluid pressure fluctuations should be considered when the normal transporting flow rate is below the slug-free flow rate limit or at the restart/shutdown scenarios. The slug-free flow rate limit depends on the pipe size, fluid properties, flowline geometry, back pressure, and flow temperature. The RBJ vibrating failure and lifespan should be evaluated based on the sustainable internal fluid pressure fluctuation magnitude and frequency with an appropriate safety factor; see the *Riser Guide*.

15 Material Selection

15.1 General Considerations

Material selection for a hybrid riser system should consider the following:

- Weight sensitivity leads to an increased use of higher material grades: this is permitted provided the other material related criteria are met
- Material compatibility between connected components should be considered to avoid dissimilar material interaction issues
- Material suitability should consider the ease of availability at fabrication yard
- Casting material should not be used
- Either internal cladding or lining should be considered based on the reservoir data

15.3 Specifications

Material specification should comply with recognized industrial standards, as indicated in Section 2, Table 1.

TABLE 1
Material Specification Standards

<i>Standards</i>	<i>Title</i>
API SPEC 5L	Specification for Line Pipe
API SPEC 2B	Specification for the Fabrication of Structural Steel Pipe
API SPEC 2H	Specification for Carbon Manganese Steel Plate for Offshore Platform Tubular Joints
API SPEC 2Y	Specification for Steel Plates, Quenched-and-Tempered, for Offshore Structures
API SPEC 2W	Specification for Steel Plates for Offshore Structures, Produced by Thermo-Mechanical Control Processing
AWS D1.1/D1.1M	Structural Welding Code – Steel
API STD 1104	Welding of Pipelines and Related Facilities
API SPEC 5CT	Specification for Casing and Tubing

In addition, material testing requirements specified by ASTM should be applied.

17 Coating and Corrosion Control

17.1 Thermal Insulation Coating

The most commonly used thermal insulation system for a hybrid riser system is an external thermal coating.

When selecting a thermal insulation coating, the following items should be considered:

- Properties of the materials/layers within insulation and field joint
- Documented properties with acceptance criteria being generally based on retention of acceptable insulation properties at end of the riser's design life
- Impact of installation methods on coating (e.g., coating reliability)

External insulation may have a detrimental effect on a riser's dynamic response, due to increased drag loading and reduced weight/drag ratio. Manufacturing and installation requirements also impose limitations on the maximum thickness of insulation that can be applied.

The most commonly used thermal insulation systems are:

- Multilayer Polypropylene (MLPP)
- Glass Syntactic Polyurethane (GSPU)

17.3 Corrosion Coating

External corrosion protection of the hybrid risers should be achieved using a combination of corrosion resistant coatings and sacrificial anodes.

Design and selection of riser cathodic protection system should be compatible with cathodic protection systems of the floater and nearby subsea systems (e.g., riser foundation pile or FLET).

Attention should be paid to provide electrical continuity from the flexible jumper all the way down to the foundation and that sufficient anodes are installed on the riser, either concentrated at the top or the bottom or using bracelet anode depending on the length of the riser.

Special consideration should be given to the protection of riser sections interfacing with ancillary components.

The most commonly used corrosion coatings are:

- Fusion Bonded Epoxy (FBE)
- Three Layer Polypropylene (TLPP)
- Three Layer Polyethylene (TLPE)

17.5 Corrosion Protection

17.5.1 Internal Corrosion Protection

Internal corrosion protection should be considered for all riser components where internal corrosion may occur. Internal corrosion protection methods may be based on corrosion resistant materials, protective coatings, corrosion allowance; and where appropriate, sacrificial cathodic protection systems.

17.5.2 External Corrosion Protection

External corrosion protection should also be considered by using corrosion resistant materials, protective coatings, corrosion allowance, and where appropriate, sacrificial cathodic protection (CP) systems.

Any sacrificial anodes, if used, should be mounted on the riser system structure, not on the riser string.

Corrosion protection of the FPI and riser systems may not be fully independent. Consideration should be given to the influence of the FPI hull's CP (impressed current or equivalent) system on the riser's CP system.

Due account should be taken in the design of the CP system of the mixture of materials present in the structure such that the long term performance of any such materials should not be degraded due to the influence of the CP system.

System components should be designed to be in direct electrical contact with each other. Where coatings or elastomers are present that prevent direct electrical contact, appropriate electrical straps should be installed to provide for electrical continuity.

17.5.3 Cathodic Protection Design

The riser's cathodic protection system can be a sacrificial type incorporating Al/Zn/In anodes. The cathodic protection designs for each component should be integrated to maintain mutual compatibility and compatibility with all materials and coating systems. Cathodic protection for the riser pipe and jumpers is supplied by anodes mounted on end structures such as the TRA and the BRA. Attenuation modeling should be performed to verify that the entire length of each riser section receives cathodic protection from end-structure mounted anodes.

Cathodic protection for the buoyancy tank, TRA, riser base assembly, foundation pile and other hybrid riser appurtenances should be designed in accordance with NACE SP0169. The cathodic protection design for the riser joints, TSJs and RBJ is to be in accordance with BS EN 12496 and ISO-15589-2. The cathodic protection design life should take into account the riser's design life. The design should consider the interface of the riser and the vessel as well as the riser and the subsea production system.

19 Applicable Codes and Standards

Due to the complexity of hybrid riser systems, different design standards are used to address individual components, while the system design should satisfy *ABS Riser Guide* or API STD 2RD as a primary design code.

Typical design codes and standards used for hybrid riser are listed in Section 2, Table 2 below. It is noted that the list is not all inclusive. Additional design standards can be added for special project requirements, and local governmental regulations.

TABLE 2
Design Codes, Standards and Specifications

<i>Document</i>	<i>Title</i>	<i>Applications</i>
ABS Riser Guide	Guide for Building and Classing Subsea Riser Systems	Primary, General
API STD 2RD	Dynamic Risers for Floating Production Systems	Primary, General
AISC	Steel Construction Manual	General
NACE SP0169	Control of External Corrosion on Underground or Submerged Metallic Piping Systems	General
ASME	Boiler and Pressure Vessel Code (Section VIII, Div. 3)	Structural Design
API RP 2SK	Design and Analysis of Station Keeping Systems for Floating Structures	Foundation Pile Design
API RP 2GEO	Geotechnical and Foundation Design Considerations	Foundation Pile Design
ABS Buckling Guide	Guide for Buckling and Ultimate Strength Assessment for Offshore Structures	Foundation Pile & BT Design
API RP 2A-WSD	Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design	Foundation Pile & BT Design
ISO 19900	Petroleum and natural gas industries — General requirements for offshore structures	BT Design
ISO 19901-6	Petroleum and natural gas industries – Specific requirements for offshore structures – Part 6: Marine operations	BT Design
BS PD 5500	Specification for unfired fusion welded pressure vessels	BT Design